MO001/4/2017

Introduction to Applied Sciences
CSP1501
Semester 1 & 2

Department of Life and Consumer Sciences

IMPORTANT INFORMATION:
Please activate your myUnisa and myLife e-mail addresses and ensure that you have regular access to the myUnisa module site CSP1501/17/S1 OR CSP1501/17/S2; depending on which semester you are registered in, as well as your group site.
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PREFACE

Dear Students

Welcome to the module Introduction to Applied Sciences (CSP1501).

This is an online module, but you could also use this printed document (MO001) to study for this module. This document is essentially a printed version of everything you will find on the module website on myUnisa. It is a convenient document that you will be able to refer to at any time, page through, and make notes on. However, we would still like to encourage you to use the module website, as this has several advantages. For example, you can easily access any part of your study material by clicking on the links in the table of contents of the learning units, and you can interact with your lecturer and fellow students on the module’s discussion forum.

This document starts with the message on the Welcome page of your module website. It then goes on to the text of the learning units of the module. Be sure to read learning unit 0, as it contains important information about the module. Also remember to read your Tutorial Letter 101, which will provide you with essential details about the module and its assessment.

At the end of this MO001 document, there is a list of the Discussion forum topics that will be available for your use on the module site.

I wish you all the best with your studies.

Your lecturer
Dear Students

Welcome to the module Introduction to Applied Sciences which is offered in the Department of Life and Consumer Sciences. I am Fhumulani Ramasunga and I will be your lecturer for this module. I trust that this module will deepen your understanding of basic sciences and help you further your studies in general.

The purpose of the module is to enable you to identify and apply basic chemistry and physics principles, which will serve as an essential foundation in your further studies. You will also be able to identify various physiological systems in the human body, and their functions. Finally, you will also acquire some basic knowledge that will enable you to adopt a sound and healthy lifestyle.

This module is offered online, but as an alternative you will also be receiving a printed study pack. You will find more details on how to study this module in learning unit 0/the introduction to the learning units, as well as in Tutorial Letter 101.

If you are reading this online, you will see the different options that are available on this site on the left-hand side of the screen. The material that you should study is contained in the learning units. Tutorial Letter 101, as well as other tutorial letters and past examination papers, are stored in Official Study Material. You may periodically receive some announcements, for example to remind you of a due date for an assignment. The schedule will remind you of important dates in the semester, for example due dates for assignments. More details about these different tools will be provided in learning unit 0.

After reading this page, you should read Tutorial Letter 101 (if you have not done so already). Then you should proceed to the learning units. Be sure to read learning unit 0/the introduction, as this contains important information.

Please note that there are two sites you should use in studying this module. The first is the module site, where you will find the learning units and where you can communicate with your lecturer. The second is your e-tutor site. The name of the e-tutor site is the same as the name of the module site, except that it has ‘-1S’ or ‘-2S’ added at the end, depending on the semester. On the e-tutor site you will be able to communicate with your e-tutor and fellow students by means of the Discussions tool.

If you have any queries about the module, you are welcome to contact me by e-mail or telephone. You may also make an appointment to see me in my office at the Unisa Science Campus in Florida.

I wish you all the best in your studies.

Kind regards
Mr Fhumulani Ramasunga
Tel.: (27) 11 471 2115
E-mail: ramasf@unisa.ac.za
Fax: (27) 11 471 2796
Office: Unisa Science Campus, Florida, Calabash Building, office 260
LEARNING UNIT 0

WELCOME AND INTRODUCTION

Dear Students

Welcome to the module Introduction to Applied Sciences which is offered in the Department of Life and Consumer Sciences. I am Fhumulani Ramasunga and I will be your lecturer for this module. This module will deepen your understanding of basic sciences and help you further your studies in general.

This is an online module, which means that you will find everything you need to complete the module on this site and your e-tutor site. Check these sites regularly for updates, posted announcements and additional resources uploaded throughout the semester. Rapid communications throughout the semester(s) have been made possible through myUnisa. By using myUnisa, you can:

• submit assignments (please note: it is advisable that you submit your assignment online as this will ensure that you receive rapid feedback and comments),
• access your study material,
• have access to the Unisa library functions,
• “chat” to your lecturer or e-tutor and fellow students, participate in online discussion forums, and
• obtain access to a variety of learning resources.

Please take some time to familiarise yourself with the site so that you get to know where the different tools and resources are. I will give you more information about this later in this learning unit.

Although I would like to encourage you to study this module online, we also recognise that it might be impossible for some of you to get online at all, while some others of you might only be able to get online occasionally. For this reason, you can also use the print-based study pack that you will receive to study for this module.

Your study material for this module includes the following:

• Your learning units
• Tutorial Letter 101
• Any other tutorial letters you may receive throughout the year
• Any additional information provided on the module site and your e-tutor site on myUnisa
• Any additional electronic communications you may receive, e.g. announcements from your lecturer or e-tutor

Details of your prescribed textbook are given in Tutorial Letter 101. You will receive Tutorial Letter 101 in print, but you can also access it on this site. You can do this by clicking on “Official Study Material” in the menu on the left.

Tutorial Letter 101 is just one of the tutorial letters you will be receiving during the year. **It is extremely important that you read this tutorial letter carefully.** You will also receive Tutorial Letter 201 during the course of the semester shortly after the due dates for submission of each assignment. This tutorial letter is closely linked to Tutorial Letter 101 and will provide you with a guide to the answers for the assignments.

Please note that there are two sites you should use in studying CSP1501. The first is the **module site**, where you will find the learning units and where you can communicate with your lecturer. In your list of modules, this usually has a name in the following format:

*Module code-year- semester e.g. CSP1501-17-SI*

The second site is your **e-tutor site**, where you can communicate with your e-tutor and fellow students. This site has the same name, but with ‘-1S’ or ‘-2S’ added at the end, depending on the semester, for example:

*CSP1501-17-SI-1S*

Your e-tutor is there to support your learning, and you can post any questions to him or her in the site’s discussion forum, in the appropriate forum or topic for general questions. In another forum, you will also be able to communicate with your fellow students.

On the e-tutor site, you should also respond to discussion questions that are given in the learning units. Your e-tutor may provide you with the opportunity to engage in additional discussions or to do specific online tasks or activities; please participate fully, as this will go a long way to assist you with your learning. Both the lecturer and e-tutor may also send you announcements from time to time.

In this learning unit, I will give you an overview of and some general information about this module. I will also tell you more about how you can study in this module, how to use myUnisa, and about the assessment in the module.

Click on “Next” below to go to the next screen, where you will find more information about contact details.

**0.1 LECTURER AND CONTACT DETAILS**

In this section I will give you my own contact details, as well as details of the academic department that offers this module. I will also give you the university’s contact details, as well as some information about the student support services at Unisa that you are welcome to use.
Please note that whenever you contact the university, whether in writing or telephonically, you should always mention the module code and your student number.

Lecturer and department

Lecturer: Mr Fhumulani Ramasunga

Telephone number: +27 11 670 2115 (during office hours 8:00 – 16:00)
E-mail address: ramasf@unisa.ac.za

Postal address:
The Lecturer [CSP1501]
Department of Life and Consumer Science
Private Bag x6
Florida
1710

The department offering this module is the Department of Life and Consumer Sciences.

Telephone number (Departmental Secretary): +27 11 471 2230
Fax number: +27 11 471 2796

UNIVERSITY

Should you need to contact the university about matters not related to the content of this module, consult the publication Study@Unisa, which you received with your study material. This brochure contains information on how to contact the university (e.g. to whom you can write for different queries, important telephone and fax numbers, addresses and details of the opening and closing times of particular facilities).
You can also make use of the following contact routes:

- E-mail (general enquiries)–info@unisa.ac.za
- International students are urged to make use of the e-mail address info@unisa.ac.za
- study-info@unisa.ac.za for queries related to application and registration
- assign@unisa.ac.za for assignment enquiries
- exams@unisa.ac.za for examination enquiries
- despatch@unisa.ac.za for study material enquiries
- finan@unisa.ac.za for student account enquiries
- myUnisaHelp@unisa.ac.za for assistance with myUnisa
- myLifeHelp@unisa.ac.za for assistance with myLife e-mail accounts
- SMS 32695 –South Africa only
- You will receive an auto response SMS with the various SMS options.
- Fax 012 429 4150

0.2 STUDENT SUPPORT SERVICES

For information about the various student support systems and services available at Unisa (e.g. student counselling, tutorial classes, language support), consult the publication entitled Study@Unisa.

- Fellow students

It is always a good idea to have contact with fellow students. You can do this using the Discussion menu option on myUnisa. You can also use the Discussion forum to find out whether there are students in your area who would like to form study groups.

- Library

Study@Unisa lists all the services offered by the Unisa library.

To log in to the library website, you will be required to provide your login details, i.e. your student number and your myUnisa password, in order to access the library’s online resources and services. This will enable you to:

- request library material,
- view and renew your library material, and
- use the library’s e-resources.

- Unisa Directorate for Counselling and Career Development (DCCD)

The DCCD supports prospective and registered students before, during and after their Unisa studies. There are resources on their website (http://www.unisa.ac.za/Default.asp?Cmd=ViewContent&ContentID=15974), and also printed booklets available to assist you with

- career advice and how to develop your employability skills,
- study skills,
- academic literacy (reading, writing and quantitative skills),
– assignment submission,
– exam preparation.

Note that the DCCD can also assist you with improving your personal well-being: see their website at http://www.unisa.ac.za/default.asp?Cmd=ViewContent&ContentID=16277.

• Student Health and Wellness

Your physical health is an important factor in your learning success. Obtaining an educational qualification is challenging and may at times involve stress, and it is therefore vital that you should try to maintain a healthy lifestyle to ensure that you will cope physically with the demands of your studies.

If you suspect that you may suffer from a chronic condition, or you know that you suffer from such a condition but are unsure about medical options and treatment, you could approach Unisa for further information and support. See Unisa’s Student Health and Wellness website, which you can access from Unisa’s main website: click on “About”, “Service Departments”, “Student Affairs” and then on “Student Health and Wellness”. Here you will find details of Unisa’s health and wellness clinics, and also some health and wellness resources.

Note that if you do have a health-related condition such as HIV/AIDS, or have a close family member with this or another health condition, then you need to take cognisance of this in planning your studies. It will be unwise to cram tasks as this creates enormous stress which negatively impacts on your performance as a student, as well as on your health. Planning your studies is essential so that you can work consistently and make progress.

It would be wise to know your health status (HIV/AIDS, blood pressure, diabetes, cholesterol, etc.). If you are informed by medical tests, with the necessary medical and supportive interventions you can prolong and improve the quality of your life and your success in your studies.

If you would like to obtain basic information about the prevention of, testing for and treatment of HIV/Aids, you can also consult the following web links:

– http://www.aids.org/topics/aids-factsheets/

You can also approach the DCCD about counselling in this regard.
• The Advocacy and Resource Centre for Students with Disabilities (ARCSWiD)

You will find more information about this centre on their web page at http://www.unisa.ac.za/default.asp?Cmd=ViewContent&ContentID=19553. You can also contact the centre at 012 441 5470/1.

0.3 PURPOSE AND OUTCOMES OF THIS MODULE

This module does not stand alone. You may wonder why these applied sciences are part of your studies. Bear in mind that to understand the basics in human life, animal life, the environment, food, clothing or nutrition it is necessary to understand the basics of science. For example, in nutrition we discuss how certain nutrients help to build healthy bones. These nutrients include minerals (elements) as studied from the periodic table of elements. Furthermore, the basics of the skeletal system need to be understood. Another example is clothing studies. Some detergents have certain effects on different textiles; therefore you need to understand how detergents work in order to grasp the problem of water contaminated with heavy metals, you need to understand the periodic table, the properties of most elements as well as human physiology. There are numerous examples because applied sciences can be applied to everyday life. The learning outcomes for this module are aimed at developing your expertise and abilities in the field of applied science.

The purpose of the module is to enable you to identify and apply basic chemistry and physics principles, which will serve as an essential foundation in your further studies. You will also be able to identify various physiological systems in the human body, and their functions. Finally, you will also acquire some basic knowledge that will enable you to adopt a sound and healthy lifestyle.

More specifically, the outcomes of this module are that, after completing the module, you should be able to explain basic concepts and principles in chemistry, physics and physiology.

The next section will give you a better idea about how the content of the module is structured.

0.4 HOW THE CONTENT OF THIS MODULE IS ORGANISED

This module essentially consists of three main parts. The first part (learning units 1-6) deals with chemistry principles. We start at the most fundamental level by looking at the basic properties of matter and at atomic structures. We then investigate chemical bonding and some basic chemical reactions and substances of which you will need a knowledge in your further studies. The second part (learning units 7-10) explores basic principles of physics, including the measurement of matter, forces between particles, and the movement of particles. In the third part (learning units 11-20) you learn more about basic aspects of human physiology, starting with the basic unit of human life, like cells and tissues, and then proceeding to the various organ systems. This structure can be represented as follows:
You can go to the table of contents to see the names and subsections of each of the learning units.

Now that you have a better idea of how the module is structured, let’s look at what your studies will involve.

0.5 LEARNING RESOURCES
Your main learning resources for this module will be these learning units, your prescribed textbook, and the other elements of the module site and e-tutor site such as discussions. These resources will be supported by tutorial letters.
The prescribed textbook to be used in conjunction with the online material is:

Title: X-kit undergraduate: Physiology.
Authors: Buckle, M, Strauss, D, Engelbrecht, A, Ismail-Wesso, I, Knight, A, Mattheyse, M & Hewett, G.
Year published: 2006.
Publisher: Pearson Education South Africa (Pty) Ltd.

More details about the textbook are given in the menu option ‘Prescribed books’ to the left of this screen, and also in Tutorial Letter 101.

The textbook is a comprehensive guide to the subject field. You will not be required to study the whole textbook, as I will guide you to what is needed while working through these learning units. You will need to study the chapters that are mentioned at the beginning of each learning unit and any recommended reading sections. If you find a topic particularly interesting then feel free to do further reading on that topic.

Please note the following: The learning units may contain links to websites and online video clips. Since the internet is dynamic, it may however be possible that a link may be outdated or might have been moved when you try to access it. In such a case, you can do your own internet search to find similar sites or videos. To do this, go to www.google.com or a similar search site and type in keywords related to the topic.

0.6 MODULE-SPECIFIC STUDY PLAN
Read your Study @ Unisa brochure for general time management and planning skills.

This is a semester module over 15 weeks and requires at least 120 hours of study time; this means that you will have to study at least 8 hours per week for this module.

The following is a recommended time schedule that you could use as a guideline for studying this module.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>HOURS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading and re-reading Tutorial Letter 101 and learning unit 0</td>
<td>2</td>
</tr>
<tr>
<td>Skimming learning units and textbook, forming a thorough general impression of the whole</td>
<td>2</td>
</tr>
<tr>
<td>First reading of learning units 1-20 and textbook (@ 1 hour per learning unit)</td>
<td>20</td>
</tr>
</tbody>
</table>
ACTIVITY | HOURS
--- | ---
In-depth study of learning units 1-20, including doing learning activities and participating on the e-tutor site where possible (@ 3 hours per learning unit) | 60
Completing three assignments (Note: Assignments 1 and 2 should take less time than assignment 3; you will need to spend more time on assignment 3) | 10
Examination revision | 24
Writing the examination | 2
Total | 120

NOTE
There is a detailed suggested study plan in Tutorial Letter 101. Be sure to consult this and draw up your own schedule accordingly. Note that you will need to work at a reasonably fast pace to work through all the learning units, and that you need to start working on your fourth assignment early in the year already.

0.7 ORIENTATION TO USING MYUNISA
I have already outlined the advantages of online learning in section 0.1 of this learning unit. In the sections that follow, I will give you an orientation to using myUnisa. We will see how the Unisa menu options work, and refer to the “rules” or “etiquette” of online communications. Finally, you will have the opportunity to try your own hand at using one of the most important tools on myUnisa, the **Discussions** tool.

0.7.1 The myUnisa menu options
You need to be able to use the various menu options on this course site. They will enable you to participate actively in the learning process.

Click on the links below to see where the various options are located.

- **Learning units:** The learning units are your main learning resource in this module and contain the content and learning activities that you need to work through to achieve the module outcomes.
- **Official Study Material.** Tutorial Letter 101 is stored under this option, as well as past examination papers.
- **Announcements:** From time to time I will use this facility to give you important information about this module. Here you will receive e-mail notification of new announcements placed on myUnisa.
- **Schedule:** This tool gives you access to important dates and details about events, such as examination dates and deadlines for your assignments.
You will need this information to help you manage your time and plan your own schedule.

- **Course contact:** If you want to send me e-mails in connection with this module, use this tool to communicate with me.
- **Additional resources:** I may use this folder to provide any additional learning support material that might help you in your studies for this module. I will send an e-mail alert or announcement to inform you if I add anything to this folder.
- **Discussions:** This tool allows us to hold discussions as if we were in a contact setting. On your e-tutor site there may be a number of discussion questions for you to answer. You can also post any specific queries to the e-tutor (in the e-tutor site) or the lecturer (on the main module site). There will also be a forum for students, where you can discuss issues among yourselves, or just support one another.
- **Assignments:** This tool allows you to submit your assignments electronically, and to monitor your results. If you can, please submit your assignments via myUnisa. If you do not know how to do this, consult Tutorial Letter 101.

### 0.7.2 myUnisa etiquette

myUnisa is the university’s online platform where lectures and students meet, interact and participate in an ongoing process of learning and teaching. In interacting online, always remember to be mindful of and respectful towards your fellow students and your lecturers. The rules of polite behaviour on the internet are referred to as *netiquette* – a term that means “online manners”.

You can access the websites below to learn more about netiquette.

- [http://networketiquette.net/](http://networketiquette.net/)
- [http://www.studygs.net/netiquette.htm](http://www.studygs.net/netiquette.htm)
- [http://www.carnegiecyberacademy.com/facultyPages/communication/netiquette.html](http://www.carnegiecyberacademy.com/facultyPages/communication/netiquette.html)

Please observe the rules of netiquette during your normal, everyday online communications with colleagues, lecturers, and friends. In particular, remember to be courteous to your fellow students when using the **Discussions** tool.

### 0.8 ASSESSMENT IN THIS MODULE

Your work in this module will be assessed by the following:

- Three written assignments, which will be used to calculate a year mark that will count 30% towards your final mark
- One written examination of 2 hours, which will count 70% towards your final mark

**Please consult Tutorial Letter 101** for details about the assessment in this module. Make sure to read the following information in the tutorial letter:

- How your assignment and exam marks will be calculated
- The due dates and unique numbers of your assignments
• How you should submit your assignments
• Examination periods, admission and marks

Tutorial Letter 101 also contains the actual assignment questions.

Remember that while Tutorial Letter 101 will be sent to you, you can also access an electronic version by clicking on the option “Official Study Material” on the homepage of the module site.

Good luck and enjoy the course!
1.1 INTRODUCTION
How would you define “matter”? Can you give a few examples?

You would have been right if you mentioned that we are all surrounded by matter on a daily basis. Anything that we use, touch, eat, etc. is an example of matter.

In this learning unit we shall look at matter, the physical states of matter, physical and chemical properties and changes in matter, and at the three categories of matter, namely elements, compounds and mixtures.

Learning outcomes

After you have completed this learning unit, you should be able to:

• identify the three physical states of matter and explain the differences between them
• explain, with examples, what the physical and chemical properties of matter are and the physical and chemical changes in matter
• explain what is meant by the law of conservation of energy and the law of conservation of matter and how it is applied in our daily activities
• classify matter and explain the differences between the different states of matter
• identify and apply the different ways of separating mixtures
• apply what you have learnt in this learning unit in your daily life

1.2 PHYSICAL STATES OF MATTER
What is matter? We come into daily contact with a number of things, such as trees, buildings, cars and people. The world is made up of all sorts of things. All these things look and feel different and are made from different materials. However, all these things have one thing in common—they are all made of something and take up space. Anything that takes up space and has weight is called matter.

Matter exists in three fundamental states: solid, liquid and gas. Can you give an example of each?
Rocks, wood and bricks are examples of solids. Water and oil are liquids; and the air we breathe is a mixture of gases.

These various states of matter behave differently in different situations. The kinetic theory of matter helps to explain the behaviour of matter, especially the flow or transfer of heat and the relationship between pressure, temperature and volume properties of gases.

In the next section, we will discuss this theory. After that, we will then look at changes in the state of matter.

1.2.1 The kinetic theory of matter

The kinetic theory of matter is based on the idea that matter is made of small constantly moving particles. The main principles of the theory are:

- All matter is made up of very small, invisible, moving particles. The size of the particles is different for each different substance.
- All particles are continuously on the move. The higher the temperature, the faster the particles move.
- Heavy particles move more slowly than light particles, at a given temperature.
- In a solid, the particles attract one another strongly. The particles are close to one another and are arranged in an orderly manner. These particles can be compared to a regiment of soldiers standing in an orderly manner at attention. The particles of a solid have very little freedom of movement, and can vibrate about fixed positions only (Figure 1.1). The particles do not take the shape or volume of the container in which they are placed.
- In a liquid, the particles are quite close together but not as closely packed as in a solid. The forces of attraction between the particles in a liquid are weaker than in a solid. This can be compared to a roomful of people mingling at a party. The particles of a liquid are relatively free to move (Figure 1.1). The particles take the shape but not the volume of the container in which they are placed.
- In a gas, the particles are free to move anywhere and the distances between particles are large. This can be compared to children running around on a playground (Figure 1.1). The particles take the shape and the volume of the container in which they may be placed.

So you can see that the kinetic theory can be used to explain many of the ways matter behaves, whether it is a solid, a liquid or a gas.

The following figure (Figure 1.1) illustrates the differences between the three physical states of matter.
In the next section, you will see that the kinetic theory can be used to explain many of the ways matter behaves, whether it is a solid, a liquid or a gas.

1.2.2 Changes in the state of matter
The state of a substance, be it a solid, liquid or gas, can be changed by heating or by cooling it (Figure 1.2).

**FIGURE 1.1**
*An illustration of the solid, liquid and gaseous physical states of matter*
*(Source: Unisa drawing)*

**FIGURE 1.2**
*Changes of states of matter*
*(Source: https://commons.wikimedia.org/wiki/File:States_of_Matter.JPG)*
To apply the kinetic theory of matter:

As a solid is heated, the particles start to vibrate faster and faster until they begin to break free from one another. The particles are now more free to move around each other and the solid starts to melt, like butter heating. A similar process occurs when a liquid turns to a gas, like water boiling.

But what happens when heat is removed from a substance? Take, for example, an ice cold cool-drink. After the glass has stood a few minutes at room temperature, droplets of liquid form on the side of the glass. Can you explain why this happens? Well, because the glass is cold, heat is removed from the surrounding area. Thus, the vapour particles (which are in gaseous state) begin to vibrate less and start to move closer to one another—therefore becoming a liquid on the glass.

Each of these states of matter has their own characteristics. Study Table 1.1 which lists the most common characteristics of each of the states of matter.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Solid</th>
<th>Liquid</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shape</td>
<td>Definite</td>
<td>Indefinite</td>
<td>Indefinite</td>
</tr>
<tr>
<td>Volume</td>
<td>Definite</td>
<td>Definite</td>
<td>Indefinite</td>
</tr>
<tr>
<td>Compressibility</td>
<td>Very low</td>
<td>Moderate to very low</td>
<td>High</td>
</tr>
<tr>
<td>Motion of particles</td>
<td>Highly restricted</td>
<td>Somewhat restricted</td>
<td>Unrestricted</td>
</tr>
<tr>
<td>Arrangement of particles</td>
<td>Highly ordered</td>
<td>Moderate ordered</td>
<td>Highly disordered (random)</td>
</tr>
</tbody>
</table>

1.3 PHYSICAL AND CHEMICAL PROPERTIES OF MATTER

Physical properties of matter are readily observable, like colour, size or smell. Physical properties include:

- taste
- odour
- physical state
- density
- hardness
- melting point
- solubility in water
- colour
- freezing point
Chemical properties of matter are only observable during a chemical reaction. Chemical properties include:

- a substance reacting (or not reacting) with air
- whether it is an acid or an alkali
- burning (or not burning) in a flame

The best way of explaining the difference between a physical and a chemical property is as follows:

A physical property tells us what a substance is—for example, it is brown, it is a liquid, it is odourless. A chemical property tells us what a substance does—for example, it reacts with an alkali to form water and a salt, it burns.

### 1.4 PHYSICAL AND CHEMICAL CHANGES OF MATTER

#### Example: Physical change

If you melt a block of ice, you still have water (H₂O) at the end of the change. If you break a bottle, you still have glass. Painting a piece of wood will not make it stop being wood. With this type of change, although the particular substance may change its state (for example, from a solid to a liquid), no new substances are formed.

Some common examples of physical changes are melting, freezing, condensing, breaking, crushing, cutting and bending.

#### Example: Chemical change

When you burn wood, the wood undergoes a chemical change, and new substances, such as carbon, are formed. Common examples of chemical changes that you may be somewhat familiar with are digestion, respiration, photosynthesis, burning and decomposition.

---

**Activity 1.1: Properties of matter**

1. List eight (8) examples of matter.
2. Classify the 8 examples you have provided under the following headings:
   - Solids
   - Fluids
   - Gases
3. Identify an object near you. List as many physical properties of this object as you can.
4. Can you identify the chemical properties of an object identified in 1.1.3? If so, name them.

---

**Feedback on activity 1.1**

The first question of the activity is quite straightforward and it’s easy to think of eight examples of any matter: a tree, a shoe, a cup, syrup, soup, etc. But
to classify these examples, one needs to think a bit deeper. Would you consider syrup as a solid or a liquid? Consider Table 1.1 with the characteristics of matter. Syrup is a liquid as it has an indefinite volume when scooped out of the jar. Consider all of your examples according to Table 1.1 and see whether your classification was correct.

Listing the physical properties of an object should be quite easy because the properties are readily observable. The object I identified is the mouse of my computer and its physical properties are black, hard, high density, no smell, high melting point, etc. The chemical properties are more difficult to identify because one has to identify what will happen in a chemical reaction: e.g. it will not burn in a flame.

1.5 COMPOSITION OF MATTER
When one considers what matter is composed of, we can divide matter into elements, compounds and mixtures.

In the sections that follow, I discuss each of these in more detail.

1.5.1 Elements
An element is a substance that cannot be broken into simpler substances by chemical means. You will learn more about atoms in study unit 2. Very little matter is made of one element alone. For example, pure gold is made of only the element gold (the symbol Au on the periodic table of elements). Most matter is made of different combinations of elements which are called compounds. Table 1.2 lists a number of elements we come across every day.

<table>
<thead>
<tr>
<th>Element</th>
<th>Where we come across it</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>Makes up $\frac{1}{5}$ of the air</td>
</tr>
<tr>
<td>Carbon</td>
<td>Charcoal, soot, burnt toast, etc.</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>Makes up $\frac{4}{5}$ of the air</td>
</tr>
<tr>
<td>Iron</td>
<td>Hammer, nails, cars, bridges, dustbins, etc.</td>
</tr>
<tr>
<td>Copper</td>
<td>Electrical wires, pans, ornaments, etc.</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Airplanes, cooking foil, bicycles, saucepans, etc.</td>
</tr>
</tbody>
</table>

Elements can be divided into **metals and nonmetals.**
• Metals

A summary of the typical physical properties of metals is given in Table 1.3. (Section 2.4 of study unit 2 has further information about metals and nonmetals.)

<table>
<thead>
<tr>
<th>Properties of metals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals are usually <strong>solid</strong> (Mercury is a metal that is a liquid at room temperature).</td>
</tr>
<tr>
<td>Metals <strong>conduct heat</strong> and electricity well.</td>
</tr>
<tr>
<td>Metals are <strong>hard</strong> and strong.</td>
</tr>
<tr>
<td>Metals usually have <strong>high density</strong>.</td>
</tr>
<tr>
<td>Metals usually have <strong>high melting and boiling points</strong>.</td>
</tr>
<tr>
<td>The surfaces of metals can be polished to shiny surfaces and reflect light (they are <strong>lustrous</strong>).</td>
</tr>
<tr>
<td>Metals can readily be formed into new shapes, for example by hammering or pressing (they are <strong>malleable</strong>).</td>
</tr>
<tr>
<td>Metals make a ringing sound when hit (they are <strong>sonorous</strong>).</td>
</tr>
</tbody>
</table>

• Nonmetals

Nonmetals do not conduct heat and electricity very well. They have very little lustre and seldom reflect light. They may be brittle and are neither ductile nor malleable. (A ductile metal can be drawn out into a thin wire.) At room temperature, a nonmetal may be a solid (sulphur, silicone and carbon), a liquid (bromine) or a gas (oxygen and nitrogen).

1.5.2 Compounds

The law of definite proportions (also called the law of constant composition) states that the elements that make up a compound are always composed with the **same elements** in the **same ratios** every time. For example, glucose is always composed of six carbon atoms, twelve hydrogen atoms and six oxygen atoms.

The properties of a compound are different to the properties of the elements from which it is made. A compound can be decomposed into the elements of which it is made. For example, water (H₂O) can be decomposed into the elements hydrogen and oxygen by means of an electric current as follows:
Electric current

Water (liquid) $\rightarrow$ hydrogen (gas) + oxygen

The compound water has chemical and physical properties that are quite different from those of the two elements hydrogen and oxygen.

1.5.3 Mixtures

A mixture can be either **homogeneous** (of the same kind) or **heterogeneous** (of different kinds).

In a homogeneous mixture such as air, soft drink or brass, the components are so finely divided and so well blended that they look like pure substances. In a heterogeneous mixture, however, the components are physically distinct and easily recognisable. Stew and vegetable soup are examples of heterogeneous mixtures.

### Activity 1.2: Composition of matter

1. Give two (2) examples of where each of the following can be found:
   - Aluminium
   - Carbon
   - Iron
   - Calcium
   - Copper
   - Silver
   - Oxygen
   - Sodium

2. Classify the elements mentioned in the previous question as metal or nonmetal elements.

3. In your opinion, what are the major differences between metals and nonmetals?

### Feedback on activity 1.2

When considering where you could find aluminium, did you only go back to Table 1.3 or did you think of examples from your daily life? Aluminium is used in kitchen utensils, exterior decorations, and in thousands of industrial applications. Although the electrical conductivity of aluminium is only about 60% than that of copper per area of cross-section, aluminium is used in electrical transmission lines because of its light weight. The alloys of aluminium are used in the construction of aircraft and rockets. Reflective aluminium coatings are used for telescope mirrors, making decorative paper, packaging, and many other uses. Alumina (synthetically produced aluminum oxide) is used in glassmaking and refractories.

You should have provided similar examples for the other substances mentioned in activity 1.2.
For more interesting information on the other elements or matter, you can visit the following website:

http://chemistry.about.com

1.6 SEPARATION OF MIXTURES
Barring a few exceptions, almost every compound is found naturally in an impure state such as a mixture of two or more substances. Often these substances need to be separated into their individual components.

Mixtures can be separated into their pure substance by either physical means or chemical means. Physical separation is much cheaper than chemical separation.

In the two sections that follow, I give some examples of physical separation methods.

1.6.1 Separation methods
These are methods in which the components of a mixture are physically separated from each other without undergoing chemical changes.

• Separation by hand

When a mixture is heterogeneous, such as a mixture of dried peas and dried beans, or a mixture of rice and small stones, the mixture can be separated into its components by hand. What else can you separate by hand?

• Separation by means of sieves or strainers

We can remove certain impurities from flour by sifting it. Water can be drained from cooked rice or pasta by means of a sieve, strainer or colander. It is important that the substances to be separated differ in particle size to allow the bigger particles to remain in the sieve and the smaller (sometimes liquid) particles to pass through.

• Separation by decanting

When an insoluble substance in a liquid is heavy, it may settle at the bottom of a container. The liquid can be poured off carefully. For example, when we do not have a tea strainer, we pour tea carefully to prevent the tea leaves from being poured into the cup with the tea.

• Separation by freezing

When a mixture of salt and water is frozen, it will freeze from the top downwards. The frozen ice at the top will be free of salt. The same method could be applied to other water-soluble substances.
• Separation by evaporation

Salt can be removed from sea-water by means of evaporation. When the water has evaporated, the salt remains.

For interest: How to grow crystal spikes in the sun

To understand separation by means of evaporation, this experiment can be great fun. Most crystals take days or weeks to form. Use this technique if you have a sunny day and want crystals FAST.

Difficulty: Easy

Time required: 1-3 hours

What you need:
• Black construction paper
• Pie or cake pan
• Warm water
• Epsom salts
• Scissors

Here’s how:

(1) First, a sunny day isn’t required, but it will help! You want rapid evaporation of the water to form the crystals, so select a warm, dry place to grow crystals (sunny patio or window is great).
(2) Use the scissors to cut black (or other dark colour) construction paper so that it will fit in the bottom of the pan.
(3) Add 1 tablespoon of Epsom salts to 1/4 cup warm water. Stir until the salt is dissolved.
(4) Put the construction paper in the pan and pour the salt solution over the paper.
(5) Put the pan in the place you have selected for growing the crystals. As the water evaporates, you will see lots of spiky crystals.
(6) Have fun! Use a magnifying glass to see your creations up close.

Tips:

(1) This is one of the fastest, least toxic methods of growing crystals. You can substitute regular salt for Epsom salts, but the resulting crystals won’t be as exciting.
(2) Wash your hands after handling Epsom salts. Don’t drink the solution and avoid spilling it on yourself.
(3) Experiment with adding water colours or food colour to the salt solution.

In the ground state (the lowest energy state) an electron will occupy the lowest possible energy level. This being the case, an electron will share an orbital with another in preference to occupying an orbital of higher energy. In doing so an electron pair is formed.
• **Separation by fractional distillation**

Fractional distillation is used to separate two miscible liquids, such as water and ethanol. Because ethanol has a lower boiling point than water, it will evaporate and can be distilled before the water boils. *(Miscible liquids are liquids that can be mixed together or can dissolve into one another in any proportion without separating.)*

Distillation is used in the industry for chemical manufacturing, pharmaceutical production, and food processing. In food processing distillation is used for:

– concentrating beverages  
– drying heat sensitive and viscous food additives  
– aroma recovery

A simple distillation apparatus is illustrated in Figure 1.3. To explain the example of the mixture of water and ethanol by means of this figure, the mixture is put in the container above the Bunsen burner. The mixture is heated to the boiling point of ethanol which is lower than that of water and measures 78.29 °C on the thermometer on top of the apparatus. The ethanol will evaporate and collect in the condenser which is cooled down. The ethanol will run down into the collection flask.

![A simple distillation apparatus](https://commons.wikimedia.org/wiki/File:Simple_distillation_apparatus.svg)

**FIGURE 1.3**  
*A simple distillation apparatus*  
*(Source: https://commons.wikimedia.org/wiki/File:Simple_distillation_apparatus.svg)*
### 1.6.2 Separation methods, continued

The following are some more physical separation methods:

- **Separation by magnetism**

  When iron filings have been mixed with a nonmagnetic substance, such as sulphur, the iron filings can be removed by means of a magnet. Pins that have accidentally been dropped on a carpet can be picked up easily with a magnet. Certain recycling centres remove metal from the waste or other materials by means of magnetism.

- **Separation by centrifugation**

  Centrifugation is used to separate cream from milk in a separator or to separate blood cells from a blood sample. The liquid containing the suspended material is spun very rapidly in a centrifuge. The materials with a higher density are thrown toward the outer portion of the apparatus and those with a lower density are concentrated near the inner portion.

- **Separation by filtration**

  A suspension is a mixture that has small particles of an insoluble substance dispersed in a liquid. A funnel is lined with filter paper, and the suspension is poured into the funnel. The liquid will pass through the funnel and is called the filtrate. The insoluble substance remains on the filter paper and is called the residue. We make use of filtration when making coffee with ground coffee beans and a cloth coffee bag or an electric coffee-maker with a filter. The apparatus required for the separation of a mixture by filtration is illustrated in Figure 1.4.

![FIGURE 1.4](https://1o411sciportfolio.wordpress.com/summary/separation-techniques/)

*FIGURE 1.4*

*Separation of a mixture by filtration*

*(Source: https://1o411sciportfolio.wordpress.com/summary/separation-techniques/)*
• **Separation by means of separating funnels**

Immiscible liquids are liquids that do not dissolve in one another, for example oil and water. When these liquids are poured into a separating funnel, they will eventually form separate layers. The liquid with the higher density will be at the bottom. The liquids can be separated by running the lower layer off through the tap of the separating funnel, which is illustrated in Figure 1.5.

![Separation of two liquids of different densities](http://purificationikwok.weebly.com/separating-funnel.html)

**FIGURE 1.5**

*Separation of two liquids of different densities*

(Source: http://purificationikwok.weebly.com/separating-funnel.html)

### Activity 1.3: Separation methods

1.3.1 Give four (4) of your own examples of mixtures that can be separated by hand.
1.3.2 Give three (3) of your own examples of mixtures that can be separated by means of a sieve or strainer.
1.3.3 Give two (2) of your own examples of mixtures that can be separated by decanting.
1.3.4 Give three (3) of your own examples of mixtures that can be separated by magnetism.
1.6.4 Feedback on activity 1.3

Various examples from our daily activities can be used in the answers for the above activity. One interesting example of separation by decanting is the decanting of a bottle of wine. Older red wines, especially vintage wines, can have sediment. Decanting aerates the wine, and ensures a clear fluid in the glass. Trained wine waiters use a subtle way of serving the wine. They shake the bottle as little as possible and pour the wine slowly.

Activity 1.4: Revision and reflection

(1) Explain the term “matter”.
(2) What is the difference between a physical and a chemical property in chemistry?
(3) What does the law of conservation of energy state?
(4) What does the law of conservation of matter state?
(5) Explain the differences between an element, a compound and a mixture.
(6) List FOUR methods, other than filtration and separation with a separating funnel, of separating mixtures.
(7) Now that you have completed the first learning unit, reflect on your progress and your learning success. Do you think that if you complete the other learning units at the same rate, you will finish studying in time? Do you feel that you have achieved the learning outcomes successfully? If not, what should you do?

Remember that you can learn more about learning strategies on the website of Unisa’s Directorate Counselling and Career Development, at http://www.unisa.ac.za/default.asp?Cmd=ViewContent&ContentID=96773.

1.7 CONCLUSION

In this unit matter was the point of focus. Matter is anything that occupies space and has weight. The three physical states of matter are solid, liquid and gas. Each of these physical states has different physical and chemical properties. A physical property tells us what a substance is, whereas a chemical property tells us what it does. Matter can be divided into elements, compounds and mixtures. A variety of methods can be used to separate mixtures.

One can think deeper and ask: “What does matter consist of?” All matter is composed of smaller particles called atoms. Learning unit 2 will clarify the facts on the interesting small particles of all matter.
LEARNING UNIT 2

Atomic structures and the periodic table of elements

2.1 INTRODUCTION

In learning unit 1 you learnt that all matter is composed of elements. Elements consist of atoms with very specific properties. In this learning unit we shall look at the atom and its particles. The prescribed textbook explains well how atoms fit into the levels of organisation, finally resulting in a complete organism (the human body). Read pages 3 to 7 in the prescribed textbook to understand the levels of structure and function.

Learning outcomes

After you have completed this learning unit, you should be able to:

- explain what an atom and a molecule is
- identify and name the particles of an atom
- draw a diagram of the structure of an atom
- identify and explain what an ion and isotope is
- explain how formulas are used to represent chemical substances
- determine the number of electrons, protons and neutrons and number of valence electrons of the first 20 elements by using the periodic table of elements

2.2 ATOMS

It is important for you to know that all matter is composed of very, very small particles called atoms. All elements consist of these particles called atoms, which are among the smallest physical entities that can exist independently. Because elements cannot be broken into simpler substances by chemical means, atoms are reported as the smallest building blocks of matter.

Atoms of the same element are identical, and atoms of different elements differ from each other. When two or more atoms combine, they form molecules. Therefore, when atoms combine to form a molecule, the molecule can consist either of atoms of the same kind or different atoms.

In the next section, I will give you an overview of the particles of atoms. After that, each will be discussed in detail.
2.3 PARTICLES OF AN ATOM

The early scientists believed that atoms could not be divided. Today we know that this is incorrect and that the atom is made up of subatomic particles. About 30 different types of subatomic particle have been identified. The detailed study of these subatomic particles concerns nuclear physicists. We need to know only about the three fundamental particles, namely protons, neutrons and electrons.

Atoms of all elements are built up from protons, neutrons and electrons, and different atoms have different numbers of these three particles. See Figure 2.1a for the basic structure of an atom. This same structure is represented somewhat differently in Figure 2.1b, which shows how the electrons are distributed around the nucleus.

![Figure 2.1A](https://commons.wikimedia.org/wiki/File:Atom-struc.svg)

**FIGURE 2.1A**

*The structure of an atom*

(Source: https://commons.wikimedia.org/wiki/File:Atom-struc.svg)

![Figure 2.1B](https://vimeo.com/87846726)

**FIGURE 2.1B**

*The structure of an atom showing electron distribution*

(Source: https://vimeo.com/87846726)
• Protons and neutrons

An atom has a nucleus which is situated in the centre of the atom. The nucleus is made up of protons and neutrons. Both these particles have a mass about the same as a hydrogen atom. The proton has a positive charge (+1) and the neutron, as its name suggests, has no charge (neutral). The protons and neutrons CANNOT move out of the nucleus.

Note that hydrogen atoms have one proton and one electron only, and no neutrons. Hydrogen is the only element which has no neutrons in its nucleus.

• Electrons

Electrons move around the nucleus and are negatively charged (-1). Electrons have a very small mass of $\frac{1}{1350}$ amu (atomic mass unit) but it is so small that it can usually be ignored when working out the total mass of the atom.

The electrons are located in layers or “shells” at different distances from the nucleus. The positions, relative masses and charges of these subatomic particles are summarised in Table 2.1.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
<th>Charge</th>
<th>Mass in amu</th>
<th>Location in the atom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>p</td>
<td>+1</td>
<td>1</td>
<td>Inside nucleus</td>
</tr>
<tr>
<td>Neutron</td>
<td>n</td>
<td>0</td>
<td>1</td>
<td>Inside nucleus</td>
</tr>
<tr>
<td>Electron</td>
<td>e⁻</td>
<td>-1</td>
<td>$\frac{1}{1350}$</td>
<td>Revolving around the nucleus</td>
</tr>
</tbody>
</table>

Activity 2.1: Atomic structure

Make your own summary of the information in the two preceding sections.

Feedback on activity 2.1

Below I list the important points regarding atomic structure which have been covered so far. Did you mention them in your summary?

• An atom can be pictured as a sphere with a central nucleus and electrons rotating around the nucleus (see Figures 2.1 and 2.5).
• The nucleus (the collective noun for which is nuclei) contains two types of particles, namely protons and neutrons.
• Protons and neutrons (in the nucleus) have approximately equal masses.
• A proton carries one positive charge, a neutron has no charge.
• The volume of the nucleus is very small compared to that of the entire atom.
• The mass of the atom is concentrated in the nucleus.
• Electrons are located outside the nucleus.
• Each electron carries one negative charge.
• An electron weighs only about $\frac{1}{1350}$ as much as a proton or neutron.

2.4 ATOMIC NUMBER AND MASS NUMBER

If atoms are electrically neutral, the number of protons in the nucleus, which are all positively charged, are exactly balanced (or cancelled) by the equal number of negatively charged electrons outside the nucleus. For example, in a neutral hydrogen atom the one proton is exactly balanced by the electron. In a helium atom the two positive charges (from the two protons) are exactly balanced by two negative charges (from two electrons), etc.

When atoms lose or gain electrons, we say they become “ionised”. Because electrons carry a charge, losing or gaining one will make an atom positive or negative.

Each element has a specific number of protons in its nucleus. This is what makes it different from all other elements. For example, hydrogen has one proton in its nucleus, helium has two, carbon has six, and so on. Because of this, scientists have given a special name for the number of protons in the nucleus of an atom and they called it the atomic number. Therefore, the atomic number of hydrogen is 1, helium has an atomic number of 2, lithium has three protons and therefore its atomic number is 3, and so on.

The various elements are usually shown in a table called the periodic table of elements (see Figure 2.2 in section 2.5). In the table, elements are arranged in the order of increasing atomic number. We can consult the periodic table to see what an element’s atomic number is.

For example:

Sulphur (S) is the 16th element in the periodic table (see the periodic table).

• Atomic number = 16
• Number of protons = 16
• Number of electrons = 16

Protons are not the only structures that contribute to the mass of an atom. The neutrons in the nucleus also contribute to the mass of the atom, although it does not have a charge. Thus the mass of an atom is equal to the number of protons plus the number of neutrons added together. This number is called the mass number of the atom. The number of neutrons can be found by subtracting the atomic number of the element from its mass number.
For example:

Potassium (K) is the 19th element in a periodic table (see the periodic table).

- Atomic number = 19
- Number of protons = 19
- Number of electrons = 19
- Mass number = 39.10 (see the periodic table)
- Number of neutrons = 39.10 – 19 = 20.10 neutrons

Thus a hydrogen atom with one proton and no neutrons has a mass number of one. Helium has two protons and two neutrons and has a mass number of four, and so on.

2.5 THE PERIODIC TABLE OF ELEMENTS

In this section I discuss the use and function of the periodic table. If you have access to the internet, you can go to http://www.chemicalelements.com for additional interesting information.

- The structure of the periodic table

In 1869 a Russian chemist, Dimitri Mendel’eev arranged the elements in a table, in order of increasing relative atomic mass. Mendel’eev put elements with similar properties into vertical columns called groups. The periodic classification has been updated a little since Mendel’eev’s time, but it is still the most important way of classifying elements. (Take note that you may find other classification methods from other authors.) See Figure 2.2 below.

![Figure 2.2: The periodic table of elements](image-url)
### TABLE 2.2

An alphabetical list of symbols and names of symbols in the periodic table

<table>
<thead>
<tr>
<th>Symbol Name</th>
<th>Symbol Name</th>
<th>Symbol Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ac–Actinium</td>
<td>Gd–Gadolinium</td>
<td>Po–Polonium</td>
</tr>
<tr>
<td>Ag–Silver (Argentum)</td>
<td>Ge–Germanium</td>
<td>Pr–Praseodymium</td>
</tr>
<tr>
<td>Al–Aluminium</td>
<td>H–Hydrogen</td>
<td>Pt–Platinum</td>
</tr>
<tr>
<td>Am–Americium</td>
<td>He–Helium</td>
<td>Pu–Plutonium</td>
</tr>
<tr>
<td>Ar–Argon</td>
<td>Hf–Hafnium</td>
<td>Ra–Radium</td>
</tr>
<tr>
<td>As–Arsenic</td>
<td>Hg–Mercury (Hydrargyrum)</td>
<td>Rb–Rabidium</td>
</tr>
<tr>
<td>At–Astatine</td>
<td>Ho–Holmium</td>
<td>Re–Rhenium</td>
</tr>
<tr>
<td>Au–Gold (Aurum)</td>
<td>Ha–Hassium</td>
<td>Rf–Rutherfordium</td>
</tr>
<tr>
<td>B–Boron</td>
<td>I–Iodine</td>
<td>Rg–Roentgenium</td>
</tr>
<tr>
<td>Ba–Barium</td>
<td>In–Indium</td>
<td>Rh–Rhodium</td>
</tr>
<tr>
<td>Be–Beryllium</td>
<td>Ir–Iridium</td>
<td>Rn–Radon</td>
</tr>
<tr>
<td>Bh–Bohrium</td>
<td>K–Potassium (Kaium)</td>
<td>Ru–Ruthenium</td>
</tr>
<tr>
<td>Bi–Bismuth</td>
<td>Kr–Krypton</td>
<td>S – Sulfur</td>
</tr>
<tr>
<td>Bk–Berkelium</td>
<td>La–Lanthanum</td>
<td>Sb–Antimony (Stibium)</td>
</tr>
<tr>
<td>Br–Bromine</td>
<td>Li–Lithium</td>
<td>Sc–Scandium</td>
</tr>
<tr>
<td>C–Carbon</td>
<td>Lr–Lawrencium</td>
<td>Se–Selenium</td>
</tr>
<tr>
<td>Ca–Calcium</td>
<td>Lu–Lutetium</td>
<td>Sg–Seaborgium</td>
</tr>
<tr>
<td>Cd–Cadmium</td>
<td>Md–Mendelevium</td>
<td>Si–Silicon</td>
</tr>
<tr>
<td>Ce–Cerium</td>
<td>Mg–Magnesium</td>
<td>Sm–Samarium</td>
</tr>
<tr>
<td>Cf–Californium</td>
<td>Mn–Manganese</td>
<td>Sn–Tin (Stannum)</td>
</tr>
<tr>
<td>Cl–Chlorine</td>
<td>Mo–Molybdenum</td>
<td>Sr–Strontium</td>
</tr>
<tr>
<td>Co–Cobalt</td>
<td>N–Nitrogen</td>
<td>Tb–Terbium</td>
</tr>
<tr>
<td>Cr–Chromium</td>
<td>Na–Sodium</td>
<td>Tc–Technetium</td>
</tr>
<tr>
<td>Cs–Caesium, Cesium</td>
<td>Nb–Niobium</td>
<td>Te–Tellurium</td>
</tr>
<tr>
<td>Cu–Copper (Cuprum)</td>
<td>Nd–Neodymium</td>
<td>Th–Thorium</td>
</tr>
<tr>
<td>Db – Dubnium</td>
<td>Ne–Neon</td>
<td>Ti–Titanium</td>
</tr>
<tr>
<td>Ds–Darmstadtium</td>
<td>Ni–Nickel</td>
<td>Tl–Thallium</td>
</tr>
<tr>
<td>Dy – Dysprosium</td>
<td>No–Nobelium</td>
<td>Tm–Thulium</td>
</tr>
<tr>
<td>Er – Erbium</td>
<td>Np–Neptunium</td>
<td>U–Uranium</td>
</tr>
<tr>
<td>Es–Einsteinium</td>
<td>O–Oxygen</td>
<td>V–Vanadium</td>
</tr>
<tr>
<td>Eu–Europium</td>
<td>Os–Osmium</td>
<td>W–Tungsten (Wolfran)</td>
</tr>
<tr>
<td>F – Flourine</td>
<td>P–Phosphorus</td>
<td>Xe–Xenon</td>
</tr>
<tr>
<td>Fe–Iron (Ferrum)</td>
<td>Pa–Protactinium</td>
<td>Y–Yttrium</td>
</tr>
<tr>
<td>Fm–Fermium</td>
<td>Pb–Lead (Plumbum)</td>
<td>Yb–Ytterbium</td>
</tr>
<tr>
<td>Fr–Francium</td>
<td>Pd–Palladium</td>
<td>Zn–Zinc</td>
</tr>
<tr>
<td>Ga–Gallium</td>
<td>Pm–Promethium</td>
<td>Zr–Zirconium</td>
</tr>
</tbody>
</table>
Each square in the periodic table contains the symbol of an element with a number above and below the symbol, as indicated below.

<table>
<thead>
<tr>
<th>2</th>
<th>The atomic number of the element (2) is given above the symbol (i.e. number of protons).</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>The symbol He represents the element helium.</td>
</tr>
<tr>
<td>4.003</td>
<td>The mass number (4.003) is given below the symbol (i.e. number of protons + neutrons).</td>
</tr>
</tbody>
</table>

**NOTE**

When doing calculations, use the number as given on the periodic table of elements. Do not round it off. For example, magnesium has a mass number 24.31. Do not round it off to 24, but use 24.31 in your calculations.

- **Important features of the periodic table**

In study unit 1 we said elements can be classified into metals and nonmetals. However, over three-quarters of the elements in the periodic table are metals and therefore a further classification beyond the simple metal/nonmetal is needed.

Note the following features of the table:

- Metals are found on the left side of the table, nonmetals on the right side of the table. (see Figure 2.2).
- Elements in the same group (in the vertical column) have similar properties. For example, group 1A (lithium, sodium, potassium, rubidium, caesium and francium) are all reactive metals.
- Even though the properties of the elements in a group are similar, their properties gradually change, in a steady, regular way as one moves down the group.
- The horizontal rows in the table are called periods. Moving from left to right across a period, the elements change from reactive metals on the left to reactive nonmetals on the right. In group 5 are the very unreactive gases, called the noble gases. In the middle of the period, the elements are rather unreactive, and sometimes show both metallic and nonmetallic properties.
- Reading from left to right and form top to bottom, the elements are in order of increasing relative atomic mass.

**NOTE**

You should know the first 20 elements of the periodic table and their names by heart. This includes the elements from hydrogen (H) to calcium (Ca). For calculation purposes, a periodic table of elements will be supplied to you during the examination.
2.6 THE SYMBOLS FOR ELEMENTS

The elements of the periodic table are represented by symbols, which are generally based on the Latin names for the elements. Some symbols should make sense to you immediately, such as C for carbon, O for oxygen and S for sulphur. This is because the English name is similar to the Latin name for these elements. Some of the others are quite baffling, such as Na for sodium, K for potassium, Fe for iron, Au for gold, and Ag for silver. This is because the English and Latin names for these elements are quite different.

Most of the elements have double letter symbols, and you have to make sure that you use an UPPER CASE for the first letter and a lower case for the second letter. That second letter is usually the first non-common letter between elements that have names starting with the same letter. For example, chromium and chlorine both start with “C” and so does the symbol. They both have “h” for the second letter but the third letter is different—it’s “l” for chlorine, “r” for chromium—and thus the symbols for those two elements are Cl for chlorine and Cr for chromium.

Examples:

- H for hydrogen
- N for nitrogen
- O for oxygen
- He for helium
- Ne for neon
- Mg for magnesium
- Cl for chlorine
- Mn for manganese

Many elements have Latin names:

Examples:

- Na: sodium (Latin: natrium)
- Cu: copper (Latin: cuprum)
- Pb: lead (Latin: plumbum)
- Ag: silver (Latin: argentum)
- Hg: mercury (Latin: hydrargyrum)
- Fe: iron (Latin: ferrum)

What is the purpose of using symbols for elements?

Symbols of elements provide the following information:

- The name of the element.
- It represents one atom of the particular element.
For example:

Fe means one atom of iron.
3Fe means three atoms of iron.

• The symbols can be used to represent molecules of different elements.

For example:

O₂ is a molecule of oxygen consisting of two atoms of oxygen.
5H₂ denotes five molecules of hydrogen, each molecule consisting of two atoms of hydrogen.

• The symbols can be used to represent molecules in the names of compounds.

For example:

CO₂ means one molecule of the compound carbon-dioxide.

• Symbols are also used in chemical equations.

**Activity 2.1: Elements**

1. Give the symbols of the following elements: Sulphur, Potassium, Mercury, and Sodium.
2. Give the names of the following symbols: F; Pb; Au; Cd.
3. How many electrons, neutrons and protons does an aluminium atom have? (Refer to section 2.3 and the periodic table.)
4. How many electrons, neutrons and protons does an argon atom have?
5. To which group does barium belong?
6. To which group does silicon belong?
7. Have a look at the following formula: 3H₂O. How many molecules of the compound water are there in the formula?
8. How many atoms of hydrogen are there in the above formula?
9. How many atoms of oxygen are there in the above formula?

**Feedback on activity 2.1**

In order to answer the questions in this activity, you need to have the periodic table handy. A suggestion is to make a photocopy of the periodic table instead of paging back to the table each time you need it. Remember that a periodic table will be given to you in the examination, therefore, please don’t learn it by heart. Learn the structure of the table and the names of the first 20 symbols, so that you will know what to look for when you are asked about the number of electrons, protons, neutrons, mass number or to which group an element belongs. See section 2.5 to assist you with this.

Aluminium has an atomic number of 13. Thus a neutral atom of aluminium has 13 protons and 13 electrons. Aluminium has a mass number of 26.98 (the protons and neutrons combined). To determine the number of neutrons: 26.98–13 = 13.98.
To determine the number of molecules or atoms in a formula it is important to understand the examples given in section 2.6 and study section 2.12.

2.6.1 For interest: Elements in the human body
The diagram below shows the elements in the human body.

![Elements in the human body](https://commons.wikimedia.org/wiki/File:201_Elements_of_the_Human_Body-01.jpg)

**FIGURE 2.3**
Elements in the human body

(See Figure 2.6 further below. Level 1 has only one block which will accommodate 2 electrons, while level 2 has 4 blocks which will be able to accommodate 8 electrons.)

Because an electron is very small and has a very small mass, it is difficult to determine its position and velocity at the same time. It is thus not possible to determine a fixed point along which an electron moves. The best we can do

---

2.7 ARRANGEMENT OF ELECTRONS IN AN ATOM
Refer back to Figure 2.1b in section 2.3 (the structure of an atom). As you can see in this illustration, we showed the electrons to be arranged around the nucleus in two different layers or “shells”. These shells are also called energy levels, and they are numbered 1, 2, 3, 4 and so on. The larger the number of the energy level, the further it is from the nucleus.

Experimental evidence led scientists to conclude that there are a maximum number of electrons that can exist in any particular energy level.

For example:

Energy level one \( (n = 1) \) can contain a maximum of 2 electrons.
Energy level two \( (n = 2) \) can contain a maximum of 8 electrons.
(See Figure 2.6 further below. Level 1 has only one block which will accommodate 2 electrons, while level 2 has 4 blocks which will be able to accommodate 8 electrons.)
is to define spaces within the energy levels, called orbitals, in which electrons will probably be found.

An electron occurring by itself in an orbital is known as an unpaired electron (Figure 2.4(a)). When two electrons occur in an orbital, the orbital is filled, and the electrons are called an electron pair (Figure 2.4(b)).

Each electron spins around its own axis. The two electrons in an orbital always spin in opposite directions from each other, as illustrated in Figure 2.4 (a).

In a symbolic representation, electrons are represented by arrows. The opposite direction of the two arrows in one orbital represents the opposite direction of spin of the two electrons, as illustrated in Figure 2.5 (b).

However, it was found that all energy levels, except the energy level nearest to the nucleus, can be subdivided. Within a particular energy level, sublevels exist which have slightly different energies. For example, the second energy level \((n = 2)\), can be subdivided into two sublevels, two electrons can be accommodated in one sublevel and six in the other (see Figure 2.7).

Electrons are constantly moving around the nucleus and it is impossible to predict the exact location of an electron at any particular time. Nevertheless scientists have calculated that there are regions around the nucleus in which the chance (probability) of finding an electron is the greatest.

Figure 2.6 is a representation of an atom and the electron’s movement around the nucleus.
Each energy level within an atom can contain a specific number of orbitals. An orbital cannot contain more than two electrons. It can be empty, or contain one or two electrons but it cannot contain more than two electrons. It has been established from experimental evidence that for the first 20 elements the orbitals are filled as follows:

- The energy level nearest to the nucleus (named: n = 1) can accommodate a maximum of two electrons in a 1s orbital (see Figure 2.7).
- The energy level second from the nucleus (n = 2) can accommodate a maximum of eight electrons, thus 4 orbitals.
- The energy level third from the nucleus (n = 3) can also accommodate a maximum of eight electrons, thus also 4 orbitals.
2.8 FILLING OF ORBITALS

You already know that the atoms of different elements contain different numbers of electrons. How are the electrons arranged in the different orbitals? In section 2.6 you were told that the maximum number of electrons which can be accommodated in any one orbital is two.

Let us imagine that orbitals are like rooms in a high-rise building and the electrons are the people living in the rooms. Look at Figure 2.8 while reading this. How would the rooms be occupied if two people are willing to share a room but unwilling to climb stairs unless it is necessary? The first person will occupy the flat on the first level. If a second person moves in he is prepared to share this room rather than climbing the steps to the second level. The third person cannot be accommodated on the first level (it is full), therefore he must go to the second level where he can occupy the next room. The fourth person will share the second room with the third person in the second level, because the next three rooms are on a slightly higher level than the second room. Three more people can be accommodated in separate rooms on the second level as illustrated in Figure 2.8 below (persons 5 to 7). Thereafter the next three tenants must share flats on the second level. Ten people may be accommodated on the first two levels but the 11th person would need to climb to the third level, etc. Note that the manner in which the people are filling up the rooms is indicated by numbers in Figure 2.8. You should always follow this sequence when drawing the symbolic representation of an electron structure.

Similarly there is a definite order in which the orbitals in an atom are occupied by electrons. The principles which govern the arrangement of electrons in orbitals are determined by the following:
(1) All electrons carry a negative charge and will therefore repel each other. An electron therefore tends to occupy an orbital on its own, if possible, rather than share an orbital.

(2) In the ground state (the lowest energy state) an electron will occupy the lowest possible energy level. This being the case, an electron will share an orbital with another in preference to occupying an orbital of higher energy. In doing so an electron pair is formed.

**Activity 2.2: Electrons in the atom**

State whether the following statements are true or false.

(1) Electrons occur in different energy levels around the nucleus.
(2) Energy level 1 is furthest from the nucleus.
(3) The path of an electron around a nucleus can be specified exactly.
(4) An energy level can contain different orbitals, represented by letters like s and p.
(5) Orbital 1s can accommodate 4 electrons only.
(6) Orbital 2p can accommodate a maximum of 6 electrons.
(7) Energy level 3 can accommodate a maximum of 8 electrons.
(8) When more than one orbital is available for electrons, they will fill up the orbitals two by two.

**Feedback on activity 2.2**

The true statements in the activity above are 1, 4, 6 and 7; the others are false. If one or more of your answers were incorrect and you are not sure why, carefully read the previous sections again and see if you can spot your errors. If not, consult your e-tutor.

### 2.9 STRUCTURE OF AN ATOM

What does an atom look like? The structures of three different atoms—namely the hydrogen, the helium and the sodium atom—are described below.

- **Electron structure of hydrogen**

The simplest atom, hydrogen (H) has an atomic number of 1 and a mass number of 1. The atomic number means that the hydrogen atom has one proton in the nucleus. To find the number of neutrons, one has to subtract the atomic number from the mass number. Since both are one, there are no neutrons in the nucleus. Since there is only one proton, there is also only one electron, which goes into the first energy level. This is illustrated in the diagram in Figure 2.9(a).

When the electron structure of hydrogen is represented symbolically, as in Figure 2.10(b), the orbital with the lowest energy state is the 1s-orbital (read this as one-s-orbital). The single electron of hydrogen is therefore found in this orbital.
Electron structure of helium

The second element, helium (He), has an atomic number of 2 and a mass number of 4. This means that there are two protons and two neutrons in the nucleus, and two electrons outside the nucleus. The two electrons fill up the first energy level, which can take only two electrons.

Electron structure of the first ten elements

For the first 20 elements the electron structure (arrangement) can be calculated as explained above. The heavier elements, however, do not follow these simple rules. For this course, however, you do not require knowledge of the orbitals and the electron arrangement for the elements from number 21 onwards.

Activity 2.3: Atomic structure of the elements

1. Draw and label a diagram of the electron structure of a sodium atom (Na).
2. Give a symbolic representation of the electron structure of a sodium atom.
3. Draw a diagram of the energy levels of a phosphorus atom (P).
4. Give a symbolic representation of the electron structure of a phosphorus atom.

Feedback on activity 2.3

It is important that you have the ability to give a diagram as well as a symbolic representation of the electron structure of the first 20 elements of the periodic table. You should have referred to relevant figures in earlier sections to guide you. The answers to questions 1 and 2 are shown below:
FIGURE 2.10
Diagram and symbolic representation of the electron structure of sodium.

Your answers to questions 3 and 4 should look similar to the diagram above, but of course the numbers of protons, neutrons and electrons will differ.

2.10 ISOTOPES

Isotopes are atoms of the same element that have the same atomic number but different mass numbers. The number of protons and electrons remains the same for the different isotopes of one element, but there are different numbers of neutrons in their nuclei.

For example, the element carbon has three isotopes. The atomic number of carbon is six. This means that it has six protons and six electrons. The mass number could however be 12, 13 or 14. The carbon atom could therefore have six, seven or eight neutrons. Carbon-12 is the most abundant carbon isotope and has a mass number of 12.

Activity 2.4: Isotopes

Explain the difference between an ion and an isotope.

Feedback on activity 2.4

Ions are formed when there is a change in an atom’s electrons, whereas isotopes refer to the number of neutrons in an atom:

- From section 2.4 you will remember that when atoms gain or lose an electron they become negatively or positively charged. When this happens, the atom is called an ion. For example, a neutral atom of carbon has six protons (which carry a positive charge) and six electrons (which carry a
negative charge) – the positive and negative charges cancel each other out and so the atom carries no charge. However, if a carbon atom gains an electron, there will seven negative electrons as against six positive protons, and the atom will be negatively charged; it will be a negative ion. Similarly, if the carbon atom loses an electron, it will become a positive ion.

- In general, an atom has the same number of protons and neutrons. However, some forms of certain elements may have atoms with one or more neutrons than protons. For example, carbon generally has six protons and six neutrons, but some carbon atoms may also have six, seven or eight neutrons. Since the neutrons are electrically neutral, this will not affect the charge of the atom. However, it will affect the atom’s mass – the more neutrons, the heavier it will be. We can therefore define an isotope as atoms of the same element that have the same atomic number but different mass numbers.

2.11 MOLECULES

A molecule is the smallest particle of a compound that can exist independently and still have the properties of that compound. Molecules are distinguished from ions by having no electrical charge.

Matter may consist of molecules formed from the same element, for example, an oxygen (O₂) molecule consists of two oxygen atoms. Matter can also consist of molecules formed by the bonding of atoms of different elements and is called a compound. Water (H₂O) for example consists of two atoms of hydrogen and one atom of oxygen.

Figure 2.11 is a summary of what we have already learnt.
2.12 COMPOUNDS, MOLECULES AND FORMULAE

When iron and sulphur combine with each other the compound iron (II) sulphide is formed. It can now be said that one molecule of the compound iron (II) sulphide has been formed. A very large number of different compounds can be formed by various combinations of the over 100 known elements.

The formulae of compounds are obtained by using the symbols of the elements from which those compounds were formed.

For example, the formula of iron (II) sulphide, FeS, indicates that the elements, iron and sulphur, have combined with each other to form the compound iron (II) sulphide (FeS). Because the two elements Fe and S combine with each other in the ratio of 1 atom of iron to 1 atom of sulphur, the formula is FeS. Note that we do not write the formula as Fe₁S₁. If no number appears after the symbol of the element, it indicates 1 atom of the element.

Let us look at water, its formula is H₂O. The small number, in this case a two, at the bottom right of the H (hydrogen) indicates the number of atoms of the element directly in front of the number—in this case hydrogen. The small 2 has NOTHING to do with the oxygen of H₂O.

Another example:

Carbon-dioxide: CO₂

The formula above indicates that one atom of carbon combines with two atoms of oxygen to form one molecule of carbon-dioxide.

3CO₂: The number in front of the formula, in this case 3, indicates that there are three molecules of carbon-dioxide present.

To calculate the number of carbon atoms and oxygen atoms in three molecules of carbon dioxide, we do the following:

In one molecule CO₂ there is one carbon atom (there is no small number on the right-hand side of the C, which indicates that there is only one carbon atom) and two oxygen atoms (the small two on the right-hand side of the O...
indicates that there are two atoms of oxygen). However, in the case of 3CO₂ (three carbon dioxide molecules) all the atoms should be multiplied by three.

There are 3 x 1 carbon atom = 3 carbon atoms
and 3 x 2 oxygen = 6 oxygen atoms in 3 carbon dioxide molecules.

Remember when there is a number in front of the formula it indicates the number of molecules of that particular compound. If there is NO number in front of the formula it indicates that there is one molecule of that particular compound.

If the formula is changed, it is not that particular compound any more.

For example:

H₂O is water—Essential for life.
H₂O₂ is hydrogen peroxide—POISONOUS.

The formula of a compound (e.g. NH₃) indicates the following:
• The name of the compound (ammonia).
• The elements which make up the compound (nitrogen and hydrogen).
• The ratio in which the different elements combined to form a molecule of the compound (such as 1:3 in the molecule NH₃).
• That we are dealing with only one molecule of the compound.

**Activity 2.4: Molecular formulae**

(1) Study the formula below and then answer the questions:

N₂O (nitrous oxide)

(1.1) How many oxygen atoms are there in N₂O?
(1.2) How many nitrogen atoms are there in N₂O?
(1.3) How many molecules of N₂O are there in this example?

(2) Study the formula below and then answer the questions:

4H₂SO₄ (sulphuric acid)

(2.1) How many oxygen atoms are there in the above formula of sulphuric acid?
(2.2) How many sulphur atoms are there in the above formula of sulphuric acid?
(2.3) How many molecules of sulphuric acid are there in this example?

**Feedback on activity 2.4**

Remember that when no number is written in front of the molecule (as in N₂O in question 1 of activity 2.4) there is only one molecule. But in the case of sulphuric acid in question 2 (4H₂SO₄) the number 4 is in front of the formula for the molecule, meaning that there are 4 molecules of sulphuric acid.
To determine the number of each type of atom, such as hydrogen (H), you then need to multiply the number of atoms with the number of molecules. Therefore:

- In 4 molecules of sulphuric acid the number of oxygen atoms = 4 (molecules) x 4 (oxygen atoms) = 16 oxygen atoms
- In 4 molecules of sulphuric acid the number of sulphur atoms = 4 (molecules) x 1 (sulphur atom) = 4 sulphur atoms
- There are 4 molecules of sulphuric acid, as the number in front of the molecular formula indicates.

2.13 VALENCE ELECTRONS

All the elements in the same vertical column of the periodic table, that is the elements in the same group or family, have the same number of electrons in their outer energy level. When you look at group 1A in the periodic table, you will see that the elements hydrogen (H), lithium (Li) and sodium (Na) each have one electron in their outermost energy level. This is illustrated in Figure 2.13 below.

![Diagram of the electron structures of hydrogen, lithium and sodium](image)

In group 2A of the periodic table, the elements beryllium (Be), magnesium (Mg) and calcium (Ca) each have two electrons in their outermost energy level.

The electrons in the outermost energy level are called valence electrons. An easy way of determining the number of valence electrons of an element is by the group number. The group number 2A, for example, indicates that the elements in this group have two valence electrons. Oxygen is in group 6 and has six valence electrons.

Activity 2.3: Revision and reflection

1. Define an atom.
2. Define a molecule.
3. Define a compound.
4. Explain the term of valence electrons.
5. How many valence electrons does sodium (Na) have?
(6) Why do elements in the same group have similar chemical properties?
(7) How do isotopes differ from one another?
(8) Think of any five items you use every day – for example a cup, a spoon, a washing machine, a glass, a key, a vitamin tablet. What are some of the main elements or compounds that these are made of? Which well-known elements do you encounter frequently, and which do you hardly encounter at all?

2.14 CONCLUSION

An atom is the smallest portion of an element that retains all the properties of the element. The nucleus of an atom consists of protons and neutrons. Electrons move in energy levels around the nucleus. Isotopes are atoms of the same element that have the same number of protons but different numbers of neutrons. Protons are atoms that have either lost or gained one or more electrons and are therefore positively or negatively charged.

It is obvious that for atoms to form a molecule there needs to be some kind of bond between the atoms to produce a new compound with different chemical characteristics. In learning unit 3 the bond between atoms, characteristics of certain atoms to bond, and giving a balanced equation for chemical bonding will be explained.
Chemical bonding

3.1 INTRODUCTION
In learning unit 1 we mentioned that the physical and chemical properties of a compound are quite different from those of the elements of which it is composed. For example, sodium chloride (NaCl) is a well-known compound, commonly known as table salt. Sodium (Na), one of the elements of which sodium chloride is composed, is a soft metal that reacts explosively with water, whereas chlorine (Cl2), the other element of the compound is a greenish-yellow poisonous gas. Water (H2O) is also completely different from the elements of which it is composed, namely the colourless and odourless hydrogen and oxygen gases. In this learning unit we shall look at how elements are joined (bound) together to form compounds.

To be able to understand the chemical bonds between atoms, we need to look at how atoms tend to react.

Learning outcomes

After you have completed this learning unit, you should be able to:

- explain why a noble gas is energetically very stable
- calculate the valencies of the first 20 elements by using the periodic table of elements
- explain the role of valence electrons in ionic and covalent bonding
- using the periodic table of elements, illustrate the Lewis structures of the first 20 elements

3.2 NOBLE GASES
As we have seen before, the atoms of most elements consist of a nucleus, containing protons and neutrons, surrounded by different shells or energy levels which contain electrons. You should note that there is a maximum number of electrons that every energy level can hold, for example:

- The first energy level can hold a maximum of two electrons.
- The second energy level can hold a maximum of eight electrons.
- The third energy level can hold a maximum of eight electrons.
The group of elements on the far right-hand side of the periodic table of elements, group 8A, is known as the noble gases. Among the noble gases are the elements, helium, neon and argon. The noble gases are mono-atomic, which means that a molecule of a noble gas consists of one kind of atom only. Diagrams of the energy levels of the noble gases show that the outer energy level is filled up with the maximum number of electrons which is eight electrons.

Below I discuss each of these in more detail.

- **Helium (He)**

  The noble gas helium has an atomic number of 2 and two electrons. Because helium has only one energy level, this energy level holds the maximum number of two electrons, as illustrated in Figure 3.1.

  ![Figure 3.1](source: Unisa drawing)

- **Neon (Ne)**

  The noble gas neon has an atomic number of 10, which means it has ten protons and ten electrons. The first energy level holds a maximum number of two electrons, and the second energy level holds a maximum of eight electrons, as illustrated in Figure 3.2.

  ![Figure 3.2](source: https://en.wikipedia.org/wiki/Noble_gas)
• **Argon (Ar)**

The noble gas argon has an atomic number of 18 and therefore 18 electrons. The first energy level holds a maximum of two electrons, the second energy level holds a maximum of eight electrons, and the third energy level holds a maximum of eight electrons, as illustrated in Figure 3.3.

![Electron structure of argon](https://ceb.wikipedia.org/wiki/Argon)

As the above illustrations show, the outermost energy levels of helium, neon and argon are full (hold the maximum number of eight electrons) and cannot accommodate any more electrons.

An atom wants to be in a position where it uses the least possible energy. The atoms of noble gases are in a state where they use very little energy, and we can therefore say that the electron configuration (electron structure) of the noble gases is **energetically very stable**.

Atoms of other elements are also driven to become energetically more stable—to have their outer energy level filled with eight electrons (or with two electrons if the first energy level is the outer energy level). To become energetically stable an atom of an element combines with another atom of the same element. One or more atoms of an element can also combine with one or more atoms of another element to become energetically stable. Since the noble gases already have completely filled outer energy levels, they will not easily combine with other atoms. They are therefore mono-atomic.

The **hydrogen** molecule (H₂) is also energetically very stable because the outer energy level is filled with the maximum number of electrons. This is because each hydrogen atom in the molecule provides one electron, forming two electrons in each hydrogen’s outer energy level. The electron configuration is illustrated in Figure 3.4.
3.3 VALENCY

The valency of an element is a number that tells us how many electrons an atom must lose, gain or share in order to acquire a noble gas electron configuration (that is, to have eight electrons in the outer energy level). This is different from valence electrons as discussed in section 2.12. Make sure you understand the difference.

You can determine the valency of most elements by looking at the periodic table of elements. Ignore the transition metals (the centre groups marked with a B). Concentrate on Groups 1A and 2A on the left-hand side and Groups 3A, 4A, 5A, 6A, 7A and 8A on the right-hand side.

For elements in Groups 1, 2 3 and 4 of the periodic table, the valency is equal to the group number, as follows:

- Elements in Group 1 have a valency of 1.
- Elements in Group 2 have a valency of 2.
- Elements in Group 3 have a valency of 3.
- Elements in Group 4 have a valency of 4.

The valency of elements in Groups 5, 6, 7 and 8 is obtained by subtracting the group number from eight, as follows:

- Elements in Group 5 have a valency of 8 – 5 = 3.
- Elements in Group 6 have a valency of 8 – 6 = 2.
- Elements in Group 7 have a valency of 8 – 7 = 1.
- Elements in Group 8 have a valency of 8 – 8 = 0.

Note that an element’s valency is not always equal to its number of valence electrons.
Now that you know how to determine the valency of an element, you also know the number of electrons one atom of that element must lose, gain or share in order to acquire a noble gas electron configuration. For example:

- Magnesium (Mg) has three energy levels. Its first energy level is filled with the maximum two electrons. Its second energy level is filled with the maximum of eight electrons. In its third energy level, it only has two electrons. To become stable, it can theoretically do one of two things: it can either gain six electrons, which would give it eight electrons in its third shell; or, it can lose the two electrons in its outer shell. Clearly, it will be easier for magnesium to lose its two outer electrons than to gain six electrons. Since it has two electrons in its outer shell, we say it has a valency of 2 – which we can also see by checking where it is located in the periodic table: it is in Group 2A.

- Chlorine (Cl) also has three energy levels. Its first energy level is filled with the maximum two electrons. Its second energy level is filled with the maximum of eight electrons. In its third energy level, it has seven electrons. It therefore needs one more electron to gain a stable, noble gas configuration. It thus has a valency of 1, which again we can establish when we see that it is in Group 7A (remember 8–7 = 1).

How can magnesium and chlorine “help” each other to get a noble gas electron configuration? One chlorine atom needs one electron to complete its outer shell, while magnesium has two electrons in its outer shell. Magnesium can thus “give” each one of its electrons to two chlorine atoms. In this way, the outer levels of the two chlorine atoms will now be stable, as will the magnesium atom. Therefore a compound would form: \(2\text{Cl}^- + \text{Mg}^{2+} = \text{MgCl}_2\) (magnesium chloride). See Figure 3.5 below.

![FIGURE 3.5](structure_of_magnesium_chloride.png)

Structure of magnesium chloride
(Source: Unisa drawing)
3.4 LEWIS STRUCTURE

Atoms are held together by one of three types of bonds, namely ionic bonds, covalent bonds or metallic bonds. You need to understand only the ionic and covalent bonds.

This is an abbreviated representation of the structure of an atom. The nucleus and all the energy levels, except the outer energy level, are represented by the symbol of the element. Each of the electrons in the outer energy level (the valence electrons) is indicated by means of dots or crosses around the symbol.

- **Let us look at the Lewis structures of carbon and oxygen.**

Carbon has six electrons—two in the first energy level and four in its outer energy level. Figure 3.6 below shows its symbolic representation.

![Carbon structure](Source: Unisa drawing)

The four electrons in the outer energy level are the valence electrons and are used in the Lewis structure. In order to determine where around the symbol the electrons should be indicated, you need to look at the symbolic representation above. Level 2s has two electrons (a pair) and Level 2p also has two electrons, but they are unpaired. The Lewis structure should indicate each of the two paired electrons and the two unpaired electrons—in total four electrons (see Figure 3.7 below).

![Lewis structure of carbon](Source: Unisa drawing)
Oxygen has eight electrons—two in the first energy level and six in the outer energy level. Thus, oxygen has six valence electrons (four paired and two unpaired). The Lewis structure of oxygen is illustrated in Figure 3.8.

![Lewis structure of oxygen](FIGURE 3.8 Lewis structure of oxygen)

The Lewis structures for the elements helium, boron and chlorine with the valence electrons indicated by crosses, is illustrated in Figure 3.9 below.

![Lewis structure for the elements helium, boron and chlorine.](FIGURE 3.9 Lewis structure for the elements helium, boron and chlorine.)

If you would like to see a more detailed explanation of how to draw Lewis structures, watch the following video clip:

https://www.youtube.com/watch?v=ulyopnxjAZ8

### Activity 3.1: Valency and Lewis structures

1. What is the valency of boron? (Refer to section 3.2.)
2. What is the valency of sulphur?
3. What is the valency of chloride?
4. What is the valency of magnesium?
5. Give the Lewis structure for silicon.
6. Give the Lewis structure of bromine.
7. Give the Lewis structure for neon.

### Feedback on activity 3.1

**Definition of valency:** Valency refers typically to the number of electrons that an atom must either gain or lose to fill its outermost shell. Because exceptions exist, the more general definition of valency is the number of electrons with which a given atom generally bonds or the number of bonds an atom forms.
Example: A neutral carbon atom has six electrons. The electron shell configuration is $1s^22s^22p^2$. Carbon has a valency of 4, since four electrons can be accepted to fill the 2nd energy level ($2s$ and $2p$).

Valence electrons, on the other hand, are different from the valency. Whilst valency is the number needed to fill the orbital to have a “full” electron configuration (see section 3.2), valence electrons are merely the number of electrons in the outer energy level of the electron configuration. Take chlorine as an example. It has a valency of 1 (it needs to bind with one electron to have eight electrons in its outermost shell). However, its number of valence electrons is seven: it has seven electrons in its outer energy level. Therefore, when drawing the Lewis structure of chloride, there should be seven dots or crosses around the symbol Cl (see Figure 3.9). The Lewis structure of silicon (Si) would therefore have four dots or crosses around the symbol Si. The Lewis structure for bromine (Br) would have seven dots or crosses like chloride. Neon (Ne) is a noble gas (group 8A) and has eight electrons in its outer energy level. Thus, it will have eight dots or crosses around the symbol Ne when the Lewis structure is drawn. By grasping this information, your understanding of chemical bonding will be much easier.

3.5 IONS

We have already mentioned that all elements want to be energetically stable—that is, to have a completely filled outer energy level. In order to obtain a filled outer energy level, elements lose or gain electrons.

Let us look at lithium, the third element in the periodic table, as an example. In a lithium atom there are three positively charged protons in the nucleus which are balanced by the three negatively charged electrons outside the nucleus. Remember that the neutrons in the nucleus carry no charge. This lithium atom is represented in Figure 3.10(a). If, however, an electron is removed from a lithium atom—as represented in Figure 3.10(b)—a lithium particle is formed which carries one unbalanced positive charge (it has three protons and two electrons). Such a particle is called an ion and this ion is positively charged, as it has one extra proton. It is written as Li⁺.

**FIGURE 3.10**

*Diagrammatic representations of (a) a lithium atom and (b) a positive lithium ion*  
(Source: Unisa drawing)
On the other hand, if you take a fluorine atom (the ninth element in the periodic table), it has nine positively charged protons in the nucleus which are balanced by the nine negatively charged electrons outside the nucleus. This fluorine atom is represented in Figure 3.11(a). If, however, an electron is gained by the fluorine atom—as represented in Figure 3.11(b)—a fluorine particle is formed which carries one unbalanced negative charge (nine protons and ten electrons). Such a particle is called an ion and this ion is negatively charged. Such a particle is called a negative ion, written as F⁻.

![Diagrammatic representations of (a) a fluorine atom and (b) a negative fluorine ion](Source: Unisa drawing)

An ion which carries a **positive charge** is called a **cation**.

An ion which carries a **negative charge** is called an **anion**.

The physical and chemical properties of the elements and the ways in which they react during chemical reactions (chemical reactivity) are largely governed by their atomic structure. Atoms tend to either lose, gain or share electrons with other atoms, resulting in the formation of chemical bonds.

Table 3.1 shows a list of some ions with their charges. Most metal ions have a charge of 2+. The only common metal ions without a charge of 2⁺ are Na⁺, K⁺, Ag⁺, Al³⁺, Fe³⁺, and Cr³⁺.


### Table 3.1: Charges of some common ions

<table>
<thead>
<tr>
<th>Positive ions (cations)</th>
<th>Negative ions (anions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>-2</td>
</tr>
<tr>
<td>Hydrogen H⁺</td>
<td>Bromide Br⁻</td>
</tr>
<tr>
<td>Sodium Na⁺</td>
<td>Chloride Cl⁻</td>
</tr>
<tr>
<td>Potassium K⁺</td>
<td>Hydroxide OH⁻</td>
</tr>
<tr>
<td>Silver Ag⁺</td>
<td>Iodide I⁻</td>
</tr>
<tr>
<td>Copper Cu²⁺</td>
<td>Nitrate NO⁻</td>
</tr>
<tr>
<td>Lead Pb²⁺</td>
<td>Oxide O²⁻</td>
</tr>
<tr>
<td>Iron (II) Fe²⁺</td>
<td>Sulphide S²⁻</td>
</tr>
<tr>
<td>Zinc Zn²⁺</td>
<td>Carbonate CO³⁻</td>
</tr>
<tr>
<td>Aluminium Al³⁺</td>
<td>Sulphate SO₄²⁻</td>
</tr>
<tr>
<td>Iron (III) Fe³⁺</td>
<td>Sulphite SO₃²⁻</td>
</tr>
<tr>
<td>Chromium³⁺</td>
<td></td>
</tr>
</tbody>
</table>

### 3.6 COMPOUNDS AND CHEMICAL BONDING

As discussed, atoms often complete their outer shells by sharing electrons with other atoms, or by losing or gaining electrons. In order to complete its outer shell, a carbon atom, for instance, requires four electrons (2 of 4). A hydrogen atom requires one. Thus, when a carbon atom shares electrons with four hydrogen atoms, each completes its outer shell.

Electron sharing binds the atoms together and satisfies the conditions of maximum stability for the molecule. The outer shell of each atom is complete, since hydrogen effectively has the required two electrons in its first (outer) shell, and carbon has eight electrons in its second (outer) shell. The molecule is thus electrically neutral, with a total of 10 protons and 10 electrons, resulting in a compound, namely methane (CH₄). See Figure 3.12.

![Methane molecular structure and Lewis diagram](https://commons.wikimedia.org/wiki/File:Methane-2D-dot-cross.png and Unisa drawing)

**FIGURE 3.12**

The compound methane (CH₄): (a) shows its molecular structure, and (b) the structure represented in a Lewis diagram.

*(Sources: [https://commons.wikimedia.org/wiki/File:Methane-2D-dot-cross.png](https://commons.wikimedia.org/wiki/File:Methane-2D-dot-cross.png) and Unisa drawing)*
Bonds that involve the **sharing** of electrons, like the bond between carbon and hydrogen, are the most stable kind of association that atoms can form with one another. They are sometimes called **covalent bonds**, and the resulting combinations of atoms are called **molecules**. A single pair of shared electrons forms a **single bond**, illustrated with a single line. Whilst, when two oxygen atoms form a molecule of oxygen, they must share two pairs of electrons: see Figure 3.13. Note that the double bond is indicated by two lines.

\[
\text{O} = \text{O}
\]

**FIGURE 3.13**
*Illustration of covalent double bond in an oxygen molecule by means of the Lewis structure*

An **ionic bond**, on the other hand, is a chemical link between two atoms caused by the **electrostatic force** between **oppositely charged ions** in an ionic compound. This is created when an atom **gains or loses electrons**, for example in the case of magnesium chloride explained in section 3.4. Another example is the ionic bond between the sodium and chloride ions in table salt, NaCl.

In summary, what is the difference between an **ionic bond** and a **covalent bond**?

In an ionic bond, the atoms are bound together by the **attraction between oppositely charged ions**. For example, sodium and chloride form an ionic bond, to make NaCl, or table salt. In a covalent bond, the atoms are bound by **shared electrons**.

For a revision of ions and bonding, you can watch the following video clips:

- [https://www.youtube.com/watch?v=900dXBWgx3Y](https://www.youtube.com/watch?v=900dXBWgx3Y)
- [https://www.youtube.com/watch?v=zpaHPXVR8WU](https://www.youtube.com/watch?v=zpaHPXVR8WU)

### 3.7 FOR INTEREST: CHEMICAL NAMES OF COMMON SUBSTANCES

Chemical or scientific names are used to give an accurate description of a substance’s composition. Even so, you would not really ask someone to pass the sodium chloride at the dinner table. It’s important to remember that common names are inaccurate and vary from one place and time to another. Therefore, don’t assume that you know the chemical composition of a substance based on its common name.
<table>
<thead>
<tr>
<th>Common name</th>
<th>Chemical name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aspirin</td>
<td>acetylsalicylic acid</td>
</tr>
<tr>
<td>Baking soda</td>
<td>sodium bicarbonate</td>
</tr>
<tr>
<td>Bleaching powder</td>
<td>chlorinated lime</td>
</tr>
<tr>
<td>Brimstone</td>
<td>sulphur</td>
</tr>
<tr>
<td>Chalk</td>
<td>calcium carbonate</td>
</tr>
<tr>
<td>Epsom salts</td>
<td>magnesium sulphate</td>
</tr>
<tr>
<td>Lime</td>
<td>calcium oxide</td>
</tr>
<tr>
<td>Salt, table</td>
<td>sodium chloride</td>
</tr>
<tr>
<td>Saltpetre</td>
<td>potassium nitrate</td>
</tr>
<tr>
<td>Sugar, table</td>
<td>Sucrose</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>impure dilute acetic acid</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>ascorbic acid</td>
</tr>
</tbody>
</table>

Activity 3.2: Ions and chemical bonding

1. In your own words, explain what an ion is. Use an example to illustrate your answer.
2. This is a discussion question that you should answer on your e-tutor site.

   Use an example to illustrate, in your own words, the difference between a covalent bond and an ionic bond. Also comment on at least one other student’s posting.

Activity 3.3: Revision and reflection

1. Explain what a noble gas is and list three (3) examples.
2. What does the term “valency” mean?
3. Give the Lewis structure for sodium.
4. Explain what an ion is.
5. Explain electron sharing.
6. How will understanding more about how chemical compounds form benefit you in further studies in fields like human physiology and nutrition? Briefly write down any ideas you have about this.

3.8 CONCLUSION

The valency of an element tells us how many electrons it must lose, gain or share for it to have a complete outer energy level. Valence electrons are those in the outer most energy level in the electron configuration.
Atoms that share electrons are bound by covalent bonds. No ions are formed with these bonds. Atoms can also be held together by an ionic bond. Electrons are then either lost or gained, and ions are formed. Here two (or more) atoms are bound together and attracted to one another because they have opposite charges.

Now that you understand how and why atoms bond, we will move on to specific atoms and their chemical properties. In study unit 4 the focus will be on oxygen and other significant gases.
LEARNING UNIT 4

Oxygen and other gases

4.1 INTRODUCTION
In the previous learning unit we looked at noble gases, valency, Lewis structures, ions, and compounds and chemical bonding. In this learning unit we will narrow our focus to look more specifically at oxygen, burning elements in oxygen, oxides, and other important gases.

Oxygen is one of the most abundant elements in the earth’s atmosphere. Despite its importance, however, oxygen is not the only gas that plays a role in our daily lives. In this learning unit we shall be studying oxygen and other gases that are important to us.

Learning outcomes
After you have completed this learning unit, you should be able to:

• describe the physical and chemical properties of oxygen
• explain, with equations, how acid oxides, basic oxides and neutral oxides are formed
• name the other important gases, and list their properties

4.2 OXYGEN
The air we breathe is a mixture of gases. Approximately four-fifths ($\frac{4}{5}$) of air consists of nitrogen, and oxygen makes up about one fifth ($\frac{1}{5}$). The rest is water vapour, carbon dioxide and noble gases. Eighty per cent of our oceans and lakes consist of oxygen. Together, silicon and oxygen form the earth’s crust. From this we can see that oxygen is all around us. Let us look at both the physical and chemical properties of oxygen.

• **Physical properties of oxygen**

Oxygen is a colourless, odourless and tasteless gas. It is slightly soluble in water and slightly heavier than air. The small amount of oxygen dissolved in water enables fish and other aquatic animals to breathe. Oxygen forms a pale blue liquid at -182.5 °C and a pale blue solid at -218.4 °C.
• Chemical properties of oxygen

Oxygen is moderately active at room temperature and extremely reactive at higher temperatures. Oxygen can combine with many other elements to form oxides. The reaction between oxygen and another element is called oxidation.

• Burning elements in oxygen

If a substance will burn in air, it will burn even better in pure oxygen. We can investigate the burning of elements in oxygen using the method illustrated in Figure 4.1.

![Figure 4.1: Burning of elements in oxygen to be inserted](Source: Unisa drawing)

Once the element has burned, the product can be examined. Table 4.1 shows the results obtained when some elements are burned in oxygen.

<table>
<thead>
<tr>
<th>Elements</th>
<th>How it burns</th>
<th>Product</th>
<th>Appearance of product</th>
<th>Acid/alkaline nature of product in water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>Glows bright red</td>
<td>CO₂ (carbon dioxide)</td>
<td>Colourless gas</td>
<td>Weak acid</td>
</tr>
<tr>
<td>Sodium</td>
<td>Brilliant yellow flame</td>
<td>Na₂O (sodium oxide)</td>
<td>White solid</td>
<td>Alkali</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Brilliant white flame</td>
<td>MgO (magnesium oxide)</td>
<td>White solid</td>
<td>Weak acid</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Blue flame</td>
<td>H₂O (water)</td>
<td>Colourless liquid</td>
<td>Neutral</td>
</tr>
<tr>
<td>Sulphur</td>
<td>Blue flame</td>
<td>SO₂ (sulphur dioxide)</td>
<td>Colourless gas</td>
<td>Acid</td>
</tr>
<tr>
<td>Iron</td>
<td>Red hot sparks</td>
<td>Fe₂O₃ (iron (II, III) oxide)</td>
<td>Black solid</td>
<td>Insoluble</td>
</tr>
<tr>
<td>Copper</td>
<td>Glows sparks</td>
<td>CuO (copper oxide)</td>
<td>Black solid</td>
<td>Insoluble</td>
</tr>
</tbody>
</table>
We must be careful of making general rules based on these few results in Table 4.1. However, looking at the properties of many more elements, though, we can make two general rules:

- The oxides of metals are always solids. The oxides of nonmetals are usually liquid or gases.
- The oxides of metals are alkaline or insoluble in water. The oxides of nonmetals are usually acidic.

4.3 OXIDES
There are three main types of oxides, namely acid oxides, basic oxides and neutral oxides.

- **Acid oxides**
  Acid oxides are formed when oxygen combines with a nonmetal.
  For example, when carbon combines with oxygen, carbon dioxide is formed. This reaction is written as follows:
  \[ C + O_2 \rightarrow CO_2 \]
  Similarly, when sulphur combines with oxygen, sulphur dioxide is formed. This reaction is written as follows:
  \[ S + O_2 \rightarrow SO_2 \]

- **Alkaline oxides**
  Basic oxides are formed when oxygen combines with a metal. (Note that in chemistry the term “basic” refers to an alkaline substance.)
  For example, when magnesium combines with oxygen, magnesium oxide is formed. This reaction is written as follows:
  \[ 2Mg + O_2 \rightarrow 2MgO \]
  When sodium combines with oxygen, sodium oxide is formed.
  \[ 4Na + O_2 \rightarrow 2Na_2O \]

- **Neutral oxides**
  Neutral oxides are neither acid nor basic.
  For example, when hydrogen combines with oxygen, water (or hydrogen oxide) is formed:
  \[ 2H_2 + O_2 \rightarrow 2H_2O \]
Similarly, when carbon combines with oxygen, carbon monoxide is formed:

\[ 2C + O_2 \rightarrow 2CO \]

### Activity 4.1: Oxides

(1) Complete the following table.

<table>
<thead>
<tr>
<th>Oxide</th>
<th>State (solid/liquid/gas)</th>
<th>Acidic or alkaline (basic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxides of metals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oxides of non-metals</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(2) Complete the table.

<table>
<thead>
<tr>
<th>Oxygen</th>
<th>combined with …</th>
<th>gives …</th>
<th>Example (chemical formula)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a nonmetal</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>a metal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>hydrogen</td>
<td></td>
<td></td>
<td>[ 2H_2 + O_2 \rightarrow 2H_2O ]</td>
</tr>
<tr>
<td>carbon</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

You can check your answers against the information given in the previous sections.

### 4.4 OTHER IMPORTANT GASES

- **Nitrous oxide**

Nitrous oxide \((N_2O)\), also known as laughing gas, is frequently used as a general anaesthetic. It does not combine with haemoglobin and, unlike carbon monoxide, is therefore not poisonous.

- **Carbon tetrachloride**

Carbon tetrachloride vapours \((CCl_4)\) are very toxic to the body and damage the liver and kidneys. Carbon tetrachloride is sometimes used as a grease solvent in spot removal, a practice that should be avoided. Its use has been banned by the US Food and Drug Administration because of its great toxicity and carcinogenic (cancer-forming) properties.
• **Chlorine**

Chlorine is a pale yellow gas with a very pungent odour. Because it kills microorganisms, chlorine is frequently used for water purification. In large amounts, chlorine vapours are toxic because they destroy lung tissues.

Note that a bleach containing sodium hypochloride (NaOCl), such as Javel, Jik or Milton, should NEVER be mixed with a cleaning agent containing ammonia, such as Handy Andy, since chlorine gas will be formed.

• **Carbon monoxide**

Carbon monoxide (CO) is a colourless, odourless and tasteless gas. It is formed when carbon combustion takes place in the presence of insufficient oxygen and the carbon is incompletely oxidised. (Combustion or “burning” is the rapid chemical combination of a substance with oxygen, involving the production of heat and light.)

Carbon monoxide combines with haemoglobin in the blood, forming such a strong bond that the blood cannot transport oxygen and is therefore dangerous when inhaled.

• **Sulphur dioxide**

Sulphur dioxide (SO₂) is used as a preservative in soft drinks and as a reducing bleach.

• **Nitrogen**

Four-fifths of the air consists of nitrogen, which is a colourless, odourless and tasteless gas that does not react easily. It forms an important part of amino acids and fertilisers.

Certain foods, such as dried coffee and milk powder, are packed into airtight containers where all the air and oxygen have been replaced by nitrogen. This helps to preserve the food.

• **Carbon dioxide**

Carbon dioxide (CO₂) forms 0,03% of the air. CO₂ is released by human, animal and plant respiration, and by fermentation and combustion. It is heavier than air and will sink to collect in caves or wells. Uses of CO₂ include the following:

- It does not burn or support combustion and is therefore used in fire extinguishers.
- CO₂ retards the growth of bacteria and is used for food preservation. Fruit juices are preserved by the addition of 1,5% of CO₂ under pressure.
- Under pressure, carbon dioxide changes to a colourless fluid and, when cooled further, to a solid known as dry ice. Dry ice is generally used to keep ice-cream frozen. Since it is dry, it will not melt into a messy substance.
- Fizzy soft drinks contain CO₂ that has been dissolved under pressure. When a soft drink bottle is opened, the pressure is reduced and the gas fizzes out of the solution.
– CO$_2$ is the gas released when yeast, baking powder or bicarbonate of soda is used as a raising agent. The yeast releases CO$_2$ during the fermentation process. The production of CO$_2$ by baking powder is discussed in learning unit 6.

**Activity 4.2: Important gases**

Answer the following questions briefly. You may have to do a bit of internet research to complete your answers.

1. This is a discussion question that you should answer in the Discussions space in your e-tutor site.
   
   Give an example of a gas used in the food or textile industry for the following, and briefly explain what specifically it is applied for:
   
   (a) Chilling and freezing
   (b) Food preservation
   (c) Packaging
   (d) Bleaching
   
   Also comment on at least one other student’s posting.

2. Explain what pollution is and give four examples.

3. Most of us, especially the ones living in the cities, breathe in air that contains a number of substances which put our health at risk. Name three such substances and give the following information for each:
   
   (a) How the substance is released into the air
   (b) Why it is harmful to our health
   (c) How the levels of the substance in the air could be controlled

4. Explain the term “greenhouse effect” and how this effect affects the world.

5. Explain why smoking is harmful to a person.

**Feedback on activity 4.2**

This activity will give you more insight on how different gaseous compounds can affect our daily lives as well as our health. Because gases are diffused through the air, we cannot see the effects directly. We might smell it, but do not recognise the possible harm to our health. After answering question 5 in activity 4.2 on smoking and health, consider how you feel about South Africa’s law on public smoking. Do you support it or not?

**Activity 4.3: Revision and reflection**

1. Give three (3) examples of elements that form oxides which are liquids or gases at room temperature.

2. Give three (3) examples of elements that form oxides which are solids at room temperature.

3. Give two (2) examples of elements that form acidic oxides.

4. Give two (2) examples of elements that form alkaline oxides.
(1) Study the table below and answer the following questions:

<table>
<thead>
<tr>
<th>Element</th>
<th>Atmospheric air</th>
<th>Exhaled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>79</td>
<td>79</td>
</tr>
<tr>
<td>Oxygen</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>0.03</td>
<td>4</td>
</tr>
</tbody>
</table>

(5.1) Which gas is used during breathing?
(5.2) Which gas is produced during breathing?
(5.3) Explain what happens to these gases between entering and leaving the lungs.

Suppose that you have a senior post in a company that uses gases in its operations. Think about the implications this may have for (a) health and safety, and (b) environmental pollution. What will you do about this?

4.5 CONCLUSION

Oxygen is the most plentiful element. The three main types of oxides that can be formed are acid oxides, base oxides and neutral oxides. Other important gases are nitrous oxide, carbon tetrachloride, chlorine, carbon monoxide, sulphur dioxide, nitrogen and carbon dioxide.

When compounds/elements are combined with oxygen, the reaction is known as oxidation. This reaction usually produces a form of energy. In the following study unit we will discuss oxidation and reduction.
LEARNING UNIT 5

Oxidation and reduction

5.1 INTRODUCTION

The previous learning unit focused on oxygen, burning elements in oxygen, oxides and other important gases. This learning unit will focus on oxidation, reduction, reducing and oxidising agents, and the applications of different aspects.

When we use the word fuel, we usually think of coal, oil, petrol and wood. You will less likely think of candle wax as a fuel, and even less of something like mealie meal porridge and milk being fuels. Yet all these materials can be oxidised to produce energy. This is what is meant by the term “fuel". As you can see from this, that oxidation (and its “opposite” chemical process, reduction) is an important concept to understand when you are studying nutrition.

Learning outcomes

After studying this unit, you should be able to:

• explain what oxidation and reduction are
• explain what an oxidising agent and a reducing agent are, and identify these agents
• apply your knowledge of redox reactions to explain the rusting of metals, the action of bleaches and the oxidation of food

5.2 OXIDATION

Oxidation means combining with oxygen, and this is usually done by burning a substance in air. Materials such as wood, coal, paraffin and candle wax all burn to release heat and light energy, and thus serve as fuels. When petrol burns in an internal combustion engine, the heat energy it gives out is partly converted to mechanical energy. Food like mealie meal porridge could be burned, but when we eat food the energy is released by a more controlled sort of oxidation usually referred to as biochemical oxidation. In spite of some differences, all the fuels we have mentioned have several things in common.

• They all react with oxygen.
• They all produce energy, usually heat, when they react with oxygen.
• They all produce carbon dioxide and water when oxidised.
Oxidation can also be defined as either one of the following:

- An electron loss
- An increase in oxidation state

**Electron loss**

As an example, let us look at the following equation:

\[
Na + Cl \rightarrow Na^+ + Cl^-
\]

The sodium atom has one electron in its outer energy level. In the reaction with chlorine, the sodium loses this electron to form a sodium ion, and its charge becomes +1. This loss of an electron is defined as oxidation. We say the sodium atom is “oxidised” during the reaction.

**Oxygen gain**

Normally, we think of oxidation only as an oxygen gain. An example is the combination of coal with oxygen during combustion, resulting in the formation of carbon dioxide, as follows:

\[
C + O_2 \rightarrow CO_2
\]

### 5.3 REDUCTION

Reduction is the process of removing oxygen. Whereas oxidation is an electron loss or an increase in oxidation state, reduction involves an electron gain or a decrease in oxidation state.

**NOTE**

Oxidation can take place without reduction.

Let us look at the following equation again:

\[
Na + Cl \rightarrow Na^+ + Cl^-
\]

As was stated earlier, sodium loses an electron and is oxidised in the reaction of sodium with chlorine. Chlorine, however, gains an electron and is reduced.

Let us look at the reaction of glucose with oxygen during our body’s metabolic processes. The combination of glucose with oxygen leads to the formation of carbon dioxide, water and energy, as follows:

\[
C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}
\]

Glucose + oxygen → carbon dioxide + water + energy

The glucose is oxidised (electron loss), but the oxygen is reduced (electrons gained). Oxidation is therefore also defined as a hydrogen loss, and reduction
as a hydrogen gain. The glucose loses hydrogen atoms, and the oxygen gains hydrogen atoms.

If you would like a more extensive explanation of oxidation and reduction (redox) reactions, watch the following video clip:

https://www.youtube.com/watch?v=Ybh8K8yOLZ0

5.4 OXIDISING AGENTS AND REDUCING AGENTS
Let us look at the following reaction in which hydrogen and lead oxide combine to form lead and water:

\[
H + \text{PbO} \rightarrow \text{Pb} + \text{H}_2\text{O}
\]

Hydrogen + lead oxide → lead + water

In the above reaction, lead oxide is reduced (its oxygen is removed/electron gain) by hydrogen. Therefore, hydrogen is the reducing agent. Hydrogen, however, is oxidised by the lead oxide. Therefore, lead oxide is the oxidising agent.

Activity 5.1: Redox reactions

(1) Explain what happens in the following reaction, using the correct names for the chemical processes that take place:

\[
\text{Fe} + \text{Cu}^{2+} \rightarrow \text{Fe}^{2+} + \text{Cu}
\]

(2) Draw your own picture or diagram to show the difference between a reducing and an oxidising agent.

5.5 EXAMPLES OF REDOX REACTIONS
In the sections that follow, I discuss the effect of redox reactions on the following:

- Metals
- Bleaching agents
- Food

5.5.1 Effect of redox reactions on metals
Some metals react with oxygen as soon as they are exposed to air. Others will only react when heated in air. Table 5.1 is a summary of the reaction of metals by heating them in air and seeing how vigorously they react.
TABLE 5.1

Reaction of some metals with oxygen when they are heated in air

<table>
<thead>
<tr>
<th>Metal</th>
<th>How it reacts</th>
<th>Product</th>
<th>Equation for reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>Burns slowly forming a white surface layer</td>
<td>aluminium oxide $\text{Al}_2\text{O}_3$</td>
<td>$4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$</td>
</tr>
<tr>
<td>Copper</td>
<td>Does not burn, it oxidises turning black on surface</td>
<td>copper oxide $\text{CuO}$</td>
<td>$2\text{Cu} + \text{O}_2 \rightarrow 2\text{CuO}$</td>
</tr>
<tr>
<td>Iron</td>
<td>Only burns when in powder or wool form</td>
<td>iron (II, III) oxide $\text{Fe}_3\text{O}_4$</td>
<td>$3\text{Fe} + 2\text{O}_2 \rightarrow \text{Fe}_3\text{O}_4$</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Burns readily with a brilliant white glow, forming a white powder</td>
<td>magnesium oxide $\text{MgO}$</td>
<td>$2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$</td>
</tr>
<tr>
<td>Sodium</td>
<td>Burns very readily with a yellow glow, forming a white powder</td>
<td>sodium oxide $\text{Na}_2\text{O}$</td>
<td>$4\text{Na} + \text{O}_2 \rightarrow 2\text{Na}_2\text{O}$</td>
</tr>
</tbody>
</table>

Table 5.1 shows that some metals react better with oxygen than others. Results like this can be used to place metals in order of reactivity. This order is called the reactivity series. Figure 5.1 shows the reactivity series for a number of metals. In this diagram, the closer a metal appears to the top of the arrow, the more reactive it is.

Potassium
Sodium
Calcium
Magnesium
Aluminium
Zinc
Iron
Tin
Lead
Copper
Silver
Gold

FIGURE 5.1

The reactivity series of some metals
Reactive metals, like sodium and magnesium, have a strong tendency to join with non-metals, like oxygen, forming compounds. Less reactive metals, like copper, have little tendency to combine with oxygen. The very unreactive ones, like gold, actually prefer to stay uncombined. This is why gold is so valuable for jewellery. It never tarnishes by combining with air, so it always keeps its shine.

In summary, we can say: Reactive metals prefer to combine and form compounds, and unreactive metals do not.

Below I discuss a specific example in more detail.

• Rust

When the exposed surface of a metal loses its bright, shiny look and becomes dull and tarnished, we say it has started to “corrode”. Some metals, such as copper, are rather unreactive and will corrode very slowly. Although aluminium is a fairly reactive metal it hardly corrodes. This can be explained by the fact that aluminium quickly forms a thin, but very strong layer of aluminium oxide which protects it from further corrosion. Unprotected iron corrodes (rusts) very quickly. However, there are methods to protect iron from rusting.

Rusting is a very serious problem which costs large amounts each year to prevent. Nevertheless, iron is a cheap strong metal and is used in building bridges, cars, ships and many other structures.

• What causes rust?

Iron rusts quickly if it is wet. Salt helps rusting too. Metal structures on ships or near the seaside rust at a very fast rate. Rust is an oxidation reaction. Both oxygen and water must be present for iron to rust. Rust is iron (III) oxide, Fe₂O₃. Rusting is a complicated reaction and involves several stages. During rusting, small electric currents flow in the metal. If the iron is in contact with water containing salt, or other ionic substances, it rusts faster because the water conducts electricity better.

• How can rust be prevented?

There are a number of ways to prevent rust.

• Protection by oil or paint

A protective layer of oil, grease or paint, or a plastic covering can be applied to keep air and water away from the iron and stops it from rusting. This only works as long as the layer is not damaged. As soon as the paint peels or the oil rubs off, rusting will start.

• Alloying

Some metals, such as aluminium, form a tough layer of oxide which protects them from further corrosion. Unfortunately the rust layer formed over iron is porous and flaky and does not protect it. However, iron can be mixed with certain metals, like chromium or nickel, which do form a protective oxide.
coat. These alloys are called stainless steels, and might contain up to 20% chromium or nickel.

- **Plating**

Iron is sometimes covered with a thin layer of another metal, such as chromium or tin, which is unreactive and does not corrode quickly. The metal protects the iron in the same way as a coat of paint would. This is called plating. Tinned food is sold in steel cans, covered with a thin layer of tin, but these too rust quickly once the tin layer is removed. For this reason food should never be left inside a tin once it has been opened.

- **Sacrificial coating**

If iron is coated with a more reactive metal, such as zinc, it will not rust even if the coating is scratched off in places. Zinc is more reactive than iron, so it is oxidised in preference. The layer of zinc is more than just a protective coating, keeping out air and water. It actually saves the iron from corroding, by corroding itself. The zinc is sacrificed for the sake of iron, and it will go on protecting the iron as long as there is some zinc left (this is why it is called a “sacrificial” coating). It is not necessary to cover the whole surface of the iron, as long as some of the iron is in contact with zinc. Zinc-coated iron is called *galvanised iron*. Many iron and steel articles that are used outdoors are galvanised such as wheelbarrows and corrugated iron furniture.

### Activity 5.2: Redox reactions and metals

1. Write down the balanced equations for the following reactions:
   - Calcium reacting with oxygen
   - Copper reacting with oxygen

2. This is a discussion question that you should answer in the discussion forum on your e-tutor site.

   When powdered magnesium is mixed with powdered copper oxide and the mixture is heated, a violent reaction occurs, forming magnesium oxide and copper. However, if the reaction is tried the other way around by mixing and heating the end products, namely magnesium oxide and copper, nothing happens. Study Figure 5.1 and then answer the following questions:
   - (a) Explain why the above reaction took place.
   - (b) Write down the balanced equation for the reaction between magnesium and copper oxide.
   - (c) What do you predict will happen if iron is heated with magnesium oxide?

3. Aluminium is heated with iron oxide.
   - (a) What kind of reaction will you expect?
   - (b) What will be oxidised, and what will be reduced in the reaction between aluminium and iron oxide?
   - (c) What will you predict will happen if iron is heated with magnesium oxide?
5.5.2 The effect of redox reactions on bleaching agents

We will now look at two different types of bleaching agents, namely oxidising bleaches and reducing bleaches.

Oxidising bleaches

Examples of oxidising bleaches include the following:

• Natural bleaches

The most harmless bleaches are the sun, dew, frost and rain. You can bleach damp, soaped washing by spreading it out on a patch of grass. The washing is bleached because the oxygen in the air and the oxygen produced by the green grass during photosynthesis oxidise stains. The alkali from the soap speeds up the bleaching process.

• Potassium permanganate

Potassium permanganate (KMnO₄) is a powerful oxidising agent that will bleach a stain. The potassium permanganate itself is then reduced to a brown stain, manganese dioxide. Oxalic acid can then be used to remove the brown stain.

• Chlorine bleaches

Javel, Jik and Milton are solutions of sodium chloride (NaCl or table salt) and sodium hypochlorite (NaOCl).

A weak solution of carbonic acid (H₂CO₃) is formed when carbon dioxide (CO₂) from the air dissolves in water (H₂O).

The chlorine gas is easily released by the carbonic acid. It combines with the water to form hydrochloric acid (HCl) and nascent oxygen as follows:

\[ \text{Cl}_2 + \text{H}_2\text{O} \rightarrow 2\text{HCl} + \text{O}_2 \]

chlorine + water \(\rightarrow\) hydrochloric acid + oxygen

The oxygen then combines with the stain. Chlorine bleach must not be used on a protein fibre such as wool or silk.

Reducing bleaches

Reducing bleaches are usually not as permanently effective as oxidising bleaches. The stain is reduced to become colourless by the removal of oxygen. Owing to the abundance of oxygen in air and water, however, the stain is easily oxidised again and reappears.
• Sulphur dioxide

Sulphur dioxide (SO₂) is used to bleach woollens. The woollens must be moist. The sulphur dioxide reacts with the water to form sulphuric acid and nascent hydrogen as follows:

\[
\text{SO}_2 + 2\text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4 + 2\text{H}
\]

sulphur dioxide + water → sulphuric acid + hydrogen

The nascent hydrogen then combines with the stain.

The acid must be neutralised with a weak washing soda solution and removed by thorough rinsing.

5.5.3 For interest: How does Borax clean?

What is Borax?

Borax (also known as sodium borate decahydrate; sodium pyroborate; birax; sodium tetraborate decahydrate; sodium biborate) is a natural mineral compound (Na₂B₄O₇. 10H₂O). It was discovered over 4 000 years ago. Borax is usually found deep within the ground, although it has been mined near the surface in Death Valley, California, since the 1800s. Although it has numerous industrial uses, in the home borax is used as a natural laundry booster, multipurpose cleaner, fungicide, preservative, insecticide, herbicide, disinfectant, desiccant, and ingredient in making “slime”. (A laundry booster is something you add to your washing machine to make your regular laundry detergent more effective, while a dessicant is a drying agent.) Borax crystals are odourless, whitish (can have various colour impurities), and alkaline. Borax is not flammable and is not reactive. It can be mixed with most other cleaning agents, including chlorine bleach.

How does Borax clean?

Borax has many chemical properties that contribute to its cleaning power. Borax and other borates clean and bleach by converting some water molecules to hydrogen peroxide (H₂O₂). This reaction is more favourable in hotter water. The pH of borax is about 9.5, so it produces a basic solution in water, thereby increasing the effectiveness of bleach and other cleaners. In other chemical reactions, borax acts as a buffer, maintaining a stable pH needed to maintain cleansing chemical reactions. The boron, salt, and/or oxygen of boron inhibit the metabolic processes of many organisms. This characteristic allows Borax to disinfect and kill unwanted pests. Borates bonds with other particles to keep ingredients dispersed evenly in a mixture which maximises the surface area of active particles to enhance cleaning power.

Risks associated with Borax

Borax is natural, but that does not mean it is automatically safer for you or for the environment than man-made chemicals. Although plants need boron, too much of it will kill them, so borax can be used as an herbicide. Borax may
also be used to kill roaches, ants, and fleas. In fact, it is also toxic to people. Signs of chronic toxic exposure include red and peeling skin, seizures, and kidney failure. The estimated lethal dose (ingested) for adults is 15-20 grams; less than 5 grams can kill a child or pet. For this reason, Borax should not be used around food. More commonly, Borax is associated with skin, eye, or respiratory irritation. It is also important to point out that exposure to Borax may impair fertility or cause damage to an unborn child.

Now, none of these risks mean that you shouldn’t use Borax. If you do a bit of research, you will find risks associated with all cleaning products. However, you do need to be aware of product risks so that you can use those products properly. Don’t use Borax around food, keep it out of reach of children and pets, and make sure you rinse Borax out of clothes and off surfaces before use.

(Source: chemistry.about.com.)

5.5.4 Effect of oxidation on food

Oxidation affects the taste, smell, texture, colour and the nutritive value of foods. Food is oxidised in a number of ways.

- Rancidity

Chemical changes occur when fat becomes rancid, and unpleasant odours are given off. The taste is also affected.

Light, heat and certain metals, such as copper and zinc, accelerate oxidation. Anti-oxidants can be used to retard rancidity in fats. Vitamin E acts as a natural anti-oxidant.

- Bleaching of flour

Oxidation is used to improve the gluten (protein) qualities and colour of flour. Freshly milled flour yields gluten that has inferior elastic properties. If flour is kept for some time, it ages and the constituents that contribute to gluten formation are oxidised from prolonged contact with the air. Chemicals can be used to speed up this process. These chemicals will also bleach the pigment (Xanthophyll) and make it snowy white instead of a cream colour.

- Oxidation of nutrients

Ascorbic acid (vitamin C) dissolves in the cooking water of foods and is also easily oxidised during cooking. The fat-soluble vitamins A, D, E and K are susceptible to oxidation, as are all fats.

- Browning of food

Peeled or sliced fruits and vegetables can become brown because oxidising enzymes are present. Enzymatic browning can be prevented by the following:
• Deactivation of the enzyme
• The enzyme can be destroyed by blanching the food (plunging it into boiling water for a short time) or by the addition of salt or acids such as lemon juice or vinegar.
• Removal of oxygen
• Oxygen can be removed by covering the food with water, or sprinkling sugar over the cut surface to draw out a film of water by osmosis.
• Addition of an anti-oxidant
• An anti-oxidant such as a vitamin can be added to the food.

5.5.5 For interest: Why do cut apples, pears, bananas and potatoes turn brown?

Apples and other produce (e.g. pears, bananas, peaches, and potatoes) contain an enzyme (called polyphenol oxidase or tyrosinase) that reacts with oxygen and iron-containing phenols that are also found in the apple. The oxidation reaction basically forms a sort of rust on the surface of the fruit. You see the browning when the fruit is cut or bruised because these actions damage the cells in the fruit, allowing oxygen in the air to react with the enzyme and other chemicals.

The reaction can be slowed or prevented by inactivating the enzyme with heat (cooking), reducing the pH on the surface of the fruit (by adding lemon juice or another acid), reducing the amount of available oxygen (by putting cut fruit under water or vacuum packing it), or by adding certain preservative chemicals (like sulfur dioxide).

On the other hand, using cutlery that has some corrosion (as is seen with lower quality steel knives) can increase the rate and amount of the browning by making more iron salts available for the reaction.

(Source: http://produce.about.com/od/Produce-Science/fl/Why-Do-Cut-Apples-Turn-Brown.htm)

Activity 5.3: Revision and reflection

1. Explain oxidation as:
   (a) an electron loss
   (b) an oxygen gain

2. Explain, with your own diagram and an example, the connection between oxidation, reduction, oxidising agents and reducing agents.

3. Why can the formation of rust be prevented by painting on an iron object?

4. Why are white sheets or nappies bleached when they are spread out on grass on a sunny day?

5. Explain the working of chlorine bleaches.

6. Why is the action of reducing bleaches not always permanent?

7. How can the enzymatic browning of food be prevented?

8. This is a discussion question that you should answer in the discussion space on your e-tutor site.
Explain the connection between oxidation and each of the following:
(a) Rancidity
(b) The gluten quality of flour
(c) The nutritive value of food

(9) After studying this unit, would you say that knowing more about chemistry may be helpful if you are going to pursue a career in nutrition or textiles? Give a reason for your answer.

5.6 CONCLUSION
Oxidation can be seen as any one of the following:

- An electron loss
- An oxygen gain
- A hydrogen loss

Reduction, on the other hand, is any one of the following:

- An electron gain
- An oxygen loss
- A hydrogen gain

Oxidation can never take place without reduction. Whatever is oxidised is the reducing agent, and whatever is reduced is the oxidising agent. Oxidation can be used both to our advantage and disadvantage.

Just as oxidation and reduction take place, certain other compounds give off hydrogen ions (H-) during a reaction. These are called acids. On the other hand, bases yield hydroxide ion when reacting with other substances. Learning unit 6 will focus on the properties and applications of acids, bases and salts.
Acids, bases and salts

6.1 INTRODUCTION
The previous learning unit focused on oxidation, reduction, reducing and oxidising agents and their applications. In this learning unit we will focus on acids, bases, salts, their properties and their applications.

Some of the most important industrial chemicals are acids and bases. Daily we come across a variety of materials such as fibres, paints, plastics and fertiliser which are provided by the chemical industry. For these and many other products we depend on cheap industrial chemicals. By knowing the properties of acids, bases, and salts, you will have a better understanding of how these chemicals work and how you can apply them at home and at work.

Learning outcomes
After you have completed this learning unit, you should be able to:

• explain what proton donors are
• list, with equations where necessary, the properties of acids, bases and salts
• explain how these properties are applied in our daily lives
• explain what the pH-scale is and where it is applied

6.2 ACIDS, WHAT ARE THEY?
All acids contain two parts. One part is hydrogen and the other part is a non-metal or a group made up of nonmetals.

The general view among most people is that acids are dangerous and corrosive. Indeed, many acids are corrosive, and they attack metals and stone. However, acids also have other typical properties.

In the sections that follow, I will first describe the properties of acids, and then discuss various applications of acids.
6.2.1 Properties of acids

- Acids release hydrogen ions when added to reactive metals.

For example, hydrochloric acid yields a hydrogen ion and a chloride ion:

\[ \text{HCl} \rightarrow \text{H}^+ + \text{Cl}^- \]

Sulphuric acid yields hydrogen ions and a sulphate radical:

\[ \text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-} \]

- Acids are neutralised by bases to form water and a salt.

For example, when hydrochloric acid and magnesium oxide (a metal oxide) react, water and magnesium chloride (a salt) are formed:

\[ 2\text{HCl} + \text{MgO} \rightarrow \text{H}_2\text{O} + \text{MgCl}_2 \]

When sulphuric acid and sodium hydroxide (a metal hydroxide) react, water and sodium sulphate (a salt) are formed:

\[ \text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow 2\text{H}_2\text{O} + \text{Na}_2\text{SO}_4 \]

- Acids react with carbonates and bicarbonates to form carbon dioxide, water and salt.

For example, when hydrochloric acid and calcium carbonate react, calcium chloride (a salt), carbon dioxide and water are formed:

\[ 2\text{HCl} + \text{CaCO}_3 \rightarrow \text{CaCl}_2 + \text{CO}_2 + \text{H}_2\text{O} \]

- Acids have a sour taste. In lemon and grapefruit juices the sour taste is due to citric acid. In vinegar the taste is due to acetic acid, and in sour milk it is due to lactic acid.

- Acids turn blue litmus paper red. Phenolphthalein, which is normally red, becomes colourless in the presence of an acid. Litmus and phenolphthalein are both indicators.

  An indicator is a substance that changes colour in the presence of acids and is used to indicate whether a substance is an acid or an alkali.

- Acids conduct electricity.

- Acids have a pH of less than 7.

The typical properties of acids are due to the fact that all acids contain hydro-

The typical properties of acids are due to the fact that all acids contain hydro-

tions, \( \text{H}^+ \).

To balance the positive hydrogen ions, acids contain negative ions. For example, in sulphuric acid, \( \text{H}_2\text{SO}_4 \), the negative ion is sulphate \( \text{SO}_4^{2-} \). In hydrochloric acid, \( \text{HCl} \), the negative ion is chloride, \( \text{Cl}^- \). Because acids contain ions they all conduct electricity.
When acids react with metals, hydrogen ions are converted to hydrogen gas. Table 6.1 shows examples of the more commonly used acids.

### TABLE 6.1
**Commonly used acids**

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Where it occurs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochloric acid</td>
<td>HCl</td>
<td>In the stomach, aids digestion</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>H₂SO₄</td>
<td>Does not occur naturally</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Has many important uses</td>
</tr>
<tr>
<td>Nitric acid</td>
<td>HNO₃</td>
<td>Does not occur naturally</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Has many important uses</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>CH₃COOH</td>
<td>In vinegar</td>
</tr>
<tr>
<td>Formic acid</td>
<td>HCOOH</td>
<td>Ants and stinging nettles inject it when they sting</td>
</tr>
<tr>
<td>Citric acid</td>
<td>C₆H₈O₇</td>
<td>In lemons, oranges and other citric fruits</td>
</tr>
</tbody>
</table>

Many acids occur naturally. Naturally occurring acids are usually weak or so diluted that they are not dangerous. However, many acids, especially those used in the chemical laboratories, can be very dangerous because they destroy living cells.

**You should never let acids get on your skin, and you should always wear eye protection when handling acids.**

### 6.2.2 Applications of acids

Acids are used in the following ways:

- **Reaction with metals**

  Because acids react with certain metals, acids can be used to remove varnish from metals. Acids can damage the metal, however. More importantly, salts that may cause metal poisoning can be formed. For example, oxalic acid is very poisonous and must never be used on cooking utensils. The green deposit on copper (copper carbonate) will react with an acid to form a poisonous copper salt. Vinegar contains acetic acid, which will react with the copper carbonate to form copper acetate, a highly poisonous salt.

  Galvanised (iron covered with zinc) containers, such as zinc pails or baths, must never be used for storing or preparing food. The organic acids in food can form poisonous zinc salts.
Food that is acid should not be preserved in metal containers or in jars with metal lids. The metal must be covered with a layer of tin or lacquer which will not react with the acid. Never eat tinned food if the can is blown out or if gas escapes from the can when it is punctured. This could be due to the reaction of acids with exposed metal (especially if the tin has been dented). Because aluminium and stainless steel do not form poisonous substances, they are freely used in the manufacture of cooking utensils.

- **Reaction with carbonates or bicarbonates**

Marble consists of calcium carbonate. An acid should therefore not be used on a marble ornament or ashtray, since the marble will dissolve. The white deposit often found on glassware is usually also calcium carbonate. You can remove this deposit by soaking the article in vinegar.

The stomach normally secretes hydrochloric acid (HCl), which is required for the digestion of protein. Patients with hypoacidity (a lower than normal hydrochloric acid level in the stomach) are given diluted hydrochloric acid orally. Far more common, however, is the condition of hyperacidity (too high an acid concentration in the stomach), which leads to heartburn. Commercial antacids contain a carbonate or bicarbonate that will react with the excess stomach acid. Sodium bicarbonate (NaHCO₃), which is normally available in most homes, can be used. Continued use of sodium bicarbonate as an antacid is, however, not advisable. It may interfere with the normal digestive processes.

Baking powder contains an acid, sodium bicarbonate and a starch, such as corn flour. The starch keeps the baking powder dry by absorbing moisture. This prevents the sodium bicarbonate from reacting with the acid before use. On contact with moisture and heat, the acid combines with the bicarbonate to release carbon dioxide.

The acid used in baking powder is normally cream of tartar or tartaric acid. Food that contains an acid or acidic ingredient, such as sour milk, syrup, apricot jam or fruit, may need sodium bicarbonate only and no baking powder.

- **Reaction with alkalis**

Strong acids, such as concentrated nitric acid (HNO₃) or concentrated sulphuric acid (H₂SO₄), are extremely corrosive. When a strong acid is spilled on the skin, the area must be washed under running water and then treated with a mild alkali, such as sodium bicarbonate, which will neutralise any remaining acid.

Prevention of crystallisation

During sugar cooking, acids (lemon juice or cream of tartar) are added to prevent crystallisation or the formation of very large crystals. The acid causes the inversion of the disaccharide sucrose (C₁₂H₂₂O₁₁) to the monosaccharides glucose (C₆H₁₂O₆) and fructose (C₆H₁₂O₆). Take note that glucose and fructose have the same chemical formula, but have different structures. The equimolar (equal number of moles) mixture of glucose and fructose is known as invert sugar. Invert sugar is not as easily crystallised as sucrose.
This reaction can be represented as follows:

\[
\text{acid plus heat} \\
\text{C}_{12}\text{H}_{22}\text{O}_{11} + \text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{C}_6\text{H}_{12}\text{O}_6 \\
\text{heat}
\]

\[
\text{sucrose + water} \rightarrow \text{glucose + fructose} \\
\text{Invert sugar}
\]

- **Disinfectants**

Boric acid (H\(_3\)BO\(_3\)) is a weak acid that can be used (in solution) as a disinfectant and eye wash. A solution of carbolic acid was the first disinfectant used by surgeons to wash their hands and surgical instruments. Carbolic acid (C\(_6\)H\(_5\)OH) is a poisonous acid with a sharp smell. It is made by distilling coal tar. Carbolic acid is sometimes used in disinfecting soaps. Today disinfectants are widely used in the healthcare, food and pharmaceutical sectors to prevent unwanted microorganisms from causing disease.

- **Preservatives**

Acids inhibit the growth of certain micro-organisms and are often used to preserve food—acids are used in chutney and pickles, for example.

- **Flavouring**

Very rich and fatty foods taste better if a weak acid, such as lemon juice, vinegar or tomato juice, is added.

- **Jam making**

Jams and jellies need a low pH of 3.5 to set. If the fruit is not acid enough, an acid such as citric or tartaric acid has to be added.

- **Effect on colourants**

Acids have different effects on the various types of colourants found in foods. The effects of both acids and alkalis are summarised in table 6.2:
TABLE 6.2  
*Effect of acids and alkalis on colouring matter in food*

<table>
<thead>
<tr>
<th>Colourant</th>
<th>What the colourant looks like in an acid medium</th>
<th>What the colourant looks like in an alkaline medium</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flavone</td>
<td>White</td>
<td>Yellow</td>
<td>Acid added to rice, meringues or cauliflower will preserve the white colour.</td>
</tr>
<tr>
<td>Anthocyanin</td>
<td>Red</td>
<td>Purple or blue</td>
<td>Lemon juice or vinegar can be added to cherries, strawberries or beetroot.</td>
</tr>
<tr>
<td>Chlorophyll</td>
<td>Olive-green</td>
<td>Bright green</td>
<td>The addition of an acid must be avoided when green vegetables are cooked, because it will destroy the vitamin C in the vegetables.</td>
</tr>
</tbody>
</table>

**Activity 6.1: Acids**

1. Write the equation for the reaction of magnesium with hydrochloric acid.
2. How do you think would (a) zinc and (b) gold react with a diluted acid?
3. Study the properties of acids in section 6.3.1 and then answer the following questions:
   - What is pH? (If you have not come across this term before you might need to do an internet search.)
   - What pH would you expect for diluted sulphuric acid to have: high or low?
4. Would you expect diluted sulphuric acid to conduct electricity? Give a reason.
(5) This is a discussion question that you should answer in the discussion space on your e-tutor site.
Do your own internet search to find information on sulphuric acid. Write down three uses of sulphuric acid in industry (between ½ and 1 page in writing).
Read through the other students’ postings and then extend your own list of the uses of acids.

(6) List three examples of the use of acids in the food industry. In each case explain the function of the acid in the application.

Feedback on activity 6.1
Acid-base chemistry is an important part of everyday life. The excess hydronium ions in acids give them interesting properties. Acids can react with metals and other materials. The strong acid HCl is produced in your stomach to help digest food. In dilute concentrations, acids are responsible for the sour taste of lemons, limes, vinegar and other substances.

The acidity (or basicity) of a solution is measured using the pH scale. The pH scale corresponds to the concentration of hydronium ions [H₃O⁺] in a solution. The pH of a solution of pure water is 7. The pH scale ranges from 0 to 14, where 7 is considered neutral, below 7 acidic and above 7 basic. The further from 7 you are on the pH scale, the more acidic or basic the solution. I will explain the pH scale in more detail later in this unit.

6.3 BASES, WHAT ARE THEY?
Most of us have suffered from acid indigestion and have taken antacid medication to relieve it. Acid indigestion is caused by an excess of hydrochloric acid in the stomach. The antacid medication contains a base which “removes” the excess acid. Bases are substances which neutralise acid. They are the chemical opposite of acids. When a base neutralises an acid a salt is formed.

Bases are usually oxides, hydroxides or carbonates of metals. One of the most common antacid medicines contains magnesium hydroxide, namely Milk of Magnesia. Perhaps the word “base” is unfamiliar, but you may have heard the word “alkali”. An alkali is a special kind of base which dissolves in water.

6.3.1 Properties of bases
• Bases are slippery and soapy, and have a biting, bitter taste.
• Bases have the following effects on indicators (indicators are substances that show whether something is acidic or basic): they turn red litmus blue, methyl orange from red to yellow, and phenolphthalein from colourless to red.
• Bases neutralise acids to form water and a salt.
For example, calcium hydroxide (a base) neutralises sulphuric acid (an acid) to form water and calcium sulphate (a salt). This reaction is written as follows:

\[ \text{Ca(OH)}_2 + \text{H}_2\text{SO}_4 \rightarrow 2\text{H}_2\text{O} + \text{CaSO}_4 \]

- Bases yield hydroxide ions in a water solution.

For example, sodium hydroxide (a base) yields sodium and a hydroxide ion:

\[ \text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^- \]

Similarly, potassium hydroxide (a base) yields potassium and a hydroxide ion:

\[ \text{KOH} \rightarrow + \text{OH}^- \]

- **Strong bases** react with certain metals to produce hydrogen gas.

For example, a reaction of aluminium (a metal), sodium hydroxide (a strong base) and water produces hydrogen gas and sodium aluminate (a water-soluble compound):

\[ 2\text{Al} + 6\text{NaOH} + 6\text{H}_2\text{O} \rightarrow 3\text{H}_2 + 2\text{Na}_3\text{Al(OH)}_6 \]

**TABLE 6.3**

**Commonly used bases**

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Where it is used</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Sodium hydroxide</td>
<td>NaOH</td>
<td>In the home, for removing grease, many uses in industry</td>
</tr>
<tr>
<td>*Calcium hydroxide (lime)</td>
<td>Ca(OH)_2</td>
<td>In farms and gardens, to neutralise the acidity of soil</td>
</tr>
<tr>
<td>*Ammonia</td>
<td>NH_3</td>
<td>In the home, as a cleaning liquid, many uses in industry</td>
</tr>
<tr>
<td>*Sodium hydrogen carbonate (bicarbonate of soda)</td>
<td>NaHCO_3</td>
<td>In the home, as an antacid medicine and in baking powder</td>
</tr>
<tr>
<td>Magnesium oxide</td>
<td>MgO</td>
<td>In the home, as an antacid medicine (Milk of Magnesia)</td>
</tr>
</tbody>
</table>

(The bases marked with a * are alkalis)

Like acids, strong alkalis can be corrosive and dangerous. Sodium hydroxide is often called caustic soda (caustic means burning). In fact, alkalis can do even more damage to the skin and eyes than acid.
Never let alkalis get on your skin, and always wear eye protection when using alkalis.

6.3.2 Applications of bases
Alkalis are used in the following ways:

• Reaction with metals
Alkalis react with aluminium. Do not soak aluminium pots or pans in water containing a highly alkaline soap or washing soda, since such a solution will create pitted marks on the saucepans. Sodium hydroxide, which is a strong base, will dissolve aluminium.

• Reaction with acids
See paragraph 6.3.2 above for the use of bicarbonate of soda as an antacid and a raising agent.

Diluted solutions of magnesium hydroxide (Mg(OH)\(_2\)), commonly called Milk of Magnesia, are also used as an antacid for the stomach.

In paragraph 6.6.2 above, the use of alkalis to neutralise acids which have caused skin burns is discussed.

• Effect on colourants
See Table 6.2 above for the effect of alkalis on flavone, anthocyanin and chlorophyll. Alkalis change the colour of chocolate and cocoa to a reddish brown colour.

• Laundering
Sodium carbonate (Na\(_2\)CO\(_3\)), commonly known as washing soda, and borax are used to soften hard water. Strong alkalis, such as sodium hydroxide (caustic soda) and potassium hydroxide (caustic potash) are used in the manufacturing of soap. Fat is boiled with the alkali. The alkali then combines with the fatty acids in the fat to form a salt, which is actually the soap, as follows:

\[
\text{Sodium hydroxide} + \text{fat} \rightarrow \text{soap} + \text{glycerine}
\]

Soapless detergents that have a pH approaching neutral can be used on very delicate articles. Wool, silk, rayon and coloured fabrics can be washed with soaps that have a pH of between 7 and 8. White cotton and linen, on the other hand, can be washed in strong alkali water with a pH of 10 to 11.

• Emulsification of grease
Since alkalis assist in the emulsification of grease, they can be used in various ways to clean dirty, greasy areas. Washing soda can be added to the water when saucepans, brooms and brushes are washed. It can also be poured down greasy drainpipes. Washing soda emulsifies the fat, which can then be washed down the drainpipe with boiling water.
When a saucer full of ammonia is placed in a warm oven, the ammonia vapour will help to emulsify the grease on the sides of the oven. In this way an oven can be easily cleaned.

- **Effect on cellulose**

The cellulose in fruit and vegetables is softened by an alkali. For this reason, bicarbonate of soda is sometimes added to the water in which vegetables such as green beans are boiled. Since the alkali also destroys some of the vitamins, especially vitamin C, this practice is not recommended.

### 6.3.3 For interest: How detergents work

Detergents and soaps are used for cleaning because pure water can't remove oily, organic soiling. Soap is made from natural products such as fats and oils, and cleans by acting as an emulsifier: basically, soap allows oil and water to mix so that oily grime can be removed during rinsing. Detergents were developed in response to the shortage of the animal and vegetable fats used to make soap during World War I and World War II. Detergents are primarily surfactants, which could be produced easily from petrochemicals. Surfactants lower the surface tension of water, essentially making it “wetter” so that it is less likely to stick to itself and more likely to interact with oil and grease.

Modern detergents contain more than surfactants. Cleaning products may also contain enzymes to degrade protein-based stains, bleaches to decolour stains and add power to cleaning agents, and blue dyes to counter yellowing.

Like soaps, detergents have hydrophobic or water-hating molecular chains and hydrophilic or water-loving components. The hydrophobic hydrocarbons are repelled by water, but are attracted to oil and grease. The hydrophilic end of the same molecule means that one end of the molecule will be attracted to water, while the other side is binding to oil. Neither detergents nor soap accomplish anything except binding to oil until some mechanical energy or agititation is added into the equation. Swishing the soapy water around allows the soap or detergent to pull the grime away from clothes or dishes and into the larger pool of rinse water. Rinsing washes the detergent and soil away. Warm or hot water melts fats and oils so that it is easier for the soap or detergent to dissolve the soil and pull it away into the rinse water. Detergents are similar to soap, but they are less likely to form films (soap scum) and not as affected by the presence of minerals in water (hard water).

Modern detergents may be made from petrochemicals or from oleochemicals derived from plants and animals. Alkalis and oxidising agents are also chemicals found in detergents. Let us now look at the functions of these molecules:

- **Petrochemicals/Oleochemicals**

These fats and oils are hydrocarbon chains which are attracted to the oily and greasy grime.
• **Oxidisers**

Sulphur trioxide, ethylene oxide, and sulphuric acid are among the molecules used to produce the hydrophilic component of surfactants. Oxidisers provide an energy source for chemical reactions. These highly reactive compounds also act as bleaches.

• **Alkalis**

Sodium and potassium hydroxide are used in detergents even as they are used in soap making. They provide positively charged ions to promote chemical reactions.

**Source:** [http://chemistry.about.com/od/howthingswork/f/detergentfaq.htm](http://chemistry.about.com/od/howthingswork/f/detergentfaq.htm)

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**Activity 6.2**

Rub margarine in the palm of your hand and wash it with cold water.

(1) What do you observe?

(2) If you wash your hands in **warm** water, what do you observe?

Rub the palm of your hand again with margarine and wash it off with warm water and dish washing liquid.

(3) What do you observe?

(4) Based on your experiment, explain, with the aid of a diagram, how soaps and detergents work to remove grease. (If necessary, for more information visit the library or look on the internet.)

(5) Ammonia is a base which is widely used in industry. Visit the library or go to the internet and find information on ammonia and then answer the questions below:

- Approximately 80% of ammonia produced is used to make nitrogenous fertilisers. Ammonia is also used to manufacture a number of other products. List three such products.
- Give a short description of how fertilisers are made from ammonia.

---

**Feedback on activity 6.2**

In the section on “How detergents work”, the action of a detergent (or as in this activity, dish washing liquid) with grease or fat is described in a simple manner. By drawing a diagram or picture (as asked in question 4 in activity 6.2) you will gain a better understanding of this matter.

Concerning fertilisers, plants need extra food and it is usually given in the form of fertilisers that contain ammonia, phosphorous and potassium. Read more about this topic by going to a library or go to the internet to find out how these substances work as fertilisers.
6.4 SALTS AND NEUTRALISATION

The neutralisation of an acid by a base occurs more often in our lives than we realise. For example, toothpaste contains a base, which is used to neutralise the acid in your mouth which causes tooth decay. Farmers use calcium hydroxide (lime) to neutralise soil acidity.

How does a base neutralise an acid? Acidity is due to hydrogen ions, H+. The base removes acidity by reacting with these ions. Usually the H+ ions are converted to water. The other product of neutralisation is a salt. For example, when sodium hydrogen carbonate (bicarbonate of soda) is used as an antacid to neutralise hydrochloric acid in the stomach, sodium chloride is formed. Sodium chloride is a salt, the same salt that we put on our food. However, the word salt is used by scientists for any compound formed by the reaction between an acid and a base.

We can think of each salt as having two “parents”—an acid and a base. Salts are ionic compounds. The base provides the positive ion and the acid the negative ion.

6.4.1 Properties of salts

Salts have the following properties:

- Salts vary from being quite soluble in water to slightly soluble or insoluble in water.
- When a weak acid reacts with a strong base, the salt that is formed is alkaline. When a strong acid reacts with a weak base, however, the result is an acidic salt.

Draw your own diagram to illustrate the second point above.

6.4.2 Applications of salts

Salts are used in the following ways:

- **Mineral salts**

  Salts are extremely important for the growth and metabolism of the body. Haemoglobin contains iron salts. Iodine salts are necessary for the proper functioning of the thyroid gland; calcium and phosphorus salts are necessary for the formation of bones and teeth. Salts regulate the acid-base balance of the body, the irritability of nerve and muscle cells and the beating of the heart. Salts maintain the proper osmotic pressure of cells.

- **Laundering**

  Table salt (sodium chloride—NaCl) is frequently used to remove stains and also helps to preserve the colour of fabrics. Therefore, when fabrics are dyed, table salt is used as a mordant. A mordant is a substance that fixes colouring matter.

  Blood stains should be removed by first washing the garment in a salt solution, which prevents haemoglobin from being released from the red blood cells.
• Cookery

Table salt is most commonly used to flavour food. It is also used as a preservative because it retards bacterial growth. Salt and vinegar are used when making chutneys. A salt solution is used for corned beef, and salt is used in the making of biltong.

Chile saltpetre (sodium nitrate – NaNO₃) is used for curing meats. Sodium nitrate combines with haemoglobin in the meat and forms nitro-haemoglobin. This substance remains red even when the meat is cooked and is responsible for the typical colour of cured ham, bacon and corned beef.

• Hard water

Hard water (water that will not allow soap to lather readily) contains certain calcium and/or magnesium salts in solution. Hard water causes “furring” in kettles, boilers and pipes leading to reduced heat transfer efficiency and in extreme cases blockage.

Hard water which contains calcium and magnesium bicarbonate can temporarily be softened by boiling. Hard water is formed by dissolved calcium bicarbonate (Ca(HCO₃)₂) and magnesium bicarbonate (Mg(HCO₃)₂) salts. When hard water is boiled, insoluble calcium and magnesium carbonates form and precipitate (separate from the water). In this way the water is softened.

In other words, calcium bicarbonate yields calcium carbonate, water and carbon dioxide, as follows:

\[
\text{Ca(HCO}_3\text{)}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O} + \text{CO}_2
\]

This method is, however, uneconomical, and the insoluble salts precipitate as boiler scale (a chalky deposit in a boiler).

Hard water can also be softened temporarily by the addition of soap. This is, however, very expensive, and a dirty scum of insoluble calcium stearate is formed on the water.

The most effective and most economical method of softening hard water temporarily is through the addition of borax, washing soda or slaked lime (calcium hydroxide—Ca(OH)₂).

Permanently hard water contains calcium and magnesium chlorides and sulphates—that is, calcium chloride (CaCl₂), calcium sulphate (CaSO₄), magnesium chloride (MgCl₂) and magnesium sulphate (MgSO₄).

Permanently hard water can be softened by the addition of soap, washing soda or borax. It can also be softened by distillation (an expensive and impractical process), by filtration through layers of permutate, by the resin tank method or by using a commercially prepared softener.
Activity 6.3

(1) Study the following table and then complete the missing details:

<table>
<thead>
<tr>
<th>Acids →</th>
<th>Sulphates containing SO₄²⁻ (made from sulphuric acid)</th>
<th>Nitrates containing NO₃⁻ (made from nitric acid)</th>
<th>Chlorides containing Cl⁻ (made from hydrochloric acid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bases ↓</td>
<td>Magnesium salt containing Mg²⁺ (made from magnesium oxide)</td>
<td>Magnesium nitrate Mg(NO₃)₂</td>
<td>Magnesium chloride MgCl₂</td>
</tr>
<tr>
<td></td>
<td>Sodium salt containing Na⁺ (made from sodium hydroxide)</td>
<td>Sodium sulphate Na₂SO₄</td>
<td>Sodium chloride NaCl</td>
</tr>
<tr>
<td></td>
<td>Calcium salt containing Ca²⁺ (made from calcium hydroxide)</td>
<td>Calcium sulphate CaSO₄</td>
<td>Calcium nitrate Ca(NO₃)₂</td>
</tr>
</tbody>
</table>

(2) According to Rand Water, South African tap water is “moderately soft to slightly hard” (http://www.aquazania.co.za/2016/01/differences-between-hard-water-and-soft-water-an-overview/).
- Explain what this means.
- Explain, with the aid of an equation, how the hardness of water can be removed through the method of ion exchange. (You will be able to find the information in a library or on the internet.)

Feedback on activity 6.3

Read section 6.3 on salts and neutralisation carefully before answering activity 6.3. Salts are ionic compounds which, when dissolved in water, break up completely into ions. A salt is always made when an acid is neutralised by a base. But the exact salt made depends upon which acid and base were used. The name of the salt has two parts:

(i) The first part comes from the metal in the base used.
(ii) The second part comes from the acid that was used.
These are the rules for the second part of the name of a salt:

<table>
<thead>
<tr>
<th>Acid used</th>
<th>Second part of salt’s name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochloric acid</td>
<td>Chloride</td>
</tr>
<tr>
<td>Sulphuric acid</td>
<td>Sulphate</td>
</tr>
<tr>
<td>Nitric acid</td>
<td>Nitrate</td>
</tr>
</tbody>
</table>

To implement this: How can we make copper sulphate? The first part of the name is “copper”, so we need a base containing copper. We could use copper oxide or copper carbonate, for example. The second part of the name is “sulphate”, so we need to use sulphuric acid.

Also: How can we make sodium chloride? The first part of the name is “sodium”, so we need a base containing sodium. We could use sodium hydroxide or sodium hydrogen carbonate, for example. The second part of the name is “chloride”, so we need to use hydrochloric acid.

Enjoy naming salts!

6.5 THE PH SCALE

The pH scale is used to indicate the degree of acidity or alkalinity of a solution. The pH scale runs from pH 1 (extremely strong acid) to pH 14 (extremely strong alkali).

- Acids have a pH of less than 7.
- Neutral substances such as distilled water have a pH of 7.
- Alkalis have a pH of greater than 7.

The stronger the **acid**, the **lower** its pH.
The stronger the **alkali**, the **higher** the pH.
You can determine the pH of a substance by using one of the universal indicators. Indicators are substances that change their colour depending on whether they are in acidic or alkaline solution. Litmus is an example of an indicator. Litmus turns red when placed in an acid solution and turns blue in an alkali. Many natural plant colours are indicators. For example, red cabbage is actually purple until it is pickled, when it turns red in the acidic vinegar.

A universal indicator is a mixture of indicators. It can have several different colours, depending on the pH. Scientists use an electrometric pH apparatus, which measures the pH by electrical means.

**Activity 6.4: Revision and reflection**

1. For an overview and revision of the information in this unit, watch the following video clip:
   - [https://www.youtube.com/watch?v=qGvBREBhhC4](https://www.youtube.com/watch?v=qGvBREBhhC4) 3201 (acids and bases)
   - [https://www.youtube.com/watch?v=WnAKhtnIjz0](https://www.youtube.com/watch?v=WnAKhtnIjz0) (salts)

What are some of the uses of acids and bases that are mentioned in the first video that I did not mention in the unit?
(2) Draw up a table and list the following household chemicals beneath one another. Indicate whether the chemical is an acid or base.
- Lemon juice
- Baking powder
- White vinegar
- Washing powder
- Soapy water
You should be capable of identifying daily substances as acids or bases. Do NOT taste them to determine its identity!

(3) Answer the following questions on indicators:
(a) What is an indicator?
(b) Give two examples of indicators.

(4) Which particle is found in all acids?

(5) What acid is responsible for acid indigestion?

(6) Why can sodium hydroxide not be used to relieve acid indigestion?

(7) Write the word equations that indicate what would be formed in each of the following reactions.
(a) Hydrochloric acid + sodium hydroxide
(b) Sulphuric acid + calcium oxide
(c) Hydrochloric acid + magnesium oxide
(d) Nitric acid + calcium carbonate
(e) Sulphuric acid + copper carbonate

(8) Answer the questions on hard water
(a) Explain hardness of water.
(b) Why does the normal water purification treatment in a water works NOT remove water hardness?
(c) Explain the difference between temporary and permanent hardness of water.
(d) Why does distilled water need very little soap to give lather?

(9) Think about the main things you learnt in this unit. Which of them do you think will be most useful in your career or daily life, and why?

6.6 CONCLUSION
An acid is a substance that donates protons, whereas a base is a substance that accepts protons. The reaction of acids with bases is called neutralisation. Water and a salt are formed during neutralisation. A salt can be either alkaline or acidic. Acids have a pH of less than 7, while alkalis have a pH of greater than 7.
LEARNING UNIT 7

Measurement of matter

7.1 INTRODUCTION

It does not matter what you do in your daily life or what kind of work you do, there will come a time when you’ll need to measure or calculate something and need be able to do it correctly. The following sections will cover the basic principles in measuring matter.

Learning unit outcomes

After you have completed this learning unit, you should be able to:

• identify the basic units of length, circumference, area, volume, mass, density and relative density
• apply the SI system of measurement
• apply the formulas and principles for calculating area and volume
• identify the different measuring instruments
• use the different measuring instruments in the correct manner

7.2 THE SI SYSTEM

When people started to measure the objects around them, they used measurements that were related to certain body parts, for example the length of a foot or an arm.

Since the length of one person’s foot or arm is not necessarily the same as the next person’s, this kind of measurement is not very accurate. We now use an international system of measurement that we can all understand, which is known as the Système International d’Unités, or the SI system. This system was introduced in 1960 and has been adopted by most countries.
7.2.1 Basic units

The SI system has the following seven base units:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Name of unit</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>metre</td>
<td>m</td>
</tr>
<tr>
<td>Mass</td>
<td>kilogram</td>
<td>kg</td>
</tr>
<tr>
<td>Time</td>
<td>second</td>
<td>s</td>
</tr>
<tr>
<td>Electric current strength</td>
<td>Ampere</td>
<td>A</td>
</tr>
<tr>
<td>Temperature</td>
<td>Kelvin</td>
<td>K</td>
</tr>
<tr>
<td>Quantity of a substance</td>
<td>mole</td>
<td>mol</td>
</tr>
<tr>
<td>Luminous intensity</td>
<td>candela</td>
<td>cd</td>
</tr>
</tbody>
</table>

We use prefixes to indicate multiples and submultiples of these units as follows:

<table>
<thead>
<tr>
<th>Name of prefix</th>
<th>Symbol</th>
<th>Meaning of prefix</th>
<th>Exponential number</th>
</tr>
</thead>
<tbody>
<tr>
<td>giga</td>
<td>G</td>
<td>$1000 \times 1000 \times 1000$</td>
<td>$10^9$</td>
</tr>
<tr>
<td>mega</td>
<td>M</td>
<td>$1000 \times 1000$</td>
<td>$10^6$</td>
</tr>
<tr>
<td>kilo</td>
<td>k</td>
<td>1000</td>
<td>$10^3$</td>
</tr>
<tr>
<td>deci</td>
<td>d</td>
<td>__</td>
<td>$10^{-1}$</td>
</tr>
<tr>
<td>centi</td>
<td>c</td>
<td>_______</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>milli</td>
<td>m</td>
<td>___________</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>micro</td>
<td>µ</td>
<td>__________________</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>nano</td>
<td>n</td>
<td>____________</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>pica</td>
<td>p</td>
<td>____________</td>
<td>$10^{-12}$</td>
</tr>
</tbody>
</table>

The litre (l) does NOT form part of the S system. However, in general, volumes of liquids are sold in litres.

The degree Celsius is also NOT an S unit, but is generally used. The SI unit for temperature is **kelvin**. Temperatures on this scale are called kelvins, **NOT** degrees kelvin. Kelvin is not capitalised, and the symbol (capital K) stands alone with no degree symbol. A temperature interval of 1 °C is the same as
a temperature interval of 1K. But 0 °C is equal to 273 K. Absolute zero is -273.15 °C, a hypothetical temperature characterised by a complete absence of heat energy.

7.2.2 Derived SI units
Derived SI units that we use in basic science are the following:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Name</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>newton</td>
<td>N</td>
</tr>
<tr>
<td>Energy</td>
<td>joule</td>
<td>J</td>
</tr>
<tr>
<td>Force</td>
<td>newton</td>
<td>N</td>
</tr>
<tr>
<td>Power</td>
<td>watt</td>
<td>W</td>
</tr>
<tr>
<td>Pressure</td>
<td>pascal</td>
<td>Pa</td>
</tr>
<tr>
<td>Electric potential difference</td>
<td>volt</td>
<td>V</td>
</tr>
<tr>
<td>Electric resistance</td>
<td>ohm</td>
<td>Ω</td>
</tr>
<tr>
<td>Illumination</td>
<td>lux</td>
<td>lx</td>
</tr>
</tbody>
</table>

7.2.3 Standard form of scientific notation for numbers
Scientific notation is a neat way of writing numbers in a short way, especially if the numbers are very large or very small. Look at the following examples.

- Multiply

\[ 4000 = 4 \times 10^3 \]

For every 0 you must multiply by 10, so in this case you must multiply by 10, three times.

4 \times 10^3 reads as: four times ten to the power three

Another example:

\[ 300 = 3 \times 10^2 \]

3 \times 10^2 reads as: three times ten to the power two

- Dividing

\[ 0.00001 = 1 \div 10 \div 10 \div 10 \div 10 = 1 \times 10^{-5} \]

For every decimal after the comma, divide by 10.

0.3 = 3 \div 10 = 3 \times 10^{-1}
0.3 has one decimal after the comma. In the notation $10^{-1}$, the minus sign indicates the decimal is after the comma and the one indicates how many decimals are after the comma, in this case one decimal.

$3 \times 10^{-1}$ reads as: three times ten to the power minus one

It is clear that you are less likely to make a mistake during copying or reading when very large or small numbers are written in this standard way. It is easy to confuse

50 000 000 and 500 000 000 but $5 \times 10^7$ and $5 \times 10^8$ are clearly different numbers.

### Activity 7.1: SI system

1. Write the following numbers in the standard form of scientific notation for numbers:
   
   (i) 30
   (ii) 60 000
   (iii) 0.008
   (iv) 0.03
   (v) 0.0007

2. If you had 0.005 litres of water, how much ml would you have?

### 7.3 LENGTH

Length is described as the linear (linear: in or along a line) measurement or extent of something from end to end. In the sections that follow, I discuss two important aspects of measuring length.

#### 7.3.1 The ruler or metre stick and method for measuring length

The simplest instrument for measuring length is the metre ruler which is 1 metre long and divided into millimetres. The most general ruler used is 300 mm (30 cm) long and is marked in centimetres and millimetres.

How many of you have tried to measure the length of a line and found that depending from which angle you look at it, it seems that it has different lengths? This is called a parallax. There is a parallax between two objects—such as the edge of an object and the millimetre mark on the ruler—it appears as if they separate and move in opposite directions when you move your head sideways. In Figure 7.1 the error of parallax is illustrated. There, the object to be measured (a pointer) lies at the 4 cm mark, but if one looks at the ruler from an angle to the right or the left, one gets an incorrect reading, as illustrated.
To avoid this kind of parallax error, one should try to keep one’s eye vertically above the point being measured.

The thickness of a ruler can also cause parallax error, because the thicker the ruler, the further the markings on the top of the ruler will be away from the actual object under the ruler that is being measured. The best way to avoid this error of parallax is to tilt the ruler on its edge when measuring.

Parallax errors and how to avoid them are explained in this video clip:

https://www.youtube.com/watch?v=NEBkLxlQmww

7.3.2 Application of centimetres

Centimetres are used to measure the following:

- Body dimensions—e.g. a 92 cm bust
- Clothing sizes—e.g. a size 42 shirt
- Textile dimensions—e.g. fabric may be 90 cm, 115 cm or 150 cm wide, or a sheet may be 200 cm wide and 250 cm long
- Zipper lengths—we generally refer to a zipper as being 15 cm, 25 cm, etc long
7.3.3 Application of millimetres

Millimetres are used to measure the following:

- Dimensions of rooms and furniture, for example:
  - A room may be 3 000 mm wide and 4 000 mm long
- Standard bed widths are as follows:
  - 750 mm—narrow single bed (bunk bed)
  - 900 mm—single bed
  - 1 050 mm—three-quarter bed
  - 1 350 mm—double bed
  - 1 500 mm—queen size bed
  - 1 800 mm—king size bed
- Diameters of pots and pans, for example 150 mm, 175 mm, 200 mm, etc.

Activity 7.2

Give accurate measurements in cm of the following:

1. The length of an A4 paper
2. The breadth of an A4 paper
3. The length of a standard double-bed mattress
4. The breadth of a standard double-bed mattress

Hint: Do each measurement three times and calculate the average.

7.4 CONVERSION OF UNITS OF MEASUREMENT

What do you do when you have to calculate the measurements of something and the measurements are given in centimetres or millimetres, but your answer must be in square metres?

You will have to convert centimetres or millimetres to metres by means of calculations.

The following sections will discuss how to go about converting lengths in different types of measurement.

7.4.1 Conversion to metres

To do these conversions you must remember the following:

\[ 1 \text{ m} = 100 \text{ cm} = 1 000 \text{ mm} \]

or

\[ 1 \text{ cm} = 0,01 \text{ m} \]
- **Conversion of centimetres to metres**

What is the metre measurement of 75 cm?

If you do a conversion from a small unit, for example cm, to a larger unit, for example m, you divide. To determine the value with which to divide, you must know that **100 cm are equal to 1 m** and therefore you must divide by 100.

The answer is calculated as follows:

\[ 75 \text{ cm} = 0,75 \text{ m} \]

Another example is the following:

How many metres are 182 cm?

\[ 182 \text{ cm} = 1,82 \text{ m} \]

Remember: Conversion of cm to m: divide by 100.

- **Conversion of millimetres to metres**

What is the metre measurement of 680 millimetres?

Remember, you are converting a small unit, the millimetre, to a larger unit, the metre. Therefore you are going to do division. You must know that 1 000 millimetres are equal to 1 metre and therefore you must divide by 1 000.

The answer is calculated as follows:

\[ 680 \text{ mm} = 0,68 \text{ metres} \]

*Another example:*

How many metres are 1 943 millimetres?

\[ 1943 \text{ mm} = 1,943 \text{ metres} \]

Remember: Conversion of mm to m: divide by 1 000.

7.4.2 Conversion to centimetres

- **Conversion of metres to centimetres**

What is the centimetre measurement of 3,6 m?

If you do a conversion from a large unit, for example metre, to a smaller unit, for example centimetre, you **multiply**. To determine the value with which to multiply, you must know that 1 m is equal to 100 cm and therefore you must multiply by a 100.

The answer is calculated as follows:

\[ 3,6 \times 100 = 360 \text{ cm} \]
Another example is the following:
How many centimetres are 0,625 m?

\[ 0,625 \times 100 = 62,5 \text{ centimetres} \]

Remember: Conversion of metres to centimetres–multiply by 100.

- **Conversion of millimetres to centimetres**

What is the centimetre measurement of 37 mm?

If you do a conversion from a small unit, in this case mm, to a larger unit, in this case cm, you divide. To determine the value with which to divide, you must know that 10 mm are equal to 1 cm and therefore you must divide by 10.

The answer is calculated as follows:

Another example is the following:
How many centimetres are 0,15 mm?

Remember: Conversion of millimetres to centimetres–divide by 10

7.4.3 Conversion to millimetres

- **Conversion of metres to millimetres**

What is the millimetre measurement of 6,371 m?

Remember, you are converting a larger unit, namely metre, to a smaller unit the millimetre, therefore you are going to **multiply**. You must know that 1 m is equal to 1 000 mm and therefore you must multiply by 1 000.

The answer is calculated as follows:
\[ 6,371 \times 1 000 = 6 371 \text{ mm} \]

Another two examples:
How many millimetres are 124 m?
\[ 124 \times 1 000 = 124 000 \text{ mm} \]

How many millimetres are 0,0762 m?
\[ 0,0762 \times 1 000 = 76,2 \text{ mm} \]

Remember: Conversion of m to mm–multiply by 1 000.

- **Conversion of centimetres to millimetres**

What is the millimetre measurement of 4,67 cm?

If you do a conversion from a large unit, for example cm, to a smaller unit, for example mm, you multiply. To determine the value with which to multiply, you must know that 1 cm is equal to 10 mm and therefore you must multiply by 10.

The answer is calculated as follows:
\[ 4,67 \times 10 = 46,7 \text{ mm} \]
Another example is the following:
How many millimetres are 208 cm?

208 x 10 = 2080 mm

Remember: Conversion of cm to mm–multiply by 10.

Activity 7.3: Conversions

(1) Do the following conversions:

1.1 53 mm = ___ cm
1.2 684 mm = ___ cm
1.3 10 cm = ___ mm
1.4 0.3 cm = ___ mm
1.5 9.14 m = ___ cm
1.6 4820 cm = ___ m
1.7 5.8 mm = ___ m
1.8 2.58 m = ___ mm

(2) This is a discussion question that you should answer in the discussion forum on your e-tutor site.

Do an internet search and find at least two websites that convert one type of unit to another (e.g. pounds to kilograms, kilojoules to joules, kilometres to metres). Post the link plus a brief explanation of the site in the relevant topic in the discussion forum.

7.5 THE DIAMETER AND RADIUS OF THE CIRCLE OR SHAPE

The diameter of a circular object is described as a straight line connecting the centre of a circle or a sphere with two points on the perimeter (any boundary around something) or surface as illustrated in Figure 7.3.

![Figure 7.2](https://upload.wikimedia.org/wikipedia/commons/1/1b/Radius_and_diameter.png)

*FIGURE 7.2
The radius and the diameter of the circle*

(Source: https://upload.wikimedia.org/wikipedia/commons/1/1b/Radius_and_diameter.png)
LEARNING UNIT 7: Measurement of matter

FIGURE 7.3
Measuring the diameter of a cylinder or sphere (ball)
(Source: http://www.tutorvista.com/content/physics/physics-i/measurement-and-experiment/measurement-length.php)

The diameter of the circular object in Figure 7.3 (it could be a cylinder or a sphere or a ball), is 15 mm. In the illustration, this is measured by a pair of wooden blocks. The wooden block on the left-hand of the circular object is on the 0 mm mark and the wooden block on the right-hand is on the 15 mm mark. The diameter is thus equal to 25 mm.

The radius of a circle is described as a straight line joining the centre of a circle or sphere to any point on the surface or circumference of the circle as illustrated in Figure 7.2. Therefore, the radius is half the length of the diameter. So, what will the radius be of the sphere in Figure 7.3?

Activity 7.4: Measurement of diameter and radius
Give all your answers in cm:
(1) Measure the diameter of a 900 g tin of jam.
(2) Measure the diameter (at the bottom) of a 2 litre plastic bottle of cola.
(3) Measure the diameter of a 25 litre tin of paint.
(4) Calculate the radius of a 900 g tin of jam.
(5) Calculate the radius of a 2 litre plastic bottle of cola.

7.6 DETERMINING THE CIRCUMFERENCE OF A CIRCLE OR SPHERE
The circumference (also called perimeter) of a cylinder can be obtained by rolling the cylinder on a ruler. Begin at any marked point on the boundary of the cylinder and roll it over the ruler until the marked point is back in its original position. Then read the distance from the ruler.
A better method to obtain the circumference of a cylinder is to wrap a piece of paper around the cylinder so that it overlaps once. Prick a tiny hole (using a pin) through the overlapping parts. Remove the paper and measure the distance between the pin pricks.

A more practical method of determining the circumference of a circle is to calculate it. The formula for calculating circumference is given below:

\[ \text{Circumference} = 2 \pi r \]

**Explanation of symbols in the formula**

- \( \pi \) (pie) is a constant found by dividing the circumference of a circle by its diameter. The value for \( \pi \) is approximately \( 22 \div 7 \) or, for more accurate calculations \( 355 \div 113 \).
- For calculations you can thus use the value of 3.14 (which is the result of \( 22 \div 7 \)).
- \( r \) is the radius of a circle, that is the distance of a straight line from the centre of the circle to any point on the boundary of the circle. In other words, the diameter (\( d \)) of a circle is twice its radius (diameter = \( 2 \times \) radius).
- The formula therefore reads: circumference equals two pie radius.

**Example of calculating circumference**

Calculate the circumference of a ball with a radius of 10 cm.

Circumference of the ball = \( 2 \pi r \)
= \( 2 \times (22 \div 7) \times 10 \text{ cm} \)
[Hint: \( 22 \div 7 = 3.14 \)]
= 62.857 cm

**Activity 7.5: Measurement of circumference**

(1) Measure the circumference of a 900 g tin of jam.
(2) Measure the circumference of a 25 litre tin of paint.
(3) Measure the circumference (at the bottom) of a 2 litre plastic bottle of cola.
(4) Calculate the circumference of a container with a radius of 25.5 cm.

**Feedback on activity 7.5**

You can measure the circumference of the tin of jam and tin of paint by using the methods described in section 7.5. Using the method of a long piece of paper would be the most practical method. To calculate the circumference of the container with the radius of 25.5 cm you should use the formula as given above: circumference = \( 2\pi r \). Thus, your calculation should look like this:

Circumference of container = \( 2 \times (3.14)(25.5) \)
= 160.14 cm
7.7 AREA
An area is any flat, curved or irregular expanse of a surface, a section or part, for example a section or part of a building or room.

Other units for area:
- km² (used for big areas like the area of countries)
- cm² (used for small areas)
- mm² (used for very small areas)

A square metre is a square with sides that are each one metre long.

Important:
- We do not use units like dm² for area.
- Note from all these units that area, indicated in m², is the length in metres times (x) the breadth in metres. Thus, from the definition that the area of a rectangle is the length of the rectangle multiplied by the breadth of rectangle, we obtain a new unit which denotes area. This is derived or formed from the SI base unit for length, namely the metre.

Practical example:
The area of a house is expressed in square metres. A small house may have an area of 110 m², whereas a large house may have an area of 250 m².
### 7.7.1 Examples of calculating area

- **Area of a square**

  ![Figure 7.6: A square](image)

  The area of the square is calculated as follows:
  
  \[
  \text{Area} = \text{length} \times \text{breadth} = 30 \text{ m} \times 30 \text{ m} = 900 \text{ m}^2
  \]

- **Area of a rectangle**

  ![Figure 7.7: A rectangle](image)

  The area of the rectangle is calculated as follows:
  
  \[
  \text{Area} = \text{length} \times \text{breadth} = 50 \text{ m} \times 40 \text{ m} = 2000 \text{ m}^2
  \]

- **Area in square centimetres and square millimetres**

  Although the SI unit of area is the square metre, area can also be calculated in square centimetres (cm²) and square millimetres (mm²).
cm², for example, (which is read as “centimetre square”) does not have to be a square with sides of 1 cm each. Each of the shapes in Figure 7.8 has an area of 1 cm².

![Figure 7.8](image)

*Each of these shapes has an area of 1 cm²*

Calculate the area of a rectangle with a length of 25 cm and a breadth of 15 cm.

\[
\text{Area} = \text{length} \times \text{breadth} = 25 \text{ cm} \times 15 \text{ cm} = 375 \text{ cm}^2
\]

### 7.7.2 Calculation of areas requiring conversion

Remember that when doing calculations, all the measurements must be in the same unit of measurement, e.g. cm, mm, or m. You cannot, for example, multiply cm with mm. The rule is to first convert all given measurements to the same unit of measurement, such as converting cm to mm. Then do the calculation. Also, first convert the measurement to the unit you want to measure it in.

For example, suppose that measurements are in mm but you need an answer in cm². In such a case, first convert the measurements from mm to cm.

**• Calculation of area requiring conversion of centimetres to metres**

Calculate the area of a block with a length of 50 cm and a breadth of 25 cm, giving your answer in square metres.

The question asks you to give your answer in metres, therefore you firstly have to convert the cm to m.

Length: 50 cm = 0.50 m

Breadth: 25 cm = 0.25 m

Then, calculate the area:

\[
\text{Area} = \text{length} \times \text{width} = 0.50 \text{ m} \times 0.25 \text{ m} = 0.125 \text{ m}^2
\]
NOTE
Always round off the answer to three decimal numbers.

• Calculation of area requiring conversion of millimetres to metres

Calculate the area of a rectangle with a length of 675 mm and a breadth of 150 mm, giving your answer in square metres.

First, do the conversions:
Length: 675 mm = 0.675 m
Breadth: 150 mm = 0.150 m

Then, calculate the area as follows:
Area = length x breadth
     = 0.675 m x 0.150 m
     = 0.101 m²

Activity 7.6: Measurement of area

(1) Calculate the area of a square with side lengths of 590.3 cm.
(2) Calculate the area of a square with side lengths of 0.86 m. Give your answer in millimetres (mm).
(3) Calculate the area of a rectangle with a length of 77.6 m and a breadth of 5.51 m. Give your answer in centimetres.
(4) See if you can find an online site or application that can help you to do area calculations.

Feedback on activity 7.6

Section 7.15 discusses clearly how you should calculate the area of a square or rectangle. For example, the area of a square with side lengths of 590.3 cm would be calculated as follows:

Area = length x breadth
     = 590.3 cm x 590.3 cm
     = 348 454.90 m²

Remember to convert the values to the metric system. For example, question 2 in the activity wants the answer in millimetres (mm). Therefore first convert the metre measurement of 0.86 m to mm as follows:

Remember it was explained earlier that to convert m to mm you need to multiply by 1 000:

0.86 m x 1000 = 860 mm

Thus you can use the measurement of 860 mm to calculate the area of the square in question 2.
Do a similar calculation in answering question 3 but remember to use the correct conversion calculation for metres to centimetres.

### 7.8 VOLUME

Volume is the magnitude of the three-dimensional space enclosed within or occupied by an object as illustrated in Figure 7.9.

![Figure 7.9: Volume of a cubic space](Source: Unisa drawing)

Although the SI unit of volume is the cubic metre (m³), volume can also be expressed in cubic decimetres (dm³), cubic centimetres (cm³) or cubic millimetres (mm³), as follows:

\[ 1 \text{ m}^3 = 10^6 \text{ cm}^3 = 10^9 \text{ mm}^3 \]

\[(10^6 = 1,000,000 \text{ and } 10^9 = 1,000,000,000)\]

Study Figure 7.10 below carefully. It will give you a clear picture of the relation between volume units.

Volume of a cube

\[ = 10 \text{ cm} \times 10 \text{ cm} \times 10 \text{ cm} = 1000 \text{ cm}^3 = 1000 \text{ ml} \]

Volume of a cube

\[ = 1 \text{ dm} \times 1 \text{ dm} \times 1 \text{ dm} = 1 \text{ dm}^3 = 1 \text{ l} \]
A cubic centimetre is a block with sides that are each 1 cm long. Such a block where the length, breadth and height have the same measurement is called a cube.

### 7.8.1 Calculating volume

The following formula is used to calculate volume:

\[
\text{Volume} = \text{length} \times \text{breadth} \times \text{height}
\]

- **Examples of calculations**

Below are some examples of volume calculations.

- **Volume in cubic metres**

Calculate the volume of a block with a length of 2 m, a breadth of 2 m and a height of 2 m.

The volume is calculated as follows:

\[
\text{Area} = \text{length} \times \text{breadth} \times \text{height} = 2\,\text{m} \times 2\,\text{m} \times 2\,\text{m} = 8\,\text{m}^3
\]

- **Volume in cubic centimetres**

The volume of an object where the length, breadth and height have different measurements can also be calculated.
Calculate the volume of a block with a length of 5 cm, a breadth of 4 cm and a height of 3 cm.

Then, calculate the area as follows:

\[
\text{Area} = \text{length} \times \text{breadth} \times \text{height} \\
= 5 \text{ cm} \times 4 \text{ cm} \times 3 \text{ cm} \\
= 60 \text{ m}^3
\]

7.8.2 Applications of volume calculations

In our daily lives we generally use litres (l) and millilitres (ml) to measure volume. There are 1 000 ml in 1 l, and 1 ml is the same as 1 cm³. Both solids (butter, flour or sugar) and liquids (milk, water, oil or vanilla essence) can be measured in ml.

<table>
<thead>
<tr>
<th>Remember</th>
<th>1 000 = 1 l</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 ml = 1 cm³</td>
</tr>
</tbody>
</table>

We use transparent measuring cups to measure the volume of liquids (Figure 7.11). Remember to avoid the error of parallax by keeping your eye at the same level as the meniscus (the upper surface of the liquid). The error of parallax occurs when the observer moves to the right, left, up or down and views the instrument or rule from different angles. An incorrect value is then obtained.

![250ml cup](https://en.wikipedia.org/wiki/Measuring_cup)

**FIGURE 7.11**

*A 250ml cup*  
(Source: [https://en.wikipedia.org/wiki/Measuring_cup](https://en.wikipedia.org/wiki/Measuring_cup))

To measure the volume of dry ingredients we use spoons or cups (Figures 7.12 and 7.13). To accurately measure the volume, you fill the spoons or cup completely, and then scrape it level with a knife or spatula.
Activity 7.7: Measurement of volume

Give accurate measurements, in centimetres, of the following:

1. The length of a 500 g box of macaroni
2. The breadth of a 500 g box of macaroni
3. The height of a 500 g box of macaroni
4. The breadth of a standard room door
5. The length of a standard room door
6. The height of a standard room door

Now do the following calculations:

7. Calculate the volume of the 500 g box of macaroni.
8. Calculate the volume of the standard room door (give this answer in m).
Fill a measuring jug with 100 ml water and place it on the kitchen counter:

(9) Stand up straight about 30 cm away from the measuring jug. Write down the amount of water you can read from the jug from your viewpoint.

(10) Bend your knees so that your eyes are at the same height as the level of water in the measuring jug. Take the reading again and write it down.

(11) Chances are you had different answers to the previous two questions. Discuss why you think you got two different readings from the same amount of water in the measuring jug.

7.9 MASS
The mass of an object remains the same anywhere in the universe. Therefore, the mass of a person will be the same on the moon as on the earth.

To determine the mass of an object, we use a mass metre, also called a balance. You can determine your own body mass by means of a bathroom scale.

Due to different densities of matter, the same volume of different matter might have different mass. For example, 500 ml water will weigh 500 g, while 500 ml flour will weigh about 300 g. Think also about lettuce and potatoes. One bowl filled with lettuce will weigh much less than the bowl filled with potatoes.

Density is discussed in section 7.22.

Some examples of mass metres are illustrated in Figure 7.14.

![Mass meters](https://pixabay.com/en/photos/balance/)

**FIGURE 7.14**
Mass meters

7.9.1 Weight
The earth attracts all objects that have mass. A small mass, for example 1 kg, will be attracted with a small force. A big mass, for example 50 kg, will be
attracted with a bigger force. The force with which the earth attracts an object is called the weight of the object and is measured in Newton.

The force with which the moon attracts an object is one-sixth of the force with which the earth attracts the same object. Therefore, on the moon, objects weigh only one-sixth of what they weigh on the earth. Although you may weigh less on the moon than on earth, you will still have to wear the same size clothing as on earth! In other words, your mass stays the same.

![Figure 7.15](image)

**FIGURE 7.15**

*A monkey weighs less on the moon than on the earth!*

*(Source: Unisa drawing)*

### 7.9.1.1 Measuring weight

To measure the force with which the earth attracts an object, we need an instrument to measure this force. The spring balance, calibrated in Newton, is the instrument used to measure this force (Figure 7.16).
When you hang a mass piece of 1 kg on the hook of a spring balance, the balance reads 9,8 N. When you hang a mass piece of 2 kg on the hook, the balance reads 19,6 N. This tells us that the weight on the earth of a 1 kg is 9,8 N and that of a 2 kg mass piece is 19,6 N.

To determine what force is needed to support the mass of an object with known mass, simply multiply the mass in kilograms of the object by 9,8 to obtain the weight in Newton.

There is no noticeable difference between the force required to support an object and the force required to lift an object at a constant rate.

7.9.2 Examples of calculations
The following formula is used to calculate weight:

Weight in Newton = mass in kg x 9,8

To simplify our calculations in the examples below, we shall use a value of 10 N instead of 9,8 N for the mass of 1 kg on earth.

- **Weight when mass is given in kilograms**

Calculate the weight on earth of a woman with a mass of 50 kg. The weight is calculated as follows:

\[
\text{Weight in Newton} = \text{mass in kg} \times 10 \\
= 50 \text{ kg} \times 10 \\
= 500 \text{ N}
\]
• Weight when mass is given in grams

Remember

Golden rule

You are not allowed to change a formula or the units of measurement in that formula.

The formula for calculating weight states that mass should be in kg, therefore, if the unit of measurement is not in kg, the unit must be converted to kg.

Calculate the weight on earth of a book with a mass of 350 g. First, convert the grams to kilograms as follows:

\[
1 \text{ 000 g} = 1 \text{ kg} \\
350 \text{ g} = 0,350 \text{ kg}
\]

The weight is then calculated as follows:

Weight in Newton = mass in kg x 10
                  = 0,350 kg x 10
                  = 3,50 N

Activity 7.8: Measurement of weight

Complete the statements by measuring the volumes of the ingredients given and then give the mass of the ingredient in grams.

1. 12,5 ml salt = ____ g
2. 15 ml bicarbonate of soda = ____ g
3. 25 ml curry powder = ____ g
4. 50 ml baking powder = ____ g
5. 75 ml sugar = ____ g
6. 100 ml raisins = ____ g
7. 125 ml maize meal = ____ g
8. 250 ml macaroni, uncooked = ____ g
9. 250 ml cake flour = ____ g
10. 500 ml rice, uncooked = ____ g

7.10 DENSITY

The SI unit of density is kilograms per cubic metre (kg/m³).

To understand what is meant by the density of a substance, we need to measure both the mass and the volume of the substance.

All substances have the following measurable properties:

• Volume (they occupy space)
• Mass
Different substances have different densities. An iron saucepan is much heavier than an aluminium saucepan of the same size. The reason is that iron is much denser than aluminium. A fruit cake has a greater density than a sponge cake.

Let us take a variety of solid cubes, each with a volume of cm\(^3\). These cubes may be made of wood, iron, glass, polystyrene, plastic, etc. If we measure the mass of each cube, we find that each cube has a different mass.

Since each substance has a volume of exactly 1 cm\(^3\), we can compare their masses per cubic centimetre. In this way we are comparing their densities.

If the volume doubles, the mass doubles, and if the volume trebles, the mass trebles.

A relationship in which one quantity is doubled when another is doubled is called a directly proportional relationship. Note that division of one of the quantities by the other always gives the same answer.

### 7.10.1 Density of liquids

<table>
<thead>
<tr>
<th>Densities of some common liquids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water = 1,0 g/cm(^3)</td>
</tr>
<tr>
<td>Petrol = 0,7 g/cm(^3)</td>
</tr>
<tr>
<td>Methylated spirits = 0,8 g/cm(^3)</td>
</tr>
<tr>
<td>Mercury = 13,6 g/cm(^3)</td>
</tr>
</tbody>
</table>

Why does ice float in water? The reason is that the density of ice is less than the density of water. When we place a cork and block of ice in water, we find that the ice penetrates the water much deeper than the cork. This happens because the density of ice is very close to the density of water. The ice almost sinks, and only about one-tenth of the ice block remains above the surface of the water. On the other hand, the density of the cork is much less than the density of water and about four-fifths of the cork remains above the surface of the water.

### 7.10.2 Applications

Some practical examples of the importance of density are briefly discussed below.

- **Test for freshness of eggs**

  The freshness of an egg can be determined by placing an egg into salt water. If the egg is fresh, it will sink, but if it is stale, it will float. Staleness is due to water loss through the porous shell, thus it will be less dense.
• Mineral additives in flour

Flour may contain added nutrients or raising agents. Shake a little bit of flour in a test tube with chloroform. The less dense flour will float on the surface, whereas the denser mineral matter will sink to the bottom.

• French salad dressing

A French salad dressing must be shaken just before it is used, because it separates into layers when it is left standing. The less dense oil forms a layer on top of the vinegar.

• Hydrometer

A hydrometer is the instrument used to find the relative density of different liquids by direct measurement. (Relative density is the number of times that a substance is heavier or lighter than water.) Hydrometers are used in winemaking, for example, to measure the amount of sugar in wine.

Activity 7: Revision and reflection

(1) Explain what the SI system is.
(2) Compile a table and complete it by filling in the following information:
   (a) The quantity of the seven fundamental units of the SI system
   (b) The name of each unit
   (c) The symbol used for each unit
(3) List the eight (8) derived SI units and give the symbol used for each of the units.
(4) Name three instruments used for measuring volume in the kitchen.
(5) What is the difference between the mass of an object and the weight of an object?
(6) Give at least one practical example, not mentioned in this learning unit, of how the knowledge you gained in this unit can help you either in the hospitality or textile industry, or in your day-to-day life.

7.11 CONCLUSION

The international system of measurement is known as the SI system, which has seven base units. Prefixes are used to indicate the multiples and submultiples of these units. Measurements should be done in metres, but millimetres and centimetres can also be used. Conversions between these measurements are important for a correct calculation.

When measuring circular objects, the diameter, radius and circumference measurements are important. For calculating an area, one needs the length and breadth measurements, while calculating a volume, height is additionally needed.

Mass is a measure of the amount of matter that makes up an object with the SI unit of kilogram. Weight is the force with which the earth attracts an object and is measured in Newton.
Density of a substance is the mass of a particular volume of a substance and is measured in kg/m³.

Forces don’t only occur between objects and the earth but also between the smaller particles of matter. This topic will be discussed in learning unit 8.
8.1 INTRODUCTION
In study unit 2 on atomic structures you learnt that all matter is composed of very, very small particles called atoms. Although the structure of matter is not discussed in detail in this learning unit, we shall look at some of the forces that exist between these particles or molecules.

Learning unit outcomes

After you have completed this learning unit, you should be able to:

• explain what is meant by the following terms:
  - surface tension
  - adhesion
  - cohesion
  - capillarity
  - elasticity
• identify which of the principles above is applicable in a given everyday life situation

• Adhesion and cohesion
The force of attraction between molecules of the same substance is known as cohesion. The force of attraction between molecules of different substances is known as adhesion.

• Application of adhesion
The adhesion of water to glass molecules is greater than the cohesion between each of the water molecules. Water will therefore wet the glass and form a concave meniscus (see Figure 8.1).

• Application of cohesion
The cohesion between mercury particles is greater than the adhesion between mercury and glass particles. Mercury does not wet the glass, but slides off cleanly. It forms a convex meniscus in a glass cylinder (see Figure 8.1).
LEARNING UNIT 8: Forces between particles

Activity 8.1: Adhesion and cohesion

(1) Drip one droplet of water on a flat surface. Drip a second water droplet 1 cm from the first. What do you observe in connection with the shape and size of the droplets?

(2) Very carefully drip a third droplet of water in between the two droplets on the surface. What happens to the droplets?

(3) What do you observe in connection with the shape and size of the droplet(s) you’ve observed?

(4) What is the phenomenon you have observed in question 2 called?

(5) Pour water from a glass jug. What do you observe in connection with the water drops on the side of the jug?

(6) What is this phenomenon called?

8.2 SURFACE TENSION

Why do you think a steel needle floats if placed gently on the surface of water?

Before the question can be answered, we must first look at the structure of water. The smallest bit of water you can have is a water molecule. Each water molecule contains two hydrogen atoms and one oxygen atom, therefore the formula for water—H₂O. The atoms in the water molecule are held together by electric forces. These electrical forces are brought about by the oxygen and hydrogen atoms sharing some of their electrons. As studied earlier, this sharing of electrons is known as covalent bonds. These covalent bonds which hold the water molecule together are fairly strong. These electrons which are shared between the oxygen and hydrogen atoms also attract the positive...
charges within these atoms. These attractions render the atoms to act like glue and stick together.

Water **molecules** also stick to each other because of the way their electrons are arranged (see Figure 8.2). In a water molecule the oxygen atom has a small negative charge (\(-\)), while the two hydrogen atoms each have a small positive charge (written as \(+\)). Each of the positive charges on the hydrogen atoms of one water molecule attracts (sticks to) the negative charges of two other oxygen atoms. These attractive forces are fairly weak, but strong enough to keep water molecules together as a liquid at room temperature.

![Hydrogen bond](https://commons.wikimedia.org/wiki/File:210_Hydrogen_Bonds_Between_Water_Molecules-01.jpg)

**FIGURE 8.2**

*Forces of attraction in water molecules*

(Source: [https://commons.wikimedia.org/wiki/File:210_Hydrogen_Bonds_Between_Water_Molecules-01.jpg](https://commons.wikimedia.org/wiki/File:210_Hydrogen_Bonds_Between_Water_Molecules-01.jpg))

You can see the electric stickiness of water in your daily lives. Water forms droplets, as for example from a tap, because of the water molecules clinging to each other. Water molecules are also attracted to some other types of molecules, which is why things are wet when you lift them out of the water—there are still water drops sticking to them.

Now, back to the question why do you think a steel needle floats if placed gently on the surface of water? It is due to surface tension which all liquids have. Liquids behave as if they have a kind of elastic skin all over their surface. The surface of the liquid tries to shrink in order for it to cover as small an area as possible. Water has a particular high surface tension due to attraction forces between water molecules. The skin effect on the surface of water is caused by the attraction of surface molecules for one another, and for molecules beneath the surface as shown in Figure 8.3. The molecules under the surface of a liquid are attracted from all sides by other molecules. A molecule at the surface of a liquid, however, is attracted by the molecules at its sides and deeper in the water, but not by the molecules above it (since there are none above it). This
creates a tension on the liquid’s surface called surface tension. It is this surface tension that makes it possible for the needle to float and not sink.

![Surface tension](https://en.wikipedia.org/wiki/Surface_tension)

**FIGURE 8.3**

*Surface tension*

(Source: https://en.wikipedia.org/wiki/Surface_tension)

- **Application in waterproof fabrics**

  The spaces between the threads in the fabric of an umbrella or a tent are much larger than water molecules. The surface tension of water, however, is so high that a single water molecule cannot leave the rest of the water molecules to pass through the fabric, therefore making the fabric waterproof and keeping the water on one side.

- **Application in cleaning processes**

  A cleaning agent must come into very close contact with the fibres when clothing is cleaned. The surface tension of warm water is lower than that of cold water. Therefore, the fabric will become wetter in warm water and can be washed more thoroughly.

  Soap and detergents also lower the surface tension between water and fat. Oiliness or dirt mixes better with water when soap or detergents are used. The dirt is then kept in the form of a suspension or an emulsion and can be washed away easily. Read section 6.6.4 of learning unit 6 on bases for a better description of how soaps and detergents work.
Activity 8.2: Surface tension

(1) Fill a basin with water. Very gently, put the following onto the surface of the water and then describe what you observe.
   (a) A very small stone
   (b) A grain of rice
   (c) A pin/needle
   (d) A feather

(2) Give an explanation for the observations you have made by applying your understanding of surface tension. Post your answers in the discussion space on your e-tutor site.

8.3 CAPILLARITY

The rise of water or another liquid in very small spaces is known as capillarity. When a very narrow glass tube (capillary tube) is dipped into water, the water will rise up inside the tube above the external surface of the water. This is due to the fact that the adhesion force between the glass and the water molecules is greater than the cohesion force between the water molecules.

Examples of the application of capillarity include the following:

- Blotting paper and paper towels work because of capillarity. Water rises in the narrow spaces between the fibres.
- Kerosene moves up the wick of a kerosene lamp because of capillarity.
- A capillary tube is used to draw a small amount of blood after pricking the tip of your finger.

8.4 ELASTICITY

An elastic material is one that can return to its original shape and size after it has been stretched. When we stretch a piece of elastic, we apply a force that increases the distance between the molecules against the cohesion and adhesion forces. When the external force is removed, the distances will return to normal.

Examples of the application of elasticity include the following:

- The elastic property of flour is due to the gluten that is present in all wheat dough. This property will allow the dough to expand and render a structured product with enclosed air.
- Wool may be a better choice of fibre for carpets and garments than synthetic fibres. The natural elasticity and resilience of wool helps it to return to its original position and to wrinkle less than synthetic fibres.

Activity 8.3: Elasticity

(1) Take a sponge and exert pressure on it with your finger. What do you observe?
(2) What do you observe when you remove your finger?
(3) Give three examples of substances that display elastic properties. (Do not use the same examples I have given earlier.)

Activity 8.4: Revision and reflection

(1) Explain the difference between adhesion and cohesion forces.
(2) Explain the term “surface tension”.
(3) Explain why the meniscus of water is different to that of mercury.
(4) Explain the term “capillarity”.
(5) Give two examples where capillarity force is applied.
(6) Explain why certain material have the property of elasticity and give two examples.
(7) This unit (and earlier units) contains some terms that may be new to you. How good are you at learning new terms quickly – what strategies do you use for this? If you would like to know more about learning new terms effectively, you could do an internet search and read sites such as "http://edition.tefl.net/articles/teacher-technique/7-tricks-to-help-remember-new-words/".

8.5 CONCLUSION

All matter is composed of very small particles. Different forces exist between these particles. Surface tension, capillary and elasticity are due to the adhesion and cohesion forces between molecules. Adhesion is the attraction between molecules of different substances, and cohesion is the attraction between molecules of the same substance.
LEARNING UNIT 9

Diffusion, osmosis, absorption and adsorption

9.1 INTRODUCTION

How is it possible for the scent of flowers to waft through a room? Why do your hands smell of garlic after you have touched a garlic clove? And why do lettuce leaves go limp if they are washed in very salty water?

In this learning unit, we shall be looking at the processes that are responsible for phenomena like these: diffusion, absorption, adsorption and osmosis. These four closely-related processes play an important role in, for example, the functioning of our bodies and in food preparation.

Learning outcomes

After you have completed this learning unit, you should be able to:

• define diffusion, osmosis, absorption and adsorption
• identify examples of diffusion, osmosis, absorption and adsorption as they occur in your daily activities
• give possible ways of preventing or bringing about diffusion, osmosis, absorption and adsorption in a given situation

9.2 DIFFUSION

Diffusion is the movement of molecules from a region of high concentration to a region of low concentration until the molecules are distributed equally throughout the whole space.

When frying meat in the kitchen you can usually smell it all over the house. Particles of gas are released from the meat and are spread or diffused throughout the house.

All gases diffuse and will fill the space which is made available to them. Why do gases diffuse? If we take it that gases consist of small particles and that these particles are constantly moving, the question is easy to explain. If the particles move at random, and they can go anywhere, sooner or later they will fill all the space available. This will even happen if the gas is heavier than air.
Heavier gases such as carbon dioxide and bromine will diffuse more slowly than lighter gases such as hydrogen because the heavier particles move slower.

Diffusion occurs in all substances (solids, liquids and gases). The rate of diffusion of a substance depends on several factors:

- The **concentration** of the substance and the concentration difference (concentration gradient) between the two areas
- The **area** in which diffusion takes place
- The **diffusion coefficient** (quantity of the substance that passes through an area in a certain time) which varies from substance to substance (due to cohesion forces)
- **Temperature**—the higher the temperature the higher the rate of diffusion
- The **density** of diffusing molecules (solid, liquid or gas)
- The **medium** in which diffusion occurs
- Whether diffusion is **free** (no membrane separating the two areas) or through a **membrane** (permeable or differentially permeable) (a permeable membrane is a membrane that allows substances to pass through it)

Diffusion plays an important role in biological processes. Oxygen moves from the lungs to the blood and from the blood to the muscle fibres by means of diffusion. After food has been digested by our digestive tract, the small molecules diffuse through the wall of the digestive tract into the bloodstream where there is a low concentration of these molecules, and the bloodstream carries the molecules to the different parts of the body.

9.3 OSMOSIS

Osmosis is the movement of water through a partially permeable membrane from a less concentrated solution to a more concentrated solution until both solutions are of the same concentration.

The process of osmosis can be explained by using the kinetic theory as shown in Figure 9.1. On the left side of the partially permeable membrane there is pure water (A) and on the right side there is a solution of water and salt (B). On both sides of this partially permeable membrane the water and salt molecules are constantly moving and constantly bombarding it. During this process some water molecules pass through one of the small holes in the membrane. If there were pure water on both sides of the membrane, the same amount of water would flow in each direction, and there would be no overall change.

However, on the side of the salt and water solution (B) the larger salt molecules are in the way of the water molecules and so the water molecules cannot move through the holes of the membrane as easily as in the case of pure water. So, the flow of water from side B to side A is slower. The overall effect is that the pure water flows through the membrane into the salt solution.

Osmosis is really only a special case of diffusion. In pure water, the concentration of water molecules is high. In a solution, e.g. a water-and-salt solution, the concentration of water is lower, because some water has been replaced by the solute, in this case the salt. Therefore, water moves from a region of
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high water concentration (pure water) to a lower concentration (the solution of water and salt).

Examples of the application of osmosis:

- When dried fruit, such as prunes or raisins, are soaked in water (high concentration of water), the water will pass through the skin (which is a partially permeable membrane) into the fruit (lower concentration of water, higher concentration of sugar). The fruit will become swollen with water.
- When stewing dried fruit, we add the sugar only once the fruit is nearly done. Otherwise, water will move from the fruit to the surrounding water, and the fruit (such as prunes) will become even more wrinkled.
- When lettuce leaves are washed, the water should not have a high salt concentration. Otherwise, cell sap will move out of the cell into the surrounding water, and the lettuce leaves will become limp.

Activity 9.1: Osmosis

1. When someone is baking or frying food, a person in another room can usually smell the food. Explain this phenomenon.
2. Take some raisins and put them in a bowl of water for approximately one hour. Drain the water from the raisins. What do you observe in connection with the raisins? Explain this phenomenon.
9.4 ABSORPTION
Absorption is the taking in of fluids or other substances into another substance.

Examples of the application of absorption:

- When working with strongly flavoured food such as fish or onions, your hands absorb the odour and your hands smell of the food.
- Certain foods, such as milk and eggs, will absorb odours from other foodstuffs in the refrigerator if they are not sealed properly. In the case of eggs, the odour molecules diffuse through the porous shells.
- In your digestive tract, digested food will be absorbed from the tract into the blood stream.
- Clothes made from absorbent fabrics are comfortable since they take up (absorb) perspiration easily.

9.5 ADSORPTION
Adsorption is the collection of substances on the surface of solids.

Adsorption is different from absorption, in which a substance diffuses into a liquid or solid to form a solution.

The term “sorption” encompasses both absorption and adsorption, while desorption is the reverse process.

Examples of the application of adsorption:

- Teacups and aluminium pots are stained by an adsorption layer of stain on the solid surface.
- We clarify soup by beating egg white and egg shell into it. The egg white and egg shell remove the small solids in the soup through the process of adsorption. (Remove the egg white and egg shell before serving the soup!)
- A strange recommendation is that charcoal tablets will help if you suffer from indigestion, since they adsorb gases. A piece of charcoal in your refrigerator will also adsorb any unwanted odours.

Activity 9.2: Adsorption

1. After you have peeled an onion, wash your hands and then smell your hands. What do you smell?
2. Give an explanation for your observation.
3. Describe the colour of the inside of a teapot which has been in use for a long period of time. Give an explanation for your observation.
Activity 9.3: Revision and reflection

(1) Give a definition of each of the following:
   (a) Diffusion
   (b) Absorption
   (c) Adsorption
   (d) Osmosis

(2) Answer this question in the discussion space in your e-tutor site. Explain the following:
   (a) Adding egg white to soup will clarify the soup.
   (b) Sugar can be added to the stewing liquid of fresh fruit at the beginning of the cooking time, but to that of dried fruit only near the end of the cooking time.

9.6 CONCLUSION

Diffusion is the movement of particular molecules from a region where there is a high concentration of those molecules to a region where there is a low concentration of those molecules. Osmosis is the diffusion of water molecules through a partially or semi-permeable membrane to a region where there is a high concentration of other molecules. During absorption, particles are taken into a substance, whereas during adsorption, substances collect on the surface of solids.
10.1 INTRODUCTION

Energy comes in a variety of forms. Can you think of a few?

The simplest definition of the types of energy suggests that two forms exist: kinetic energy and potential energy. Kinetic energy is the energy due to motion. A rock falling from a cliff, wind blowing leaves off trees, and water flowing over a waterfall are all examples of kinetic energy. Potential energy is the energy stored by an object that can be potentially transformed into another form of energy. Water stored behind a dam, the chemical energy of the food we consume, and the gasoline that we put in our cars are all examples of potential energy.

Some other forms of energy include heat, electricity, sound, energy of chemical reactions, magnetic attraction, energy of atomic reactions, and light. Heat energy is a form of energy created by the combined internal motion of atoms in a substance and will be discussed in the following sections.

Without heat, all life on Earth—plants, animals and humans—would die. Too much heat, however, can also destroy life on Earth. In this learning unit we shall look at this very important form of energy and its application in our daily lives.

Learning outcomes

After you have completed this learning unit, you should be able to:

- distinguish between heat and temperature
- describe how substances (solids, liquids and gases) react when they are heated, and give examples of practical applications of these reactions
- identify the factors that affect the rate of evaporation, and apply this knowledge to given situations
- identify the different ways in which heat is transferred, and give examples of these processes in your day to day activities

10.2 HEAT AS A FORM OF ENERGY

Heat is a form of energy. When matter, such as coal or water, is heated, its temperature rises and the molecules start to move about faster and faster. Heat is caused by this vibration or movement of molecules in a substance. When a
substance is cold, the molecules vibrate or move more slowly than when the substance is hot. The molecules in solids vibrate, but do not move around as the molecules in liquids or gases do.

The law of conservation of energy states that energy can be neither created nor destroyed during a chemical reaction. Energy can only be changed from one form to another.

The law of conservation of matter states that matter (a form of energy) can be neither created nor destroyed during a chemical reaction.

Heat can be obtained from various other forms of energy:

- From the sun (nuclear energy → heat)

The sun is our main source of natural heat. Increasing use is being made of solar energy in our homes. Solar panels are installed on the roofs of houses, and heat is absorbed by water running through black plastic tubing. Money can be saved by heating water in this way because electrical consumption is reduced.

- From electricity (electric energy → heat)

Electric potential energy is converted to heat energy in electrical appliances, e.g. stoves or heaters.

- From food (chemical energy → heat)

Chemical potential energy is converted to heat energy in our bodies.

- From friction (kinetic energy → heat)

This kind of energy can be transferred into heat energy when we rub our hands together or strike a match to light a fire.

- From burning fuels (chemical energy → heat)

Chemical potential energy is converted to heat energy from a wooden fire or a gas stove.

10.3 HEATING OF MATERIALS

As a material is heated its temperature rises. The temperature tells us how hot the material is and is measured using a thermometer. Different kinds of thermometers have been designed for different uses. The most common thermometers are liquid-in-gas thermometers. Usually, the liquid inside the glass is mercury (see Figure 10.1) but alcohol is also used. When the temperature rises, mercury in the bulb expands and moves up the narrow capillary tube to show a higher temperature.
LEARNING UNIT 10: Heat and temperature

FIGURE 10.1
A 0°C to 100°C mercury-in-glass thermometer
(Source: Unisa drawing)

Mercury is a suitable liquid for thermometers for the following reasons:

- It is easy to see.
- It can be used over a wide temperature range without freezing or boiling (melting point for mercury is -39 °C, and its boiling point is 357 °C).
- It expands and contracts rapidly.
- It does not stick to glass.

Most thermometers have a scale marked in degrees centigrade. This is known as the Celsius scale. There are various thermometers which have different functions.

- **Clinical thermometers**

A clinical thermometer is used to take the temperature of a person. It has two special features:

- The temperature scale is calibrated between 35 °C and 42 °C which covers only the few degrees on either side of normal body temperature which is 37 °C.
- The capillary tube for the mercury thread has a narrow part (constriction) just above the bulb. When the thermometer is put under the person’s tongue, the mercury is heated. The mercury expands and it forces its way past the constriction. This causes the mercury thread to break at the constriction. The mercury above the constriction stays there, showing the patient’s temperature. Once the temperature has been taken, the thermometer is shaken, to force the mercury back past the constriction into the bulb.
• Oven thermometers

Individual oven thermometers are available for ovens without built-in thermometers and for testing the temperature of ordinary electric ovens. They are calibrated up to 315 °C.

• Sugar thermometers

Sugar thermometers are used in sugar cookery as the end product is highly dependent on the temperature the heated sugar reaches. Different temperatures in sugar cookery result in crystalline candies, hard candies, toffees, caramels, taffy and brittles.

• Deep-fat frying thermometers

These thermometers measure up to 200 °C. Raw mixtures, such as uncooked koeksisters, should be fried at 180 °C, and pre-cooked foods, such as fish cakes, at 190 °C.

• Meat thermometers

The internal temperature of a roast is measured with a meat thermometer. The different types of meat, for example mutton, pork and beef, will be done at different internal temperatures. The thermometer has a blunt point that needs to be inserted into the meat in order to measure the internal temperature.

10.4 EXPANSION AND CONTRACTION OF SOLIDS, LIQUIDS AND GASES

In general, gases expand more than liquids and liquids expand more than solids for a given temperature change. Solids expand very little when they are heated, but this expansion can not be ignored. The force produced by an expanding solid can crack concrete and buckle railway lines. Read the kinetic theory of matter again in study unit 1.

• What causes expansion?

When a substance is heated, its molecules move and vibrate faster and collide with more force. The molecules are therefore pushed further apart and the substance expands.

As a substance is cooled down, the molecules move more slowly, collide less often and when they collide it is with less force. This enables the molecules to move closer to each other and the substance contracts. As the substance cools further, the molecules move more slowly and further contraction takes place. In theory, contraction will continue until the molecules stop moving altogether. Scientists believe that the molecules of all substances stop moving at the same temperature, called the absolute zero.
• **Expansion of water, why is it different?**

When water is cooled to a temperature of 4 °C, it contracts. Then, an unusual thing happens. As the water cools further from 4 °C to 0 °C it expands slightly. At 4 °C, 1 kg of water occupies 1,000 cm³, but at 0 °C it occupies 1,005 cm³.

Another unique property of water is that as water at 0 °C changes to ice, it expands considerably. Because of these unusual changes, ice is less dense than water. Ice floats on water and water itself is most dense at 4 °C.

When water turns to ice at 0 °C, every 100 cm³ of water forms 109 cm³ of ice. This is why water pipes crack and burst during very cold weather.

This is also why lettuce discolours and fades when it has mistakenly been frozen. The reason for this appearance is that the liquid in the plant cells (intracellular fluid) expands and break the cell walls. Thus, when it thaws, the fluid leaks out and the cells don’t keep their shape. It is therefore recommended not to freeze fresh fruit and vegetables.

This unusual behaviour of water also has its advantages. It enables fish and other living organisms to survive in frozen dams. Water at the surface cools, contracts and sinks to the bottom. Once the water at the bottom of the dam reaches 4 °C, it stays there because this water has the maximum density. Water nearer to the surface which cools below 4 °C will stay there because it is less dense. Eventually, a layer of ice may form on the water. Ice is a poor conductor of heat and the water below it cools very slowly. Frozen ponds and dams therefore have water beneath the ice in which fish and animals can survive in.

• **Examples of practical applications of the expansion of solids**

Examples of the applications of the expansion of solids include the following:

• In the past, railway lines were laid with small gaps (openings) between each rail. In hot weather, the rails expanded and the gaps closed, and prevented the rails from buckling. Nowadays, the rails are welded into lengths of a kilometre or more and fastened by heavy clips to concrete sleepers. (Sleepers are blocks that are laid horizontally underneath the tracks to keep the rail lines in place.) This stops the rails bending and buckling in hot weather. If these 1 km steel rails were allowed to expand, their length would increase by 1,1 cm for each 1 °C rise in temperature.
A thick glass will crack more readily than a thin one when very hot water is poured into it. The inner layer of glass heats up and expands while the outer layer is still cold.

The thermostat that regulates the temperature in most stoves operates on the expansion of metals.

**Examples of practical applications of the expansion of liquids**

Examples of the applications of the expansion of liquids include the following:

- Thermometers apply the principle that a liquid, namely mercury, expands.
- When water expands as a result of being heated, its density decreases. Hot water will therefore rise and float on top of cold water. This principle is used in a hot-water tank.
- Water contracts when it cools down to 4 °C and then expands when it cools down further to 0 °C. A sealed glass bottle filled with water or soft drink will break when it is left in a freezer due to the frozen water taking up more space.

**Examples of practical applications of expansion of gases**

Examples of the applications of the expansion of gases include the following:

- Carbon dioxide, the gas released by baking powder and by yeast, expands when heated and, in this way, causes the dough to rise.
A soufflé or soufflé omelette rises because the air trapped in the egg foam expands when it is heated.

Warm air, which is less dense than cold air owing to expansion, moves to higher levels. In the case of sash windows, this aids proper ventilation.

**FIGURE 10.3**

Ventilation

(Source: Unisa drawing)

10.5 LATENT HEAT

Latent heat is the heat that is taken up or given off when a substance alters its condition, while its temperature remains constant.

When water is heated, its temperature rises until it reaches boiling point. Steam is then formed. Even if one continues to heat the water, the temperature will not increase any further. This is because heat is necessary to change a substance from a liquid (water) to a gas (steam). This additional heat is known as latent heat. Latent heat is absorbed when solids change to liquids and when liquids change to gases. Latent heat is given off when liquids change to solids and when gases change to liquids.

Examples of the application of latent heat include the following:

- A steam burn is far worse than a burn caused by boiling water, because the steam releases latent heat when it condenses.
- Ice is far more effective in cooling a soft drink than ice cold water, since ice absorbs latent heat when it melts.
- When we make ice-cream at home, the container is placed in a freezing mixture of three parts of ice to one part of table salt. The ice melts to dissolve
the salt and thereby absorbs the latent heat from the ice-cream container, causing a considerable drop in temperature.

Activity 10.1: Sources of heat, and heat expansion

(1) List four (4) sources of heat and in each case give an example of how these sources generate heat. (Do not use the same examples as those given earlier.)

(2) Explain why it is important to measure the temperature of a boiling sugar mixture when making sweets.

(3) Give two examples where the principle of expansion of solids is applied in your daily life.

(4) Give two examples where the principle of expansion of gases is applied in your daily life.

10.6 FUSION AND VAPORISATION

• Fusion (melting)

For a solid to melt, its particles must break away from their fixed positions and be able to move around each other more freely in the liquid state. The heat of fusion provides energy which makes particles in the solid vibrate faster and break away from each other.

• The effect of impurities on the melting point

When a solid is mixed with an impurity, the solid melts at a lower temperature. For example, ice will melt at temperatures as low as -20 °C when salt is mixed with it. That is why anti-freeze is added to car radiators, and roads in Europe and America are treated with salt during icy weather. The impurities (e.g. salt) lower the freezing point of the mixture and prevent ice from forming.

• Evaporation

When a liquid is boiled, the molecules are given enough energy to overcome the forces holding them together. They can then move around freely in the gaseous state. The energy to overcome these forces is provided by the heat of evaporation. Generally more heat is needed to boil a liquid and tear the molecules apart than to melt a solid. Thus, the heat of evaporation of a substance is usually larger than its heat of fusion.

• Factors influencing the rate of evaporation

The rate at which a liquid evaporates is influenced by the following factors:

• The size of the exposed area

The larger the area that is exposed to air, the higher the rate of evaporation will be. Therefore, lettuce that has been cut and left open will wilt because of the exposed area. If covered with cling wrap for example, the moisture won’t evaporate.
• Temperature

An increase in temperature increases the rate of evaporation. The rise in temperature causes the kinetic energy of the molecules to increase.

• Movement of air

Wet washing dries far more quickly on a windy day than on a calm day. The wind removes the molecules that have already evaporated and that surround the washed article.

Moisture in air

When air is moist, evaporation takes place very slowly.

• Type of fluid

Certain fluids, such as petrol, spirits and benzene, evaporate more rapidly than other fluids.

• Evaporation as a cooling process

We have already seen that a substance needs latent heat to change from a liquid to a gas.

The body regulates its temperature by perspiring. When the perspiration evaporates, the body temperature is lowered.

• Application

Examples of the application of evaporation in cooling include the following:

• When water is poured into a canvas bag, it oozes through the canvas, evaporates, and absorbs latent heat from the remaining water in the bag. The water in the bag is cooled.
• Ice chests used on farms or in towns where there is no electricity work on the same principle as the canvas bags. The walls of these ice chests consist of ash or coal between layers of wire netting. Water drips into the ash or coal from a pan on the roof. The water evaporates, and latent heat is absorbed from within the ice chest.
• In refrigerators, fluid that evaporates readily, such as fluid ammonia, is used.

At normal air pressures, these fluids are gases, but in a refrigerator an electric motor compresses the gas until it becomes a fluid. Upon evaporation, the fluid absorbs latent heat from inside the refrigerator.

10.7 HOW DOES HEAT GET FROM ONE PLACE TO ANOTHER?

• Conduction

Anyone who has used a metal fork when cooking food knows that the fork gets so hot after a short while that you are unable to hold it in your hand. How does this happen?
The heat travels from the fire or stove, through the metal and on to your hand. This is an example of **conduction**.

Some substances, such as metals, are good conductors of heat. Good conductors are used whenever we want heat to travel though something quickly. Thus metals are used for kettles, cooking pans and radiators.

Other substances, such as wood, cork, plastic, fibreglass and wool, are poor conductors of heat—they are also known as **insulators**. Poor conductors are used whenever we want to prevent heat moving from one place to another. Thus, handles of pots and pans are usually made from wood or bakelite. Compare different substances in Table 10.1 in order to see which materials are conductors and which are insulators.

**TABLE 10.1**

*The relative conductivities of some everyday materials*

<table>
<thead>
<tr>
<th>Material</th>
<th>Relative conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silver</td>
<td>19 000</td>
</tr>
<tr>
<td>Copper</td>
<td>16 000</td>
</tr>
<tr>
<td>Aluminium</td>
<td>8 800</td>
</tr>
<tr>
<td>Brass</td>
<td>4 500</td>
</tr>
<tr>
<td>Iron (steel)</td>
<td>3 100</td>
</tr>
<tr>
<td>Plastic</td>
<td>50-500</td>
</tr>
<tr>
<td>Porcelain</td>
<td>75</td>
</tr>
<tr>
<td>Glass</td>
<td>35</td>
</tr>
<tr>
<td>Water</td>
<td>25</td>
</tr>
<tr>
<td>Brick</td>
<td>23</td>
</tr>
<tr>
<td>Cardboard</td>
<td>88</td>
</tr>
<tr>
<td>Wood</td>
<td>60</td>
</tr>
<tr>
<td>Felt</td>
<td>17</td>
</tr>
<tr>
<td>Wool</td>
<td>12</td>
</tr>
<tr>
<td>Air</td>
<td>10</td>
</tr>
</tbody>
</table>

• How is heat conducted?

When a material is heated, the molecules nearest to the heat source get energy from the source and move around more rapidly. The molecules bump into those near to them and cause the neighbouring molecules to move faster. With time, molecules further and further away from the heat source are speeded up and heat is conducted to all parts of the material.
Metals are very good conductors of heat because they contain electrons which are free to move from one atom to another. When a metal is heated, these free electrons move around much faster and much further than the metal atoms. The electrons bombard the metal atoms in the cooler parts and heat is conducted much more quickly than in other substances.

• Applications of conduction

Examples of the application of conduction include the following:

• Pots and pans are made of substances that are good conductors of heat. Copper is an excellent conductor of heat and is frequently used in pots, known as copper-bottomed pots.
• Eiderdowns or duvets keep us warm because the air that is trapped between the down is a poor conductor of heat. The heat thus tends to stay under the duvet rather than moving away, and the person under the duvet stays warm.
• Hay boxes used to be very popular as an economical way of cooking food. A hay box is a wooden box filled with hay or straw cushions. A covered pot with boiling food, such as soup, stew or rice, is placed inside the box and surrounded with hay or straw cushions. Hay is such a poor conductor of heat that the pot remains hot enough to cook the food overnight. It is very easy to make your own hay box. Use a sturdy cardboard box with a lid. If hay or straw is not available, fill the cushions loosely with small polystyrene balls or try thickly scrunched up newspaper. Maybe this is the way to go green and save electricity!

Try to think of some more examples of good and poor conductors of heat that we use daily.

• Convection

Heat can travel from one place to another through a liquid or gas. When a fire is lit it heats up the air nearest to it. This warm air rises whilst cooler air falls and moves in to replace it. These streams of moving air are an example of convection.

• Convection in liquids and gases

When a liquid or gas heats up and the molecules start moving faster, the liquid or gas expands and becomes less dense than the colder molecules (the liquid or air) around it. The warmer molecules rise and colder, denser liquid or gas molecules flow into its place. This causes currents or circulation within the liquid or gas.

• Applications of convection

Examples of the application of convection include the following:

• Cloud formation—Convection currents in the atmosphere carry warm air upwards. As the air rises away from the surface of the earth, it cools. If the air contains enough vapour and if the temperature falls enough, then tiny droplets of water will condense forming clouds.
- **Gilding**—Giders depend on rising convection currents, called thermals, to keep airborne. By moving from one thermal to another, a glider can stay in the air for a number of hours. Eagles and other birds also use convection currents to glide around and near high cliffs.

- **Radiation**

You know how hot you become when sitting in the sun on a hot summer’s day. Do you realise that these sun rays have travelled millions of kilometres as electromagnetic waves? This is an example of radiation.

- **Application of radiation**

Examples of the application of radiation include the following:

  - The sun’s heat reaches us through radiation. The heat is transferred by means of electromagnetic waves.
  - When food is grilled, heat is transferred through radiation from the grill in the oven.

---

**Activity 10.2: Evaporation and conduction**

(1) Study the factors influencing the rate of evaporation. List which factors will have an influence on the drying of a bed sheet and give a clear reason for your answer.

(2) Give three (3) examples where the principle of conduction is applied in your daily life.

(3) Look at Table 10.1 before answering this question. Explain why a dry dish cloth would be a better option to handle a hot pan than a wet dish cloth?

---

**10.8 ABSORPTION AND REFLECTION**

Smooth, shiny, light-coloured objects reflect both light and heat. A dull, black or dark surface absorbs heat. A good absorber of heat is also a good radiator of heat.

- **Applications of reflection**

Examples of the applications of reflection include the following:

  - Refrigerators and ice-cream carts are normally painted white or in light colours. Light colours reflect light and heat, and very little heat is absorbed.
  - Electric bar heaters have shiny metal plates behind the elements. These plates reflect the heat towards the person in front of a heater.
FIGURE 10.4

Which of three cars above would you prefer in summer?

(Source: Unisa drawing)

- The thermos flask

If you study the construction of the thermos flask, keeping the processes of conduction, convection and radiation in mind, you will soon realise that heat can hardly get in or out of the flask. A thermos flask is designed to keep heat in (keeps hot liquids hot) or keep heat out (keep cold liquids cold). The flask is specially made to prevent heat getting into or out of it (see Figure 10.5). Notice the double glass walls with a vacuum between them to minimise heat losses by conduction and convection. Radiation is reduced by silvering both walls on the vacuum side.

FIGURE 10.5

The thermos flask

(Source: Unisa drawing)
Heat loss is prevented due to:

- **Lack of conduction**

  The glass walls of the thermos flask, the plastic or cork stopper and the vacuum between the double glass walls are very poor conductors of heat.

- **Lack of convection**

  Since no gas or liquid can leave a sealed thermos flask, heat cannot spread by convection.

- **Lack of radiation**

  The double glass walls of the flask are silver on the inside. Since the shiny surface reflects heat back into the flask, very little heat is lost.

**Activity 10.3: Revision and reflection**

1. What is heat?
2. What is temperature?
3. Name and describe the different thermometers used in food preparation.
4. Explain why a substance expands when heated.
5. Explain what latent heat is.
6. Explain each of the following terms:
   - Conduction
   - Convection
   - Radiation
7. Explain why coffee remains hot for an hour or two in a thermos flask.
8. Answer this question in the discussion space of your e-tutor site.

  Suggest at least one way, not mentioned in this learning unit, to keep food or drink warm OR cool in an area with no electricity. Explain the scientific process underlying your solution (e.g. evaporation, conduction, etc.). Also comment on some other students’ postings.

**10.9 CONCLUSION**

Heat is a form of energy caused by the vibration of molecules. The temperature of the material tells us how hot the material is and is measured using a thermometer. Most substances (including solids, liquids and gases) expand when they are heated. Heat can be transferred by conduction, convection and radiation. Heat can also be absorbed or reflected. Latent heat is the heat that is taken up or given off when a substance alters its condition, while its temperature remains constant. When heat is added to some solids, it will melt (fusion will take place). On the other hand, when heat is added to a liquid, it will evaporate.
11.1 INTRODUCTION
The previous learning units discussed some basic principles in chemistry and physics. Most of these principles can be directly applied to the way in which the human body functions. The following 10 learning units will focus on human physiology and how these principles can be applied. Physiology is the branch of biology that deals with the functions of living bodies and their parts.

The human body is composed structurally of different levels of organisation, beginning with atoms, molecules and compounds. See Figure 11.1 below. Can you tell what the different levels are?

(Source: https://commons.wikimedia.org/wiki/File:Cellules,_tissus,_organes_et_syst%C3%A8mes-ta.svg)
The atoms, molecules and compounds combine to form the smallest independent unit of life, namely a **cell**. A number of specific cells combined form **tissues**. These tissues combined form **organs** and a number of organs combined or working together form a **system**. These systems working together make up the complete organism known as the human body.

**Learning outcomes**

After you have completed this learning unit, you should be able to:

- define cells, tissue, organs and systems
- give a description of an organ and a system

### 11.2 CELLS

Cells are the smallest independent units of life, and all life is dependant on the many chemical activities of cells. Body cells have numerous functions which include growth, metabolism and reproduction.

Each human organism begins as a single cell, a fertilised egg, which divides to create two cells, each of which divides in turn, resulting in four cells, and so on. If cell multiplication were the only event occurring, the end result would be a spherical mass of identical cells. During development, however, each cell becomes **specialised** for the performance of a particular function, such as producing force and movement (muscle cells), generating electric signals (nerve cells) or fighting against foreign bodies/antigens (immune cells). The process of transforming an unspecialised cell into a specialised cell is known as **cell differentiation**.

In addition to differentiating, cells migrate to **new locations** during development and form selective adhesions with other cells to produce **multicellular structures**. In this manner, the cells of the body are arranged in various combinations to form a hierarchy of **organised structures** from chemical level to organism level. Pages 3-7 in your prescribed textbook explain this in detail.

The human cell will be dealt with in detail in learning unit 12.

### 11.3 TISSUES

Differentiated cells with similar properties aggregate to form **tissues**. Tissues are divided into four groups, namely connective, epithelial, muscle and nervous tissue. Body tissue is dealt with in detail in learning unit 13.

### 11.4 ORGANS

The above-mentioned tissues combine with other types of tissues to form **organs** (the heart, lungs, kidneys, and so on). Organs can consist of any combination of body tissues. Organs can take on many forms. To mention but a
few, they can be sack-like, tube-like, or like a covering layer. (Can you think of an example of each of these types?) The different organs will be discussed later in this module online guide when the systems of the body are dealt with.

11.5 SYSTEMS

A system is a group of organs that work together to perform a major body function. The digestive system, for example, contains several organs that provide a mechanism to convert the food we eat into nutrients to build and maintain our bodies. All body systems are specialised, and their functions are coordinated to produce a dynamic and efficient organism—your body.

The structures of each system are closely related to their functions. The body systems covered in these learning units are listed below:

- Skeletal system (learning unit 14) collectively known as the musculoskeletal system.
- Muscular system (learning unit 15)
- Nervous system (learning unit 16)
- Cardiovascular system (learning unit 17)
- Respiratory system (learning unit 18)
- Urinary system/excretory system (learning unit 19)
- Digestive system (learning unit 20)

Four other systems that will not be discussed in this study guide include the reproductive system, immune system, endocrine system and integumentary system (skin).

Since physiology deals with the structure and functioning of the body, it is important for you to understand the structures in sequence (logical order, from highest to lowest level and vice versa). Your prescribed textbook explains this on pages 11-16.

Activity 11.1: Tissues, organs and body systems

1. Explain the main differences between tissues and organs.
2. The figure below shows seven body systems in random order. See if you can identify which is which. See if you can already supply some of the missing labels.
Using your answer to question 2 above to help you fill in the seven (7) systems covered in your study manual with their major functions. Also name the organs in each system and complete the table below:

<table>
<thead>
<tr>
<th>System</th>
<th>Function</th>
<th>Organs</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
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</tbody>
</table>

Feedback on activity 11.1

In order to summarise the seven systems as discussed in the module online guide, go to the table of contents and look at the headings of learning units 14-20. Your prescribed textbook summarises the organs and functions on pages 5 and 6. Make sure you are familiar with this content.

Activity 1.12: Revision and reflection

(1) Give the definition of each of the following:
   - A cell
   - An organ
   - A membrane
   - A system

(2) Answer the questions on pages 15-16 in your prescribed textbook.

(3) Consider all 11 body systems mentioned in this unit. Which of them do you think you are least aware of in your day-to-day activities? What are the functions of this particular system? Could you live without it?

11.6 CONCLUSION

The aim of this learning unit was to introduce you to the different units of the human body. The human body can firstly be subdivided into systems that perform major functions in the human body. These systems can in turn be subdivided into organs that have important specialised functions of their own. Organs can be subdivided into tissues. Tissues are formed by aggregated small units of life—namely differentiated cells. Figure 1.1 (p 4 in the prescribed textbook) clearly summarises this.

In the following learning unit we will discuss the structure and functions of different types of cells in the human body.
LEARNING UNIT 12

The human cell

12.1 INTRODUCTION

The human body is made up of billions of very small units called cells. The basic composition and structure of a cell are discussed as well as the functions of the different cells. Specialised cell structures and their functions are also dealt with.

Human cells perform a number of functions to maintain their own life and thereby the life of the whole body. If a cell is to survive, it must continually move the substances that are necessary for these functions through the cell membrane. The transportation or movement of substances through the cell membrane, known as a self-servicing process, is also discussed in this learning unit.

Learning outcomes

After you have completed this learning unit, you should be able to:

• define a cell
• describe and illustrate the basic structure of a cell
• identify and describe the different cell structures and their functions
• identify and explain the different processes of movement through cell membranes
• define homeostasis

12.2 COMPOSITION OF A CELL

A cell consists of approximately 39 of the over 100 elements found on earth. The main elements of the human cell are hydrogen, oxygen, carbon, nitrogen, phosphorus and sulphur. Most of the elements are present in the form of compounds, which can be inorganic or organic. I discuss both of these in more detail in the sections that follow.

12.2.1 Inorganic compounds

The inorganic compounds found in a cell are water, salts and gas.
• Water

Water is the most abundant compound in the human body. Because it is part of the body and many substances are dissolved or dispersed in it, it is no longer pure water, and it is now called a body fluid. This body fluid serves as a conveyer of nutrients and as a solvent for both inorganic and organic compounds. It is also the medium in which all the chemical reactions of the body take place. Body fluid can be either inside the cell (intracellular fluid) or outside the cell (extracellular fluid).

The extracellular fluid is located in the following three places:

• Inside the blood vessels, where it is called blood plasma.
• Inside the lymph ducts, where it is called lymph.
• In the small spaces between the cells, where it is called intercellular fluid.

The different types of body fluid and their locations can be summarised as follows:

<table>
<thead>
<tr>
<th>Body fluid</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intracellular</td>
<td>Inside the cells</td>
</tr>
<tr>
<td>Extracellular</td>
<td></td>
</tr>
<tr>
<td>Blood plasma</td>
<td>Inside blood vessels</td>
</tr>
<tr>
<td>Lymph</td>
<td>Inside lymph vessels</td>
</tr>
<tr>
<td>Intercellular</td>
<td>Between cells</td>
</tr>
</tbody>
</table>

• Salts

Most mineral salts are present in the human body in the form of ions, both positive and negative.

• Gas

Oxygen and carbon dioxide are present in solution and play a role in respiration.

12.2.2 Organic compounds

The organic compounds found in a cell are proteins, carbohydrates and fats.

• Proteins

Proteins are present in a great variety and are the most important compounds of a living cell. They are the main structural components of the cell, and play an important role in certain vital cell functions.
• Carbohydrates

Carbohydrates are also present in a great variety. They are the main source and store of energy. They form structural components of certain parts of the cell.

• Fats

Fats are present mainly in the form of microscopic droplets. They supply energy and are part of certain structural units.

Study pages 23 to 25 of Chapter 2 in the prescribed textbook, from the section: molecules up to the section: chemical solutions.

12.3 CELL STRUCTURE

Cells consist of an outer membrane known as the plasma membrane (also known as the cell membrane and the cytoplasmic membrane) and the nucleus which is situated approximately in the centre of the cell (refer to Figure 3.1 in the prescribed textbook for the structure). Located between these two structures is a semifluid known as the cytoplasm. Inside the cytoplasm lie intricate arrangements of fine fibres and hundreds of very small but distinctive structures called organelles.

The structure of a cell is summarised diagrammatically in Figure 12.1.
Figure 12.2 shows the various components of the cell, which I will discuss in more detail in the sections to follow.

**FIGURE 12.2
Detailed cell structure**


### 12.3.1 Cell membranes

The plasma membrane, because it encloses the cytoplasm, is also called the cytoplasmic membrane. Membranes form both the outer boundary of the cell and the internal walls of the nucleus and certain organelles in the cell. The membranes on the inside of the cell are called the internal membranes.

- **Membrane structure**

Both the cytoplasmic and the internal membranes consist of lipid molecules, mainly phospholipids, and protein molecules. The protein molecules are situated asymmetrically in the cell membrane. Figure 12.3 shows the basic membrane structure.
• General membrane functions

The cell membranes perform a variety of functions that are essential for the healthy survival of a cell and the body as a whole:

– The cytoplasmic membrane serves as a boundary between the cell’s internal fluid (intracellular fluid) and the surrounding extracellular fluid between cells (intercellular fluid).
– The cytoplasmic membrane determines the movement of substances in and out of the cell. It is selective in its movement of substances according to the specific function and need of each cell. The protein molecules situated in the plasma membrane are responsible for the process of active transport (see section 12.6.2) of solutes, while other membrane proteins are important for the shape of the cell.
– The cytoplasmic membrane helps with cell communication.
– The plasma membrane identifies a cell as coming from one particular individual.
– The internal membranes serve as the boundaries between the different internal cell structures.

• Specialised membrane structures

The cytoplasmic membranes of certain cells have specialised structures to enable them to perform specialised functions.

– Microvilli are extensions of the cytoplasmic membrane and the cytoplasm. They increase the surface area of a cell extensively. Microvilli are found in the epithelial cells that line the intestines. The larger surface increases a cell’s rate of absorption (see Figure 12.4).
– Cilia are projections of the cytoplasmic membrane and the cytoplasm on one side of certain cells. For example, cells containing cilia are found in
the mucous membrane of the upper respiratory tract. Together, the cilia move with wavelike movements that propel a fluid in one direction. The function of the cilia of the respiratory mucous membrane is to propel mucus upwards and out of the respiratory tract.

- The **flagellum** is a single hair-like projection of cytoplasmic membrane found on the surface of one particular type of cell, namely the spermatozoa or male sex cell. The flagellum’s function is to propel the spermatozoa forward in the fluid environment of the female body.

![Cell with cilia and microvilli](https://commons.wikimedia.org/wiki/File:Blausen_0208_CellAnatomy.png)

**FIGURE 12.4**

*Cell with cilia and microvilli*

(Source: [https://commons.wikimedia.org/wiki/File:Blausen_0208_CellAnatomy.png](https://commons.wikimedia.org/wiki/File:Blausen_0208_CellAnatomy.png))

### 12.3.2 Cytoplasm

Cytoplasm is the part of a cell between the outer plasma/cytoplasmic membrane and the nucleus. It contains hundreds of small organs or **organelles** and a varying number of bits of nonliving substances plus many fibrils and microtubules. The organelles consist of molecules that are arranged in such a way that each can perform a specific function. Organelles can be enclosed by internal membranes, or they can be nonmembranous.

The organelles that have membranous walls, named membranous organelles, are the endoplasmic reticulum, Golgi apparatus, lysosomes and mitochondria. Ribosomes and centrioles are nonmembranous organelles. Read pages 56 to 58 in the prescribed textbook on the structures and functions of these organelles.
12.3.3 Nucleus

The nucleus is the largest cell structure within the protoplasm and occupies the central position of the cell. It is also the most important of the cell structures, since it manages all cell activities. Figure 12.5 shows the structure of the nucleus.

![Cell nucleus](https://commons.wikimedia.org/wiki/File:Diagram_human_cell_nucleus.svg)

Two perforated membranes enclose the fluid of the nucleus, called the nucleoplasm. The nucleoplasm contains one or more small, dense oval bodies, called nucleoli (plural for nucleolus) which are responsible for producing RNA. The nucleoplasm also houses chromosomes. (The material of which the chromosomes are made is called chromatin.)

The cells of all normal human beings contain 46 chromosomes (with the exception of the reproductive cells, which contain only 23 chromosomes). The chromosomes consist of RNA (ribonucleic acid) and DNA (deoxyribonucleic acid). The DNA is the genetic material (genes) responsible for encoding the information that is necessary to make proteins (protein synthesis).

Since DNA can replicate itself, it passes on an exact replica of the genetic code to daughter cells during mitosis. The instructions from the DNA are transferred to the RNA, which in turn pass the instructions on to the ribosomes (the non-membranous organelles that synthesise proteins and enzymes).
LEARNING UNIT 12: The human cell

Therefore, the main functions of the nucleus are as follows:

- To manage protein production
- To pass on hereditary characteristics

Study the **structure of a typical cell** carefully in Figure 3.1 on page 55 of your prescribed textbook.

In order to understand the cell structure and organelle functions better, study the first sections of Chapter 3 in the prescribed textbook, pages 53-58, up to the section: exchange between the cell and its environment.

### 12.4 CELL SIZE AND SHAPE

The size and shape of cells vary considerably, depending on their function.

- **Cell size**

  Most human cells are so small that they can be seen only under an electron microscope. The female reproductive cell, however, is large enough to be seen by the naked eye.

- **Cell shape**

  Cells vary in shape. For example, nerve cells have projections that are many centimetres long, whereas human red blood cells are shaped like tiny flattened biconcave disks. (Biconcave: both sides curved inwards.)

**FIGURE 12.6**

*Red blood cells (left) and a nerve cell (right)*

Activity 12.1: Human cell

(1) Draw a diagram of the human cell and label the following structures in the drawing:
- Cell membrane/cytoplasmic membrane
- Nucleus
- Golgi apparatus
- Chromosomes
- Ribosomes
- Nucleolus
- Endoplasmic reticulum
- Mitochondria

(2) If you have internet access, go to http://www.sheppardsoftware.com/health/anatomy/cell/cell_game.htm and play the “Cell game”. Drag the labels into the correct position. How quickly can you complete the game?

12.5 CELL FUNCTIONS

Living cells undergo physical and chemical processes that are necessary for survival. Not all processes and functions are performed by all cells. Certain cells are specialised to perform specific functions. The general functions performed by most cells are as follows:

- **Respiration**
  All cells take in oxygen, which is used for the oxidation of food substances and results in the liberation of chemical energy.

- **Excretion**
  All cells eliminate waste products.

- **Absorption and assimilation**
  All cells absorb digested food material and other substances for further utilisation.

- **Secretion**
  Some cells synthesise useful substances from absorbed and assimilated substances and set them free as secretory products or secretions, when necessary.

- **Irritability**
  Most cells respond to stimuli. The stimulus can be either a change in the environment outside the body or a change inside the body that results in a change to the environment of the cell.

- **Conductivity**
  Some cells, such as those found in muscle tissue, can transmit a wave of excitation (stimuli) along their own surfaces and pass the wave of excitation on to the next cell.
• **Contractibility**

When stimulated, some cells, such as those found in muscle tissue, can contract or shorten and return to their original length when the stimulus is removed.

• **Division**

Most cells are capable of mitosis (can divide) to produce similar daughter cells. This is particularly important where cells have to be replaced, such as epithelial cells lining the small intestine.

### 12.6 HOMEOSTASIS

A change to the content or environment of human cells may be harmful and even fatal. Therefore, the cells need to adapt whenever a change occurs in order to keep a stability or remain in equilibrium. The relative stability or constancy of the internal environment of the human body is known as **homeostasis**.

Such stability can be achieved only through the operation of carefully coordinated physiological processes. The activities of the cells, tissues, and organs must be regulated and integrated with each other in such a way that any change in the extracellular fluid initiates a reaction to minimise the change.

A collection of body components that functions to keep a physical or chemical property of the internal environment relatively constant is termed as the **homeostatic control system**. The processes used for homeostatic control can be either passive or active processes, depending on the source of energy used. Read the section on homeostasis on pages 8 to 11 (chapter 1) in your prescribed textbook again.

### 12.7 PROCESSES OF MOVEMENT THROUGH MEMBRANES

There are different ways of movement of particles through cell membranes: passive processes and active transport. In the sections that follow I discuss both types in more detail.

#### 12.7.1 Passive processes

The energy used in the passive processes of transportation is kinetic energy and is generated by molecules that are always moving. Passive processes or movement can take place through either a living or nonliving cell membrane. Passive processes that are important to our study of the human cell are **diffusion**, **osmosis** and **filtration**.

Note that in the kidney, passive processes are also assisted by active transport of solutes through kidney tubule cells.

#### 12.7.1.1 Diffusion

The following section on diffusion relates to processes in the human body.
The direction of diffusion of a substance is determined by the difference in concentration of the diffusing substance between the two areas. The particles will move down the concentration gradient from the higher to the lower concentration.

In living cells all dissolved molecules can diffuse into a cell or from one cell to another so that they are evenly distributed. Water, oxygen, carbon dioxide, mineral salts and the building blocks of organic molecules can enter or leave a cell as a result of diffusion. However, in living systems, molecules and ions are sometimes transported across the cell membranes against the concentration gradient.

Three types of diffusion are found in living cells to provide the vital particles:

- Simple diffusion. This is the simple movement of particles from a higher to a lower concentration. In plants, water is normally absorbed by simple diffusion.
- Facilitated diffusion. This is also the movement of particles from a higher to a lower concentration across a cell membrane, but in this case it is done with the help of “carrier molecules”. This is explained in more detail below.
- Active transport. This is also a type of diffusion, but unlike the processes above it is not a passive process. In this case, particles are actively transported from a lower to a higher concentration. Active transport is discussed later in this unit.

Facilitated diffusion is illustrated in Figure 12.7 below.

![Facilitated Diffusion](https://commons.wikimedia.org/wiki/File:2706_Facilitated_Diffusion.jpg)

Facilitated diffusion is a process by which molecules are transported across the plasma membrane with the help of membrane proteins. The molecule attaches to the protein molecule and moves down a channel within the protein molecule to be released inside the cell.
12.7.1.2 Osmosis

Osmosis has been discussed in learning unit 9. Please also refer to that section and also study the following information in relation with the human body.

Note the important differences between diffusion and osmosis:

– Osmosis involves the movement of water molecules only, while diffusion includes other molecules.
– Osmosis happens through a selectively permeable membrane while diffusion might involve no membranes.

As the process of osmosis occurs, the water volume on the side containing the solute (e.g. glucose) increases. This increase in volume would be resisted if pressure were applied to the surface of the liquid with the solute (glucose molecules). See Figure 12.8.

The amount of pressure needed to stop osmosis in such a case is called osmotic pressure. The osmotic pressure of a solution is a potential pressure and is due to the presence of nondiffusible solute particles in that solution. (Note that in the experiment shown in Figure 12.8, pressure is applied by means of a plunger. Inside the cellular environment, however, the pressure is applied by the solute particles themselves.) Furthermore, the greater the number of solute particles in the solution, the greater the osmotic pressure of that solution.

In a situation where osmosis occurs, water tends to move towards the region of greater osmotic pressure. The amount of osmotic pressure depends on the difference in concentration of solute particles on opposite sides of the membrane. Therefore, the greater the difference in concentration, the greater the tendency for water to move towards the region of higher solute concentration.

When cells are put into a water solution that has a greater concentration of solute particles (higher osmotic pressure) than what the cells have, there will
be a loss of water from the cells. The cells will begin to shrink—such cells are said to become crenated. At some stage equilibrium might be achieved, and the shrinking will stop. A solution of this kind, in which more water leaves the cell than what enters it, because the concentration of solute particles is greater outside the cell, is called hypertonic. In other words, a hypertonic solution is a solution containing a higher concentration of membrane-impermeable solute particles than normal extracellular fluid. Refer to Figure 12.9 below.

On the other hand, if there is a greater concentration of solute particles inside a cell than in the water around the cell, water will diffuse into the cell. Water will start to accumulate within the cell, and it will begin to swell. Although cell membranes are somewhat elastic, they may swell so much that they burst. A solution in which more water enters a cell than leaves it because of a lesser concentration of solute particles outside the cell is called hypotonic.

A solution (outside the cell) that contains the same concentration of solute particles than inside the cell is called isotonic to that cell. In such a solution, water enters and leaves a cell in equal amounts, so the cell’s size remains unchanged.

Diffusion and osmosis take place at the same time. Diffusion occurs inside AND outside the cell membrane, whereas osmosis occurs inside OR outside the cell membrane.

In body tissue or blood it is very important to control the concentration of solute in solution that moves into the tissue or blood. If the concentrations are not controlled, osmosis will take place and may cause the cells to swell or shrink, and they may be damaged. For example, if red blood cells are exposed to distilled water (which is hypotonic to them) water will diffuse into the cells and they will burst (haemolyse).
Watch the following video clip for a revision of the concepts discussed in this section:

https://www.youtube.com/watch?v=GwYCr0VubNM

12.7.1.3 Filtration

The passage of substances through membranes by diffusion or osmosis is due to movement of the molecules of those substances. In other instances, molecules are forced through membranes by hydrostatic pressure or blood pressure that is greater on one side of the membrane than on the other. This process is called filtration.

Filtration is commonly used to separate solids from a liquid. One method is to pour a mixture onto filter paper in a funnel (see learning unit 1). The paper serves as a porous membrane through which the liquid can pass, leaving the solids behind. Hydrostatic pressure, which is the pressure created by the weight of water due to gravity, forces the water through to the other side.

The same happens in the lymphatic system. Water and solutes reach the different parts of the body by means of the blood. Tissue fluid is formed when water and dissolved substances are filtered through (forced out) the thin walls of the blood capillaries into the intercellular fluid in the microscopic spaces between the cells. Once the water and solutes are in the intercellular fluid, they can enter the cells. The larger particles such as blood protein molecules are left inside the blood capillaries. The force for this movement comes from blood pressure, created largely by heart action, which is greater within the vessels than outside.

Another example of filtration in the body is in the kidneys. Filtration takes place when water and dissolved wastes are forced out of the blood vessels and into kidney tubules by blood pressure. This is the first step in the formation of urine.

For more clarification on passive transport, study pages 59 to 61 of Chapter 3 in the prescribed textbook, up to the section: Active transport.

Activity 12.2: Passive transport

Revise the sections on passive transport and then summarise the differences between the processes of filtration, diffusion and osmosis.

Feedback

You should have mentioned the following main points:

- Both water and solutes can filter or diffuse through a membrane.
- Only water can move through a membrane (osmosis).
12.7.2 Active transport

When molecules or ions move through the cell membrane by means of the passive transport methods, namely diffusion, facilitated diffusion, or osmosis, they move from a region of higher concentration to a region of lower concentration. However, there are instances where the molecules or ions have to pass through the cell membrane in the opposite direction; that is, particles (molecules or ions) move from a region of lower concentration to one of higher concentration.

For example, sodium ions can diffuse through cell membranes. Yet the concentration of these ions typically remains many times greater on the outside of the cells (in the extracellular fluid) than on the inside (in the intracellular fluid). Furthermore, sodium ions are continually moved from the regions of lower concentration (inside) to regions of higher concentration (outside). Movement of this kind is called active transport. Active transport depends on life processes within the cells and requires energy from chemical reactions within the living cell. The process is illustrated in Figure 12.10 below.

Because this process requires energy and works (or pumps) against the gradient, it is sometimes referred to as a physiological pump. The mechanism involves specific carrier molecules: protein molecules found within cell membranes. At the surface of the cell membrane, the carrier molecules have binding sites that combine with the particles that have to be transported through the cell
membrane. This kind of combination triggers the release of some cellular energy, provided by a substance called ATP, and it causes the shape of the carrier protein to change. As a result, particles are moved through the membrane. Once on the other side, the transported particle is released as a result of an enzyme action, and the carrier molecules can accept another particle at its binding site.

Particles that are carried across cell membranes by active transport include various sugars and amino acids as well as a variety of ions such as those of sodium, potassium, calcium and hydrogen. Movements of this kind are important to cell survival and are involved with the maintenance of homeostasis.

A type of plain active transport by which substances may move through cell membranes is called **endocytosis**. In this case molecules or other particles that are too large to enter a cell by diffusion or active transport may be conveyed within a tiny vesicle (sac) formed by a section of the cell membrane.

There are four forms of endocytosis, namely **phagocytosis**, **pinocytosis**, **exocytosis** and **receptor-mediated endocytosis**. These are illustrated in Figure 12.11 below.

![Endocytosis](https://en.wikipedia.org/wiki/Endocytosis)

**FIGURE 12.11**

*The three types of endocytosis*


- **Phagocytosis** (Phago: derived from the Greek word for “eat”.)

The process of phagocytosis works as follows:

Certain kinds of cells, including some white blood cells, are called phagocytes because they can take in tiny solid particles such as bacterial cells. When the phagocyte comes across such a particle, the particle becomes attached to the outside of the cell membrane. This stimulates a portion of the membrane to project outwards, forming a small pocket around the particle and slowly draws it into the cell and releases the particle in the cell’s cytoplasm. The part of the cell membrane surrounding the particle detaches from the surface, and a
vesicle containing the particle is formed. Harmful bacteria and other harmful foreign substances are usually moved into a cell in this way. They can then be destroyed by the enzymes contained in the lysosomes of the cytoplasm.

- **Pinocytosis** *(Pino: derived from the Greek word for drink.)*

The process of pinocytosis works in the same way as that of phagocytosis, except that a droplet of liquid (instead of a solid particle) on the outside of the cell is engulfed or enclosed by the membrane and released into the cytoplasm of the cell.

- **Receptor-mediated endocytosis**

Receptor-mediated endocytosis moves very specific kinds of particles through membranes (see Figure 12.11). The process involves the presence of particular protein molecules that extend through the cell membrane and are exposed in its outer surface. These proteins serve as receptor sites to which specific substances (ligands) from the fluid surroundings of the cell can bind. Thus, when molecules that are capable of binding to the receptor sites are present, only those molecules are selected to enter the cell, leaving other kinds of molecules outside of the cell.

Receptor-mediated endocytosis is of particular importance because it allows a cell to remove specific kinds of substances from its surroundings, even when these substances are present in very low concentrations.

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Study page 61 of Chapter 3 in the prescribed textbook regarding active transport.
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- **Exocytosis** is explained in the prescribed textbook on page 61.

12.7.3  **Differences between passive and active processes**

The differences between passive and active processes can be summarised as follows:

- Passive processes equalise the concentration of substances on both sides of a cell membrane.
- Active processes increase the concentration of a substance on one side of a cell membrane.
- Passive processes use kinetic energy.
- Active processes use chemical energy.
- Passive processes occur through living and nonliving membranes.
- Active processes occur only through living membranes.
11.10 Activity 12.3

(1) Figure 12.12 represents a red blood cell in solutions of varying tonicity. Indicate what kind of solution each drawing represents and explain what is happening and why. (See section 12.6.1 on osmosis.)

FIGURE 12.12
A red blood cell in solution of varying tonicity.
(Source: Unisa drawing)

(2) Study the diagram below and then answer the questions that follow.

FIGURE 12.13
One type of body process
(Source: Unisa drawing)

(a) Name the process illustrated in the diagram.
(b) Where in the body does this process occur?
(c) What in the body provides the force needed to pull the liquid through the solids?
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(3) You should answer this question in the discussion space on your e-tutor site.

Study the diagram below and then answer the questions that follow.

![Diagram of cell membrane and transport](https://en.wikipedia.org/wiki/Facilitated_diffusion)

**FIGURE 12.14**

*Transportation of a molecule across a cell membrane.*

*Source: https://en.wikipedia.org/wiki/Facilitated_diffusion*

(a) What kind of transport mechanism is illustrated in the diagram?
(b) What provides the force necessary for this process to take place?
(c) What is the source of this force?
(d) How are the molecules transported across the cell membrane?

**Activity 12.3: Revision and reflection**

1. Define a cell.
2. List the inorganic compounds that a human cell is composed of.
3. List the organic compounds that a human cell is composed of.
4. Why does a cell membrane allow substances to move in and out of the cell?
5. Name the two (2) main processes involved in the movement of substances through the cell membrane.
6. In what ways do these two processes differ from each other?
7. Explain how a physiological pump works.
8. Based on what you learnt in this unit, why is it important to drink enough fluids and not become dehydrated?

**12.8 CONCLUSION**

The basic composition and structure of human cells was explained. The different parts of a cell and the functions of each were discussed. Specialised cell structures and their functions, as well as the variations in the size and shape of human cells were pointed out.

Cell functions were listed and self-servicing cell processes, i.e. the intake and output of substances through the cytoplasmic membrane of a cell, were dis-
cussed. The processes were divided into two main types, namely active and passive processes, according to their source of energy. The different processes under each type were explained, and their differences were pointed out.

In the following learning units the effect of aggregated differentiated cells will be discussed, namely body tissue.
13.1 INTRODUCTION
The body consists of numerous cells that are grouped together according to their type. Similar cells that are grouped together form body tissue, which is divided into four types, namely epithelial tissue, connective tissue, nervous tissue and muscle tissue. Can you give examples of where you would find each of these in your body?

Learning outcomes
After you have completed this learning unit, you should be able to:

- identify the different types of body tissue
- give the characteristics, location and functions of epithelial tissue
- identify the different kinds of connective tissue
- give the functions and locations of the different kinds of connective tissue
- give the characteristics, location and major functions of nervous tissue
- give the different types of muscle tissue with their locations and functions
- define a membrane
- describe the functions of membranes

13.2 BODY TISSUE
Each organisation of cells (tissue) specialises in one or more functions that serve the body as a whole. Even when it is performing specialised functions with other cells of the same tissue type, each cell retains the self-servicing functions necessary for its own survival.

The size, shape and arrangement of cells vary in different kinds of tissue. The amount and kind of intercellular substance also vary.

On the basis of the differences mentioned above, body tissue is classified into four types, namely epithelial, connective, nervous and muscle tissue. In the sections that follow I discuss the various types of tissue in more detail.

13.2.1 Epithelial tissue
The characteristics, location and functions of epithelial tissue are discussed in the following sections.
Epithelial tissue is widely distributed throughout the body. It covers all body surfaces—inside and out. It also forms the major tissues of the glands.

Since epithelium covers organs, forms the inner lining of body cavities, and lines hollow organs, it always has a free surface—one that is exposed to the outside or to an open space internally. The underside of the tissue is anchored to connective tissue by a thin, nonliving layer called the basement membrane.

Generally, epithelial tissues lack blood vessels. However, they are nourished by substances that diffuse from underlying connective tissues, which are well supplied with blood vessels.

Epithelial tissue is subjected to a lot of wear and tear because of its location and functions. It must be replaced constantly by the process of mitosis (cell division performed by most cells). Injuries to the epithelium are likely to heal rapidly as new cells replace lost or damaged ones. For example, skin cells and the cells that line the stomach and intestine are continually being damaged and replaced.

Since epithelial tissue forms a large part of the skin, take this information into consideration when studying the cutaneous membrane (see section 13.4).

A section through epithelial tissue is illustrated in Figure 13.1.
• **Location of epithelial tissue**

Epithelial tissue is found in a number of places:

– It covers the body.
– It lines the internal cavities of the body.
– It lines the blood and lymphatic vessels and the respiratory and digestive tracts.
– It forms glands.

• **Functions of epithelial tissue**

Epithelial tissue has the following functions:

– It specialises in absorption (in the intestines) and secretion (in the glands).
– It provides protective barriers (in the skin).

13.2.2 **Connective tissue**

Connective tissue is found all over the body. It binds structures together, provides support and protection, serves as a framework, fills spaces, stores fat, produces blood cells, provides protection against infection, and helps to repair damage.

The general characteristics, location, and types of connective tissue, with their functions, are discussed in the sections that follow.

13.2.2.1 **Characteristics of connective tissue**

Connective tissue cells are usually further apart than epithelial cells, and they have more than enough intercellular material, or “matrix”, and a ground substance whose consistency varies from fluid to semisolid or solids. (The “ground substance” of connective tissue is a transparent, gel-like material that fills the spaces between cells.)

Connective tissue cells are able to reproduce. In most cases, they have good blood supply and are well nourished. The matrix of different types of connective tissue may be fluid (for example blood), semifluid (for example areolar tissue), or solid (for example bone). Although some connective tissues, such as bone and cartilage, are quite rigid, loose connective tissues, adipose connective tissue, and fibrous connective tissue are more flexible.

The matrix is composed of protein fibres and an amorphous (without form) ground substance. Embedded in the matrix are different cells.

The cells of connective tissue vary in type. One group of cells are called resident cells, such as fibroblasts, because they are usually present in relatively stable numbers. Another group is known as wandering cells, as they only appear temporarily in the tissue, usually in response to an injury or infection. The wandering cells include several types of white blood cells.
The main cell types are the following:

- **Fibroblasts** are the most common kind of cells in connective tissue. They are relatively large and usually shaped like a star. The function of fibroblasts is to produce protein fibres in the intercellular matrix of connective tissue.

- **Macrophages** (histiocytes) are nearly as numerous as fibroblasts in some connective tissues. Macrophages are usually attached to fibres but can become detached and actively move around. Macrophages are specialised to carry on phagocytosis. Since they function as scavenger cells that can clear foreign particles from tissues, macrophages represent an important defence against infectious agents. They also play a role in immunity.

- **Mast cells** are quite large and are widely distributed in connective tissue and are usually found near blood vessels. Their function is not well understood, but they are known to contain heparin, a compound that prevents blood clotting. They also contain histamine, a substance that promotes some of the reactions associated with inflammation and allergies such as asthma and hay fever.

The fibroblasts in connective tissue produce fibres. Types of fibres include the following:

- **Collagenous fibres** are thick and look like threads and are composed of the protein collagen, which is the major structural protein of the body. These fibres are grouped in long, parallel bundles, and they are flexible but only slightly elastic. A major property of these fibres is that they have great tensile strength—that is, they are capable of resisting considerable pulling forces. Thus, collagenous fibres are important components of body parts that hold structures together.

- When collagenous fibres are present in large numbers, the tissue containing them is called **dense connective tissue**. Such tissue appears white, and for this reason collagenous fibres are sometimes called white fibres. Loose connective tissue, on the other hand, is supplied with very little collagenous fibres.

- **Elastic fibres** are composed of bundles of microfibrils embedded in a protein called elastin. These fibres are branched and form complex networks in various tissues. They are not as strong as collagen fibres, but they are very elastic. They can easily be stretched or deformed and will then return to their original shape and length when the force acting on them is removed. Elastic fibres are generally found in body parts that are normally subjected to stretching, such as the ligament at the back of the neck, the vocal cords and various air passages of the respiratory system. Elastic fibres are sometimes called yellow fibres because the tissue in which they are well supplied appear yellowish.

- **Reticular fibres** are a thin collagenous type of fibre. They form highly branched networks and form delicate supporting networks in a variety of tissue. They join connective tissue to other tissues, such as the basement membrane, and make up the fibrous network of the liver, pancreas, spleen and lymph glands.

Connective tissue is the most abundant and widespread tissue in the body and provides the framework that supports all the other types of tissue.
### Activity 13.1: Cells and fibres in connective tissue

Complete the following table:

<table>
<thead>
<tr>
<th>Component of connective tissue</th>
<th>Brief explanation – what is this?</th>
<th>Function/s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cells</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fibroblast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Macrophage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mast cell</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fibres</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collagenous fibres</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dense connective tissue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elastic fibres</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reticular fibres</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 13.2.2.2 Functions of connective tissue

The functions of connective tissue are the following:

- To support (for example, bone supports muscle, and tendons support bone and muscle)
- To connect (for example, muscle to muscle, bone to bone, and bone to muscle)
- To defend (for example, against an invasion of germs and foreign proteins)
- To transport (for example, nutrients, gases, body secretions and waste products)

### 13.2.2.3 Types of connective tissue

Connective tissue can be divided into four main groups:

- Connective tissue (true connective tissue)
- Cartilage (supporting connective tissue)
- Bone (supporting connective tissue)
- Blood (fluid connective tissue)

These four main groups of connective tissue will now be discussed.
• **True connective tissue**

True connective tissue is divided into five smaller groups, namely:

- **Areolar** (loose) connective tissue: It forms delicate thin membranes throughout the body such as around blood vessels and nerves.
- **Fibrous** (dense) connective tissue: It is a strong dense tissue and can withstand pulling forces and limited stretch found in tendons and ligaments.
- **Yellow elastic** connective tissue: Consists of more flexible yellow fibres (elastic) found in the walls of organs such as the stomach and larger arteries.
- **Reticular** connective tissue: Thin fibres forming a net-like structure found in the interior of the liver, tonsils, lymph nodes, etc.
- **Adipose** connective tissue: A specialised form of loose connective tissue containing fat cells and found beneath the epidermis, around organs, behind the eyeballs, etc.

There are very small differences between these five groups and they can be distinguished by the proportion of protein fibres and cells in each group of tissue.

• **Cartilage**

Cartilage is a specialised connective tissue that provides support and aids movement in joints. Similar to other connective tissue, it consists of cells, fibres, and ground substance. Cartilage cells are embedded within the matrix in small cavities. Cartilage does not contain blood vessels; however, oxygen, nutrients and cellular wastes diffuse through the matrix.

Main location of cartilage:

- Trachea, larynx, bronchi, nose
- Rib cartilage
- Ends of long bones
- Rims of some sockets (e.g. hip and shoulder joints)
- Wrist and knee joints
- Areas that require lightweight support and flexibility, such as external ear, epiglottis in throat
- Larynx

Major functions:

- Reinforces respiratory passages
- Aids free movement of joints
- Assists growth of long bones
- Allows rib cage to move during breathing
- Provides support and protection
- Provides flexibility and lightweight support

• **Bone**

Bone, illustrated in Figure 13.2, is the most rigid of the connective tissues and forms the skeleton (bones) of the body. Its hardness is due largely to the presence of mineral salts such as calcium phosphate and calcium carbonate in
the intercellular matrix. This intercellular material also contains a considerable amount of collagen. Bones are discussed in more detail in learning unit 14.

![Compact Bone & Spongy (Cancellous Bone)](https://en.wikipedia.org/wiki/Bone_tissue)

**FIGURE 13.2**

*Bone connective tissue*

(Source: [https://en.wikipedia.org/wiki/Bone_tissue](https://en.wikipedia.org/wiki/Bone_tissue))

Major functions:

- Bone provides an internal support for body structures.
- Protects vital parts in the cranial (head) and thoracic (chest) cavities such as the brain, lungs, spinal cord and heart.
- Serves as an attachment for muscles.
- It contains red bone marrow, which functions in forming blood cells.
- Stores various inorganic salts.

• **Blood**

Blood is composed of cells that are suspended in a fluid intercellular matrix called blood plasma. These cells include red blood cells, white blood cells and blood platelets. You will learn more about blood plasma, blood cells and blood clotting in learning unit 17.

Major functions:

- Acts as the transport system of the body.
- By means of the white blood cells forms part of the defence system that protects the body against micro-organisms and foreign bodies.
- Maintains normal cell function by the constant exchange of nutrients and wastes in all cells.
Activity 13.2: Types of connective tissue

(1) Tabulate the four main groups of connective tissue with their functions.
(2) Complete the following table:

<table>
<thead>
<tr>
<th>Type of true connective tissue</th>
<th>Appearance</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areolar</td>
<td></td>
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</tbody>
</table>

13.2.3 Nervous tissue

- **Characteristics**

Nervous tissue is found in the brain, spinal cord and associated nerves. The nervous tissue is composed of various cells, including impulse-conducting cells called **neurons** (the fundamental units of the nervous system), nonconducting **neuroglia** (protective, supportive and nourishing cells), and peripheral **glial cells** (neurilemma cells), which form various types of sheaths and help to protect, nourish and maintain cells of the peripheral nervous system.

Three types of neurons can be identified according to their function, namely afferent neurons, efferent neurons and interneurons. This is discussed in more detail in learning unit 16. A nerve cell is illustrated in Figure 13.3.
• **Main location of nervous tissue**

Nervous tissue is found in the brain and spinal cord, which forms the central nervous system, and in the peripheral nervous system, which constitutes all the nerves outside the central nervous system and is distributed throughout the body.

• **Major functions**

Nervous tissue conducts impulses, such as smells, tastes, light waves, sounds, etc. to the brain. The brain interprets the impulses and, if a reaction is necessary, sends the appropriate message to the part of the body that must react to the impulse. The three types of neurons that conduct these impulses are the following:

– **Afferent** neurons transmit nerve impulses to the spinal cord and the brain.
– **Efferent** neurons transmit nerve impulses from the brain or spinal cord to the muscles or glands.
– **Interneurons** conduct impulses from afferent neurons to efferent neurons.

13.2.4 Muscle tissue

Muscle tissue enables the body and parts of the body to move. It is **contractile**—the muscle cells can change shape by becoming shorter and thicker. As they contract, the muscle fibres within the cell pull at their attached ends and cause the body parts to move.
Muscle tissue can be classified into three types according to its location, namely **skeletal** muscle, **cardiac** muscle and **visceral (smooth)** muscle. A muscle cell is illustrated in Figure 13.4.

**Figure 13.4**
A muscle fibre and myofibril  
(Source: Unisa drawing)

- **Skeletal muscle**
Skeletal muscle tissue is found in muscles that are usually attached to bone, and by its contraction, movement is obtained. Because these muscles can be controlled by conscious effort they are also known as voluntary muscles. Muscle cells are long and threadlike, with alternating light and dark cross markings due to the presence of muscle fibres. Each cell has many nuclei just beneath its membrane. When the cell is stimulated by an action of a nerve fibre, it contracts and then relaxes. If the connecting nerve fibre is damaged, it may not be possible to control the muscle fibre's action, and the muscle fibre is paralysed.

Skeletal muscles are responsible for moving the head, trunk and limbs. They are also responsible for the movements in facial expressions, writing, talking, swallowing and breathing.

- **Cardiac muscle**
Cardiac (of the heart) muscle tissue forms the walls of the heart. Cardiac muscle is controlled involuntary (not under control of the will). In fact, cardiac muscle can continue to function even without stimulation from nerve impulses. This tissue makes up most of the heart and is responsible for pumping blood through the heart chambers and into the blood vessels.

- **Smooth muscle**
Smooth muscle tissue is found in the walls of hollow internal structures such as blood vessels, the intestines, stomach, the uterus, urinary bladder. Smooth muscles usually cannot be stimulated to contract by conscious effort, and therefore are known as involuntary muscles.
Smooth muscle cells are shorter than those of skeletal muscles, and they each have a single, centrally located nucleus. Smooth muscle tissue is responsible for the movements that force food through the digestive tract, constrict blood vessels, and empty the urinary bladder.

You can watch a slide show and do an online activity on connective and muscle tissue at https://www.wisc-online.com/learn/general-education/anatomy-and-physiology1/ap14504/muscle-and-connective-tissue.

13.3 MEMBRANES
Membranes (not to be confused with cell membranes) are thin, pliable layers of epithelial and/or connective tissue. They line body cavities, cover surfaces, or separate or connect certain regions, structures, or organs of the body. The four kinds of membranes discussed under this section are mucous, serous, synovial and cutaneous membranes.

• **Mucous membranes**

Mucous membranes line openings or passageways of the body that open to the outside of the body, such as the mouth and nasal cavity. They consist of a layer of loose connective tissue covered by varying kinds of epithelial tissue. The functions of the mucous membranes are as follows:

• To protect (against bacterial invasion, for instance)
• To secrete mucus
• To absorb water, salts and other solutes

• **Serous membranes**

Serous membranes line the closed cavities of the body, such as the thoracic (thoracic cavity contains heart and lungs) and abdominal cavities (abdominal cavity contains stomach, intestines, etc.). They also cover the organs lying in these spaces. Between the two layers there is a small space kept moist by a small amount of serous fluid.

The function of the serous membranes is to prevent friction of the moving organs (such as heart, lungs, etc.). Friction is prevented by the moist serous sheets of membrane lining the organs and the cavities in which they move.

• **Synovial membrane**

The synovial membrane lines joint cavities and tendon sheaths (tendons: muscle part that joins the bones). It is smooth and moist, like the serous membrane. The function of the synovial membrane is to protect body parts against friction.

• **Cutaneous membrane**

This membrane is found in the skin and in the accessory organs of the skin.

The skin, the largest organ of the body, consists of cutaneous membrane. The skin is made up of two main layers, namely the dermis and the epidermis.
The dermis is a thin layer consisting of several layers of epithelial tissue. The epidermis consists of fibrous connective tissue. Underlying the dermis is subcutaneous tissue consisting of areolar tissue and in many places adipose tissue. Millions of microscopic nerve endings are located in the skin.

The functions of the cutaneous membrane are the following:

– To help in the maintenance of normal fluid and electrolytic balance (electrolyte: to do with body salts)
– To help in regulating body temperature
– To protect against the entry of micro-organisms
– To protect against injury of underlying structures
– To bar entry of excess sunlight, most chemicals and even water

The skin also has certain accessory organs, namely hair, nails and glands.

### Activity 13.3: Body tissue

1. What kind of tissue would you find in the following areas?
   - Around the nerves
   - In the vocal cords
   - In the tendons

2. Label the following parts of the skin on the diagram below. Sebaceous subcutaneous fat; dermis; root of hair; and epidermis.
13.4 REVISION AND REFLECTION

(1) Explain what body tissue is.
(2) List the four (4) major types of body tissue.
(3) Discuss the main characteristics of epithelial tissue.
(4) What are the functions of epithelial tissue?
(5) Classify connective tissue into its different types and state the function of each type.
(6) What is the function of nervous tissue?
(7) What is the function of muscle tissue?
(8) Name the different types of muscle tissue and state whether they are voluntary or involuntary.
(9) Tabulate the four different types of membranes and describe the function of each.
(10) This unit contained a great deal of factual information. How did you do with studying it? Remember that diagrams and mind maps can help you come to grips with sets of factual information. To learn more about mind maps, visit the following websites:

http://www.wikihow.com/Make-a-Mind-Map

http://www.mind-mapping.co.uk/make-mind-map.htm

13.5 CONCLUSION

Body tissue is an organisation of a great many similar cells with varying amounts of kinds of nonliving, intercellular substances between them. Body tissue can be classified into four types, namely epithelial, connective, nervous and muscle tissue. Each type of tissue has different functions and locations. See the following diagramatic representation of the classification of body tissue:
Membranes are thin, pliable layers of epithelial and/or connective tissue. There are four kinds of membranes, namely mucous, serous, synovial and cutaneous membranes. Each type of membrane has different functions.

The following learning unit will deal with the part of the body that gives structure to it—the skeletal system.
14.1 INTRODUCTION
Support and movement of the body are the primary functions of the skeletal and muscular systems. Without rigid bone tissue, the other soft body tissues will not be able to move or maintain their posture.

Learning outcomes

After you have completed this learning unit, you should be able to:

- describe the structure of bone tissue
- identify the four types of bones found in the body
- identify the five functions that bones perform in the body
- differentiate between the axial skeleton and the appendicular skeleton
- explain the importance of joints in the movement of the body
- classify the different types of joints
- explain the effect of various vitamins and other factors on bone development

14.2 FUNCTIONS OF BONES
Bones perform five functions in the body:

- **Support**
  They act as a framework.

- **Protection**
  They protect delicate structures such as the brain and the lungs in bony boxes.

- **Movement**
  They form joints (levers) between the different bones. Muscles anchored to the bones contract and relax, thus enabling movement of these bony levers.
• **Reservoir**

Bone is a reserve source of elements such as calcium and phosphorus. It serves as a major calcium reservoir from which calcium can be withdrawn to maintain the homeostasis of blood calcium.

• **Blood formation**

Bone marrow is the most important blood-forming tissue in the body.

### 14.3 MICROSCOPIC STRUCTURE OF BONES

Bone tissue consists of living cells in a predominantly nonliving intercellular substance called the bone matrix. This matrix consists mainly of calcified (impregnated by calcium salts), collagen fibres, and is responsible for the hard, rigid characteristics of bone tissue. Bone cells (or osteocytes) lie imprisoned in small spaces between hard layers of matrix.

These matrix layers also enclose great numbers of microscopic canals in which tissue fluid circulates. The bone cells receive food and oxygen and excrete their waste products via blood vessels that enter the rigid bone matrix by way of the canals. The bone marrow, situated in the cavity of long bones, also receives its blood supply from the blood vessels running through these canals.

For further understanding on how bones are formed study pages 243-246 of chapter 11 in the prescribed textbook.

### 14.4 TYPES OF BONES

Bones can be classified according to their shape into long bones, short bones, flat bones and irregular bones.

• **Long bones**

Long bones are located in the upper and lower arms and legs, in the fingers and in the toes. A long bone consists of several different parts, as illustrated in Figure 14.1 and described below.
• **Diphsis**

This is the main shaft-like portion. It is hollow, cylindrical in shape and composed of thick compact bone that enables it to provide strong support without being too heavy.

• **Epiphyses**

This is the bulbous sponge like end of long bones. Red or yellow bone marrow fills the sponge-like space of the epiphyses. (Note the terms “proximal” and “distal” epiphysis in the picture above. “Proximal” essentially means close to
and “distal” means far away from. In this case, the proximal end is the part that is closest to the hip and main part of the body, while the distal end is furthest away from them.)

- **Articular cartilage**

  This is the thin layer of cartilage or connective tissue that covers the surfaces of joints to cushion the joints against jars and jolts.

- **Periosteum**

  This is the dense white fibrous **membrane** that covers the bone, except at joint surfaces.

- **Medullary cavity**

  This is also called the marrow cavity and is the tube-like hollow part in the diaphysis containing yellow bone marrow.

- **Endosteum**

  This is the **membrane** that lines the medullary cavity.

- **Short, flat and irregular bones**

  These three bone types differ in shape but their structure is more or less similar. All three types have an inner portion of spongy bone (also called cancellous bone), such as the spongy portion in the epiphysis of long bones. They are covered on the outside with a layer of compact bone, which is similar to the compact bone of the diaphysis of long bones.

  Red bone marrow is found in the spaces that exist in the cancellous bone of some flat and irregular bones, for example in the vertebrae (spine) and sternum (breast bone). The process of blood formation takes place in the red bone marrow.

14.5 **THE SKELETON**

Together, all the bones of the body form the skeleton (see Figure 14.2).
FIGURE 14.2

The human skeleton

(Source: https://upload.wikimedia.org/wikipedia/commons/thumb/c/ca/Human_skeleton_front_en.svg/397px-Human_skeleton_front_en.svg.png)
The skeleton consists of two main divisions, namely the **axial skeleton** and the **appendicular skeleton**.

- **The axial skeleton**

  The axial skeleton derives its name from the fact that it forms the upright axis of the body. From this axis the appendicular skeleton (arms and legs) is projected and rotates around the axial skeleton. The axial skeleton consists of 80 different bones. It can be divided into the following five subdivisions:

- **The skull**

  The skull rotates on the spinal column. The skull can be divided into the cranial bones (brain box) and the face bones. The cranium protects the brain, and the face bones protect or form the sensory organs such as eyes, ears, nose.

- **Hyoid bone**

  This is a single, irregular U-shaped bone in the neck. Several muscles, such as the tongue muscle, are attached to it.

- **Vertebral column**

  Also called the spinal column, the vertebral column forms the lengthwise axis of the skeleton on which the skull turns. It encloses the spinal nerves and articulates with the ribs. In order to strengthen the vertebral column and make balance in the upright position possible, the vertebral column is curved.

- **Sternum**

  Also called the breast bone, this is a flat bone at the front of the rib cage, and the seven upper ribs are attached to it.

- **Ribs**

  These are 24 paired flat bones, situated on each side of the thoracic cavity (rib cage). They are arched to form a protective cage for the heart and lungs.

- **The appendicular skeleton**

  The appendicular skeleton consists of the 64 bones of the upper extremities and the 62 bones of the lower extremities, a total of 126 bones.

- **Upper extremities**

  These consist of the bones of the shoulders, upper arms, lower arms, wrists and hands.

- **Lower extremities**

  These consist of the bones of the hips, thighs, lower legs, ankles and feet.
Activity 14.1: Bones

Study the following diagrams of bones in the body. Give the type of bone to which each are classified according to its shape. Also give two (2) examples of where this class of bone is found in the body.

Figure 14.1.1

Bones

(Source: Unisa drawing)

Label the following parts of a long bone in the diagram below: Distal epiphysis, proximal epiphysis, marrow, periosteum, medullary cavity and compact bone.

Figure 14.1.2

Structure of the bone

(Source: Unisa drawing)
Go to a library or search the internet and find information on the role of vitamins and hormones on bone development and then complete the table below. (*Where there is an asterisk, mention the effect of both excess and deficiency.)

<table>
<thead>
<tr>
<th>Factors influencing bone development</th>
<th>Effect on bone development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin D</td>
<td></td>
</tr>
<tr>
<td>*Vitamin A</td>
<td></td>
</tr>
<tr>
<td>Vitamin C</td>
<td></td>
</tr>
<tr>
<td>*Growth hormone</td>
<td></td>
</tr>
<tr>
<td>Thyroid hormone</td>
<td></td>
</tr>
<tr>
<td>Physical exercise</td>
<td></td>
</tr>
</tbody>
</table>

14.6 JOINTS
The skeleton and muscles are able to provide movement because the adjacent bones can move against each other. This joining of bones at certain points and the different degrees of movement they possess are known as joints or articulation, which can be defined as follows:

Joints are the articulating (joining) surface of the various bones that ensure smooth co-ordinated body movements.

Joints perform the following two seemingly contradictory functions:

- Joints hold bones firmly bound together.
- Joints permit movement between bones.

Joints are classified according to the degree and type of movement they allow.

- **Immovable joints**

  Immovable joints are found between bones that come into close contact with one another. The surfaces of the bones that form these joints are so firmly attached to each other that there is virtually no movement at all.

  Immovable joints are found in the following:
  - The structures between the bones of the skull
  - The teeth in the sockets of the jaw

- **Slightly movable joints**

  These joints allow only a limited degree of movement and are very strong. They are found in the following:
– Cartilaginous discs between the vertebrae
– The cartilage in the symphysis that binds the pubic bones together at the front of the pelvic girdle (a symphysis is a place where two bones are closely joined)

- **Synovial joints (freely movable joints)**

Of all the types of joints, **synovial joints** allow the greatest range of movement. These are the only joints that are freely movable and include most of the joints in the body, such as the hip, shoulder, finger, elbow, knee and ankle. A synovial joint is illustrated in Figure 14.3.

![Structure of a synovial joint](https://en.wikipedia.org/wiki/Synovial_membrane)

**FIGURE 14.3**

*Structure of a synovial joint*


---

**Activity 14.2: Joints**

(1) Identify the body part and the kind of joint illustrated in Figures A-D below and then complete the table.

![Figure A](source: Unisa drawing)

![Figure B](source: Unisa drawing)
LEARNING UNIT 14: Skeletal system

<table>
<thead>
<tr>
<th>Body part</th>
<th>Joint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure E</td>
<td>Finger Synovial joint</td>
</tr>
<tr>
<td>Figure A</td>
<td></td>
</tr>
<tr>
<td>Figure B</td>
<td></td>
</tr>
<tr>
<td>Figure C</td>
<td></td>
</tr>
<tr>
<td>Figure D</td>
<td></td>
</tr>
</tbody>
</table>

Activity 14.3: Revision and reflection

(2) Briefly explain the functions of bone.
(3) Explain how a bone cell receives its nutrition.
(4) Give the two main divisions of the skeleton and list the bones in each division. Provide your answer in a table format.
(5) Define a joint.
(6) What new insights, if any, did you gain in this unit about the importance of keeping your skeletal system healthy? Remember that osteoporosis, or bone brittleness, is a condition which is very common among older people. Are you currently doing enough to ensure your bone health in later life?

14.7 CONCLUSION

The skeletal system, specifically bones, has five main functions in the body: it provides support and protection, it enables movement, serves as a reservoir and pays an instrumental role in blood formation. Bones can be classified according to their shape into long, short, flat and irregular bones. All these bones together form the skeleton. The skeleton is subdivided into the axial skeleton and the appendicular skeleton. Joints between the different bones ensure that the bones are firmly bound together and permit movement between some of the bones. Joints are classified into immovable joints, slightly moveable joints and synovial joints.

The skeleton forms an important structural part of the body, but is only mobile when functioning in conjunction with muscles. The muscular system will be discussed in the following learning unit.
15.1 INTRODUCTION

Those of you who exercise regularly will probably already have some familiarity with the muscular system, especially if you hurt a muscle at some stage! You may have heard a trainer or coach refer to “abs” and “pecs”, and you probably know what these are – but how much do you really know about the structure and function of muscles?

Learning unit 13 introduced muscle tissue to you. The muscular system of the human body consists of more than 500 muscles, and is responsible for all motion activities of the body. These motion activities are possible because of the irritability, contractility, extensibility and elasticity of muscle tissue.

Muscle tissue can be divided into three types, namely visceral (smooth) muscles, cardiac muscles and skeletal muscles. I will discuss all three in the sections that follow. Finally, I will also give you a brief overview of the nerve supply of skeletal muscles.

Learning outcomes

After you have completed this learning unit, you should be able to:

- distinguish between the various muscle types
- describe the structural organisation of skeletal muscle
- give the functions of skeletal muscle
- describe the structure of skeletal muscle fibres and skeletal muscle organs
- discuss the nerve supply of skeletal muscle

15.2 VISCERAL MUSCLES

Visceral muscle is involuntary and smooth (nonstriated). It is found in the walls of all hollow internal structures such as blood vessels, intestines, gland ducts, etc.

The functions of visceral muscle are the following:

- It is responsible for all the characteristic movements associated with the digestive canal.
• Visceral muscle controls and adjusts the diameter of the blood vessels and ducts of glandular tissue.

15.3 CARDIAC MUSCLES
Cardiac muscle is striated and involuntary, and is only found in the heart itself. The functions of cardiac muscle are the following:

• It forms the walls of the heart.
• It is responsible for the beating (repetitive contraction and relaxation) of the heart to pump the blood to all the body tissues.

15.4 SKELETAL MUSCLES
Skeletal muscle is striated and voluntary. It forms 40% of the body’s weight and is the “red meat” of the body. It is attached to the bones to move them about. Movement is however not the only function of skeletal muscle.

• Functions of skeletal muscle
Skeletal muscle has the following functions:

– Movement
Skeletal muscles contract and relax to produce movement of the entire body or movement of certain parts. Movement is a function performed by the muscular system in conjunction with the skeletal system. However, bones and joints cannot move by themselves, and likewise, muscles cannot move the body by themselves. A third system is also involved, namely the nervous system. Nerves carry the message from the brain, telling the muscles to contract so that the bones can lift or move.

– Heat production
Muscle cells, like all other body cells, produce heat by the process of catabolism. (Catabolism is the breakdown of complex molecules to simpler ones, with an accompanying release of energy.) A lot of the body heat is generated by the activity of skeletal muscle fibres because they are both highly active and numerous.

– Posture
By the constant partial contraction of many skeletal muscles different postures such as standing, sitting, bending, etc are maintained.

• Structure of skeletal muscle cells
Each skeletal muscle cell has a nucleus and alternating light and dark bands in the cytoplasm. These bands are caused by the presence of actin and myosin protein filaments that can slide past one another when the muscle cell contracts. Skeletal muscle cells are richly supplied with mitochondria, which
supply the energy (ATP) needed to help the filaments slide past one another. Revise section 13.3.4 on muscle fibres.

- **Structure of skeletal muscle**

The structures called skeletal muscles are organs of various shapes, sizes and arrangement of fibres. They range from broad to narrow, from tiny to large, and from short to long. The arrangement of their fibres can be parallel to the length of the muscle or oblique or curved.

The different parts of a skeletal muscle are illustrated in Figures 15.2 and 15.3.
Each muscle is enveloped by a dense fibrous connective tissue sheath called the **epimysium**. Connective tissue, called **perimysium**, also extends into the muscle as partitions between bundles of muscle fibres and between individual fibres, called **endomysium**. Because these three connective tissue structures are continuous with the fibrous connective tissue called tendons, which attach muscles to bones, muscles are firmly attached to the structures they pull on during contraction. Study pages 247-248 in the prescribed textbook for a further description of the structure of skeletal muscles.

### 15.5 NERVE SUPPLY TO MUSCLES

In order to contract, muscles must be stimulated. Muscles are supplied with nerves, both **sensory** (afferent) and **motor** (efferent).

Many motor nerves supply a muscle, with each single nerve fibre supplying a bundle of muscle fibres. Such a single nerve fibre with its bundle of muscle fibres is called a **motor unit**. The more muscle fibres there are in a unit, the slower and coarser the muscle action is in contrast to a motor unit consisting of only a few muscle fibres to each nerve, such as the muscles of the eye where precise, rapid movements are possible.
Each nerve ends in a motor end-plate or **neuromuscular junction**, where an impulse reaching the ends of the axon fibre releases a chemical substance. (The axon is part of the nerve cell.) This chemical substance acts upon the sarcolemma of the adjacent muscle fibre, stimulating it to contract. See Figure 15.4.

**FIGURE 15.4**

*Neuromuscular junction. 1: Axon 2: Sarcolemma 3: Vesicle containing chemical substance 4: Receptor of the substance on the sarcolemma 5: Mitochondria*

(Source: https://commons.wikimedia.org/wiki/File:Synapse_diag4.png)

With repeated stimulation, the muscle will remain in a contracted state, but it will relax and return to its original shape and length once the stimulation stops.

The afferent or sensory nerves leading from the muscles to the brain, “report” to the brain what the condition of the muscle is. They tell the brain what the degree of contraction of the muscle is. The brain can respond to this information together with information received from sensory nerve endings (sensory receptors) and activate the skeletal muscles more or less as the situation may require.

---

**Activity 15.1: Skeletal muscles**

1. Label the following parts of the voluntary (skeletal) muscle in the diagram below: Muscle, perimysium, muscle fibre, nuclei and myofibrils. (Refer to Figure 15.2 in an earlier section.)
FIGURE 15.5
Muscle structure
(Source: http://bio1152.nicerweb.com/Locked/media/ch50/muscle.html)

(2) Tabulate the following types of muscle tissue and give for each their major location, major functions and mode of control:
- Skeletal muscle
- Cardiac muscle
- Smooth muscle

Activity 15.2: Revision and reflection
(1) Give a short description of the structure of skeletal muscle.
(2) List the major events in muscle contraction and relaxation.
(3) Review the study schedule you drew up earlier this year. Are you still on track, or should you revise your schedule?

15.6 CONCLUSION
Muscle tissue can be divided into three types, namely visceral (smooth) muscles, cardiac muscles and skeletal muscles. Each type of muscle has different functions and is located in different parts of the body. The structure of skeletal muscle as given in the related figures is important for the functional role it plays in body movements. These movements are dependent on the nerve supply and impulses it receives from it. The nervous system will be discussed in the following learning unit.
Learning unit 16

Nervous system

16.1 INTRODUCTION

For a moment, consider all the processes that your body is carrying out while you are sitting here studying. You are probably sitting upright and not falling over or feeling unbalanced. Your heart is beating, you are breathing, seeing, hearing, smelling, feeling whatever may be in your hands, and you can become aware at any time of any sensation in your feet, your legs, or any other part of your body. At the same time, your body might still be working on digesting something you ate or drank a while ago, and on getting rid of any harmful substances or organisms that might be around. And finally, your body is continually generating energy for all these processes to go on.

What coordinates and controls all these multiple processes? The nervous system functions as the co-ordinator of the body as a whole. This is achieved by controlling the body through communication, a function in which nervous tissue specialises.

The organs of the nervous system are divided, according to their location, into the central nervous system and the peripheral nervous system. According to the type of effectors (organs or muscles) that they are connected to ("ener-vate"), the nervous system can also be subdivided into the somatic and the autonomic nervous systems. I will explain these concepts in more detail in the sections that follow.

Learning outcomes

After you have completed this learning unit, you should be able to:

• identify the different nerve cells and give the function of each
• locate the organs of the nervous system in a diagram
• explain how an impulse is conducted
• explain what are reflexes and reflex arcs
• distinguish between the somatic and the autonomic nervous systems

16.2 NERVE TISSUE

The nervous system is composed of two main kinds of cells, namely neurons (the functional units) and neuroglia (special connective tissue cells).
Study the first sections up to the section: How the nervous system is organised of Chapter 5, pages 100-103 in the prescribed textbook.

- **Neurons**

Neurons are the specialists of the nervous system. They conduct impulses and provide the body with its means of communication, control and integration.

Clusters of neuron cell bodies have a grey colour—hence the name grey matter for the nervous tissue of the brain and spinal cord where these cell bodies are located.

- **Neuroglia**

The name neuroglia comes from a Greek word meaning glue. These cells cluster around neurons within the central nervous system and offer structural support. Although neuroglia serve the same general function as connective tissue in other organs, they do not have the ability to transmit impulses.

In the sections that follow, I will describe the structure of neurons, and different types of neurons.

**16.2.1 Structure of neurons**

The cell bodies of neurons resemble other cells since they contain a nucleus, cytoplasm, the various organelles and a cytoplasmic membrane that encloses the entire neuron. Neurons differ from other cells in that they have elongated extensions of the cell body, called “cell processes” (not to be confused with the general metabolic processes that occur inside the cell). These processes, also known as nerve fibres, are the **dendrites** and the **axon**.

A neuron consists of the cell body, dendrites and the axon, as illustrated in Figure 16.1 below.
Inside the cell body for example, are mitochondria, lysosomes, a Golgi apparatus and neurofibrils, a fine network of fibrils in the cytoplasm of the cell body which extend into the cell processes. Nissl bodies are scattered throughout the cytoplasm. They are clumps of flat membranous vesicles with many ribosomes between them. Nissl bodies specialise in protein synthesis and maintain the neuron processes and chemicals involved in the transmission of nerve impulses from one neuron to another. Near the center of the cell body is a large, spherical nucleus with conspicuous nucleolus.

Two kinds of nerve fibres, called dendrites and axons, extend from the cell bodies of most neurons. Although a neuron usually has many dendrites, it has a single axon.

- **Dendrites**

These are many fine processes that branch extensively like tiny trees out of the cell body. They provide the main physical surface from which the nerve cells receive incoming impulses. The dendrites conduct these impulses towards the cell body.
– Axon

The axon usually arises from a slight elevation of the cell body. Axons vary in both length and diameter. Their length can vary from a fraction of a centimetre to about one metre. A neuron’s axon is specialised to conduct impulses away from its cell body.

The axons and dendrites may develop sheaths that completely envelop them, or they may remain naked. The two main types of sheath that envelope certain fibres are the following:

* Myelin sheath

This is a white lipid-protein material that surrounds many of the nerve fibres of the body. It is formed by Schwann cells that wrap around the axon. It is not a continuous sheath, but is interrupted at intervals by constrictions called the nodes of Ranvier.

* Neurolemma

This is a delicate cytoplasmic membrane which is also formed by the bodies of Schwann cells that are wrapped once around all peripheral nerve fibres. There is no neurolemma within the central nervous system.

A nerve fibre and its coverings are illustrated in Figure 16.2.

![FIGURE 16.2](https://en.wikipedia.org/wiki/Myelinogenesis)

A nerve fibre and its coverings

(Source: [https://en.wikipedia.org/wiki/Myelinogenesis](https://en.wikipedia.org/wiki/Myelinogenesis))
16.2.2 Classification of neurons

Neurons can be classified according to their function and structure. The following three types of neurons are classified according to the direction of the impulse they carry.

- **Sensory/afferent neurons**

These neurons convey impulses from the body to the central nervous system, for example from the skin, skeletal muscle and cardiac muscle.

- **Motor/efferent neurons**

These neurons transmit impulses from the central nervous system to some effectors, for example the muscles and glands.

- **Interneurons**

Also called central neurons, they transmit impulses from one part of the brain or spinal cord to another. Interneurons are also situated between sensory and motor neurons.

The three types of neurons are illustrated in Figure 16.3.

![Figure 16.3](http://resources.teachnet.ie/farmnet/Nervous.htm)

**FIGURE 16.3**

*A diagrammatic representation of the structures of three kinds of neurons*

(Source: [http://resources.teachnet.ie/farmnet/Nervous.htm](http://resources.teachnet.ie/farmnet/Nervous.htm))
ACTIVITY 16.1: Motor neuron

(1) Label the following structures in the diagram of a motor neuron illustrated below: Dendrite, axon, nerve ending, cell body, nucleus and myelin.

(Source: https://pixabay.com/en/neuron-nerve-cell-axon-dendrite-296581/)

(2) Tabulate the three (3) types of neurons and give the location and function of each.

16.3 STRUCTURES OF THE NERVOUS SYSTEM
The human nervous system is illustrated in Figure 16.4.

(Source: https://commons.wikimedia.org/wiki/Category:Diagrams_of_the_human_nervous_system#/media/File:Nervous_system_diagram.png)
The nervous system is divided into two parts or systems, namely the **central** nervous system and the **peripheral** nervous system. The central nervous system consists of the brain and the spinal cord, and the peripheral nervous system of the other nerves in the body. Together, they perform the functions of communication, control and integration.

I will discuss both these systems in the following sections.

**Study the section on How the nervous system is organised, pages 103-105 of Chapter 5 in the prescribed textbook.**

### 16.3.1 Peripheral nervous system

The peripheral nervous system consists of both afferent and efferent neurons and of interneurons that connect the peripheral to the central nervous system. In other words, the peripheral nervous system consists of nerves leading to and from the spinal cord and brain to all body parts and organs, both internally and externally. They conduct mainly **sensory stimuli** to the brain and the **response stimuli**, originating from the brain, back to the body parts and organs.

Two types of nerves are distinguished, namely **spinal** and **cranial** nerves, depending on whether they originate from the spinal cord or the brain.

#### 16.3.1.1 Central nervous system

The central nervous system consists of two organs, namely the spinal cord and the brain.

* **The spinal cord**

The spinal cord is located in the spinal cavity and consists of a central core of grey matter surrounded by white matter. The spinal cord serves as a two-way conduction path between the peripheral nerves and the brain. **Ascending tracts** conduct impulses up the cord to the brain, while **descending tracts** conduct impulses down the cord from the brain to the peripheral nerves. The spinal cord is also the centre of certain **reflex arcs** where afferent neurons connect to efferent neurons. A “reflex arc” is the nerve pathway involved in a reflex action, for example when you instantly pull your hand away from a hot object.

* **The brain**

The brain is composed of several structural parts consisting of nerve cells and fibres. The different structural parts specialise in different functions, but are also interdependent for many of their functions. The main structural parts are the brain stem, the cerebellum and the cerebrum. The brain is illustrated in Figure 16.5.
The brain stem

The brain stem is the lowest part of the brain and joins the brain to the spinal cord. The brain stem can be subdivided into the medulla oblongata, the pons and the midbrain, with the medulla connecting the spinal cord to the rest of the brain. See Figure 16.6.

Figure 16.6
Structure of the brain stem
(Source: https://commons.wikimedia.org/wiki/File:1311_Brain_Stem.jpg)
Because these centres are essential for survival, each one is discussed individually.

- **Medulla oblongata**

Reflex centres such as the cardiac and respiratory centres are located in the medulla. The medulla is regarded as one of the most important parts of the brain.

- **Pons**

This is the centre for the regulation of respiration.

- **Midbrain**

This contains centres such as the pupillary reflex centre. (Pupillary reflex: widening or narrowing of the pupil of the eye.)

Connected to the midbrain are two important structural parts that are sometimes classified with the midbrain, namely the **thalamus** and the **hypothalamus**.

- **The cerebellum**

The cerebellum lies to the back of the brain stem and below a part of the cerebrum. The cerebellum performs the following three main **functions**:

  - It co-ordinates the activities of groups of muscles to produce smooth movements.
  - It controls skeletal muscles to maintain equilibrium (balance).
  - It helps to control posture.

- **The cerebrum**

The cerebrum is the largest and topmost part of the human brain. It consists of grey matter—hence the name “grey matter” for the brain.

The cerebrum has the following three main functions:

  - It coordinates and integrates body functions.
  - It has to do with human intellect—the ability to think and understand.
  - It can compare, evaluate and remember stimuli.

A deep groove partly divides the cerebrum into two halves, the right and left hemispheres. Each hemisphere specialises in certain functions. The left hemisphere appears to specialise (amongst others) in language-related functions such as talking, writing and reading, while the right hemisphere appears to specialise in auditory (hearing) and tactile perception (tactile: touch) and in visual space orientation (shape and form recognition and depth perception).

It must be stressed that only a few of the many functions of the different brain structures were mentioned in the above discussion of the brain. There are many, many more to ensure a well-organised body.
ACTIVITY 16.2: The nervous system

(1) Label the structures in the diagram of the brain below:

(Source: Unisa drawing)

(2) Complete the following diagram. Fill in both the structure and its function in every box.

(3) Tabulate the skills associated with the left and right cerebral hemispheres of the brain.

16.4 SENSORY STIMULATION

We are made aware of changes or conditions in both our external and internal environments by sensory stimulation. Environmental stimulation is picked up
by sensory receptors and passed along afferent nerve fibres to the central nervous system.

16.5 IMPULSE CONDUCTION
Impulses can be conducted along a nerve or across a synapse.

- Conduction along a nerve

The nerve endings (receptors) react to changes in the environment (stimuli) by generating a receptor *impulse* in the otherwise resting membrane. This, in turn, activates an action in the nerve fibres. This is brought about by changes in the charge of the cells involved. In a resting cell, there is an electrically negative charge on the inside of the cytoplasmic membrane, and an electrically positive charge on the outside of the cytoplasmic membrane. This electrical difference is normally maintained owing to the uneven distribution of sodium (Na) and potassium (K) ions across the cytoplasmic membrane. When the environment changes, the area inside the cytoplasmic membrane becomes positive, and the area outside the membrane becomes negative. This generates an electrical impulse.

In summary, we can say that a nerve impulse is a self-propagating wave of electrical negativity that travels along the otherwise electrical positive surface of a neuron’s cytoplasmic membrane.

The minerals sodium (Na) and potassium (K) are of the utmost importance in the conduction of nerve impulses.

Impulse conduction along a nerve fibre is illustrated in Figure 16.6.

![Figure 16.6](Unisa drawing)

It must again be stressed that impulses always move from the dendrite to the cell body, and then along the axon to the dendrite of the next nerve cell. The
The impulse is transmitted across the synapse (space) between the two nerves.

**Conduction across a synapse**

A synapse is the area of loose contact between the axon of one neuron and the dendrite of a second neuron that permits transmission of an impulse in one direction only.

*We also need to know what a synaptic cleft is.*

A synaptic cleft is the small space between the two nerves.

An impulse is conducted or carried across the synaptic cleft by means of a chemical reaction where vitamins and hormones are involved. Neurotransmitter molecules are released by the membrane of the axon terminals into the synaptic cleft. These neurotransmitters diffuse across the cleft and bind to the pre-and post-synaptic neuron.

A synapse is illustrated in Figure 16.7.

![Figure 16.7: The synapse](https://commons.wikimedia.org/wiki/File:Anatomy_and_physiology_of_animals_Magnification_of_a_synapse.jpg)

**Activity 16.3: Impulse conduction**

You should answer this question in the discussion space on your e-tutor site.

Use your own words to explain to someone who knows nothing about the nervous system how an impulse is conducted along a nerve fibre and across
a synapse. You can draw your own pictures to illustrate your explanation if you like (but they should not be identical to the ones in the previous section).

Your e-tutor should give you feedback on your answer.

You can also watch the following video clips for an illustration and additional explanation of processes involved in impulse conduction:

https://www.youtube.com/watch?v=p5zFgT4aofA
https://www.youtube.com/watch?v=XdCrZm_JAp0

16.6 REFLEXES
A reflex is a conscious or unconscious response to a stimulus.

Study the section on Reflexes and reflex arcs, stretch reflexes and withdrawal reflexes, pages 106-108 of Chapter 5 in the prescribed textbook.

A reflex results in either muscle contraction or glandular secretion. There are two types of reflexes, namely somatic reflexes, which result in contractions of skeletal muscle, and autonomic reflexes, which are contractions of smooth or cardiac muscles or secretions of glands.

The functional unit of the nervous system that enables reflex activity to take place is the reflex arc. It consists of the following five essential parts, functioning in the sequence in which they are given:

- A sensory receptor to receive the stimulus
- An afferent (sensory) neuron to transmit the impulse to the central nervous system
- One (monosynaptic) or more than one (polysynaptic) synapse within the central nervous system to transmit the impulse to an interneuron leading to the brain or directly to the efferent neuron
- An efferent (motor) neuron to transmit the impulse either directly from the afferent neuron or indirectly, after intervention, by means of the interneuron from the brain to the effector organ (either a muscle or a gland)
- An effector organ to react to the original stimulus or to the instruction from the brain in response to the original stimulus

A reflex action is illustrated in Figure 5.3 and 5.4 of Chapter 5 in the prescribed textbook on pages 106 and 107.

For example, the hand is withdrawn quickly from a harmful source such as a flame (a somatic response across a reflex arc), and the heart rate and constriction of blood vessel walls are continuously being adjusted to meet physical or physiological needs (autonomic response across an autonomic reflex arc).
You can watch the following video clip for an illustration of the reflex arc:
https://www.youtube.com/watch?v=wLrhYzdbbpE

16.7 SOMATIC AND AUTONOMIC NERVOUS SYSTEMS
The nervous system can also be subdivided into the somatic and the autonomic systems.

• Somatic nervous system

The somatic nervous system consists of those nerves of the peripheral nervous system and parts of the central nervous system that activate voluntary muscles such as skeletal muscles. Most sensory nerves carrying impulses from the senses (sight, smell, taste, sound, etc) are part of the somatic nervous system. The somatic nervous system stands under voluntary control.

• Autonomic nervous system

The autonomic nervous system controls the internal environment of the body, such as heart rate, adjustment of circulation and secretion of glands to meet body needs— in other words, all involuntary body reactions and functions.

The autonomic nervous system is also involved in the emotional reactions of the body, such as fear or pleasure. The autonomic nervous system receives impulses from external and internal receptors, and controls the cardiac as well as all the visceral muscles of the body.

Activity 6.4: Revision and reflection
(1) Explain how a reflex action takes place when a person burns their hand.
(2) What is the difference between an afferent and an efferent neuron?
(3) What is the difference between an axon and a dendrite?
(4) Tabulate the three main parts of the brain with their locations and functions.
(5) Describe the structure and function of a synaptic cleft.
(6) Differentiate between the somatic and the autonomic nervous systems.
(7) What do you think might be easier to do: program a robot to perform calculations and play chess, or program it to pick up objects and walk steadily across an uneven, rocky surface? What does your answer tell you about your nervous system?

16.8 CONCLUSION
The nervous system is a complex and well controlled system which functions as the co-ordinator of the human body. Nerve tissue consists of neurons and neuroglia. Different types of neurons have different functions. The structure of the nervous system can be divided into the peripheral nervous system and the central nervous system. The central nervous system consists of two organs, namely the spinal cord and the brain, while the brain is composed of several structural parts in order to serve very important physiological functions. These
structural parts are the brain stem, cerebellum and cerebrum. The nervous system can receive sensory stimulation and conduct impulses. It can also have a reflex which is a conscious or unconscious response to a stimulus.

As the structure of the nervous system is divided into two parts, it can also be divided into two parts according to its function—the somatic nervous system that activates voluntary muscles and the autonomic nervous system that controls the internal environment of the body. The autonomic nervous system is responsible amongst others for controlling the cardiovascular system. The cardiovascular system will be discussed in more detail in the following learning unit.
17.1 INTRODUCTION

You know by now that all the cells in your body need nutrients to function, and also produce some waste products that have to be eliminated. But how do nutrients get to the cells, and how do the waste products get to the places where they are eliminated?

The cardiovascular system is basically a transport system. Blood is transported to every part of the body to maintain internal homeostasis of body tissues and fluids. The cardiovascular system is composed of blood vessels and the heart, and consists of a closed circle of tubes (blood vessels) through which blood is pumped by the contractions of a muscular organ (the heart). Blood is found in all the organs of the cardiovascular system, namely the blood vessels and the heart.

Study the introductory sections of Chapter 9 of the prescribed textbook, pages 191-194.

Learning outcomes

After you have completed this learning unit, you should be able to:

- identify the different types of blood vessels
- identify the structures and functions of the heart
- identify the different types of blood cells
- explain the functions of blood plasma and of the different types of blood cells

17.2 BLOOD VESSELS

Blood vessels can be subdivided into three types, namely arteries, capillaries and veins.

Study the section on The blood vessels, pages 200-202, Chapter 9, in the prescribed textbook.
• **Arteries**

All arteries, except the pulmonary artery (artery leading to the lungs) and its branches, carry oxygenated blood. Arteries divide into smaller vessels called arterioles. The **walls of arteries and arterioles** consist of the following three layers:

- An outer coat of **white fibrous** tissue
- A middle coat of **smooth elastic muscle** tissue
- An inner coat of **endothelium** tissue

The fibrous and smooth elastic muscle tissue gradually decreases in thickness as the size of the artery decreases. These two layers are very thin in the smaller arterioles and completely absent in capillaries, the very fine vessels into which arterioles divide.

Arteries have the following **functions**:

- Arteries and their smaller branches, arterioles, serve as **distributors of the blood** from the heart to the body tissues.
- Arterioles have a second function, namely that of resistance vessels. By constricting or dilating (opening), they help maintain normal **blood pressure**.

• **Capillaries**

A network of microscopic capillaries is found throughout the body. The walls of capillaries consist of a single layer of flat endothelium cells, resulting in a thin membrane that is permeable to allow through substances such as oxygen, carbon dioxide, glucose, fluids, leucocytes and waste products.

Capillaries function as **exchange vessels** for nutrients, fluids, gases and waste products between intercellular fluid and blood. Thus the whole purpose of the cardiovascular system is fulfilled through the walls of the capillaries.

• **Veins**

All veins, except the pulmonary vein (vein from the lungs), contain blood without oxygen. Small venules join up to form larger veins. The walls of veins and venules consist of the same three layers as the walls of arteries. The inner walls are also equipped with **valves** to prevent blood from flowing back to the capillaries.

Veins have the following **functions**:

- Veins and their smaller branches, venules, serve as **collectors of blood** from the capillaries.
- Veins **return blood** to the heart.
- Veins serve as **reservoir vessels** to accommodate various amounts of blood.

The cardiovascular system is illustrated in Figure 17.1.
17.3 THE HEART
The position of the heart in the chest is illustrated in Figure 17.2.
• **Structure of the heart**

The heart is a four-chambered muscular organ, about the size of a man's fist. It lies in the chest cavity, slightly to the left-hand side.

The heart consists of the following layers:

- The **pericardium**, a tough white fibrous tissue that forms a loose-fitting sack around the heart
- The **epicardium**, a double layer of serous membrane, a tight-fitting membrane that covers the heart directly
- There is a small amount of pericardial fluid between these layers, which reduces the friction of the beating heart
- The **myocardium**, a muscular layer forming the main layer of the heart
- The **endocardium**, a thin smooth serous membrane that lines the heart chambers, and also covers the sponge work of muscle bars in the ventricles, valves and tendons, and continues out of the heart to line the blood vessels

The heart is divided into two parts by a lengthwise wall of tissue. Each part is composed of an upper and a lower chamber called the atrium and the ventricle, respectively. The ventricles are larger and have thicker walls than the atria because they have to pump the blood out of the heart and along the arteries, whereas each atrium has to pump the blood only into its corresponding ventricle (refer to Figure 9.2 in the prescribed textbook, p.195).

The heart is like two pumps, the upper atrium and lower ventricle, each with two chambers. A lengthwise septum separates the heart into two parts.

The right atrium has the following three openings:

- The **superior vena cava** (svc), which returns venous blood from the upper part of the body
- The **inferior vena cava** (ivc), which returns venous blood from the lower part of the body
The opening of the **coronary sinus**, which returns venous blood from the myocardium

None of these openings have valves.

Blood **flows through the heart** in the following way:

- The venous blood collected in the right atrium flows **to the right ventricle** via the **tricuspid valve**, which consists of three flaps. This valve allows blood to flow into the ventricle, and it closes to prevent blood from flowing back into the atrium.
- Blood from the right ventricle is pumped **to the lungs** through the **pulmonary semilunar valve** at the opening of the pulmonary artery. These valves are half moon in shape and face towards the flow of blood. This allows the blood to leave the heart freely. When it fills with back flowing blood, it closes up to prevent blood from returning to the heart.
- Blood rich in oxygen (oxygenated blood), returns from the lungs through four pulmonary veins, which enter the **left atrium**. There are no valves at the entrances to these veins.
- Blood from the left atrium flows **into the left ventricle** through the **bicuspid valve**, which has two flaps.
- Blood from the left ventricle is then pumped **out of the heart** through the three-flapped **aortic semilunar valve** in the opening of the aorta. This valve functions exactly like the pulmonary semilunar valve.

- **Function of the heart**

The heart functions as a pump to keep the blood moving through the circuit of vessels–arteries, arterioles, capillaries, venules and veins–in order to supply the capillaries with blood adequate in volume and composition to meet the changing needs of the cells.

You can watch the first half of the following video clip for an explanation of blood flow through the heart:

[https://www.youtube.com/watch?v=oHMmtqKgs50](https://www.youtube.com/watch?v=oHMmtqKgs50)

**ACTIVITY 17.1**

(1) Label the following structures in the diagram of the heart below: Left pulmonary veins, bicuspid valve, left ventricle, inferior vena cava, right ventricle, right atrium, and aorta.
FIGURE 17.1.1

The heart
(Source: Unisa drawing)

(2) Draw your own mind map to show the meaning of the following concepts and how they are related: veins, arterioles, capillaries, valves, venules, arteries.

(3) Give brief answers to the following questions and post them in the discussions space on your e-tutor site.

Consult your prescribed book or search the internet and find information on blood pressure to answer the following questions.

3.1 Explain the term “blood pressure”.
3.2 Explain what arterial blood pressure is.
3.3 Discuss the effects of prolonged, uncontrolled high blood pressure on the heart and arteries.
3.4 Name the five (5) general methods used to treat high blood pressure.
3.5 Give the values regarded as normal blood pressure.

17.4 BLOOD PLASMA

Blood plasma is the liquid part of blood. Approximately 90% of blood plasma consists of water with organic substances (proteins, glucose, lipids, etc) and inorganic substances (sodium, potassium, chlorine, etc.) dissolved or suspended in it. The plasma proteins are the most important substance of the plasma, since they are responsible for important functions. Most of the other substances present are merely transported by the blood plasma.

- **Plasma proteins**

Blood plasma proteins can be divided into two main groups, namely albumins and globulins.
Blood proteins contribute to the following:

- The osmotic pressure of the blood
- The maintenance of normal blood viscosity (viscous: semifluid)
- Normal blood volume
- Blood clotting
- Regulation of the acid-base balance
- Transportation of certain substances by means of adsorption

**Functions of blood plasma**

The functions of blood plasma are as follows:

- To provide a fluid base for the blood cells
- To transport absorbed nutrients from the digestive tract to the body cells
- To help regulate body temperature
- To transport the waste products secreted by the cells to the excretory organs (kidneys, liver)
- To transport hormones, enzymes and other biochemical substances throughout the body
- All the functions contributed by the plasma proteins

17.5 BLOOD CELLS

Blood cells consist of three main types, namely **red blood cells** (erythrocytes), **white blood cells** (leucocytes) and **platelets** (thrombocytes). (Note that these words, like many scientific terms, are made up of words from ancient Greek. In this language, “cyte” means “cell”; “erythro” means “red”; “leuco” means “white” and “thrombo” means “lump” or “blood clot”.)

I discuss these types of cells in more detail in the sections that follow.

17.5.1 Red blood cells

Red blood cells (or erythrocytes) are shaped like circular biconcave disks, without nuclei. They are uniform in size, shape and colour. Red blood cells consist of a framework called stroma in which **haemoglobin** is deposited. The haemoglobin not only gives the red blood cell its red colour but is also responsible for the main function of red blood cells.
A red blood cell is illustrated in Figure 17.3.

Let us look at the structure and production of red blood cells in more detail.

• **Haemoglobin**

Haemoglobin consists of pigment, iron and a protein, namely globin. The pigment and the iron form a nonprotein portion and is called haem. Combined with the protein (globin), the nonprotein forms haemoglobin. Each red blood cell contains several million molecules of haemoglobin. The entire function of haemoglobin depends on its ability to combine loosely with oxygen (not a true covalent bond), as follows:

\[
\text{Haemoglobin (Hb) + oxygen (O}_2\text{) } \rightarrow \text{oxyhaemoglobin (HbO}_2\text{)}
\]

The oxygen is readily released to the body cells, where carbon dioxide is taken up and released to the air in the lungs. There oxygen is again taken up and the process is repeated.

• **Stroma**

Stroma is the part of a tissue or organ that has a connective or structural role. The cells of stroma tissue serve as a matrix or framework in which other cells are embedded. Apart from haemoglobin, the stroma in the circulatory system also contains a variety of antigens (proteins) that vary in type in different individuals. The different antigens give rise to different blood groups.

• **Red blood cell production and destruction**

Study the section on *How red blood cells form*, pages 172-174, Chapter 8, in the prescribed textbook.

Red blood cell production (erythropoiesis) occurs in red bone marrow. Red blood cells arise from primitive undifferentiated cells called haemocytoblasts. Each haemocytoblast accumulates haemoglobin, loses its nucleus and cytoplasmic granules, becomes smaller, enters the bloodstream and assumes the
shape of the red blood cells. For complete maturation, vitamin B12 is necessary. Absorbed vitamin B12 is stored in the liver and carried to the red bone marrow as needed. Proteins, several minerals, folic acid, copper, cobalt and iron are essential for red cell formation.

At the end of their life, which lasts about 120 days, the worn-out red blood cells are removed from the blood, mainly by the spleen. The iron portion of the haem is recovered and sent either to the liver or the red bone marrow for re-use. The remainder of the haem is converted into a bile pigment, called bilirubin, and is excreted by the liver as part of the bile.

When the blood is hypoxic (in other words, when it has insufficient oxygen), a glycoprotein called erythropoietin appears in the blood and stimulates the red bone marrow to produce more red blood cells (erythropoiesis).

– Functions of red blood cells

Red blood cells are responsible for the following:

– The transport of oxygen (O2) from the lungs to the cells
– The transport of carbon dioxide (CO2) from the cells to the lungs

Red blood cells also play a part in the acid-base balance of body fluids.

17.5.2 White blood cells

White blood cells (or leucocytes) are divided into groups according to the size of the nucleus, the presence or lack of granules in the cytoplasm, and their structure. Two main types can be distinguished, namely phagocytes and immunocytes. A white blood cell is illustrated in Figure 17.4.

![A white blood cell](https://commons.wikimedia.org/wiki/File:Anatomy_and_physiology_of_animals_A_granulocyte.jpg)

FIGURE 17.4
A white blood cell

(Source: https://commons.wikimedia.org/wiki/File:Anatomy_and_physiology_of_animals_A_granulocyte.jpg)

The various types of white blood cells are shown in Figure 17.5, and then discussed below.
• Phagocytes

The main function of phagocytes is to destroy and remove foreign material (antigens) and the aged and damaged tissue of the body. They originate in the red bone marrow and are subdivided into granulocytes and monocyte macrophages.

• Granulocytes

Granulocytes are leucocytes with granules in their cytoplasm. They are formed in the red bone marrow. They have a short life-span and leave the circulation within 24 hours, move through the capillary wall into the various tissues, where they are destroyed while fighting bacteria, foreign material and aged cells of the body. Granulocytes are subdivided into three types, namely neutrophils, eosinophils and basophils, as follows:

– Neutrophils

The neutrophils are the most numerous of all the leucocytes (white blood cells). By means of phagocytosis the neutrophils ingest bacteria and kill them with lysosomal enzymes. (Phagocytosis is the engulfing and destruction of microbes and other foreign particles by the cell.)
– Eosinophils

The granules in the cytoplasm of the eosinophils are big, uniform and coarse. Eosinophils are more active during allergic conditions, worm infestations and infections.

– Basophils

The granules in the cytoplasm of basophils are large, irregular and reddish-purple in colour. They are mostly active during inflammation.

- **Monocyte macrophages**

These are leucocytes with a big nucleus and **without granules** in the cytoplasm. They move out of the capillaries to become macrophages, filled with lysosomes, and attack all foreign material by engulfing and digesting it.

- **Immunocytes**

Immunocytes can be subdivided into lymphocytes and plasma cells. They are responsible for the immunity of the body against diseases. Plasma cells secrete antibodies, which select the objects that the phagocytes must attack. They reject foreign material in the body, for example the rejection of a new heart during a heart transplant. They also kill body cells that become cancerous.

17.5.3 Blood platelets

Platelets (also called thrombocytes) are the third blood cell type.

They are not really cells in the true sense of the word since they are fragments of large megakaryocytes of the bone marrow. They are small colourless cells, without nuclei and are usually oval in shape. The life-span of the blood platelets is about eight to ten days.

Platelets protect the body by doing the following:

- Clinging to foreign substances in the bloodstream, thus isolating them
- Plugging leakages in blood vessel walls
- Clotting the blood in case of injury

The main types of blood cells are shown in Figure 17.6.
17.5.4 Location of blood cell functions

Red blood cells and platelets perform their respective functions of transportation of gases and protection and repair in only one connective tissue, namely the blood. White blood cells perform their protective function in ALL body tissues since they circulate in the intercellular fluid amongst body tissues as well as in the blood plasma in the blood vessels.

17.6 BLOOD CLOTTING

Study the section on *How bleeding stop, or haemostasis*, pages 174-176, Chapter 8, in the prescribed textbook.

Normally, blood contains antithromboplastin and heparin, both concerned with the prevention of blood clotting in the blood vessels. When an injury occurs, the crushed tissue cells, the platelets (thrombocytes) and the red blood cells set free a neutralising agent, called thromboplastin, to counteract the antithromboplastin and the heparin. With the anticlotting substances neutralised, the blood can clot to maintain the homeostasis of body fluids.

The three substances concerned with blood clotting are thromboplastin, fibrinogen (a globulin protein in the blood plasma) and calcium ions.

The following steps are involved in blood clotting:

- The platelets (thrombocytes) stick to the edges of the injured blood vessel and form a loose, nonpermanent plug.
- Thromboplastin is set free.
- In the presence of calcium ions, thromboplastin changes prothrombin to thrombin.
• Thrombin changes fibrinogen to insoluble fibrin fibres in which blood cells and plasma are caught up.
• The fibrin fibres contract, squeezing out the serum (plasma without the thrombin and fibrin) and a strong clot forms.

In this way, the broken blood vessel is plugged or repaired, and homeostasis of body fluid maintained.

A simplified overview of the clotting process is shown in the following video clip:
https://www.youtube.com/watch?v=HFNWGCx_Eu4

**ACTIVITY 17.2: Blood plasma and blood cells**

1. Give the functions of blood plasma.
2. Draw up a table with the following components: Red blood cells, white blood cells, granulocytes (neutrophils, eosinophils, asophils), monocytes, immunocytes (lymphocytes, plasma cells), and platelets. For each component provide a description and give its functions.

**Activity 17.3: Revision and reflection**

1. List the structures responsible for blood circulation in the body.
2. Define arteries
3. What are the functions of the veins?
4. Distinguish between the walls of arteries, veins and capillaries.
5. What is the function of the heart?
6. What is the function of the heart valves?
7. Discuss the structure of the heart. Include the valves and the openings of the heart in your discussion.
8. What is blood?
9. What does blood consist of?
10. How is erythropoiesis stimulated?
11. Discuss the role that platelets play in blood clotting.
12. Explain the effect of the presence of antigens in blood (refer to section 17.4.)
13. Describe the process of blood clotting.
14. Do you think that understanding how the circulatory system works will be of any benefit to someone studying nutrition? Give a reason for your answer.

**17.7 CONCLUSION**

The main function of the cardiovascular system is to transport vital compounds to and from the various body tissues.

The cardiovascular system is mainly composed of the heart and blood vessels. There are three types of blood vessels, namely arteries, capillaries and veins.

The heart is the pump of the cardiovascular system. The heart’s structure is complex in order to complete the necessary functions. The upper part con-
ists of the atriums, namely the left and right atriums. The lower part consists of the ventricles, namely the left and right ventricles. The right atrium has three openings for the inlet of blood, namely the superior vena cava (returns venous blood from the upper part of the body), the inferior vena cava (returns venous blood from the lower part of the body), and the opening of the coronary sinus (returns venous blood from the myocardium). The blood gathered in the right atrium is poor in oxygen and needs to be pumped to the lungs, therefore, from the atrium it is pumped to the right ventricle via the tricuspid valve. Blood from the right ventricle is pumped to the lungs through the pulmonary semilunar valve to the pulmonary artery. Blood rich in oxygen (oxygenated blood) returns from the lungs into the left atrium. The blood then flows to the left ventricle through the bicuspid valve. From here the blood is pumped out of the heart into the aorta, which transports the oxygenated blood to the rest of the body.

Blood plasma is the liquid part of blood and contains blood plasma proteins. Blood cells can be divided into erythrocytes, leucocytes and blood platelets, and each type has various different functions in the human body.

In order to oxygenate blood and deliver oxygen to the body, the blood needs to be carried to the lungs where the gaseous exchange can take place. The next learning unit will discuss this in detail.
18.1 INTRODUCTION

On average, humans can survive for three days without water, and for three weeks without food. However, we can barely survive for three minutes without breathing! The system responsible for supplying our bodies with air, and more precisely oxygen, is thus of crucial importance.

Respiration is the exchange of gases between the body and its environment. This exchange does not take place directly, but in stages. Since air cannot reach the cells directly, it is brought into a special organ where gas exchange can take place between the blood and the air. The blood is then distributed throughout the body where gas exchange can take place between the blood and the body cells.

The system that brings the air into contact with the blood is known as the respiratory system. Its organs consist of two types, those that serve as passageways for the air to enter the body and the organ that actually regulates gas exchange between the air and the blood. The following sections will give more information on these organs.

Study the introductory sections of Chapter 7 in the prescribed textbook, pages 149-150, up and until the section on Breathing.

Learning outcomes

After you have completed this learning unit, you should be able to:

- identify the organs of the respiratory system
- distinguish between inspiration and expiration
- explain the difference between external and internal respiration
- explain the transportation of gases by the blood
- describe the mechanisms controlling respiration and the factors influencing it
18.2 ORGANS OF THE RESPIRATORY SYSTEM

The organs of the respiratory system consist of five air-conducting organs and two respiratory organs. The respiratory system is illustrated in Figures 18.1 above and 7.1A and 7.1 in the prescribed textbook (pp. 151-152). The two classes of organs are discussed in more detail in the sections that follow.

18.2.1 Air conducting organs

The five air-conducting organs are the nose, pharynx, larynx, trachea and bronchi.

- **The nose**

Air enters the respiratory system through the nostrils, the external portion of the nose. The nasal cavities are lined with mucous membrane containing nerve endings, which are responsible for the sense of smell, and tiny hairs. The nose functions as a passageway for air moving in and out of the respiratory tract. While moving through the nasal passageways, the following occurs:

- The air is humidified by the mucous membrane.
- The air is warmed by blood vessels just under the mucous membrane.
- The air is filtered by the tiny hairs.
- The air is chemically examined by the nerve endings.
The nose also aids in phonation (speech production).

- **Pharynx**

The pharynx serves as a hallway for both the respiratory and the digestive systems. Air from the nose and food from the mouth pass through to the lungs and to the stomach, respectively. The pharynx wall consists of a thick muscular layer, which is lined with a mucous membrane, and a middle layer of strong fibrous tissue. These muscles enable the pharynx to perform its functions of swallowing and phonation.

- **Larynx**

The larynx or voice box is situated between the pharynx and the trachea. It consists of cartilage and muscle tissue covered with a lining of mucous membrane. Two short fibrous bands called the vocal cords, stretch across the interior of the larynx. Expired (exhaled) air causes these cords to vibrate and produce a sound or voice. The length of the cords can be altered by muscular contraction to change the pitch of the voice. Short tense vocal cords produce a high pitch, whereas long relaxed vocal cords produce a low pitch. The quality of the voice further depends upon factors such as the size and shape of the nose, mouth and pharynx.

The larynx also protects the trachea from solids or liquids entering during swallowing.

- **Trachea**

The trachea is a tubular organ approximately 11 centimetres long, with the upper half located in the neck and the lower half located in the chest. It contains C-shaped cartilage disks to keep the tube open, to ensure the free passage of air. The mucous membrane lining the trachea contains cilia (small hair-like projections) that move foreign particles upwards so that they can be removed from the respiratory tract by the cough reflex.

- **Bronchi**

The trachea branches into two bronchi, the right and left primary bronchi. Like the trachea, both bronchi contain cartilage rings in their walls to ensure an open passageway. The right bronchus enters the right lung, divides into three secondary bronchi, supplying each of the right lung’s three lobes. The left bronchus enters the left lung, divides into two secondary bronchi, supplying each of the left lung’s two lobes.

The secondary bronchi continue to branch, dividing into smaller and smaller tubes called bronchioles.

The lung lobes are subdivided into lobules, and a bronchiole enters each lobule and divides into 50 to 80 terminal bronchioles in each lobule. These terminal bronchioles mark the end of the air-distributing or conducting passageways of the respiratory system.
18.2.2 Respiratory organs

The respiratory system contains two similar cone-shaped respiratory organs, the \textbf{lungs}. They lie within the pleural cavities of the thorax (cavity containing the lungs and the heart). The thoracic cavity is divided by membranes called the pleura into three divisions. The two divisions containing the two lungs are called the pleural cavities, and the middle division containing the heart is called the cardiac cavity.

The cavities are covered by the parietal layer of the pleura, and the lungs are covered by the visceral layer of the pleura. The potential space (pleural space) between the two layers contains just enough pleural fluid for lubrication. When the lungs inflate with air, the layers slide smoothly against each other and respiration is painless.

The right lung consists of three lobes, whereas the left lung has only two lobes. The lungs are light, spongy and elastic. All the structures entering or leaving a lung—arteries, veins, bronchi and nerves—do so at a slit on the medial (facing the middle) surface, called the hilum.

In each lobule, the terminal bronchioles divide into microscopic alveolar ducts. The alveolar ducts terminate in several \textbf{alveolar sacs}, the walls of which consist of numerous \textbf{alveoli}. The alveoli are covered with blood capillaries. The very thin walls of both the alveoli and the capillaries are in close contact with one another and form an enormous surface area, the \textbf{respiratory membrane}. Rapid diffusion of gases between alveolar air and pulmonary capillary blood takes place through this membrane.

The lungs perform the following two functions:

- The distribution of air received through the bronchi to each alveolus (This function is performed by the bronchial tree.)
- Gas exchange between air and blood (This function is performed by the alveoli in conjunction with the capillaries.)
ACTIVITY 18.1: Respiratory system

(1) Label the diagram below.

![Diagram of the respiratory system]

FIGURE 18.1.1
(Source: Unisa drawing)

(2) Tabulate the major functions of the following structures of the respiratory system: Nasal cavity, paranasal sinuses, pharynx, larynx, trachea, diaphragm, bronchi, bronchioles, alveoli, lungs and pleura.

18.3 RESPIRATION

Before we look at the process of respiration, some terms have to be defined.

The lungs’ main function is to take in oxygen and eliminate carbon dioxide.

Respiration also has other secondary purposes such as heat regulation and discarding excess water. Living cells in the human body absorb oxygen from the fluid around them while they also eliminate the excess carbon dioxide resulting from the oxidation processes in the tissues.

Study the section on Breathing, pages 150-155, Chapter 7 in the prescribed textbook.
There are two stages of respiration:

- **External respiration**

  External respiration implies the exchange of carbon dioxide and oxygen between the body and the external environment. Respiration takes place in the lungs where:

  - oxygen diffuses *from the alveoli into the blood* for transport to the tissues; and
  - carbon dioxide and water diffuse *from the blood into the alveoli* for expulsion to the air outside. See Figure 18.2 for a better understanding.

  ![Figure 18.2: Gaseous exchange in the alveolus across the respiratory membrane](https://en.wikipedia.org/wiki/Blood%E2%80%93air_barrier)

  During the process where the blood releases carbon dioxide and water, and takes up oxygen, the crimson (deep red) colour of the blood changes to scarlet (bright red) and is known as **arterial blood**.

- **Internal respiration**

  Internal respiration implies the exchange of oxygen and carbon dioxide between the tissue cells and the blood via the *interstitial fluid*. Oxygen diffuses from the blood to the tissue cells, and carbon dioxide diffuses via the intestinal fluid from the tissues to the blood for the transport to the lungs. The blood changes from scarlet red to a crimson red and is now called **venous blood**.

  This process takes place in and around all the cells that make up the body tissues.
18.4 GAS TRANSPORTATION
The transportation of oxygen and carbon dioxide is discussed below.

• Oxygen

Study the section on Oxygen transport, pages 157-159, Chapter 7, in the prescribed textbook.

Upon entering the blood from the alveolar air, a small amount of oxygen dissolves in the plasma. The rest forms a chemical compound, oxyhaemoglobin, with the haemoglobin of the red blood cells and is transported as such.

Any factor affecting the amount of haemoglobin in the red blood cells, such as anaemia or insufficient iron, will affect the amount of oxygen that reaches the body cells.

Oxygen-rich blood leaves the lung capillaries and reaches the heart via the pulmonary veins (the only veins that carry oxygen-rich blood). The blood is then circulated throughout the body via the arteries. (Arterial blood carries oxygen.)

• Carbon dioxide

Carbon dioxide is formed in the tissues at various rates, depending on the rate of metabolism. Upon entering the blood from the tissue cells the carbon dioxide is transported in three ways:

– Some carbon dioxide dissolves in the blood plasma and is transported in solution.
– Ninety per cent of the carbon dioxide undergoes chemical reactions and is transported as bicarbonate—one-third (1/3) in the erythorocytes and two-thirds (2/3) in the plasma.
– A small amount of the carbon dioxide combines directly with the haemoglobin to form carbaminohaemoglobin.

Oxygen-poor (carbon dioxide-rich) blood leaves the tissue capillaries and returns first to the heart via the veins, and then to the lungs via the pulmonary artery (this is the only artery that carries oxygen-poor blood).

If you would like a more detailed explanation of gas exchange during respiration, you can watch the following video clip:

https://www.youtube.com/watch?v=qDrV33rZlyA

18.5 CONTROL OF BREATHING
Breathing is controlled by a respiratory centre consisting of nerve cells situated in the medulla of the brain. It consists of two interacting mechanisms:
one controlling inspiration and the other controlling expiration, thus achieving rhythmic breathing.

The normal automatic pattern of breathing can be interrupted by a number of factors:

- Voluntary control—when one is holding one’s breath
- Sharp pain
- Arterial blood pressure
- Emotions
- Irritation of air passages causing coughing

### Activity 18.2: Respiration and mechanism of breathing

1. Explain the difference between arterial blood and venous blood.
2. Draw your own diagram that explains how both oxygen and carbon dioxide are transported in the blood. Post your diagram as an attachment in the discussion space of your e-tutor site. After you have posted it, look at the diagrams that other students have drawn to see how you can improve your own.
3. Study Figure 7.2 in the prescribed textbook (page 153) and then answer the following question:

   Identify the actions of the mechanisms of breathing illustrated in the two diagrams. In each case give a detailed explanation of what the mechanism entails.

You can also watch the following video clip on the mechanism of breathing:

[https://www.youtube.com/watch?v=zNHxXSkm1gU](https://www.youtube.com/watch?v=zNHxXSkm1gU)

### Activity 18.3: Revision and reflection

1. Explain what the term “pulmonary ventilation” means.
2. Briefly explain internal and external respiration.
3. Explain how oxygen is transported in the blood.
4. Name the two mechanisms that interact during breathing.
5. Why is respiration necessary?

### 18.6 CONCLUSION

Respiration is the exchange of gases between the body and its environment. Specialised organs are necessary to perform this function during respiration, namely the air-conducting organs (nose, pharynx, larynx, trachea and bronchi) and the lungs.

Respiration happens in two stages: external (between the air and the alveoli to the blood) and internal (between the blood and interstitial fluid). Oxygen and carbon dioxide are transported in various ways important for human living.
In order to ensure enough oxygen and removal of the waste product, namely carbon dioxide, breathing needs to be controlled. A respiratory centre consisting of nerve cells in the medulla of the brain controls breathing.

In order to maintain homeostasis, the body needs to get rid of waste products, such as carbon dioxide during respiration. Other waste products also accumulate in the system and need to be excreted or broken down. The next learning unit will discuss this topic.
Learning unit 19

Excretory system

19.1 INTRODUCTION
All tissue cells of the body utilise the nutrients they absorb from the digestive tract and the oxygen absorbed by the lungs to perform their various functions. During the utilisation process (metabolic processes), various waste products are formed. The excretory system eliminates these waste products to maintain homeostasis.

Learning outcomes

After you have completed this learning unit, you should be able to:

• distinguish between the excretory and urinary systems
• identify the structures of the urinary system
• list the functions of the kidneys
• explain what urine is and discuss the factors that contribute to normal urine production
• describe the processes that produce urine
• explain how urine volume is regulated

19.2 WASTE PRODUCTS
Two types of waste products must be eliminated. The first type consists of the waste products left over in the digestive tract after all the nutrients have been absorbed, and is called excreta or faeces.

The second type consists of the waste products originating in the cells mainly as by-products of chemical reactions. These waste products are excreted by the cells and transported via the blood to the excretory organs for elimination. The waste products excreted by the cells are the following:

• Carbon dioxide (carbon atoms from the citric acid cycle that takes place in the body, plus the oxygen from the lungs)
• Water (metabolic water)
• Urea (end product of protein metabolism)
• Heat (released during catabolic processes)
• Excess salts
19.3 ORGANS OF THE EXCRETORY SYSTEM

The excretory system consists of the different organs that eliminate waste products. The waste products, the organs responsible for their excretion and the form in which they are excreted are presented in Table 19.1.

**TABLE 19.1**  
*Organs of the excretory system*

<table>
<thead>
<tr>
<th>Organ</th>
<th>Waste product</th>
<th>Excretion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alimentary canal</td>
<td>Undigested food matter</td>
<td>Faeces</td>
</tr>
<tr>
<td>(digestive tract)</td>
<td>Water</td>
<td></td>
</tr>
<tr>
<td>Skin (sweat glands)</td>
<td>Water</td>
<td>Perspiration</td>
</tr>
<tr>
<td></td>
<td>Carbon dioxide</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Excess salts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td></td>
</tr>
<tr>
<td>Lungs</td>
<td>Carbon dioxide</td>
<td>Expired air</td>
</tr>
<tr>
<td></td>
<td>Water vapour</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td></td>
</tr>
<tr>
<td>Kidneys</td>
<td>Water</td>
<td>Urine</td>
</tr>
<tr>
<td></td>
<td>Excess salts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Metabolic by-product/s of protein</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carbon dioxide</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat</td>
<td></td>
</tr>
</tbody>
</table>

The *digestive tract*, the *sweat glands* of the skin and the *lungs* are in direct contact with the environment and can therefore rid themselves directly of the waste products that they eliminate. Learning unit 20 elaborates on the digestive system and learning unit 18 on the lungs, but the skin’s excretory function is not dealt with in detail (see learning unit 13).

The *kidneys* are deep inside the body and have no direct opening to the outside. A whole excretory subsystem called the urinary system is responsible for the elimination of the waste products removed from the blood by the kidneys.

19.4 ORGANS OF THE URINARY SYSTEM

The urinary system consists of two kidneys, two ureters, one bladder and one urethra. The function of these organs is to eliminate chemical waste products
from the body in the form of a solution called urine. These organs are illustrated in Figure 19.1.

![Organs of the urinary system](https://commons.wikimedia.org/wiki/File:Anatomy_and_physiology_of_animals_Urinary_system.jpg)

**FIGURE 19.1**

*Organs of the urinary system*

(Source: https://commons.wikimedia.org/wiki/File:Anatomy_and_physiology_of_animals_Urinary_system.jpg)

Study the first sections of Chapter 6 in the prescribed textbook, pages 128-135, up to the section *Body fluids*.

In the sections that follow, I will discuss various aspects of the urinary system in more detail.

**Activity 19.1: Excretory and urinary system**

1. In your own words, explain the difference between the excretory system and the urinary system.
2. What are the waste products produced by the kidneys and how are they excreted?

You can find the answers to these questions in the previous sections. If you have any difficulties with the answers, you should contact your e-tutor for help.

**19.5 THE KIDNEYS**

The kidneys are highly developed and sensitive organs. They are the living filters of the body which are able to adjust the **water balance** of the body and **eliminate impurities** and metabolic excesses.
Mature kidneys are red-brown, bean-shaped organs, situated at the back of the abdominal cavity, on either side of the backbone, just behind the lower ribs. Each kidney is enclosed in a tough fibrous capsule. They are held in position by the renal fascia and are embedded in renal adipose tissue (fat) for protection against jolts and jars. (Note: The word “renal” refers to the kidneys; it is originally from the Latin word “renes” which means kidneys.)

In the sections that follow I discuss various aspects of the kidneys.

19.5.1 Internal structure of the kidney
The kidney consists of, from the outside, the **renal cortex**, **renal medulla** and **renal pelvis** which gradually changes into the ureter, while the capsule of the kidney is continuous with the outer coat of the ureter (see Figure 19.2).

![Kidney Anatomy](https://en.wikipedia.org/wiki/Renal_calyx)

The renal cortex is the outer, lighter, somewhat granular (grainy) section of the kidney. It folds into the renal medulla between the pyramids to form renal columns. The cortex consists mainly of the blood capillaries called **glomeruli**.

The renal medulla is the next section of the kidney and consists of approximately 12 cone-shaped columns of tissue called the **renal pyramids**. These pyramids in turn consist mostly of microscopic tubules. The narrow section of the pyramids end in **papillae**, which are sieve-like connections bound to the extensions of the renal pelvis.

The renal pelvis is a funnel-shaped, sac-like chamber in the hilum of the kidney. (The hilum is an indentation in the surface of the kidneys where blood vessels...
and nerve fibres enter and leave it.) It has cup-shaped extensions, the calyces, each of which meets with one or more papillae of the renal pyramids. On the hilum side it gradually narrows to become the **ureter**.

### 19.5.2 Microscopic structure of the kidney

Each kidney is made up of more than a million microscopic, functional filtering units called nephrons. If seen under a microscope, these nephrons resemble tiny funnels with long, highly coiled stems. (See Figure 19.3.)

![Figure 19.3: The nephron](https://commons.wikimedia.org/wiki/File:2611_Blood_Flow_in_the_Nephron.jpg)

**FIGURE 19.3**

*The nephron*  
(Source: https://commons.wikimedia.org/wiki/File:2611_Blood_Flow_in_the_Nephron.jpg)

Each nephron consists of the following parts:

- The **Malpighian body**, situated within the cortex and consisting of the following two parts:
  - **Bowman's capsule** (also called glomerular capsule), the cup-shaped top of the nephron
  - **Glomerulus**, a network of blood capillaries tucked into the Bowman's capsule
• **First (proximal) convoluted** (convoluted: rolled up) tube, the nephron tube that leads directly off the Bowman’s capsule and is coiled (the first convolution of the tube is situated within the cortex)

• **Loop of Henlé**, the extension of the nephron tube directly after the first convolution and starting in the area of the cortex (the tube is straight and extends into the medulla region where it loops back and once again extends upwards and returns to the cortex region)

• Second (distal) convoluted tube, the result of the nephron tube again coiling and forming convolutions in the area of the cortex

• Collecting tubule, a straight part of the nephron tube that leads off from the second convoluted tube (it extends once again into the medulla region where it joins the other collecting tubules (tubule: small tube))

19.5.3 *Kidney blood supply*

The kidneys can only fulfil their function of removing waste products from the blood if enough blood circulates through the kidneys. Therefore, each kidney is well supplied with blood by the renal artery. Figures 9.14 and 9.15 show blood supply to the kidneys.

**FIGURE 19.4**

*Blood supply to the kidneys*

(Source: [https://en.wikipedia.org/wiki/Renal_column](https://en.wikipedia.org/wiki/Renal_column))
In the region of the hilum, the renal artery divides into several branches, which travel up the renal columns as interlobular arteries. These arteries divide into arcuate arteries, which give rise to straight arteries that move into the nephrons. From here the very small afferent arterioles arise.

Each arteriole divides into about 50 capillaries to form the glomerulus. The capillaries from the glomerulus unite to form the efferent arteriole, which divides a second time to form a fine mesh work of capillaries around the convoluted tubules and loops of Henlé. These capillaries unite to form the interlobar veins, then the arcuate veins, and finally the renal vein, which drains into the inferior cava. (See Figures 19.4 and 19.5.)

19.5.4 Functions of the kidneys

The kidneys are vital organs which play an essential part in maintaining homeostasis by performing the following vital functions:

- Regulation of osmotic pressure of body fluids by regulating the amount of water and salt that the body excretes.
- Regulation of salt concentration by regulating the concentration of the various salts in the body.
- Excretion of protein metabolism by-products such as urea, uric acid, creatinine and ammonia.
- Regulation of the acid-base balance of the body (pH) by regulating the excretion or retention of salts.
- Regulation of water volume by regulating the amount of water retained or excreted by the body in the form of urine.
- Blood pressure regulation.
Activity 19.2: The kidneys

(1) Label the diagram with the following internal structures: Renal pyramid, renal column, renal cortex, renal vein, ureter, renal pelvis and renal capsule.

(Source: Unisa drawing)

(2) What are the microscopic filtering units of the kidney called? Make your own sketch of such a unit to show its main parts. Post your sketch in the discussion space of your e-tutor site.

(3) Briefly give the function of the kidneys with regard to each of the following:
   - Body fluids in general
   - Salt
   - Protein
   - pH
   - Water volume in the body

19.5.5 Urine

In the sections that follow I discuss the formation of urine, the control of urine volume, the physical properties of urine, and finally its chemical composition.

19.5.6 Urine formation

Filtration, re-absorption and secretion are the three processes by which the nephrons in the kidney form urine (see Figure 19.6).
Filtration

This is the process where liquid filtrates from the glomerulus capillaries into the Bowman’s capsule and renal tubules. The glomerulus is an ideal filtering apparatus. The blood pressure in the glomerulus is so high that water and true solutes are forced through the walls of the capillaries into the space within the Bowman’s capsule, while the large particles such as red blood cells and most plasma proteins remain in the blood stream and flow out of the glomerulus. This liquid forced from the glomerulus is called glomerulus filtrate because it is formed by blood filtering through the glomerulus wall and the inner wall of the Bowman’s capsule. Glomerular filtrate contains urea, but it also contains many other substances such as glucose, vitamins, minerals and amino acids.

Re-absorption

Glomerular filtration flows out of the Bowman’s capsule into long coiled kidney tubules where glucose and other useful substances needed by the body are re-absorbed into the blood-stream. Most of the re-absorption occurs in the first (proximal) convoluted tube.

Secretion

Secretion is the process that involves the movement of substances out of the blood into the glomerular filtrate. The substances that are secreted by tubule cells are ammonia, hydrogen ions, potassium ions and certain drugs. This tubular secretion represents the final adjustment in the formation of urine for
excretion by the bladder. Secretion takes place in the second convoluted tube and the collecting tubules.

Note that if there is glucose present in the urine, this may be an indication of kidney malfunction or an excess amount of glucose in the blood as in the case of Diabetes Mellitus (which needs to be confirmed by blood glucose test).

The nephron’s three functions of filtration, re-absorption and secretion are summarised in Table 19.2.

### TABLE 19.2
*Functions of the different parts of the nephron in urine formation*

<table>
<thead>
<tr>
<th>Part of nephron</th>
<th>Process in urine formation</th>
<th>Substance moved and direction of movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malphigian body</td>
<td>Filtration</td>
<td>Water and solutes filter out of blood capillary into Bowman’s capsule</td>
</tr>
<tr>
<td>First convoluted tube</td>
<td>Re-absorption</td>
<td>Water and certain solutes such as glucose (useful substances)</td>
</tr>
<tr>
<td>Loop of Henle</td>
<td>Re-absorption</td>
<td>Water, sodium and chloride ions</td>
</tr>
<tr>
<td>Second convoluted tube and collecting tubes</td>
<td>Re-absorption</td>
<td>Water, sodium and chloride ions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ammonia, potassium ions, hydrogen ions and certain drugs</td>
</tr>
</tbody>
</table>

You can watch the following video clip for a revision of the kidney structure and urine formation:

https://www.youtube.com/watch?v=lfGYd1wrTgE

19.5.7 Control of urine volume

The body continually controls the concentration, composition and amount of urine it secretes. The kidneys release much diluted urine during periods of over-hydration (when the body has high water content) and very concentrated urine when the body is dehydrated (when the body has lowered water content).
The hormones in the body that regulate the urine volume are summarised in Table 19.3.

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Organ</th>
<th>Process</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antidiuretic hormone (ADH)</td>
<td>Pituitary gland</td>
<td>Increases re-absorption</td>
<td>More water is retained</td>
</tr>
<tr>
<td>Aldosterone</td>
<td>Adrenal cortex</td>
<td>Stimulates re-absorption of sodium; therefore increases re-absorption of water</td>
<td>More salt is retained; therefore more water is retained</td>
</tr>
</tbody>
</table>

19.5.8 Physical properties of urine

Urine is a transparent watery solution, straw to yellow in colour with an average pH of about 6 in healthy individuals. The volume and composition of urine varies greatly in healthy individuals depending on many factors such as age, gender, diet, exercise and metabolism.

The average amount of urine excreted by an adult each day is between one and one and a half litres. Normal excretion may be affected by the following factors:

- In a hot climate, more water is lost through perspiration, and therefore the volume of urine produced decreases.
- The quantity of liquid that an individual drinks in a day affects the amount of urine produced.
- When large amounts of water are lost through vomiting, diarrhoea or haemorrhage, the amount of urine produced is decreased.

Note that the amount of urine excreted by children in a day is great in proportion to their body mass. Therefore, the fluid intake of children must be watched closely to ensure that it is adequate.

Sometimes the kidneys do not excrete normal amounts of urine. This may be caused by one or more of the following:

- Kidney disease
- Cardiovascular disease
- Certain drugs
- Mental stress
19.5.9 Chemical composition of urine

Study the section on *Body fluids*, pages 135-140, Chapter 6 in the prescribed textbook.

The chemical composition of urine, with approximate percentages indicated, is as follows:

- **Water (96%)**
- **Inorganic substances (1%).** These include:
  - Sodium
  - Phosphates
  - Chloride
  - Sulphates
  - Calcium
  - Iron
  - Potassium
  - Ammonia
- **Organic substances (3%).** These include:
  - Urea
  - Urobilinogen
  - Uric acid
  - Porphyrins
  - Creatinine
  - Creatine
  - Hippuric acid

Activity 19.3: Urine

1. Complete the following table.

<table>
<thead>
<tr>
<th>Processes by which the nephrons form urine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
</tr>
<tr>
<td>---------</td>
</tr>
<tr>
<td>Filtration</td>
</tr>
<tr>
<td>Reabsorption</td>
</tr>
<tr>
<td>Secretion</td>
</tr>
</tbody>
</table>

2. What affects the amount of urine formed?

19.6 URETERS, BLADDER AND URETHRA

Apart from the kidneys, the ureters, bladder and urethra also play an important role in secretion. See Figure 19.7 for the location of these structures.
FIGURE 19.7
A schematic drawing showing the location of the ureter, urinary bladder and urethra

(Source: https://commons.wikimedia.org/wiki/File:Urethra.png)

• Ureters

The two ureters are tubes that convey the urine from the renal pelvis to the bladder (see Figure 19.7). The muscular layer of the ureters produces peristaltic waves that move the urine downwards from the kidneys to the bladder.

• Bladder

The urinary bladder is a hollow muscular organ (see Figure 19.7). It serves as a storage sac for urine until it is expelled. When the bladder is empty, the inner lining of the sac is thrown into folds. These folds disappear as the bladder becomes filled with urine.

The process by which urine is expelled from the bladder is called micturition. The desire to urinate is stimulated by nerves in the wall of the bladder when it is extended. The walls of the bladder contract, the muscles of the urinary meatus are relaxed, and the bladder is emptied. (Urinary meatus: external opening of urinary system.)

The process of micturition is a voluntary act and may be started or stopped at will. In babies and very young children, control over this action is undeveloped, and micturition occurs whenever the bladder is distended (swollen).

• Urethra

The urine passes from the bladder into the urethra, a small tube, and through its external opening, the urinary meatus (see Figure 19.7). This tube is a narrow membranous canal that passes urine to the exterior.
ACTIVITY 19.4: Revision and reflection

(1) Distinguish between the renal vein and the renal artery.
(2) Label the following urinary system structures in the diagram below: bladder, ureter, right kidney, diaphragm, main vein, and urethra.

FIGURE 19.1.2
Uninary system structures

(3) List the chemical waste products secreted by the kidneys.
(4) What is urine?
(5) Discuss the factors that contribute to normal urine production.
(6) Discuss the processes by which urine is produced.
(7) Discuss the regulation of urine volume.
(8) Do you think a knowledge of the excretory system may be important for someone who is studying nutrition? Explain your answer.

19.7 CONCLUSION

The excretory system consists of the different organs that eliminate waste products, namely the alimentary canal, skin (sweat glands), lungs and kidneys. The urinary system consists of two kidneys, two ureters, one bladder and one urethra. The kidney has a much specialised structure in order to control homeostasis on various levels. The nephron is the smallest functional part of the kidney and consists mainly of the Malpighian body (Bowman’s capsule and glomerulus), the first convoluted tupe, the Loop of Henle, the second convoluted tube and the collecting tube. Urine formation happens by three processes, namely filtration, re-absorption and secretion. Urine has certain physical and chemical properties. It is conveyed from the kidneys to the bladder by the ureters. When the bladder is filled, urine is excreted through the urethra.

In order to perform the excretory function and many other functions as discussed in this manual, the body needs energy which is derived from food. The food needs to be digested in order to supply the energy. The following learning unit will discuss the digestive system.
20.1 INTRODUCTION
Most of us probably have more knowledge of the digestive system than of any other body system, given how important a role the intake of food plays in our lives!

All cells, and therefore the entire body, require energy. We get our energy from food. The digestive system processes the food that has been eaten to the stage at which the cells can absorb the food to maintain life. The organs of the digestive system, with their location and functions, are dealt with in this unit. To be able to understand how we utilise food, you may need to understand how the digestive system is put together and how it functions.

This learning unit is subdivided into three main sections. First, we will examine the digestive system as well as the various organs and accessory organs that comprise it. Then we will investigate the processes of digestion and absorption of proteins, carbohydrates, fats and vitamins. Finally we will also briefly look at metabolism and the role of the digestive enzymes. Before you start studying the unit in earnest, it may be helpful for you to first skim through it and draw a mind map of the unit’s structure, showing all its different sections.

Learning outcomes

After you have completed this learning unit, you should be able to:

• name all the organs that form the digestive system
• indicate the location of each organ
• give the specific function of each organ
• distinguish between absorption and digestion, and give an overview of the absorption and digestion of proteins, carbohydrates, fats and vitamins
• explain what is meant by “metabolism” and briefly describe the metabolism of proteins, carbohydrates and fats
• explain how energy is generated in the body
• identify the different enzymes active in the digestive organs and give their functions.
20.2 THE DIGESTIVE SYSTEM
The digestive system is a tube-like system, which is open at both ends; one open end is your mouth, the other is your anus. Its tube-like walls consist of four layers of tissue, namely a mucous lining, a submucous layer of connective tissue in which the main blood vessels of the tract are embedded, a muscular tissue layer and a fibroserous layer.

A number of main organs form the tube or tract, and several accessory organs open into these organs. The main organs are the mouth, pharynx, oesophagus, stomach, small intestine and large intestine. The accessory organs are the salivary glands, teeth, tongue, liver, gall bladder and pancreas.

Some structural differences in the four layers of the different main organ walls occur because of their varied functions and will be pointed out where they are of importance. The following sections will focus on the main and accessory organs of the digestive system.

20.3 ORGANS OF THE DIGESTIVE SYSTEM
The main organs of the digestive system are discussed in the following sections in the order in which they follow each other to form the digestive tract (or tube). The accessory organs are discussed where relevant (see Figure 20.1 below and Figure 10.1 in the prescribed textbook).

![Figure 20.1: Organs of the human digestive system](https://upload.wikimedia.org/wikipedia/commons/0/03/2401_Components_of_the_Digestive_System.jpg)
20.3.1 The mouth

The mouth (buccal cavity) is the first organ of the digestive tract. It is a large cavity with lips that open or close voluntarily to the exterior to receive food. The mouth contains the tongue, a muscular accessory organ situated at the bottom of the cavity, and the teeth, calcified accessory organs embedded in its upper and lower jaws (bony sides of the mouth). The ducts (tubes) of the salivary glands, also accessory organs of the digestive system, open into the mouth. The function of the mouth is to receive food.

The accessory organs located in the mouth cavity are the following:

- The **tongue** consists of skeletal muscle that originates in skull bones covered with mucous membrane. Rough elevations or papillae (nipple-shaped projections) occur on the surface. Nerve ends, sensitive to taste stimuli, are located on the sides of the papillae. The **functions** of the tongue are the following:
  - To pick up taste stimuli.
  - To assist in the chewing of food.
  - To assist in swallowing.
  - To assist in speech (not a function of the digestive system).
  - To assist in digestion by moving the food around in the mouth, thus mixing it with saliva (secretion of the salivary glands).

- The **teeth** consist of three layers, namely the innermost pulp (containing nerves and blood vessels), the middle layer of dentine and the top layer of enamel (crowning the top). Twenty deciduous (temporary) teeth start to develop as early as the sixth week of prenatal (before birth) life. They appear between the ages of about six months and two years. They are shed between the ages of about six and 13 years, when they are replaced by 32 permanent teeth.

The function of the teeth is to chew or break the food into smaller pieces.

- Three glands, called the salivary glands, are accessory organs that open into the mouth cavity, as follows:
  - The parotid glands are situated below and in front of the ears, and their ducts open into the mouth next to the second molars (flat topped teeth).
  - The submandibular glands are situated below the lower jaw, and their ducts open in the floor of the mouth.
  - The sublingual glands are situated below the tongue, and their ducts also open in the floor of the mouth (see Figure 20.1 in section 20.4).

The sublingual glands are situated below the tongue, and their ducts also open in the floor of the mouth.

The **functions** of the salivary glands are the following:

- To secrete saliva consisting of mucus and the enzyme ptyalin (amylase), which breaks down certain carbohydrates.
- To moisten food.

20.3.2 The pharynx

The pharynx (throat) consists of muscles and is lined with mucous membrane. The mouth, nose and tubes from the inner ear open into the pharynx.
pharynx itself opens into the trachea (wind pipe) and oesophagus (see Figure 20.1 in section 20.4). The trachea is not part of the digestive system, but of the respiratory system and will therefore not be discussed further. The functions of the pharynx are as follows:

- It serves as a hallway for both the digestive and respiratory systems.
- It enables the individual to swallow.

### 20.3.3 The oesophagus

The oesophagus is a collapsible tube, about 25 cm long. It joins the pharynx to the stomach. Its muscular walls contract and relax alternatively, causing waves of peristaltic movement along its entire length. This movement forces food down the stomach.

The oesophagus ends in the cardiac sphincter, which controls the opening into the stomach (see Figure 20.1 in section 20.4).

The functions of the oesophagus are the following:

- To move food along to the stomach
- To prevent the contents of the stomach from flowing backwards

### 20.3.4 The stomach

The digestive tube opens into a pouchlike organ known as the stomach. The empty stomach is about 30 cm long. It is situated beneath the diaphragm and is divided into three parts, namely the fundus, the body and the pylorus. The pylorus opens into the small intestine. At the junction between the pylorus and the duodenum, a band of smooth muscle called the pyloric sphincter acts as a valve to control the flow of food into the duodenum (see Figure 20.2).
The walls of the stomach are modified into the following three layers:

- **The mucous layer**, or mucosa, forms folds or rugae to allow for expansion to accommodate food at meal times. It also contains many microscopic glands. These glands secrete the gastric juice composed of water, hydrochloric acid (HCl), the enzymes pepsin and rennin (rennin is secreted only during infancy), and mucus. Gastrin, a hormone that stimulates the secretion of gastric juice, and a gastric intrinsic factor (a special protein carrier connected with the absorption of Vitamin B₁₂) are also found in the gastric juice.
- **The muscular layer** consists of three layers of muscle fibres. Sphincter muscles guard both openings of the stomach.
- **The fibroserous layer**, or serosa, extends to form a double filmy fold from the lower edge of the stomach over the intestines. A second fold connects the stomach and liver (for the location of these organs, see Figure 20.1).

The **functions** of the stomach are the following:

- To receive the food from the oesophagus and pass small amounts at a time on to the small intestine.
- To secrete enzymes, the hormone gastrin, HCl, mucous and the intrinsic factor.
- To mix the food with the gastric juice.
- To absorb a limited amount of water, alcohol and certain drugs.
- To soften the food by mixing it with the acid of the gastric juice.

#### Activity 20.1: Digestive system

Complete the table below:

<table>
<thead>
<tr>
<th>Component of the digestive system</th>
<th>Basic structure</th>
<th>Main function/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oesophagus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stomach</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 20.3.5 The small intestine

The small intestine extends from the pyloric sphincter and is about seven metres in length. The walls of the small intestine consist of the following layers:

- **The mucous layer**. This layer forms folds, but unlike the rugae of the stomach walls, they are permanent folds. Small finger-like projections of the mucosa,
called villi, further enlarge the surface of the small intestinal wall. Each cell situated on the inner lining of the small intestine also has microvilli (special cell structures) that even further enlarge the surface (see Figure 20.3).

- The muscular layer, which consists of two layers.

![Villi in the small intestine](https://commons.wikimedia.org/wiki/File:Anatomy_and_physiology_of_animals_Wall_of_small_intestine_showing_villi.jpg)

FIGURE 20.3

_Villi in the small intestine_


The small intestine is divided into three sections, namely the duodenum, the jejunum and the ileum.

- The **duodenum** is about a third of a meter long. Both the pancreas and the gall bladder (receiving sac of liver secretions) open into the duodenum.
- The **jejunum** forms the next two-fifths of the small intestine and is coiled up in the abdominal cavity.
- The **ileum** is the last section of the small intestine and is only about a third of a meter long.

The villi that are present in large numbers in the duodenum gradually decrease until only a few are present in the ileum.

The functions of the small intestine are the following:

- To receive food from the stomach.
- To secrete the alkaline digestive enzymes, namely peptidase, lipase, sucrase, maltase and lactase.
- To receive the digestive enzymes from the pancreas.
- To receive the liver secretion, bile, via the gall bladder.
- To mix the food, passed on from the stomach, with the alkaline digestive juices (succus entericus: combined secretions of liver, pancreas and small intestine).
• To absorb nutrients and water.
• To secrete the hormone secretin, which stimulates secretions by the liver and the pancreas.

Three accessory organs—namely, the liver, gall bladder and pancreas—open into the small intestine. They are discussed in more detail in the section that follows.

20.3.6 Accessory organs opening into the small intestine
These three organs are very important in the body, particularly the liver.

• The liver

Study the section on the liver, pages 219-221, Chapter 10 in the prescribed textbook.

The liver is not part of the digestive tract, but is essential for the functioning of the digestive system. The liver is the largest gland in the body and is divided into four lobes. It weighs 1 200 g to 1 600 g. The liver is situated in the top right portion of the abdominal cavity.

The liver has a rich blood supply. Venous blood containing digested food is brought to the liver in the hepatic portal vein. Oxygenated blood is supplied by the hepatic artery. The blood leaves the liver via a central vein in each lobule, which drains into the hepatic vein.

The functions of the liver are as follows:

• It synthesises bile, which drains into the gall bladder before being released into the duodenum.
• It is an important site of metabolism (processing) of carbohydrates, protein and fats.
• It regulates the amount of blood sugar, converting excess glucose to glycogen.
• It removes excess amino acids by breaking them down into ammonia and finally urea.
• It stores and metabolises fats.
• It synthesises fibrinogen and prothrombin, which are essential for blood clotting, and heparin, an anticoagulant.
• It plays an important role in the detoxification of poisonous substances.
• It breaks down worn out red blood cells and other unwanted substances.

• The gall bladder

The gall bladder is a sac-like organ, located under the liver. It receives bile, which is continuously secreted by the liver, and delivers it into the duodenum when needed.
The pancreas

The pancreas is situated behind and below the stomach and is surrounded by the curve of the duodenum. Its digestive secretions are poured into the duodenum when stimulated by the hormone secretin (see Figure 20.1 in section 20.4).

The functions of the pancreas are the following:

- It secretes hormones, such as insulin and glucagon.
- It secretes the digestive enzymes trypsin, peptidase, amylase and lipase.

20.3.7 The large intestine

The large intestine is the last part of the digestive tract and ends in the anus where waste products are eliminated. The large intestine is about a metre and a half long and larger than the small intestine in diameter. The large intestine is subdivided into the colon, the rectum and the anus.

Although there are no villi in the large intestine, its walls contain numerous mucous glands. Faeces gather from the large intestine in the rectum. The voluntary sphincter muscle of the anus enables the individual to control the elimination of the unabsorbed food residue.

The functions of the large intestine are the following:

- To absorb water.
- To hold food residue until elimination.
- To secrete mucus to lubricate the faeces (food residue eliminated by digestive tract).
### Activity 20.2: Digestive system

Complete the table below:

<table>
<thead>
<tr>
<th>Component of the digestive system/accessory organ</th>
<th>Basic structure</th>
<th>Main function/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small intestine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liver</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gall bladder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pancreas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large intestine</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 20.4 DIGESTION AND ABSORPTION

In the sections that follow we shall first examine absorption in general, and then look at the digestion and absorption of proteins, carbohydrates, fats and vitamins.

Study the section on *digestion*, pages 215-218, Chapter 10 in the prescribed textbook.

#### 20.4.1 Absorption

Absorption is the **passage (movement) of digested food substances, water, salts and vitamins through the membrane of the intestine into the blood and lymph**.

Absorption of digested food takes place mainly in the small intestine, whereas water is absorbed in the small and in the large intestines.

Absorption is dependent on a number of physical factors, but for the most part, nutrients are actively transported by physiological pumps across the intestinal cells. Only water and alcohol cross the intestinal cells by means of diffusion. In the fasting state, the villi in the intestine are at rest, but during absorption, they become alternately elongated and then contracted, causing
a pump-like action that squeezes the absorbed substances into the lymph and blood capillaries of the villi.

The absorbed nutrients are transported by the blood (the lymph eventually enters the bloodstream) to every part of the body, where it is metabolised in the cells.

20.4.2 Digestion and absorption of proteins
Both digestion and absorption of proteins are discussed.

• Digestion of proteins
No digestion of protein takes place in the mouth. The protein food is only chewed and thus divided into small parts. The digestion of proteins starts in the stomach and is completed in the small intestine.

The proteins are then absorbed, as described below and illustrated in Figure 20.3.

• Absorption of proteins
Proteins are digested into their component amino acids, which are absorbed into the blood and carried to all body tissues. The cells in each tissue use the amino acids to synthesise their own proteins according to their needs.

FIGURE 20.4
Absorption of proteins
(Source: Unisa drawing)
20.4.3 Digestion and absorption of carbohydrates

Both digestion and absorption of carbohydrates are discussed.

- Digestion of carbohydrates

The digestion of carbohydrates starts in the mouth. The food is divided into small particles by chewing and is mixed with saliva. This is followed by swallowing, and the food passes through the oesophagus into the stomach.

The saliva contains an enzyme ptyalin, which initiates the hydrolysing of starch to sugar. This is a chemical breakdown of the starch molecule. The extent of the breakdown is determined by the length of time that the food remains in the mouth. The longer the food remains in the mouth, the more the breakdown will be.

From the mouth, the food moves through the oesophagus into the stomach. But only a limited breakdown of starch occurs during the time when the food is eaten and the time that the food reaches the stomach.

In the stomach, the mechanical action of the stomach turns the food into a softer mass called chyme. The stomach secretes gastric juices, which contain several vital substances necessary for normal digestion. Hydrochloric acid (HCl) secreted by the stomach changes some sucrose to fructose and glucose. The acid medium in the stomach also inactivates the ptyalin.

No further digestion of starch takes place until it reaches the small intestine. Food that is high in carbohydrates remains in the stomach for a relatively short time, and then moves into the small intestine. Bile and pancreatic juices are released into the small intestine. The pancreatic juices neutralise the acidic chyme as it leaves the stomach and enters the small intestine. From this point on, the chyme remains at a neutral (pH 7) or slightly alkaline pH at which the enzymes of both the intestine and pancreas work best.

The small intestine is the most important place for digestion and absorption of carbohydrates. The carbohydrates entering the small intestine include the following:

- The monosaccharides and disaccharides in the food eaten.
- Small amounts of glucose and fructose resulting from the breakdown of sucrose in the stomach.
- Intact starch molecules that did not come in contact with ptyalin as the food passed through the mouth to the stomach.
- Dextrins and maltose resulting from the action of ptyalin.
- Cellulose and other carbohydrates, such as pectin, which are not digested by humans.

The surface of the intestinal wall is composed of millions of small, finger-shaped structures called villi. These villi along the intestinal wall move constantly in the presence of chyme. The peristaltic action of the intestine moves the chyme along while digestion is being completed.
The following reactions take place:

- Pancreatic amylase converts starch and dextrin to the disaccharide maltose.
- Maltase hydrolyses maltose to two glucose molecules.
- Sucrase converts sucrose into glucose and fructose.
- Lactase splits lactose into galactose and glucose.

By the time carbohydrates reach the lower part of the small intestine the monosaccharides are released and absorption takes place. Cellulose and other indigestible carbohydrates proceed into the large intestine and are excreted in the faeces.

### Absorption and transport of carbohydrates

Absorption of nutrients takes place in the small intestine via the epithelial cells of the villi. Once within the epithelial cell, the monosaccharide molecules pass through to the bloodstream. The monosaccharides are then transported through the portal vein to the liver. Here all nonglucose monosaccharide molecules are converted to glucose.

Glucose can be utilised in three different ways:

- It can be changed to **glycogen in the liver** and stored there and in muscles until it is needed.
- It can be **released into the blood** and carried to all body tissues and cells.
- It can be **converted to fatty acids** and ultimately stored as fat.

### Activity 20.3: Carbohydrate digestion

Draw your own diagram or mind map to summarise how carbohydrates are digested at various locations in the digestive system.

Once you have produced such a diagram, and if you have internet access, you could look at the following websites for help and ideas to see if you can improve your diagram:

- [http://easysciencenote.blogspot.co.za/2012/12/carbohydrate-digestion.html](http://easysciencenote.blogspot.co.za/2012/12/carbohydrate-digestion.html)
- [https://za.pinterest.com/pin/231935449535517916/](https://za.pinterest.com/pin/231935449535517916/)

### 20.4.4 Digestion and absorption of fats

Both digestion and absorption of fats are now discussed.

#### Digestion of fats

Before fat can be absorbed across the intestinal wall and transported to various tissues, it must be broken down chemically into units that are small enough to
be taken up by the cells lining the intestinal tract. Fat must undergo emulsification before it can be digested. Emulsification breaks fat into small particles.

After entering the stomach some of the emulsified fat in the food mass is changed by the action of gastric lipase, which splits off one or two fatty acids from diglycerides or triglycerides, leaving monoglycerides, diglycerides, and free fatty acids. (Take note: diglycerides consist of one glycerol molecule with two fatty acids attached to it. Triglycerides consist of one glycerol molecule with three fatty acids attached to it.)

From the stomach the food mass passes into the small intestine, where the presence of fat stimulates the release of the hormone cholecystokinin. This triggers the release of bile, which is synthesised in the liver and stored and released from the gallbladder. Bile acts on unemulsified fat from the food to break it into water-soluble globules known as micelles which are small in size and have a larger surface area.

Pancreatic lipase, an enzyme secreted from the pancreas, now breaks down the fat by splitting the fatty acids from the glycerol core, forming diglycerides, monoglycerides, fatty acids, and glycerol, all of which can be absorbed by the cell lining of the small intestine.

- Absorption of fats

The short-chain fatty acids and some glycerol are absorbed through the intestinal wall. They are directly transported to the liver via the portal vein. In the liver they are reformed into fat molecules and incorporated into lipoproteins to be carried to various body tissues. When monoglycerides, diglycerides, medium- and long-chain fatty acids, and glycerol enter the cells lining the intestinal wall, the majority recombine to form triglycerides, and are secreted into the villus of the intestinal cells. From there they enter the lymphatic circulation as chylomicrons.

In the liver lipids are combined with protein to form lipoproteins. These lipoproteins are synthesised to help carry fat to various tissues where it can be stored or utilised for energy.

20.4.5 Absorption of vitamins

The water-soluble vitamins are directly absorbed into the bloodstream. Some are freely absorbed, and others require an energy source and/or combination with another substance to facilitate absorption and transport. (This will be dealt with in nutrition modules.)

Fat-soluble vitamins are soluble in fat and share some common characteristics with lipids in body absorption and metabolism (see section 20.5.5).
Activity 20.4: Digestion of fats and vitamin absorption

(1) Draw your own diagram or mind map to summarise how fats are digested at various locations in the digestive system. Once you have produced such a diagram, and if you have internet access, you could look at the following website for help and ideas to see if you can improve your diagram:


(2) Briefly explain the difference between the absorption of water-soluble and fat-soluble vitamins.

20.5 METABOLISM

Metabolism encompasses all the chemical reactions taking place inside the living cell in its utilisation of food.

The aim of metabolism is to ensure optimal cell functioning by the following:

- Release of energy and simple molecules needed by the cells
- Synthesis of substances necessary for growth, reproduction and repair
- This is achieved by two major processes, namely catabolism and anabolism, which take place continually and concurrently inside all cells.

Therefore, metabolism consists of the breaking down of molecules (catabolism) and, on the other hand, the building up of molecules (anabolism). These processes are necessary because the nutrients we eat are not in the right form to be utilised by the body. They are digested and absorbed, and then further simplified in the catabolic process and rearranged or rebuilt in the anabolic process to form molecules suitable for use by the human body. Energy is needed for these breaking down and building up processes and is provided by the catabolic process itself.

- **Metabolism of protein**

The metabolism of proteins is the metabolism of the different amino acids. Each body cell utilises the available amino acids to synthesise (make) all the proteins required for its own function. The cells also use amino acids to release energy. Certain specialised cells, such as those of the liver, also synthesise proteins and nonprotein substances that contain nitrogen and are required for the functioning of the body as a whole.

- **Metabolism of carbohydrates**

When glucose enters a cell, catabolism is initiated. Energy is released at various stages, forming water (\(H_2O\)) and carbon dioxide (\(CO_2\)) from the breakdown of glucose. A large part of this energy is in the form of heat. Less than half of the energy is transferred to compounds within the cells and is used for operating the body.
The release of energy from carbohydrates occurs via a process called the **Krebs cycle**. To complete the different reactions in this cycle, various nutrients are required, including thiamine (vitamin B₁), riboflavin (vitamin B₂), niacin (vitamin B₃), pantothenic acid, pyridoxine (vitamin B₆), iron and copper.

**• Metabolism of fats**

When fat is used for energy, the fat molecule is split into **glycerol** and **fatty acids**. The three-carbon glycerol fragment is metabolised through the Krebs cycle. These different chemical reactions ultimately produce energy, carbon dioxide and water.

**• Energy production**

As you have gathered from this study unit thus far, you should know that our bodies use energy to do everyday tasks. You also know that we get our energy from the food that we eat. Food therefore carries potential energy. During catabolism, potential energy present in food is gradually set free in two forms, namely heat and chemical energy.

– **Heat**

The relatively large amount of heat produced during catabolism cannot be used as energy for the anabolic processes, but it serves to maintain body heat. The more active the cell, the quicker the rate of metabolism and the more heat is produced. This is why you start feeling hot when doing strenuous work or exercise.

– **Chemical energy**

The main “carrier” of energy in biological systems is a molecule known as **adenosine triphosphate (ATP)**. High-energy ATP bonds are formed in the mitochondria of cells (see study unit 12) in the presence of oxygen. Mitochondria are therefore known as the power-plants of the cell.

High-energy ATP bonds store a greater amount of energy than ordinary chemical bonds and are very labile (easily changed). ATP molecules are very important compounds because they supply energy directly to the anabolic reactions of all living cells.

When an ATP bond is broken, it yields an **ADP molecule**, a **phosphate molecule** and **energy**. This ADP molecule combines directly with a phosphate molecule and energy from the catabolic process, once more to form ATP. This cycle, the ATP/ADP system, is diagrammatically illustrated in Figure 20.5.
20.6 DIGESTIVE ENZYMES
A summary of the digestive enzymes, their originating organs and the nutrients on which they have an effect is given in Table 20.1.

**TABLE 20.1**

*Digestive enzymes*

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Enzyme used for catabolism</th>
<th>Originating organ</th>
<th>Medium (pH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate</td>
<td>Ptyalin</td>
<td>Salivary glands</td>
<td>Alkaline</td>
</tr>
<tr>
<td></td>
<td>Amylase</td>
<td>Pancreas</td>
<td>Alkaline</td>
</tr>
<tr>
<td></td>
<td>Sucrase</td>
<td>Small intestine</td>
<td>Alkaline</td>
</tr>
<tr>
<td></td>
<td>Maltase</td>
<td>Small intestine</td>
<td>Alkaline</td>
</tr>
<tr>
<td></td>
<td>Lactase</td>
<td>Small intestine</td>
<td>Alkaline</td>
</tr>
<tr>
<td>Fat</td>
<td>Bile (not an enzyme)</td>
<td>Liver</td>
<td>Alkaline</td>
</tr>
<tr>
<td></td>
<td>Lipase</td>
<td>Pancreas</td>
<td>Alkaline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small intestine</td>
<td>Alkaline</td>
</tr>
<tr>
<td>Protein</td>
<td>Pepsin (rennin)</td>
<td>Stomach</td>
<td>Acid</td>
</tr>
<tr>
<td></td>
<td>Trypsin</td>
<td>Stomach</td>
<td>Acid</td>
</tr>
<tr>
<td></td>
<td>Peptidase</td>
<td>Pancreas</td>
<td>Alkaline</td>
</tr>
<tr>
<td></td>
<td>Peptidase</td>
<td>Pancreas</td>
<td>Alkaline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small intestine</td>
<td>Alkaline</td>
</tr>
</tbody>
</table>
A summary of digestion, absorption and defecation is given in the table below. The gut is a tube from the mouth to the anus. Enzymes are released into this tube, food is broken down into a soluble form by enzymes and absorbed into the bloodstream, and indigestible matter is passed out of the anus.

For further information and illustrations about the digestive system and processes, you can consult the following website:

http://classes.midlandstech.edu/carterp/Courses/bio211/chap23/chap23.htm

You can also watch the following video clips:

https://www.youtube.com/watch?v=4dG2PYD94es (overview)

https://www.youtube.com/watch?v=EYfB6g3Gl0c (protein digestion and absorption)

https://www.youtube.com/watch?v=9HNz_QW838Q (carbohydrate digestion and absorption)
Activity 20.5: Revision and reflection

1. Label the following structures in the diagram of the digestive system below: Parotid salivary gland, mouth cavity, sublingual salivary gland, oesophagus, liver, stomach, gall bladder, spleen, colon, ileum and rectum.

   ![Diagram of the digestive system]

   **FIGURE 20.1.1**

   The digestive system


2. Tabulate the source and digestive action of each of the following digestive enzymes: Pepsin, sucrase, lipase and trypsin.

3. What are the main functions of the digestive system?

4. Tabulate the main organs and the accessory organs of the digestive system. Indicate in which main organ each accessory organ is situated, or into which main organ it opens.

5. Give the functions of each of the following digestive organs:
   - Mouth
   - Stomach
   - Small intestine
(6) Give the functions of the following accessory organs:
• Tongue
• Liver
• Pancreas

(7) Define digestion and absorption.

(8) This is a discussion question. You should post your answer to this question in the discussion space of your e-tutor site.
Suppose that you have just eaten a cheese sandwich. (Note that cheese contains both protein and fats.) Describe the route that the sandwich follows and what happens to it from the moment it is placed in the mouth until it reaches the body cells.

(9) Name and briefly explain the two processes that form part of the metabolism.

(10) In table format, briefly indicate how proteins, carbohydrates and fats are metabolised.

(11) Draw a diagram to explain how energy is generated in the body.

(12) Think back about everything you learnt in the module. What would you say were the three most important insights you gained? Why were they important for you? You may wish to share this with your fellow students in the discussion space of your e-tutor site.

20.7 CONCLUSION

In this learning unit, the main organs and the accessory organs of the digestive system were discussed. The location of each one was pointed out, and the functions of each were listed. We also saw how nutrients are digested, absorbed and metabolised, and how this creates energy in the body.

By studying this module, you have gained a thorough, fundamental knowledge of the chemical and physical properties of the world and of human anatomy and physiology. This will serve as an excellent foundation for any further studies in your chosen academic and career field.
DISCUSSION FORUMS AND TOPICS IN CSP1501

Note that you will have an e-tutor site (e.g. CSP1501-17-S1-1S) where you will be able to ask questions about the content of the module, participate in discussions relating to the module, and communicate with your fellow students (see the next section). On the main website for the module (e.g. CSP1501-17-S1) you will also be able to post general queries to the lecturer, and queries about the assessment. The forums on the site will be as follows:

- General queries to the lecturer
- Assessment queries

You can create your own topics in the first forum. In the second forum, the following topics will be created:

- Queries about assignment 1
- Queries about assignment 2
- Queries about assignment 3
- Queries about the examination

Please post your query in the appropriate topic.
THE E-TUTOR SITE FOR
CSP1501

Your e-tutor is there to support your learning, and you can post any questions to him or her in the site’s discussion forum, in the appropriate forum or topic. In another forum, you will also be able to communicate with your fellow students.

On the e-tutor site you should also respond to discussion questions that are given in the learning units. Your e-tutor may provide you with the opportunity to engage in additional discussions or to do specific online tasks or activities; please participate fully, as this will go a long way to assist you with your learning. Both the lecturer and e-tutor may also send you announcements from time to time.

The forums on the site will be as follows:

- Introductions
- General queries to the e-tutor
- Discussion questions and activities
- Student lounge (for communicating with your fellow students)
- Any additional forums created by the e-tutor

The forum “Discussion questions and activities” will contain the discussion questions/activities in the learning units. These are the following:

- Activity 3.2, question 2
- Activity 4.2, question 1
- Activity 5.2, question 2
- Activity 5.3, question 8
- Activity 6.1, question 5
- Activity 7.3, question 2
- Activity 8.2, question 2
- Activity 9.3, question 2
- Activity 10.3, question 8
- Activity 12.3, question 3
- Activity 14.1, question 3
- Activity 16.3
- Activity 17.1, question 3
- Activity 18.2, question 2
- Activity 19.2, question 2
- Activity 20.5, question 8