Open Educational Resources (OER) for Open Schooling

The Commonwealth of Learning (COL) Open Schools Initiative launched an Open Educational Resources (OER) Project to provide materials under the Creative Commons license agreement to support independent study in 17 specially selected secondary school subjects. Funded by the William and Flora Hewlett Foundation its aim is to broaden access to secondary education through the development of high quality Open Distance Learning (ODL) or self-study materials.

These specially selected OER subjects include:

1. Commerce 11
2. Coordinated Science 10 (Biology, Chemistry and Physics)
3. English 12
4. English Second Language 10
5. Entrepreneurship 10
6. Food & Nutrition
7. Geography 10
8. Geography 12
9. Human Social Biology 12
10. Life Science 10
11. Life Skills
12. Mathematics 11
13. Mathematics 12
14. Physical Science 10
15. Physical Science 12
16. Principles of Business
17. Spanish

Open Educational Resources are free to use and increase accessibility to education. These materials are accessible for use in six countries: Botswana, India, Lesotho, Namibia, Seychelles and Trinidad & Tobago. Other interested parties are invited to use the materials, but some contextual adaptation might be needed to maximise their benefits in different countries.

The OER for Open Schooling Teachers’ Guide has been developed to guide teachers/instructors on how to use the Open Educational Resources (OER) in five of these courses.

1. English
2. Entrepreneurship
3. Geography
4. Life Science
5. Physical Science

The aim of this teachers’ guide is to help all teachers/instructors make best use of the OER materials. This guide is generic, but focuses on Namibian examples.

Print-based versions are available on CD-ROM and can be downloaded from www.col.org/CourseMaterials. The CD-ROM contains the module and folders with additional resources, multimedia resources and/or teacher resources. Note that not all subjects have multimedia resources.
Acknowledgements:

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Ministry of Education Trinidad& Tobago: www.moe.gov.tt
National Open School of Trinidad & Tobago (NOSTT): www.moe.gov.tt/NOSTT
Botswana College of Distance and Open Learning (BOCODOL): www.bocodol.ac.bw
Ministry of Education Zambia: www.moe.gov.zm

Commonwealth of Learning, 2012

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The Commonwealth of Learning (COL) is an intergovernmental organisation created by Commonwealth Heads of Government to encourage the development and sharing of open learning and distance education knowledge, resources and technologies.
Coordinated Science
Biology, Chemistry and Physics for S4 & S5 levels (Grade 10)

COL Open School Initiative
The Seychelles
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About this course manual

Coordinated Science Biology, Chemistry and Physics for S4 & S5 levels (Grade 10) has been produced by COL Open School Initiative. All course manuals produced by COL Open School Initiative are structured in the same way, as outlined below.

How this course manual is structured

The course overview

The course overview gives you a general introduction to the course. Information contained in the course overview will help you determine:

- If the course is suitable for you.
- What you will already need to know.
- What you can expect from the course.
- How much time you will need to invest to complete the course.

The overview also provides guidance on:

- Study skills.
- Where to get help.
- Course assignments and assessments.
- Activity icons.
- Units.

We strongly recommend that you read the overview carefully before starting your study.

The course content

The course is broken down into units. Each unit comprises:

- An introduction to the unit content.
About this course manual

- Unit outcomes.
- New terminology.
- Core content of the unit with a variety of learning activities.
- A unit summary.
- Assignments and/or assessments, as applicable.

Resources

For those interested in learning more on this subject, we provide you with a list of additional resources at the end of this course manual. These may be books, articles or web sites.

Your comments

After completing the Coordinated Science course we would appreciate it if you would take a few moments to give us your feedback on any aspect of this course. Your feedback might include comments on:

- Course content and structure.
- Course reading materials and resources.
- Course assignments.
- Course assessments.
- Course duration.
- Course support (assigned tutors, technical help, etc.)

Your constructive feedback will help us to improve and enhance this course.
Coordinated Science

Course overview

Welcome to Coordinated Science Biology, Chemistry and Physics for S4 & S5 levels (Grade 10)

The coordinated science is a course which coordinates the contents of biology, chemistry, and physics so that ‘ideas developed in one science are taken up in another,’ to avoid ‘the duplication of teaching’ (University of Cambridge, 2010, p.6). As such you will study biology, chemistry and physics in an alternating manner as per the Course Overview below.

Coordinated Science Biology, Chemistry and Physics for S4 & S5 levels (Grade 10)—is this course for you?

This course is equivalent to the IGCSE coordinated science and is intended for people who wish to:

- study biology, chemistry and physics at Secondary 4 and 5 levels (age 15+/Grade 10), equivalent to IGCSE;
- re-sit their IGCSE examination;
- complete their IGCSE science course
- upgrade their science academic knowledge to advance their career

This course can also be used as a supplementary document for Secondary 4 and 5 science teachers and students in the conventional school setting. To be more specific, this course is designed for three categories of students:

- full-time students outside the conventional school setting;
- full-time students within the conventional school setting; and
Course overview

- part-time students outside the conventional school setting.

To follow the course, you need to:

- have completed Science in the National Curriculum (Seychelles) course at Secondary 3 level (which is equivalent to Grade 9 science);
- have some mathematical skills, like solving equations and plotting and interpreting graphical information;
- have good and safe laboratory skills;
- be an independent learner and be ready to seek help from others;
- able to work in collaboration with other learners as necessary;
- be able to work on your own (without immediate supervision) and organize your own study time;
- have good note-taking and self-assessment skills;
- have basic ICT skills, such as word processing, excel, use of internet and emails;
- know your personal limitations and factors that can inhibit/slow the progress of your studies;
- have access to study centres, science laboratory, library, computer and internet when and as necessary.

Course outcomes

Upon completion of coordinated science, biology, chemistry and physics course you will be able to:

- **state** scientific phenomena, facts, laws, definitions, concepts and theories;
- **use** scientific vocabulary, terminology and conventions (including symbols, quantities and units);
- **manipulate** scientific instruments and apparatus, including techniques of operation and aspects of safety;
- **identify** scientific quantities and their determination;
- **outline** scientific and technological applications with their social,
economic and environmental implications;

- translate information from one form to another;
- manipulate numerical and other data;
- use information, experimental observations and data to identify patterns, report trends and draw inferences;
- present reasoned explanations for phenomena, patterns and relationships;
- make predictions and hypotheses;
- solve problems;
- make observations, measurements, estimates
- record observations, measurements, estimates
- evaluate experimental observations and data;
- plan scientific investigations;
- criticise methods of investigations and suggest possible improvements (including the selection of techniques, apparatus and materials);
- report trends and draw inferences.
Timeframe

This coordinated science course consists of 54 units, however, only the first 12 units of the course will be accessible in 2012. The other units will become available (be developed) at a later stage.

If you are accessing the first 12 units of this coordinated science course, your timeframe is as follows:

If you are a full-time student outside the conventional school setting, you are expected to complete the 12 units in 12 weeks. Your formal study time is 8 hours per week. You are encouraged to devote at least 4 hours extra each week for self-study (such as review and practice exercises).

If you are a full-time student within the conventional school setting, you are expected to complete the course in 24 weeks. Your formal study time is 4 hours per week. You are encouraged to devote at least 3 hours extra each week for self-study (such as review and practice exercises).

If you are a part-time student, you are expected to complete the course in 24 weeks. Your formal study time is 4 hours per week. You are encouraged to devote at least 2 hours extra each week for self-study (such as review and practice exercises).

Your total amount of study time for the first 12 units of the coordinated science course is 96 hours. Refer to Table 1 for a summary of the timeframe.

<table>
<thead>
<tr>
<th>Student category</th>
<th>Duration</th>
<th>Recommended formal study time per week</th>
<th>Recommended Self-study time per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>full-time student outside the</td>
<td>12</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>conventional school setting</td>
<td>weeks</td>
<td>hours</td>
<td></td>
</tr>
<tr>
<td>full-time student within the</td>
<td>24</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>conventional school setting</td>
<td>weeks</td>
<td>hours</td>
<td></td>
</tr>
<tr>
<td>part-time student</td>
<td>24</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1: A summary of the timeframe for the first 2 units of the coordinated science course.
If you are accessing all the 54 units of this coordinating science course, your total amount of formal study time is as follows:

If you are a full-time student outside the conventional school setting, you are expected to complete the course in 52 weeks (one year). Your formal study time is 8 hours per week. You are encouraged to devote at least 4 hours extra each week for self-study (such as review and practice exercises).

If you are a full-time student within the conventional school setting, you are expected to complete the course in 104 weeks (two years). Your formal study time is 4 hours per week. You are encouraged to devote at least 2 hours extra each week for self-study (such as review and practice exercises).

If you are a part-time student, you are expected to complete the course in 104 weeks (two years). Your formal study time is 4 hours per week. You are encouraged to devote at least 2 hours extra each week for self-study (such as review and practice exercises).

Your total amount of study time for the 54 units of the coordinated science course is 416 hours. Refer to Table 2 for a summary of the time frame.

**Table 2: Summary of the timeframe for the 54 units of the coordinate science course**

<table>
<thead>
<tr>
<th>Student category</th>
<th>Duration</th>
<th>Recommended formal study time per week</th>
<th>Recommended Self-study time per week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weeks</td>
<td>Hours</td>
<td></td>
</tr>
<tr>
<td>Full-time student outside the conventional school setting</td>
<td>52</td>
<td>416</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Full-time student within the conventional school setting</td>
<td>104</td>
<td>416</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Part-time student</td>
<td>104</td>
<td>416</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>
Study skills

As an adult learner your approach to learning will be different to that from your school days as you will be choosing what you want to study, you will have professional and/or personal motivation for doing so and you will most likely be fitting your study activities around other professional or domestic responsibilities.

Essentially you will be taking control of your learning environment. As a consequence, you will need to consider performance issues related to time management, goal setting, stress management, etc. Perhaps you will also need to reacquaint yourself in areas such as essay planning, coping with exams and using the web as a learning resource.

Your most significant considerations will be time and space i.e. the time you dedicate to your learning and the environment in which you engage in that learning.

The materials in this course have been designed to get you actively involved in the construction of your learning. The content in the various topics will be organized in a meaningful sequence, starting from known to unknown in the form of a dialogue between you and your teacher. The material will provide opportunities for you to use the knowledge and practice the skills learnt in order to further enhance your learning.

Your personal experience and knowledge is a vital contribution to your learning. Hence the material will draw considerably on Grade 9 Science, your past experience, and real life examples. A variety of learning activities and resources will be used to support and enrich your learning experience.

Through the various activities you will have the opportunity to demonstrate and apply your understanding of the content learnt. There will be numerous occasions for you to experiment, simulate, carry out case studies, design models and solve problems.

The concepts that you learn will be revisited and built on as needed, throughout the unit. While you study the materials you will also be asked to refer to related content, concepts and ideas in Physics, Chemistry and Biology throughout the course. This will help you to understand the linkage between related content, concepts and ideas.

You will be provided with feedback for each activity and assessment. This will help you evaluate your understanding of the content and revisit the topics as necessary or proceed to the next step. During the course you will sit two examinations to test your progress in the course.

We recommend that you take time now—before starting your self-study—to familiarize yourself with these issues. There are a number of excellent resources on the web. A few suggested links are:
• http://www.how-to-study.com/
  The “How to study” web site is dedicated to study skills resources. You will find links to study preparation (a list of nine essentials for a good study place), taking notes, strategies for reading text books, using reference sources, test anxiety.

• http://www.ucc.vt.edu/stdysk/stdyhlp.html
  This is the web site of the Virginia Tech, Division of Student Affairs. You will find links to time scheduling (including a “where does time go?” link), a study skill checklist, basic concentration techniques, control of the study environment, note taking, how to read essays for analysis, memory skills (“remembering”).

• http://www.howtostudy.org/resources.php
  Another “How to study” web site with useful links to time management, efficient reading, questioning/listening/observing skills, getting the most out of doing (“hands-on” learning), memory building, tips for staying motivated, developing a learning plan.

The above links are our suggestions to start you on your way. At the time of writing, these web links were active. If you want to look for more go to www.google.com and type “self-study basics”, “self-study tips”, “self-study skills” or similar.
Support for Students within the Conventional Schools

For students within the conventional schools, the course materials will be available at their respective secondary school. Teachers and learners will be free to use those self-contained course materials to support the teaching and learning process. The materials will also be used by students in classes with no regular science teacher. A Student Guide and a Teacher Classroom Guide will guide the learners and the teachers on how to use the course OERs for maximum benefit.

Support for Distance Education Learners

In addition to the Student Guide, tutorial support will be provided to students studying outside the conventional school setting. Tutorials will be provided through periodical face-to-face contact between learners and identified tutors at the Study Centres. The different Study/Regional Centres will be at regional Secondary Schools. Tutorials can be either group or individual. The Open School Teacher Guide will guide the tutors on how to make the optimal use of the OERs.

Group tutorials will be mainly for:

- carrying out certain experiments to give students first-hand experiences;
- discussions;
- gaining better comprehension of the printed materials; and
- getting help in working on assignments.

Individual tutorial will be mainly for:

- providing feedback on assignments and assessments
- giving specific and additional study skills support

You are strongly advised to attend tutorial sessions organized at your respective centre, as they could prove very useful in helping you to: comprehend some of the more complex concepts/ideas or difficult issues in the materials, share views with the tutor and fellow learners, clarify doubts, get help in working on assignments and be reminded of deadlines.
and other important dates. It is very important for you to come to tutorials thoroughly prepared.

Should you be encountering any problems affecting their studies, including technical issues (e.g. computer problems), do not hesitate to contact your course coordinator.

Assignments

You are expected to complete three assignments: each assignment will have a component of biology, chemistry, and physics. Each assignment is worth 10% (a total of 30%) of the total marks for the course. The assignments will be posted to you by the Course Coordinator three weeks prior to the due date.

You can submit your assignments electronically to the Course coordinator at (email address will be communicated later) or by post on the address provided by your Course coordinator.

As a full-time student outside the conventional system you are expected to submit the first assignment at the end of week 19 by which time you should have completed units 1 to 18. You should submit the second assignment at the end of week 39 by which time you should have completed units 19 to 38. Your third assignment is due at the end of week 55 by which time you should have completed units 39 to 54.

As a full-time student within the conventional system or as a part-time student, you are expected to submit the first assignment at the end of week 38 by which time you should have completed units 1 to 18. You should submit the second assignment at the end of week 78 by which time you should have completed units 19 to 38. Your third assignment is due at the end of week 104 by which time you should have completed units 39 to 54.

Please ensure that you submit your assignments on the dates specified. Should you need an extension, you should contact the Course Coordinator at least three (3) working days before the due date.

Please refer to Table 1 for a breakdown of the assignments.
Course overview

Table 1: A breakdown of the assignments

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Full time students outside conventional system</th>
<th>Full time students within conventional system and part-time students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Due date</td>
<td>Units to be assessed</td>
</tr>
<tr>
<td>1</td>
<td>Week 19</td>
<td>1-18</td>
</tr>
<tr>
<td>2</td>
<td>Week 39</td>
<td>19-38</td>
</tr>
<tr>
<td>3</td>
<td>Week 51</td>
<td>39-54</td>
</tr>
</tbody>
</table>

Assessments

This course contains both formative and summative assessments

1. Formative assessments

Formative assessment throughout the course will be used to help you monitor and evaluate your progress as you work through the course material. Formative assessment will be in the form of a series of activities and self-assessment tasks throughout each unit. Each unit will contain one or more self-assessment. The self-assessment tasks may be at the end of the topics and/or at the end of the unit. The answers for the self-assessments tasks will be given at the end of the unit while those for the activities may be given immediately after the activity or at the end of the topic/unit depending on the type of activity.

2. Summative assessments

Summative assessment will be given to assess your mastery and ability to integrate and apply the course content. Summative assessments will take the form of assignment and examinations. All summative assessment tasks are teacher-marked.

There will be two examinations. Each examination will contain three papers: paper 1 will contain 40 multiple choice questions; paper 2 will contain 12 structured questions (4 from each biology, chemistry, and physics); paper 3 is an alternative to the practical paper and will contain 6 questions (2 from each biology, chemistry and physics). Each assessment will be worth 35% of the course. Paper 1 is worth 10%, paper 2 is worth...
15 % and paper 3 is worth 10 %.

You will sit for paper 1 and paper 2 on the same day and for paper 3 one week after papers 1 and 2. You will sit for the first examination half way through the course and the second examination within the next three weeks after completion of the course.

Papers 1 will be 45 minutes long, Paper 2 will be 2 hours long and Paper 3 will be 1 hour long. You are expected to complete each paper in the allocated time. You will sit for all examinations under supervision at designated centres. Refer to Table 2 for a summary of the examination papers, duration and due dates.

The teacher is expected to complete the marking of the examination papers within two weeks after the examination.

Table 2: Summary of examination papers, duration and due dates.

<table>
<thead>
<tr>
<th>Paper</th>
<th>Duration</th>
<th>Full time students outside conventional system</th>
<th>Full time students within conventional system and part-time students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Due date</td>
<td>Due date</td>
</tr>
<tr>
<td>Paper 1: Multiple choice question</td>
<td>45 minutes</td>
<td>week 29</td>
<td>week 54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>week 58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>week 107</td>
</tr>
<tr>
<td>Paper 2: Structured question paper</td>
<td>2 hours</td>
<td>week 29</td>
<td>week 54</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>week 58</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>week 107</td>
</tr>
<tr>
<td>Paper 3: Alternative to practical</td>
<td>1 hour</td>
<td>week 30</td>
<td>week 55</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>week 59</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>week 108</td>
</tr>
</tbody>
</table>
Examination 1 will cover unit 1 to unit 28 and Examination 2 will cover unit 29 to unit 54. Please refer to Table 3 for clarification.

Table 3: Units to be covered for Examinations 1 and 2.

<table>
<thead>
<tr>
<th>Examination</th>
<th>Units to be assessed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-28</td>
</tr>
<tr>
<td>2</td>
<td>29-54</td>
</tr>
</tbody>
</table>
Getting around this course manual

**Margin icons**

While working through this course manual you will notice the frequent use of margin icons. These icons serve to “signpost” a particular piece of text, a new task or change in activity. They have been included to help you to find your way around this course manual.

A complete icon set is shown below. We suggest that you familiarize yourself with the icons and their meaning before starting your study.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Assessment</th>
<th>Assignment</th>
<th>Case study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discussion</td>
<td>Group activity</td>
<td>Help</td>
<td>Note it! / Important!</td>
</tr>
<tr>
<td>Outcomes</td>
<td>Reading</td>
<td>Reflection</td>
<td>Study skills</td>
</tr>
<tr>
<td>Summary</td>
<td>Terminology</td>
<td>Time</td>
<td>Tip</td>
</tr>
<tr>
<td>Computer-Based Learning</td>
<td>Audio</td>
<td>Video</td>
<td></td>
</tr>
</tbody>
</table>
The coordinated science course consists of 54 units. The first 12 units of the coordinated science course – Grade 10 are as listed below.

UNIT 1: BIOLOGICAL CLASSIFICATION
UNIT 2: THE ELEMENTS OF CHEMISTRY
UNIT 3: THE STRENGTHS OF SOLIDS
UNIT 4: ATOMS, BONDING AND THE PERIODIC TABLE
UNIT 5: PARTICLES IN MOTION
UNIT 6: CELLULAR ORGANISATION
UNIT 7: CLASSIFYING ELEMENTS
UNIT 8: MOTION
UNIT 9: FORCE AND MOTION
UNIT 10: DIET AND HEALTH
UNIT 11: SUPPORT AND MOVEMENT
UNIT 12: GRAVITY

NOTE: The other units that will make up the coordinated science course are listed below.

UNIT 13: DIGESTION
UNIT 14: PETROCHEMICALS
UNIT 15: DYES AND DRUGS
UNIT 16: PHOTOSYNTHESIS
UNIT 17: FUELS
UNIT 18: CHEMICALS FROM PLANTS
UNIT 19: ENERGY TRANSFER
UNIT 20: GASEOUS EXCHANGE IN ANIMALS
UNIT 21: MATERIALS AND STRUCTURES
UNIT 22: TRANSFERRING ENERGY BY HEATING
UNIT 23: TRANSPORT SYSTEMS
UNIT 24: OXIDATION AND REDUCTION
UNIT 25: USING ELECTRICITY
UNIT 26: RESPIRATION
UNIT 27: ENERGY AND ELECTRICITY
UNIT 28: IONS AND ELECTROLYSIS
UNIT 29: LIGHT AND SOUND
UNIT 30: SOLVENTS AND SOLUTIONS
UNIT 31: WAVES
UNIT 32: MAKING USE OF WAVES
UNIT 33: ACIDS AND ALKALIS
UNIT 34: COLLOIDS
UNIT 35: RESPONDING TO THE ENVIRONMENT
UNIT 36: SOIL, ROCKS AND RATES
UNIT 37: KINETIC ENERGY AND MOMENTUM
UNIT 38: HOMEOSTASIS
UNIT 39: FERTILISERS
UNIT 40: MAGNETISM AND ELECTRICITY
UNIT 41: REPRODUCTION
UNIT 42: HUMAN REPRODUCTION
UNIT 43: COMMUNICATIONS
UNIT 44: INHERITANCE
UNIT 45: ELECTRONS
UNIT 46: RADIOACTIVITY
UNIT 47: ORGANISMS IN THEIR ENVIRONMENT
UNIT 48: ENERGY RESOURCES
UNIT 49: ENERGY DISTRIBUTION
UNIT 50: BATTERIES
UNIT 51: CYCLES AND THEIR EFFECTS
UNIT 52: EVOLUTION
UNIT 53: METALS AND ALLOYS
UNIT 54: ELECTRONICS
Coordinated Science
Biology, Chemistry and Physics for Secondary 4 & Secondary 5 levels
(Grade 10)
# Acknowledgements

The COL Open School Initiative wishes to thank those below for their contribution to this course manual:

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</thead>
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<td>Alex Souffe</td>
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Introduction

Welcome to your first unit in the Coordinated Science course! The unit is entitled Biological classification. Classifying is a fundamental skill in biology. Through the activities in this unit, you will understand the principle and importance of classification in biology and learn to appreciate the wide variety of organisms around you.

Classification requires good observation. Hence, the activities that you will do in this unit will require that you exercise your observational skills to the greatest extent. This will enable you to identify common characteristics in sets of organisms that allow for them to be grouped together. You will also get the opportunity to develop and use dichotomous keys to identify plant and animal species with particular focus on locally occurring ones.

Since the units in the Coordinated Science course have been developed in such a way to allow you to continuously see the relationships between Biology, Chemistry and Physics, we shall be referring you to other units in the course where the concept of classification is also dealt with. Hence, in the biology units Evolution (Unit 52) and Organisms and their Environment (Unit 47) you will be able to use your knowledge of biological classification to further develop ideas of differences and similarities between organisms.

Your knowledge of classification will equally be useful when you work on the chemistry unit Classifying the Elements (Unit 7) and the unit Atoms, Bonding and the Periodic Table (Unit 4).

In this unit you will learn about:

- why it is important to classify organisms in groups;
- the principles of biological classification;
- how to construct and use dichotomous keys;
- the binomial nomenclature and its use in naming living organisms;
- the hierarchical structure of the classification system;
- similarities and differences between various groups of vertebrates and invertebrates and the diagnostic characteristics that are used to sort them into groups;
The outcomes for the unit are listed below. The outcomes written in bold are the extended outcomes and they are intended for students who are aiming for Grade B or higher in the examinations.

You are also required to keep a portfolio for some of the work that you will do in this unit. All you need is a file or a pocket to put your work in. On the cover page of the portfolio write your name and the title of the unit and the start and completion dates.

You will be required to submit the portfolio to your teacher/tutor on completion of the unit as part of the assessment.

Upon completion of this unit you will be able to:

- explain why organisms are classified into groups;
- use a simple dichotomous identification key;
- use the binomial system of naming organisms.
- name at least two different organisms using their binomial names;
- state that organisms belong to different species, which are discrete breeding groups;
- list the main features of the five main classes of vertebrates (fish, amphibians, reptiles, birds, mammals);
- construct a simple dichotomous key to enable identification of organisms;
- describe the main features of three classes of arthropods (insects, crustaceans and arachnids);

**Terminology**

**Arthropods:** The group of invertebrates that have an exoskeleton, segmented bodies and jointed limbs.

**Binomial nomenclature:** A two-part naming system of individual organisms comprising of a genus name and a species name.

**Chordates:** Animals with a dorsal nerve cord and a skeletal notochord, present at some point in their development.
**Classification:**
The categorisation of organisms and other items into defined groups on the basis of defined characteristics.

**Dichotomous key:**
Branching keys with pairs of contrasting descriptions.

**Kingdom:**
The first and largest category in the biological hierarchical classification system.

**Species:**
The smallest category in the biological hierarchical classification system.

---

Students, Table 1.0 below shows the number of formal study hours needed for you to complete this unit and the number of hours that you need to devote for self-study.

<table>
<thead>
<tr>
<th>Category of students</th>
<th>Number of formal study hours needed</th>
<th>Number of hours for self-study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time student outside the conventional school setting</td>
<td>12 hours 30 minutes</td>
<td>6 hours 15 minutes</td>
</tr>
<tr>
<td>Full-time student within the conventional school setting</td>
<td>12 hours 30 minutes</td>
<td>6 hours 15 minutes</td>
</tr>
<tr>
<td>OR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part-time student</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1.0: The proposed study time for full time and part-time students
Topic 1.1: Why classify organisms?

You will need 1 hour and 10 minutes at the most to complete this topic. It is advisable that you spend another 35 minutes of your own time to further practice the classification processes learnt.

There are so many different types of living organisms (living things) around us and new organisms are still being discovered every day. What if tomorrow you discovered a creature that you have not seen before in your home garden? Would you be able to figure out what known animal this creature might be related to? What would you look for about this creature for comparison with the known animal?

It would be natural for you to start studying the creature by looking for common characteristics and finding relationships with known animals. This is exactly what scientists who study living organisms do. They look for the differences and similarities between the living organisms and organize them into categories based on their relationships.

1.1.1 Using similarities and differences to classify organisms

If you observe living organisms closely, you will see a number of similarities and differences between them. These similarities and differences allow us to classify the living organisms around us. Classifying provides us with an ordered way of describing the organisms, and helps us to make sense of the information around us.

Let us see how this works in Activity 1.1.1 below. You are expected to complete the activity in 30 minutes.
Activity 1.1.1
You need 30 minutes to do the activities below.

In this investigation you will learn how similarities and differences help us to classify living organisms.

Problem
How do similarities and differences allow us to classify living organisms?

Procedure
a. Go outside. Take a look around you and pay attention to the sounds of animals and the plants around you. Make a list of five of the different living organisms that you observe.

b. Study the list carefully and look for one main difference between the organisms. Use the difference that you have noted to divide the living organisms into two groups (Group A and Group B) on Table 1.1.1 below.

You should also make use of the difference that you have observed to write suitable headings for Group A and Group B.

<table>
<thead>
<tr>
<th>Group A:</th>
<th>Group B:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<tr>
<td></td>
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</tbody>
</table>

Table 1.1.1: Difference between five living organisms
Analysis

Look at the organisms in either Group A or Group B in Table 1.1.1 above.

i). In what way/s are the organisms similar?

ii). In what way/s are the organisms different?

iii). What information do you need in order to classify the organisms further?

Conclusion

How useful are similarities and differences in the classification of organisms?
Going further: Using similarities and differences to identify a living organism

Study the five types of bananas below.

*Five types of bananas*

![Picture of bananas](www.ocati.com/images/bananitosfruitR.jpg)

**Figure 1.1.1**


i. Choose one type of banana. Write it down below.

ii. Starting from the large group of five types of bananas, find one main difference between the types of bananas. Use this difference to put the five types of bananas into two groups in the space below.
iii. Continue the exercise above, but use only the group containing your chosen type of banana each time. Do this exercise until you are left with only your chosen type of banana.

iv. Use the information in the groups above to describe the specific characteristics of your chosen type of banana.
Feedback to Activity 1.1.1

I am sure that through Activity 1.1.1 above, you have realized that there are lots of similarities and differences between the living organisms around us. Noting these similarities and differences allow us to find specific characteristics of each living organism which in return allows us to pinpoint to and isolate specific organisms.

Here is one suggestion how you could have organized the different types of bananas to describe a chosen type of banana. I have chosen the lady’s finger banana.

Looking at the five different types of bananas below:

<table>
<thead>
<tr>
<th>Five types of bananas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lady’s finger</td>
</tr>
</tbody>
</table>

We immediately notice that their color is different. Three types of bananas are green; two types are reddish in colour. Hence:

<table>
<thead>
<tr>
<th>Three of the five types of bananas are green in colour.</th>
<th>Two of the five types of bananas are reddish in colour.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lady’s finger</td>
<td>Plantain</td>
</tr>
</tbody>
</table>

As lady’s finger is a green type of banana, we shall continue by considering only the group of green bananas. One difference between these green bananas is that two types are short and one type is long. Hence:

<table>
<thead>
<tr>
<th>Two of the green types of bananas are short.</th>
<th>One of the green types of bananas is long.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lady’s finger</td>
<td>Plantain</td>
</tr>
</tbody>
</table>

We continue by looking at the group of bananas with lady’s fingers. One difference that we notice is that the lady’s finger bananas are bigger than the blue bananas. Hence:

<table>
<thead>
<tr>
<th>The lady’s finger bananas are bigger.</th>
<th>The blue bananas are smaller.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lady’s finger</td>
<td>Blue banana</td>
</tr>
</tbody>
</table>
Hence, my chosen type of banana (lady's finger) is green and short and the bananas are bigger than the blue bananas.

In the above exercise we have focused on the sense of sight since we made use of pictures. Note that in real life, we could also have used our sense of smell, taste and touch to classify the five types of bananas.

To sum up we realize that classifying allows us to identify, describe and comprehend the numerous living organisms in the world. It helps us organize our world and allows us to develop and refine concepts about the wide variety of living organisms around us.

By now you might have realized that we need to create a classification system to help compare and identify specific organisms, and discover how they might be related. Classification systems include big groups that are subdivided into smaller groups.

Do you happen to know the classification system used by scientists who study living organisms?

In Topic 1.2 you will learn how scientists who study living organisms, organize them into categories based on their relationships. However, before proceeding to Topic 1.2, let us see how much you have learnt in Topic 1.1, by doing the self-assessment exercise below.
Self-assessment 1.1

You need 20 minutes to do this self-assessment. This self-assessment is based on Topic 1.1. The answers are given at the end of this topic. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 1.1. This will help you learn and reflect better on areas for improvement.

a. What are the main ideas that we need to consider when classifying living organisms?

b. What are the advantages of classifying living organisms?

c. Using the example given in the classification of types of bananas in Activity 1.1.1 above, compare the following leaves by finding similarities and differences between them to help you identify the *wild passion fruit* leaf.
i. Now that you have identified the characteristics of the wild passion fruit leaf, describe it as fully as you can.

ii. Is there another way how you could have compared and classified the leaves to identify the wild passion fruit leaf?

Well done! I have provided you with the Answers to Self-assessment 1.1 below.
Answers to Self-assessment 1.1

a. When we classify living organisms, we reflect on the similarities and differences between the organisms. This helps us to see patterns in the different categories of living organisms and enables us to identify and describe the different organisms.

b. Classifying living organisms help us make sense of the vast number of living organisms around us. Classifying helps us to comprehend the numerous living organisms in the world. It allows us to develop and refine concepts about the organisms. It also helps us organize our world and allows us to identify organisms around us.

c. A possible classification to help identify the wild passion fruit leaf:

i. The wild passion fruit leaf is therefore a heart-shaped lobed leaf.

ii. Yes, objects and organisms can be grouped into many different ways. I am sure that you have grouped the leaves in a different way. Share your work with other students and note the different ways how the leaves have been grouped. You should realize that the way of classifying/grouping depends on the purpose of the grouping, and also the individual’s preference.

This brings us to the end of topic 1.1. Reflect back on what you have learned about classifying organisms. What are some ways you can classify organisms? Why is classification important? I hope you know the answers to these questions. If you do not, make sure you review this topic before moving on.

The next topic will deal with classification keys. We will keep build on knowledge gained in topic 1.1.
Topic 1.2: Classification Keys

Students doing the extended syllabus will need 2 hours 30 minutes to do this topic and 1 hour and 15 minutes of your own time to further practice using dichotomous keys. Those of you who are doing the core syllabus will only need 1 hour 40 minutes at the most to do this topic. It is advisable that you spend another 50 minutes of your own time to further practice using dichotomous keys.

In Topic 1.1, you created your own classification system to help you identify individual organisms from a larger group of organisms. What did you consider to help you identify individual organisms?

Good! You drew on the similarities and differences between the organisms and used these to help you identify specific characteristics of particular organisms. Special characteristics of organisms allow us to group them together. We can use these characteristics to develop classification keys.

1.2.1 Characteristics of a classification key

Group Activity 1.2.1

You need 10 minutes for this activity.

Some of you might have an idea of what a classification key is. Those of you who are not sure and who have access to the internet, type the question “What is a classification key?” and do some Google search for definitions. If you do not have access to the internet, look for book definitions of the term. Once you have found a good definition, share your ideas with colleagues before continuing to the next section. Also, try to explain this using pictures and diagrams that you may have seen on the internet or in a book.
Feedback to Group Activity 1.2.1

I am not going to give you a textbook definition of what a classification key is, but you would have realized from your discussions that it involves the diagnosis of the characteristics that an object or organism has and grouping objects or organisms according to these observed characteristics.

In a classification key we start with the more general characteristics and progressively move to the more specific characteristics of the object or organism. The key leads to a series of questions or choices about the characteristic of the object or organism. By the time you have answered all the questions about the diagnosed characteristic, the object or organism should be identified.

It is important for us to note that early classification systems were based simply on characteristics that were observable to the eye. Present day scientists now focus on genetics, cellular make-up and other internal characteristics when they classify organisms.

It is now time for you to learn how classification keys are constructed. You will learn about dichotomous keys below. We shall start by looking at what are dichotomous keys and the types that are used.

1.2.2 What are dichotomous keys?

A dichotomous key is a tool designed to assist people with the identification of items in the natural world. “Dichotomous” means “divided into two parts”, with contrasting or opposite ideas or descriptions. Therefore, dichotomous keys always give us two choices in each step. These are initially very general and become more specific as you proceed through the steps.

By analyzing the characteristics of the object/organism in question and using the steps and choices given in the key, you can identify an object/organism based upon established features.

When you construct a dichotomous key, it is important to note that each pair of contrasting descriptions must deal with the same characteristic.
Reflection 1.2.1

You need 10 minutes for this activity.

In the classification of the leaves in the Self-assessment 1.1 above,

a. What was the first characteristic that you used to differentiate between the four leaves?

b. Give a couple of examples of incorrect pair of statements. In other words, what kind of statement will NOT have helped you differentiate between the four leaves?

You will have realized by now that you used principles of a dichotomous key to help you identify the wild passion fruit leaf and your chosen type of banana in Activity 1.1.1 above. Equally, if you use ideas that are NOT contrasting or different, you cannot move on to identify the species of choice.

Let us now look at different types of dichotomous keys.

1.2.3 Types of dichotomous keys

Dichotomous keys can be written as a branching or spider key, or as a list
We will now look at each type of key in Activity 1.2.1 below.

**Activity 1.2.1**

**You need 20 minutes to complete the activities below.**

We shall first make a list key, and use the same information to construct a branching or spider key.

Suppose you have the following five fruits:

![Fruits Images](http://www.google.com/images)

After studying the fruits, you might consider the following characteristics as the main characteristics in the different steps of the key: **number of seeds, shape of seed, colour of flesh and shape of fruit.** To begin the key, let us consider the characteristic **number of seeds**, hence the question

1. **Does the fruit have many seeds?**

This question will allow us to have two groups of fruits:

- **Fruits with one seed** (avocado and mango)
- **Fruits with more than one seed** (watermelon, apple and pawpaw)

We shall now start the list key from the above question, using the two groups of fruits. To do that we need to look at each group separately to find a characteristic that will help us differentiate further between the fruits in each group. Hence step 1 of the key is as follows:

1. (a) Fruits with one seed .......................................... go to step 2
   (b) Fruits with more than one seed ......................... go to step 3

Step 2 needs to consist of a pair of statements that will lead to the identification of the avocado and the mango. We shall consider **shape of seed** as the diagnostic characteristic, hence the question:

2. **Is the seed round?**

In step 2 we therefore have:

2. (a) Fruits with round seed ...................................... avocado
   (b) Fruits with oval seed........................................ mango
As we have identified the avocado and the mango, we now move to step 3 to lead us to the identification of the three fruits with more than one seed.

Step 3 needs to consist of a pair of statements that will lead to the identification of the water melon, apple and pawpaw. We shall consider the **colour of flesh** as the diagnostic characteristic, hence the question:

3  *Is the flesh varied in colour?*

In step 3 we therefore have:

3  (a) **Fruits with flesh of two distinct colours** .............. water melon
    (b) **Fruits with flesh in one colour** .......................... go to step 4

Step 4 needs to consist of a pair of statements that will lead to the identification of the pawpaw and the apple. We shall consider **shape of the fruit** as the diagnostic characteristic, hence the question:

4  *Is the fruit oval?*

In step 4 we therefore have:

4  (a) **Fruit with oval shape** ................. pawpaw
    (b) **Fruit with heart shape** ....................... apple

Using only the questions in the list key above, I have also represented the list key in diagram form below.

**1.2.3.1 A list key**

1. **Does the fruit have many seeds?**  
   No  Go to 2  
   Yes  Go to 3

2. **Does the fruit have round seed?**  
   No  It is a mango  
   Yes  It is an avocado

3. **Is the flesh varied in colour?**  
   No  Go to 4  
   Yes  It is a water melon

4. **Is the flesh oval shaped?**  
   No  It is an apple  
   Yes  It is a pawpaw

Figure 1.2.2: A list key
The two options which we begin within a list key are the essential characteristics which will lead us through the key to identify the fruits. Starting with the first question, follow through the list key until you have identified each individual fruit.

Notice how each time we have used one characteristic which clearly allows us to differentiate between the fruits.

To test your understanding of the list key, I would now like you to tell us about the pawpaw by writing its characteristics below.

If you have said that the pawpaw is a fruit with many seeds, its flesh is of one colour and it is oval shaped, then you have no difficulty understanding a list key.

Now that you have understood a list key, you have learnt the essential aspects of dichotomous keys. You are therefore ready to learn about a branching/spider key. Let us now see how a branching/spider key can help us identify the fruits.

1.2.3.2 A branching/spider key

![Diagram of a branching key]

Figure 1.2.3: A branching key

Drawn by: Mariette Lucas (2010)
To see if you have understood the key, answer the following questions:

a. Which of the fruits has one seed which is oval-shaped?

b. Differentiate between the watermelon and the avocado.

I am sure that you did not have any difficulty answering the two questions using the dichotomous branching/spider key.

Surely you could tell that the mango is a fruit with one seed, which is oval-shaped. In the case of the watermelon and the avocado we can tell that the watermelon is a fruit with many seeds and flesh which has two distinct colours, whereas the avocado is a fruit with one round seed.

Now look back at the branching/spider key and the list key. In each case you had to identify five different fruits.

Compare the number of characteristics or steps that were used in each type of key and the number of fruits that were classified. What relationship do you notice?
You have probably noticed that there were five fruits to be identified and we used only four characteristics or four steps to identify each individual fruit. This is always the case with dichotomous keys; there should be one step less than the total number of organisms to be identified in the key.

Let us now get your impressions about the two types of keys.

Which one of the two types of keys do you find easier to understand?

You are right! Branching/spider keys are easy to use, but they take up a lot of space when fully drawn out. It is for this reason that the listed form is usually used more often by scientists.
1.2.4 Using dichotomous keys

You have used dichotomous keys in Activity 1.2.1 above. You should have realized that using a dichotomous key is like following the branches of a tree, where each additional branch gets smaller and smaller until you reach a single branch tip. Each branch tip represents a single species or object.

In using a dichotomous key, you should keep the following in mind:

- Begin with the first pair of statements and follow the descriptions of each successive pair of statements until you reach the name of the organism / object that you are trying to identify.
- Always read both statements in each branch carefully, even if the first seems to be the most obvious at first.
- Always ensure that you understand the meaning of the words involved. Do not guess.
- Do not guess measurements. Always use a measuring instrument if required.
Activity 1.2.2

You need 15 minutes to complete this activity.

1. Pictures of four birds of Seychelles are shown below.

1a. Bird with long thin curved beak…………………\textit{Seychelles sunbird}

1b. Bird with short pointed beak…………………….go to 2

2a. Bird with black and white tail feathers…………..go to 3

2b. Bird with brown tail feathers……………………\textit{Madagascar fody}

3a. Yellow patch around the eyes.......................\textit{Indian mynah}

3b. Blueish patch around the eyes......................\textit{Barred ground dove}

Source: Birds of Seychelles (1990)
a). Use the list key to identify the birds. As you identify each bird write its name in the space provided underneath the pictures above.

b). Describe the Indian mynah.


Well done! I have provided you with the Feedback to Activity 1.2.2 at the end of this topic. You are, however, strongly advised to first complete the activities on your own before you refer to the feedback. This will help you learn and reflect better on areas for improvement.

You will get plenty of other opportunities to use dichotomous keys in this unit as well as other units in the course.

**Feedback to Activity 1.2.2**

a). The names of the birds are as follows:

![Image of birds](image1)

**Malagasy fody**

**Indian Mynah**

![Image of birds](image2)

**Barred ground dove**

**Goldfinch**

**Figure 1.2.4**

Source: **Birds of Seychelles (1990)**

b.) The Indian mynah has a short pointed beak, black and white tail and yellow patch around the eyes.
1.2.5 Constructing Dichotomous Keys

This section is for students who are doing the extended objectives only. If you are a student doing the core objectives, you may also attempt this section, if you wish to do so. If you choose not to do this section, you would have an extra 50 minutes to review the unit.

It is easy for you to make your own dichotomous key for any group of living organisms or non-living things that you want to organize, using physically observable characteristics.

If you follow the guidelines below, you will be able to construct dichotomous keys for many different organisms. Please note that the more similarities the group of organisms has, the more difficult it is to develop a key.
**REMEMBER** – There are usually several different ways in which you can construct a key, but at each stage, you need to focus on the special characteristics of a particular organism, and this would enable a person to name the organism you are referring to.

In **constructing keys**, keep the following in mind:

- Use constant characteristics (e.g. colour, shape,...) rather than changing ones (e.g. temperature, speed,...)
- Use measurement rather than terms like “large” and “small”.
- Use characteristics that are available to the user of the key rather than varying or recurrent ones.
- Make the choice a positive one – an object “is” instead of “is not”.
- If possible, start both choices of a pair with the same word.
- If possible, start different pairs of choices with different words.
- Begin the descriptions with the name of the part to which they apply.

Now it is your turn to construct a dichotomous key. You will need to ask for the assistance of the laboratory technician or your Science teacher to advice you about the safety precautions when working with living organisms on the activities below.
Group Activity 1.2.2

For this activity you need 15 minutes.

Find 4 different organisms, for example 4 different types of insects/fish or dogs or 4 different types of leaves/plants or flowers or any other living organisms that have some similarities. With a partner, design either a list key or a branching key for the 4 organisms that you have chosen.

Remember to follow the guidelines discussed above in “constructing a dichotomous key”. The branching/spider key and the list key above should help you construct your key.

Draw your key in the space below.

Review the guidelines on how to use a dichotomous key above. Then, test your key to ensure that there are no errors and that the statements are clear. Ensure that you are quite satisfied with your key before letting others use it.
Group Activity 1.2.3

You need to give your friends at least 20 minutes to complete the key and use another 10 minutes to reflect and modify it.

Now test your key with a group of students in the class or any other group of people.

Give a clean copy of the key to the group of people/students that you have identified. You also need to give them the four organisms that you used (for example the 4 different types of insects) and a fifth organism, belonging to any of the groups. This would allow for further verification of the reliability of the key.

You need to clearly explain to the students how they should use the key to identify the given organisms. Then ask the students to follow through the key to identify the 5 organisms.

You need to stay beside the students while they are working. Take note of any questions that they ask and give them any assistance that they require.

Once the activity is over, answer the questions below.

a). How easy was it for the students to identify the organisms from your key?
b). What were some of the difficulties that your colleagues experienced while using the key?

Now use the observations and comments made to improve your key.

I hope that you found the exercise interesting. As you go through the unit, you will have opportunities to further practice using and constructing keys.

It is now time to see how much you have learnt in this topic. You will do this by doing the self-assessment below.
Self-assessment 1.2

You should be able to do this self-assessment in about 15 minutes. The answers are given at the end of this topic. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 1.2. This will help you learn and reflect better on areas for improvement.

This key is about domestic cats. Study the key; then answer the questions which follow.

![Classification of domestic cats diagram](image)

Figure 1.2.5: Classifying domestic cats
Designed by Mariette Lucas (2010)

a. Describe the Tabby cat.

b. Which domestic cat is short-haired and has a triangular head?

c. What similarity exists between all four cats?
d. Using the information on the key, write the names of the cats under their pictures.


Photos of tabby cat and smoke cat taken by Mariette Lucas (2010).
I am sure that you understand classification keys very well by now. I have provided you with the Answers to Self-assessment 1.2 below.

**Answers to Self-assessment 1.2**

a. The Tabby cat is a long-haired domestic cat with striped coat.

b. The Siamese is short-haired domestic cat with a triangular head.

c. All four cats are domestic cats.

d. 


Photos of tabby cat and smoke cat taken by Mariette Lucas (2010).

Well done! This brings us to the end of topic 1.2. Are you comfortable with classification keys now? If you have access to the internet, try the following classification activity by clicking on “launch interactive” [http://www.pbs.org/wgbh/nova/nature/classifying-life.html](http://www.pbs.org/wgbh/nova/nature/classifying-life.html)

Please note that this site is provided for information only and we do not support or endorse any links from this site.

If you are ready, let’s move onto topic 1.3 which deals with binomial nomenclature. From the title, you should be able to tell that the topic will be dealing with naming something.
Topic 1.3: Binomial Nomenclature

To do this topic you will need 1 hour of formal study time. It is advisable that you spend another 30 minutes of your own time to find the binomial names of some other organisms that you know.

Almost every one of us has a pet.

Which animal is your pet? Suppose you were to tell students in ten different countries which animal your pet is, would they all know which animal you are talking about? How can you be sure?

You are right! Even if there are billions and billions of living organisms on earth, it is easy for the same organism to be recognized across the world. This is thanks to biologists who have classified them into meaningful groups according to how closely they are linked to each other.

Biologists have also found it important for the different groups of organisms to be named in an organized way, giving each organism its uniqueness. What do you think would happen if the yellow fin tuna, which is found in the Seychelles waters as well as in many different parts of the world, had different scientific names? Write your ideas below.

As you must have realized, this would have caused a lot of confusion and disorder in the world wide data banks about this species of tuna. It is therefore very important for scientists to use exactly the same names for particular kinds of living organisms.

Early naturalists used long complicated phrases to name the different types of animals and plants. This naming system was known as the “polynomial system.” In this system, a plant might be described by a phrase of ten or more words. Polynomial names could become very
complex and were often misinterpreted when translated from one language to another.

A more reliable and efficient naming system was developed in the mid 18th century. This system is known as the “binomial nomenclature”. It is a universal system that is used in all countries irrespective of language barriers.

1.3.1 Scientific names of organisms

The binomial nomenclature is a system developed for the naming of organisms. Binomial means “two names”. Hence the binomial nomenclature is a two-part naming system used by scientists to name each of the different species of organisms. The first part of the name gives the genus (first letter capitalized) and the second part gives the species (lowercase), with both genus and species written in Latin and in italics. The genus refers to a group of closely related species, and the species refers to the smallest group of organisms. You will learn more about genus, species and other larger groupings of organisms in the topic ‘Hierarchical classification’ in this unit.

The binomial nomenclature was developed by a Swedish naturalist called Carolus von Linnaeus in 1735.

Let us find out how the binomial nomenclature works by using the example of the tea rose.

A rose is a perennial flower shrub or vine. Rose plants form a group of erect shrubs, and climbing or trailing plants, with stems that are often armed with sharp prickles. There are over 100 species of roses ranging from various species of wild roses, modern and old garden roses, landscape roses and carpet roses. All the different species of roses belong to the genus “Rosa”. The tea rose is one of the species of old garden rose named for their fragrance (odorata.) The binomial name or scientific name for the tea rose is therefore Rosa odorata.

Source: http://en.wikipedia.org/wiki/Rose
Activity 1.3.1

You should be able to complete this activity within 30 minutes.

a. Let us practice writing the binomial (scientific) names of some organisms using their genus name and species name.

In Table 1.3.1 (a) below, I have given you either the genus name or the species name of six living organisms that you are familiar with or their scientific name. Refer to the example of the tea rose that I have done for you and write the missing information on the table.

<table>
<thead>
<tr>
<th>Living organisms</th>
<th>Common name</th>
<th>Genus</th>
<th>Species</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.g. Tea rose</td>
<td>Rosa Odorata</td>
<td>Rosa</td>
<td>Odorata</td>
<td>Rosa odorata</td>
</tr>
<tr>
<td>Domestic cattle (cow)</td>
<td>Bos Primigenius</td>
<td>Bos</td>
<td>Primigenus</td>
<td></td>
</tr>
<tr>
<td>Killer whale</td>
<td>Orcinus Orca</td>
<td>Orcinus</td>
<td>Orca</td>
<td></td>
</tr>
<tr>
<td>Malaria mosquito</td>
<td></td>
<td></td>
<td></td>
<td>Anopheles quadrimaculatus</td>
</tr>
<tr>
<td>Mauritius blue pigeon</td>
<td>Alectroenas Nitidissima</td>
<td>Alectroenas</td>
<td>Nitidissima</td>
<td></td>
</tr>
<tr>
<td>Breadfruit</td>
<td></td>
<td></td>
<td></td>
<td>Artocarpus altilis</td>
</tr>
<tr>
<td>Pawpaw</td>
<td>Asimina Triloba</td>
<td>Asimina</td>
<td>Triloba</td>
<td></td>
</tr>
</tbody>
</table>

Table 1.3.1(a): Binomial naming system of organisms

b. Those of you who can access the internet go to Wikipedia, the free encyclopedia, and look for the scientific names of the following organisms: guinea pig, coconut, black parrot, human beings and domestic dog. If you find the names of organisms other than the ones given here, you may use them instead. Note that Wikipedia is a collaborative encyclopedia and information on that site may not always be correct. It is therefore important that you refer to other sources or websites to verify your information.
Those of you, who do not have access to the internet, do your research in biology books and under the topic “classification.” If you do not find information on the given organisms use any five organisms for which you can find the scientific names.

In Table 1.3.2 below, write the common name of each organism, their scientific name, the genus name and species name.

<table>
<thead>
<tr>
<th>Living organisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common name</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Table 1.3.2: Binomial naming system of organisms

Well done! I have provided you with the feedback for the exercises (a) and (b) of Activity 1.3.1 at the end of this topic. You are, however, strongly advised to first complete the activities on your own before you refer to the feedback. This will help you learn and reflect better on areas for improvement.

It is now time for us to see how much you have learnt in Topic 1.3. Do the self-assessment below to test your understanding.

**Self-assessment 1.3**

You should be able to complete this self-assessment in 15 minutes. This self-assessment is based on Topic 1.3. The answers are given at the end of the topic. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 1.3. This will help you learn and reflect better on areas for improvement.
a. Using your own words complete this cloze passage.

The___________________________is a two-part naming system used by scientists to name the different species of organisms. The first part of the name gives the ______________________ (first letter capitalized) and the second part gives the ______________________ (lowercase). The genus and species names are written in__________________________and in _______________________. The binomial nomenclature was developed by a Swedish naturalist called ______________________in 1735.

b. Write the scientific name for the following organisms;

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human beings</td>
<td></td>
</tr>
<tr>
<td>Malarial mosquito</td>
<td></td>
</tr>
<tr>
<td>Seychelles black parrot</td>
<td></td>
</tr>
</tbody>
</table>

Table 1.3.1: Binomial naming system of organisms

c. The common name and the scientific name of five different organisms are given in Table 1.3.4 below. Use the information in the table to answer questions (a), (b), and (c) which follow.
<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lion</td>
<td><em>Panthera leo,</em></td>
</tr>
<tr>
<td>Barn owl</td>
<td><em>Tyto alba</em></td>
</tr>
<tr>
<td>Leopard</td>
<td><em>Panthera pardus</em></td>
</tr>
<tr>
<td>Tiger</td>
<td><em>Panthera tigris</em></td>
</tr>
<tr>
<td>Gray wolf</td>
<td><em>Canis lupus</em></td>
</tr>
</tbody>
</table>

Table 1.3.4 Binomial naming system of organisms


i). Which organisms are related? How could you tell?

ii). The domestic dog is related to the gray wolf. What would be its genus name?

iii). How can you differentiate between the genus name and the species name of an organism?
I am sure that you have successfully managed to answer the self-assessment questions above. I have provided you with the Answers to Self-assessment 1.3 at the end of the topic.

**Feedback to Activity 1.3.1**

a. We hope that you have been able to find some of the scientific names of the animals and plants given. These are given in Table 1.3.1(b) below

<table>
<thead>
<tr>
<th>Common name</th>
<th>Genus</th>
<th>Species</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic cattle (cow)</td>
<td><em>Bos</em></td>
<td><em>primigenius</em></td>
<td><em>Bos primigenius</em></td>
</tr>
<tr>
<td>Killer whale</td>
<td><em>Orcinus</em></td>
<td><em>orca</em></td>
<td><em>Orcinus orca</em></td>
</tr>
<tr>
<td>Malaria mosquito</td>
<td><em>Anopheles</em></td>
<td><em>quadrimaculatus</em></td>
<td><em>Anopheles quadrimaculatus</em></td>
</tr>
<tr>
<td>Mauritius blue pigeon</td>
<td><em>Alectroenas</em></td>
<td><em>nitidissima</em></td>
<td><em>Alectroenas nitidissima</em></td>
</tr>
<tr>
<td>Breadfruit</td>
<td><em>Artocarpus</em></td>
<td><em>altulis</em></td>
<td><em>Artocarpus altulis</em></td>
</tr>
<tr>
<td>Pawpaw</td>
<td><em>Asimina</em></td>
<td><em>triloba</em></td>
<td><em>Asimina triloba</em></td>
</tr>
</tbody>
</table>

Table 1.3.1 (b): Binomial naming system of organisms

b. In Table 1.3.2 we have also provided you with some of the English equivalents of the Latin words to help you make sense of the names that scientists have given to each organism.
### Living organisms

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Genus</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domestic Pig</td>
<td><em>Sus domestica</em></td>
<td><em>Sus</em></td>
<td><em>domestica</em></td>
</tr>
<tr>
<td>Coconut</td>
<td><em>Cocos nucifera</em></td>
<td><em>Cocos</em></td>
<td><em>nucifera</em></td>
</tr>
<tr>
<td>Seychelles Black Parrot</td>
<td><em>Coracopsis nigra barklyi</em></td>
<td><em>Coracopsis</em></td>
<td><em>nigra barklyi</em></td>
</tr>
<tr>
<td>Human beings</td>
<td><em>Homo sapiens</em></td>
<td><em>Homo</em> (man)</td>
<td><em>sapiens</em> (wise)</td>
</tr>
<tr>
<td>Domestic dog</td>
<td><em>Canis familiaris</em></td>
<td><em>Canis</em> (descendant of the common wolf)</td>
<td><em>familiaris</em> (domesticated)</td>
</tr>
</tbody>
</table>

Table 1.3.2: Binomial naming system of organisms
Answers to Self-assessment 1.3

a. The **binomial nomenclature** is a two-part naming system used by scientists to name the different species of organisms. The first part of the name gives the **genus** (first letter capitalized) and the second part gives the **species** (lowercase). The genus and species are written in Latin and in **italics**. The binomial nomenclature was developed by a Swedish naturalist called **Carolus von Linnaeus** in 1735.

b.

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human beings</td>
<td><em>Homo sapiens</em></td>
</tr>
<tr>
<td>Malarial mosquito</td>
<td><em>Anopheles quadrimaculatus</em></td>
</tr>
<tr>
<td>Seychelles black parrot</td>
<td><em>Coracopsis nigra barklyi</em></td>
</tr>
</tbody>
</table>

Table 1.3.1(b): Binomial naming system of organisms

(c i). The lion, the leopard and the tiger are related. They belong to the same genus.

c (ii). The domestic dog’s genus name would be **canis**. Its scientific name is **Canis familiaris**.

c (iii). The genus name begins with a capital letter whereas the species name is in small letters. Both are written in italics and in Latin.

Now that you are at the end of topic 1.3, how comfortable are you with naming organisms? Think of three organisms to name. Were you able to name them correctly? If you were, move onto topic 1.4. If you were not, make sure to review topic 1.3 one more time.

In the next topic, we will learn about the hierarchical classification system. Make sure to reflect back on what you learned about classification systems to help you understand this new form of naming organisms.
Topic 1.4: Hierarchical Classification

You are expected to complete this topic within 1 hour 50 minutes. It is advisable that you spend another 55 minutes of your own time to further practice using hierarchical classification.

In Topic 1.3 you learnt that Carolus von Linnaeus invented a very useful system for the naming of organisms.

a). What is the system called?

b). What does this naming system comprise of? Give one example of the scientific name of an organism to support your explanation.

As you realized the binomial nomenclature is a two-part naming system comprising of the genus and the species name of an organism. You will also recall that when classifying, we start with big groups and progressively subdivide the organisms into smaller groups until we can identify individual organisms.

Carolus von Linnaeus also created a hierarchical biological classification system using seven taxonomic categories. These seven categories are: Kingdom, Phylum (plural-phyla), Class, Order, Family, Genus (plural-
genera), and Species. Beginning with Kingdom (the big group), each successive level of classification becomes more and more specific.

You may want to use a mnemonic tool to help you remember the hierarchical classification system. All you need to do is to make a sentence that is easy for you to remember using the first letter of the taxonomic group, beginning with kingdom and ending with species. Here is one example I have created for you: “Kenneth Paul Can Own Five Gigantic Stores.”

**Activity 1.4.1**

You should be able to complete these activities in 10 minutes.

a. Using the above mnemonic tool, list the seven taxonomic categories in order.

b. In which of the following taxonomic categories would organisms have more common characteristics and resemble each other more; in a class or in a family? Explain your answer.

We hope that you found the mnemonic tool useful in helping you remember the taxonomic categories in order. With practice you should become very good in using it. You may also wish to create your own memory aid tool for these categories. Should you find an easier one, you
are welcomed to share it with other colleagues and teachers.

Well done! I have provided you with the Feedback to Activity 1.4.1 at the end of the topic. You are, however, strongly advised to first complete the activities on your own before you refer to the feedback. This will help you learn and reflect better on areas for improvement.

Feedback to Activity 1.4.1

a. The seven taxonomic categories are: Kingdom, Phylum, Class, Order, Family, Genus, and Species.

b. Members of a class have more varied characteristics than members of a family. Members of a class are grouped into different orders and members of each order are further grouped into more specific families.

Let us learn more about each of the different taxonomic categories below

1.4.1 Kingdoms

As highlighted above, the biological classification system consists of seven taxonomic categories. The first and largest category is called a kingdom.

Scientists have grouped organisms into a six-kingdom system according to the relationships among the different groups of organisms that exist on earth. The six-kingdom system is as follows:

Figure 1.4.1: The six kingdom system
Drawn by Mariette Lucas (2009)

Table 1.4.1 below briefly describes each of the six kingdoms agreed on by modern scientists.
<table>
<thead>
<tr>
<th>The six kingdoms</th>
<th>Main characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>Have only one cell, no nucleus. Too small to be seen with the naked eye.</td>
</tr>
</tbody>
</table>
| Archaea          | Have one cell, no nucleus.  
Similar in size to the bacteria but with different genetic makeup. |
| Protista         | Most have one cell, with a nucleus and other cell structures.  
Examples: algae, amoeba |
| Plantae          | They have many cells and cannot move from one place to another. They use energy from the sun to make their own food.  
Examples: ferns, vegetables, flowers, trees. |
| Fungi            | Most have many cells. Fungi cannot move from one place to another. They absorb nutrients from other organisms.  
Examples: mushrooms, yeast, moulds |
| Animalia         | They have many cells. Most can move from one place to another. They get energy by feeding on other organisms.  
Examples: insects, crabs, birds, reptiles. |

Table 1.4.1: Description of the six kingdoms  
The activity below will help you master the characteristics of kingdoms.

**Activity 1.4.2**

The activities below should not take you more than 10 minutes.

a. Think of as many organisms that you know that would belong to the kingdom animalia. What does this tell you about the types of organisms in a kingdom?

b. Examine the characteristics of organisms in each of the six kingdoms. What conclusion can you draw about the characteristics of organisms in specific kingdoms?

**Feedback to Activity 1.4.2**

You must have realized from the above activity that each kingdom contains many organisms, each different from one other but sharing the same basic characteristics.

All organisms belonging to the animal (animalia) kingdom, for example, have many cells; most can move from one place to another and they get energy by feeding on other organisms. However, these are very general characteristics. To be able to identify individual organisms a kingdom has to be further divided into smaller groups.
Let us now look more closely at the animal (animalia) kingdom to understand further about the other five taxonomic groups.

1.4.2 Phylum

Organisms in each of the six kingdoms can be divided into different phyla (plural of phylum) based on their body plan, as well as their developmental and internal organisation. In the animal kingdom, those animals that have a backbone belong to the sub-phylum vertebrates of the phylum chordata. Animals in the phylum chordata, all have a dorsal nerve cord and a skeletal notochord (flexible, rod shaped body) at some point in their development, but it is only in the vertebrates that the notochord has been replaced by a number of interlocking bones (vertebrae) forming an internal bony skeleton.

The other animals are the non-chordates. They are all invertebrates (animals without a backbone) and they belong to many different phyla such as arthropoda, mollusca, and annelida. Animals of each phylum have very different characteristics. Arthropods for example have firm exoskeleton, and jointed appendages (body and limbs). Molluscs all have a head, a muscular foot and a dorsal hump containing internal organs. They also have soft skin and a calcareous shell. Annelids are wormlike invertebrates with well developed segmentation and a fluid-filled cavity between the body wall and the gut.

Which of the following animals would belong to the phylum chordata: shark, duck, dragonfly, snail, and frog? Give reasons for your answer. Also, if you have access to the internet, look up at least two other animals that belong to the phylum chordata.
I am sure that you have said that the shark, the duck and the frog belong to the phylum chordata since they have a skeletal notochord. These animals also belong to the sub-phylum vertebrates since they have an internal bony skeleton (vertebrae), which has replaced the notochord. As for other examples, you should have come up with pretty much anything that has a dorsal nerve cord and a skeletal notochord.

Let us now consider the sub-phylum vertebrates, to learn about the various classes of vertebrates.

### 1.4.3 Class

Each phylum and sub-phylum is divided into a number of classes. Organisms in each class have very distinct features which separate them from organisms in the other classes of the same phylum. The sub-phylum, vertebrate, for example, is made up of five classes of animals: fish, reptiles, amphibians, birds and mammals. Animals in each of the five classes of vertebrates are very different from each other. Birds for example have skin covered with feathers, dry scales on their legs and they have wings; mammals on the other hand have hair or fur on the body; their young develop inside the mother’s uterus attached to the mother through an umbilical cord and placenta.

Before we proceed further, let us review the first three levels of the biological classification system.

### Activity 1.4.3

You should be able to complete the activities below in 10 minutes.

a. Write a short paragraph to explain to a friend the first three taxonomic categories in the biological classification system.
b. Complete the diagram below to show how *Homo sapiens* (human beings) are classified in the first three taxonomic groups.

![Diagram of taxonomic classification]

Figure 1.4.2: Classifying *Homo sapiens*

*Figure created by author*

Well done! I have provided you with the Feedback to Activity 1.4.3 at the end of the topic. You are, however, strongly advised to first complete the activities on your own before you refer to the feedback. This will help you learn and reflect better on areas for improvement.
Feedback to Activity 1.4.3

That was good work. It shows that you have understood the first three taxonomic categories well. You may wish to compare your answers with mine below.

a. Indeed, you’re right if you said that the first three taxonomic categories are kingdom, phylum and class. Kingdom is the largest category and comprises of six different kingdoms (bacteria, archaea, protista, plantae, fungi and animalia).

Phylum is the next category and it includes sub phyla. In the kingdom animalia for example, animals are either chordates or non-chordates. The vertebrates are a sub-phylum of the phylum chordates. All invertebrates are non-chordates. Non-chordates belong to different phyla such as arthropoda, mollusca and annelida.

Organisms in a phylum or sub-phylum are further divided into classes. For example, animals in the sub-phylum vertebrates are divided into five classes. These are birds, fish, reptiles, amphibians and reptiles.

b. Figure 1.4.2 below shows how *homo sapiens* are classified

![Diagram of Homo sapiens classification](image)

Figure 1.4.2: Classifying Homo sapiens

You can now read further about the last four taxonomic categories of the biological classification system.
1.4.4 Order

Each of the various classes of organisms is further divided into many orders. Let us consider the class Mammalia from the sub-phylum vertebrata, from the animal kingdom. One such order is called carnivora. Animals belonging to this order feed on the flesh of other animals. They usually have strong, sharp claws, well developed canines, and pre-molars and molars with cutting edges. Carnivorous mammals include animals such as dogs and foxes, weasels, seals and bears.

1.4.5 Family

Within each order there are a number of families. Mammals in the carnivora order for example belong to many different families. Carnivorous mammals such as otters, badgers and weasels belong to the mustelidae family. Mustelids have thick fur with a dense undercoat and a less dense outer coat. They have short ears and five toes on each foot. Some mustelids have an elongated body with a flexible backbone.

The domestic cat and other big / wild cats such as the tiger, lion, cheetah, leopard, jaguar, and cougar belong to the felidae family.

Let us do the short activity below to better understand orders and families.
Activity 1.4.4

I expect that you will not take more than 10 minutes to complete this activity.

Look carefully at some of the animals in the felidae family.


a. Give at least two ways how the animals in the felidae family look similar.

_____________________________________________________

_____________________________________________________

_____________________________________________________

b. Animals such as dogs, wolves, foxes and jackals belong to the canidae family. What characteristic do they share with animals in the felidae family?

_____________________________________________________

_____________________________________________________

_____________________________________________________
Well done! I have provided you with the Feedback to Activity 1.4.4 at the end of the topic below. You are, however, strongly advised to first complete the activities on your own before you refer to the feedback. This will help you learn and reflect better on areas for improvement.

Feedback to Activity 1.4.4

a. I am sure that you have realized that these animals (usually called felids) are cat-like. They are generally agile climbers, most are secretive animals and they are often nocturnal. They have soft-furred bodies, acute vision and hearing, and claws and teeth that are well adapted for grasping and tearing.

b. Animals of the canidae family such as dogs, foxes and jackals, and animals of the felidae family both belong to the carnivore order.

Let us now look at the genus and species groups.

1.4.6 Genus

Each family consists of varying numbers of genera (plural for genus). The animals in the felidae family are grouped in many different genera such as the genus Felis which includes animals such as the domestic cat. The genus pantherae includes all big cats that can roar, such as lions, tigers, leopard and jaguar.

1.4.7 Species

Animals in the same species are very closely related. They can interbreed and produce fertile offspring. The genus felis consists of a number of different species of cats, one of which is the domestic cat. The species name of the domestic cat is catus. Species is the smallest group in the biological classification system.

Now that you have learnt about the seven taxonomic categories of the biological classification system, show us how you would classify one animal by doing Activity 1.4.5 below. You may wish to ask your science teacher to help you find some of the required information or you can do your own Google search for some websites.
Activity 1.4.5

This activity should not take you more than 15 minutes.

a. Choose an animal and draw a chart below to represent how the animal fits in all the seven taxonomic categories of the biological classification system.

b. Ask your teacher to verify the correctness of the information on your chart. Then share your chart with your friends. You should all be able to convince each other that you have understood the biological classification system.

c. Copy the information that you have obtained for your chosen animal as well as three other animals from your friends in Table 1.4.2 below. Look for the scientific names of each animal and write them alongside their common names below. I have completed the example of the lion for you.
Well done! You have proved that you have really understood the biological taxonomic groups.

<table>
<thead>
<tr>
<th>Taxonomic categories</th>
<th>Animals Common names and scientific names</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kingdom</td>
<td>Animalia</td>
</tr>
<tr>
<td>Phylum</td>
<td>Chordata</td>
</tr>
<tr>
<td>Sub-phylum</td>
<td>Vertebrates</td>
</tr>
<tr>
<td>Class</td>
<td>Mammals</td>
</tr>
<tr>
<td>Order</td>
<td>Carnivora</td>
</tr>
<tr>
<td>Family</td>
<td>Felidae</td>
</tr>
<tr>
<td>Genus</td>
<td>Panthera</td>
</tr>
<tr>
<td>Species</td>
<td>Leo</td>
</tr>
</tbody>
</table>

Table 1.4.2: Biological classification of animals
The chart shows how the domestic cat is categorised in the biological classification system.

![Diagram of classification system]

**Figure 1.4.2: Classification of the domestic cat**

Source: Drawn by Serge Mondon; original idea Mariette Lucas (2010).

Use Figure 1.4.2 above to help you answer questions (a) to (e) below.

a. Which animal does not belong to the phylum chordata? Give a reason why you think it does not belong.
b. As the groups get smaller, the animals are more alike. State at least one way how the animals in the order carnivora are alike.

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

c. Which is the smallest group of animals in Figure 1.4.2?

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________

d. What common characteristic do animals of the same species share that cannot be shared by animals in other species?

______________________________________________________________________________

______________________________________________________________________________

______________________________________________________________________________
e. What is the scientific name of the domestic cat?

f. Look at the animal below.

Figure 1.4.3: An animal for classification
Source of photo: wildlifemysteries.wordpress.com

Draw a diagram in the space below to show how the animal fits in the first three taxonomic categories of the biological classification system.
That was an interesting exercise, wasn’t it? I have provided you with the Answers to Self-assessment 1.4 below.

**Answers to Self-assessment 1.4**

a. The ant does not belong to the phylum chordate, because it does not have a dorsal nerve cord and a skeletal notochord at some point in its development. It is a non-chordate and belongs to the phylum arthropoda.

b. Animals belonging to the carnivora order feed on the flesh of other animals. They usually have strong, sharp claws, well developed canines, and pre-molars and molars with cutting edges. Carnivorous mammals include animals such as dogs and foxes, weasels, seals and bears.

c. Species is the smallest group in the hierarchical classification system.

d. Animals of the same species can interbreed to produce fertile offspring.

e. The scientific name of the domestic cat is *Felis catus*.

f. The animal is the deer.

   i. It is related to animals such as cattle, goat, sheep, giraffe, camels, bison, antelope, llamas and wildebeest. They are all ruminants and digest plant-based food. They belong to the order **artiodactyla**.

   ii. Scientific Classification of the deer

   ```
   Kingdom: Animalia
   Phylum:   Chordata
   Class:    Mammalia
   Order:    Artiodactyla
   ```

How did you find this topic? Quickly reflect back on what you have learned. Are you able to use the hierarchical classification system with ease now? If you are, let’s move on.

In the next topic, we will be looking closely at vertebrates.
Topic 1.5: Vertebrates

You will need 3 hours at the most to do the activities in this topic. It is advisable that you spend another 1 hour and 30 minutes of your own time to research and consult people and/or documents to obtain the required information for some of the activities. You need to make prior arrangements with the persons that you need to consult to economize on your study time.

Think of an animal.

I am sure that you probably thought of a mammal such as a dog or a cow. This is because we are most familiar with mammals. Hence, many others would have come up with the same answer. You may wish to try asking the question to a few people around you.

As you are already aware, mammal is one class of vertebrates from the phylum chordata.

From what you have read in the previous section above,

\[a). \text{What do you understand by the term "vertebrates"? Write what you currently understand below.}\]

______________________________________________________________________________________

______________________________________________________________________________________

______________________________________________________________________________________

______________________________________________________________________________________

\[b). \text{What are the five classes of vertebrates? List them below.}\]

______________________________________________________________________________________

______________________________________________________________________________________

______________________________________________________________________________________

______________________________________________________________________________________
For sure, vertebrates have a hard, usually bony internal skeleton with a backbone. The backbone is made up of many small bones called vertebrae. The vertebrae are joined together making it possible for the vertebrates to move about easily.

There are five classes of vertebrates. They are fish, amphibians, reptiles, birds and mammals. Remember that animals in each of the five classes of vertebrates are very different from each other. We shall look at each of the five classes of vertebrate in the sections which follow. Let us start with fish.

1.5.1 Fish

Whenever we talk of fish, we suddenly think of a water environment. This is because all fish live and breathe in water. Some fish live in fresh water and some in sea water.

Fish are ectotherms (cold-blooded animals). They are unable to produce their own body heat. Their temperature depends on the temperature of their surroundings.

There are three main classes of fish. The two most common classes are the chondrichthyes (cartilaginous fish) and the osteichthyes (bony fish).

We shall start off by looking at the descriptions of cartilaginous fish.

Cartilaginous fish have placoid scales (flat and with sharp, tiny spines), a skeleton of cartilage and separate gill slits. Some examples of cartilaginous fish are:

- **Ray fish**
  *Dasyatis centroura*

- **White shark**
  *Carcharodon carcharias*
Bony fish have circular and thin scales with smooth edges, a bony skeleton and gills covered with an operculum. **Note that cartilaginous fish do not have an operculum, but have gill slits.** Some examples of bony fish are:

![Yellow fin tuna](Thunnus Albacares)

![Blue marlin](Makaira Nigricans)

![Flying fish](Cypselurus melanurus)

Figure 1.5.1

Fish drawn by Serge Mondon (2009).

Most fish have a streamlined body that helps them move swiftly through water. A fish has different types of fins which in different ways help the fish move through water.

The **caudal fin** (tail fin) helps to propel the fish forward in the water.

The **dorsal fin** (on the top side), the **anal fin** (behind the anus) and the paired **pelvic fins** or **ventral fins** (below the pectoral fins) help to stabilize the fish to stop it from rolling from side to side.

The paired **pectoral fins** (behind the operculum) help with fine movements; and also in moving the fish forward. Together with the pelvic fins the pectoral fins also serve as brakes.

Now use the information above to learn more about fish in Activity 1.5.1 below.
Activity 1.5.1

You should complete the activities below in about 50 minutes.

Study the cartilaginous and the bony fish above carefully.

a. Describe the main features of a fish.

b. Now compare your ideas with the main parts of a fish shown on the drawing below. Did you leave out any of the characteristics or did you include them all?

Figure 1.5.2: Main parts of a fish

You should also note that the operculum is found in bony fish only!

c. Using the information in the text above, label the pectoral fins, the pelvic fins, the caudal fin, the anal fin and the dorsal fin on the drawing of the fish below.
d. Look for three different types of fish and find both their common name and the binomial name of each fish. Then, with the assistance of a fisherman or your parents/friends/relatives, compare the parts of the three fish and describe them as fully as you can.

Make a leaflet of the three fish and show it to your teacher. You may also wish to give a copy of the leaflet to the fisherman or the person who assisted you. Keep your original leaflet in the portfolio.

e. Those of you, who have an aquarium at home or a stream close by, try to observe how a fish swims and how it breathes. You may wish to read further about this and include such information in your leaflet as well.

I am sure that you have made some interesting observations. I have provided you with the feedback to Activity 1.5.1 at the end of the topic below.
Feedback to Activity 1.5.1

a. Fish are cold-blooded animals. They have fins, gills and their skin is covered with scales.

b. The fins of the fish are as follows:

![Figure 1.5.3 (b): Labelled diagram of the fins of the fish
Drawn by: Serge Mondon (2009).]

We shall now look at the amphibians.

1.5.2 Amphibians

Amphibians comprise animals like the frog, toad and salamander. They have smooth, moist skin with no scales. Like the fish they are ectotherms (cold-blooded animals). Amphibians begin their life in water and most of them spend their adult life on land. They lay their eggs in water. Therefore the young amphibians have gills and breathe like fish. They also have tails which they use for swimming.

Amphibians undergo a process called **metamorphosis** (change in body form) as they grow. The changes take place both internally and externally. As the young amphibians grow older, they grow legs and they lose their gills. They breathe air through lungs and also through their moist skin. Many of the amphibians also lose their tail as they grow.
Figure 1.5.4 below shows how these changes take place in the frog.

**Life cycle of the frog**

Once the legs are developed and the lungs have replaced the gills, the frog moves on land. Its tail is re-absorbed and it grows into an adult frog.

The tadpoles then grow forelegs and their tails grow smaller. Lungs start to grow.

Frogs lay large numbers of eggs in water or in wet places.

After 21 days the eggs hatch into tadpoles. The tadpoles breathe with gills and feed on algae and plant material in water.

After about 5 weeks, the tadpole begins to change both internally and externally. First it grows hind legs.

Figure 1.5.4: Life cycle of the frog

Drawn by: Serge Mondon (2009)

Now that we have learnt about amphibians, we shall learn about reptiles.
1.5.3 Reptiles

Turtles, lizards, snakes, crocodiles and alligators are all reptiles. Look at the pictures of reptiles below; do you notice any common characteristics among them? Write a couple of your observations below.

Figure 1.5.5: Some reptiles


I am sure that it was not easy for you to come up with common characteristics of the reptiles, unless you have had firsthand experience with these animals. I have described the common of reptiles below.

All the reptiles have a dry and scaly skin. The scales tend to be horny with bony plates. Most have paired limbs with five toes on each limb. Most reptiles live on land, but some species have adapted special features to live in freshwater (e.g. crocodiles) and in marine environments (e.g. turtles). Reptiles lay rubbery-shelled eggs on land. They are also ectotherms (cold-blooded animals).

Let us now look more closely at one reptile, i.e. the turtle.
1.5.3.1 Turtles

Most turtles have a bony shell (or leathery skin for some species) on the top side of their body called the carapace, and a softer shell underneath the body called the plastron. Turtles live in water or near water. They have flatter or more streamlined shells which help in swimming. Many turtle species are endangered species.

Like all reptiles, turtles lay their eggs on land. Female turtles lay their eggs in holes which they dig in the sand. When the eggs hatch out, the young turtles rush down to the water. This journey is often very dangerous, and many of the young turtles are killed by predators.

The life cycle of the turtle is shown below.

Life cycle of the turtle

---

Baby turtles may take between 5 to 20 years before they mature and come to reproductive age.

Turtles mate on land or in water. Some turtles can store sperm and lay fertile eggs up to four years after mating.

As the temperatures drop with sunset, the hatchlings quickly pop their way out of the hole and scurry towards the sea. On the way and even in the sea, many can be eaten by birds, crabs, sharks and other predators.

The female turtle lays her eggs on land. She digs a hole in the sand with their hind legs. The eggs are laid gently into the hole and buried. Turtles can lay between on to 200 eggs at one go, depending on the species.

The eggs hatch about 60 days after being laid. Baby turtles dig their way up the hole when hatched. They wait under the last layer of sand until nightfall.

Figure 1.5.6: Life cycle of the turtle

Pictures adapted from: Seychelles Division of Environment; Conservation and National Parks Section (1994).
Turtles are species that are protected worldwide and there are penalties for people caught killing or interfering with turtles which come to nest on our beaches. You will find out more about this in Activity 1.5.2 below.

**Activity 1.5.2**

In 20 minutes you should complete the activities below.

Turtles’ nests and nesting sites are protected by law in most countries.

a. Find an article on the preservation of turtles in the national newspapers or any journals published by Environment Departments or related organizations in your country. Read the article and write an extract on the banner below. Remember to note the source of the information as well on the banner.

b. Keep a referenced copy of the article in your portfolio. You may also wish to look for and keep other related articles.

c. Use the new knowledge that you have gained about the preservation of turtles to write a letter to the Environment Department in your country to give your support for such initiatives. Keep a copy of your letter and any responses that you may get from the departments in your portfolio.

I am sure that you are now better aware of the efforts being made worldwide, and more specifically in your respective countries, to protect turtles. You should spread this awareness around and help in the
preservation of turtles and other endangered organisms.

Now that you are familiar with fish, amphibians and reptiles, we shall look at the birds.

1.5.4 Birds

Suppose you are to find out whether an animal is a bird. What main question would you ask?

I’m sure it was not difficult for you to realize that birds have features like the hen shown below.

The hen is an example of a bird. Birds have the following parts.

Birds are endotherms (warm blooded animals) with feathers. Hence birds produce their own body heat and maintain a warm body temperature. The feathers are light to enable flight and help trap heat from the body. All birds have a pair of wings, although not all use their wings for flight. The shape of a bird’s wings determines its style of flight; which could be gliding, soaring, or flapping. The lower parts of birds’ legs are covered with scales. Birds lay eggs with hard shell. They have hollow bones which make their bodies light.

1.5.4.1 Flightless birds

Even if all birds have wings, not all can fly. Some of the flightless birds are shown below.
Activity 1.5.3

You should complete these activities in 40 minutes.

a. Each of the four flightless birds shown above is described below. Read each description and try to identify and name the birds. Write the correct description next to the picture of the correct bird.

The ostrich is the largest living species of birds. It is native to Africa. Although ostriches do not fly they can run at great speeds.

Penguins spend most of their lives in water. They are good swimmers and have flipper-like wings and webbed feet. The back and heads of all penguins are black and their breasts are white. Male and female penguins are similar in appearance.

Now extinct, the dodo which was found in Mauritius has a large hooked bill and short thick yellow legs. It had undeveloped wings and tail, and was a sluggish bird which fast became extinct.

Emus have underdeveloped wings that are hidden under thick hair like feathers. The top part of the neck is naked. Emus are quite fast runners and are found in places such as Australia.

b. Find out whether there are flightless birds in your country from the Department of Environment.

For example, in Seychelles information could be sought from the following address:

<table>
<thead>
<tr>
<th>Division of Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Section</td>
</tr>
<tr>
<td>Fond Boffay</td>
</tr>
<tr>
<td>Praslin/Seychelles</td>
</tr>
<tr>
<td>Tel: 232984</td>
</tr>
</tbody>
</table>


Make a mini poster about the bird. Use pictures of the bird and its main characteristics to embellish your poster. Remember to write both its common and scientific names. How about writing its local name as well...! When your mini poster is ready, discuss it with your teacher, and then file it in your portfolio.
I hope that you have learnt some valuable information about flightless birds. I am sure that you have started to develop an interest in the protection of flightless birds, so that they do not become extinct like the dodo of Mauritius. Should you have an opportunity, it would be worthwhile to participate in the protection of birds and other animals.

It should not have been that difficult for you to identify the birds in (a) above. I have provided you with the Feedback to Activity 1.5.3 at the end of the topic below. You are, however, strongly advised to first complete the activities on your own before you refer to the feedback. This will help you learn and reflect better on areas for improvement.
Feedback to Activity 1.5.3

The following are the features of the different flightless birds.

Feedback

Now extinct, the dodo (*Raphus cucullatus*), which was found in Mauritius, had a large hooked bill and short thick yellow legs. It had undeveloped wings and tail, and was a sluggish bird which fast became extinct.

Emus (*Dromaius novaehollandiae*) have underdeveloped wings that are hidden under thick hair like feathers. The top part of the neck is naked. Emus are quite fast runners and are found in places such as Australia.

Penguins spend most of their lives in water. They are good swimmers and have flipper-like wings and webbed feet. The back and heads of all penguins are black and their breasts are white. Male and female penguins are similar in appearance. N.B Different species of penguins have different names. The Galapagos species is named *Speniscus mendiculus*.

The ostrich (*Struthio camelus*) is the largest living species of birds. It is native to Africa. Although ostriches cannot fly, they can run at great speeds.

We shall now have a look at the mammals.
1.5.5 Mammals

Mammals are the most familiar group of animals to us, human beings. After all, we are also mammals! The main characteristics of mammals are that they have hair or fur on the body; their young develop inside the mother’s uterus attached to the mother through an umbilical cord and placenta, but there are a few exceptional mammals that lay eggs. Young mammals feed on their mother’s milk from the mother’s mammary glands. Most mammals live on land and have four legs. Mammals are endotherms (warm blooded animals).

Activity 1.5.4

You should complete the reading and the activity below in no less than 10 minutes.

Find a picture of a mammal and stick it in the space below. Alongside your picture, make a list of ten other mammals.
I am sure that your list included mammals such as cows, lions and rats. These mammals belong to one of the subclasses of mammals, i.e. the **placental** mammals. This is normal as this subclass contains a much larger and more widespread species.

There are three main subclasses of mammals; the **monotremes**, the **marsupials** and the **placental** mammals. We shall start by looking at the monotremes, which is the smallest subclass of mammals.

**Monotremes** include only two species of mammals which lay eggs. These are the duck billed platypus, and the echidna. Both species are found in Australia, Tasmania and Papua New Guinea. They have fur and their young feed on the mother’s milk. The special features of each species are given in Table 1.5.1 below.

<table>
<thead>
<tr>
<th>Echidna</th>
<th>Duckbilled platypus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad body with short legs</td>
<td>Semi aquatic, excellent</td>
</tr>
<tr>
<td>and body covered with stiff</td>
<td>swimmers and divers, with flat</td>
</tr>
<tr>
<td>spines mixed with long coarse</td>
<td>snout resembling a duck’s</td>
</tr>
<tr>
<td>hairs.</td>
<td>bill and webbed feet.</td>
</tr>
<tr>
<td>Small head with slender</td>
<td>The body length is between 30 to 40cm</td>
</tr>
<tr>
<td>snout and body between 35 to</td>
<td>with a flattened tail of length 10 to 15cm.</td>
</tr>
<tr>
<td>53cm long</td>
<td>Small eyes, no external ears, but a good</td>
</tr>
<tr>
<td>Long sticky tongue used to</td>
<td>sense of sight and</td>
</tr>
<tr>
<td>feed on termites, ants and</td>
<td>hearing.</td>
</tr>
<tr>
<td>other small insects.</td>
<td>Feeds on insects, worms, and shellfish</td>
</tr>
<tr>
<td></td>
<td>found in mud in rivers.</td>
</tr>
</tbody>
</table>

Table 1.5.1: Comparison of the echidna and the platypus

The **marsupials** include animals such as the kangaroo, the koala bear the opossum and the wombat. Marsupials give birth to underdeveloped young which continue their full development in the mother’s pouch, feeding on milk from the mother’s breast. Most marsupials are found in Australia and Tasmania, but some are also found in America.

We will further look at three of the marsupials below.

The **kangaroo** is found in Australia and neighboring islands. It has a small head and large ears. The front legs are short compared to the long, strong hind legs which are used for hopping. The kangaroo’s tail is also very useful in hopping.

There are two main families of kangaroos; a family of large kangaroos (e.g. the red kangaroo up to 2 m in height) and one of smaller kangaroos (e.g. the rat kangaroo, up to 30 cm tall).

![Red Kangaroo](www.cdli.ca) ![Rat Kangaroo](etc.usf.edu)

**Opossums** can be found in Australia and America. They have an unusually long tail, with long pointed face, and body length ranging from 17 to 104 cm including the tail. They are nocturnal animals (animals that are active at night) and most species are arboreal (animals that live mostly in trees) and omnivorous.

**Koalas** are native to Australia and have a specialized diet of eucalyptus leaves. They live in trees. They look like miniature bears with a round face and a large projecting nose. They are between 69 cm to 79 cm long and the males are larger than the females. They have thick wooly fur and paws that are well adapted for gripping and climbing trees.

The **placental mammals** are the largest group of mammals on earth. The
young develop inside the mother’s uterus and when born they are fully
developed.

Placental mammals are grouped into over 19 orders, depending on their
specific characteristics. Some of these orders include rodenta (e.g. 
beavers, porcupines, and mice), carnivora (e.g. cheetahs, wolves, dogs, 
and lions), primates (e.g. monkeys, apes, human beings) and marine 
mammals such as whales, seals and dolphins.


We have learnt about the five classes of vertebrates above. To help you 
review the topic, do the self-assessment below.

Self-assessment 1.5

You should be able to complete the self-assessment in 25 minutes. This 
self-assessment is based on Topic 1.5. The answers are given at the end
of the topic. You are strongly advised to answer all questions before you
refer to the Answers to Self-assessment 1.5. This will help you learn and 
reflect better on areas for improvement.

1. Six animals are shown in Figure 1.5.8 below.

Answer the questions (a), (b), and (c) below by studying the 
animals and the list key below.

![Figure 1.5.8: A group of vertebrates](http://en.wikipedia.org/wiki/koala

Pictures drawn by Serge Mondon (2009).
<table>
<thead>
<tr>
<th></th>
<th>a. The animal is an endotherm</th>
<th>Go to 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b. The animal is an ectotherm</td>
<td>Go to 3</td>
</tr>
<tr>
<td>2</td>
<td>a. Body covered with feathers</td>
<td>Go to 4</td>
</tr>
<tr>
<td></td>
<td>b. Body covered with hair or fur.</td>
<td>Go to 5</td>
</tr>
<tr>
<td>3</td>
<td>a. Breathe with gills</td>
<td>Blue tang</td>
</tr>
<tr>
<td></td>
<td>b. Breathe with lungs</td>
<td>Snake</td>
</tr>
<tr>
<td>4</td>
<td>a. Can fly</td>
<td>Cattle egret</td>
</tr>
<tr>
<td></td>
<td>b. Cannot fly</td>
<td>Ostrich</td>
</tr>
<tr>
<td>5</td>
<td>a. Belongs to the carnivora order</td>
<td>Wolf</td>
</tr>
<tr>
<td></td>
<td>b. Belongs to the rodenta order</td>
<td>Mouse</td>
</tr>
</tbody>
</table>

Table 1.5.2: A list key of vertebrates

a. Describe the snake.

b. Birds have legs and their body is covered with feathers.
   i. Name the vertebrates in Figure 1.5.8 that are birds.

ii. Name one difference between the two birds in the key?
c. To which vertebrate group does the wolf belong? Explain why you classified the wolf in this group.

2. In what ways is an amphibian different from a fish?

3. To which vertebrate group do you belong? Explain your answer.

4. Complete Table 1.5.3 (a) below. You should:
a. Write the correct class of vertebrate next to its characteristics.

b. Give two examples of animals that belong to each class of vertebrate, and

c. Indicate whether the class of animals is warm blooded or cold blooded by writing the correct term in the temperature regulation column.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Class of vertebrate</th>
<th>Examples of animals</th>
<th>Temperature regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>They have hair on the body; their young develop inside the mother’s uterus and feed on the mother’s milk.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most have a streamlined body that helps them move swiftly through water. They have scales, fins and gills.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>They have smooth, moist skin with no scales. They begin their life in water and most spend their adult life on land. They lay their eggs in water.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>They have a dry and scaly skin. The scales tend to be horny with bony plates. Most have paired limbs with five toes on each limb. Most live on land, but some species live in water. They lay rubbery-shelled eggs on land.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Characteristics of the different classes of vertebrates

<table>
<thead>
<tr>
<th>Class of vertebrate</th>
<th>Characteristics</th>
<th>Example</th>
<th>Temperature regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammal</td>
<td>They have hair on the body; their young develop inside the mother’s</td>
<td>Humans, whales, etc</td>
<td>Warm blooded</td>
</tr>
</tbody>
</table>

Table 1.5.3(a): The five classes of vertebrates

I am sure that you have done very well. I have provided you with the Answers to Self-assessment 1.5 at the end of the topic below.

**Answers to Self-assessment 1.5**

1. Answers to questions based on the list key:

   a. The snake is an ectotherm and it breathes with lungs.

   b. The two birds

      i. The two birds are the ostrich and the cattle egret

      ii. The ostrich cannot fly but the carrel egret can fly.

   d. The wolf is a mammal it gives birth to live young and feeds its young with milk. Mammals have hair or fur and are endotherms.

2. Fishes have the following characteristics: Most have a streamlined body that helps them move swiftly through water. They have scales, fins and gills. Amphibians have the following characteristics: They have smooth, moist skin with no scales. They begin their life in water and most spend their adult life on land. They lay their eggs in water.

3. We belong in the mammal group. We have hairs on our body and we develop inside our mother’s womb and feed of our mother’s milk.

4. Characteristics of the different classes of vertebrates
womb and feed on their mother’s milk.

<table>
<thead>
<tr>
<th>Fish</th>
<th>Most have a streamlined body that helps them move swiftly through water. They have scales, fins and gills.</th>
<th>Hagfish, salmon, etc</th>
<th>Cold blooded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amphibian</td>
<td>They have smooth, moist skin with no scales. They begin their life in water and most spend their adult life on land. They lay their eggs in water.</td>
<td>Frogs, salamanders, etc</td>
<td>Cold blooded</td>
</tr>
<tr>
<td>Reptile</td>
<td>They have dry and scaly skin. The scales tend to be horny with bony plates. Most have paired limbs with five toes on each limb. Most live on land, but some species live in water. They lay rubbery-shelled eggs on land.</td>
<td>Crocodiles, lizards, etc</td>
<td>Cold blooded</td>
</tr>
<tr>
<td>Bird</td>
<td>They have feathers, a pair of wings and a beak. The lower parts of their legs are covered with scales. They lay eggs with a hard shell.</td>
<td>Seagulls, parrots, etc</td>
<td>Warm blooded</td>
</tr>
</tbody>
</table>

Table 1.5.3(b): The five classes of vertebrates

What did you learn about vertebrates? Can you guess what invertebrates are based on what you learned about vertebrates? Let us now proceed to learn about the invertebrates.
Topic 1.6: Invertebrates

Please note that this topic is for students who are doing the extended objectives only. If you are a student doing the core objectives, you may also attempt this topic if you like. If you decide not to follow this topic, you are encouraged to use the 3 additional hours to read further on the 5 topics covered above.

You will need 3 hours at the most to do the activities in this topic. It is advisable that you spend another 1 hour 30 minutes of your own time to research and consult people and/or documents to obtain the required information for some of the activities. You need to make prior arrangements with the persons that you need to consult to economize on your study time.

Now that you have a good idea about the types of animals in the vertebrate group, you should be thinking about the other, usually smaller, animals around you! These animals are without a backbone.

Do you have any idea how we call this group of animals?
Can you name some animals belonging to this group?

Recall that when we were working on the phylum category of the biological classification system, we learnt that these animals are non-chordates. They are animals without a backbone and are known as invertebrates. Invertebrates are the most abundant animal groups on earth. The phylum arthropoda is one of the invertebrate phyla with the most species.

Arthropods have a body with jointed parts, a number of pairs of jointed limbs and a hard exoskeleton. Ninety percent of all arthropods belong to the class of insects. Apart from insects, the arthropod phylum includes other classes such as crustaceans (e.g. crabs) and arachnids (e.g. spiders).

We are now going to look closely at insects, arachnids, and crustaceans. We shall start with the insects in Activity 1.6.1 below.
1.6.1 Insects

Activity 1.6.1

In 40 minutes you should complete the reading and the activity below.

a. Some examples of insects are shown below.

![Some insects](image)

Figure 1.6.1: Some insects

Drawn by Serge Mondon (2009)

All the insects have the following characteristics in common:

- **Insects have three body parts; a **head, thorax and an abdomen**.**
- They have a **pair of antennae** and a **pair of compound eyes** made up of hundreds of separate lenses and sensory cells, as well as simple eyes on their heads.
- Their thorax is made up of three segments and on each segment; one pair of legs is attached. Hence an insect has **three pairs of legs**. Some insects also have one or two pairs of wings attached to the second and third segments of the thorax.
- Insects have **11 segments on their abdomen** and they also have an exoskeleton.

Use the information above to label the body parts of the insect shown below.

![Unlabelled diagram of insect](image)

Figure 1.6.2 (a): An unlabelled diagram of insect
b. With a colleague, plan a visit to the Natural History Museum in your country or look for insects in your environment. Take photographs or look for pictures of some of the insects that you see there.

Find information about the insects that you have observed from books, the internet or resource persons. Make a photo album or a sketch album of the insects. Include any information that you have gathered about them. Show your album to your teacher and keep it in your portfolio.

I’m sure that you enjoyed the above activity. It should not have been too difficult for you to label the insect. I have provided you with the Feedback to Activity 1.6.1 at the end of the topic below. You are, however, strongly advised to first complete the activities on your own before you refer to the feedback. This will help you learn and reflect better on areas for improvement.
Feedback to Activity 1.6.1

The body parts of an insect are:

![Labelled diagram of an insect](image)

Figure 1.6.2: Labelled diagram of an insect
Drawn by Serge Mondon (2009)

The labelled picture above is that of an adult insect. Baby insects are usually very different from the adult. You may have seen baby insects around you, such as the caterpillar. Let us learn more about the life cycle of insects.

1.6.1.1 Life cycle of insects

Insects develop in special ways. They undergo metamorphosis as they develop. Metamorphosis means change of form. In some insects such as cockroaches and locusts, the change in form is less abrupt and the development to adult form is more direct. Such insects are said to undergo incomplete metamorphosis. Other insects such as butterflies and mosquitoes undergo complete metamorphosis. This means that each stage of development is quite distinct from the other.
I have presented an example of an insect that undergoes incomplete metamorphosis and one that undergoes complete metamorphosis on Table 1.6.1 below.

<table>
<thead>
<tr>
<th>Incomplete metamorphosis (e.g. grasshopper)</th>
<th>Complete metamorphosis (e.g. butterfly)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Eggs are laid in the ground.</td>
<td>• Eggs are laid on the underside of leaves.</td>
</tr>
<tr>
<td>• Egg develops into larva, known as instar or nymph which resembles the adult. The first nymph possesses simple eyes and legs, but no wings.</td>
<td>• Eggs develop into larva (caterpillar) [1 to 2 weeks] which differs in body structure from the adult. The larva has no antennae or compound eye. It eats a lot and grows fast. The larva molts several times.</td>
</tr>
<tr>
<td>• Each successive instar resembles the adult more and more. Frequent shedding of exoskeleton (molting) takes place. Wings gradually develop and are fully formed at the last stage (fifth instar).</td>
<td>• The larva develops into pupa [1 to 2 months], which rests for complete development of the body structure, including the process for the wings to dry and exoskeleton to harden.</td>
</tr>
<tr>
<td>• The fifth instar develops into a fully fledged adult [25 to 30 days].</td>
<td>• A fully developed adult hatches out of the pupa [2 weeks].</td>
</tr>
</tbody>
</table>

Table 1.6.1: Insect development


Keeping a caterpillar and watching how it develops into a butterfly or a moth is an interesting activity. In the first activity of Activity 1.6.2 below, I have given you the steps to follow if you would want to see how a caterpillar grows into a moth or a butterfly.

The activity is optional. Those of you who can try it are welcomed to do so.
Activity 1.6.2

You should all be able to complete the second activity below in 10 minutes.

a. Follow the steps below to know how to care for caterpillars (optional)

**Step 1:** With the help of a farmer or the owner of a flower or a vegetable garden, look for some caterpillars or their eggs. If you find the eggs, gently break off the leaf with the eggs and place it in a clear plastic container with air holes in the lid.

**Step 2:** Using a paint brush, transfer a newly-hatched caterpillar or a caterpillar found on a leaf in a transparent container. Give the caterpillar plenty of fresh food (leaves of the plant from which you took the caterpillar) everyday.

**Step 3:** Keep a record of the activities of and the changes that the caterpillar goes through. Here are some ideas of the types of observations and records that you could make:

i. Use a hand lens to help you make a labelled drawing of the caterpillar. With your hand lens try to look for the **breathing holes**, the **true legs** on the front segments and **prolegs** on the rear (back) segments, the **mouth parts** and the **head**.

ii. How much does the caterpillar eat each day?

iii. Measure the caterpillar each day and use your measurements to keep a caterpillar growth record.

**Step 4:** Keep a record of your caterpillar study in your portfolio.

Those of you who are interested could further their studies by comparing caterpillars of butterflies and those of moths, or make a collection of the different species of butterflies or moths in Seychelles or worldwide.

b. Use the information in Table 1.6.1 above as well as your own observations to draw the life cycle of a grasshopper and that of a butterfly in the spaces provided below.

You may also wish to use general biology books such as Jones and Jones (1987) and D.G. Mackean (2002) to get more information on the life cycles of the butterfly and the moth.
i. Complete the life cycle of the grasshopper

![Grasshopper Life Cycle Diagram]

ii. Give an example of two other insects with life cycles similar to that of the grasshopper.

---

iii. Complete the life cycle of the butterfly

![Butterfly Life Cycle Diagram]

iv. Give an example of two other insects with life cycles similar to that of the butterfly.

---
I am sure that you have been able to clearly differentiate between the two groups of insects. I have provided you with the Feedback to Activity 1.6.2 at the end of the topic below. You are, however, strongly advised to first complete the activities on your own before you refer to the feedback. This will help you learn and reflect better on areas for improvement.

Feedback to Activity 1.6.2

i. Life cycle of the grasshopper (incomplete metamorphosis)

![Life cycle of the grasshopper]

Life cycle of the grasshopper
Designed by Mariette Lucas (2009)

ii. Insects with similar life cycles include the dragonfly, cockroach, mayfly, and cicada.

iii. Life cycle of the butterfly (Complete metamorphosis)

![Life cycle of the butterfly]

Life cycle of the butterfly
Designed by Mariette Lucas (2009)
iv. Insects with similar life cycles include bees, wasps, ants, beetles, the housefly, fruit flies and mosquitoes.

I am sure that you now have a good understanding of insects. You will have the opportunity to compare insects with arachnids after you have studied the specific characteristics of arachnids below.

1.6.2 Arachnids

Arachnids are different from insects. They have two body parts. The head is fused with the thorax, forming one part known as the **cephalothorax**. Arachnids have simple eyes but no antennas, nor wings. Four pairs of legs are attached to the cephalothorax. The second part of the body is the abdomen.
Activity 1.6.3

You should be able to complete this activity in 20 minutes.

A spider is an arachnid.

Using the information in the text above, label the body parts of the spider, on the diagram.

![Unlabelled diagram of a spider](image)

Figure 1.6.3 (a): An unlabelled diagram of a spider
Drawn by Serge Mondon (2009)

From the above exercise, can you think of other examples of arachnids? Find pictures or draw two arachnids that you know in the space below.

I have provided you with a labelled diagram of a spider in the Feedback to Activity 1.6.3 at the end of the topic below. Some examples of arachnids are also given. You are, however, strongly advised to first complete the activities on your own before you refer to the feedback. This will help you learn and reflect better on areas for improvement.
Feedback to Activity 1.6.3

The body parts of a spider are as shown below.

Figure 1.6.3 (b): Labelled diagram of a spider

Scorpions, ticks and mites are all arachnids.

Let us now learn about another group of arthropods.

1.6.3 Crustaceans

Another group of common arthropods is the crustacean. This includes animals such as crabs, lobsters, crayfish and shrimps.

The body of crustaceans is composed of segments which are grouped into three regions: a head, a thorax and an abdomen. Sometimes the head and the thorax may be fused to form a cephalothorax. On the head there are two pairs of antennae and a pair of compound eyes raised on stalks. The abdomen has around 11 segments. Most crustaceans live in water and have gills for breathing.
Activity 1.6.4

You need 45 minutes to do this activity.

Conduct a research on 5 different crustaceans either from biology books or from the internet, and make a book of crustaceans. Your book should have the following content:

- The first page of your book should contain a general description of crustaceans, including how they are classified scientifically using the taxonomic categories.

- A page for each crustacean including a picture or diagram of the crustacean, its common name and scientific name, a brief description of its habitat and special characteristics.

- A page of references used to get the information included in the book.

Keep your crustaceans’ book in your portfolio. You have to submit the portfolio to your teacher/tutor once you have completed the unit.
Self-assessment 1.6

You need 30 minutes to do the self-assessment below. This self-assessment is based on Topic 1.6. The answers are given at the end of the topic. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 1.6. This will help you learn and reflect better on areas for improvement.

a. Using your own words complete this cloze passage:

Invertebrates are animals that do not have -----------------------------

The largest phylum of invertebrates is the -----------------------------

This includes classes of animals such as -------------------------------, arachnids, and ------------------------------- Arthropods are animals with -------------------------------

b. Insect is the largest class of arthropods.

i. Name five insects

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________

ii. List three features of insects.

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________

iii. Complete the table below to show the main differences between insects and arachnids.

<table>
<thead>
<tr>
<th></th>
<th>Insects</th>
<th>Arachnids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1.6.2 (a): Comparing insects and arachnids

<table>
<thead>
<tr>
<th>Body parts</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wings</td>
<td></td>
</tr>
<tr>
<td>Eyes</td>
<td></td>
</tr>
</tbody>
</table>

c. Insects undergo a process called metamorphosis in their development.
   
i. What does this term *metamorphosis* mean?

ii. With the help of a diagram give an example of an insect that undergoes incomplete metamorphosis in the space below.

---

d. Draw a table in the space below, then classify the following animals as either insects, arachnids or crustaceans:

   scorpion, prawn, palm spider, beetle, honey bee, hermit crab, housefly, mite, and lobster.
I have provided you with the Answers to Self-assessment 1.6 at the end of the topic below.
Answers to Self-assessment 1.6

Answers to Assessment

a. Invertebrates are animals that do not **have an internal skeleton**.

The largest phylum of invertebrates is the **arthropoda**. This includes classes of animals such as **insects**, arachnids, and **crustaceans**. Arthropods are animals with **segmented bodies and limbs**.

b. Insects:

i. **Some insects** are mosquitoes, houseflies, butterflies, grasshopper, cockroach, bees, wasps, ants.

ii. Insects have the following features:

   - Three body parts; head, thorax, abdomen
   - Six legs attached to the thorax
   - Compound eyes and simple eyes
   - One pair of antennae
   - Some have wings

iii. The main differences between insects and arachnids are:

<table>
<thead>
<tr>
<th></th>
<th>Insects</th>
<th>Arachnids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legs</td>
<td>6 legs</td>
<td>8 legs</td>
</tr>
<tr>
<td>Body parts</td>
<td>Three parts; head, thorax and abdomen</td>
<td>Two body parts; cephalothorax, and abdomen</td>
</tr>
<tr>
<td>Wings</td>
<td>Two pairs</td>
<td>Absent</td>
</tr>
</tbody>
</table>
c. Metamorphosis:

i. Metamorphosis means change of form.

ii. A cockroach undergoes incomplete metamorphosis. Its life cycle is shown below:

![Figure 1.6.6: Cockroach life cycle](http://en.wikipedia.org/wiki/Cockroach)

Figure 1.6.6: Cockroach life cycle


d. Classifying invertebrates

<table>
<thead>
<tr>
<th>Arachnids</th>
<th>Insects</th>
<th>Crustaceans</th>
</tr>
</thead>
<tbody>
<tr>
<td>• scorpion</td>
<td>• beetle</td>
<td>• prawn</td>
</tr>
<tr>
<td>• palm spider</td>
<td>• honey bee</td>
<td>• hermit crab</td>
</tr>
<tr>
<td>• mite</td>
<td>• housefly</td>
<td>• lobster</td>
</tr>
</tbody>
</table>
You have now completed the study on Biological Classification. I am sure that you have gained a lot of new knowledge and that you are now much more observant and conscious of your surroundings.

I hope that you have enjoyed the activities that I have devised in this unit to help you learn about Biological Classification. I do hope that you are now ready and very keen to continue the course.

I wish you the best in your studies. I know that you will make it!!

Below I have provided you with a summary of what you have learnt in the unit.
In this unit you learned that it is important to classify organisms and that scientists have developed systems to help with the classification and naming of the billions of organisms on earth.

You have learnt that dichotomous keys are keys that use a system of comparing two groups of organisms at a time, moving from more general characteristics of the different groups to the more specific characteristics of individual species. We can differentiate between two types of dichotomous keys. They are list keys and branching or spider keys.

We also looked at the importance of the binomial nomenclature in the naming of individual organisms. It is due to this system that individual animals can be differentiated from each other. The system uses a genus and species name for all organisms. The genus name always starts with a capital letter and both the genus part and the species part of the name are always written in italics.

We also learnt about the instrumental contribution of the Swedish scientist, Carolus von Linnaeus in the development of the hierarchical classification system, in which organisms are classified from large to more specific groups. As such all organisms belong to a kingdom, a phylum, a class, an order, a family, a genus, and their specific species.

Finally, we have provided you with examples of how plants and animals are grouped. We discussed animals from the phylum chordate, more specifically the vertebrates under their specific classes; mammals, fish, reptiles, birds and fish. We have looked in detail at the specific characteristics of animals in each of these classes. We also looked at the phylum arthropoda, with specific focus on animals from the class insects, arachnids, and crustaceans.
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## Unit 2

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<tr>
<td>Unit summary</td>
<td>90</td>
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</tbody>
</table>
Unit 2

The elements of chemistry

Introduction

Think of the last sandwich you ate. What was it made of? Maybe you had a tuna sandwich, so it contained tuna, mayonnaise, bread and some carrots. Take the mayonnaise, for instance made of other ingredients such as oil, egg yolks and vinegar. Similarly, everything around us is made of something, which scientists call matter.

In this unit you are going to learn about matter, the states of matter, the arrangement of particles in the states of matter, and what causes the change of state in solids, liquids and gases. You will learn about physical and chemical changes that occur to matter around you. You will learn about atoms, elements, molecules, compounds and mixtures. You will also learn that matter can be pure substances and mixtures, and that mixtures can be separated using different techniques.

The outcomes for the unit are listed below. The outcomes written in **bold** are the extended outcomes and they are intended for students who are aiming for a Grade of B or higher in the examinations.
Upon completion of this unit you will be able to:

- **distinguish** between physical and chemical changes;
- **distinguish** between the three states of matter;
- **explain** how the three states of matter can be inter-converted in terms of the kinetic theory;
- **define** the terms atom, element, molecule, compound, and mixture;
- **use** appropriate separation techniques (magnet, sublimation, evaporation, filtration, distillation, crystallisation, separating funnel, chromatography, or fractional distillation) to separate different mixtures;
- **discuss** the application of each of those separation techniques;
- **state** that each element has a particular chemical symbol;
- **state** the relative charge and the approximate relative mass of a proton, a neutron and an electron;
- **explain** the meaning of nucleon number and proton number;
- **explain** that ‘amount of substance’ is measured in moles and that one mole of any substance contains the same number of particles;
- **calculate** the number of moles present in a given mass of substances (in grams), or to the number of atoms or molecules;
- **calculate** the mass (in grams) in given moles of different substances;
- **derive the empirical formulae of substances from percentages and percentage composition from molecular formulae.**

### Terminology

**Avogadro’s constant**

The Avogadro constant \((N_A)\) is the number of particles (atoms, or molecules) in 1 mole which is equal to \(6.02 \times 10^{23}\).

**Boiling point:**

The temperature at which a liquid boils. Each liquid has its own boiling point.

**Chemical change:**

A chemical change is a change which is not easily reversed. A chemical change always results in the formation of a new substance.

**Compound:**

A compound is a pure substance which contains two or more elements chemically bonded together.

**Element:**

An element is a substance that cannot be split up into other simpler substances by any known chemical processes.

**Matter:**

Matter is anything that has a mass and occupies
Melting point: The temperature at which a solid changes into a liquid. Each solid has its own melting point.

Mixture: A mixture contains two or more substances which can easily be separated by physical methods.

Mole: The mole (mol) is the SI (Système International) unit of the “amount of substance” (or the number of particles (atoms or molecules) of a substance). The mole is a unit which allows us to count the number of atoms by weighing them.

Physical change: A physical change is a change which is easily reversible by a simple change in the condition(s). A physical change does not result in the formation of new substances.

Saturated solution: A saturated solution is formed when excess solute (solid to be dissolved) is added to a solvent (a liquid that dissolves the solute). The solution is said to be saturated when the solute added can dissolve no more.
Table 2.0 below shows the number of formal study hours needed for you to complete this unit and the number of hours that you need to devote for self-study.

<table>
<thead>
<tr>
<th>Category of students</th>
<th>Number of formal study hours needed</th>
<th>Number of hours for self-study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time student outside the conventional school setting</td>
<td>7 hours and 10 minutes</td>
<td>3 hours and 35 minutes</td>
</tr>
<tr>
<td>Full-time student within the conventional school setting</td>
<td>7 hours and 10 minutes</td>
<td>3 hours and 35 minutes</td>
</tr>
<tr>
<td>OR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part-time student</td>
<td>7 hours and 10 minutes</td>
<td>3 hours and 35 minutes</td>
</tr>
</tbody>
</table>

Table 2.0: The time needed for you to work on this unit

**Topic 2.1: Types of changes**

You will need 50 minutes to complete this Topic. It is advisable that you spend another 25 minutes of your own time to further review the characteristics of physical and chemical changes.

In your everyday life, you may have observed that changes are always taking place. Sometimes the changes that take place can be reversed. For example, if you take some ice from a freezer, the ice melts and changes to water. If you want the ice back, you just have to put the water back into the freezer. On other occasions the changes that take place cannot be reversed. For instance, if you burn wood, you get charcoal. You could try as hard as you want, but you will never be able to change the charcoal back to wood. Changes also take place inside your body. In Unit 11 – Digestion, you will learn how the food that you eat undergoes changes as it passes through your digestive system. There are special names given to those two types of changes.
In this topic you are going to learn about the types of changes that take place in the world around us. Let us start off with a simple activity.

Activity 2.1.1

You should spend 5 minutes to carry out this simple experiment at home to show a reversible change.

For this experiment you will need a candle and some matches or a lighter.

Procedure: You are required to:

- Light a candle and let it burn for about three minutes or so.
- After the three minutes, blow out the flame and let it cool.
- Observe what happens to the candle wax when heated and when cooled.

Observation: write your observations in the spaces below.

When heated:


When cooled:


Feedback to Activity 2.1.1

I hope you didn’t burn yourself and was not uncomfortable with the smell of the smoke when you put the candle out! Well, you should have seen that when the candle burns, the candle wax melts and becomes a liquid, but upon cooling, the liquid wax becomes a solid again, although it did not return to its original shape. I’m sure you have seen those changes before, but you may have never thought about it in this way. These types of changes are known as **physical changes**.
There are two types of changes that occur in the world around us. They are **physical changes** and **chemical changes**.

A **physical change** is a change which is easily reversible by a simple change in the condition(s). A physical change does not result in the formation of new substances. In the experiment above, the candle wax remained as candle wax when it melted; it was only the state that the wax was in that changed. It changed from solid to liquid when it melted and back to solid when it cooled.

A **chemical change** is a change which is not easily reversed. A chemical change always results in the formation of a new substance. For example, earlier we saw that when we burn wood, we get a new substance called charcoal.

Now carry out the following experiments at home to further illustrate chemical changes.
Activity 2.1.2

You should spend approximately 10 minutes on this activity.

As you have seen earlier, new substance(s) are formed during chemical changes. You are now required to carry out these experiments at home to become familiar with more examples of chemical changes.

**Experiment 1**

For this experiment you will need a box of matches.

You are required to crush an egg shell, or snail shell or a small piece of coral. Be careful not to crush your finger in the process. Use ¼ of a teaspoon and add some vinegar until the shell is fully immersed (vinegar which is also known as acetic acid is a very weak acid) to it. Now observe what happens.

**Observation:**

Write down the changes that you observed in the space below.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

**Experiment 2**

**Equipment:** For this experiment, you will need:

- an empty 500 ml clear plastic bottle (a small coca cola PET will do);
- some hot water;
- 2 tablespoons of sodium bicarbonate (also known as bicarbonate of soda or baking soda. Be careful not to confuse baking soda with baking powder as they are two different substances);
- some concentrated vinegar (vinegar which is also known as acetic acid is a very weak acid); and
- a few drops of detergent (optional)
- a few drops of food colouring (optional)
Procedure: You are required to carry out this experiment over a sink:

- Fill the empty bottle 3/4 full with warm water. (Do NOT use hot water)
- Add 2 tablespoons of sodium bicarbonate to the hot water. (You can add a few drops of detergent and a few drops of food colouring to make your experiment more spectacular).
- Add about 20 ml of concentrated vinegar to the mixture.
- Watch what happens.

Observation: Write down your observation in the space below.

Feedback to Activity 2.1.2

I hope that you have enjoyed these simple experiments, especially experiment 2. Experiment 2 is a reaction that is used to illustrate a volcanic eruption. If you want to learn about making a model volcano during your spare time to amuse your relatives and friends refer to http://chemistry.about.com/od/chemicalvolcanoes/ss/volcano_2.htm for the details. Please note that this link is an external link for information only. We are not endorsing or recommending that you visit any other links that are made from that site.

From experiment 1 in Activity 2.1.2, you should have observed that bubbles were formed and eventually all the crushed shell reacted with the vinegar and was no longer visible.

From experiment 2, if you did not use the detergent and food colouring, you should have observed some bubbles coming from the bottle as the vinegar reacted with the baking soda. If you have used the detergent and food colouring, you should have observed a reddish coloured foam evolving from the bottle.

All of the changes that you have seen in experiments 1 and 2 in Activity 2.1.2 are not reversible, so they are all chemical changes.
Apart from physical changes being easily reversible and chemical changes not being easily reversible, there are other differences between chemical and physical changes. Table 2.1.1 provides a summary of the characteristics of physical and chemical changes.

<table>
<thead>
<tr>
<th>Physical change</th>
<th>Chemical change</th>
</tr>
</thead>
<tbody>
<tr>
<td>These changes are easily reversed.</td>
<td>These changes are not easily reversed.</td>
</tr>
<tr>
<td>These changes do not produce any new substances.</td>
<td>These changes always produce new substances.</td>
</tr>
<tr>
<td>There is no change in the masses of substances involved.</td>
<td>The total mass is unaltered but the mass of each product formed usually differs from that of each of the starting substances.</td>
</tr>
<tr>
<td>The physical properties of the substance change, but the chemical properties do not change.</td>
<td>The physical and chemical properties of the substance change.</td>
</tr>
<tr>
<td>These changes involve very little heat absorption or evolution, except for latent heat changes which occur during a change of state.</td>
<td>These changes may involve a considerable amount of heat being absorbed or evolved.</td>
</tr>
</tbody>
</table>

Table 2.1.1: The characteristics of physical and chemical changes

Now that you have learnt about physical and chemical changes around you, in the next two topics, we are going to take a closer look at what enable these substances to undergo such changes. To start off with, we are going to focus on the states of matter.

Topic 2.2: The three states of matter
You will need 60 minutes to complete Topic 2.2. You are advised to spend another 30 minutes of your own time to review the topic.

As you have seen at the beginning of this unit, everything in the world we live in is made up of matter. The air you breathe in, the water and the tea you drink, the curry you eat, and the chair you sit on, are all made up of matter. You are also made up of matter.

The question that you are probably eager to ask is “what is matter?” Well, let me throw the question back at you – ‘What do you think matter is?’ Jot down your ideas in the space below.

____________________________________________________________________________________

____________________________________________________________________________________

Well, now let me tell you what matter is. In science, **matter is anything that has a mass and occupies space** (has a volume).

Before we move on to learn more about matter let us see if you really know what matter is through this discussion.
Discussion 2.2.1

You should not spend more than 10 minutes on this discussion.

You are required to meet up with three or four colleagues to discuss whether the following are matter or non-matter.

a. Categorise the following as matter or non-matter: air, wind, flame, smoke, sound, magnets, magnetism, electricity, electrons, soil, dissolved salt, apple, oxygen.

b. Discuss the properties which all the things you have classified as matter have in common. Record the result of your discussion in the space provided.

I hope you had a good discussion and did not find much difficulty with the classification. I think you would agree that some were quite tricky. For example, flame and smoke: while smoke is matter, flame is not matter. Please refer to the Feedback to Discussion 2.2.1 at the end of this Topic for the other expected answers.

As you have seen, matter is anything that has a mass and occupies space. **Matter can exist in three states.** The three states of matter are: **solid, liquid and gas.** In other words all the things around you can be classified as solids, liquids and gases.

Take water, for example: water, is the most common matter which can easily exist in all three states. In the solid state, we refer to water as **ice,** in the liquid state we call it **water** and in the gaseous state, we call it **water**
vapour or steam.

In the next activity you will be expected to provide some examples of solids, liquids and gases.

**Activity 2.2.1**

You should be able to do this activity within 5 minutes.

You are now going to categorise the following matter as solids, liquids and gases in the Table below: carbon dioxide, lemonade, hydrogen, rock, sugar, juice, seawater, oxygen, pencil. An example is done for you.

<table>
<thead>
<tr>
<th>Solid</th>
<th>Liquid</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>Petrol</td>
<td>air</td>
</tr>
</tbody>
</table>

Well, I hope that this task was easy for you. Please, refer to the Feedback to Activity 2.2.1 at the end of the topic for the correct answers.

Now that we have learnt that solids, liquids and gases are the three states of matter, we are going to study the differences between them.

As you may have already noticed, there are certain differences between ice, water and water vapour/steam. For instance, ice which is a solid, has a definite shape. As a liquid, water will take the shape of the container it is in. As a gas, the water vapour which escapes from boiling water can take different shapes.

Apart from the difference in their shape, there are other differences between solids, liquids and gases. Table 2.2.1 below gives a summary of the main differences between the three states of matter.
The particles (which can be atoms, molecules or ions) are closely packed together (see Diagram A below).

The forces of cohesion (forces of attraction) are so strong that the particles can only vibrate (move) about a fixed point (see Diagram B below).

Has definite shape. Has no fixed shape: it takes up the shape of its container Has no fixed shape; it can change shape

Has definite size. Its volume is fairly constant because the distances between the particles are relatively fixed. The volume is hardly affected by changes in temperature and pressure. Has no fixed volume, and its volume is greatly affected by small changes in temperature and pressure.

The particles are not so closely packed as in a solid (see Diagram C).

The forces of cohesion are weak, (see Diagram C) so the particles (atoms, molecules or ions) are relatively free to move (see Diagram D).

The forces of cohesion are insignificant, so the particles are completely free to move (see Diagram F).

The particles do not occupy fixed positions (see Diagram E).

Table 2.2.1: The main differences between solid, liquid and gas

Diagrams A to F were drawn by: Rosianna Jules, September, 2009
You now know about the differences in the states of matter. Next, you are going to learn about what causes the change in the states of matter. You will start by reflecting on simple everyday life experiences in the reflection below.

**Reflection 2.2.1**

You should spend about 5 minutes on this reflection.

Think about water which can exist as solid, liquid and gas. Based on your personal experiences, what do you think causes water to change from one state of matter to another?

I hope that the task was easy for you. You may have thought about the time you made some ice and when you boiled some water to make a cup of tea. In making ice you changed the liquid (water) to solid (ice) by freezing. By boiling the water to make tea, you changed some of the liquid (water) to gas (water vapour).

We will now take a closer look at the factors that cause the states of matter to change.

The change of state, which is also called the inter-conversion of state, is caused mainly by the addition or the removal of heat. In other words, the change of states of matter depends mainly on change in temperature.

Pressure is also a condition that causes the inter-conversion of state. You will learn about the effects of pressure on matter in Unit 5 – Particles in Motion. In this unit, however, we are only going to focus on the effects of temperature on the states of matter.
The question that we need to answer now is ‘why does a change in temperature cause the states of matter to change?’

In Table 2.2.1 we saw the differences between solid, liquid and gas. From Table 2.2.1 we can also deduce that all states of matter are made up of particles which are in constant motion.

This deduction about matter forms the basis of the kinetic theory of matter. You will learn more about the kinetic theory in Unit 5 – Particles in Motion. But for now what you need to know is that according to the kinetic theory,

- matter consists of particles;
- there are spaces and forces of cohesion between the particles; and
- the particles in matter are in constant random motion.

The kinetic theory allows us to explain how a change in temperature causes the inter-conversion of state of matter.

As you have seen in Table 2.2.1 above, in the solid state, the particles (atoms, molecules or ions) are closely packed together and the forces of cohesion between the particles are so strong that the particles can only vibrate about a fixed point (see Diagram A in Figure 2.2.1 below).

Therefore when a solid is heated, it expands by a small amount. If the heating continues, the particles gain heat energy and vibrate more. As the kinetic energy increases, the conversion of state becomes possible. At a certain temperature, known as the melting point, the particles gain enough energy to overcome the forces of cohesion (forces of attraction) and the solid changes into the liquid state (see Diagram C in Figure 2.2.1 below). Figure 2.2.1 represents the change of solid to liquid on heating.
In the liquid state, the forces of cohesion are weaker than in the solid state, hence, the particles are relatively free to move. On heating, a liquid expands more than a solid. The particles in the liquid gain kinetic energy and when the energy gained is large enough to overcome the forces of cohesion, these particles will escape from the surface of the liquid in the form of a gas (see Diagram E in Figure 2.2.2). This process is known as **evaporation**. Evaporation takes place at any temperature. On continued heating, at a certain temperature known as the **boiling point**, the liquid boils and vaporises at the fastest rate. Figure 2.2.2 represents the change of liquid to gas on continued heating.

It is important for you to note that each liquid has its own boiling point. The boiling point of a liquid increases in the presence of impurities and/or with an increase in pressure. The boiling point of a liquid decreases with a decrease in pressure.
We can also show the effects of an increase of temperature on a substance being heated graphically. The resulting graph is referred to as the **heating curve**. The heating curve is a graph which shows the temperature changes as a substance is heated. Figure 2.2.3 below shows the effect of an increase of temperature on a substance being heated.

![Graph showing the effect of an increase of temperature on a substance being heated](image)

Figure 2.2.3: Graph showing the effect of an increase of temperature on a substance being heated

Graphics by: Rosianna Jules, September, 2009

Figure 2.2.3 shows that the temperature increases on continued heating. The two horizontal parts of the graph, also known as the plateaus or phase changes, occur when there is a change of state.

The first change of state is at the melting point of the solid. At the melting point the temperature remains constant while the solid melts.

The second change of state occurs at the boiling point of the liquid. At the boiling point the temperature remains the same while the liquid boils.

The reverse is true when a gas is cooled to become a liquid or when a liquid is cooled to become a solid. Figure 2.2.4 shows the effect of a decrease of temperature on a substance left to cool over time.
As the gas is cooled, the particles lose kinetic energy causing the gas to change into a liquid. This process is known as condensation. If the liquid is cooled, the particles lose more kinetic energy. At a temperature known as the freezing point, the liquid changes into a solid. Figure 2.2.4 above shows the effect of a decrease of temperature on a substance left to cool over time. This graph is known as the cooling curve.

The melting point of a solid is the same as the freezing point of its liquid. For example: the melting point of ice is 0°C and the freezing point of water is 0°C.

The change of state is best presented as follows:

<table>
<thead>
<tr>
<th>Melting heating</th>
<th>Evaporation heating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid ⇌ Liquid</td>
<td>Gas ⇌ Liquid</td>
</tr>
<tr>
<td>cooling</td>
<td>cooling</td>
</tr>
</tbody>
</table>

| Freezing | Condensation |

There are also substances that do not change into the liquid state when the solid is heated, or when the gas is cooled. For example, when solid iodine is heated, it changes straight into the gaseous state. When iodine gas is
cooled, it changes straight into the solid state. This process is known as *sublimation*. Some other substances that sublime include: ammonium chloride, sulphur, carbon dioxide, naphthalene and benzoic acid.

We have come to the end of Topic 2.2. I hope that you now understand what matter is and also the three states of matter very well. If there is anything that you are not sure about, do not hesitate to go back and review this section. If you are confident, proceed to the next topic.

**Feedback for Topic 2.2**

**Feedback to Discussion 2.2.1**

From your discussion, you may have realized the following:

a. From the list:
   i. the following are matter: air, smoke, magnets, electrons, soil, dissolved salt, apple and oxygen.
   ii. the following are not matter: wind, flame, sound, magnetism and electricity.

b. All the things that are matter have a mass and occupy space (has a volume)
   A flame is not matter; the heat and light it produces are energy but not matter. The smoke that rises from the flame contains matter (small particles and gases), so smoke is matter.
   Wind itself is not matter; it is the movement of air. Similarly, sound is also not matter; it is the movement of air against your eardrum. Air, however, is matter.
   Electricity is not matter; it is the movement of electrons. Electrons on the other hand is matter.
Feedback to Activity 2.2.1

<table>
<thead>
<tr>
<th>Solid</th>
<th>Liquid</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>Petrol</td>
<td>air</td>
</tr>
<tr>
<td>sugar</td>
<td>juice</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>rock</td>
<td>lemonade</td>
<td>hydrogen</td>
</tr>
<tr>
<td>pencil</td>
<td>sea water</td>
<td>oxygen</td>
</tr>
</tbody>
</table>

I hope that you got all of the answers correct. Well done! If you did not, do not worry; just go through Topic 2.2 again.

In the topic above we studied the three states of matter. Can you recall what they were? How can we go from one state to another? What are some examples of matter in these phases?

In the next topic, we will examine atoms, elements, molecules, compounds and mixture. Any guesses on what these are? Let's move on to find out.

**Topic 2.3: Elements, atoms, molecules, compounds and mixtures**

You will need 1 hour 30 minutes to complete Topic 2.3. You are advised to spend another 45 minutes of your own time to review the topic.

In Topic 2.2 you learned that everything around us is made of matter which can be in the solid, liquid and gaseous state. You might be anxious to know what you are going to learn in this topic. Well, I will not tell you yet. Let us wait and find out after this discussion.
Discussion 2.3.1

You should spend not more than 10 minutes on this discussion.

Now think about some of the things around you, such as sugar, seawater, water, juice, salt, oxygen and air. These substances can be classified into two groups. In the first group we have sugar, water, salt and oxygen and in the second group we have seawater, juice and air.

Meet with one or two colleagues and discuss why these things can be classified as such.

Well, you might have come up with different ideas. What you should have realised is that those things in the first group, e.g. sugar and water are made of only one type of substance, while those in the second group, e.g. juice and seawater are made of two or more substances. For example, sugar is made only of sugar crystals while juice contains water, sugar, flavouring, etc.

Matter which is made of only one type of substance is said to be a pure substance, like water and sugar. Matter which is made of more than one substance mixed together is said to be a mixture, like juice and seawater.

A pure substance has a fixed composition and can be a chemical element, a molecule or a chemical compound. By contrast, a mixture is made of two or more substances not chemically joined together. So if we take juice, we can separate the sugar, the water, and the other ingredients from each other.

In this topic we are going to look at elements, atoms, molecules, compounds and mixtures. We will start off by learning about elements.

2.3.1 Elements

An element is a substance which cannot be split into simpler substances by a chemical reaction.
Some examples of elements that you might be familiar with are: oxygen, carbon, nitrogen, silver, gold, copper, mercury, and iron. Most of the elements exist as solids or gases at room temperature. For example: silver and gold are solids while oxygen and nitrogen are gases.

Scientists have discovered just over 100 elements and have classified them in a table known as the **Periodic Table** (see Figure 2.3.1 below for a copy of the Periodic Table). You will learn more about the Periodic Table in the unit entitled *Classifying Elements*. Also, visit the following link if you have access to the internet to see pictures of each element.


Each element has a particular chemical symbol made of 1 letter (e.g. N for nitrogen) or 2 letters (e.g. Ca for calcium) derived from the name of the element as shown on the Periodic Table in Figure 2.3.1 below. The chemical symbol also represents 1 atom of the element. (You will learn about atoms in the next sub-topic.) If you look closely at the Periodic Table you will notice that the chemical symbol of some of the elements is not derived from the conventional name given on the Periodic Table. This is because for those elements, their symbol is derived from their Latin name. Some examples are given in Table 2.3.1 below.

<table>
<thead>
<tr>
<th><strong>Conventional name of element</strong></th>
<th><strong>Latin name of the element</strong></th>
<th><strong>Symbol</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>Natrium</td>
<td>Na</td>
</tr>
<tr>
<td>Lead</td>
<td>Plumbum</td>
<td>Pb</td>
</tr>
<tr>
<td>Gold</td>
<td>Aurum</td>
<td>Au</td>
</tr>
<tr>
<td>Silver</td>
<td>Argentum</td>
<td>Ag</td>
</tr>
</tbody>
</table>

Table 2.3.1: Conventional name, Latin name and symbol of some elements

When 1 letter is used for the symbol of an element, it is always a capital letter, for example: H for hydrogen, O for oxygen, and K for potassium. By contrast when two letters are used, only the first letter is a capital letter, the second letter is always a small letter, for example: He for helium, Li for lithium and Na for sodium.
Figure 2.3.1: The Periodic Table

**Activity 2.3.1**

You should spend no more than 10 minutes on this activity.

Study the Periodic Table in Figure 2.3.1. Complete the table below with the appropriate name or symbol of the elements. Please note that the elements are not listed in order. The first one has been done for you.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Symbol</th>
<th>Elements</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>Carbon</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
<td>Ar</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>Calcium</td>
<td></td>
</tr>
<tr>
<td>Lithium</td>
<td>Ne</td>
<td>Chlorine</td>
<td>Be</td>
</tr>
<tr>
<td>S</td>
<td></td>
<td>Be</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>P</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Boron</td>
<td>O</td>
<td>Aluminium</td>
<td>Mg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silicon</td>
<td></td>
</tr>
</tbody>
</table>

I hope that the task was easy for you. All you had to do was refer to the Periodic Table. However, you need to know the first 20 elements and their symbol in the correct order. Please, refer to the Feedback to Activity 2.3.1 at the end of the topic for the correct answers.
You will learn more about the Periodic Table as you proceed through the course. Now we are going to look at what an element is made of.

### 2.3.2 Atoms

We can define an **atom** as the smallest part of an element that can take part in a chemical change or chemical reaction. An atom cannot be split up into simpler particles.

An atom is extremely small and is measured in nanometers (10⁻⁹). An atom is said to consist of 3 sub-atomic particles.

#### 2.3.2.1 Sub-atomic particles

The sub-atomic particles of an atom are: p – proton
e – electron
n – neutron

If you read the symbol vertically, it reads as ‘pen’. You can use this acronym to help you remember the names of the sub-atomic particles. This technique is often used in science, especially in chemistry. You can make up your own acronyms as you go along to help you remember other important information.

The **proton** is a positively charged particle and has a mass of 1, equal to the mass of hydrogen.

The **electron** is a negatively charged particle and has a negligible mass of \( \frac{1}{1840} \).

The **neutron** is not charged (it is neutral) and has a mass of 1 similar to that of a proton.

The protons and neutrons are found in the nucleus of the atom and together they are known as **nucleons**. The electrons on the other hand, revolve around (orbit) the nucleus along imaginary paths referred to as **shells**. Table 2.3.1 gives a comparison of the three sub-atomic particles.
2.3.2.2 Atomic notation

If you refer to the Periodic Table (Figure 2.3.1) you will notice that there are two numbers, a superscript (number at the top) and subscript (number at the bottom), attached to each element. These numbers have special meanings and they are used when writing the atomic notation (also known as nuclear notation) of an element.

The atomic notation of an element shows the chemical symbol of the element, its nucleon number (mass number) and its proton number (atomic number).

![Figure 2.3.1: How to write the atomic notation of any element](image)

Now let us see what the nucleon number and the proton number are all about.

2.3.2.2.1 Nucleon number / mass number

The nucleon number (A) or the mass number of an element is the sum of the number of protons and neutrons in the nucleus of the atom. This is best represented as:

\[
\text{nucleon (mass) number (A)} = \text{number of proton(s)} + \text{number of neutron(s)}
\]
The nucleon number is denoted by a superscript (number at the top) next to the symbol for the element as shown below.

\[
\text{Nucleon number (A) } ^{12}_1 \text{C (Carbon atom)}
\]

The nucleon number or mass number of an element is a whole number closest to the atomic mass of the element. The nucleon number is important in identifying isotopes. Isotopes are atoms of the same elements with the same proton (atomic) number but different mass (nucleon) number. You will learn more about isotopes later in the unit entitled *Atoms, Bonding and the Periodic Table.*

Please make note of the following:

- The mass number (nucleon number) and the atomic mass (also called the relative atomic mass, \(A_r\)) are NOT the same thing. The relative atomic mass (\(A_r\)) of an element tells us the number of times one atom of that element is heavier than one-twelfth, \(1/_{12}\), of an atom of the carbon-12 isotope.
- The relative atomic mass of an element takes into account the mass of the isotopes of that element and the ratio of the isotopes.

### 2.3.2.2 Proton number / atomic number

The proton number (\(Z\)) or the atomic number of an element is the number of protons in the nucleus of the atom. In an atom, the number of protons is equal to the number of electrons in the shells. The proton number is denoted by a subscript (number at the bottom) next to the symbol for the element as shown in Figure 2.3.1 above.

The proton number indicates:

- a. the number of protons in an atom;
- b. the number of electrons in an atom;
- c. where the element is ranked on the Periodic Table. For example, sodium has a proton number of 11. Hence, it is the eleventh (11th)
element on the Periodic Table.

The nucleon number (mass number) is the biggest number next to the symbol of the element whereas the proton number (atomic number) is the smallest number.

By knowing the nucleon number and proton number of an atom, you can calculate the number of neutrons in that atom.

To get the number of neutrons in an atom, you need to subtract the proton number from the nucleon number of the element.

\[
\text{number of neutrons} = \text{nucleon number (A)} - \text{proton number (Z)}
\]

For example, the number of neutrons in:

a. Sulphur \(^{32}\)S is:

I am sure that you can give me the answer straight away as this subtraction can be done in your head. However, to ensure that you understand the process, I will show the calculation step by step.

Firstly, we write down the formula:

\[
\text{number of neutrons} = \text{nucleon number (A)} - \text{proton number (Z)}
\]

Secondly, we substitute the known values:

\[
\text{number of neutrons} = 32 - 16
\]

Finally, we calculate the difference

\[
\text{number of neutrons} = 16
\]

So, there are 16 neutrons in sulphur.

Let us try another example; this time let us find the number of neutrons in sodium.

b. Sodium \(^{23}\)Na is:

\[
\text{number of neutrons} = \text{nucleon number (A)} - \text{proton number (Z)}
\]
number of neutrons \( = 23 - 11 \)

number of neutrons \( = 12 \)

Therefore, there are 12 neutrons in sodium.

Those were easy, were they not? I bet you want to try some more. But please wait a bit; you will have the opportunity to practise those in the Self-Assessment 2.1 at the end of this topic.

Now we are going to talk about molecules.

### 2.3.3 Molecules

A **molecule** is the smallest particle of an element or a **covalent compound** that normally exists on its own and still retains its properties. A molecule normally consists of two or more atoms chemically bonded together.

Please note that you will learn about covalent compounds in Unit 4: *Atoms, Bonding and the Periodic Table*. But for now you may know, just to satisfy your curiosity, that a covalent compound is formed when the elements are chemically joined together by the sharing of their outer electrons.

All the molecules of the same pure substance contain the same atoms in the same proportion and arrangement. For example:

a. all molecules of neon are always made up of 1 neon atom.

\[
\text{Ne} \]

b. all molecules of oxygen always consist of 2 oxygen atoms;

\[
\text{O} - \text{O} \]
c. all molecules of water always consist of 2 hydrogen atoms and 1 oxygen atom;

The number of atoms in a molecule gives the atomicity of the molecule. You can calculate the atomicity of a molecule (that is, the number of atoms in a molecule) from its molecular formula. The names given to molecules with the different atomicity are as follow:

- A molecule with 1 atom (atomicity of 1) is described as a monatomic molecule, e.g. a neon molecule (N), or a helium molecule (He).
- A molecule with 2 atoms (atomicity of 2) is described as a diatomic molecule, e.g. oxygen (O₂) and chlorine (Cl₂).
- A molecule with 3 atoms (atomicity of 3) is described as a triatomic molecule, e.g. water (H₂O) and carbon dioxide (CO₂).
- A molecule with more than 3 atoms (atomicity of more than 3) is described as a polyatomic molecule, e.g. ammonia (NH₃) and ethane (C₂H₆). Ammonia contains 4 atoms—1 nitrogen atom and 3 hydrogen atoms; and ethane contains 8 atoms—2 carbon atoms and 6 hydrogen atoms.

What elements or molecules do you think your body contains? Think about what we breathe in and out on a daily basis as well as what we drink. 99% of the body’s mass is made up of these 6 elements: oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus. If you have access to the internet, take a look at the following website for more information: http://chemistry.about.com/cs/howthingswork/f/blbodyelements.htm Please note again that we are providing this for information only and we do not endorse or recommend any links from this site.

You will learn more about the formation of molecules in Unit 4: Atoms, Bonding and the Periodic Table. You are now going to learn about compounds.

### 2.3.4 Compounds

A compound is a pure substance which contains two or more elements chemically bonded (joined) together.
I believe that you are now thinking that you have just read the same thing regarding molecules. Yes, molecules and compounds are both made of two or more elements chemically bonded together. As you have seen above, a molecule can be a smaller part of a covalent compound. So, apart from the monatomic molecules, all molecules are formed by covalent bonding (sharing of electrons). By contrast, a compound is formed either by covalent bonding or by electrovalent bonding, also known as ionic bonding. In electrovalent/ionic bonding, the elements are joined together by losing or gaining electrons.

Do not worry; everything will become clearer when you learn about chemical bonding in Unit 4.

The chemical and physical properties of a compound are different from the elements it is made of. A compound can be split into simpler substances by a chemical reaction, although it is very difficult.

Some compounds that you might be familiar with include: sodium chloride (table salt), sodium bicarbonate (baking soda), sucrose (sugar), water, acetic acid (vinegar) and ethanol (alcohol).

As mentioned above, you will learn more about compounds in Unit 4.

Now, what will you get if you add a pinch of salt, some diluted vinegar, and some oil together?

Yes, you will get a mixture which we call a vinaigrette or salad dressing. You are now going to learn about mixtures.

**2.3.5 Mixtures**

As you have learnt earlier, a mixture is made up of two or more substances not chemically joined together. A mixture can easily be separated by physical methods to obtain pure substances from it.

By knowing the composition of the mixture, you could use appropriate techniques of separation to separate the mixture into its original constituents. In the next topic you will learn about the different separation
techniques that can be used to obtain pure substances from:

a. solid-liquid mixtures, such as salt dissolved in water, and rice and water;

b. liquid-liquid mixtures, such as oil and water; alcohol and water; and crude oil.

c. solid-solid mixtures, such as salt and pepper, and iron filings and copper tunings.

Now let us briefly compare the differences between a compound and a mixture. A summary of the differences between a compound and a mixture is given in Table 2.3.2.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>It always has a chemical formula since its composition by mass is fixed.</td>
<td>It does not have a chemical formula as its composition may vary.</td>
</tr>
<tr>
<td>It is always homogeneous (fixed composition).</td>
<td>It may be homogeneous or heterogeneous (varying composition).</td>
</tr>
<tr>
<td>Its properties are different from those of its constituents.</td>
<td>Each constituent retains its own properties.</td>
</tr>
<tr>
<td>The constituents cannot be easily separated by simple physical methods.</td>
<td>Its constituents can easily be separated by simple physical methods.</td>
</tr>
</tbody>
</table>

Table 2.3.2: Summary of the differences between a compound and a mixture

I hope that you have understood what elements, atoms, molecules, compounds and mixtures are. Before we move on to the different separation techniques, you should now check how much you have understood so far by completing the self-assessment below.

Self-assessment 2.1

You should spend 15 minutes on this self-assessment. This self-assessment is based on Topics 2.1 - 2.3. The answers are given at the end of topic 2.3. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 2.1. This will help you learn and reflect better on areas for improvement.
Please answer the following question in the space provided.

1. 
   a. State 2 differences between a physical change and a chemical change.

<table>
<thead>
<tr>
<th>Physical change</th>
<th>Chemical change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

   b. Write true or false next to each statement.

<table>
<thead>
<tr>
<th>Statement</th>
<th>True OR False</th>
</tr>
</thead>
<tbody>
<tr>
<td>i.</td>
<td></td>
</tr>
<tr>
<td>ii.</td>
<td></td>
</tr>
<tr>
<td>iii.</td>
<td></td>
</tr>
<tr>
<td>iv.</td>
<td></td>
</tr>
<tr>
<td>v.</td>
<td></td>
</tr>
<tr>
<td>vi.</td>
<td></td>
</tr>
</tbody>
</table>

   i. A physical change is reversible.
   ii. Burning or combustion is a physical change.
   iii. Condensation is a chemical change.
   iv. Evaporation takes place at a fixed temperature.
   v. The three states of matter are solids, liquids and gases.
   vi. Water freezes at 0 °C and melts at 0 °C.

2. The following table gives the boiling points and melting point of some substances. (Take the room temperature as 30° C).
<table>
<thead>
<tr>
<th>Substance</th>
<th>Boiling point in °C</th>
<th>Melting point in °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron</td>
<td>3000</td>
<td>1535</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1110</td>
<td>650</td>
</tr>
<tr>
<td>Mercury</td>
<td>357</td>
<td>-39</td>
</tr>
<tr>
<td>Oxygen</td>
<td>-183</td>
<td>-218</td>
</tr>
<tr>
<td>Sodium</td>
<td>890</td>
<td>98</td>
</tr>
<tr>
<td>Sulphur</td>
<td>445</td>
<td>115</td>
</tr>
</tbody>
</table>

a) Which substance is a liquid at room temperature?

b) Which substance is a gas at room temperature?

c) Which substances are solid at room temperature?

d) Which substance stays a liquid over the widest range of temperature?

3. Complete the following table:

| Sub-atomic particle | Relative mass | Charge |
4. Complete the table below with the missing name or symbol of the element.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium</td>
<td></td>
</tr>
<tr>
<td>Ne</td>
<td></td>
</tr>
<tr>
<td>Helium</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Al</td>
<td></td>
</tr>
<tr>
<td>Silicon</td>
<td></td>
</tr>
</tbody>
</table>

5. Below is the atomic notation of an element.

\[ ^{31}_{15}P \]

a) What is the name of the element?

__________________________

b) Describe what the number 31 stands for?

__________________________

c) What does the number 11 stand for?

__________________________
d) What is the number of 

i. Electrons 

ii. Protons 

iii. Neutrons in that element 

I hope that you have found this self-assessment as easy as ABC. Please refer to the Answers to Self-assessment 2.1 at the end of this topic to verify your answers.
Feedback to Topic 2.3

Feedback to Activity 2.3.1

<table>
<thead>
<tr>
<th>Elements</th>
<th>Symbol</th>
<th>Elements</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>Carbon</td>
<td>C</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>Argon</td>
<td>Ar</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N</td>
<td>Calcium</td>
<td>Ca</td>
</tr>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>Chlorine</td>
<td>Cl</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>Beryllium</td>
<td>Be</td>
</tr>
<tr>
<td>Sulphur</td>
<td>S</td>
<td>Fluorine</td>
<td>F</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H</td>
<td>Helium</td>
<td>He</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>P</td>
<td>Aluminium</td>
<td>Al</td>
</tr>
<tr>
<td>Boron</td>
<td>B</td>
<td>Magnesium</td>
<td>Mg</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O</td>
<td>Silicon</td>
<td>Si</td>
</tr>
</tbody>
</table>
Answers to Self-assessment 2.1

1.

a) You could have given any 2 of these answers.

<table>
<thead>
<tr>
<th>Physical change</th>
<th>Chemical change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Easily reversed.</td>
<td>Not easily reversed.</td>
</tr>
<tr>
<td>Does not produce any new</td>
<td>Always produce new substances.</td>
</tr>
<tr>
<td>substances.</td>
<td></td>
</tr>
<tr>
<td>No change in the masses of</td>
<td>Total mass is unaltered but the mass of each product usually differs from that of each reactant.</td>
</tr>
<tr>
<td>substances involved.</td>
<td></td>
</tr>
<tr>
<td>Physical properties change,</td>
<td>Physical and chemical properties change.</td>
</tr>
<tr>
<td>chemical properties do not</td>
<td></td>
</tr>
<tr>
<td>change.</td>
<td></td>
</tr>
<tr>
<td>Involves very little heat</td>
<td>May involve a considerable amount of heat being absorbed or evolved.</td>
</tr>
<tr>
<td>absorption or evolution.</td>
<td></td>
</tr>
</tbody>
</table>

b)

<table>
<thead>
<tr>
<th>i.</th>
<th>True</th>
</tr>
</thead>
<tbody>
<tr>
<td>ii.</td>
<td>False</td>
</tr>
<tr>
<td>iii.</td>
<td>False</td>
</tr>
<tr>
<td>iv.</td>
<td>True</td>
</tr>
<tr>
<td>v.</td>
<td>False</td>
</tr>
<tr>
<td>vi.</td>
<td>True</td>
</tr>
</tbody>
</table>

2.

a) Mercury

b) Oxygen

c) Iron, magnesium, sodium, & sulphur

d) Iron
3.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron</td>
<td>$1$</td>
<td>$0$</td>
</tr>
<tr>
<td>Electron</td>
<td>$\frac{1}{1840}$</td>
<td>$-1$</td>
</tr>
<tr>
<td>Proton</td>
<td>$1$</td>
<td>$+1$</td>
</tr>
</tbody>
</table>

4.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Symbol</th>
<th>Elements</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium</td>
<td>Li</td>
<td>Chlorine</td>
<td>Cl</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>Boron</td>
<td>B</td>
</tr>
<tr>
<td>Helium</td>
<td>He</td>
<td>Aluminium</td>
<td>Al</td>
</tr>
<tr>
<td>Potassium</td>
<td>K</td>
<td>Silicon</td>
<td>Si</td>
</tr>
</tbody>
</table>

5.

a) Phosphorus

b) The nucleon number. It is the sum of neutron and protons in the nucleus of the atom.

c) Proton nucleon

d)

i. 15 electrons

ii. 15 protons

iii. 16 neutrons

This brings us to the end of this unit. How did you find it? Are you clear on what an atom, element, molecule, compound, and mixtures are? What is the smallest unit of matter? What do combinations of elements represent?

Quite often in chemistry, we want to deal with one phase or one part of a mixture at a time. Hence, it is important to know how to separate various mixtures. Let’s find out how in the next topic!
You will need 2 hours and 20 minutes to complete Topic 2.4. You are advised to spend another 1 hour and 10 minutes of your own time to review the topic.

In topic 2.3 you learned that there are different types of mixtures and that there are different types of separation techniques that can be used to separate those mixtures. In this topic you are going to learn about and practice some separation techniques that can be carried out at home or in a school science laboratory.

If you have access to the internet, go to www.youtube.com and search for “separation techniques in chemistry” and take a look at some relevant videos. Note that when doing any search on the internet, it is important to note that not everything that comes up from the search is relevant or correct, so you need to gain the skill of “filtering” through the irrelevant or incorrect materials.

There are several techniques that people from all walks of life use to separate mixtures. For instance, after infusing your tea if you are using tea leaves (not tea bags), you will use a strainer to remove the leaves from the infused tea. This simple and everyday technique is called filtration.

Before you learn more about filtration and other separation techniques, I would like you to find out more about some traditional ways of separating mixtures.
Activity 2.4.1

You should spend around 10 minutes on this activity.

Your task here is to ask around for more information about the types of separation techniques that your ancestors used to separate different types of mixtures. Record your information in the space provided below.

---

---

---

---

---

---

I’m sure that you have found some surprising information. For instance, you might have learnt that some people may have used a clean piece of cloth to strain their tea. The fibrous mesh from the coconut tree ('tanmi koko' in Creole) was also used as strainer.

Now we are going to learn about some techniques to separate different types of mixtures. As we have seen earlier, mixtures can be of different composition. We will start off with the separation of solid-liquid mixtures.

2.4.1 Separation of solid-liquid mixtures

There are different methods to separate solid-liquid mixtures. These are filtration, evaporation, decanting, crystallization, and simple distillation. However, you need to choose appropriate techniques depending on what you want to obtain. We will now discuss each of these methods.

2.4.1.1 Filtration

Filtration is a technique used to separate an insoluble solid (like the tea
leaves) from a liquid (the infused tea). In the laboratory we use a filter funnel and a special paper known as filter paper for filtering mixtures.

Let’s take a closer look at filtration. First, I am going to teach you how to prepare the filter paper to make a cone to filter your mixture.

**Activity 2.4.2**

You should spend less than five minutes on this activity.

Making a cone out of paper may be quite tricky for some people. So please carefully follow the simple instructions below to make yours.

**Step 1**

Fold the round filter paper provided in half to form a semi-circle.

**Step 2**

Fold the paper in half again to form a quarter of a circle.
Step 3

Open the folded filter paper by holding 3 parts of the quarter circle together on one side to form a cone.

Step 4

Put the cone into a filter funnel and wet it with a little bit of distilled water to hold it in place.

Figure 2.4.1: Procedures for folding the filter paper

Procedures demonstrated by: Carole Jacques

All photos for Activity 2.4.2 by: Rosianna Jules, July 2009

You are now ready to start filtering your mixture!

You are now going to carry out an activity in pairs or in a small group in the science laboratory.
**Group activity 2.4.1**

You should spend about 10 minutes on this activity.

**Equipment:**

In your group, you will need: a filter funnel, a filter paper, some soil water (muddy or marshy water will also work) and 2 beakers.

**Instruction:**

1. Add a small amount of soil to a beaker half filled with water, and stir using a stirrer. Alternatively you can use muddy or marshy water.

2. Set up your apparatus as shown below. (You may ask for help from the tutor or laboratory technician if necessary.)
3. Carefully pour some of the mixture into the filter paper. Make sure that it does not spill over the rim of the filter paper. (If it spills over, you will have to start over as it might spoil your result.)

Figure 2.4.2: Setting up for filtration

Procedures demonstrated by: Carole Jacques

All photos for Group activity 2.4.1 by: Rosianna Jules, July 2009

4. Observe what happens and write down your observations in the space below. You may illustrate your observations with a labelled diagram.

Magic! Did you notice the difference in the appearance of the substance which was to be filtered and the substance which was collected in the beaker? If not, have another look at your result before moving on.
Feedback to Group Activity 2.4.1

I hope that was interesting for you. You should have noticed that, just like when you strain your tea, the solid particles remain in the filter paper and the liquid part goes through the filter paper. In addition, you should have noticed that the liquid which passed through the filter paper and was collected in the beaker was clearer than the one which was poured into the filter paper.

The solid which remained in the filter paper is called the residue. The liquid that passed through the filter paper and collected in the beaker is known as the filtrate.

Applications of filtration

Filtration is used in the treatment of water. A filter or sand bed is used to remove the solid impurities before the water is treated with chlorine to make it safe for drinking.

Filtration is also used in industries in the manufacture of:

- sugar, and
- beer

You can use filtration to obtain the solid (residue) or the liquid (filtrate) from the mixture. However, the filtrate will not be pure as there are different substances dissolved in it.

The next method we are going to look at, allows us to obtain the pure liquid from the mixture. This method is known as simple distillation.

2.4.1.2 Simple distillation

Before we talk about simple distillation, I would like you to carry out this simple activity in your kitchen.
Activity 2.4.3

You should spend about 10 minutes on this activity.

**Equipment:**

You will need two clean glasses, some drinking water, two teaspoons of salt, a saucepan with a lid (a transparent glass lid is preferable if you have one) and a stove (or any fire source you use when cooking).

**Instruction:**

1. Dissolve two teaspoons of salt in a glass of water. (You can dip your finger into the salt solution and taste it; do not drink the salt solution).
2. Pour the salt solution into the saucepan, cover it with the lid.
3. Heat the salt solution to boil. **Be careful when using fire.**
4. Observe what happens as the salt solution boils.
5. After two minutes of boiling, remove the lid and tilt it to one side so that you can collect some of the liquid droplets formed under the lid into a clean glass. **Be careful of the steam when uncovering the saucepan.**
6. Taste the liquid that you have just poured into the glass.
7. Write your observation in the space provided.

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

I hope that you have found this activity simple to perform. Please refer to the feedback for the expected observation.
Feedback to Activity 2.4.3

You should have observed that the salt solution, as expected, tastes salty. However, liquid that was collected under the lid was not salty as it was pure water. You should have also observed that, as we have seen in Topic 2.1, as the water boils, it vaporises, forming water vapour or steam. As the water vapour or steam cannot all escape (because of the lid), it condenses (turns back to water (a liquid)) under the lid.

From Activity 2.4.3 we can conclude that if we evaporate a salt solution (a solid-liquid mixture) and allow the vapour to condense, we can obtain pure water (the pure liquid). Evaporation and condensation are the two processes involved in simple distillation. We are now going to learn more about simple distillation.

**Simple distillation** is used to recover (obtain) a liquid from a solid-liquid mixture or from a liquid-liquid mixture. As mentioned above, simple distillation involves evaporation followed by condensation.

The liquid with the lowest boiling point distils (evaporates and condenses) first. So the thermometer is used to measure the temperature so that it can be maintained to ensure the complete distillation of the liquid for each successive boiling point. By monitoring the temperature, each liquid can be collected separately.

As the liquid with the lowest boiling point in the distillation flask boils, its vapour rises and moves into the Liebig condenser in order to escape. As the vapour passes through the inner tube in the condenser, the vapour is cooled by the water flowing around that tube causing it to condense into a liquid. The liquid which is collected in the beaker or flask is called the **distillate**.

Figure 2.4.3 below shows a green coloured mixture being distilled to obtain pure liquid.
You are now going to illustrate the process of simple distillation by distilling some seawater or a coloured solution.

**Group activity 2.4.2**

You should spend around 15 minutes on this activity.

You will need to carry out this group activity in the school science laboratory.

1. The laboratory technician will help you to set-up your apparatus as shown in Figure 2.4.3 above.
2. Light up the burner to heat the mixture and observe what happens.
3. Write your findings in the space below.

__________________________
__________________________
__________________________
__________________________
I hope that you have found this group activity interesting. Please read on for the feedback.

**Feedback to Group activity 2.4.2**

You should have noticed that when the seawater or the coloured liquid was heated, it vaporized. When the thermometer read 100°C, it showed that the vapour being formed is water vapour or steam. As steam passed through the Liebig condenser, it condensed on the cold surface inside the Liebig condenser and water (the distillate) is collected in the beaker.

**Applications of simple distillation**

Simple distillation is used to:

- purify seawater to obtain fresh drinking water in many countries;
- obtain alcohol in the production of brandy or whisky.

**2.4.1.3 Decanting**

Decanting is normally used to separate a liquid from an insoluble solid that has settled in the bottom of the container. The solid that has settled is known as the precipitate or sediment. The liquid to be separated is carefully poured out of the container without disturbing the precipitate or sediment as illustrated by Figure 2.4.4 below.

For example, decanting is used when separating rice grains from water when rinsing the rice before cooking.
Applications of decanting

Decanting is used in the production of:
- wine, and
- olive oil

2.4.1.4 Evaporation

As you have seen in Topic 2.2, evaporation is a process whereby particles escape from the surface of a liquid. We can use evaporation to obtain any solid that is not heat-sensitive from a solution, by heating the solution directly to allow evaporation to dryness. For example, a sodium chloride solution can be evaporated to give sodium chloride (table salt).

However, if the solid is heat-sensitive, the evaporation should be done over a water bath as shown below.
A solution is a mixture of solutes (solids which dissolved in the solvent to form the solution).

A solvent is the liquid that dissolves the solute to form a solution.

2.4.1.5 Crystallisation

Crystallisation is used to obtain pure crystals (solids) which are sensitive to heat by cooling a hot, saturated solution of the substance. The solution is said to be saturated when the solute added can dissolve no more.

You can make your own crystals at home.

Activity 2.4.4: Making crystals

You should spend around 10 minutes to set up the crystallisation process and about 3 minutes on the following day to separate the crystals from the solution.

For this activity you will need some sugar, a small saucepan and a gentle heating system.

Procedure

1. You need to make a saturated sugar solution by dissolving excess sugar (the solute) in a heat proof container (a small saucepan) of water (the solvent) over gentle heat. If you wish, you can add two drops of food colouring to the solution to make it a little bit more interesting.

2. Allow the saturated solution to cool overnight.

3. Filter the contents of the container to separate the crystals from the solution. (You can use a tea strainer to do that).
I hope that you have enjoyed this activity. Did you get the sugar crystals? If you did not get the crystals, it may be because you did not have a saturated sugar solution. You could try again, this time make sure that you add excess sugar.

Applications of crystallisation

Crystallisation can be used to obtain:
- zinc nitrate crystals by cooling a hot saturated solution of zinc nitrate; and
- copper (II) sulphate by cooling a hot saturated solution of copper (II) sulphate.

So far we have seen the different separation techniques that can be used to separate solid-liquid mixtures. We are now going to talk about the separation of liquid-liquid mixtures.

2.4.2 Separation of liquid-liquid mixtures

Mixtures of liquids can be separated by using a separating funnel, simple distillation or fractional distillation depending of the physical properties of the liquids in the mixture, such as their boiling points and their miscibility (ability to mix together). For example, mixtures of immiscible liquids (liquids that do not mix together), like water and oil, can easily be separated using a separating funnel while mixtures of miscible liquids (liquids that mix together), like water and vinegar, cannot be separated using that same technique.

We are now going to see how we can separate mixtures of immiscible liquids using a separating funnel.

2.4.2.1 Separating funnel

A separating funnel can be used to separate immiscible liquids like a mixture of oil and water shown in Figure 2.4.6 below.
You are now going to learn how to use the separating funnel.

1. Set up the equipment as shown in Figure 2.4.6 above.
2. Ensure that the tap at the neck of the separating funnel is closed.
3. Pour the mixture of immiscible liquids into the separating funnel.
4. Allow the mixture to settle so that the denser liquid (liquid with the higher density) sinks to the bottom of the filter funnel.
5. When the liquids have settled into separate layers (as shown above) you can open the tap and carefully allow the densest liquid to flow into the container.
6. Close the tap as soon as all of the densest liquid has flowed out.
7. You can run out the next denser liquid in a separate container.

Now let us look at simple distillation and fractional distillation as the two other techniques for separating liquid-liquid mixtures. Simple distillation and fractional distillation are appropriate for separating miscible liquids.

### 2.4.2.2 Simple distillation

You have seen earlier that simple distillation can be used to obtain a pure liquid from a solid-liquid mixture. We can also make use of simple
distillation to separate mixtures of liquids. The greater the difference in the boiling points of the liquids in the mixture, the easier it is to separate the mixture by simple distillation.

If the difference in boiling points of the liquids in the mixture is 25° C or less, it is best to separate the mixture by a more complex distillation process known as **fractional distillation**.

### 2.4.2.3 Fractional distillation

As mentioned above, fractional distillation is used to separate mixtures consisting of liquids with close boiling points. For example, alcohol can be separated from water by fractional distillation because the boiling point of alcohol is 78° C and that of water, as you know, is 100° C. The mixture separates into different parts known as **fractions**.

In the school laboratory, a fractionating column with perforated plates (Figure 2.4.7 below) or filled with glass beads is fitted to a distilling flask as shown in the diagram below.

![Fractional distillation diagram](http://en.wikipedia.org/wiki/Fractional_distillation)

**Figure 2.4.7:** Diagram showing the set-up of fractional distillation for a school laboratory

On heating, the liquid with the lowest boiling points evaporates and condenses on the cold glass beads. As the column warms up on continuous heating, the vapour rises further before condensing.

This process of evaporation and condensation is repeated over and over again. Eventually, the liquid with the lowest boiling points comes out of the top of the fractionating column into the Liebig condenser where it condenses into a liquid. Once all the liquid with the lowest boiling point has been separated, the temperature rises to match the boiling point of the next liquid. The process repeats until all the liquids in the mixture have been separated.

Application of fractional distillation

Fractional distillation has many industrial applications. For example it is used:

1. to distil crude oil to obtain several useful components, such as petrol, benzene and diesel;

2. in the liquefaction of air to obtain liquefied nitrogen and oxygen. Nitrogen is distilled off first at -196°C and oxygen at -183°C.

So far you have seen how to separate solid-liquid mixtures and liquid-liquid mixtures. We are now going to learn about the different techniques used to separate solid-solid mixtures.

2.4.3 Separation of solid-solid mixtures

Solid-solid mixtures can be separated using different separating techniques based on the properties of the solids. Before we go any further, let us see if you can think of a way to separate the following solid-solid mixtures.
Activity 2.4.5

You should spend around 10 minutes on this activity.

1. You are provided with two mixtures of solids:
   a. Mixture A is a mixture of salt and rice.
   b. Mixture B is a mixture of small needles and sawdust.
2. Think of an appropriate technique to separate each mixture to obtain the solids separately.
3. Write your answers in the space provided.

Mixture A can be separated by:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Mixture B can be separated by:

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

I hope that you have come up with a way to separate each of the two mixtures.

The best way to separate Mixture A is by adding water to the mixture to dissolve the salt and then filter the mixture so that the rice will remain on the filter. The salt solution will go through the filter and can then be evaporated to obtain the salt.

The best way to separate Mixture B is by using a magnet to attract all the needles in order to separate them from the sawdust.
Now let us take a closer look at the techniques for separating solid-solid mixtures. Mixtures of solids can be separated using (a) dissolution followed by filtration; (b) magnets; and (c) sublimation.

2.4.3.1 Dissolution and filtration

Dissolution and filtration is used when one solid is soluble, while the other is not. Because the solubility varies with the solvent used, it is very important to choose the appropriate solvent to dissolve the soluble solid.

For example, if we want to separate rice from a mixture of rice and salt, we need to add water to the mixture to dissolve the salt. This process is known as dissolution. The mixture is then filtered to separate the insoluble solid. Evaporation, as seen in 2.4.1.4, can then be used to obtain the salt (soluble solid) if necessary. (Feel free to go back to review evaporation if you need to.)

Activity 2.4.6

You should spend around 5 minutes on this activity.

Based on what you have learnt above about filtration, when filtering the mixture of rice and salt solution above, what will be:

(a) the residue?

The residue will be ____________________________

(b) the filtrate?

The filtrate will be ____________________________

You are correct! The residue will be the rice and the filtrate will be the salt solution. The salt solution is then evaporated to obtain the salt.
2.4.3.2 Using magnets

If one of the solids in the mixture exhibit magnetic properties, then that solid can be extracted using a magnet.

For example in a mixture of iron filings and sulphur, a magnet can be used to separate the iron filings from the mixture.

2.4.3.3 Sublimation

Sublimation is used to separate mixtures containing a solid which can sublime. As mentioned earlier in Topic 2.2, the substances which can sublime include: ammonium chloride, iodine, benzoic acid and naphthalene. Figure 2.4.8a and Figure 2.4.8b show the diagrams to illustrate the sublimation set up.

![Diagram to illustrate sublimation set up](http://en.wikipedia.org/wiki/File:Sublimation_apparatus.svg)

Alternatively, you can place an inverted funnel on an evaporating dish containing the mixture consisting of a substance which sublimes. The sublimate collects on the cool parts of the funnel as shown in Picture B below.

![Diagram showing sublimate collecting](http://en.wikipedia.org/wiki/File:Sublimation_apparatus.svg)
2.4.3.4 Paper chromatography

Paper chromatography is a technique used for the separation and identification of mixtures. Chromatography is based on the:

1. solubility of the different solids in the mixture dissolved in the same solvent; and
2. selective absorption of the components by the filter paper.

When separating colourless substances, we can make the substances more visible by using ultraviolet light and by spraying them with locating agents. Locating agents are chemicals that react with and colour the separated substances.

Now you are going to do a simple paper chromatography.

**Activity 2.4.5**

**Equipment:**

You will need: a strip of filter paper about 1cm wide, a water soluble pen, and a boiling tube with rubber bung.

**Instructions:**

1. Cut a strip of filter paper about 1 cm wide.
2. Put a spot of water soluble ink (the mixtures) about 1 cm from the bottom of one end of the strip of filter paper. The filter paper is known as the **stationary medium**.
3. Allow the ink to dry.
4. Put a little water (solvent) in the boiling tube. Water or any other solvent used is known as the **moving medium**.
5. Hang the strip of filter paper so that the end with the dot of ink just touches the water. You have to ensure that the dot of ink is above the level of the water.
6. Leave the set up undisturbed for a while and observe what happens.
7. Stick your chromatogram and write down your observations in the space provided.
You may have noticed that black ink contains different colours of dyes. As the water (solvent) moves or flows along the filter paper, the dye which is more soluble in the water (solvent) and less absorbed by the filter paper, travels further up the filter paper. The dye which is less soluble and more absorbable travels the least.

Application of chromatography:

Chromatography is used in

1. the manufacture of medicine;
2. the analysis of protein and carbohydrates;
3. food industries
4. crime scene investigations
Now let us see how much you have understood about this section.

**Self-assessment 2.2**

You should spend less than 10 minutes on this self-assessment. This self-assessment is based on Topic 4. The answers are given at the end of the topic. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 2.2. This will help you learn and reflect better on areas for improvement.

Answer the following questions in the space provided.

1. Which separation technique is most suitable for obtaining:
   a) Ammonium chloride from a white powder consisting of ammonium chloride and sodium chloride?
   
   ______________________

   b) Small pieces of iron from a mixture of iron and copper tunings?
   
   ______________________

   c) The different pigments from an extract of flower petals?
   
   ______________________

   d) Benzene from a liquid mixture of benzene and petrol?
   
   ______________________

   e) Sugar from a sugar solution.
   
   ______________________
f) Oil from a mixture of oil and water.

2. Describe what the following terms mean.
   a) Filtrate
   
   b) Residue
   
   c) Distillate
1.

   a) sublimation   b) a magnet
   c) chromatography d) fractional distillation
   e) crystallisation f) separating funnel

2.

   a. The filtrate is the substance (liquid) that goes through the filter paper during filtration.

   b. Residue is the solid particles that remain in the filter paper during filtration.

   c. Distillate is the pure substance that is collected during distillation.

I hope that you have enjoyed learning about separation techniques. I am sure that you have now realised that you are using some of those techniques in your everyday life. If you, however, feel that you need to go over certain techniques again, feel free to do so.

Now in the last topic in this unit, we are going to learn how to quantify the number of particles in an atom. The topic entitled ‘The mole concept’ is especially for those of you who are ready to go that extra mile, or those who are aiming for Grades A or B in the examination. In other words, those of you who are not studying the extended objectives, you are not obliged to follow this topic. However, this does not prevent you from trying it. It involves a lot of calculations and if you love mathematics, you might enjoy doing it. If you choose not to do it, you can use the time to review the previous topics as necessary or make a head start on Unit 3.
Topic 2.5: The Mole Concept

As mentioned above, this topic is for those of you who are studying the extended objectives. If you are a student doing the core objectives, you may also attempt this topic, if you like. If you choose not to follow this topic, you are encouraged to use the additional 90 minutes to further review the topics covered.

You will need 1 hour 30 minutes to complete Topic 2.5. You are advised to spend another 45 minutes of your own time to review the topic.

In this topic, you will learn how to quantify the number of particles in an atom.

In everyday life, we measure pieces of matter either by counting or weighing them, depending on what is most convenient for us. For instance, when baking a cake, it is more convenient to count the eggs and weigh the sugar rather than the other way round. Because the sugar crystals are so small, counting individual sugar crystals is simply ridiculous. Hence, for convenience, we weigh sugar using the mass units, kilograms (kg) or grams (g).

Similarly, because of the very large numbers of atoms that are involved in any chemical reaction are much too small to count individually, to quantify the large numbers of atoms, we use Avoagadro’s constant (often referred to as Avogadro’s number) and the mole. The mole is a unit which allows us to count the number of atoms by weighing them.

Now let us learn more about Avogadro’s constant and the mole.
2.5.1 Avogadro’s constant

The Avogadro constant (\(N_A\)) is the number of particles (atoms, or molecules) in 1 mole which is equal to \(6.02 \times 10^{23}\).

This means that:

- 1 mole of hydrogen atom (H) contains \(6.02 \times 10^{23}\) atoms of hydrogen.
- 1 mole of carbon-12 contains \(6.02 \times 10^{23}\) atoms of carbon-12.
- 1 mole of Hydrogen molecules (\(H_2\)) has \((6.02 \times 10^{23}) \times 2\) molecules of Hydrogen.
- 1 mole of water (\(H_2O\)) contains \((6.02 \times 10^{23}) \times 3\) molecules of water.
- 1 mole of methane gas (\(CH_4\)) contains \((6.02 \times 10^{23}) \times 5\) of molecules of methane.

I hope that you have understood these examples. Now you are going to learn what the term mole means.

2.5.2 The Mole

The mole (mol) is the SI (Système International) unit of the ‘amount of substance’ (or the number of particles (atoms or molecules) of a substance). One mole contains the same number of particles, that is, \(6.02 \times 10^{23}\) (Avogadro’s number) of particles as there are atoms in exactly 12 grams of carbon-12 isotope.

One mole has a mass exactly equal to the substance’s relative atomic mass (\(A_r\)) or relative molecular mass (\(M_r\)). Very often, especially in calculations, these masses are expressed as molar mass. This is because the molar mass gives you the quantitative value of a substance. Hence, contrary to the relative atomic mass (\(A_r\)) and relative molecular mass
(Mr), the molar mass has a unit which is grams per mol (the unit symbol is: \( \text{g mol}^{-1} \) which can also be written as: \( \frac{\text{g}}{\text{mol}} \) or g/mol).

The relative molecular mass of a substance (compound or a molecule) is the sum of the relative atomic masses of the elements in the formula of the substance. Similarly, the molar mass of a substance is the sum of the atomic masses of the elements in the formula of the substance but has the unit \( \text{g mol}^{-1} \) attached to it.

So to calculate the relative molecular mass and the molar mass of 1 mole of a substance you need to know the following:

- the relative atomic mass of the substance (which is usually given. If not you can get that value from the Periodic Table); and
- the formula of the substance to get:
  - the elements present; and
  - the number of moles of each element present;

Now let us see how to calculate the relative molecular mass (Mr) or the molar mass of some substances.

First of all, here are the \( A_r \) (relative atomic mass) for the elements we will be using in the examples: \( A_r (\text{H}) = 1; A_r (\text{C}) = 12; A_r (\text{O}) = 16; A_r (\text{Al}) = 27; A_r (\text{Ca}) = 40. \)

So, for example, for:

1. 1 mole of carbon dioxide (CO₂) which contains one mole of carbon atoms and two moles of oxygen atoms, the Mr (relative molecular mass) is 44 and the molar mass is 44 g mol\(^{-1}\). See Table 2.5.1 below for the calculation.
2. 1 mole of aluminium oxide (Al₂O₃) which contains 2 moles of aluminium and 3 moles of oxygen, the Mr is 102 and the molar mass is 102 g mol\(^{-1}\). See Table 2.5.1 below for the calculation.

More examples are given in Table 2.5.1 below.

<table>
<thead>
<tr>
<th>1 mole of the substance</th>
<th>Calculations using relative atomic masses ( (A_r) ) and number of mole</th>
<th>Relative Molecular mass ( (M_r) )</th>
<th>Molar mass ( (\text{g mol}^{-1}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substance</td>
<td>Equation</td>
<td>Mr (g mol⁻¹)</td>
<td>Molar Mass (g mol⁻¹)</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>--------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>C + 20 = (1 × 12) + (2 × 16) = 12 + 32 = 44</td>
<td>44</td>
<td>44 g mol⁻¹</td>
</tr>
<tr>
<td>Aluminium oxide (Al₂O₃)</td>
<td>2Al + 3O = (2 × 27) + (3 × 16) = 54 + 48 = 102</td>
<td>94</td>
<td>94 g mol⁻¹</td>
</tr>
<tr>
<td>Carbon-12 (C)</td>
<td>C = (1 × 12) = 12</td>
<td>12</td>
<td>12 g mol⁻¹</td>
</tr>
<tr>
<td>Oxygen (O)</td>
<td>O = (1 × 16) = 16</td>
<td>16</td>
<td>16 g mol⁻¹</td>
</tr>
<tr>
<td>Water (H₂O)</td>
<td>2H + O = (2 × 1) + (1 × 16) = 2 + 16 = 18</td>
<td>18</td>
<td>18 g mol⁻¹</td>
</tr>
</tbody>
</table>

Table 2.5.1: Examples of how to calculate the Mr (relative molecular mass) and molar mass of 1 mole of some substances using the Aᵣ (relative atomic mass)

Please note that the calculations for relative molecular mass and molar mass are the same. The only difference is that the molar mass has the unit g attached to the value.

I hope that you have clearly understood these calculations as you will need them to proceed in this topic. If you are having any doubts, please go through it again and if necessary ask for further help from your colleagues and your tutor.

As you work through this topic, you will learn about calculations involving the use of the molar mass, the mole and Avogadro’s constant.

### 2.5.3 Conversions involving Avogadro’s number and the mole

You can convert moles to mass of substances (in grams), or moles to number of atoms or molecules, and vice versa using different formulae.
Let us look at how to do these conversions. Later on in Self-assessment 2.3, you will have the chance to practise some of the conversions on your own.

2.5.3.1 Converting moles to masses

If you are given the number of moles of a substance, you can calculate its mass using formula 1 below.

Formula 1:

\[
\text{mass} = \text{number of moles} \times \text{molar mass}
\]

Now let us look at two examples that involve the use of Formula 1. Let us go through this calculation together.

Example 2.5.3.1.1: What is the mass of 0.1 mole of calcium (Ca)? \( A_r (\text{Ca}) = 40 \).

First, write down the formula:

\[
\text{Mass} = \text{number of moles} \times \text{molar mass}
\]

Second, calculate the molar mass of calcium:

\[
\text{Molar mass of calcium} = (1 \times 40) = 40 \text{ g mol}^{-1}
\]

Please remember that the molar mass:
- is the sum of the relative atomic mass of the elements present in the formula of the substance; and
- is measured in g mol\(^{-1}\) (grams per mole) which can also be written as g/mol or \( \frac{g}{mol} \).
Third, substitute the values in the formula

\[
\text{Mass of } 0.1 \text{ mole of calcium} = \text{number of moles} \times \text{molar mass}
\]

\[
= 0.1 \text{ mol} \times \frac{40 \text{ g}}{\text{mol}}
\]

\[
= 4.0 \text{ g}
\]

0.1 is the number of moles of calcium

40 g/mol is the molar mass of calcium

The 2 mol cancel out each other leaving the unit for mass (g)

So, the mass of 0.1 mole of calcium is 4 g

Let us try another example.

**Example 2.5.3.1 2:** What is the mass of 0.5 mole of sodium carbonate \( \text{(Na}_2\text{CO}_3) \)? \( \text{Ar (Na)} = 23, \text{Ar (C)} = 12, \text{and Ar (O)} = 16. \)

First, write down the formula:

\[
\text{Mass} = \text{number of moles} \times \text{molar mass}
\]

Second, calculate the molar mass of sodium carbonate:

Molar mass of sodium carbonate is:

\[
\text{Na}_2\text{CO}_3 = 2\text{Na} + \text{C} + 3\text{O}
\]

\[
= (2 \times 23) + 12 + (3 \times 16)
\]

\[
= 46 + 12 + 48
\]

\[
= 106 \text{ g mol}^{-1}
\]

So, the molar mass of sodium carbonate = 106 g mol\(^{-1}\)
Third, substitute the values in the formula

Mass of 0.5 mole of sodium carbonate

\[ \text{Mass} = \text{number of moles} \times \text{molar mass} \]

\[ = 0.5 \text{ mol} \times \frac{106 \text{ g}}{\text{mol}} \]

0.5 is the number of moles \( \text{Na}_2\text{CO}_3 \)

\[ = 53 \text{ g} \]

The unit mol cancels out each other leaving the unit for mass (g)

Hence, 0.5 mole of sodium carbonate has a mass of 53 g.

I hope that you have understood the conversion of moles to mass. Now we are going to look at the conversion of mass to moles.

### 2.5.3.2 Converting masses to moles

If you are given the mass of a substance, you can calculate the number of moles using the formula 2 below.

Formula 2:

\[ \text{Number of moles} = \frac{\text{mass (g)}}{\text{molar mass (g mol}^{-1})} \]

Please note that:

\[ \frac{1}{(\text{g mol}^{-1})} \] is expressed as \( \frac{1}{\text{g}} \times 1 \text{ mol} \)
Example 2.5.3.2.1: What is the number of moles present in 9 g of water?

\[ A_r (H) = 1 \text{ and } A_r (O) = 16 \]

First, write down the formula:

\[ \text{number of moles} = \frac{\text{mass (g)}}{\text{molar mass (g mol}^{-1})} \]

Second, calculate the molar mass of water

Molar mass of water is:

\[ H_2O = (2 \times 1) + 16 = 18 \]

Molar mass of water = 18 g mol\(^{-1}\)

Third, substitute the values in the formula

\[ \text{number of moles in 9 g of water} = \frac{\text{mass (g)}}{\text{molar mass (g)}} \times 1 \text{ mol} \]

\[ = \left( \frac{9 \text{ g}}{18 \text{ g}} \right) \times 1 \text{ mol} \]

\[ = 0.5 \text{ mol} \]

So 9 g of water = 0.5 mole of water or \( \frac{1}{2} \) mole of water

Now let us try another example.
Example 2.5.3.2.2: What is the number of moles of Ca\(^{2+}\) present in 15 g of Ca\(^{2+}\) ions? \(A_r (Ca) = 40\).

First, write down the formula:

\[
\text{number of moles} = \frac{\text{mass (g)}}{\text{molar mass (g mol}^{-1}\text{)}}
\]

Second, calculate the molecular mass of calcium

Molar mass of Ca\(^{2+}\) = \(1 \times 40 \text{ g mol}^{-1}\)

= 40 g mol\(^{-1}\)

Third, substitute the values in the formula

number of moles in 15 g of Ca\(^{2+}\) = \(\frac{\text{mass (g)}}{\text{molar mass (g) \times 1 mol}}\)

\[
= \frac{15 \text{ g}}{40 \text{ g}} \times 1 \text{ mol}
\]

= 0.375 mol

So 15 g of Ca\(^{2+}\) = 0.375 moles of Ca\(^{2+}\)

Now that you have learnt how to convert mole to mass and mass to moles, you are going to learn how to convert mole to the number of particles. If you may recall in topic 2.5.1 you learnt that the number of particles (atoms, or molecules) in 1 mole equals to Avogadro’s constant which is \((6.02 \times 10^{23})\).
2.5.3.3 Converting moles to number of particles

If you are given the number of moles of a substance, you can calculate the number of particles using Formula 3 or Formula 4 below.

Formula 3:

\[
\text{Number of particles} = \text{number of moles of the substance} \times \text{Avogadro’s number} \times 6.02 \times 10^{23}
\]

OR

Formula 4:

\[
\text{Number of particles} = \text{number of moles of the substance} \times \text{Avogadro’s number} \times \text{number of moles of atoms in that substance}
\]

Please note that:

- Formula 3 is used when finding the number of particles in an element.
- Formula 4 is used when calculating the number of particles in a molecule or a compound. In this case, you need to consider the number of moles of atoms present in the formula of the molecule or compound.

Let us try two examples together.
Example 2.5.3.3.1: How many atoms are there in $\frac{1}{4}$ mole of carbon?

First, write down the formula:

Number of particles $= \text{number of moles} \times \text{Avogadro's number}$

This implies that:

Number of atoms of carbon $= \text{number of moles of carbon} \times \text{Avogadro's number}$

Second, substitute the values in the formula:

Number of atoms of carbon $= \frac{1}{4} \times (6.02 \times 10^{23})$

So $\frac{1}{4}$ mole of carbon contains $1.505 \times 10^{23}$ particles.

Let us try another example.

Example 2.5.3.3.2: How many atoms are there in $\frac{1}{2}$ mole of methane (CH$_4$) molecule?

First, write down the formula:

Number of particles $= \text{number of moles of the substance} \times \text{Avogadro's number} \times \text{number of moles of atoms in the substance}$

Since 1 molecule of methane is made up of 5 moles of atoms (that is, 1 mole of carbon atoms and 4 moles of hydrogen atoms), to find the number of atoms we need to multiply Avogadro’s number by 5.
Second, substitute the values in the formula

\[ \text{Number of particles} = \frac{1}{2} \times (6.02 \times 10^{23}) \times 5 \]

\[ = 15.05 \times 10^{23} \]
\[ = 1.505 \times 10^{24} \]

So the number of atoms in \( \frac{1}{2} \) mol of methane is \( 1.505 \times 10^{24} \).

Now let us learn how to convert the number of particles to moles.

### 2.5.3.4 Converting number of particles to moles

If you are given the number of particles, you can calculate the number of moles using the formula below.

**Formula 5:**

\[
\text{Number of moles} = \frac{\text{number of particles}}{\text{Avogadro's constant} (6.02 \times 10^{23})}
\]

**Example 2.5.3.4.1:** What is the number of moles of sodium ions (Na\(^+\)) present in \( 2.3 \times 10^{23} \) of sodium ions?

First, write down the formula:

\[
\text{Number of moles} = \frac{\text{number of particles}}{\text{Avogadro's constant}}
\]
Second, substitute the values in the formula

\[
\text{The number of moles of Na}^+ = \frac{\text{number of particles}}{\text{Avogadro's constant}} = \frac{2.3 \times 10^{23}}{6.02 \times 10^{23}} = 0.382
\]

So the number of moles of sodium ions (Na\(^+\)) present in \(2.3 \times 10^{23}\) of sodium ions is 0.382 moles.

Let us try another example.

*Example 2.5.3.4.2:* What is the number of moles of carbon present in \(3 \times 10^{23}\) of carbon atoms?

First, write down the formula:

\[
\text{Number of moles} = \frac{\text{number of particles}}{\text{Avogadro's constant}}
\]

Second, substitute the values in the formula

\[
\text{The number of moles of C} = \frac{3 \times 10^{23}}{6.02 \times 10^{23}} = 0.498
\]

So, the number of moles of carbon present in \(3 \times 10^{23}\) of carbon atoms is 0.498 moles.

I hope that the examples were easy to follow. Please feel free to revise this section if you have to. You are now going to learn how to convert the number of particles to mass.
### 2.5.3.5 Converting number of particles to masses

If you are given the number of particles, you can calculate the mass using the formula below.

**Formula 6**

\[
\text{mass} = \frac{\text{number of particles}}{\text{Avogadro’s constant } (6.02 \times 10^{23})} \times \text{molar mass}
\]

Now let us try two examples together.

**Example 2.5.3.4.1:** What is the mass of sodium atoms present in \(4.5 \times 10^{23}\) atoms of sodium? \(A_r (\text{Na}) = 23\)

First, write down the formula:

\[
\text{mass} = \frac{\text{number of particles}}{\text{Avogadro’s constant } (6.02 \times 10^{23})} \times \text{molar mass}
\]

Second, calculate the molar mass of sodium

Molar mass of sodium is:

\[
\text{Na} = 1 \times 23 = 23 \text{ g mol}^{-1}
\]

Remember, g mol\(^{-1}\) is read as grams per mol

Third, substitute the value in the formula

\[
\text{Mass of sodium atoms} = \frac{\text{number of particles}}{\text{Avogadro’s constant}} \times \text{molar mass}
\]

\[
= \frac{4.5 \times 10^{23}}{6.02 \times 10^{23}} \times 23 \text{ g}
\]

\[
= 17.19 \text{ g}
\]

So, in \(4.5 \times 10^{23}\) atoms of sodium there are 17.19 g of sodium atoms.
Now let us try a second example.

*Example 2.5.3.4.2:* What is the mass of Ca\(^{2+}\) present in \(3.01 \times 10^{23}\) Ca\(^{2+}\) ions? \(A_r (\text{Ca}) = 40\)

First, write down the formula:

\[
\text{mass} = \frac{\text{number of particles}}{\text{Avogadro's constant} \times \text{molar mass}}
\]

Second, calculate the molar mass of calcium ions

Molar mass of Ca\(^{2+}\) is:

\[
\text{Ca}^{2+} = 1 \times 40 = 40 \text{ g mol}^{-1}
\]

Third, substitute the value in the formula

Mass of sodium atoms \(= \frac{\text{number of particles}}{\text{Avogadro's constant}} \times \text{molar mass}\)

\[
= \frac{3.01 \times 10^{23}}{6.02 \times 10^{23}} \times 40 \text{ g}
\]

\[
= 20 \text{ g}
\]

So, in \(3.01 \times 10^{23}\) atoms of Ca\(^{2+}\) ions there are 20 g of Ca\(^{2+}\) ions.

Now that you know how to convert number of particles to mass, you are going to learn how to convert mass to the number of particles.
2.5.3.6 Converting masses to number of particles

If you are given the mass of a substance, you can calculate the number of particles in the given mass using the formula below.

Formula 7:

\[
\text{number of particles} = \frac{\text{mass}}{\text{molar mass}} \times \text{Avogadro’s constant}
\]

Example 2.5.3.5.1: How many molecules of water are there in 4.5 g of water?

First, write down the formula:

\[
\text{number of particles} = \frac{\text{mass}}{\text{molar mass}} \times \text{Avogadro’s constant}
\]

Second, calculate the molar mass of water

Molar mass of water is:

\[
\text{H}_2\text{O} = 2 \times 1 + 16 = 18 \text{ g mol}^{-1}
\]

Third, substitute the value in the formula

\[
\text{number of particles of water} = \frac{\text{mass}}{\text{molar mass}} \times \text{Avogadro’s constant}
\]

\[
= \frac{4.5 \text{ g}}{18 \text{ g}} \times 1 \text{ mol} \times (6.02 \times 10^{23})
\]

\[
= 1.505 \times 10^{23}
\]

Let us try another example.
Example 2.5.3.5.2: How many atoms of lithium are there in 0.7 g of lithium? $A_r (\text{Li}) = 7$

First, write down the formula:

$$\text{number of particles} = \frac{\text{mass}}{\text{molar mass}} \times \text{Avogadro's constant}$$

Second, calculate the molar mass of water

Molar mass of lithium is:

$$\text{Li} = 1 \times 7$$

$$= 7 \text{ g mol}^{-1}$$

Third, substitute the value in the formula

$$\text{number of particles of water} = \frac{\text{mass}}{\text{molar mass}} \times \text{Avogadro's constant}$$

$$= \frac{0.7 \text{ g}}{7 \text{ g}} \times 1 \text{ mol} \times (6.02 \times 10^{23})$$

$$= 0.602 \times 10^{23}$$

$$= 6.02 \times 10^{22} \text{ atoms}$$

I hope that you have understood the various conversions presented in this topic.

Now it is your turn to practice some of these conversions.
Self-assessment 2.3

You should spend less than 15 minutes on this self-assessment. This self-assessment is based on Topic 5. The answers are given at the end of the topic. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 2.3. This will help you learn and reflect better on areas for improvement.

Use the relative atomic mass (Ar) given to answer the questions below. The Ar for:

<table>
<thead>
<tr>
<th>Element</th>
<th>Ar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen (H)</td>
<td>1</td>
</tr>
<tr>
<td>Carbon (C)</td>
<td>12</td>
</tr>
<tr>
<td>Oxygen (O)</td>
<td>16</td>
</tr>
<tr>
<td>Sulphur (S)</td>
<td>32</td>
</tr>
<tr>
<td>Iron (Fe)</td>
<td>56</td>
</tr>
<tr>
<td>Magnesium (Mg)</td>
<td>24</td>
</tr>
<tr>
<td>Sodium (Na)</td>
<td>23</td>
</tr>
</tbody>
</table>

Show all your work in the space provided.

1. What is the mass of 0.66 mole of sulphur dioxide?

2. What is the number of moles of Fe$^{2+}$ present in 2.8 g of Fe$^{2+}$ ions?
3. How many atoms are there in \( \frac{1}{2} \) mole of water (H\(_2\)O)?

*Show work here.*
4. What is the number of moles of H\(^+\) present in \(3.01 \times 10^{23}\) of hydrogen ions?

Show work here.

I hope that by following the steps in the examples above, you have found this exercise easy. Check the Answers to Self-assessment 2.3 below for the correct answers.
Answers to Self-assessment 2.3

1.

Ar (S) = 32, Ar and Ar (O) = 16.

First, write down the formula:

\[ \text{Mass} = \text{number of moles} \times \text{molar mass} \]

Second, calculate the molar mass of sulphur dioxide:

Molar mass of sulphur dioxide is:

\[ \text{Molar mass of \( \text{SO}_2 \) = S + 2O} \]
\[ = 32 + (2 \times 16) \]
\[ = 32 + 32 \]
\[ = 64 \text{ g mol}^{-1} \]

So, the molar mass of sulphur dioxide = 64 g mol\(^{-1}\)

Third, substitute the values in the formula

Mass of 0.66 mole of sulphur dioxide = number of moles \times molar mass

\[ = 0.66 \text{ mol} \times \frac{64 \text{ g}}{\text{mol}} \]

Hence, 0.66 mole of sulphur dioxide has a mass of 42.24 g.
2. \( A_r(\text{Fe}) = 56 \)

First, write down the formula:

\[
\text{number of moles} = \frac{\text{mass (g)}}{\text{molar mass (g mol}^{-1})}
\]

Second, calculate the molar mass of \( \text{Fe}^{2+} \):

Molar mass of \( \text{Fe}^{2+} \) is:

\[
\text{Fe}^{2+} = (1 \times 56) = 56 \text{ g mol}^{-1}
\]

Molar mass of \( \text{Fe}^{2+} = 56 \text{ g mol}^{-1} \)

Third, substitute the values in the formula

\[
\text{number of moles in } 2.8 \text{ g of } \text{Fe}^{2+} = \frac{\text{mass (g)}}{\text{molar mass (g)}} \times 1 \text{ mol}
\]

\[
= \left(\frac{2.8 \text{ g}}{56 \text{ g}}\right) \times 1 \text{ mol}
\]

\[
= 0.05 \text{ mol}
\]

So, \( 2.8 \text{ g of } \text{Fe}^{2+} = 0.05 \text{ mole of } \text{Fe}^{2+} \)

3.

First, write down the formula:

Number of particles = number of moles of the substance \times Avogadro’s number \times number of moles of atoms in the substance

Since 1 molecule of water is made up of 3 moles of atoms (i.e. 2 moles of hydrogen atoms and 1 mole of oxygen atoms), to find the number of atoms we need to multiply Avogadro’s number by 3.
Second, substitute the values in the formula

\[
\text{Number of particles} = \frac{1}{2} \times (6.02 \times 10^{23}) \times 3
\]

\[
\text{Number of moles of H}_2\text{O} = \frac{9.03 \times 10^{23}}{3}
\]

So the number of atoms in \(\frac{1}{2}\) mol of water is \(9.03 \times 10^{23}\).

4.

First, write down the formula:

\[
\text{Number of moles} = \frac{\text{number of particles}}{\text{Avogadro’s constant}}
\]

Second, substitute the values in the formula

The number of moles of H\(^+\) = \(\frac{3.01 \times 10^{23}}{6.02 \times 10^{23}}\) = 0.5

So the number of moles of hydrogen ions (H\(^+\)) present in \(3.01 \times 10^{23}\) of hydrogen ions is 0.5 moles.

Do not be disappointed if you did not get all of them correct! Keep on practicing, and you will improve.

Now let us review what we have done in this unit.
In this unit you learned about the characteristics of physical and chemical changes that occur in the world around us. You should now be in a better position to classify the changes around you as physical changes or chemical changes. You have also learned that solids, liquids and gases are the three states of matter, and that matter is anything that has a mass and occupies space. With knowledge about the characteristics of the three states of matter, you should now be able to explain the inter-conversion of the states of matter in terms of the kinetic theory. With the knowledge you have gained about the different separation techniques and their application, you should be able to use appropriate separation techniques to separate solid-solid mixtures; solid-liquid mixtures; and liquid-liquid mixtures.

In this unit you also learned about atoms, elements, molecules, compounds and mixtures, and their characteristics. You have also learned about the charge and relative mass of the sub-atomic particles (protons, electrons and neutrons). With knowledge of the atomic notation (which involves the symbol of the element, the proton number and nucleon number) you should be able to deduce the numbers of protons, neutrons and electrons in an atom. For those of you who are aiming for a higher mark, you should know how chemists measure the amount of substance using the mole concept as well. With the understanding of the mole and Avogadro’s constant, you can now convert moles to mass of a substance, or mole to number of atoms or molecules, and vice versa using the appropriate formula.

We have now come to the end of Unit 2. I hope that you have enjoyed learning about the elements of chemistry and have clearly understood all the contents of this unit. Should you feel the need to review certain contents, please do so before you tackle Unit 3, entitled The strengths of solids. I hope that you will enjoy learning the contents of Unit 3.
## Contents

### Unit 3

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Unit 3

The strengths of solids

Introduction

In this unit you will learn about how forces can alter the shape and size of an object. The unit is divided into the following topics; elasticity, uses and choice of materials, moments, scalar and vector quantities.

Upon completion of this unit you will be able to:

- *investigate* the relationship between the extension of a spring and the force applied to it.
- *state* Hooke’s law.
- *explain* that the strength of solids is derived from the forces between their constituent atoms and molecules.
- *illustrate* the spring-like nature of forces by comparing the behaviour of materials under tension and compression with the behaviour of springs.
- *justify* why materials selected for a particular use has to depend upon the materials’ properties.
- *prove experimentally* that equal and opposite forces acting on the same body may have a turning effect.
- *calculate* the turning effects (moment) of a force.
- *prove experimentally* that for a body to be in equilibrium both the forces and their turning effects (moments) must balance.
- *differentiate* between vector and scalar quantities.
- *represent* graphically two vector quantities and their resultant.

Compression: The reduction of the volume or size of matter by applying pressure.

Effort: Force applied to a simple machine that produces an effect on a load.

Terminology

Compression: The reduction of the volume or size of matter by applying pressure.

Effort: Force applied to a simple machine that produces an effect on a load.
**Elasticity:** The ability of an object or substance to return quickly to its original size after being bent, stretched or compressed.

**Equilibrium:** A static or dynamic state in which all forces or processes are in balance and there is no resultant change.

**Extension:** Increase in size, due to application of a force.

**Force:** A physical influence that tends to change the position of an object with mass, equal to the rate of change in momentum of the object.

**Lever:** A rigid bar that pivots about a point (fulcrum) and is used to move or lift a load at one end by applying force at the other end.

**Moment or torque:** The turning effect of a force.

**Pivot/fulcrum:** The point or support about which a lever turns.

**Scalar:** A physical quantity which has a magnitude (size) but has no direction.

**Tension:** A force that pulls or stretches a substance.

**Vector:** A physical quantity which has both magnitude and direction.
Table 3.0 below shows the number of formal study hours needed for you to complete this unit and the number of hours that you need to devote for self-study.

<table>
<thead>
<tr>
<th>Category of students</th>
<th>Number of formal study hours needed</th>
<th>Number of hours for self-study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time student outside the conventional school setting</td>
<td>5 hours</td>
<td>2 hours and 30 minutes</td>
</tr>
<tr>
<td>Full-time student within the conventional school setting</td>
<td>5 hours</td>
<td>2 hours and 30 minutes</td>
</tr>
<tr>
<td>OR Part-time student</td>
<td>5 hours</td>
<td>2 hours and 30 minutes</td>
</tr>
</tbody>
</table>

Table 3.0: The time needed for you to work on this unit

**Topic 3.1: Elasticity**

You will need 1 hour and 20 minutes to complete this topic. It is advisable that you spend another 40 minutes of your own time to further review the topic.

A vital property of matter is their elasticity. This is the ability of matter to regain their original size and shape after being stretched or compressed. Materials vary in their degree of elasticity; hence some materials are more elastic than others.

In this topic you will learn more about the elasticity of matter. After studying the topic, and having completed the tasks and activities which
follow, you should have a greater appreciation of the vast implications of elasticity in everyday life.

Activity 3.1.1
You should do this activity within 10 minutes.

- Take a rubber band and measure its length. Then, gently stretch the rubber band and release it as shown in the photographs below.

![Stretched elastic band](image)

![Un-stretched elastic band](image)

Figure 3.1.1: Measuring the length of a stretched and an un-stretched rubber band

Photo by: Mariette Lucas, March 2009

- Observe what happens to the elastic band. What do you notice?

- Repeat the activity, but this time use a spring instead. Compare your observations with what you observed when you stretched the elastic band
Feedback to Activity 3.1.1

You should have noticed that the length of the elastic band and the spring increases (extends) when pulled and regains its original length when released.

The tasks you did above were about elasticity. Elasticity is the property of a material which causes it to extend (stretch) or compress when a force acts on it and to regain its original size and shape after the force is removed.

The catapult is an instrument which functions using elasticity.

Figure 3.1.2: A catapult

Photo by: Mariette Lucas, March 2009

Look carefully at the picture of the catapult above. What is the function of the elastic band in the catapult?

We are sure that you have figured out that the purpose of the elastic band is to provide energy to the catapult. When stretched, the elastic band stores energy which is then transferred to the catapult when the elastic
As you have seen the catapult is an example of where elasticity becomes useful. Bungee jumping is also an activity where elasticity is used. It involves jumping from a tall structure while being connected to a large elastic cord. The bungee jumper relies a lot on the elasticity of the rope. It is especially important that the elasticity of the rope is well calculated to avoid the jumper from hitting the ground or slowing down too quickly.

You have surely encountered several other instances where elasticity is applied in everyday life; give two examples of these.

We are sure that you might have thought of more than two examples. Some common day-to-day examples where we can observe the application of elasticity are: spring balances, chest expanders, trampoline, car suspensions, springs, car seats and others.

**Activity 3.1.2**

You should complete this activity within 30 minutes. You will now perform the following experiment to further understand the concept of elasticity.

- You need a ruler, a spring, a pointer, a mass hook or a plastic bag and five 100 g masses or five 1 N (newton) weights.
- Set up the equipment as shown in the diagram below.
You may use appropriate masses depending on the strength of your spring.

A load is a force. Force is measured in newton (N), mass is measured in kilogram (kg). A mass of 1kg will exert a force of 10 N.

- First, record the length of the spring indicated by the pointer in Table 3.1.1 below.
- Next, add the load of 1 N (or a mass of 100 g) to the spring and record the length of the spring shown by the pointer.
- Keep on adding 100 g masses and record the respective length each time.

<table>
<thead>
<tr>
<th>Load (N)</th>
<th>Mass (g)</th>
<th>Length of spring (cm)</th>
<th>Extension of spring (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>400</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
To calculate the extension of the spring, you need to use the following relationship:

\[ \text{Extension} = \text{Length with load} - \text{Length without load} \]

Using the above relationship, three examples are given in the table below.

<table>
<thead>
<tr>
<th>Load (N)</th>
<th>Mass (g)</th>
<th>Length of spring (cm)</th>
<th>Extension of spring (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2 – 2 = 0</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>5.7</td>
<td>5.7 – 2 = 3.7</td>
</tr>
<tr>
<td>2</td>
<td>200</td>
<td>9.4</td>
<td>9.4 – 2 = 7.4</td>
</tr>
</tbody>
</table>

Table 3.1.2: Examples of how to calculate extension of the spring

Please note that in the calculations in the table above, the original length of the spring is 2 because when there is no load (weight/mass) on the spring the length of the spring is 2 cm. The original length of your spring may vary.

- Using your results, calculate the extension of the spring each time and record them in Table 3.1.1 above.
- Now that you have all the results, draw a line graph on the graph paper (Figure 3.3.1) below to show the extension against the load. The axes have been labelled for you but you need to decide on your own scale.
What conclusion can you draw from this experiment?

Feedback to Activity 3.1.2

You should have noticed that each time you added a load of one newton (or mass 100 g), the spring extended by the same amount. The way the spring behaves is governed by Hooke’s law.

Now let us explain what Hooke’s law is.

Hooke’s law states that the extension is directly proportional to the load (force applied).
Certain solid materials follow a similar pattern when they are stretched or compressed. Normally when a material is gently stretched or compressed and then released, it will return to its original size and shape.

If you have access to the internet, take a look at this website of an animation of Hooke’s law.

Please note again that we are providing this link only for information purposes and we do not endorse or recommend any links from the site.

What do we call this property of solids?

You are right! The property of a solid material that allows it to be gently stretched or compressed and return to its original size and shape when released is called elasticity.

You may have noticed that sometimes when you stretch an elastic material it does not return to its original shape or size. If you have not experienced this, get the small spring from an old pen and stretch it. You will notice that the spring does not return to its original shape. In other words, the spring is deformed.

Now let us explain what happens if you keep adding loads to the spring. If you continue to stretch or add loads to the spring, beyond a certain point, the spring will not obey Hooke’s law. The spring will be damaged or deformed. The point at which the deformation starts is known as the \textbf{elastic limit}. This is shown by point X, on the graph below.
Now let us see how much you have understood about elasticity.
Self-assessment 3.1

You should complete this self-assessment in less than 15 minutes. This self-assessment is based on Topic 3.1. The answers are given at the end of this topic. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 3.1. This will help you learn and reflect better on areas for improvement.

1. Put in the missing words in the definition of elasticity:

Elasticity is the property of a material which causes it to _____________ (stretch) or compress when a _____________ acts on it and to regain its original size and _____________ after the force is _____________.

2. Tick the situation which is an example of an application of elasticity?
   A. Sitting on a wooden chair  [ ]
   B. Crushing marble chips  [ ]
   C. Using a bow and arrow  [ ]
   D. Chopping firewood  [ ]


4. Use the graph below to answer the questions that follow.

Figure 3.1.6: Graph showing extension of spring against load
a. What is the extension of the spring for a load of 5 N?

b. What load would have caused the spring to extend by 3.5 cm?

c. The spring would reach elastic limit with a load of 10 N. Complete the graph to show the elastic limit of the spring. Use the letter X to indicate this.

Please refer to the Answers to Self-assessment 3.1 at the end of the topic below to verify your answers.
Answers to Self-assessment 3.1

1. Elasticity is the property of a material which causes it to extend (stretch) or compress when a force acts on it and to regain its original size and shape after the force is removed.

2. C

3. Hooke’s Law states that: the extension is directly proportional to the load.

4. a) 2.5 cm
   b) 7 N
   c) The graph showing the extension of spring against load and elastic limit is given below

If you have access to the internet, take a look at the following video that explains Hooke’s law. http://www.khanacademy.org/video/intro-to-springs-and-hooke-s-law?playlist=Physics

Again, please note that this link is provided for information only and we do not endorse any of the links that are associated from the site.

So far you have seen that elasticity is an important property of certain solid materials, but the materials can become deformed if too much force is applied to it. In the next topic you are going to learn how materials are chosen for different uses.

Topic 3.2: Uses and choices of materials

You will need 1 hour to complete this Topic. It is advisable that you spend another 30 minutes of your own time to further revision.
Materials have different properties and serve different purposes. Hence, we need to choose specific materials for certain jobs.

Now let us start by checking if you could make the right choice of material.

Between the following materials, which would be most suitable to make a knife: plastic, aluminium, soft iron or steel? Give reasons for your choice.

Now let us discuss the answer to the question above. As you know, a knife has to be strong, sharp and with a cutting edge that does not wear out fast. You must therefore have realized that steel is the best material for making knives.

So, suitable materials that we need to use for a particular job must possess advantageous properties in their elasticity, strength, thermal conductivity or electrical conductivity.

The strength of a solid is a factor which is of paramount importance for the making of tools. There are two main factors that affect the strength of a solid. These are the:

- **Molecular structure** as in diamond (natural) and in alloys (artificial); and
- **Design features** as in L-shaped iron girders or H-shaped iron girders.

In this unit we will focus on design features. You will have the opportunity to learn more about molecular structure in Unit 21: Materials and structures.
Activity 3.2.1

You should complete this activity in no more than 20 minutes.

Through this activity you will learn the relationship between design features and the strength of structures.

You will need: two small identical empty cardboard boxes, such as empty juice boxes; one side of a shoe box, two 10 N weights; one pair of scissors; a ruler, and a pencil.

Procedure:

Step 1: Construction of the structure

- First label your juice boxes as Box One and Box Two.
- Cut off one of the largest sides of Box One and Box Two.
- Measure the breadth and the height of side 1 of Box Two.
- Cut a piece of equal dimensions from the shoe box. Label it as A.

- Measure the length and the height of side 2 of Box Two.
- Cut a piece of equal dimensions from the shoe box. Label it as B.

- Make a slit halfway along the length of A, from the edge to the centre. Repeat the same with B.
Assemble A and B as shown below.

Insert the assembled parts in Box Two as shown below.

All graphics for Step 1 by: Serge Mondon, June 2009

Designed by: Lionel Goonetilleke, June 2009

Step 2: The experiment
- Turn the open side of Box One and Box Two face down on a table.
- Place the 10 N weights one at a time on top of Box One and observe.
- Now remove the weights and place them one at a time on Box Two and observe what happens.

1. Write down your observations.

2. Using your observations, explain the relationship between design features and the strength of structures.
Well, we hope that you have enjoyed this task. Now check for the Feedback to Activity 3.2.1 for the expected observations. If your observations did not match up to those in the feedback, feel free to try the task again.

Feedback to Activity 3.2.1

1. The box which had special support structures did not collapse while the box without the support structure collapsed.

2. The box which had special support structures did not collapse because the support structures gave additional strength to the box. This shows that we can strengthen structures by incorporating special design features.

In construction and packaging, special design features are used to give additional strength to structures such as buildings and packaging boxes. Some of these examples and types of special design features are shown below:

![Figure 3.2.1: Structures with special design features](Photo by: Mariette Lucas, March 2009)

Activity 3.2.2

You should be able to complete this activity in less than 15 minutes.

1. Look around you and make a list of five other structures with special design features. Draw or take pictures of any new design features that you find.

   a. 
   b. 
   c. 

   d. 
   e. 
2. Look carefully at the different structures in Figure 3.2.1 above and those that you have found. What is each structure used for? List two intended purposes/jobs for which structures are made and the materials that are used to make these special structures on Table 3.2.1 below.

<table>
<thead>
<tr>
<th>Intended Job</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Insert your drawings or pictures here.
Table 3.2.1: Materials used to make the special features for intended purposes

3. Draw lines to match each job with the most suitable material. Please note that one of the materials will not be used.

<table>
<thead>
<tr>
<th>Intended jobs/purposes</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>A  Making a cutting tool such as a pair of scissors</td>
<td>Plastic</td>
</tr>
<tr>
<td>B  Packaging</td>
<td>Steel</td>
</tr>
<tr>
<td>C  Manufacturing nails</td>
<td>Copper</td>
</tr>
<tr>
<td>D  Manufacturing of lenses</td>
<td>Soft iron</td>
</tr>
<tr>
<td>E  Making the handle of a saucepan</td>
<td>Glass</td>
</tr>
<tr>
<td>F  Connecting wires in electric circuits</td>
<td>Paper</td>
</tr>
</tbody>
</table>

We hope you did not find the activity too hard to complete. Now refer to the feedback to verify your answers.

Feedback to Activity 3.2.2

1. Some structures with special design features are bicycles, roofs, bridges, chairs, kites, and cars.
2. The answers will vary based on your answers to question number 1.
3. The answers are as follows:

A  Steel  
B  Paper  
C  Soft iron  
D  Glass  
E  Plastic  
F  copper
Please note that you will learn further about what causes a material to be strong when you study the topic on molecular structures and alloys in a later unit in this course.

**Topic 3.3: Moments**

You will need 2 hours to complete Topic 3.3. It is advisable that you spend another 1 hour of your own time to further practice calculating moments.

Now you are going to learn about moments. The term **moment** may sound new to you, but it is a principle that you have been using in many of your day to day activities.

**Activity 3.3.1**

You should spend about 5 minutes on this activity.

Try to close a door by pushing near the hinge and further away from the hinge. (You may repeat the activity two or three times.) When was it easier to close the door? Why do you think so?
Feedback to Activity 3.3.1

You should have realised that it was easier to close the door by applying the force further away from the hinge. When closing the door further away from the hinge you should have noticed that you used less force than when closing the door closer to the hinge.

We use moment when we close and open a door. The moment of a force depends both on the size of the force and how far it is applied from the fulcrum or pivot. The fulcrum or pivot is the point about which the lever turns. In other words, the fulcrum is the point about which the turning takes place. In the case of the door, the hinge is the fulcrum or pivot. You will learn about lever later in the Topic.

There are many other situations where moment is used. Using a key to lock or unlock a door, turning a door handle, using spanners to tighten or loosen a nut, turning the knob of a tap, turning a bicycle handle, turning the steering wheel of a car and the seesaw are examples where moment is in use.

Now consider the examples given above where moment is in use. What is common among these examples?

You are correct! What is common among all these examples mentioned is that they all involve turning. So, moment has a turning effect. You are now going to learn about the turning effect or the moment of a force.

The term moment of a force or the turning effect is measured by multiplying the force by the perpendicular distance of the line of action of the force from the fulcrum or pivot.

Moment is measured in newton metre (N m) and calculated as follows:

\[
\text{Moment (Nm)} = \text{Force (N)} \times \text{perpendicular distance (m)}
\]
Now let us calculate the moment of the force for the situation in Figure 3.3.1, if Joe is applying a force of $300 \text{ N}$ to loosen the nut and at a distance of $0.3 \text{ m}$ from the fulcrum.

The moment of the force is calculated as follows:

First, state the formula:

$$\text{Moment (N m)} = \text{Force (N)} \times \text{perpendicular distance (m)}$$

Second, substitute the values:

$$\text{Moment (N m)} = 300 \text{ N} \times 0.3 \text{ m}$$

$$= 90 \text{ N m turning anti-clockwise}$$

It is important to note that the moment also has a direction: it can be clockwise or anti-clockwise. For example, the tightening of a nut usually has a clockwise moment while the loosening of a nut is normally anti-clockwise.
For some more practice, let us consider a common example, such as the seesaw.

\[ mg = 500 \text{ N} \]

\[ mg = 500 \text{ N} \]

Figure 3.3.2: A seesaw

Graphics by: Rosianna Jules, June 2009

Note that \( mg \) represents weight which is the product of the mass \( (m) \) and the acceleration due to gravity \( (g) \) on the object. The value of \( g \) is 10 m/s\(^2\) (read as 10 metres per second squared). You will learn more about these concepts in the unit ‘Force and motion’.

Let us calculate the moment due to object B in Figure 3.3.2 above.

*Remember: Formula first:*

\[ \text{Moment (N m)} = \text{Force (N)} \times \text{perpendicular distance (m)} \]

*Then substitute the values:*

\[ \text{Moment (N m)} = 500 \text{ N} \times 2 \text{ m} \]

\[ = 1000 \text{ N m turning clockwise} \]

You will agree that calculating moment is not difficult as long as you remember the formula. Now it is your turn to practise calculating moments.
Activity 3.3.2

You should spend about five minutes on this activity.

Calculate the moment due to object A in the space provided.

Feedback to Activity 3.3.2

From your working you should have noticed that the moment of object A is the same as that of object B. In other words, the magnitude (size) of the clockwise moment of object B is equal to the magnitude of the anti-clockwise moment of object A.

So when two objects of the same weight are placed at equal distance from the pivot (provided the beam is uniform—that is the beam balances at its centre) like in the example of the seesaw above, we say that it is in equilibrium.

Always remember that weight is a force.
Activity 3.3.3

You should spend no more than 20 minutes on this activity.

You will now try out an experiment to help you understand the principle of moments better.

Follow the steps to set up the apparatus as shown in the diagram below.

![Figure 3.3.3: Set up to show the principle of moments](Graphics by: Rosianna Jules, March 2010)

**Steps:**

1. Balance a meter ruler or better still a moment ruler at its centre.

   If it doesn’t balance, the ruler is not uniform. To correct that, add some plasticine on the lighter side. You may need to adjust the position of the plasticine.

2. Get two objects of different known masses, \( W_1 \) and \( W_2 \).

3. Work out the weight of \( W_1 \) and that of \( W_2 \) using the equation:

   \[
   \text{weight} = \text{mass} \times \text{acceleration due to gravity} \\
   W = mg
   \]

4. Draw a table as the one shown in Table 3.3.1 below and use it to record the weight of \( W_1 \) and \( W_2 \).

5. Suspend \( W_1 \) on the left side of the ruler and \( W_2 \) on the right side.

6. Keeping \( W_1 \) stationary, move \( W_2 \) to bring the system to equilibrium.

7. Measure the distance from \( W_1 \) to the pivot and \( W_2 \) to the pivot and record your results on the table.
8. Now move $W_1$ closer to the pivot, and adjust $W_2$ to bring the system to equilibrium.

9. Again, measure the distance from $W_1$ to the pivot and $W_2$ to the pivot and record your results on the table.

10. You may repeat the experiment a few more times if you wish.

11. Calculate the clockwise and the anti-clockwise moment for each trial.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Anti-clockwise</th>
<th>Clockwise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$W_1$ (N)</td>
<td>$W_2$ (N)</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.3.1: Record of experimental results to illustrate the principle of moments

**Feedback to Activity 3.3.3**

From your experiment you should have noticed that when the system is in equilibrium the clockwise and the anti-clockwise moments are equal.
Now we are going to consider what happens when we have more than two forces in equilibrium.

According to the principle of moments, when an object is in equilibrium, the total clockwise moment is equal to the total anti-clockwise moment.

\[ \text{Total anti-clockwise moment} = \text{total clockwise moment} \]

Now let us calculate the total clockwise and anti-clockwise moments for the situation in Figure 3.3.4.

At equilibrium,

the total anti-clockwise moment = total clockwise moment

Remember that, in order to calculate individual moment we need to use the formula:

\[ \text{Moment (N m)} = \text{Force (N) x perpendicular distance (m)} \]

So by substituting the values, the total clockwise and anti-clockwise moments are calculated as follows:

\[
\begin{align*}
(400 \text{ N} \times 1.25 \text{ m}) + (200 \text{ N} \times 1 \text{ m}) &= (100 \text{ N} \times 2 \text{ m}) + (500 \text{ N} \times 1 \text{ m}) \\
500 \text{ N m} + 200 \text{ N m} &= 200 \text{ N m} + 500 \text{ N m} \\
700 \text{ N m} &= 700 \text{ N m}
\end{align*}
\]

That was easy, wasn’t it? You can use the same principle of moments to calculate the unknown force or unknown distance of any system in equilibrium.
Now we will use the principle of moments to calculate an unknown force (weight). Consider the equilibrium system in Figure 3.3.5 below. Calculate the value of the force $A$ acting on the system when the system is in equilibrium.

![Figure 3.3.5: Diagram showing more than two forces in equilibrium.](image)

Remember: at equilibrium, 

\[
\text{total anti-clockwise moment} = \text{total clockwise moment}
\]

Step 1: work out the total clockwise and anti-clockwise moment using the formula:

\[
\text{Moment (N m)} = \text{Force (N)} \times \text{perpendicular distance (m)}
\]

Step 2: By substituting the values we get:

\[
(60 \text{ N x 1 m}) + (40 \text{ N x 0.75 m}) = (24 \text{ N x 0.75 m}) + (A \times 2 \text{ m})
\]

\[
60 \text{ N m} + 30 \text{ N m} = 18 \text{ N m} + (A \times 2 \text{ m})
\]

Step 3: Subtract 18 N m from both sides of the equation

\[
90 \text{ N m} - 18 \text{ N m} = 30 \text{ N m} - 18 \text{ N m} + (A \times 2 \text{ m})
\]

\[
72 \text{ N m} = (A \times 2 \text{ m})
\]

Step 4: Divide both sides by 2 m. Note that the unit of distance (m) cancels out leaving the unit for force (N).

\[
\frac{72 \text{ N m}}{2 \text{ m}} = \frac{(A \times 2 \text{ m})}{2 \text{ m}}
\]

\[
36 \text{ N} = A
\]
So the force exerted by A is 36N.

As we have mentioned earlier, you can use the same principle to calculate the perpendicular distance from the pivot to a force.

There are numerous applications of the principle of moments in our everyday life. The lever is one example of such applications. Let us now see how the principle of moments is applied in levers.

A lever is any device which can turn about a pivot (fulcrum). In a working lever, a force called the effort is used to overcome the resisting force, which we call the load.

The example of the seesaw given in Figure 3.3.2 earlier is one type of lever.

![Copy of Figure 3.3.2 showing a seesaw](graphics.png)

Graphics by: Rosianna Jules, June 2009

**Activity 3.3.4**

You should spend about 5 minutes on this activity.

- Consider that object A is exerting a downward force to bring about movement.
- Draw your own diagram to show this.
- Label the pivot, the load and the effort on your diagram.
Well, we hope that this small task was easy for you. Please refer to the Feedback to Activity 3.3.4 below for the expected answer.

**Feedback to Activity 3.3.4**

Use the crowbar example below to evaluate your work.

The crowbar functions as a lever when we use it to move objects, as shown in the diagram below.

![Figure 3.3.6: A crowbar functioning as a lever](Graphics by: Mariette Lucas, June 2009)

It is possible to calculate the magnitude of any one of the quantities (effort, load, distance from pivot to load, and distance from pivot to effort), provided three of the quantities are given.

For example, to calculate the magnitude of the effort needed to move a rock (load) which weighs 600N, assuming that the distance from the
pivot to the load is 0.5m and the distance from the pivot to the effort is 2m, as illustrated by Figure 3.3.6 below, the work would be as follows:

At equilibrium:

\[
\text{Total clockwise moments} = \text{Total anti - clockwise moments} \\
\text{Effort} \times \text{distance 1} = \text{load} \times \text{distance 2}
\]

\[
\text{Effort} \times 2 \text{ m} = 600 \text{ N} \times 0.5 \text{ m}
\]

\[
\frac{\text{Effort} \times 2 \text{ m}}{2 \text{ m}} = \frac{300 \text{ N m}}{2 \text{ m}}
\]

\[
\text{Effort} = 150 \text{ N}
\]

Now that you have learned about moments, it is time for you to test your understanding.

**Self-assessment 3.2**

You should be able to complete this self-assessment in less than 25 minutes. This self-assessment is based on Topic 3.3. The answers are given at the end of this topic. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 3.2. This will help you learn and reflect better on areas for improvement.

1. Give three examples where moment is used.

2. State the principle of moment.
3. What is a lever?

4. Use the principle of moments to calculate the missing values in the table below.

<table>
<thead>
<tr>
<th>Anti-clockwise</th>
<th></th>
<th></th>
<th>Clockwise</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight ( W1 ) (N)</td>
<td>Distance ( d ) (m)</td>
<td>Moment ( (W1 \times d) )</td>
<td>Weight ( W2 ) (N)</td>
<td>Distance ( D ) (m)</td>
<td>Moment ( (W2 \times D) )</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>0.4</td>
<td>1</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>0.15</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Figure 3.3.7 shows a rock that Jill is moving using a crowbar.

![Figure 3.3.7: The rock Jill is moving with a crowbar](image)

Graphics by: Rosianna Jules, October 2010

i. What device is the crowbar functioning as?
ii. What do the letters A, B and C stand for on the diagram?

A represents the

B represents the

C represents the

iii. What force should Jill apply at A to move the rock? Show the work in the space provided.

iv. If Jill is applying a force of 245 N, at what distance from the pivot should she apply the effort? Show the work in the space provided.
Well, we hope that this assessment was not too difficult for you. Please refer to the Answers to Self-assessment 3.2 at the end of the topic below to verify your answers. Don’t be too disappointed if you did not manage to get all the correct answers. Just go back and review the topic again.

**Answers to Assessment**

**Answers to Self-assessment 3.2**

1. Some examples where moment is used include locking or unlocking a door lock, tightening or loosening a nut using spanners, turning a door handle, turning the knob of a tap, turning a bicycle handle, turning the steering wheel of a car and the seesaw.

2. The principle of moments states that when an object is in equilibrium, the total clockwise moment is equal to the total anti-clockwise moment.

3. A lever is any device which can turn about a pivot /fulcrum.

4. The underlined values are the missing values for the anti-clockwise and clockwise moments.

<table>
<thead>
<tr>
<th>Anti-clockwise</th>
<th>Clockwise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight $W1$ (N)</td>
<td>Distance $d$ (m)</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>0.15</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
</tr>
</tbody>
</table>

5. 
   i. The crowbar functions as a **lever**.
   
   ii. A represents the **effort**; B represents the **fulcrum** or pivot; C represents the **load**

   iii. Jill should apply force of 196 N at A to move the rock. The work is shown below.

   We use the principle of moment to find the unknown force, which is in this case the effort.
First, write down the principle of moment

At equilibrium:

Total clockwise moments = Total anti – clockwise moments

Second, write down the formula

\[ \text{Effort} \times \text{distance 1} = \text{load} \times \text{distance 2} \]

Third, substitute the known values

\[ \text{Effort} \times 1.5 \text{ m} = 420 \text{ N} \times 0.7 \text{ m} \]

Fourth, divide both sides by 1.5 m (the perpendicular distance of the effort from the pivot to get the effort)

\[ \frac{\text{Effort} \times 1.5 \text{ m}}{1.5 \text{ m}} = \frac{294 \text{ N} \text{ m}}{1.5 \text{ m}} \]

\[ \text{Effort} = 196 \text{ N} \]

iv. Jill should apply the force at 1.2 m from the pivot to move the rock. The work is shown below.

As mentioned in Topic 3.3.3, we can use the same principle of moment to find an unknown distance.

First, write down the principle of moment

At equilibrium:

Total clockwise moments = Total anti – clockwise moments

Second, write down the formula

\[ \text{Effort} \times \text{distance 1} = \text{load} \times \text{distance 2} \]

Third, substitute the known values

\[ 245 \text{ N} \times \text{distance 1} = 420 \text{ N} \times 0.7 \text{ m} \]

Fourth, divide both sides by 245 N (the effort Jill is applying to move the rock)

\[ \frac{245 \text{ N} \times \text{distance 1}}{245 \text{ N}} = \frac{294 \text{ N} \text{ m}}{245 \text{ N}} \]

\[ \text{distance 1} = 1.2 \text{ m} \]

We have now come to the end of topic 3.2. Can you recall what you learned about moments? If you are trying to use a stick as a lever to lift something, where should you be pushing? When working to understand all of these concepts, it helps to relate it to everyday occurrences.
What do you know about quantities in relation to physics? Can you think of any that you know? Let’s take a look at scalar and vector quantities in the next section.

**Topic 3.4: Scalar and vector quantities**

You will need 40 minutes to complete Topic 4. It is advisable that you spend another 20 minutes of your own time to further review this topic.

The physical quantities used in science are divided into two classes: scalar and vector quantities.

### 3.4.1 Scalar quantities

A **scalar** quantity is a physical quantity which has a size (magnitude) but it has no direction. Here we are concerned only about how small or large the quantity is, and not about the direction.

One example of a scalar quantity is time.

Distance is another scalar. Suppose you walk a distance of 80m from your house to your neighbour’s house, the direction is irrelevant. You can reach your neighbour’s house along any route.

Speed is also a scalar. If you walked at a speed of 2m/s to reach your neighbour’s house, it took you 40s for you to reach your neighbour’s house.

\[
\text{Speed} = \frac{\text{distance}}{\text{time}}
\]

Speed is dependent on distance and time as shown above. Both distance and time are scalars which makes speed a scalar.

Some other examples of scalar quantities are mass, temperature, and volume.
3.4.2 Vector quantities

A vector is a quantity that has both magnitude and direction.

Displacement is a vector quantity. Displacement refers to a distance travelled in a particular direction. It has a magnitude (the distance travelled/moved) and a direction for the movement. Therefore, displacement has a magnitude as well as a specific direction and hence is a vector quantity.

Velocity is also a vector quantity. Velocity is the distance travelled per unit time, or the rate of change of position, or the rate of displacement. You will learn more about velocity in the unit ‘Motion’.

A vector can be represented by a straight arrow drawn to scale. The straight line represents the magnitude and the arrowhead gives the direction.

Say for example a force of 10 N is applied towards the East. This can be represented by a straight arrow drawn to scale, where 1cm represents 2 N. Hence, the length of the arrow is 5 cm pointing in the easterly direction.

3.4.3 Adding forces

Sometimes we need to add two or more forces to find their effect or resultan vector. Scalar quantities are added by ordinary mathematics as shown by the example below:

For example, a mass of 100 g and a mass of 50 g when added will result in 150 g as shown below.

\[ 100 \text{ g} + 50 \text{ g} = 150 \text{ g} \]

Vector quantities are added geometrically, taking account of their directions as well as their magnitude or size.

3.4.4 Adding vectors

Normally in real life situations, more than one force acts on an object. Sometime the forces act in the same direction, sometimes in the opposite directions or even in different directions. Vectors can be added algebraically to determine the overall effect, which is known as the resultant vector.
### 3.4.4.1 Forces acting in the same direction

Consider a girl and a boy pulling a box with equal force of 100 N each as shown below.

\[
\begin{align*}
100 \text{ N} & \quad \text{100 N} \\
\quad & \\
\quad & 200 \text{ N}
\end{align*}
\]

The resultant vector is \(100 \text{ N} + 100 \text{ N} = 200 \text{ N}\)

Please note that the resultant vector is represented by a straight line with two arrowheads as shown above.

### 3.4.4.2 Forces acting in the opposite direction

For example, when you sit on a chair, your weight acts downwards and the chair pushes upwards with a force equal to your weight. Since you remain at rest, the two forces must be equal in magnitude but opposite in direction as shown in the diagram below.

\[
\begin{align*}
\quad & 500 \text{N} \\
\quad & 500 \text{N}
\end{align*}
\]

Figure 3.4.1: Illustrating forces acting in opposite direction

Photo of Carole Jacques sitting by: Rosianna Jules, June 2009
Calculating the resultant force is calculating the difference between the forces, so we use subtraction.

The resultant vector is $500 \text{ N} - 500 \text{ N} = 0 \text{ N}$

Please note that for equal forces acting in opposite direction, the resultant force is always 0 N.

Now, let us try an example for unequal forces acting in opposite direction.

The resultant vector is $300 \text{ N} - 150 \text{ N} = 150 \text{ N}$ due East. This is illustrated as:

We think that you will agree that these calculations are very simple. Now it is your turn to practise calculating the resultant vectors and to test your understanding of Topic 3.4.

**Self-assessment 3.3**

You should complete this self-assessment which is based on Topic 3.4 within 15 minutes. The answers are given at the end of this topic. You are strongly advised to answer all questions before you refer to the Answers to Self-assessment 3.3. This will help you learn and reflect better on areas for improvement.
1. What is a scalar quantity?

2. List two scalar quantities.

3. Some quantities are listed here: volume, time, displacement, temperature, velocity, force. Underline the vector quantities.

4. State the difference between a scalar quantity and a vector quantity.

5. Figure 3.4.2 represents three friends playing tug of war. Please note that the vectors are not drawn to scale. Jim and Sarah are pulling towards the East while Sam is pulling towards the West.

   Figure 3.4.2: Diagram representing a tug of war

   Graphics by: Rosianna Jules, October, 2010

   a. Who won the tug of war?
b. Why do you say so?

c. Draw a diagram, using the scale of 1 cm: 12 cm, to represent the resultant force.

Answers to Self-assessment 3.3

1. A scalar quantity is a quantity which has magnitude but it has no direction.

2. Some examples of scalar quantities are length, mass, temperature, time, volume, speed.

3. Volume, time, displacement, temperature, velocity, and force.

4. A scalar quantity has magnitude, whereas a vector quantity has both magnitude and direction.

5.

a. Sam won the tug of war.

b. Because the resultant vector is 24 N due West (Sam’s side).

The resultant vector for Jim and Sarah (pulling in the same direction) is:

\[ 144 \text{ N} - 108 \text{ N} = 152 \text{ N} \]

The resultant vector for the tug of war is
276 N – 152 N = 24 N due West

c. You diagram should look similar to that below.

You should have drawn a straight line that is 2 cm long (ratio of 1cm: 12 cm) with two arrowheads due West.

---

**Unit summary**

In this unit you learned that elasticity is the property of a material which causes it to extend (stretch) or compress when a force acts on it and to regain its original size and shape after the force is removed. You have also learnt that Hooke’s law for extension states that the extension is proportional to the load. You will now have realized that elasticity has various useful applications in our day to day life and that if the material is stretched beyond its elastic limit, it will be deformed. You should also be able to choose appropriate materials for specific purposes and explain the importance of special design features in strengthening materials.

You have also learned about moment, the moment of a force and the application of moments in our everyday life. You should now be able to use the principle of moment which state that at equilibrium, the total anticlockwise moment = total clockwise moment, to calculate unknown forces or distances in an equilibrium system.

Furthermore, you have also learned that quantities can be scalar, like time and speed, or vector like displacement. Vector quantities have both a magnitude and a direction while scalar quantities have only magnitude. You should now be able to calculate the resultant vector for forces acting in the same or opposite directions.

If you think that you have not grasped all these concepts, please go back and review as necessary. We hope that you have enjoyed this unit. All the best with the remaining units.
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Unit 4

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</tbody>
</table>
Unit 4

Atoms, Bonding and the Periodic Table

Introduction

In Unit 2 you learned that elements are arranged in the Periodic table and that atoms are made of sub-atomic particles: protons, neutrons and electrons. In this unit you are going to learn how electrons are arranged in shells around the nucleus of the atoms. You will also learn how elements can achieve stability by forming ionic or covalent bonds with other elements and illustrate these bond formations by using the ‘dot and cross’ diagrams. Finally, you will have the opportunity to determine the formula of compounds or molecules using either the valency of the atoms or ions involved, or the compound’s composition by mass.

Upon completion of this unit you will be able to:

- **explain** that, in the Periodic Table, the elements are arranged in order of proton number;
- **define** the terms groups and periods;
- **explain** how the electrons in an atom are arranged;
- **draw** the diagrammatic representation of the first 20 elements of the Periodic table;
- **explain** how the arrangement of elements in the Periodic Table are done in terms of atomic structure;
- **explain** the relationship between the group number and the number of outer electrons;
- **discuss** the significance of the noble gas electronic structure;
- **use** symbols of elements to write formulae of simple compounds when given a list of symbols and combining powers;
- **work out** chemical formulae using the composition by mass;
- **describe** the term covalent bond;
- explain how molecules are formed;
- explain the relationship between the number of bonds formed by an atom in a molecule and its atomic structure;
- describe how ions are formed;
- describe, with reference to simple examples, how atoms turn into ions.

### Terminology

**Anions:** Anions are negatively charged ions formed by the gain of electrons.

**Bond:** The strong electrical force of attraction between the atoms or ions in the structure.

**Cations:** Cations are positively charged ions formed by the loss of electrons.

**Covalent bond:** The bond formed between non-metals by the sharing of electron pair(s).

**Duplet configuration:** The first shell is completely-filled with its 2 electrons.

**Ionic bond:** The bond formed by the complete transfer of electrons from a metal atom to non-metal atom.

**Ions:** Ions are positively and negatively charged particles formed by the loss and gain of electrons respectively.

**Isotopes:** Isotopes are atoms of the same element with the same proton (atomic) number but different mass (nucleon) number.

**Octet configuration:** An electronic configuration where the outermost shell is complete with 8 electrons.

**Periodic Table:** The Periodic Table is an arrangement of elements in order of their atomic number.

**Stable electronic configuration:** An electronic configuration where the outermost shell has a duplet or octet configuration.
Table 4.0 below shows the number of formal study hours needed for you to complete this unit and the number of hours that you need to devote for self-study.

<table>
<thead>
<tr>
<th>Category of students</th>
<th>Number of formal study hours needed</th>
<th>Number of hours for self-study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full-time student outside the conventional school setting</td>
<td>6 hours</td>
<td>3 hours</td>
</tr>
<tr>
<td>Full-time student within the conventional school setting</td>
<td>6 hours</td>
<td>3 hours</td>
</tr>
<tr>
<td>OR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part-time student</td>
<td>6 hours</td>
<td>3 hours</td>
</tr>
</tbody>
</table>

Table 4.0: The time needed for you to work on this unit

**Topic 4.1: The Periodic Table**

You will need 30 minutes to complete this Topic. It is advisable that you spend another 15 minutes of your own time to further review the topic.

In Unit 2, *The Elements of Chemistry*, Topic 2.3, you learnt that each element has a particular chemical symbol and that these elements are arranged in the Periodic Table. During the 19th century, many chemists have tried to arrange the elements according to different criteria. The most successful attempt was from the Russian, Dimitri Mendeleev, who published a Periodic Table in 1869 which now forms the basis of the modern Periodic Table.

In this topic, you are going to learn about:

- how the elements are arranged in the Periodic Table;
- groups and periods and;
- the alternative names given to the different groups of elements.

If you have access to the internet, try taking a look at the following link that gives you information on individual elements as well as the various trends of the periodic table.

http://www.teachersdomain.org/asset/lsp07_int_graphperiodic/

Please note again that we are providing this link for information only. We do not endorse or recommend any links from this page.

4.1.1 The arrangement of elements in the Periodic Table

The Periodic Table is an arrangement of elements in terms of the increasing order of their proton number, which as you will recall, is also known as the ‘atomic number’. This arrangement relates to both the physical properties and the chemical properties of the elements. Because of this relationship, the Periodic Table is divided into periods and groups (see Figure 4.1 below).

Figure 4.1.1: The Periodic Table of elements

Now let us see what periods and groups are.

4.1.1.1 Periods

A period is the horizontal row of elements in the Periodic Table. There are 7 periods in the Periodic Table.
• Period 1 contains only two elements: hydrogen and helium.

• Periods 2 and 3 contain eight elements and are known as the short periods.

• Periods 4, 5, 6 and 7 contain between 18 and 32 elements and are known as the long periods.

All elements in the same period have the same number of shells. As you move from one element to the next, from left to right across the period:

• the atomic number of the successive element increases by one. For example, in period 2 starting from the left, Lithium has an atomic number of 3, its successive element, Beryllium has an atomic number of 4, and Boron which follows has an atomic number of 5.

• the number of electrons in the outer shell of each successive element also increases by one.

This regular increase in the number of electrons from one element to the next leads to a rather regular pattern of change in the chemical properties of the elements across a period. For example:

i. the metallic properties of the elements decrease as we move from left to right across the Periodic Table; and

ii. the ability of elements to reduce other elements and compounds decreases while their oxidizing ability increases as we move from left to right across the Periodic Table. (You will learn about reduction and oxidation later on in the course.)

4.1.1.2 Groups

A group is the vertical column of elements in the Periodic Table. All the groups are numbered, except the groups of transition metals. The groups are numbered using Roman numerals (I, II, III, IV, V, VI, VII, and VIII). Group VIII is also known as group zero (0). Some groups also have alternative names given to them as listed in the Table 4.1.1 below.
Elements in the same group have the same number of electrons in their outer shells and similar chemical properties.

You will learn about group properties later in Unit 7 but as you go on, it is important to understand the trends you observe in the periodic table. Always think about the reason behind a particular element being located at that place in a periodic table. If you do this, it will help you understand the periodic table better.

In Topic 4.2 which follows, you are going to learn about the arrangement of electrons in an atom.

**Topic 4.2: The Electronic Structure of Atoms**

You will need 1 hour and 20 minutes to complete this Topic. It is advisable that you spend another 40 minutes of your own time to further review the electronic structure of atoms.

As you have seen in Unit 2, Topic 2.3, atoms are made of three subatomic particles: protons, electrons and neutrons. You also learned that the electrons in an atom are arranged in a series of shells or energy levels. In this topic you will learn:

- how the electrons are distributed in the shells of an atom;
- how to represent the structure of atoms diagrammatically;
- how to write the electronic configuration of atoms, and
- the relationship between the position of the element in the Periodic Table and the electronic configuration.

### Table 4.1.1: The groups and their alternative names

<table>
<thead>
<tr>
<th>Group number</th>
<th>Alternative names</th>
</tr>
</thead>
<tbody>
<tr>
<td>VII</td>
<td>The Halogens</td>
</tr>
<tr>
<td>VIII or 0</td>
<td>The Noble gas or Inert gases</td>
</tr>
</tbody>
</table>

Your logo here
4.2.1 Diagrammatic representation of atoms

By convention or as a standard rule, the shells of electrons are shown as concentric circles. These circles correspond to the region where an electron would most likely be situated.

The shells are designated by the letters K, L, M, N, O, P and Q. Each shell can take a maximum number of electrons. The maximum number of electrons in the first four shells is shown as shown in Table 4.2.1 below.

<table>
<thead>
<tr>
<th>Shell number</th>
<th>Shell name</th>
<th>Maximum number of electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>K</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>L</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>N</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 4.2.1: Maximum number of electrons per shell for the first four shells

Generally one shell must be filled with its maximum number of electrons before electrons can occupy the next shell. The first shell, shell K, is filled first. When a shell is filled with its maximum number of electrons, it is called a complete shell.

The distribution of electrons in the shells of an atom is referred to as the electronic structure or electronic configuration or electronic arrangement. The distribution of electrons can also be represented diagrammatically or numerically.

In order to draw the electronic structure of an atom, you need to know the proton number of the atom so that you can get the number of electrons in the atom. Figure 4.2.1 below illustrates the electronic structure of hydrogen and fluorine atoms diagrammatically and numerically.
Please note that:

1. usually, when drawing the atomic structure of an element, an electron is represented by a dot (●) or cross (×) instead of the (ē);

2. the electronic configuration shows the distribution of electrons in the shells of an atom. Hence, when drawing the electronic structure of an atom it is often not required to show the composition of the nucleus (number of protons and number of neutrons); and

3. in the numerical representation of the electronic structure:
   a. the first number denotes the number of electron(s) in the first shell, the second number denotes the number of electron(s) in the second shell and so on; and
   b. each shell is separated by a comma.

Now it is your turn to practise drawing and writing the electronic configuration of the first 20 elements. Activity 4.2.1 will also help you to recapitulate the names and symbols of the first 20 elements.
Activity 4.2.1

You should spend about 15 minutes on this activity.

Figure 4.2.2a below shows the first 20 elements of the Periodic Table. (Please note that Figure 4.2.2a is not an actual drawing of the full Periodic Table. It is drawn this way for convenience).

Follow the pattern for hydrogen and helium to complete Figure 4.2.2a below with:
   a  the missing name of the elements;
   b  the missing symbol;
   c  the missing electronic diagram to show the distribution of electrons; and
   d  the missing electronic configuration.
Figure 4.2.2a Periodic Table for you to complete the electronic configuration of the first 20 elements.

Graphics by: Rosianna Jules, July 2010
I hope this was straightforward for you. Please use Feedback to Activity 4.2.1 at the end of the topic to verify your answers.

4.2.2 The relationship between the position of the element in the Periodic Table and its electronic configuration

By knowing the proton (atomic) number of an element and the maximum number of electrons that each shell can hold, you can easily deduce the electronic configuration (electronic arrangement or electron distribution) of the element.

From the electronic configuration of an element you can easily deduce the position of the element in the Periodic Table. The group is indicated by the number of electrons in the outer shell or the valence shell (often referred to as the outermost shell) of the element. The period is indicated by the number of shells in which the electrons are distributed.

Now let us consider hydrogen, fluorine and calcium with the proton number 1, 9 and 20 respectively. Here are their electronic configurations: hydrogen 1, fluorine 2, 7 and calcium 2, 8, 2.

Now let us explain what each of these electronic configuration means. Let us start with hydrogen, followed by fluorine and calcium.

Hydrogen: 1

This means that hydrogen has only 1 electron in its first shell. Hence, hydrogen is in Group I (because of the single electron in the outermost shell) and in Period 1 (because the electron occupies only 1 shell).

Fluorine: 2, 7

This means that fluorine has 2 electrons in the first shell, and 7 electrons in the second shell (the valence shell). This implies that fluorine is in Group VII (because of the 7 electrons in the outermost shell) and in Period 2 (because the electrons occupy 2 shells).

Calcium: 2, 8, 2
This means calcium has 2 electrons in the first shell, 8 in the second and 2 in the third shell (the valence shell). So Calcium is in Group II (because of the 2 electrons in the outermost shell) and in Period 3 (because the electrons occupy 3 shells).

Now let us summarise this information in Table 4.2.2.

<table>
<thead>
<tr>
<th>Element</th>
<th>Atomic number</th>
<th>Electronic configuration</th>
<th>Group</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Fluorine</td>
<td>9</td>
<td>2, 7</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Calcium</td>
<td>20</td>
<td>2, 8, 2</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4.2.2: The relationship between the electronic configuration and the position of the element in the Periodic Table
Feedback to Topic 4.2

Feedback to Activity 4.2.1

Figure 4.2.2b: The electronic arrangement and configuration of the first 20 elements

Graphics by: Rosianna Jules, July 2010

Now that you know about electronic configuration, in the next topic you are going to learn what happens to the electrons in the valence shell during chemical combination, i.e., when elements react together.

Topic 4.3: Chemical Bonding

You will need 2 hours and 20 minutes to complete this Topic. It is advisable that you spend another 1 hour and 10 minutes of your own time to further review chemical bonding.

The number of electrons in the outer shell (or the number of valence electrons) allows us to deduce the stability of the element and the type of
reaction that the element will undergo to obtain a stable (full) outer shell of electrons. In this topic you are going to learn about:

- the stability of Group VIII (8) elements;
- ionic bonding;
- covalent bonding; and
- metallic bonding

We will start off with the stability of the rare gases.

### 4.3.1 Stability of rare gases

Elements in group VIII are known as the **rare gases**, the **noble gases** or the **inert gases**. Group VIII elements are known as the inert gases because they are **stable**.

**Activity 4.3.1**

You should spend about 5 minutes on this activity.

Based on your knowledge of electron distribution, why do you think the elements in group VIII are said to be stable?

You are right! The elements in group VIII are stable because they have completely-filled outermost shells. In other words, the valence shell of noble gases is complete with its maximum number of electrons. Table 4.3.1 shows how electrons are distributed in the shells or energy levels of the rare gases.
Group VIII (Rare gases) | Proton number | Electron distribution
--- | --- | ---
Helium | 2 | 2
Neon | 10 | 2 8
Argon | 18 | 2 8 8
Krypton | 36 | 2 8 18 8
Xenon | 54 | 2 8 18 18 8
Radon | 86 | 2 8 18 32 18 8

Table 4.3.1: The distribution of electrons in the energy levels of the rare gases

Apart from the rare gases, all other elements are unstable because they have an incompletely-filled valence shell. Unstable elements usually bond with each other to obtain stability. By contrast, because of their complete outermost (valence) shell, group VIII elements do not take part in chemical reactions.

We are now going to learn about bonding.

### 4.3.2 Bonding

Unstable elements or elements that do not possess a duplet or an octet configuration can acquire stability (a complete outer shell) either by:

1. the transfer of electrons (gaining or losing electrons) or
2. the sharing of electrons.

During the process of obtaining stability, the reacting atoms develop some kind of attraction between them. This attraction is referred to as bonding. So, the term bond refers to the strong electrical force of attraction between the atoms or ions in the structure.
There are 3 main types of bonding. These are:

1. ionic bonding;
2. covalent bonding; and
3. metallic bonding.

If you have access to the internet, take a look at this site to get a visual idea of what an ionic bond and a covalent bond is.

http://www.mhhe.com/physsci/chemistry/animations/chang_7e_esp/bom1s2_11.swf

Please note again that we are providing the link for information only and we do not recommend or endorse any of the links from the site.

Now let us look at each type of bonding. We will start off with ionic bonding.

### 4.3.2.1 Ionic bonding

An ionic bond or electrovalent bond is formed when one or more electrons are completely transferred from the outer shell of a metal atom to the outer shell of a non-metal atom.

Normally, metals with 1, 2 or 3 electrons in their outer shells donate (give away) their electrons to become stable. On the other hand, non-metals with 5, 6 or 7 electrons in their outer shell, gain (accept) 3, 2 or 1 electrons respectively to become stable.

It is easier for metals to donate their electrons because less energy is required to lose 1, 2, or 3 electrons rather than to gain 7, 6 or 5 electrons. Similarly, less energy is needed to gain 3, 2 or 1 electron(s) rather than to lose 5, 6 and 7 electrons.

Atoms which donate their electrons become positively charged. Atoms which gain (accept) the electrons become negatively charged. The positively and negatively charged particles are called ions. A positively charged particle is called a cation and a negatively charged particle is called an anion. Table 4.3.2 shows the ions formed by elements in groups I, II, III, VI, V and VII.
### Elements

<table>
<thead>
<tr>
<th>Elements</th>
<th>Number of valence electrons</th>
<th>Electron transfer (loss -; gain +)</th>
<th>Charge acquired</th>
<th>Ions formed</th>
<th>Type of ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithium (2, 1)</td>
<td></td>
<td>-1 ė</td>
<td>+1</td>
<td>Li⁺</td>
<td>CATIONS</td>
</tr>
<tr>
<td>Sodium (2, 8, 1)</td>
<td></td>
<td></td>
<td>+1</td>
<td>Na⁺</td>
<td></td>
</tr>
<tr>
<td>Potassium (2, 8, 8, 1)</td>
<td></td>
<td></td>
<td>-1</td>
<td>K⁻</td>
<td></td>
</tr>
<tr>
<td>Beryllium (2, 2)</td>
<td></td>
<td>-2 ė</td>
<td>+2</td>
<td>Be²⁺</td>
<td></td>
</tr>
<tr>
<td>Magnesium (2, 8, 2)</td>
<td></td>
<td></td>
<td>+2</td>
<td>Mg²⁺</td>
<td></td>
</tr>
<tr>
<td>Calcium (2, 8, 8, 2)</td>
<td></td>
<td></td>
<td>+2</td>
<td>Ca²⁺</td>
<td></td>
</tr>
<tr>
<td>Aluminium (2, 8, 3)</td>
<td></td>
<td>-3 ė</td>
<td>+3</td>
<td>Al³⁺</td>
<td></td>
</tr>
<tr>
<td>Nitrogen (2, 5)</td>
<td></td>
<td>+3 ė</td>
<td>-3</td>
<td>N₃⁻</td>
<td>ANIONS</td>
</tr>
<tr>
<td>Phosphorous (2, 8, 5)</td>
<td></td>
<td></td>
<td>-3</td>
<td>P₃⁻</td>
<td></td>
</tr>
<tr>
<td>Oxygen (2, 6)</td>
<td></td>
<td>+2 ė</td>
<td>-2</td>
<td>O²⁻</td>
<td></td>
</tr>
<tr>
<td>Sulphur (2, 8, 6)</td>
<td></td>
<td></td>
<td>-2</td>
<td>S²⁻</td>
<td></td>
</tr>
<tr>
<td>Fluorine (2, 7)</td>
<td></td>
<td>+1 ė</td>
<td>-1</td>
<td>F⁻</td>
<td></td>
</tr>
<tr>
<td>Chlorine (2, 8, 7)</td>
<td></td>
<td></td>
<td>-1</td>
<td>Cl⁻</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.3.2:** Ions formed by elements in groups I, II, III, VI, V and VII

Later in the course you will also learn how ions are formed during electrolysis.

Now you are going to carry out an activity to check your understanding.
Activity 4.3.2

You should spend approximately 10 minutes on this activity.

Based on your knowledge about an atom:

1. Briefly describe why:
   
   a. an atom which loses electrons becomes a positively charged ion.

2. What are cations and anions?

   Cations are:

   Anions are:

That must have been quite easy for you. Use Feedback to Activity 4.3.2 below to verify your answers.
Feedback to Activity 4.3.2

1. As you have seen in Unit 2, protons are positively charged and electrons are negatively charged. Therefore:
   a. atoms which donate their electrons become positively charged because their ions have more protons than electrons.
   b. atoms which gain (accept) the electrons become negatively charged because their ions have more electrons than protons.

2. Cations are positively charged ions, and anions are negatively charged ions.

Now, let us consider the ionic bonds formed during the formation of sodium chloride and calcium chloride.

Example 4.3.2.1.1: Formation of sodium chloride

Each sodium atom has an unstable electronic configuration of 2, 8, and 1. To become stable with an electron arrangement of 2 and 8, a sodium atom loses 1 electron to a chlorine atom to form a positively charged sodium ion, Na⁺.

On the other hand, each chlorine atom also has an unstable electronic configuration of 2, 8, and 7. To obtain the stable electron arrangement of 2, 8, and 8, a chlorine atom gains 1 electron from a sodium atom to become a negatively charged chloride ion, Cl⁻.

The oppositely charged particles are attracted to each other by strong electrostatic forces (attraction) to form an ionic bond. The compound formed is called sodium chloride and has the formula NaCl.

Dot and cross diagrams showing only the outer electrons are used to illustrate the formation of ionic and covalent bonds. Figure 4.3.1 below illustrates the bond formation in sodium chloride.
The equation for this reaction is as follows:

\[ \text{Na} - e^- \rightarrow \text{Na}^+ \]

\[ \text{Cl} + e^- \rightarrow \text{Cl}^- \]

\[ \therefore \text{Na} + \text{Cl} \rightarrow \text{Na}^+ \text{Cl}^- \]

Because equal numbers of positive and negative charges cancels out each other, you can write the formula as NaCl.

Sodium chloride is a giant structure of ions. Sodium chloride has a regular pattern which is called a crystal. A sodium chloride crystal consists of a regular arrangement of equal numbers of sodium ions and chloride ions. This arrangement is called a lattice. Each sodium ion (Na\(^+\)) is surrounded at equidistant by 6 chloride ions (Cl\(^-\)). The same is true for the chloride ions: each chloride ion is surrounded at equidistant by 6 sodium ions. Figure 4.3.2 shows the sodium chloride lattice.
Please note that:

1. boron does not form ions.
2. an ionic bond is formed by the complete transfer of electrons. It is completely wrong to say that the atoms swap electrons.
3. dot and cross diagrams are used to illustrate bond formation. Both dots and crosses represent electrons.
4. when drawing dot and cross diagrams, the electrons from the same type of atom are represented by the same symbol: either by dots or by crosses. For example, you should represent the electrons from two chlorine atoms either by dots or by crosses, not both.
5. to make the dot and cross diagrams simpler, only the outer electrons are drawn. However, you should always remember that the electrons in the inner shells are still there.

Now let us consider our second example: the formation of calcium chloride.
Example 4.3.2.1.2: Formation of calcium chloride

Calcium atom has an unstable electronic configuration of 2, 8, 8, and 2. So each calcium atom loses the 2 outer electrons to 2 chlorine atoms to form a positively charged calcium ion, Ca\(^{2+}\), with a stable arrangement of 2, 8, and 8.

For each calcium atom, 2 chlorine atoms are needed because chlorine has an unstable electron arrangement of 2, 8, and 7 (a chlorine atom can accept only 1 electron). By gaining 1 electron, the chlorine atoms become negatively charged chloride ions, Cl\(^-\), with a stable electron arrangement of 2, 8, and 8. Figure 4.3.3 illustrates the formation of calcium chloride by dot and cross diagrams.

![Figure 4.3.3: The formation of calcium chloride](image)

The equation for this reaction is as follows:

\[
\begin{align*}
\text{Ca} - 2\bar{e} & \rightarrow \text{Ca}^{2+} \\
2\text{Cl} + 2\bar{e} & \rightarrow 2\text{Cl}^- \\
\therefore \text{Ca} + 2\text{Cl} & \rightarrow \text{Ca}^{2+}2\text{Cl}^- 
\end{align*}
\]

As you have seen, equal numbers of positive and negative charges cancels out each other, therefore the formula is written as CaCl\(_2\).

Now it is your turn to practice some dot and cross diagrams.
Activity 4.3.3

You should spend approximately 15 minutes on this activity.

In the space below draw dot and cross diagrams to illustrate the formation of the following ionic compounds. Write the equation for each reaction.

a. Magnesium oxide

b. Sodium oxide
In this sub-topic we have seen that ionic bonds are formed by the complete transfer of valence electrons between metals and non-metals. We are now going to learn about covalent bonding and the formation of covalent bonds.

4.3.2.2 Covalent bonding

Covalent bonds are formed between non-metals. Non-metals are elements in groups IV, V, VI and VII. Covalent bonding occurs when non-metals share the electrons in their outer shell to achieve stability. So, atoms which have 4, 5, 6 or 7 electrons in their outer shells, share 4, 3, 2, or 1 electrons, respectively.
Please note the following:

Each pair of electrons shared between two atoms results in the formation of a covalent bond between the atoms.

1. If two atoms share 1 pair of electrons, then a **single covalent bond** is formed between them, like in a hydrogen, \( H_2 \), molecule. The single bond in the \( H_2 \) (read as H two) molecule is shown as \( H - H \).

2. If two atoms share 4 electrons (2 pairs), then a **double covalent bond** is formed between the atoms, like in the case of an oxygen molecule. The double bond in \( O_2 \) molecule is shown as \( O = O \).

3. If two atoms achieve a stable octet configuration by sharing 3 pairs of electrons, then a **triple covalent bond** is formed between them, as in the case of a nitrogen molecule. The triple bond in \( N_2 \) is shown as \( N \equiv N \).

Now let us illustrate the formation of covalent bonds by using dot and cross diagrams. For our examples, we shall consider the formation of a hydrogen molecule, a carbon dioxide molecule, and a water molecule.

**Example 4.3.2.2.1: Formation of hydrogen molecule**

Hydrogen is a very unstable element with only 1 electron in its shell. Two hydrogen atoms can achieve stability (obtain a full shell) by sharing a pair of electrons, bringing in one electron from each hydrogen atom. The pair of electrons shared between the two hydrogen atoms results in a single covalent bond between the two atoms.
Example 4.3.2.2.2: Formation of water molecule

Each water (H₂O, read as: H - two - O) molecule is formed by the sharing of electrons between hydrogen and oxygen. 2 atoms of hydrogen share 2 electrons (1 electron each) with 1 oxygen atom to form a water molecule. Two single covalent bonds are formed in each water molecule.

Because hydrogen and oxygen exist as gas molecules, 2 hydrogen molecules are needed to react with 1 oxygen molecule to form 2 molecules of water as shown in Figure 4.3.5 below.

Please note that all common gases, such as oxygen, hydrogen, chlorine, and nitrogen, exist as molecules formed by covalent bonding (or the sharing of electrons). So during chemical combination or chemical reaction, these common gases will participate as molecules.
Example 4.3.2.2.3: Formation of a carbon dioxide molecule

Carbon atoms and oxygen atoms have an unstable electronic configuration of 2, 4 and 2, 6 respectively. To achieve stability, 1 carbon atom shares its 4 valence electrons with 2 oxygen atoms (1 oxygen molecule). So each oxygen atom shares 2 electrons with 2 electrons from the carbon atom as shown in Figure 4.3.6. Two double covalent bonds are formed in each carbon dioxide molecule.

![Formation of carbon dioxide molecule](image)

Figure 4.3.6: Formation of carbon dioxide molecule

Graphics by: Rosianna Jules, September 2010

Now as you may expect, it is your turn to practice.
Activity 4.3.4

You should spend about 15 minutes on this activity.

In the space provided:

1. draw dot and cross diagrams to show the covalent bond formation for the following molecules;

2. briefly describe how the bond(s) is formed and state the number of bond(s) formed in each molecule.

a. Nitrogen molecule (N₂)

b. Chlorine molecule (Cl₂)
c. Methane molecule (CH₄)

I hope that this exercise was very easy for you. Refer to the Feedback to Activity 4.3.4 at the end of the topic to verify your answers.

Remember, practice makes perfect!

Covalent bonds are also found in large molecules referred to as macromolecules such as sugars, proteins and plastics. You will learn about macromolecules later in this course.

So far you have seen that ionic bonds are formed between metals and non-metals and covalent bonds are formed between non-metals. Now you are going to learn about metallic bonding which is found in metals.

### 4.3.2.3 Metallic bonding

Metallic bonds are found only in metals. All metals consist of a closely-packed regular arrangement of positive ions, which are surrounded by a ‘sea’ of electrons. The regular arrangement of positive ions accounts for why metals are crystalline solids.
Positive ions repel each other. Metallic bonding is the force of attraction between two positive ions and the delocalised electrons (free electrons or ‘sea’ of electrons) between them. This explains why metallic solids:

1. are good conductor of electricity;
2. are good conductors of heat; and
3. are malleable and ductile (can easily be bent or hammered into shape)

Now let us look in more detail why metals conduct electricity and heat and why metals are malleable and ductile.

1. Electric current is the flow of electrons. Metals can conduct electricity because they possess free electrons which move through the lattice carrying negative charges as illustrated in Figure 4.3.7.

![Figure 4.3.7: Free electrons carrying negative ions](Graphics by: Rosianna Jules, September 2010)

2. Metals conduct heat because of the rapid random movement of the mobile electrons within the metal lattice as shown in Figure 4.3.8.

![Figure 4.3.8: Illustration of the conduction of heat in metals](Graphics by: Rosianna Jules, September 2010)
3. Metals are malleable and ductile because when force is applied on the metal, the layers in the lattice can slide past each other without breaking the metallic bonds which hold the metal together as shown in Figure 4.3.9.

![Figure 4.3.9: Malleability of metals](image)

**4.3.3 The properties of ionic, covalent and metallic bonds**

The properties of ionic and covalent compounds differ considerably. Table 4.3.3 shows the differences in the properties of ionic, covalent and metallic bonding.

<table>
<thead>
<tr>
<th>Ionic bonding</th>
<th>Covalent bonding</th>
<th>Metallic bonding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionic bonding results in the formation of giant structures.</td>
<td>Covalent bonding can form either: molecular structures, e.g. hydrogen molecule and methane which may exist as discrete molecules; macromolecules, e.g. proteins, starch, and plastics; or giant structures, e.g. silicon dioxide.</td>
<td>Metallic bonding form giant structures e.g. copper, lead</td>
</tr>
<tr>
<td>They consist of an aggregate (a collection) of ions arranged in a crystalline lattice.</td>
<td>Some solid covalent compounds like sugar</td>
<td></td>
</tr>
<tr>
<td>They may be in powdered form like calcium carbonate (CaCO3).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Ionic bonding

- Ionic compounds are usually solids at room temperature.
- Ionic compounds have high melting and boiling points.
- Ionic compounds conduct electricity when molten or in an aqueous solution.
- They are normally soluble in water and insoluble in organic solvents such as benzene and ether.
- For example, sodium chloride (table salt) is soluble in water but insoluble in oil. (You can try that at home for yourself).
- Some compounds such as copper oxide, and calcium carbonate are insoluble.

### Covalent bonding

- Covalent compounds are usually gases or volatile liquids at room temperature.
- Covalent compounds normally have low melting and boiling points.
- They do not conduct electricity with the exception of hydrochloric acid (HCl) and ammonia (NH3).
- They are normally soluble in water but soluble in organic solvents.
- Ethanol is an exception because it is soluble in water.

### Metallic bonding

- They form crystalline solids.
- They have high density.
- Metal bonding results in good conductors of electricity.
- Metal bonding is because the sea of electrons can move throughout the structure.

<table>
<thead>
<tr>
<th>Ionic bonding</th>
<th>Covalent bonding</th>
<th>Metallic bonding</th>
</tr>
</thead>
<tbody>
<tr>
<td>exist as crystals.</td>
<td>Covalent compounds are usually gases or volatile liquids at room temperature.</td>
<td>They form crystalline solids.</td>
</tr>
<tr>
<td>Ionic compounds are usually solids at room temperature.</td>
<td>However, a few covalent compounds, such as sugar and naphthalene, are solids at room temperature.</td>
<td>This is because of the regular arrangement of particles in the structure.</td>
</tr>
<tr>
<td>Ionic compounds have high melting and boiling points.</td>
<td>Covalent compounds normally have low melting and boiling points.</td>
<td>They have high density.</td>
</tr>
<tr>
<td>Ionic compounds conduct electricity when molten or in an aqueous solution.</td>
<td>They do not conduct electricity with the exception of hydrochloric acid (HCl) and ammonia (NH3).</td>
<td>Metal bonding results in good conductors of electricity.</td>
</tr>
<tr>
<td>They are normally soluble in water and insoluble in organic solvents such as benzene and ether.</td>
<td>They are normally soluble in water but soluble in organic solvents.</td>
<td>Metal bonding is because the sea of electrons can move throughout the structure.</td>
</tr>
<tr>
<td>For example, sodium chloride (table salt) is soluble in water but insoluble in oil. (You can try that at home for yourself).</td>
<td>Ethanol is an exception because it is soluble in water.</td>
<td></td>
</tr>
<tr>
<td>Some compounds such as copper oxide, and calcium carbonate are insoluble.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3.3: The differences in the properties of ionic, covalent and metallic bonding
Now that you know about ionic, covalent and metallic bonding, let us learn how to work out the chemical formula using different chemical combinations.

**Feedback to Activity 4.3.3 and Activity 4.3.4**

**Feedback to Activity 4.3.3**

a. Ionic formation of magnesium oxide

The equation for this reaction is as follows:

\[
\begin{align*}
\text{Mg} - 2e^- & \rightarrow \text{Mg}^{2+} \\
\text{O} + 2e^- & \rightarrow \text{O}^{2-} \\
\therefore \text{Mg} + \text{O} & \rightarrow \text{Mg}^{2+}\text{O}^{2-}
\end{align*}
\]

Because the numbers of positive and negative ions are equal, the formula can be written as MgO.

b. Ionic formation of sodium oxide
The equation for this reaction is as follows:

\[ 2\text{Na} - 2e^- \rightarrow 2\text{Na}^+ \]
\[ \text{O} + 2e^- \rightarrow \text{O}^{2-} \]
\[ \therefore 2\text{Na} + \text{O} \rightarrow 2\text{Na}^+\text{O}^{2-} \]

Because the numbers of positive and negative ions are equal, the formula can be written as NaO.

c. Ionic formation of aluminium chloride

The equation for this reaction is as follows:

\[ \text{Al} - 3e^- \rightarrow \text{Al}^{3+} \]
\[ 3\text{Cl} + 3e^- \rightarrow \text{Cl}^- \]
\[ \text{Al} + 3 \text{Cl} \rightarrow \text{Al}^{3+}3\text{Cl}^- \]

Because the numbers of positive and negative ions are equal, the formula can be written as \(\text{AlCl}_3\).

**Feedback to Activity 4.3.4**

Use the dot and cross diagrams below to verify your answers.

a. Nitrogen molecule (\(\text{N}_2\))

2 nitrogen atoms share 3 electrons each to obtain a stable octet configuration. The 3 pairs of electrons result in a triple bond between them.

![Diagram of nitrogen molecule](image)

Graphics by: Rosianna Jules, September 2010

b. Chlorine molecule (\(\text{Cl}_2\))

2 chlorine atoms share 1 electron each to achieve a complete outer shell. A single bond is formed between them.

![Diagram of chlorine molecule](image)

Graphics by: Rosianna Jules, September 2010
c. Methane molecule (CH₄)

In the formation of methane, 1 carbon atom shares its four electrons with 4 hydrogen atoms (2 hydrogen molecules). Four single bonds are formed in each molecule of methane.

We are now at the end of topic 4.3. Reflect back on what ionic and covalent bonds are. Can you provide some examples of each? In your day to day life, where would you find ionic bonds? How about covalent bonds?

In the next topic we will learn how to represent these combinations of atoms through what is called a chemical formula.

**Topic 4.4: Chemical Formulae**

You will need 2 hours and 50 minutes to complete this Topic. It is advisable that you spend another 1 hour and 25 minutes of your own time to further review this section on chemical formulae.

In this topic you are going to learn about:
- the combining power of an atom or ion
- how to write chemical formulae; and
- how to work out the chemical formula of different chemical combinations.
4.4.1 The combining power of an atom or ion

By knowing the combining power of an atom, you can easily work out the chemical formula of any compound or molecule.

The combining power of an atom normally relates to the valency of the atom (before it is combined) or the valency of its ion (the charge on its ion). Table 4.4.1 shows the formula of some common ions.

<table>
<thead>
<tr>
<th>Positive ions (cations)</th>
<th>Negative ions (anions)</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>1</code> Hydrogen H⁺</td>
<td><code>1</code> Chloride Cl⁻</td>
</tr>
<tr>
<td><code>2</code> Magnesium Mg²⁺</td>
<td><code>2</code> Oxide O₂⁻</td>
</tr>
<tr>
<td><code>3</code> Aluminium Al³⁺</td>
<td><code>3</code> Nitride N³⁻</td>
</tr>
<tr>
<td>Sodium Na⁺</td>
<td>Bromide Br⁻</td>
</tr>
<tr>
<td>Calcium Ca²⁺</td>
<td>Sulphate SO₄²⁻</td>
</tr>
<tr>
<td>Potassium K⁺</td>
<td>Phosphate PO₄³⁻</td>
</tr>
<tr>
<td>Copper Cu²⁺</td>
<td>Nitrate NO₃⁻</td>
</tr>
<tr>
<td>Lead Pb²⁺</td>
<td>Carbonate CO₃²⁻</td>
</tr>
<tr>
<td>Ammonium NH₄⁺</td>
<td>Hydroxide OH⁻</td>
</tr>
<tr>
<td>Silver Ag⁺</td>
<td>Sulphide S²⁻</td>
</tr>
<tr>
<td>Zinc Zn²⁺</td>
<td>Permanganate MnO₄⁻</td>
</tr>
<tr>
<td></td>
<td>Dichromate Cr₂O₇²⁻</td>
</tr>
</tbody>
</table>

Table 4.4.1: The formula of some common ions

As you already know, elements in group IV do not form ions. Hence, Carbon and Silicon, as atoms, have a combining power (valency) of 4.

Now let us look at how to write a chemical formula.

4.4.2 How to write a chemical formula

The chemical formula of a compound or a molecule consists of 2 or more elemental symbols written in close proximity to one another. The metal
atoms or the positive ions are always written first, followed by the non-metal atoms or negative ions.

The combining power of the atoms or ions of each element in the formula of a compound or a molecule, is indicated by a subscript after the symbol of that particular atom or ion.

For compounds which contain complex ions like NH$_4^+$ (ammonium), SO$_4^{2-}$ (sulphate), NO$_3^-$ (nitrate) and CO$_3^{2-}$ (carbonate), each complex ion is written as a single unit. When more than one unit of these ions are present in a compound, the unit is written in brackets and the number of units is written as a subscript.

Three chemical formulae and the particles present in each molecule or compound are given in Table 4.4.2 below:

<table>
<thead>
<tr>
<th>Name of compound/molecule</th>
<th>Formula of compound/molecule</th>
<th>The particles present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>H$_2$O</td>
<td>2 hydrogen atoms + 1 oxygen atom</td>
</tr>
<tr>
<td>Sugar</td>
<td>C$<em>6$H$</em>{12}$O$_6$</td>
<td>6 carbon atoms +12 hydrogen atoms + 6 oxygen atoms</td>
</tr>
<tr>
<td>Calcium chloride</td>
<td>CaCl$_2$</td>
<td>1 calcium ion +2 chloride ions</td>
</tr>
<tr>
<td>Magnesium nitrate</td>
<td>Mg(NO$_3$)$_2$</td>
<td>1 magnesium ion + 2 nitrate ions</td>
</tr>
</tbody>
</table>

Table 4.4.2: Some chemicals, their formulae and the particles present

Now, before you learn how to work out the chemical formula of some compounds or molecules, let us check your understanding so far.
**Activity 4.4.1**

You should spend about 10 minutes on this activity.

Complete the table below with either the name, chemical formula, or the particles present in the compounds or molecules.

<table>
<thead>
<tr>
<th>Name of compound/molecule</th>
<th>Formula</th>
<th>The particles present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium oxide</td>
<td>Na₂O</td>
<td>1 calcium ion + 2 hydroxide ions</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td></td>
<td>1 sodium + 1 sulphate ion</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td></td>
<td>1 sulphur atom + 2 oxygen atoms</td>
</tr>
<tr>
<td></td>
<td>N₂</td>
<td></td>
</tr>
</tbody>
</table>

This must have been very easy for you. Check the Feedback to Activity 4.4.1 for the answers.
Feedback to Activity 4.4.1

Use the table below to verify your answer.

<table>
<thead>
<tr>
<th>Name of compound/molecule</th>
<th>Formula</th>
<th>The particles present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium oxide</td>
<td>Na₂O</td>
<td>2 sodium ions + 1 oxide ion</td>
</tr>
<tr>
<td>Calcium hydroxide</td>
<td>Ca(OH)₂</td>
<td>1 calcium ion + 2 hydroxide ions</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>1 carbon atom + 2 oxygen atoms</td>
</tr>
<tr>
<td>Sodium sulphate</td>
<td>Na₂SO₄</td>
<td>2 sodium ions + 1 sulphate ion</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>SO₂</td>
<td>1 sulphur atom + 2 oxygen atoms</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
<td>2 nitrogen atoms</td>
</tr>
</tbody>
</table>

Now that you know about the combining power of some atoms and ions and how to write chemical formulae, let us look at how to work out the formula of some compounds and molecules.

4.4.3 Working out chemical formulae

You can work out the chemical formula of a compound or molecule by using:

- the valency of the atoms or ions of the elements involved; or
- the composition by mass.
We will start off with determining the chemical formulae by using the valency of the atoms or ions involved.

### 4.4.3.1 Working out a chemical formulae using valency of atoms or ions involved

Let us consider the following as examples: silver nitrate, calcium carbonate, ammonium sulphate, and aluminium oxide.

When writing chemical formulae, you need to balance the positive and negative charges.

#### Example 4.4.3.1.1: Silver nitrate

The ions in silver nitrate are $\text{Ag}^+$ and $\text{NO}_3^-$.

As there are equal numbers of positive and negative charges (ratio $\text{positive: negative} = 1:1$), the formula is $\text{AgNO}_3$.

#### Example 4.4.3.1.2: Calcium carbonate

The ions in calcium carbonate are $\text{Ca}^{2+}$ and $\text{CO}_3^{2-}$.

With equal numbers of positive and negative charges (ratio $\text{positive charges: negative charges} = 1:1$), the formula for calcium carbonate is $\text{CaCO}_3$.

#### Example 4.4.3.1.3: Ammonium sulphate

The ions present in ammonium sulphate are $\text{NH}_4^+$ and $\text{SO}_4^{2-}$.

Here, the ratio of $\text{positive charges: negative charges} = 1:2$. In order to balance the charges (that is, to have equal numbers of positive and negative charges), there needs to be twice as many ammonium ions in the formula. In other words, for each sulphate ion we need 2 ammonium ions. Therefore the formula for ammonium sulphate is $(\text{NH}_4)_2\text{SO}_4$.
Some of you may understand this better if we put the information in a table. By cross multiplying the valency, you get the number of particles (atoms/ions) of each element in the chemical formula.

<table>
<thead>
<tr>
<th>Particles</th>
<th>NH₄⁺</th>
<th>SO₄²⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valency</td>
<td>+1</td>
<td>-2</td>
</tr>
<tr>
<td>Multiplying factor</td>
<td>x 2</td>
<td>x 1</td>
</tr>
<tr>
<td>Formula</td>
<td>(NH₄)₂SO₄</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4.3: Working out the formula of ammonium sulphate

**Example 4.4.3.1.4: Aluminium oxide**

The ions in aluminium oxide are Al³⁺ and O²⁻.

The ratio *positive charges: negative charges* is 3:2. So to balance the charges, for every 2 aluminium ions, we need 3 oxide ions. The formula for aluminium oxide is Al₂O₃.

Now let us see this in the table, if it is easier for you.

<table>
<thead>
<tr>
<th>Particles</th>
<th>Al³⁺</th>
<th>O²⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valency</td>
<td>+3</td>
<td>-2</td>
</tr>
<tr>
<td>Multiplying factor</td>
<td>x 2</td>
<td>x 3</td>
</tr>
<tr>
<td>Formula</td>
<td>Al₂O₃</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4.4: Working out the formula of aluminium oxide

Now it is your turn to practice. Don’t panic, just follow the examples.
Activity 4.4.2

You should spend approximately 20 minutes on this activity.

Refer to Table 4.4.1 above for the combining power of some ions. Use those combining power to complete the table below. An example has been done for you to give you guidance.

<table>
<thead>
<tr>
<th>Name of compounds or molecules</th>
<th>Formula of combining ions/atoms</th>
<th>Formula of compounds or molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper nitrate</td>
<td>Cu$^{2+}$ and NO$_3^-$</td>
<td>Cu(NO$_3$)$_2$</td>
</tr>
<tr>
<td></td>
<td>Al$^{3+}$ and Cl$^-$</td>
<td>MgSO$_4$</td>
</tr>
<tr>
<td>Zinc chloride</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sliver nitrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K$^+$ and MnO$_4^-$</td>
<td></td>
</tr>
</tbody>
</table>

How was this activity? I bet you did not expect it to be that easy. Please refer to Feedback to Activity 4.4.2 to verify your answers.
Feedback to Activity 4.4.2

Use the table below to verify your answers to Activity 4.4.2.

<table>
<thead>
<tr>
<th>Name of compounds or molecules</th>
<th>Formula of combining ions/atoms</th>
<th>Formula of compounds or molecules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper nitrate</td>
<td>Cu(^{2+}) and NO(_3^-)</td>
<td>Cu(NO(_3))(_2)</td>
</tr>
<tr>
<td>Aluminium sulphate</td>
<td>Al(^{3+}) and SO(_4^{2-})</td>
<td>Al(_2)(SO(_4))(_3)</td>
</tr>
<tr>
<td>Magnesium sulphate</td>
<td>Mg(^{2+}) and SO(_4^{2+})</td>
<td>MgSO(_4)</td>
</tr>
<tr>
<td>Zinc chloride</td>
<td>Zn(^{2+}) and Cl(^-)</td>
<td>ZnCl(_2)</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>NH(_4^+) and NO(_3^-)</td>
<td>NH(_4)NO(_3)</td>
</tr>
<tr>
<td>Sliver nitrate</td>
<td>Ag(^+) and NO(_3^-)</td>
<td>AgNO(_3)</td>
</tr>
<tr>
<td>Potassium permanganate</td>
<td>K(^+) and MnO(_4^-)</td>
<td>KMnO(_4)</td>
</tr>
</tbody>
</table>

I suppose that was easy for you and you got the correct answers. Now let us look at how to determine the chemical formula of a compound given its composition by mass.

### 4.4.3.2 Working out chemical formulae using its composition by mass

It is also possible to work out the chemical formula of a compound or molecule from its composition by mass. The formula obtained is referred to as the **empirical formula** (i.e. the simplest formula). Let us consider some examples.
Example 4.4.3.1: Determining the formula of Copper oxide using the composition by mass

If 3.2 g of copper oxide is produced by 2.56 g of copper, what is the formula of the copper oxide formed? The relative atomic mass (Ar) of copper and oxygen are as follows: \(\text{Ar(Cu)} = 64, \text{Ar(O)} = 16\).

First, write down the equation with the reacting masses

\[
3.2 \text{ g Copper oxide} \rightarrow 2.56 \text{ g Copper} + x \text{ g Oxygen}
\]

Next, subtract the mass of copper from copper oxide to get the unknown mass of oxygen

\[
x \text{ g Oxygen} = 3.2 \text{ g Copper oxide} - 2.56 \text{ g Copper}
\]

\[
x \text{ g Oxygen} = 0.64 \text{ g}
\]

Mass of Oxygen = 0.64 g

So 3.2 g of copper oxides produces 2.56 g of copper and 0.64 g of oxygen.

Now divide the reacting masses of copper and oxygen by their relative atomic mass (Ar) to find the number of moles of copper and oxygen in copper oxide. (This calculation uses the formula learned in Topic 2.5.3.2: Converting masses to moles).

Now, divide by the smallest number of moles to get the ratio of the reacting masses.

\[
\frac{0.04}{0.04} = 1 \quad \frac{0.04}{0.04} = 1
\]

So copper and oxygen reacts in the ratio 1:1. So the simplest formula for copper oxide is CuO.
Example 4.4.3.2.2: Determining the formula of calcium carbonate using the percentage composition by mass

What is the formula of a compound which contains 40.4% calcium; 11.8% carbon; and 47.8% oxygen? (Ar (C) = 12; Ar(O) = 16; Ar(Ca) = 40).

The calculation involving percentage composition of different elements is best completed using a table as shown below.

<table>
<thead>
<tr>
<th>First write down the elements involved</th>
<th>Ca</th>
<th>C</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second write down the % composition</td>
<td>40.4%</td>
<td>11.8%</td>
<td>47.8%</td>
</tr>
<tr>
<td>Next, divide % composition by Ar to get ratio of number of atoms</td>
<td>(\frac{40.4}{40} = 1.01)</td>
<td>(\frac{11.8}{12} = 0.98)</td>
<td>(\frac{47.8}{16} = 2.99)</td>
</tr>
<tr>
<td>Finally, divide number of atoms by smallest ratio to get the combining ratio of the elements in the compound</td>
<td>(\frac{1.01}{0.98} = 1)</td>
<td>(\frac{0.98}{0.98} = 1)</td>
<td>(\frac{2.99}{0.98} = 3)</td>
</tr>
<tr>
<td>Formula</td>
<td>CaCO_3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.4.5: Deriving the formula of a compound from the % composition by mass

Now, it is your turn to give it a go.
Activity 4.4.3

You should spend about 20 minutes on this activity.

1. Determining the formula of Magnesium oxide

Magnesium burns in oxygen to produce magnesium oxide. The relative atomic mass of magnesium and oxygen are $A_r(Mg) = 24$, $A_r(O) = 16$

The results of the experiment are as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of crucible + lid</td>
<td>27.18 g</td>
</tr>
<tr>
<td>Mass of crucible + lid + magnesium</td>
<td>27.54 g</td>
</tr>
<tr>
<td>Mass of crucible + lid + magnesium oxide</td>
<td>27.78 g</td>
</tr>
<tr>
<td>Mass of magnesium oxide</td>
<td>27.78 - 27.18 = 0.60</td>
</tr>
</tbody>
</table>

From these results, determine the formula of magnesium oxide.
2. Determining the formula of an iron oxide compound

A compound contains 25% of iron and 75% of oxygen. Work out the formula of the compound. \( \text{Ar(Fe)} = 56, \text{Ar(O)} = 16 \).

How was the exercise? I hope you have found it easy to do. Refer to Feedback to Activity 4.4.3 for the solution.
Feedback to Activity 4.4.3: Determining chemical formula using composition by mass

1: Determining the formula of Magnesium oxide

The relative atomic mass of magnesium and oxygen are $A_r(Mg) = 24$, $A_r(O) = 16$.

First, write down the equation with the known masses

\[ y \text{ g magnesium} + x \text{ g Oxygen} = 0.60 \text{ g of magnesium oxide} \]

Second, calculate the reacting masses of magnesium and oxygen.

a. To obtain the reacting mass of magnesium subtract the mass of crucible + lid from the mass of crucible + lid + magnesium

So, the reacting mass of magnesium $= 27.54 - 27.18 = 0.36 \text{ g}$

b. To obtain the reacting mass of oxygen, subtract the mass of magnesium from the mass of magnesium oxide

So, the reacting mass of oxygen:

\[ x \text{ g Oxygen} = 0.60 \text{ g magnesium oxide} - 0.36 \text{ g magnesium} \]
\[ x \text{ g Oxygen} = 0.24 \]

mass of Oxygen $= 0.24 \text{ g}$

So, 0.36 g of magnesium reacts with 0.24 g of oxygen to produce 0.60 g of magnesium oxide.

Now divide the reacting masses of magnesium and oxygen by their relative atomic mass ($A_r$) to find the number of moles of magnesium and oxygen in magnesium oxide.
Number of moles  

<table>
<thead>
<tr>
<th>Element</th>
<th>Moles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesium</td>
<td>$\frac{0.36}{24}$</td>
</tr>
<tr>
<td>Oxygen</td>
<td>$\frac{0.24}{16}$</td>
</tr>
</tbody>
</table>

= 0.015  

Now divide by the smallest number of moles

<table>
<thead>
<tr>
<th>Magnesium</th>
<th>Oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.015</td>
<td>0.015</td>
</tr>
</tbody>
</table>

= 1  

So magnesium and oxygen reacts in the ratio 1:1. So the simplest formula for magnesium oxide is MgO.

2. Determining the formula of iron oxide

A compound contains 70 % of iron and 30 % of oxygen. Work out the formula of the compound. ($A_r(Fe) = 56; A_r(O) = 16$).

The calculation is shown in the table below.

<table>
<thead>
<tr>
<th>Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
</tr>
</tbody>
</table>

| First write down the elements involved |
| Fe | O |

| Second write down the % composition |
| 70 | 30 |

| Next, divide % composition by $A_r$ to get ratio of number of atoms |
| $\frac{70}{56}$ | $\frac{30}{16}$ |

= 1.25  

= 1.875

| Then, divide number of atoms by smallest ratio to get the combining ratio of the elements in the compound |
| $\frac{1.25}{1.25}$ | $\frac{1.875}{1.25}$ |

= 1  

= 1.5
Finally, as the ratio is a decimal, calculate to the smallest whole number (in this case, multiply the ratio by 2)

<table>
<thead>
<tr>
<th>Formula</th>
<th>Fe₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 \times 2</td>
<td>1.5 \times 2</td>
</tr>
<tr>
<td>= 2</td>
<td>= 3</td>
</tr>
</tbody>
</table>

I hope that you have got both answers correct. If not, do not be disappointed, but have another go at it after reviewing the topic.

Now let us review what you have learned in this unit. Also, make sure not to forget about the self-assessment located after the unit summary.

Unit summary

In this unit you learned about atoms, bonding and the Periodic Table. You learned that the Periodic Table is an arrangement of elements in increasing order of their proton number. The Periodic Table is divided into 7 periods (the horizontal rows) and 8 groups (the vertical columns). You should now know that the Period relates to the number of electron shells that the element possesses and that all elements in the same period have the same number of shells. You should also be aware that the groups relate to the number of electrons in the outermost shell of the atom. With the knowledge of the Periodic Table, you should be able to explain that the metallic properties of the elements decrease as we move from left to right across the Periodic Table. The elements on the left of the Periodic Table are metals, while the elements on the far right are non-metals.

In this unit you have also learned that the electrons are distributed in concentric circles called shells, and that one shell must be filled with its maximum number of electrons before electrons can occupy the next shell. With that knowledge, you should be able to draw the electronic structure and write the electronic configuration of the first 20 elements. Now that you know about the electronic configuration, you should be able to explain that elements in group VIII are stable because they have a completely-filled outer shell. Meanwhile, the elements in groups I to VIII can achieve stability by combining with other elements either by the transfer or the sharing of electrons. Elements in groups I to group III can achieve stability by the transfer (loss or gain) of electrons while those in group IV to group VII can become stable by the sharing of electrons.
You have learned about the three types of bonds: ionic bonds, covalent bonds and metallic bonds. Ionic bonds are formed by the complete transfer of electrons between metals and non-metals. Covalent bonds, on the other hand, are formed by the sharing of electrons between non-metals, while metallic bonds are found only in metals. You have also learned to draw dots and cross diagrams to show the formation of ionic bond and covalent bonds.

After studying this unit, you should be able to work out the chemical formulae of different compounds and molecules by using either the valency of the atoms or ions involved, or its composition by mass.

We have now come to the end of Unit 4. I hope that you have clearly understood all the contents of the unit. Should you feel the need to review certain contents, please do so before you tackle Unit 5. All the best with Unit 5!
Assessment

Self-assessment 4.1

You are encouraged to spend no more than 45 minutes on this self-assessment.

This self-assessment covers the whole unit and requires that you use the knowledge you have acquired to answer the questions. The answers are given at the end of the unit. You are strongly advised to answer all questions in the space provided before you refer to the Answers to Self-assessment 4.1. This will help you learn and reflect better on areas for improvement.

1. Write true or false next to each of the following statements.

<table>
<thead>
<tr>
<th>Statements</th>
<th>True/False</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The vertical columns in the Periodic Table are called <em>Periods</em>.</td>
<td></td>
</tr>
<tr>
<td>2. Elements in the Periodic Table are arranged in order of increasing atomic mass</td>
<td></td>
</tr>
<tr>
<td>3. The electron shells are also referred to as the energy level.</td>
<td></td>
</tr>
<tr>
<td>4. An ionic bond is formed by the complete transfer of electrons.</td>
<td></td>
</tr>
<tr>
<td>5. Covalent bonds are formed between non-metals only.</td>
<td></td>
</tr>
<tr>
<td>6. Covalent compounds have high boiling and melting points.</td>
<td></td>
</tr>
</tbody>
</table>

2. Use the outline of the Periodic Table below to answer the questions that follow.
a) Which element is represented by the following numbers?

<table>
<thead>
<tr>
<th>Element No.</th>
<th>Name of element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

b) In the table below write all the numbers which represent the following groups of elements:

<table>
<thead>
<tr>
<th>Group of elements</th>
<th>Element No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali metals</td>
<td></td>
</tr>
<tr>
<td>Alkali earth metals</td>
<td></td>
</tr>
<tr>
<td>Halogens</td>
<td></td>
</tr>
<tr>
<td>Inert gases</td>
<td></td>
</tr>
<tr>
<td>With a valency of 4</td>
<td></td>
</tr>
<tr>
<td>Elements which form +2 ions</td>
<td></td>
</tr>
<tr>
<td>Elements which form +3 ions</td>
<td></td>
</tr>
</tbody>
</table>
Elements which form -2 ions

Elements which do not form ions

The transition elements

3. Use the following information about 10 elements to answer the questions that follow.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>H&lt;sub&gt;1&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>C&lt;sub&gt;12&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>O&lt;sub&gt;16&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>N&lt;sub&gt;14&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>Na&lt;sub&gt;23&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>Mg&lt;sub&gt;24&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>Al&lt;sub&gt;27&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>Cl&lt;sub&gt;35&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>K&lt;sub&gt;39&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>Ca&lt;sub&gt;40&lt;/sub&gt;</td>
<td></td>
</tr>
</tbody>
</table>

a) Draw and write the electronic configuration of oxygen and calcium.

<table>
<thead>
<tr>
<th>Oxygen</th>
<th>Calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

b) Write down the ions formed by the following elements.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td></td>
</tr>
<tr>
<td>Magnesium</td>
<td></td>
</tr>
</tbody>
</table>
c) Sodium and chlorine react together to form a compound.

i. What is the name of the compound?

ii. What type of bond is formed between sodium and chlorine?

iii. Explain why this type of bond is formed between these two elements when they combine.

iv. Use a dot and cross diagram to show the formation of this compound.
v. Write the equation for the formation of this bond.

vi. Why is it wrong to call the compound formed between sodium and chlorine a molecule?
d) The diagram below shows the dot and cross diagram for the substance T.

![Diagram of substance T]

i. Which elements are represented by the letter A and B?

A is ____________________________________________________________

B is ____________________________________________________________

ii. What is the name of compound T?

T is ____________________________________________________________

iii. What is the name of the bond shown in compound T?

_________________________________________________________________

iv. Explain why this type of bond is formed between these two elements.

_________________________________________________________________

_________________________________________________________________

_________________________________________________________________
4. When 28.68 g of lead oxide was heated in dry hydrogen, 24.84 g of lead (Pb) was collected. \( \text{Ar (Pb)} = 207, \text{Ar (O)} = 16. \)

a) How many grams of oxygen were present in the oxide?

b) Calculate the number of moles of oxygen atoms.

c) Calculate the number of moles of lead in the oxide.
d) How many moles of oxygen were combined with 1 mole of lead?

\[
\text{\textit{Your answer here.}}
\]

e) Write down the formula for the lead oxide used.

\[
\text{\textit{Your answer here.}}
\]

Refer to the Answers to Self-assessment 4.1 for the solutions. Do not be disappointed if you did not succeed on all the questions. You can review the unit and try again. Remember, you also learn from your mistakes!
Answers to self-assessments

Answers to Self-assessment 4.1

1. True or False

<table>
<thead>
<tr>
<th>Statements</th>
<th>True/False</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The vertical columns in the Periodic Table are called Periods.</td>
<td>False (vertical columns are called Groups and horizontal rows are called Periods)</td>
</tr>
<tr>
<td>2. Elements in the Periodic Table are arranged in order of the increasing atomic mass</td>
<td>False (they are arranged in terms of increasing proton (atomic) number)</td>
</tr>
<tr>
<td>3. The electron shells are also referred to as the energy level.</td>
<td>True</td>
</tr>
<tr>
<td>4. An ionic bond is formed by the complete transfer of electrons.</td>
<td>True</td>
</tr>
<tr>
<td>5. Covalent bonds are formed between non-metals only.</td>
<td>True</td>
</tr>
<tr>
<td>6. Covalent compounds have high boiling and melting points.</td>
<td>False (this is true for ionic bonds)</td>
</tr>
</tbody>
</table>

2. The Periodic Table

a) Which element is represented by the following numbers?

<table>
<thead>
<tr>
<th>Element No.</th>
<th>Name of element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>8</td>
<td>Oxygen</td>
</tr>
<tr>
<td>9</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Element No.</td>
<td>Name of element</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>11</td>
<td>Sodium</td>
</tr>
<tr>
<td>18</td>
<td>Argon</td>
</tr>
<tr>
<td>20</td>
<td>Calcium</td>
</tr>
</tbody>
</table>

b) In the table below, write all the numbers which represent the following groups of elements:

<table>
<thead>
<tr>
<th>Group of elements</th>
<th>Element No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alkali metals</td>
<td>3, 11, 19, 37</td>
</tr>
<tr>
<td>Alkali earth metals</td>
<td>4, 12, 20, 38</td>
</tr>
<tr>
<td>Halogens</td>
<td>9, 17, 35, 53</td>
</tr>
<tr>
<td>Inert gases</td>
<td>2, 10, 18, 36, 54</td>
</tr>
<tr>
<td>With a valency of 4</td>
<td>6, 14</td>
</tr>
<tr>
<td>Elements which form +2 ions</td>
<td>4, 12, 20, 38</td>
</tr>
<tr>
<td>Elements which form +3 ions</td>
<td>13</td>
</tr>
<tr>
<td>Elements which form -2 ions</td>
<td>8, 16</td>
</tr>
<tr>
<td>Elements which do not form ions</td>
<td>2, 5, 6, 10, 14, 18, 36, 54</td>
</tr>
<tr>
<td>The transition elements</td>
<td>21, 22, 23, 24, 25, 26, 27, 28, 29, 30</td>
</tr>
</tbody>
</table>

3.

a) Electronic structure and electronic configuration

| Oxygen | Calcium |
b)  

<table>
<thead>
<tr>
<th>Elements</th>
<th>Ions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium</td>
<td>K⁺</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>N³⁻</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O²⁻</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg²⁺</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Al³⁺</td>
</tr>
</tbody>
</table>

c) Reaction of sodium and chlorine
   i. Sodium chloride
   ii. Ionic bonds
   iii. An ionic bond is formed between sodium and chlorine because there is a complete transfer of an electron from sodium to chlorine. Sodium has 1 electron and chlorine has 7 electrons in their outer shell. So to achieve a stable octet configuration it is easier for sodium to lose 1 electron and for chlorine to gain 1 electron than lose 7 electrons.
iv. Bond formation between sodium and chlorine

![Diagram showing sodium and chlorine ions](image)

v. The equation for this reaction:

\[
\begin{align*}
Na - e^- & \rightarrow Na^+ \\
Cl + e^- & \rightarrow Cl^-
\end{align*}
\]

\[ \therefore \text{Na} + \text{Cl} \rightarrow \text{Na}^+\text{Cl}^- \]

As there are equal numbers of positive and negative charges the formula is written as NaCl.

vi. It is wrong to refer to sodium chloride as a molecule because sodium chloride exists as ions within a giant lattice structure.

d) Compound T

i. A is carbon, B is oxygen

ii. Carbon dioxide

iii. Double covalent bond (covalent bond is also correct)

iv. Covalent bonds are formed when the sharing of electrons take place. Two double covalent bonds are formed in carbon dioxide. To achieve a stable octet configuration, carbon shares its 4 electrons with 2 oxygen atoms (an oxygen molecule). Each oxygen atom shares 2 electrons with the carbon atom.

4.

a) Mass of oxygen
Mass of oxygen = mass of oxide - mass of lead
Mass of oxygen = 28.68 g - 24.84 g
Mass of oxygen = 3.84 g

b) Number of moles of oxygen atoms

Number of moles of oxygen atoms = \( \frac{3.84}{16} \)
Number of moles of oxygen atoms = 0.24

c) Number of moles of lead atoms

Number of moles of lead atoms = \( \frac{24.84}{207} \)
Number of moles of lead atoms = 0.12

d) Number of moles of oxygen reacting with 1 mole of lead

<table>
<thead>
<tr>
<th></th>
<th>Lead</th>
<th>Oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.12 mole of lead atoms reacts with 0.24 mole of oxygen atoms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Divide by 0.12 (the smallest number) to get the combining ratio</td>
<td>0.12</td>
<td>0.12</td>
</tr>
<tr>
<td>= 1</td>
<td>= 2</td>
<td></td>
</tr>
<tr>
<td>So 1 mole of lead atoms reacts with 2 moles of oxygen atoms</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

e) The formula is PbO₂