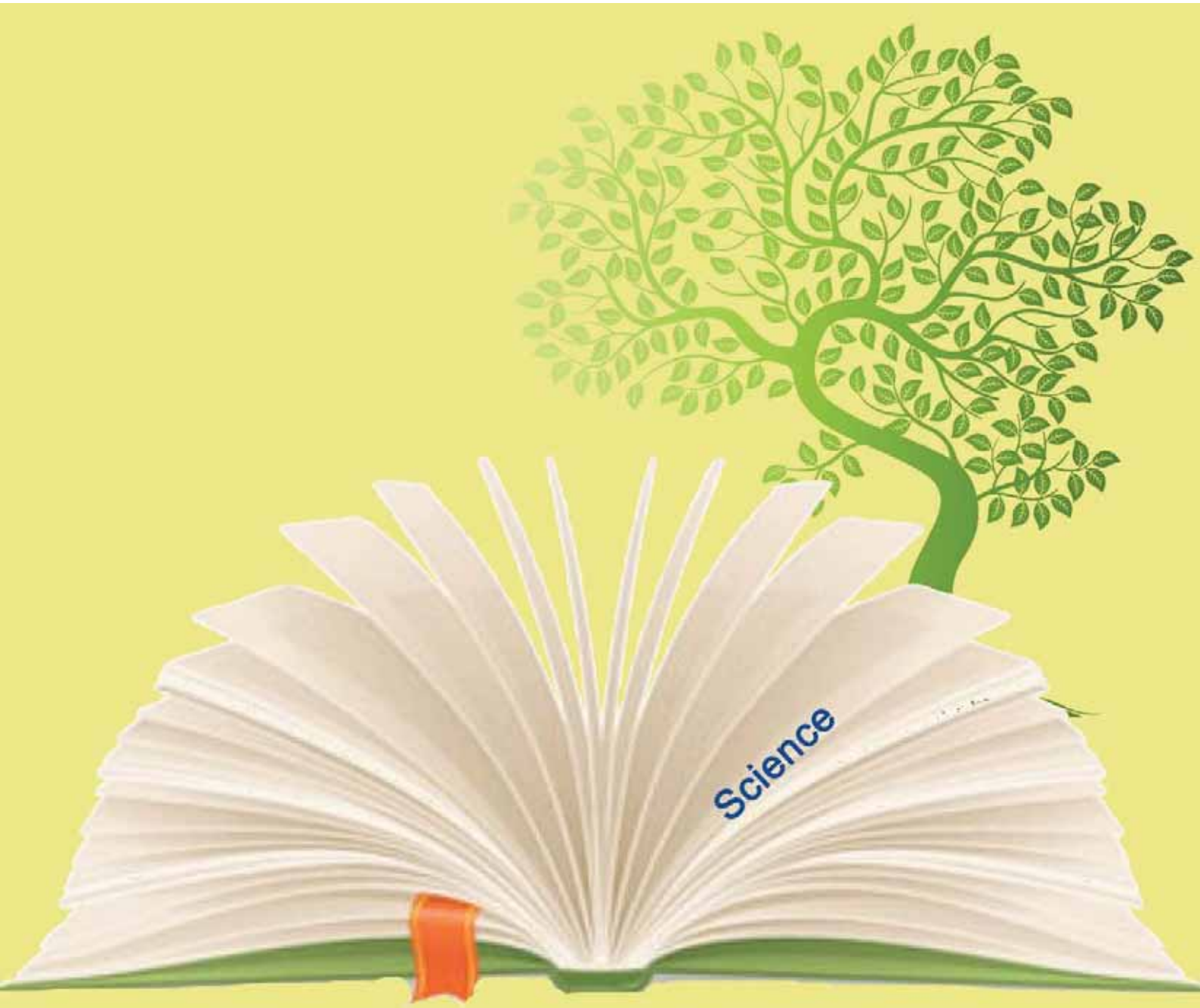

OPEN EDUCATIONAL RESOURCES

4

OPEN SCHOOLS

Taking Education to the People

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, Seychelles: www.education.gov.sc
Ministry of Education and Training, Lesotho: www.gov.ls/education
Ministry of Education Trinidad& Tobago: www.moe.gov.tt
National Open School of Trinidad & Tobago (NOSTT): www.moe.gov.tt/NOSTT
Ministry of Education and Skills Development, Botswana: www.moe.gov.bw
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.

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COURSE MATERIAL

Chemistry

Grade 12

COL Open Schools Initiative
Lesotho

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About the Course

The materials for Grade 12 Chemistry have been produced by the Commonwealth of Learning's COL Open Schools Initiative. All course content produced by the COL Open Schools Initiative are structured in the same way, as outlined below.

How the Course 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 need to know before starting the course
- 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:

- How to improve your study skills
- Where you can get help
- How to complete course assignments and assessments
- How to find your way around the course using the margin icons
- What is included in each unit

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

The Course Content

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

- An introduction to the unit content
- 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

If you are interested in learning more about this subject, we provide you with a list of additional resources at the end of this course. These may be books, articles or websites.

Your Comments

After completing Grade 12 Chemistry, we would appreciate it if you could take a few moments to give us your feedback on any aspect of this course. Your feedback might include comments on things such as:

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

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

Course Overview

Welcome to Grade 12 Chemistry

These materials form Part 1 of the Physical Science Course that is designed to prepare students for the Cambridge Overseas School Certificate Examination. Units 1 to 9 of the overall course are devoted to chemistry, while the remaining units cover aspects of physics.

The first nine units deal with chemistry concepts and their application to situations you are likely to encounter in everyday life. They are designed to meet the requirements of the national Grade 12 syllabi in many nations across the Commonwealth. They should thus provide a sound foundation for learners who wish to further their education in any field of study for which chemistry is a prerequisite.

Is this Course for You?

This course is intended for open and distance learners who wish to acquire knowledge and understanding of physical sciences. In order to cope with these course materials, you must have passed mathematics and science at the Junior Secondary Certificate or Grade 10 level. This course is designed as a two year course examinable at the end of the two years in November by the University of Cambridge through the Examinations Council of Lesotho.

These units on chemistry are intended to:

- Enhance your scientific skills, including: measurement, interpretation, application, accuracy and precision.
- Broaden your knowledge and acquaint you with scientific concepts.
- Develop attitudes relevant to science and chemistry such as:
    - objectivity
    - integrity
    - enquiry
    - initiative
    - inventiveness

Course Outcomes

Outcomes

Upon completion of the first nine units of this course, you will be able to:

- *Conduct* an experiment and *interpret* different experimental results.
- *Explain* the behaviour and characteristics of different elements based on the periodic table.
- *Calculate* different quantities involved in chemical reactions.
- *Describe* the structure and properties of different substances.
- *Describe* the behaviour and characteristics of different chemical reactions.
- *Describe* the composition and behaviour of the atmosphere and the environment.
- *Discuss* the composition and characteristics of organic compounds.

Timeframe

How long?

Students at conventional schools in Lesotho normally take two years to prepare themselves for the Cambridge Overseas School Certificate examination in Physical Science. This is equivalent to six or seven hours per week for 40 weeks per year over two years, a total of roughly 500 study hours.

However, those who register with an open school often have to make time for their studies while fulfilling other responsibilities at home or at work. For this reason, a more flexible study schedule may be necessary. Nevertheless, it is essential that you create a timetable for yourself. If you do not set aside time on a regular basis to work through these materials, you may not be able to complete the course.

Study Skills

As an adult learner, your approach to learning will be different from that of your school days. You can choose what you want to study, you may be motivated by personal and/or professional goals and you will have to find time for your studies while coping with other responsibilities at home or at work.

Essentially you will need to take control of your learning environment. You should consider a number of issues that can affect your performance including how to manage your time, how to set goals or how to manage stress. You may also need to re-acquaint yourself with 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*. That is the time you dedicate to your learning and the environment in which you engage in that learning.

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/

  This "how-to-study" website is dedicated to information on study skills. You will find links to resources on study preparation (a list of nine essentials for a good study place), taking notes, and strategies for reading text books, using reference sources and coping with test anxiety.

- http://www.ucc.vt.edu/stdysk/stdyhlp.html

  This is the website of the Virginia Tech Division of Student Affairs. You will find links to resources on time scheduling (including a "where does time go?" link), a study skills checklist, basic concentration techniques, control of the study environment, note taking, how to read essays for analysis and memory skills ("remembering").

- http://www.howtostudy.org/resources.php

  This is another "how-to-study" website 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 and 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 something similar in the address pane of your web browser.

Learning Approaches

Part of taking control of your learning environment involves being mindful of your learning approach to the material. When this course was developed, a specific learning approach was kept in mind. It is helpful if you take the same approach when doing your own self-study!

The *Nine Events of Instruction* was developed by Robert Gagné and is a framework for your own learning (adapted from edutechwiki):

1. **Gain attention**: when a new situation, problem or information is presented, how can you relate it to your own life? What questions can you ask? This will help motivate you to learn more.

2. **Describe the goal**: Refer to the course and unit outline. These are the goals you wish to accomplish by the end of the unit/course. How can you use this knowledge in future units, in other courses or in your day-to-day life?

3. **Stimulate recall of prior knowledge**: pay attention to where we tell you how new information relates to information you have already learned. Ideas that you learn in this course are connected. By recognizing those connections, you will remember and understand things more easily.

4. **Present the material to be learned**: Pictures, diagrams, and examples throughout the course will help aid you in learning.

5. **Provide guidance for learning**: Icons in the margins will help you to identify the type of activity you should be doing to learn. Please see the Margin Icons section (p. 10) in the course overview for more information.

6. **Elicit performance "practice"**: It is very important that you perform the self-assessment activities. Try to do those activities without referring to the answers until you have completed as much as you can. This will help tell you what you need to study more.

7. **Provide informative feedback**: Both the answers to the self-assessments and your tutor's feedback will help with this, but it means nothing if you do not learn from it. Take time to understand why you were incorrect. This may involve follow-up with your tutor!

8. **Assess performance test**: This will help you understand whether or not you have learned the content.

9. **Enhance retention and transfer**: Can you solve similar problems in new situations? Try teaching the information to someone else!

Good luck!

Need Help?

Help

As you study Grade 12 Chemistry, you may encounter academic and social issues that hinder your progress. For example, you may have questions or need help to make sense of the materials. To help you overcome some of these problems, the Lesotho Distance Teaching Centre (LDTC) established a Student Advice Section, whose main objective is to offer you counselling before, during and after the course. Whenever you come across an issue that impedes your studies, you should write or call the LDTC office, where someone will assist you:

Address: The Director

Lesotho Distance Teaching Centre

P.O. Box 781

Maseru

Tel: + 266 22316961

Fax: +266 22310245

Email ldtc@ymail.com

LDTC also has offices in five other districts. These offices are housed in the Ministry of Education and Training's District Resource Centres and are manned by LDTC officers. All services provided by the head office in Maseru are available in the districts. In this way, if you live in one of these districts you do not have to travel to Maseru to get study materials and other services. Please feel free to drop into these Resource Centres any time between 8:00 and 4:30 p.m. to get advice or help with any problems relating to your studies, assignments, face-to-face sessions or end of course examinations. The districts are:

Qacha's-Nek (Tel. +266 22950702)

Mokhotlong (Tel. + 266 22920396)

Thaba-Tseka (Tel. + 266 22900492)

Quthing (Tel. +266 22751459)

Leribe (Tel. +266 22400022)

Since LDTC uses print as its main medium of instruction, you will receive information through letters, leaflets, pamphlets and booklets. But you too must write whenever you have information or news to share.

From time to time, tutorials will also be arranged so that you can get advice and assistance on any points of confusion. A schedule listing the dates of these tutorials will be given to you when you register.

Chemistry Resources

Help

If you have access to the internet, there are a plethora of excellent chemistry resources out there that include videos, animations, games and different explanations of the ideas you will be introduced to in this course. Please make sure to take advantage of the following resources as you work through the course.

http://www.chemguide.co.uk/

General chemistry guides with clear descriptions.

http://www.docbrown.info/index.htm

Chemistry notes and quizzes.

http://www.khanacademy.org/

Excellent general science tutorials.

http://www.ausetute.com.au/index.html

Free chemistry tutorials.

Assignments

Assignments

The Grade 12 Chemistry course has 9 units that are going to be bound together into workbooks. At the end of each workbook you will be expected to do a self-marked assignment. The aim of these assignments is to test how well you have studied and understood the contents of each workbook. After completing such assignments, check your work against the model answers provided. If you did not get at least 80% of them correct, go back through the unit and study the material carefully before trying the assignment again. Please read your workbooks and answer the assignment questions in the set order. Following the logical order will enhance your comprehension and help you to complete your work on time.

Your tutors are here to help! If you need help, please attend the face-to-face tutorials held by the tutors. During these sessions you are given the chance to meet your tutors and to get immediate answers to all your questions. The tutorials also afford you a chance to meet and interact with other learners. If you still have some difficulty understanding the material, ask your tutor at the next scheduled meeting.

Assessments

Assessments

In addition to the assignment, each unit also includes an assessment to test your understanding of the content. The time you should take to complete the assessment is shown at the top of each paper, as well as the total marks available and the marks for each question.

When you finish each assessment, please submit it to the Student Advice Section at LDTC Head Office. You may do this through the post or drop it at the office if you live nearby. LDTC engages teachers (tutors) on a part-time basis to mark these assessments and assist you. Each assessment has a cover sheet on which you can seek an explanation of any part you could not understand. The tutors will answer all of your queries and give you feedback on your assessment. The deadlines for submitting these assignments will be provided by your tutor at the first meeting each year. Feedback will be provided to you about two weeks after the submission dates.

Getting Around the Course

Margin Icons

While working through this course you will notice that little pictures or icons appear frequently in the left-hand margin. 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. A complete set of these icons is shown below. We suggest that you familiarize yourself with the icons and their meaning before starting your studies.

Activity	Assessment	Assignment	Case study
Discussion	Group activity	Help	Note it!
Outcomes	Reading	Reflection	Study skills
Summary	Terminology	Time	Tip

Unit 1

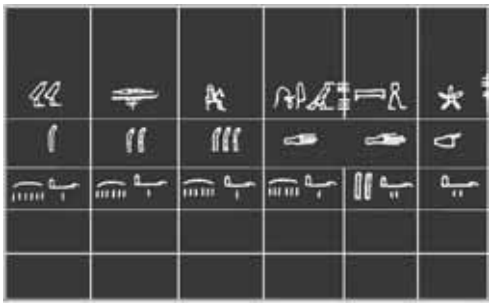
Experimental Techniques

Study Skills

Before you start this unit, take a look around your study space. Is it free from distractions like T.V.? Does it have enough light? Does it contain a large enough desk or table? Does it have all the study materials you need? (i.e. pens, pencils, calculator etc.) If not, fix this! Having a good study space is important for good studying. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In ancient times, people used their bodies as references for measurement! The length of a foot, the width of a finger, and the distance of a step were all accepted measurements. In ancient Egypt, a cubit was the distance from the elbow to the fingertips. Today a cubit is about 18 inches. How are things measured today? Why is measurement important?



Egyptian Cubits accessed from Wikimedia Creative Commons, 2010.

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All of the activities that you do every day involve some measurement. When you cook you measure the amount of ingredients. When you go to meet your tutor, there is measurement of time and distance involved. It is therefore not surprising that in your study of chemistry you will use measurements when you carry out your experiments. In chemistry, you need to use the right apparatus for experiments, the correct measurements and the appropriate units.

The way we measure things and the units we use have changed since ancient times as new technologies have been invented. As science advances, we may find new things to measure that need their own units!

We are going to discuss the techniques used in chemistry experiments to get accurate results. It is important to get accurate results in science because our conclusions depend on our observations. So our learning of the environment depends on the results we obtain.

Time

This unit consists of 55 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Conduct* an experiment and *interpret* different experimental results.

Study Skills

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Name* the apparatus used to measure time, temperature, mass and volume.
- *Explain* how to accurately measure time, temperature, mass and volume.
- *Draw* how an apparatus should be arranged for a given experiment.
- *Describe* how to purify a given mixture by use of a suitable solvent, filtration, crystallisation and distillation.
- *Interpret* chromatographs.
- *Identify* the purity of substances by their fixed points and chromatography methods.
- *Identify* cations, anions and gases based on experimental results.

Terminology

Anion:	A negatively charged ion i.e. Cl^- ion (chloride).
Cation:	A positively charged ion i.e. Na^+ ion (sodium).
Chromatogram:	A visual output of a chromatograph.
Electrolyte:	A solution that contains ions.
Emulsion:	A cloudy mixture produced from shaking immiscible liquids.
Filtrate:	A liquid that is produced after filtering a mixture
Fixed point:	Fixed temperatures that do not change at specified conditions.

Immiscible liquids:	Liquids which do not mix such as oil and water.
Miscible liquids:	Liquids that dissolve in one another such as water and ethanol.
Mixture:	Two or more substances mixed together but not combined chemically.
Heterogeneous Mixture:	Mixtures where you can see two distinct parts i.e. raisins in water.
Homogeneous Mixture:	Mixtures which have a uniform appearance (looks like one substance) i.e. Cola.
Solid-solid mixture:	A mixture of two or more solids such as sand and sugar. Also known as a mechanical mixture.
Solute:	A substance that is dissolved in a given solution. i.e. the solute for sea water is salt and other dissolved compounds.
Solvent:	The component of a solution that is present in the greatest amount. It is the substance in which the solute is dissolved i.e. the solvent for sea water is water.
Solution:	A mixture of two different substances in one phase (state). Can be solid, liquid or gas.
Suspension:	A mixture in more than one phase. For example, a mixture of oil and water has two layers (it is in two phases). A mixture of soil and water has two states (solid and liquid). It is in two phases.
States of Matter	Matter interacting to form a homogeneous phase i.e. solid liquid or gas.
Phase:	A form of matter that has relatively uniform chemical and physical properties.

Section 1-1: Measurement

Introduction

In section 1-1, we are going to discuss the idea of measurement. There are many different kinds of measurements (time, temperature, mass, volume), each of which must be examined separately so that the overall idea of measurement can be fully understood. In a measurement, we have a value (or quantity) and its units. There are many different things which can give us values and the units. For example, a farmer may want to know: How long does it take to walk from the village to the field? How

big is the field? How many seeds does she need to buy? These questions and others similar to them will require a value with units to provide a satisfactory answer. Hence, knowledge of the idea of measurement is essential in our daily lives.

In section 1-1, we will deal with the measurement of time, temperature, mass and volume. We will also learn how to accurately measure each of them using the appropriate apparatus.

Time

In chemistry, time is regarded as the duration you take to do something. For example, how long does a chemical reaction take? What is the time needed to boil water?

The measurement of time is not new, but the instruments people use to measure time keep on changing. Figure 1 below shows one of the instruments used a long time ago to measure time. As technology and science changes, it requires changes in the ways we do things. Time is one of the things which requires a change in the way we measure it.

At the end of this topic you should be able to:

- *name* the apparatus used to measure time.
- *explain* how to accurately measure time.

Time

There are 5 pages on the topic of time. You should spend approximately 20 minutes on this topic.

Figure 1: Hourglass accessed from Wikimedia Creative Commons, 2010.

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Before the invention of the clock, people measured time using:

- The hourglass: as shown in Figure 1. The sand falls at a constant rate which can be related to time.
- The sundial: the length and direction of the shadow on the sundial estimates the time of the day.

There was a lot of estimation and the results were not accurate. This caused problems because some of the units were not applicable to all quantities. For example, one cannot correlate the length of the shadow to the time it takes to boil water.

Time is now measured with clocks such as a wall clock, a wristwatch or a digital watch. Figures 2, 3 and 4 illustrate these apparatus. A watch that is mostly used in the chemistry laboratory is a stopwatch as shown in Figure 5.

Figure 2: Wall clock accessed from Wikimedia Creative Commons, 2010.

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Figure 3: A wristwatch accessed from Wikimedia Creative Commons, 2010.

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Figure 3: A Digital watch accessed from Wikimedia Creative Commons, 2010.

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Figure 4: A stopwatch: accessed from Wikimedia Creative Commons, 2010.

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A stopwatch or stop clock is suitable for chemistry experiments because at the start of the reaction or activity, you can start the clock and stop the clock when the reaction is complete.

Measuring and Converting Time

The International System (SI) unit for time is seconds. Larger units such as minutes and hours are also used to measure time. Chemists use seconds to measure the rate of a chemical reaction. Remember that there are 60 seconds in a minute, 60 minutes in an hour, 24 hours in a day and 365 days in a year.

If I want to convert 300 seconds into minutes:

$$300\ s \times \frac{1\ min}{60\ s} = 5\ min$$

If I want to convert 5.6 hours into seconds, I first have to convert hours into minutes, and then into seconds.

$$5.6\ h \times \frac{60\ min}{1\ h} = 336\ min \times \frac{60\ sec}{1\ min} = 20{,}160\ s$$

Reading

If you have access to the internet, please go to: http://www.alysion.org/dimensional/fun.htm for more practice with time conversions.

Activity

Activity 1

'Malonya wanted to know the time it takes a magnesium cube to react with hydrochloric acid. She recorded the time at the start of the reaction as 10:58:30. That is: 10 hours, 58 minutes and 30 seconds. When the reaction stops, the time was 11:35:23.

How long did the reaction take?

_____
_____
_____

Compare your answer with the one at the end of the section. Spend the time needed to understand how time is calculated.

Activity

Activity 2

1. How many seconds are there in one minute?_____
   _____
2. How many minutes are in one hour?
   _____
   _____
3. How many seconds in one hour?_____
   _____
4. How many minutes in one day?_____
   _____

Compare your answers to those at the end of the section. Make sure you understand how to do each calculation before continuing.

Temperature

We all know that a sunny summer day is hot. We also know that a winter day is normally cold. The question may be: how hot or cold is it on the day? As shown earlier, to provide an answer we have to provide a value and units so that we can compare the hotness or coldness of the days. From this topic, we will be able to get values and units to show how hot and cold the day is.

At the end of this topic you should be able to:

- *name* the apparatus used to measure temperature.
- *explain* how to accurately measure temperature.

Time

There are 6 pages on the topic of temperature. You should spend approximately 20 minutes on this topic.

Measuring Temperature

Temperature is a measure of how hot or cold a substance is. To measure temperature of a substance accurately, we use instruments called thermometers.

How to measure temperature

Look at the image of the thermometer below. Note the scale and the red-coloured alcohol in the tube.

Figure 5: A thermometer accessed from Creative Commons, 2010.

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A thermometer is made of a small thin tube which contains alcohol and a thin bulb at the end. When it becomes warmer, the alcohol expands and moves up the glass tube. The readings show how high the alcohol has risen. Mercury was commonly used in thermometers before it was known that mercury was poisonous. Modern thermometers are now digital.

Units of Temperature

The SI unit of temperature is the Kelvin (symbol K). The most commonly used unit, also use in Lesotho, is the degrees Centigrade or degrees Celsius (the symbol ^{o}C). The relationship between the Celsius and Kelvin scale is: 0°K = - 273.15 ^{o}C or 0°K = °C – 273.15.

Discussion

Read about Absolute Zero at
http://www.colorado.edu/physics/2000/bec/temperature.html

What is absolute zero? Do you think it will ever be possible for scientists to create absolute zero conditions? Discuss this with a friend!

The other unit which is rarely used is the degree Fahrenheit (^{o}F). This is used in the United States of America. On this scale the freezing point of water corresponds to 32 ^{o}F and the boiling point to 212 ^{o}F.

Fixed Points or Fixed Temperatures

Substances boil and melt at temperatures that do not change. We call these temperatures fixed temperatures or fixed points. Here are some examples of fixed points:

The boiling point of water at sea level is fixed as 100 ^{o}C.

The melting point of ice is fixed as 0 ^{o}C.

The melting point of common salt (sodium chloride) is 801 ^{o}C

The boiling point of common salt is 1465 ^{o}C

These temperatures remain fixed if the substance is pure. If a substance is mixed with another, the fixed point changes. For example, sea water is a mixture of water, salt and other substances. The boiling point of sea water is above 100 ^{o}C and melting point is below 0 ^{o}C. This means impure substances have different boiling and melting points compared to pure substances.

Activity 3

Activity

1. When people make ice cream, they add rock salt to the ice surrounding the cream mixture. Why do you think this is done?

   _____

2. What is the freezing point of water in ^{o}C?

   _____

3. The boiling point of copper is 2600 ^{o}C, what is the boiling point of copper in K?

   _____

   _____

Check your performance against the given solutions at the end of the section. Continue if you are satisfied with your ability to answer the questions. If not, review the above content and try the activity again.

Activity 4

The labels on two gas cylinders were accidentally removed. A chemist conducted some tests and determined the following:

Activity

X melts at -219 °C and boils at -183 °C

Gas Y melts at -210 °C and boils at -196 °C

Use the table below to identify gases X and Y.

Table 1: Boiling Points of Some Common Gases

Substance	Boiling point/ °C	Melting point/ °C
Methane	- 161.6	-182.5
Oxygen	-183	-219
Nitrogen	-196	-210

Adapted from Lewis & Waller (1986, p.9)

Gas X is: _____

Gas Y is: _____

How to Use a Thermometer

When you measure the temperature of a liquid, make sure that the

be measuring the temperature of the beaker not that of the liquid. Figure 8 shows the correct way of measuring the temperature of a liquid in the laboratory.

Activity 5

Activity

1. Molise wants to measure the temperature of a liquid. He uses the apparatus shown in Figure 7. Notice that the thermometer is touching the bottom of the beaker. He finds the temperature to be 92 °C.

Figure 7: Incorrect measurement of temperature. Photo by Molise Nhlapo at the Lesotho College of Education Chemistry Laboratory, 2010.

2. Palesa measured the temperature of the same liquid using the apparatus as shown in Figure 9 below. Notice that the bulb of the thermometer is not touching the bottom of the beaker, she reads 61.5 ^{o}C.

Figure 6: Correct way of measuring temperature of liquids. Photo by Molise Nhlapo at the Lesotho College of Education Chemistry Laboratory, 2010.

3. What is the correct temperature of the liquid?

_____
_____
_____
_____

4. What is the cause of the difference in temperatures?

_____
_____
_____
_____

After completing the questions, compare your answers to the correct answers at the end of the section. Take the time needed to understand each answer before continuing.

Types of Thermometers

Laboratory thermometer

Figure 9: Laboratory thermometer accessed from Wikimedia Creative Commons, 2010.

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This is the thermometer we use to measure temperature of substances in the laboratory. It has marks on the tube called graduations. These are the marks that show temperature. Graduations for laboratory thermometers usually go from -10 ^{o}C to 110^{o}C.

Clinical Thermometer

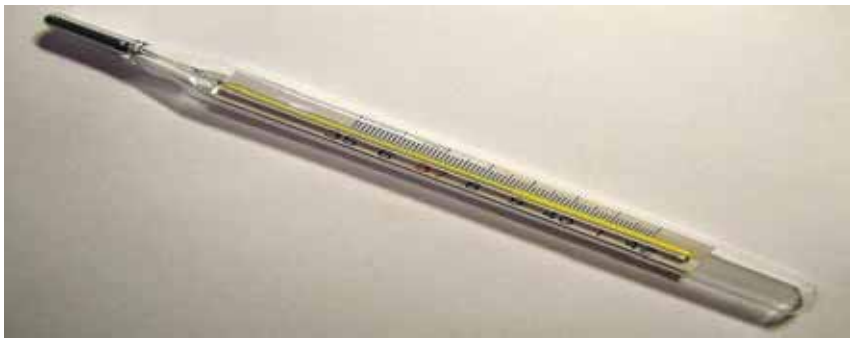

Figure 7: Clinical thermometer accessed from Wikimedia Creative Commons, 2010.

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The clinical thermometer is a thermometer used to measure body temperature. It is used by doctors and nurses to check if a person is healthy or sick. Clinical thermometer measures temperatures between 35 ^{o}C to 42 ^{o}C.

A clinical thermometer has a curved tube above the bulb called a constriction. The constriction helps the liquid in the tube stay in position when the instrument is removed from the body. The body temperature of a healthy person is 37 ^{o}C. Anything above or below that temperature means that the person is not well.

Reflection

Can you think of other ways that we use thermometers in our day-to-day life?

Mass

At the end of this topic you should be able to:

- *name* the apparatus used to measure mass.
- *explain* how to accurately measure mass.

Time

There are 4 pages on the topic of mass. You should spend approximately 20 minutes on this topic.

Case Study

Read the following story and answer the question that follows:

Case study

Chief Namo of Belo village had to settle a case between two women: 'Mathato and 'Mazime. 'Mazim borrowed maize powder from 'Mathato. When she returned the powder, 'Mathato refused to take it claiming that 'Mazime did not compress the powder and was returning it flat in the basin while she had given 'Mazime the compressed and heaped powder. 'Mathato believed she had given 'Mazime more powder than she was returning.

If you were chief Namo, what would you advise the women to do next time they exchange items like this?

_____
_____
_____
_____
_____

Compare your answer to the one at the end of the section.

We often need to know how heavy an object is. Objects are made of different substances. The amount of the substance in an object is called mass. All things have a mass. We measure mass with scales and balances.

Examples of instruments used to measure mass are bathroom scales, electronic balances and triple beam balances (See Figures 11, 12 and 13). Bathroom scales are usually used at home and in clinics to measure the mass of people. We use electronic balances or triple beam balances to

measure the mass of chemicals used in school laboratories. We need to know the exact mass of quantities used. The most accurate balance used in school laboratories is electronic balance.

Figure 8: Mechanical bathroom scale accessed from Creative Commons, 2010.

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Figure 9: Electronic balance accessed from Wikimedia Creative Commons, 2010.

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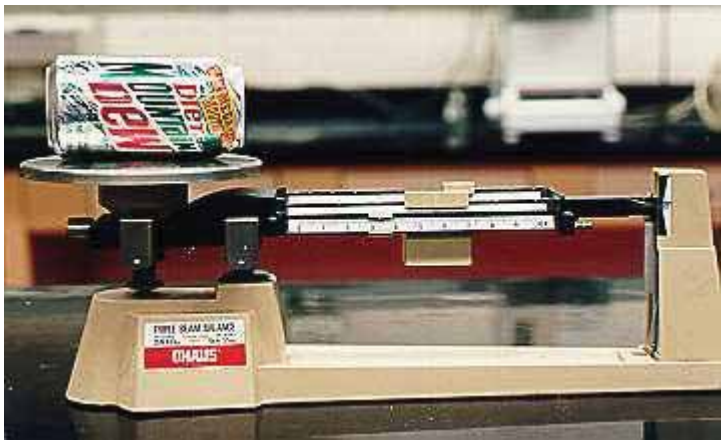

Figure 10: Triple beam balance accessed from Wikimedia Creative Commons, 2010.

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Units of Mass

The following table gives some units of mass.

Activity

Unit	Abbreviation	Value in kilograms
Kilogram	kg	1kg
Gram	g	0.001kg
Milligram	mg	0.000001kg

Grams are the most common units of mass used. But if something is heavier, a kilogram is used and if it is very light, we use milligram.

Activity 6

Which is most appropriate unit for measuring mass for each of the following objects?

A bean: _____

Your body: _____

A feather: _____

A box of chalk: _____

Compare your answers with those at the end of the section. Review the related content for any question that you missed.

Volume

Volume is the amount of space filled by something. We usually use this term when working with liquids and gases. This is because sometimes solids do not fill all the space.

To measure volume we use different instruments. At home we estimate the volume of water and milk using cups or other containers. In chemistry laboratories we use specialized equipment, such as measuring cylinders.

At the end of this topic you should be able to:

- *name* the apparatus used to measure volume,
- *explain* how to accurately measure volume.

Time

There are 13 pages on the topic of mass. You should spend approximately 2 hours on this topic.

Measuring Cylinder

Measuring cylinders (also called graduated cylinders) are one of the various instruments used in the science laboratory to measure the volume of liquids.

Figure 11: Measuring cylinder accessed from Wikimedia Creative Commons, 2010.

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How to Use the Measuring Cylinder

When you use an instrument, you should be able to read the information on it accurately. If you do not know how to get information from the instrument, you will get incorrect results. Let us look at how this instrument is used.

Follow these steps to measure using the measuring cylinder:

1. Put the measuring cylinder on a flat surface.
2. Pour an unknown amount of the liquid in the measuring cylinder.
3. Readings on graduated cylinders need to be taken at eye level from the bottom of a meniscus, as shown in Figure 17. When the meniscus appears between two of the markings on the scale, estimate its value.

If your eye level is below or above the meniscus, as shown in Figures 15 and 16, you would have slightly different values than when your eyes are at the level of the meniscus. Why would the values be different?

_____

_____

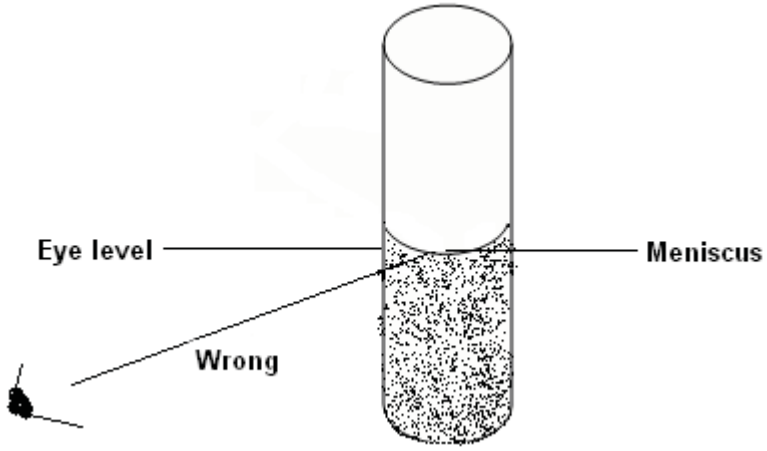

Figure 12: Reading the measuring cylinder from below the meniscus accessed from Wikimedia Creative Commons, 2010.

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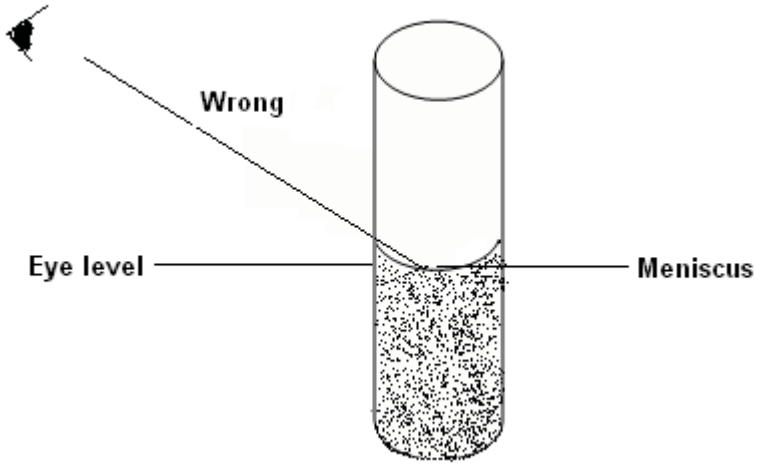

Figure 13: Reading the measuring cylinder from above the meniscus accessed from Wikimedia Creative Commons, 2010.

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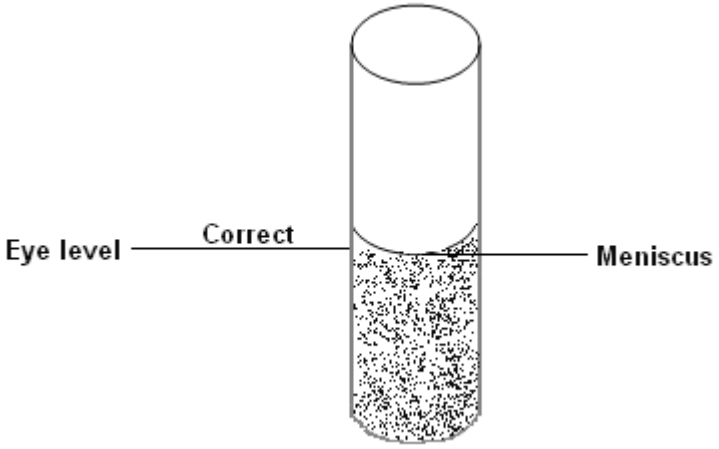

Figure 14: Shows how to take a correct reading from a measuring cylinder accessed from Wikimedia Creative Commons, 2010.

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Have you noticed when you climb into a bathtub full of water, the water level rises? When a solid is put into the water, it displaces the water (it takes the place of water). We can use this knowledge to find the volume of a solid.

Activity 7

Activity

Problem: Kuena and Shobi are asked to find the volume of a block before it reacts with an acid to produce gas.

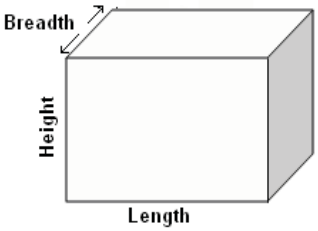

Figure 15: A metal block accessed from Wikimedia Creative Commons, 2010.

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- Shobi measured the length, breadth and height of the block. He then used the formula for the calculation of volume to find the volume of the metal block.
- Kuena filled the measuring cylinder to 200 ml mark with water. She then placed a block into the cylinder as shown in figures 19 and 20. She then subtracted the first volume from the second and got the answer.

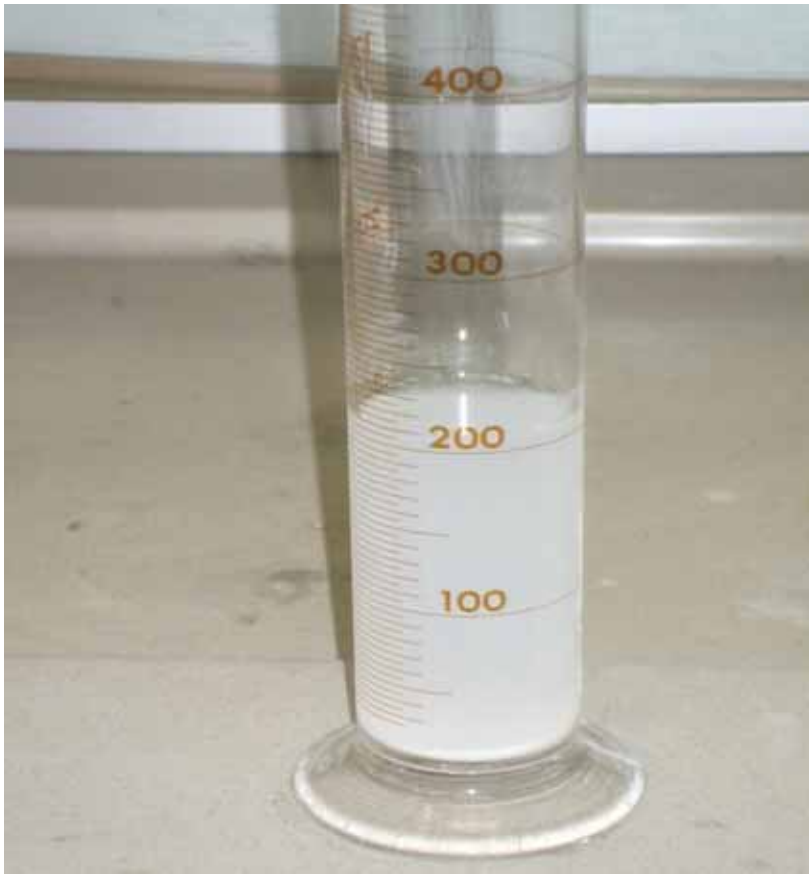

Figure 16: Measuring cylinder with water. Photo taken by Molise Nhlapo at Lesotho College of Education Chemistry Laboratory, 2010.

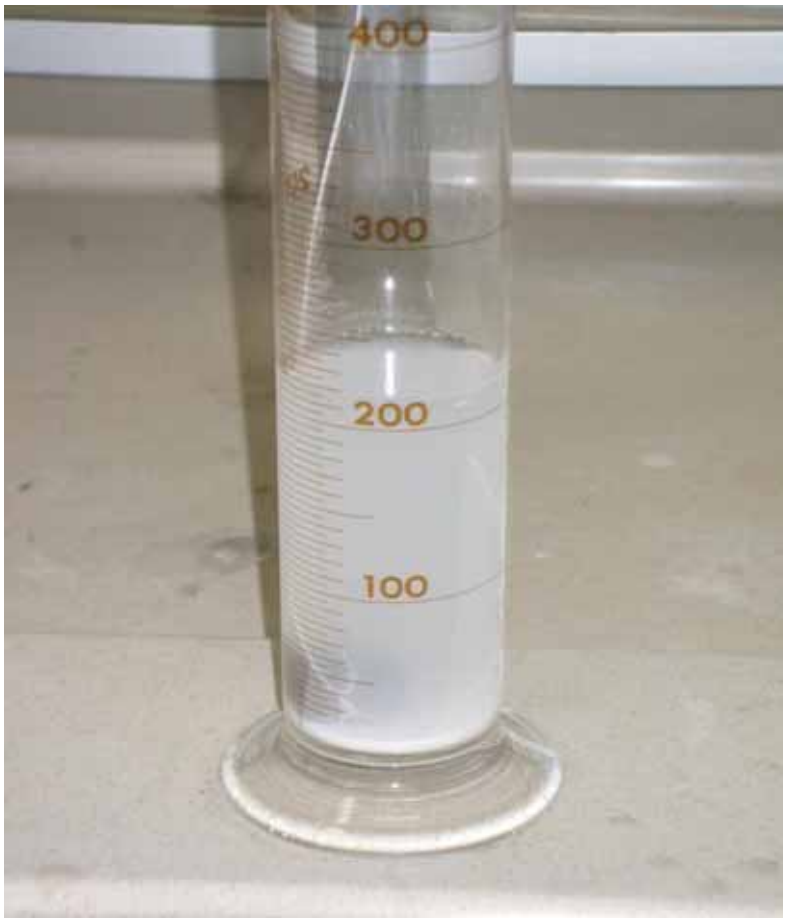

Figure 17: Water and a block in measuring cylinder. Photo taken by Molise Nhlapo at Lesotho College of Education Chemistry Laboratory, 2010.

1. Do you think the answers from the two activities will be the same or different? Why?

_____
_____
_____

2. Which method do you think would work on irregular solids like stone? Why?

_____
_____

Compare your answers with those at the end of the section. Continue on once you understand the explanations.

Pipette

A pipette is another instrument used for measuring volume. It is used for measuring specific quantity of a liquid. Pipettes come in different sizes. Figure 21 shows a pipette that can hold and measure exactly 5 ml.

Figure 18: Pipette, Photo taken by Molise Nhlapo at Lesotho College of Education Chemistry Laboratory, 2010.

Burette

A burette is another instrument used to measure volume. It measures from the top since the liquid goes out from the bottom. Figure 22 shows a diagram of a burette.

Figure 19: Burette. Photo taken by Molise Nhlapo at the Lesotho College of Education Chemistry Laboratory, 2010.

A liquid to be measured is poured into the top and once the required amount is poured, the first reading is taken. Refer to Figure 23. Burettes are read in the same way as a measuring cylinder: by taking an eye-level reading of the bottom of the meniscus.

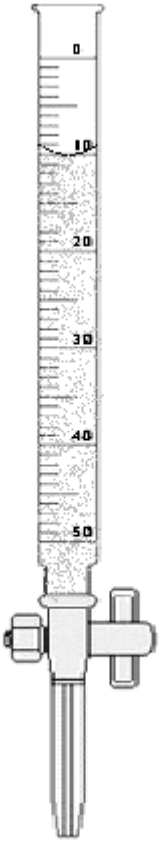

Figure 20: Burette showing the reading of 10 ml accessed from Wikimedia Creative Commons, 2010.

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To measure the sample, the tap (or stopcock) located towards the bottom of the burette is opened to let the liquid out. The tap can control the rate and amount of liquid dispensed. You can make it go out in drops and close the tap at any point. When the required amount is dispensed, the second reading is taken as shown in Figure 24.

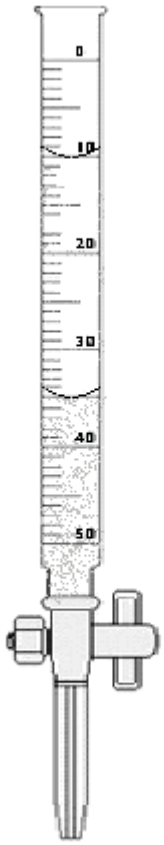

Figure 21: Burette showing reading of 35 ml accessed from Wikimedia Creative Commons, 2010.

Note it!

The difference between the starting and the final reading is the volume of the liquid.

Units of Volume

The table below shows units of volume:

Unit	Abbreviation	Dimensions
Cubic meter	m^3	1m x 1m x 1m
Cubic decimeter	dm^3	1dm x 1dm x 1dm
Cubic centimeter	cm^3	1cm x 1cm x 1cm
Litre	l	1dm x 1dm x 1dm
Millilitre	ml	1cm x 1cm x 1cm

The SI unit of volume is m^3.

1 cm^3 is equal to 1 ml. This is the common unit of volume used.

Activity 8

Activity

Study the following recipe and answer the questions that follow:

Recipe for scones

Ingredients

- *1 Kg of self-rising flour*
- *250g of rama*
- *20g of sugar*
- *1g of salt*
- *1 litre of milk*
- *3 eggs*
- *10ml of vanilla essence.*
- *15g of orange peel.*

Method

1. *Mix sugar with rama well*
2. *Add the salt*
3. *Beat the eggs and add to mixture*
4. *Add vanilla and orange peel to mixture*
5. *Add self-rising flour to mixture*
6. *Add milk and mix well to make a smooth dough*
7. *Roll out the dough and cut into desired shape*
8. *Place the dough into muffin pans*
9. *Bake for 15 – 20 minutes at 250 ^{o}C.*

Questions:

(a) Which laboratory instrument can you use to accurately measure: 1 litre of milk?

_____

(b) Which laboratory instrument can you use to accurately measure: 10 ml of vanilla essence?

_____

(c) Which laboratory instrument can you use to accurately measure: the flour, rama, sugar, salt, and orange peel?

_____

Compare your answers with those at the end of the section. Be sure that you understand each answer before continuing. If you have any misunderstandings, review this content and work through the activity again.

Note it!

Key Points to Remember:

The key points to remember in this subunit on measurement are:

1. Time is measured using clocks (or watches).
2. The SI unit for time is the second (s). Minutes and hours are larger units which are also used, however, chemists use the second to measure rate of chemical reaction.
3. For chemistry experiments, a stopwatch (or stop clock) is the appropriate instrument to use.
4. Temperature is measured using instruments called thermometers.
5. The SI unit for temperature is the kelvin (K). However, the commonly used unit is degrees centigrade or degrees celcius (^{o}C)
6. Body temperature is measured using a thermometer called a clinical thermometer.
7. Pure substances have unique melting and boiling points (also called fixed points or fixed temperatures). If a substance is not pure, its fixed points will change (from the known values of a pure substance).
8. Fixed points are used to check the purity of substances.
9. To measure accurately, the bulb of the thermometer must be in contact with the substance being measured, and it must not be in contact with the container as this will cause an inaccurate reading.
10. Mass is measured with scales and balances.
11. The SI unit for mass is the Kilogram (Kg). The other commonly used units are grammes (g) and milligrammes (mg).
12. There are 1000 mg in a gram and 1000 grams in a Kg.
13. Volume is measured with a measuring cylinder for liquids. Other instruments include a pipette and a burette (for very accurate volume measurements of liquids).
14. The SI unit for volume is the cubic meter (m^3). The common units in use are cubic centimetres (cm^3), millilitres (ml) and litres (l).
15. There are 1 cm^3 = 1 ml and there are 1000 ml in a L.

You have completed the measurement section. The ideas in this section form the foundation of all of the material you are going to see later in your learning, so make sure that you understand the concepts. When you are ready to proceed, go to the next section: separating mixtures. You will start using some of the ideas you learned in this section, such as fixed points.

Answers to Activities on Measurement

Activity 1

We know that 60 seconds = 1 minute

60 minutes = 1 hour

For us to be able to subtract 30 seconds from 23 we need to borrow (change 1 minute to 60 seconds). So,

11:35:23 becomes: 11:34:83

Similarly, when we want to subtract the minutes, it is not possible to take away 58 minutes from 34 minutes. So, we have to borrow (change 1 hour to 60 minutes). So,

11:34:83 becomes: 10:94:83

Then, now we can subtract:

10:94:83

-10:58:30

36:53

Therefore, the reaction took 36 minutes and 53 seconds.

Activity 2

1. ***60 seconds in one minute***
2. ***60 minutes in one hour***
3. ***3600 seconds in one hour (60 × 60)***
4. ***We note that 1 day = 24 hours***

1 hour = 60 minutes

Therefore, 24 hours x 60 minutes / hour = 1440 minutes

That is, 1 day = 1440 minutes

Activity 3

a) ***Rock salt forces the ice surrounding the can of ice cream mix to melt. The "brine solution" or liquid that forms in the wooden bucket absorbs heat from the mix and gradually lowers the temperature of the mix until it begins to freeze.***

b) ***$0\,^{o}C$***

c) ***Boiling point of copper in Kelvin = $2600 - 273.15^{o} = 2326.85$***

Activity 4

Gas X is oxygen and gas Y is nitrogen

Activity 5

The correct temperature is Palesa's, 61.5 ^{o}C

Molise is placing the thermometer on the heated part of the beaker. The thermometer is measuring the temperature of the bottom part of the beaker not the water in the beaker.

Case study

The best way to prevent the argument over items exchanged, people should use appropriate instruments to measure the mass of the items they exchange.

Activity 6

Appropriate unit for:

- a bean = grams

- your body = kilograms

- a feather = milligrams

- a box of chalk = grams

Activity 7

The answers from the two activities will be the same because the volume of the block is the same. It was just measured using different but valid methods. However, using the formula of multiplying the length by the width by the breadth will be slightly more accurate.

Kuena's method with water displacement in a graduated cylinder is most appropriate for irregular solids. Measurements of dimensions would not be required or necessarily possible.

Activity 8

(a) The milk could be measured with a graduated cylinder. Typical burettes and pipettes are too small to measure 1 litre.

(b) The vanilla essence could be measured with a burette or pipette. It could also be measured accurately with a small graduated cylinder or beaker.

(c) The masses could be measured with an electronic or triple beam balance. For 10ml of vanilla essence we can use a burette, pipette, also a small measuring cylinder or a small beaker.

Section 1-2: Separation of Mixtures

Introduction

How are the people in the image on the right able to collect salt from the sea to sell at markets? We know that sea water has salt dissolved in it, but what is the chemical process involved in separating the salt from the water?

Sea salt farmers in Thailand accessed from Wikimedia Creative Commons, 2010.

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Sometimes we need pure substances in chemistry. Most of the chemicals in nature are combined with others. Therefore, there is a need to separate mixtures so that we can find the properties of pure substances. You have learned about some important laboratory techniques in section 1-1. In this section we are going to discuss another laboratory technique: chemical separation.

At the end of section 1-2, you should be able to:

- *describe* how to purify a given mixture by use of a suitable solvent, filtration, crystallisation and distillation.
- *draw* how apparatus should be arranged for a given experiment.
- *Identify* cations, anions and gases based on experimental results.
- *identify* the purity of substances by their fixed points and chromatography methods.
- *Interpret* chromatographs.

Time

There are 20 pages on the topic of separation of mixtures. You should spend approximately 4-5 hours on this topic.

Types of Mixtures

You have learned about different mixtures at the junior level. The following list of mixtures shows some of those you have learned: Solution, solid-solid mixture, suspension, miscible liquids, immiscible liquids and emulsion.

Refer to the terminology section for their descriptions.

Activity

Filtration:

Activity 1

Khauhelo's grandmother likes to drink herbal medicine once a month. The problem is that, she does not want to drink any leaves or small solid particles with her medicine. What should Khauhelo do to give her grandmother a medicine without any solid particles?

_____

_____

_____

Check answer at the end of the section.

Khauhelo can just pick out the leaves, but the small solid particles will remain. The best way is to filter the mixture.

Filtration is used to separate a solid suspension from a liquid. The solid should be insoluble with the liquid in order for the method to work. It is like separating tea leaves from tea using a sieve. Consider the following apparatus in Figure 25:

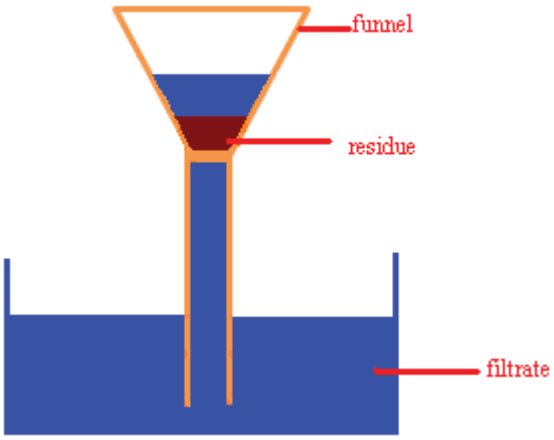

Figure 22: Filtration apparatus accessed from Wikipedia Creative Commons, 2010.

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The filter paper acts like a fine sieve that only allows the liquid to pass through. The undissolved solid remains on the filter paper. These solid particles are called **residue** and the liquid that passes through is called **filtrate.**

Crystallization

Activity

Activity 2

In this activity we will demonstrate crystallization using salt, a coffee mug, a saucer, a funnel, cloth, water, a heat source and a teaspoon.

1. Boil a small amount of water
2. Half fill the coffee mug with the boiled water.
3. Add a teaspoon full of salt into the water and stir the mixture.
4. Gradually add more salt until no more dissolves
5. Filter the solution so that the undissolved salt remains in the mug.
6. Pour about 5ml of the filtrate into a saucer.
7. Put the saucer in safe place for one day.

(a) What do you observe in the saucer?

_____
_____

(b) Are the crystals in the saucer similar in size and shape to those of the salt you were adding to water? If not how are they different?

_____
_____
_____

Compare your answers with those at the end of the section.

As the water evaporates from the saucer, it leaves salt crystals behind. The salt crystals are bigger than the particles of table salt and have regular shapes.

At primary level you learned about a method of separation called **evaporation**. In evaporation, a solution is heated so that water evaporates leaving a solid behind. In the activity above, evaporation occurs naturally and in this case the solid left forms interesting shapes. These solids are called crystals and the process is called **crystallization**.

Distillation:

Simple distillation

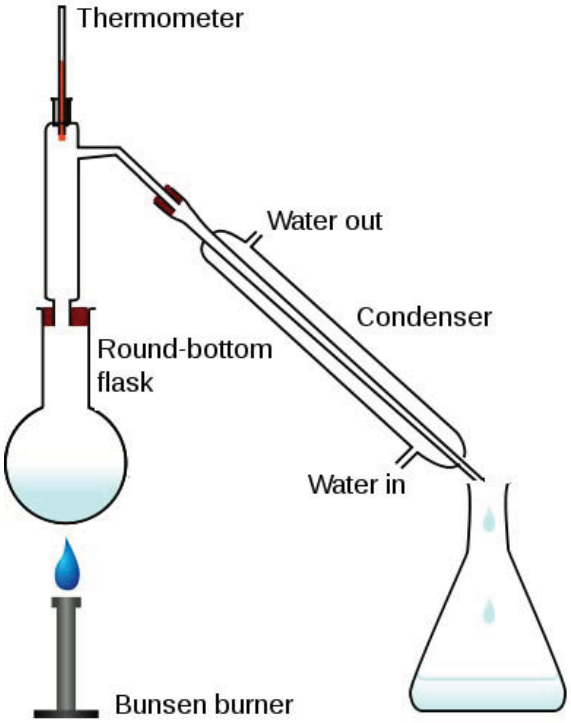

Figure 23: Simple distillation apparatus accessed from Wikimedia Creative Commons, 2010.

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If you have access to the internet, please go to:
http://youtu.be/gHKp5vF_VoE for an animation of simple distillation.

Activity 3

Activity

Palesa was given the task of separating water and salt from a solution made of salt and water. She did it using equipment set up as shown in figure 26. Analyse the setup for her procedure below.

a) How does this method of separation work?

_____
_____
_____
_____

Compare your answer with the one given at the end of the section. Before continuing, be sure you understand how this method of separation works.

This method is used to separate a solution such as water and salt. In simple distillation, when water boils, it evaporates and leaves salt behind. When passing through the condenser, the water vapour condenses into a liquid form.

Activity 4

Consider a mixture of water and ethanol:

Activity

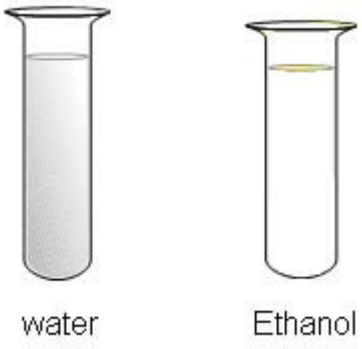

Figure 24: Water and ethanol accessed from Wikimedia Creative Commons, 2001.

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Ethanol boils at 78.5 ºC and water at 100 ºC:

1. Will water or ethanol boil first when the mixture is heated?

_____
_____
_____

2. Is simple distillation used to separate water and ethanol? Why or why not?

_____
_____
_____

Compare your answers with those given at the end of the section. Note that the key points to the above activity are highlighted in the next paragraph.

In Activity 4, the key points are:

1. The substance with the lower boiling point boils first. Ethanol has a lower boiling point so ethanol will boil first.
2. As the mixture of ethanol and water is heated, both substances will start to evaporate before they boil. Therefore, the vapour will

contain both ethanol and water like the mixture (with more ethanol vapour). This means simple distillation will not separate the two substances. This is mainly because the boiling points are too close to each other for simple distillation to work. For simple distillation to work, the boiling points have to be far apart.

Fractional Distillation

To separate this mixture of water and alcohol, we use the fractional distillation method. Look at the picture below:

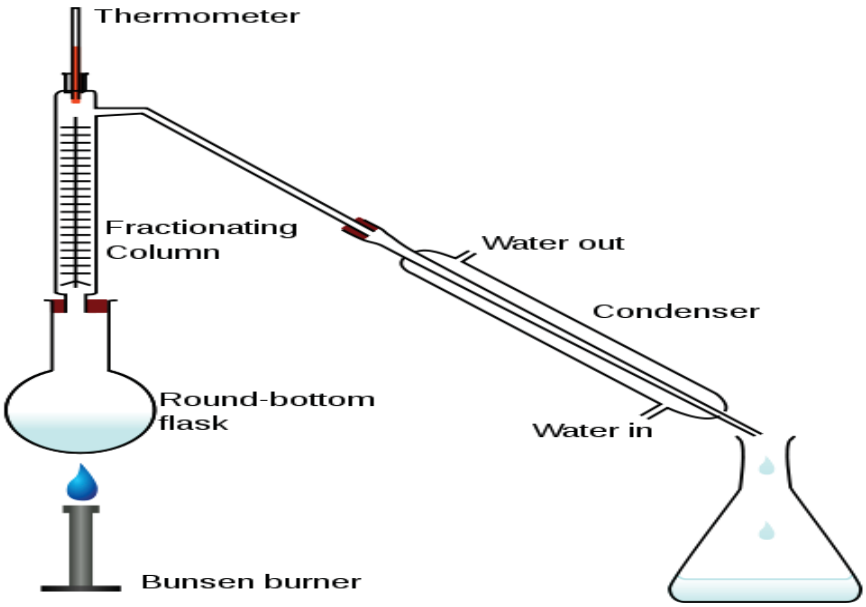

Figure 25: Fractional distillation apparatus accessed from Wikimedia Creative Commons, 2010.

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The difference between simple distillation and fractional distillation is that a fractionating column is placed between the boiling flask and the condenser.

The fractionating column is usually filled with glass or plastic beads. These beads improve the separation between the liquids being distilled. The glass beads in the fractionating column provide more surface area on which the vapour of the liquid with a higher boiling point can condense.

What happens during fractional distillation?

- The mixture is heated up to the temperature of the lower boiling point liquid (ethanol, which boils at 78.5 ^{o}C).
- The vapours from the boiling mixture will consist mainly of the vapour of the lower boiling point liquid (ethanol) but there will still be a bit of the higher boiling point liquid vapour (water) as well. However, the vapour of the higher boiling point liquid will condense on the beads and run back into the mixture. The vapour of the liquid with the lower boiling point (ethanol, which boils at

78.5 °C) will go up the column and condense at the condenser where it will be collected in collecting container at the lower end of the condenser.

- This will occur until all the liquid with the lower boiling point has evaporated from the mixture.
- Then, the temperature will rise to the boiling point of the liquid with the higher boiling point (water, which is 100 °C).
- Now, the liquid with a higher boiling point (water) will start to evaporate to the top of the fractionating column and condense at the condenser, where the liquid will be collected in another collecting container. This gives a better separation between the liquids than simple distillation.

In your own words, summarize the differences between the setup of fractional distillation and simple distillation. Note in particular how fixed points are used.

_____

_____

If you have access to the internet, please go to: http://youtu.be/gHKp5vF_VoE for an animation of fractional distillation.

Fractional Distillation of Crude Oil

Distillation is the most common form of separation used in petroleum refineries; e.g. crude oil is separated by fractional distillation into different parts called fractions. The different parts we get from crude oil include petrol, paraffin, diesel, jet oil and lubrication oil.

Figure 29 summarises the process and shows what each fraction is used for.

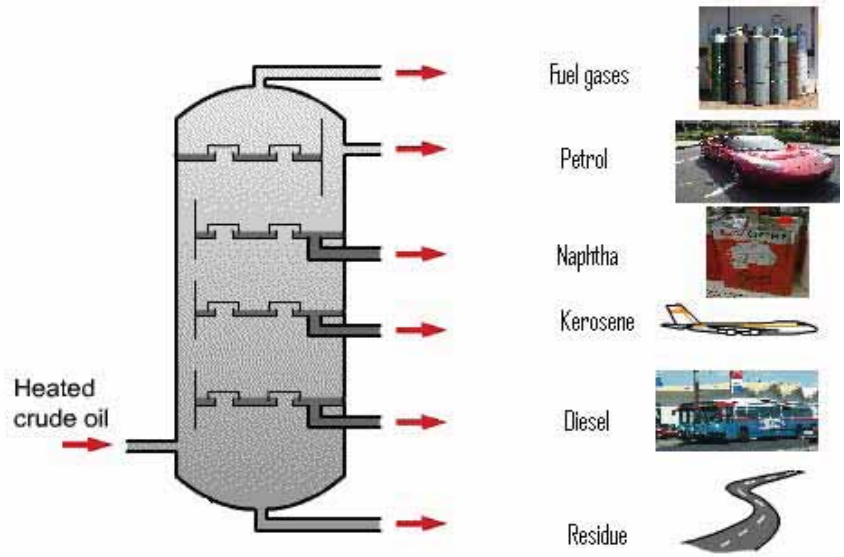

Figure 29: Fractional distillation of crude oil accessed from Wikimedia Creative Commons, 2010.

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Reflect

Crude oil is a finite resource meaning that it will one day run out. Considering the world's dependence on oil and oil products, what are the consequences of running out of oil? What are the alternatives? Is running out of oil necessarily a bad thing? Discuss with your friends! If you have access to the internet, go to: http://youtu.be/gHKp5vF_VoE

Paper Chromatography

Refuoe wanted to paint her house and she had difficulty choosing a paint colour. She finally decides that she is going to make her own colour by mixing different colours. She mixed white paint with red paint.

Which colour do you think she would get by mixing red and white paint?

_____

_____

Compare your answer to the explanation below. Take time to understand how the method works and where it can be used.

She might get a pink colour from a red and white paint. In this case pink is a mixture of red and white paint. In chemistry, we also identify some solutes with the colours of the solutes separated from their mixtures. We call this method chromatography.

Figure 30 below shows how chromatography works.

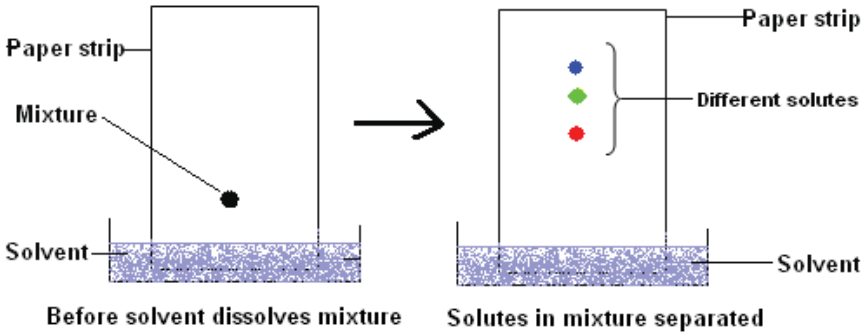

Figure 26: Paper chromatography. Hand drawn by graphic designer at LDTC.

A small dot of ink on a filter paper contains ink with different colours. The solvent in the container moves along the paper stripe and meets the ink (mixture of colours) and starts to travel with them. Different components in the mixture travel different distances.

Activity 5

Activity

Mofeli was asked to identify the substances of mixture X. He was told that mixture X could contain substances A, B, C, D and/or E and that all substances dissolve in benzene. He performed an experiment by placing mixture X and the substances on chromatography paper in a solution of benzene. Figure 31 shows the starting positions while Figure 32 shows the results.

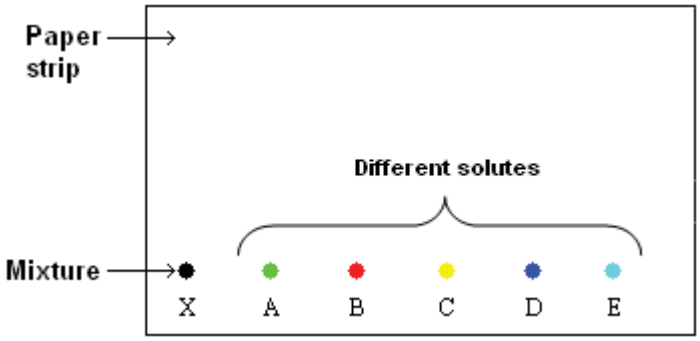

Figure 27: Starting positions of mixture x and solutes. Hand drawn by graphic designer at LDTC.

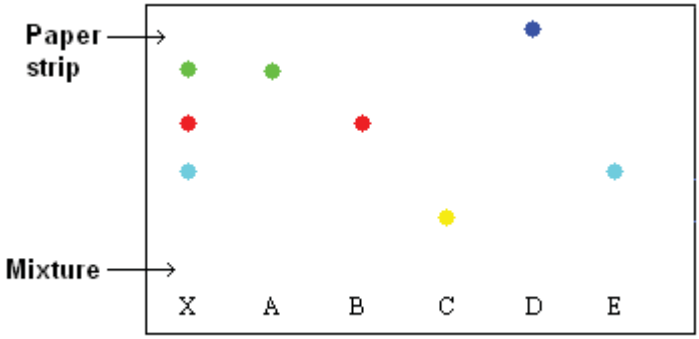

Figure 28: Dissolved solutes travel different distances. *Hand drawn by graphic designer at LDTC.*

Question:

Which substances are in mixture X?

_____

_____

Compare your answers to those at the end of the section. As needed, review the material again slowly. To answer the question you should look at the chromatograms and decide based on what you see. If your decision is based on your observations, you are working like a scientist.

A substance will travel the same distance whether in a mixture or not. For example, substance A travels to the same point on the chromatograph whether alone or in a mixture. For substances D and E, we know that they are not in the mixture because there is no comparable colour that travelled the same distance in the mixture.

Using a Suitable Solvent

Activity

Activity 6

Nkele has accidentally spilled sugar on the ground. When picking it up, the sugar is now mixed with sand and she needs to use the sugar. Suggest what Nkele should do to separate sand from sugar.

_____
_____
_____
_____
_____
_____

Compare your answer to the one at the end of the section. Make sure you understand the explanation before continuing.

This method is called the suitable solvent method. To separate a mixture of salt and sugar, the suitable solvent is alcohol. It dissolves sugar but not salt.

Identification of Anions, Cations and Gases

An atom has electrons moving around the nucleus. Electrons are negatively charged. When electrons are lost from an atom, the atom becomes positively charged and it is now called a cation. Some atoms gain electrons and they become negatively charged. A negatively charged atom is called an anion. This section deals with tests for anions and cations. We will also discuss the tests for some gases.

Study Skills

Sometimes it is difficult remembering the difference between anions and cations. To remember them, simply arrange them alphabetically.

anion - negative ion
cation - positive ion

Anion comes before cation and negative comes before positive, then pair them up.

Test for Anions

Activity 7

Activity

Look at the equation below:

ACID + CARBONATE ⟶ SALT + WATER + CARBON DIOXIDE

1. Identify anions in the equation._____
2. Identify cations in the equation._____
3. How would you test for this gas?_____
4. Give three examples of carbonates._____

   _____

Compare your answers to those at the end of the section. Ensure that you remember the test for carbonates.

The equation in the activity above is a general equation that shows that every time a carbonate reacts with an acid, carbon dioxide is formed. Examples of carbonates include calcium carbonate ($CaCO_3$), copper carbonate ($CuCO_3$) and zinc carbonate ($ZnCO_3$). The common group in these compounds is CO_3^{2-}. This is a carbonate group. It is an anion. When a carbonate reacts with an acid it produces carbon dioxide gas.

Some substances (such as carbonates) react with an acid to produce a gas. We can test the presence of the carbonate by passing the produced gas through limewater and if it turns limewater milky (test for carbon dioxide), then this indicates the presence of the carbonate.

Therefore, to test for anions called carbonates we should:

(a) Add acid to a substance

(b) Pass the gas produced through limewater

(c) If the limewater turns milky, then the substance contains a carbonate anion.

The table below gives other tests for specific anions.

Name	Formula	Test	Result
Chloride	Cl^-	add nitric acid then add silver nitrate	Silver chloride (AgCl) formed – white
Bromide	Br^-	add nitric acid then add silver nitrate	Silver bromide (AgBr) – cream white
Iodide	I^-	add nitric acid then add silver nitrate	Silver iodide (AgI) formed – yellow

Sulphate	SO_4^{2-}	add HCl then add barium chloride	Barium sulphate ($BaSO_4$) – white
Nitrate	NO_3^-	add sodium hydroxide, warm the mixture, then add aluminium powder and test gas produced	Ammonia gas formed, the characteristic smell of ammonia (pungent).

Test for Cations

1. Test for Cations in Solution

Ionic compounds dissolve in water to form ions. We say they ionise. The positively charged ions, cations, are mostly metal ions. Examples of cations that are not metals ions are hydrogen (H^+) and ammonium (NH_4^+) ions.

To test for ammonium ion:

1. We add sodium hydroxide to the sample.
2. If the sample has ammonium ions, ammonia gas will be produced.
3. To test for ammonia gas, a damp red litmus paper is passed over the gas. If the gas is ammonia, the litmus paper will turn blue.

The tests for other cations are summarised in the table below:

Cation	Formula	Test	Results
Calcium	Ca^{2+}	Add sodium hydroxide in drops	***White substance formed***
Magnesium	Mg^{2+}	Add sodium hydroxide in drops	***White substance formed***
Aluminium	Al^{3+}	Add sodium hydroxide in drops	White substance formed then disappears
Copper(II)	Cu^{2+}	Add sodium hydroxide in drops	Light blue substance formed
Iron (II)	Fe^{2+}	Add sodium hydroxide in drops	Green substance formed then turns to red brown colour.
Iron (III)	Fe^{3+}	Add sodium hydroxide in drops	Red brown substance formed.

Activity 8

Activity

Malara has two colourless liquids. She knows that one is water and the other is ammonium hydroxide. She wants to know which liquid is ammonium hydroxide and which one is water.

How would you advise Malara to test which solution is ammonium hydroxide?

_____

_____

_____

Compare your answer to this activity with the one at end of the section. The test which uses the characteristic smell of a substance is one of the important tests to remember when identifying ions present in solutions. Scientists use their senses during investigations. The sense of smell can be useful during investigations in science, but please note that you should not smell anything in the lab unless directed to by your instructor.

2. Test for Cations Using Flame Test

Another way to test for cations is by heating the solid compound. Different cations produce flames with different colours.

Activity 9

Activity

The flames formed by different cations are listed below.

Identify the colour of flame for each cation:

Figure 29: Lithium ion (Li^+) accessed from Wikimedia Creative Commons, 2010.

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Lithium ion's (Li^+) flame colour is_____

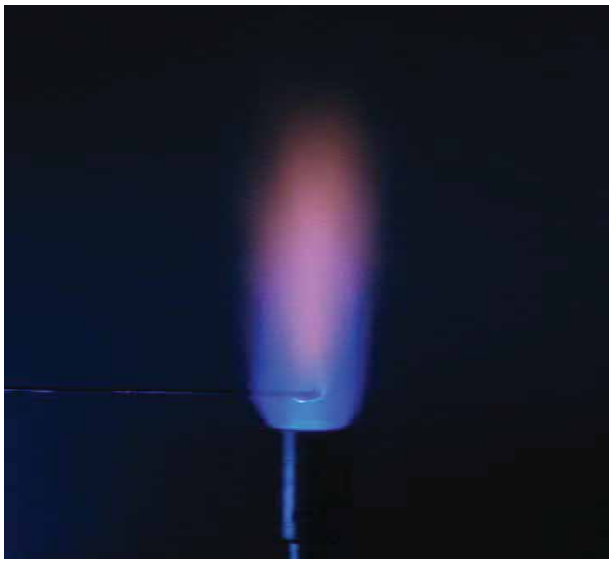

Figure 30: Sodium ion (Na^+) accessed from Wikimedia Creative Commons, 2010.

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Sodium ion's (Na^+) flame colour is_____

Figure 31: Potassium ion (K^+) accessed from Wikimedia Creative Commons, 2010.

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Potassium ion's (K^+) flame colour is_____

Figure 32: Calcium ion (Ca^{2+}) Accessed from Wikimedia Creative Commons, 2010.

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Calcium ion (Ca^{2+}) flame colour is_____

Figure 33: Barium ion (Ba^{2+}) Accessed from Wikimedia Creative Commons, 2010.

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Barium ion's (Ba^{2+}) flame colour is_____

Compare your answers with those at the end of the section. Here you are using the sense of sight to make observations. The sense of sight is also very important in science.

3. Test for Gases

a. Test for hydrogen gas

To test for hydrogen gas, we put a lighted splint near the opening of a container of hydrogen gas as shown in Figure 38.

Figure 34: Burning splint placed in hydrogen gas. Photo taken by Molise Nhlapo at Lesotho College of Education Chemistry Laboratory, 2010.

What do you think will happen to the lighted splint?

_____

_____

Compare your answer with what follows.

Figure 39 below shows what happens when a burning splint is placed in hydrogen gas.

Figure 35: Burning splint goes off. Photo taken by Molise Nhlapo at Lesotho College of Education Chemistry Laboratory.

There will be a small explosion. A "POP" sound is made.

After the "POP" sound the burning splint goes out (Figure 39 above). The hydrogen gas in the test tube reacts with the oxygen in the air. The pop sound is a small explosion as the gases react to form water vapour (steam) which does not support combustion so the burning splint goes out. The size of the explosion depends on the amount of hydrogen and oxygen present. If a large amount of hydrogen reacts with oxygen a dangerous explosion can occur. One should be careful when handling hydrogen near flames.

a. Test for Oxygen

One of the properties of oxygen is that it is used in burning or combustion of fuel (i.e. wood). We use this property to test for oxygen gas.

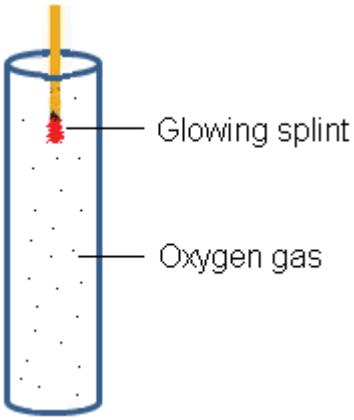

Figure 36: Glowing splint placed in oxygen gas. Hand drawn by graphic designer at LDTC.

The glowing splint produces a flame when it is placed in oxygen gas.

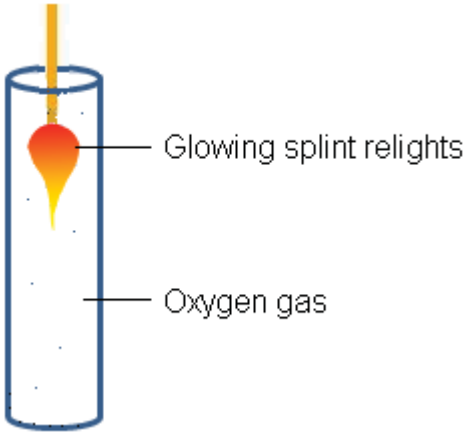

Figure 37: Oxygen relights glowing splint. Hand drawn by graphic designer at LDTC.

Oxygen supports burning. That means many substances burn in oxygen. Notice that only a few particles of oxygen remain. This is because most of the oxygen has reacted. When the oxygen in the test tube has completely reacted, the flame may go out or continue with the help of oxygen in the surrounding air. However, the flame will be smaller than when the splint was in pure oxygen.

b. Test for Carbon Dioxide Gas

One way of producing carbon dioxide is by reacting a carbonate with an acid. Figure 42 shows a set up where calcium carbonate reacts with hydrochloric acid to give calcium chloride and carbon dioxide. The carbon dioxide produced goes through the delivery tube into the test tube of lime water.

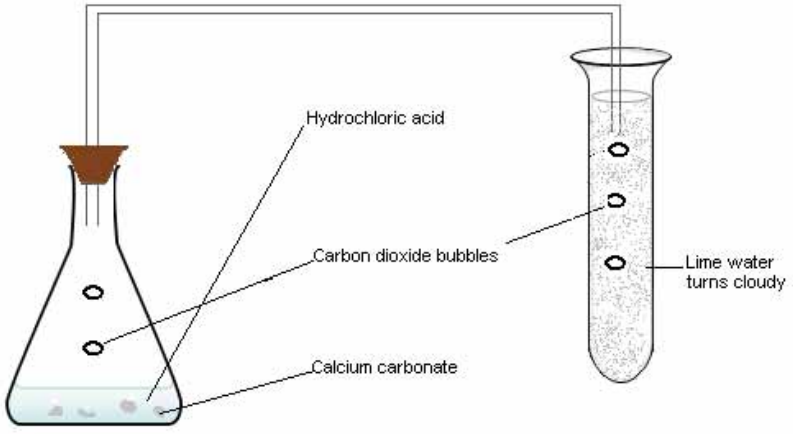

Figure 38: Set up showing a test for carbon dioxide gas accessed from Wikimedia Creative Commons, 2010.

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Calcium carbonate + hydrochloric acid ⟶ calcium chloride + carbon dioxide + water

Some of the properties of gases are similar. For example, gases such as oxygen, hydrogen and carbon dioxide are all colourless, odourless and tasteless. But gases also have unique properties such as:

- Oxygen relights a glowing splint.
- Carbon dioxide turns limewater milky.
- If hydrogen is ignited with a burning splint, the splint will go out with a "pop" sound.

Here are some more tests for gases:

Test	Gas	Results
Damp blue litmus paper is put into gas	Chlorine (Cl_2)	Blue litmus paper turns red
Damp red litmus paper put into gas	Ammonia (NH_3)	Red litmus paper turns blue
Universal indicator paper put into gas	Ammonia (NH_3)	Red universal indicator turns blue

Arrangement of Apparatus in Chemistry

Arrangement of apparatus during a chemistry experiment is very important. If the arrangement is wrong, a scientist may not get correct results. Consider the example below.

Example

Makhauta wants to test whether carbon dioxide is produced from hydrochloric acid and copper carbonate. She performs an experiment and uses the apparatus shown in Figure 43.

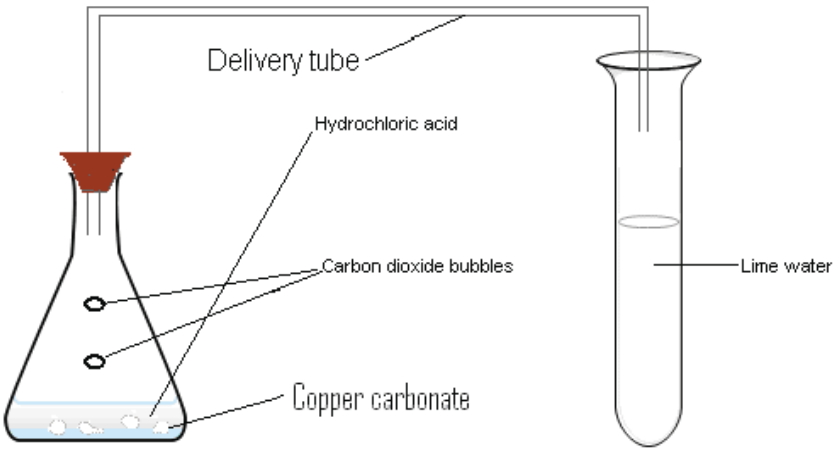

Figure *39: Apparatus for carbon dioxide test accessed from Wikimedia Creative Commons, 2001.*

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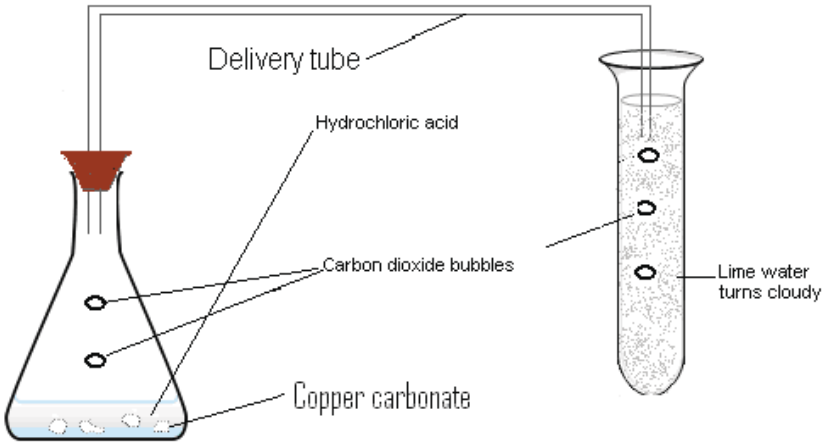
From this experiment, she finds that there is no change in the limewater after three minutes. She then concludes that carbon dioxide is not produced from the reaction of hydrochloric acid and copper carbonate.

What is wrong with the apparatus? How could you correct the mistake?_____
_____
_____

Solution

The mistake in this apparatus is that the delivery tube is not immersed into the lime water so that the gas produced would bubble through lime water. The correct arrangement is shown in Figure 44.



40: Correct arrangement of apparatus for carbon dioxide test accessed from Wikimedia Creative Commons, 2010.

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Key Points to Remember:

Note it!

The key points to remember in section 1-2 on separating mixtures are:

1. Filtration is used to separate a mixture of an insoluble solid suspended in (or settled at the bottom of) a liquid.
2. Simple distillation is used to separate a mixture of a soluble substance(s) where the mixture is forming one phase but the boiling points of the solute and the solvent are far apart enough for boiling to separate their vapours. In some countries this is used to obtain pure drinking water from the sea water (salty water).
3. Fractional distillation is used to separate a mixture of miscible liquids (completely mixing and forming one phase) with boiling points too close to each other. This is the method used to separate different fractions (parts) of crude oil (petroleum).
4. Paper cromatography is used to separate a mixture of coloured substances. Each substance moves across the paper at a different speed so the faster separate from the slow moving. Therefore, their colours will separate.
5. Suitable solvent is used to separate a mixture of solid substances where one will dissolve and the other is insoluble in the solvent chosen. Then, the mixture is filtered.
6. Sometimes in chemistry, it becomes necessary to know the composition of a sustance. Therefore, we test for

different anions, cations and gases using known properties of colour change, formation of precipitates and evolution of characteristic gases.

7. Proper apparatus arrangement in chemistry experiments is very important for reliable results.

You have now completed the section of this unit on Experimental Techniques. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Answers to Activities on Separation of Mixtures

Activity 1

Khauhelo can just pick out the leaves but the small solid particles will remain. The best way is to filter the mixture.

Activity 2

As the water evaporates from the saucer, it leaves some salt crystals behind. Crystals are bigger than salt particles and have regular shapes. Chemists have found sodium chloride crystals to be cubic.

Activity 3

When the mixture boils, water evaporates leaves sugar behind because sugar has higher boiling point than water. When water vapour passes through cold surface in the condenser, it condenses back to liquid.

Activity 4

1. ***Ethanol will boil first***
2. ***They will not be separated because their boiling points are too close to each other.***

Activity 5

There are three substances in mixture X

Mixture X contains substances A, B and C

Substances D and E are not in mixture X

Activity 6

Sugar dissolves in water while sand does not. Nkele should dissolve mixture in water and filter it. Then evaporate to get the sugar crystals.

Activity 7

1. ***Carbonate and hydroxyl***
2. ***Hydrogen ion***
3. ***Carbon dioxide***
4. ***By bubbling the gas into limewater. If the limewater turns milky or cloudy, then the gas is carbon dioxide***
5. ***Calcium carbonate, sodium carbonate, copper carbonate, zinc carbonate, magnesium carbonate.***

Activity 8

Malara should add sodium hydroxide to the solution. If a gas is formed, she should test it with a damp red litmus paper. The red litmus paper will turn blue if the gas is ammonia. This shows that the solution is ammonium hydroxide.

Activity 9

Cation	*Colour of flame*
Li^+	*Bright red*
Na^+	*Yellow*
K^+	*Lilac*
Ca^{2+}	*Brick red*
Ba^{2+}	*Apple green*

Unit Summary

Summary

The key points you learned in this unit were:

Section 1-1: Measurement:

- The right apparatus should be used to get accurate results.
- Time is measured using clocks, or watches.
- Temperature is measured with thermometers.
- Mass is measured with scales or balances.
- Volume is measured with measuring cylinders, pipettes or burettes.

Section 1-2: Separating mixtures:

There are different methods used to separate mixtures.

- We use simple distillation, chromatography, suitable solvents and fractional distillation.
- Fractional distillation is also used to separate crude oil into petrol, diesel, paraffin and other fractions.

Identification of cations, anions and gases:

- It is essential to identify chemicals in chemistry.
- Anions are identified while in solution whereas cations can be identified using either flame test or tests in solutions.
- The solutions of cations and anions produce specific colours when they are mixed with some chemicals.
- The identification of the cations and anions usually follows the typical scientific process where conclusions are made from observations from tests and experiments. The formation of coloured precipitates usually leads to detection of cations.
- Different metals also yield different colours of flames when they are put over a Bunsen burner flame.
- Gases are identified using their unique properties. Therefore, the evolution of gases is usually used to detect the anions.

You have completed the material for this unit on Experimental Techniques. You should now spend some time reviewing the content in detail. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit where you will learn about elements of the periodic table and how ions and cations are formed.

Assignment 1

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:27]

Answer all the questions that follow:

1. Which instrument would you use to measure the following quantities:

(a) The boiling point of a sugar solution. (1)

_____

(b) The time that it takes a chemical reaction between magnesium and hydrochloric acid to complete. (1)

_____

(c) 50 ml of sodium hydroxide solution for a titration process. (1)

_____

(d) 5 g of potassium permanganate. (1)

_____

2. Kuena collected water from a pond. The water has fern leaves, mud, animal urine and other soluble and insoluble substances.

a) How can Kuena separate:

(i) Leaves from water? (2)

_____

_____

(ii) Water from soluble solids? (2)

_____

_____

b) She heated the sample water and it boiled at temperature above 100 ^{o}C. What does this tell you about the purity of that pond water? (2)

_____

_____

c) She accidentally spills sugar into the sample:

(i) Describe what she should do to obtain the sugar from the sample. (2)

_____

_____

_____

_____

_____

(ii) What is this method called? (1)

_____

_____

_____

3. (a) Refuoe suspects that a solution contains one of the cations; iron (III), aluminium or calcium. How would she identify which cation is present in the solution?

(i) Fe^{3+} (2)

_____

_____

(ii) Al^{3+} (2)

_____

_____

(iii) Ca^{2+} (2)

_____

_____

(b) After recognising that calcium is present in the solution, she wanted to know what the solution is. She performed the following test:

She added hydrochloric acid and then barium chloride solution. A white precipitated was formed immediately.

(i) What is the name of the anion present in the solution? (1)

_____

_____

(ii) What is the name of the compound dissolved in this sample? (1)

_____

_____

4. Say what is wrong with the arrangement of apparatus in the following diagrams. State how the mistake could be corrected.

(a) (1)

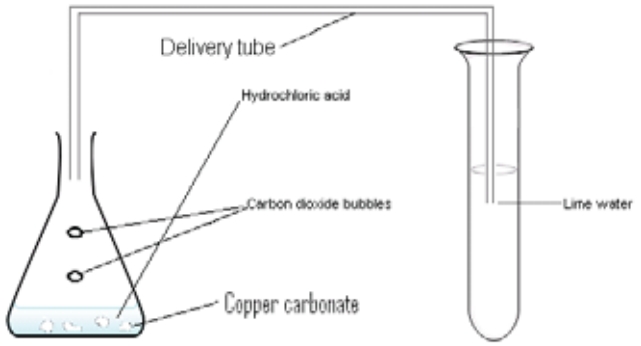

Figure 41: Test for carbon dioxide gas from Wikimedia Creative Commons, 2010.

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(b) (1)

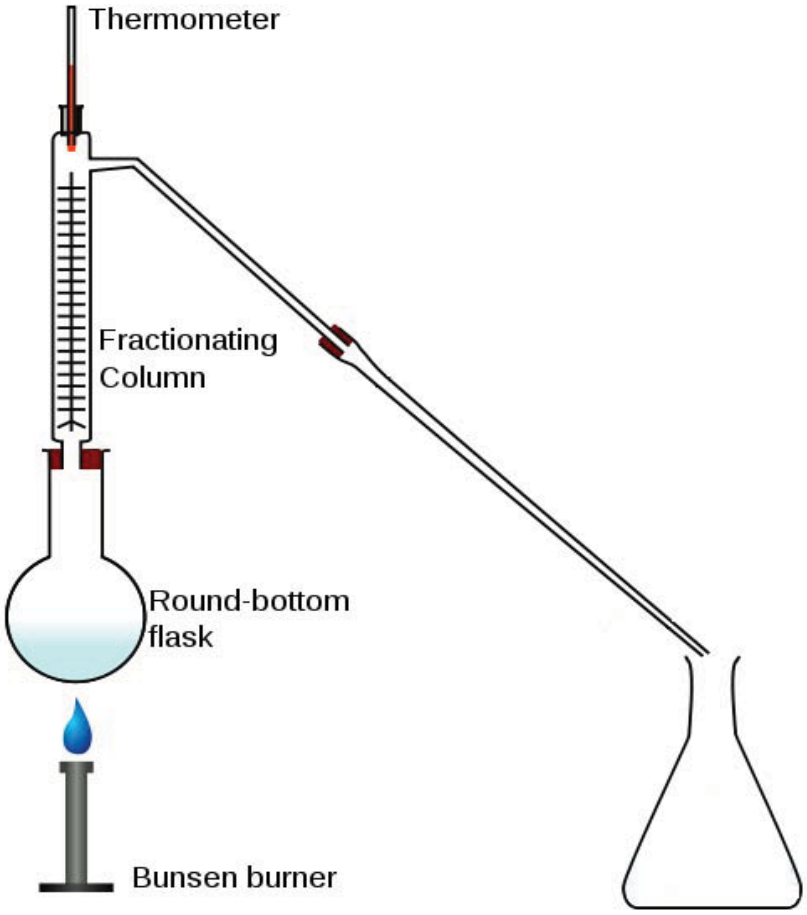

Figure 42: Fractional distillation apparatus from Wikimedia Creative Commons, 2010.

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5. Molise suspects that an unknown solution M contains the known substances A, B and C. He performs a paper chromatography as follows to analyse the solution:

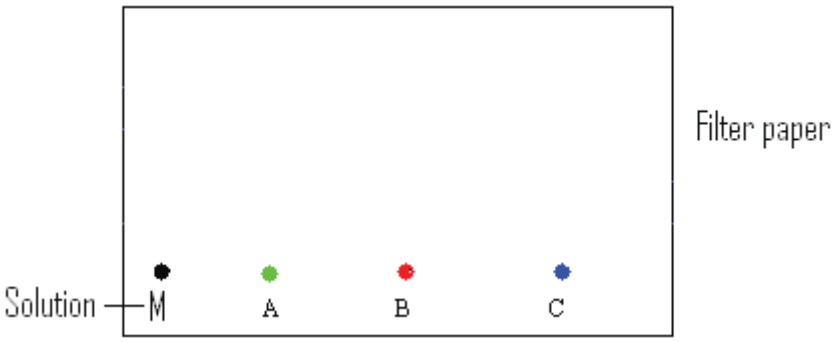

Figure 43: Unknown solution M and substances A, B and C on same line. Hand drawn by graphic designer at LDTC.

After the experiment, the paper looks like the one shown in Figure 48:

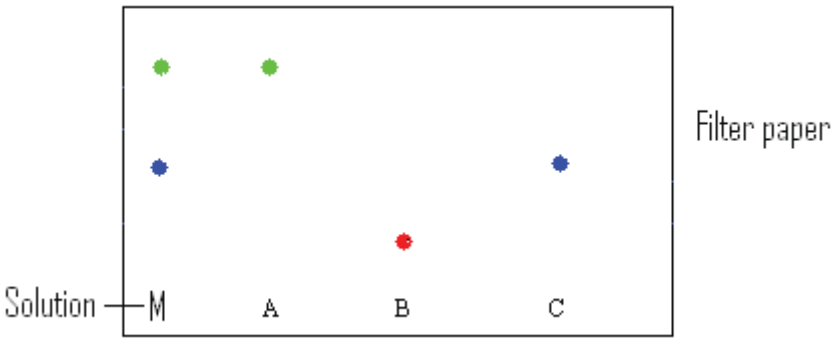

Figure 44: Chromatograms. Hand drawn by graphic designer at LDTC.

Using the results of the chromatography, identify substances present in unknown solution M. (1)

_____
_____
_____
_____
_____

6. An acid is added to a substance and a gas is formed. Kotelo thinks the gas is either hydrogen or carbon dioxide.

   a) How would he identify which gas it is? (2)

   _____
   _____
   _____
   _____

   b) If the gas is carbon dioxide, what is the likely ion present in the substance that was added to the acid? (1)

   _____
   _____
   _____

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Study Skills

Remember that is it important to review your misunderstandings and make sure that you understand why you got a question wrong. Did you misinterpret the information? Did you forget a key piece of information? Did you read the question wrong?

Help

If you need help, remember that your tutor is there to help! Contact them as soon as possible if you have questions.

Answers to Assignment 1

1.

(a) Thermometer.

(b) Clock/ watch/stop clock.

(c) Pipette/ burette or measuring cylinder

(d) Electronic balance or triple beam balance.

2.

a)

(i) You could also pick them up but you may miss some small particles. The best way is by using filtration.

(ii) Fractional distillation. In this case we are interested in obtaining water from the solution. Simple distillation would wrong since the water will evaporate, it will not be collected.

b) This shows that the water from the pond is impure. Pure water boils at 100 ^{o}C whereas impure water boils at a temperature above 100 ^{o}C.

c)

(i) Kuena should add ethanol to the sample because sugar will dissolve in ethanol. The solution of sugar and ethanol can be separated by distillation.

(ii) The method is called use of a suitable solvent.

3. (a) By adding drops of sodium hydroxide in all solutions.

a) If iron (III) irons are present, a red-brown substance will be formed.

b) If aluminium ions are present, a white substance will be formed and then disappear after some few drops.

c) If calcium ions are present, a white substance will be formed.

(b)

(i) Anion present is sulphate (SO_4^{2-}).

(ii) The name of the compound is calcium sulphate ($CaSO_4$)

4. (a) In Figure 45, the conical flask is not closed with a stopper, so the gas will escape not enter the delivery tube.

(b) In Figure 46, the condenser is not connected. This will cause the vapour to pass through without being collected.

5. Solution M contains substances A and C.

6.

a) By using a burning splint. If the splint goes out with a "pop" sound, the gas is hydrogen. If not, pass the gas through limewater. If limewater turns milky, the gas is carbon dioxide. If not, the gas is not hydrogen or carbon dioxide.

b) If the gas is carbon dioxide, the acid was added to carbonate.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent chemistry course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 1

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 15 minutes.

(Total Marks:12)

1. When Ntene heated a white solid, a gas was produced and the solid turned blue. Identify the gas and the solid. (2)
2. Malonya added 50 ml of water in a measuring cylinder to measure the volume of a stone. She found the volume of the stone to be 11.3 ml. What is the reading on the measuring cylinder after she had added the stone? (2)
3. A certain gas is said to be lighter than air. A student set up apparatus as follows to produce and collect this gas.

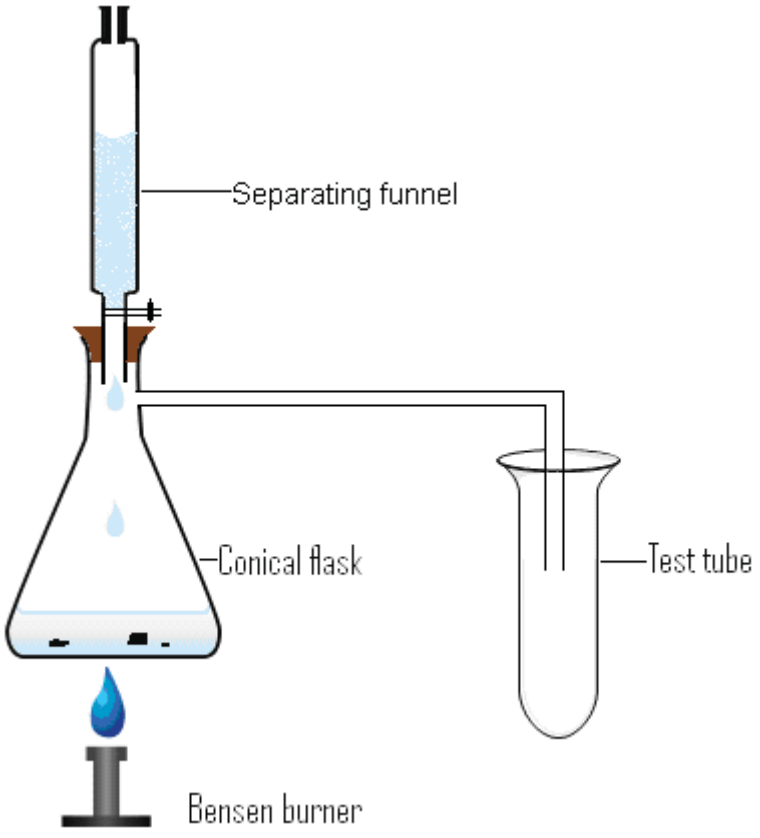

Figure 45: Preparation of a gas from Wikimedia Creative Commons, 2010.

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a. Draw the proper arrangement of apparatus for collection of this gas. (1)

b. State why you think it is appropriate. (1)

4. If salt is added to water, what happens to the boiling point of water? (1)

5. The diagram below shows the result of a chromatography experiment. S and U are unknown solutions and A, B, C, D and E are pure substances.

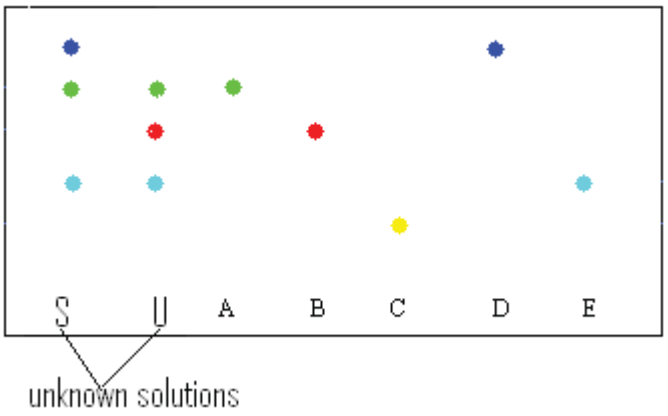

Figure 46: Chromatograms. Hand drawn by graphic designer at LDTC.

a. Which pure substance(s) is not in either of the solutions?
(1)

b. Which pure substance(s) is in both of the solutions?
(1)

6. Look at the apparatus in Figure 51:

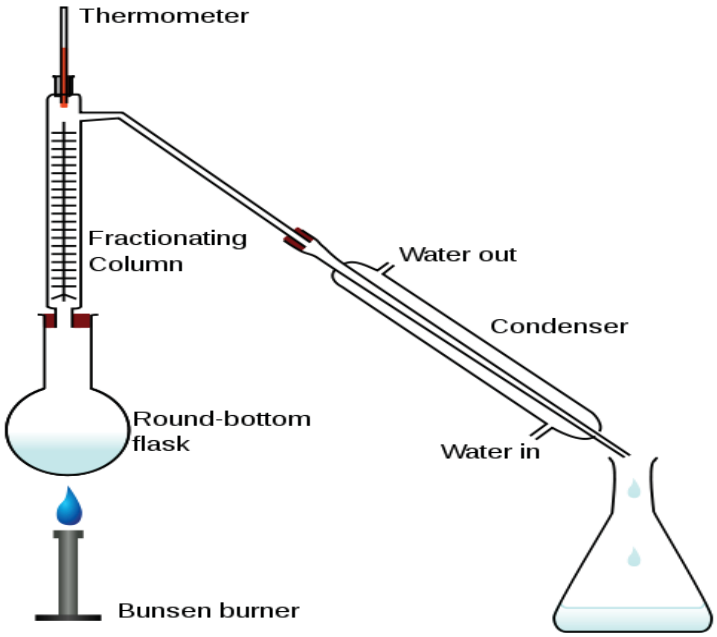

Figure 47: Fractional distillation apparatus accessed from Wikimedia Creative Commons, 2010.

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a) What is this apparatus used for? (1)

b) What is the purpose of the condenser in the apparatus? (1)

c) What is the reason for running cold water through the condenser? (1)

Chemistry

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 2

The Periodic Table

Study Skills

Before you start this unit, think about how you read and study the content of this course. Are you emotionally ready to learn? Are you attentive or does your mind start to wander? Are you learning the material with an active mind? This means that you are evaluating what you are reading, trying to anticipate what you will see next and asking questions. This type of attitude is important to your success as a self-paced learner. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In 1669, Hennig Brand was convinced that lead could be changed into gold using urine. In the process of heating and purifying urine, he discovered phosphorus! Phosphorus is an element on the periodic table and is used today in the manufacturing of fertilizers. Some of the most important scientific discoveries happened by accident!

The universe is made up of many things which are different in many ways. Look at the things around you, in what state are they? What are the substances around you made from? How are these substances made from other substances? In the previous section, you learned about experimental techniques such as measurement, separation of mixtures and identification of ions and chemicals in the lab. In this section, you are going look even closer at the elements in the periodic table.

You will learn how to classify different elements in the periodic table according to their groups and periods and draw the atomic structures of the first 20 elements of the periodic table. You are also going to find out how different substances are made from reactions of different elements in the periodic table. In addition, you are going to look at the properties of different substances resulting from specific bonding.

Time

This unit consists of 23 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Explain* the behaviour and characteristics of different elements based on the periodic table.

Study Skills

Unit Outcomes:
When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

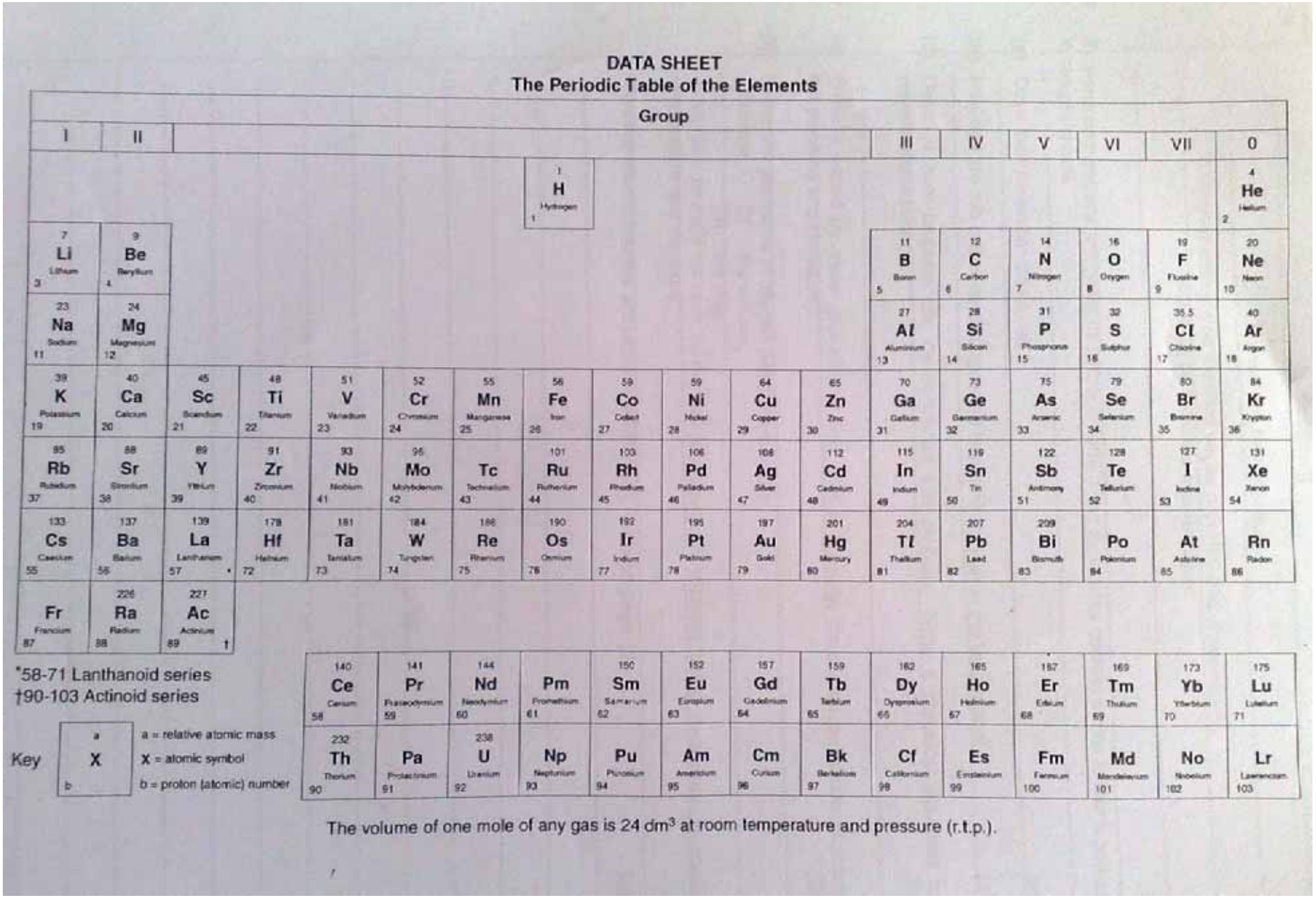
Upon completion of this unit you will be able to:

- *Describe* the atomic structure of an element given mass number and atomic number.
- *Describe* the classification of elements in the periodic table using the group number and period number.
- *Predict* the properties of different elements given their position in the periodic table.
- *Explain* how ions are formed by electron loss or gain.
- *Describe* how molecules are formed by sharing pairs of electrons.
- *Construct* 'dot and cross' diagrams to show electron arrangement in covalent and ionic compounds.
- *Differentiate* between the properties of covalent and ionic compounds.

Terminology

Atom:	The smallest particle of an element which can exist on its own.
Compound:	A substance formed by chemical combination of two or more elements in a fixed proportion.
Covalent bonding:	A chemical bonding which is formed as a result of a pair or pairs of electron being shared between two atoms
Electron:	The fundamental sub-atomic particle with a negative charge and is placed in the shells around the nucleus of an atom.
Ion:	An atom which has either lost or gained an electron thereby becoming either positively or negatively charged respectively.

Ionic bonding:	A chemical bonding which is formed as a result of metals donating electrons to non-metals in order to fill up the outer most shells of non-metals.
Metal	A group of elements that easily loses the electrons from its outer shell. Metals are good conductors of electricity. Please see: http://hyperphysics.phy-astr.gsu.edu/hbase/pertab/metal.html
Neutron:	A fundamental sub-atomic uncharged particle placed in the nucleus of an atom.
Non-metals	A group of elements that easily gains electrons into its outer shell. Non-metals are poor conductors of electricity. Please see: http://hyperphysics.phy-astr.gsu.edu/hbase/pertab/metal.html
Nucleon number:	The total number of protons and neutrons found in the nucleus of an atom.
Proton:	A fundamental sub-atomic particle with a positive charge and is placed in the nucleus of an atom
Proton number	The number of protons in the nucleus of an atom.



DATA SHEET
The Periodic Table of the Elements

Group I	Group II											Group III	Group IV	Group V	Group VI	Group VII	Group 0
							1 H Hydrogen 1										4 He Helium 2
7 Li Lithium 3	9 Be Beryllium 4											11 B Boron 5	12 C Carbon 6	14 N Nitrogen 7	16 O Oxygen 8	19 F Fluorine 9	20 Ne Neon 10
23 Na Sodium 11	24 Mg Magnesium 12											27 Al Aluminium 13	28 Si Silicon 14	31 P Phosphorus 15	32 S Sulphur 16	35.5 Cl Chlorine 17	40 Ar Argon 18
39 K Potassium 19	40 Ca Calcium 20	45 Sc Scandium 21	48 Ti Titanium 22	51 V Vanadium 23	52 Cr Chromium 24	55 Mn Manganese 25	56 Fe Iron 26	59 Co Cobalt 27	59 Ni Nickel 28	64 Cu Copper 29	65 Zn Zinc 30	70 Ga Gallium 31	73 Ge Germanium 32	75 As Arsenic 33	79 Se Selenium 34	80 Br Bromine 35	84 Kr Krypton 36
85 Rb Rubidium 37	88 Sr Strontium 38	89 Y Yttrium 39	91 Zr Zirconium 40	93 Nb Niobium 41	96 Mo Molybdenum 42	Tc Technetium 43	101 Ru Ruthenium 44	103 Rh Rhodium 45	106 Pd Palladium 46	108 Ag Silver 47	112 Cd Cadmium 48	115 In Indium 49	119 Sn Tin 50	122 Sb Antimony 51	128 Te Tellurium 52	127 I Iodine 53	131 Xe Xenon 54
133 Cs Caesium 55	137 Ba Barium 56	139 La Lanthanum 57 *	178 Hf Hafnium 72	181 Ta Tantalum 73	184 W Tungsten 74	186 Re Rhenium 75	190 Os Osmium 76	192 Ir Iridium 77	195 Pt Platinum 78	197 Au Gold 79	201 Hg Mercury 80	204 Tl Thallium 81	207 Pb Lead 82	209 Bi Bismuth 83	Po Polonium 84	At Astatine 85	Rn Radon 86
Fr Francium 87	226 Ra Radium 88	227 Ac Actinium 89 †															

140 Ce Cerium 58	141 Pr Praseodymium 59	144 Nd Neodymium 60	Pm Promethium 61	150 Sm Samarium 62	152 Eu Europium 63	157 Gd Gadolinium 64	159 Tb Terbium 65	162 Dy Dysprosium 66	165 Ho Holmium 67	167 Er Erbium 68	169 Tm Thulium 69	173 Yb Ytterbium 70	175 Lu Lutetium 71
232 Th Thorium 90	Pa Protactinium 91	238 U Uranium 92	Np Neptunium 93	Pu Plutonium 94	Am Americium 95	Cm Curium 96	Bk Berkelium 97	Cf Californium 98	Es Einsteinium 99	Fm Fermium 100	Md Mendelevium 101	No Nobelium 102	Lr Lawrencium 103

*58-71 Lanthanoid series
†90-103 Actinoid series

Key: a = relative atomic mass; X = atomic symbol; b = proton (atomic) number

The volume of one mole of any gas is 24 dm^3 at room temperature and pressure (r.t.p.).

Figure 1: Periodic table of elements.

Note it!

If you have internet access, please go to: http://www.ptable.com/ for an interactive periodic table.

Section 2-1: Elements

These groups of substances have different properties. Elements that have different properties are classified together and this can be determined from their atomic structures.

At the end of section 2-1, you should be able to:

- *draw* the atomic structure of different elements.
- *classify* elements into their respective groups based on the atomic structure.

Time

Section 2-1 has 23 pages. You should spend approximately 6-7 hours on this topic.

Particles in an Atom

All elements in the periodic table are placed in their specific positions using a certain criteria. The position of each element has been determined using the number of electrons in their outmost shells and the number of shells each atom possesses. For example in the periodic table sodium is shown as:

$$^{23}_{11}\mathrm{Na}$$

The number 23 gives the atomic mass (mass number) which is a combination of masses of protons and neutrons.

Atomic mass = number of protons + number of neutrons

From the above equations you can see that the number of neutrons is the difference between the number of protons and mass number.

Number of neutrons = atomic mass – number of protons

A proton is positively charged and a neutron is neutral. The proton has a mass of 1 atomic mass unit (amu). The neutron also has a mass of 1 amu. The mass of an

electron is about $\frac{1}{1837}$ mass of a proton.

The number 11 gives the atomic number (proton number). In any neutral atom, the number of protons and the number of electrons is the same.

Number of protons = number of electrons

Protons are positively charged while electrons are negatively charged. Since the particles are equal in number that means an atom is chemically neutral. Protons are positively charged and electrons are negatively charged (unlike charges) as a result the two particles attract each other.

Try the following:

Given that atom X has 9 electrons, and 10 neutrons, find the following:

a) Number of protons _____

b) Atomic mass _____

c) The name of element X from the periodic table

_____

Compare your answers with the ones given below.

a) Number of protons is 9. The number of electrons and the number of protons are the same.

b) Atomic mass 19. The nucleon number of the total number of protons and neutrons.

c) Element X is Fluorine

If you have access to the internet, please go to:

http://education.jlab.org/elementmath/

http://www.chem4kids.com/files/atom_structure.html

and http://www.kscience.co.uk/animations/atom.swf

Atomic Structure and Classification of Elements in the Periodic Table

In the atomic structure of any element, the neutrons and the protons are always placed in the nucleus (centre) of an atom. The electrons are arranged in the shells around the nucleus. The electrons are placed in shells starting with the shell which is closest to the nucleus. Each of the shells can only accommodate a certain number of electrons. When all the electrons have been arranged in shells, then we can show the number of electrons in each of the shells and the arrangement helps us to place elements in their correct positions in the periodic table.

The diagram under Activity 1 shows atomic structure of Sodium. The electrons are shown by the dots. Sometimes we use crosses to represent electrons. ‘dot and cross’ diagrams are used to show the electron arrangement in covalent and ionic compounds.

Activity

Activity 1

In this activity we are going to explore atomic structure and how atoms are placed in the periodic table.

1. Study Figure 2 and answer the questions that follow.

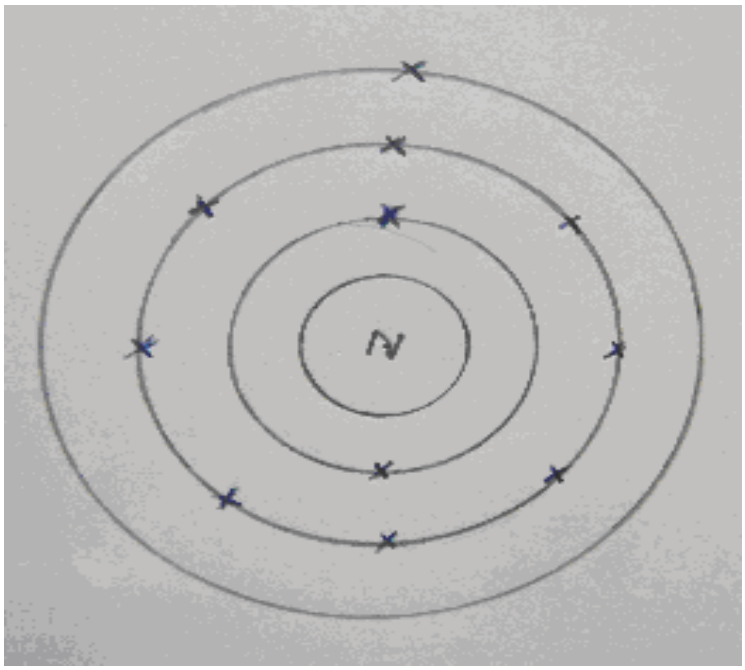


Figure 2: Atomic structure of sodium. Hand drawn by graphic designer at LDTC.

a) How many electrons are in the first shell_____

b) How many electrons are in the second shell? _____

c) How many electrons are in the third shell? _____

d) How many shells are surrounding the nucleus? _____

2. Now look at the atomic structures of nitrogen and oxygen below and answer the questions that follow:

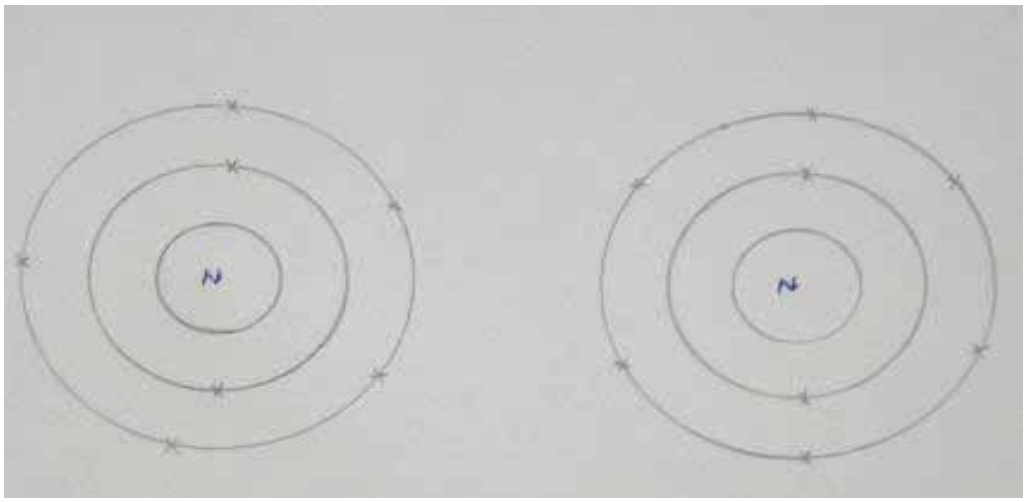


Figure 3: Atomic structures of nitrogen and oxygen. Hand drawn by graphic designer at LDTC.

a) How many electrons are in the first shell of the nitrogen atom? _____

b) How many electrons are in the second shell of the nitrogen atom? _____

c) How many shells are surrounding the nucleus of the nitrogen atom? _____

d) How many electrons are in the first shell of the oxygen atom? _____

e) How many electrons are in the second shell of the oxygen atom? _____

f) How many shells are surrounding the nucleus of the oxygen atom? _____

3. Look at the copy of the periodic table provided at the beginning of this unit. You will notice that the columns of the periodic table are labelled IA, IIA IIIA and so on while the rows are numbered 1, 2, 3 and so on. The columns in the periodic table give the group of elements while the rows give the periods of the elements. Now answer the questions that follow.

a) In which group of the periodic table is sodium? _____

b) In which period of the periodic table is sodium? _____

c) In which group of the periodic table is nitrogen? _____

d) In which period of the periodic table is nitrogen? _____

e) In which group of the periodic table is oxygen? _____

f) In which period of the periodic table is oxygen? _____

4. There is a relationship between your answers to the number of electrons in the outmost shell of the above atoms, the number of shells surrounding the nucleus in the above atoms, group number and the period of the above atoms. What is the relationship?

_____

_____

_____
_____
_____

When you have answered all the questions based on the atomic structures above, compare your answers with those given at the end of this subunit. Continue with the next topic if you have 80% or more correct. If not, review this content and try the activity again.

Note the following important points:

Note it!

- You should have found that the number of electrons in the outmost shell of an atom corresponds to the group number (columns in the periodic table) while the number of shells surrounding the nucleus corresponds with the period (rows in the periodic table) of an atom.

- The way the electrons have been arranged in their shells around the nucleus is fixed. The first shell is considered to be full when it has **two** electrons. All other shells are considered to be full when they have **eight** electrons in their outmost shells. The way electrons are arranged in their shells is called electronic configuration or electronic structure.
- The electronic configuration of sodium atom is given as 2, 8, 1, that of nitrogen is 2,5 while that of oxygen is 2,6. The three numbers in the configuration of sodium signifies the number of shells surrounding the nucleus. These three numbers give the period in which sodium is found. The period is three. The first number which is 2 tells us that the first shell is full since it can only accommodate 2 electrons; the second shell can take a maximum of eight electrons, while the last number which is 1 is the last electron and also gives the group number in which sodium is found.
- In the electronic configuration of nitrogen, the two numbers 2, 5 also give the period in which nitrogen is found which is 2 while the last number 5 gives us the group in which nitrogen is found.
- Again, in oxygen the two numbers 2,6 give the period of oxygen which is two while the last number gives us the group in which oxygen is found in the periodic table.

Activity 2

Activity

In this activity we are going to practice how to draw the atomic structure of an element and try to place the element in its correct position in the periodic table.

1. Element X has atomic number of 19 and atomic mass of 39.
    a) How many protons are there in element X?_____
    b) How many electrons are in an atom of element X?_____

c) Draw a dot diagram of the atomic structure of element X in the given space below. Show the numbers of each particle and their positions, and arrangement of electrons in the shells.

d) In which group of the periodic table have you placed element X and why? _____
_____

e) In which period of the periodic table have you placed element X and why?
_____
_____

f) Show the electronic configuration of element X

g) Identify element X from the periodic table_____
_____

Now compare your answers with those given at the end of the section. Be sure you understand each answer before you continue to the next topic.

Group 1 Elements

Group 1 elements are some of the most reactive elements in the periodic table. They have to be kept under oil to prevent them from reacting with either air or water! Figure 4 shows sodium stored under oil to prevent it from reacting with air or water. This group is very important as many of the compounds formed from this group are used in our everyday live especially as salts that our body needs. Think of the table salt and chocolates that we use which contains sodium, and samba chips which contain potassium.

Figure 4: Sodium kept in oil accessed from Wikimedia Creative Commons, 2010.

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Activity

Activity 3

1. Let us look at the group 1 elements. You should be familiar with some of the names of the elements in this group. Now try to answer the following questions:

a) What do we call this group: group 1 elements? _____

b) How many electrons do you expect to find in the outer shell of group 1 elements? _____

c) What happens to the number of shells in an element in group 1 as we go down the group?

_____

d) What happens to the mass number as we go down the group?

_____

e) What happens to the atomic number as we go down the group?

_____

f) What happens to the number of electrons as we go down the group?

_____

g) What happens to the distance between the electron in the outmost shell and the nucleus? _____

_____

h) How strong do you think the attraction between the electron in the last shell and the nucleus is?

_____

_____

2. Draw a dot diagram of the atomic structure of lithium in the answer space below to confirm your answers.

3. When Hennig Brand discovered phosphorous by purifying urine, he quickly discovered that if he had to keep the phosphorus covered by water at all times. Why do you think he had to do this?

_____

_____

Now compare your answers with those given at the end of this subunit. Make sure you understand all of the content before continuing.

Key points to remember:

Note it!

- Group one is a group of metals that have 1 electron in the outer shell of their atomic structure.
- When you go down the groups the number of shells increases, which means the number of protons has increased while the number of electrons and protons is the same.
- The atomic mass is increasing as it is made up of protons and neutrons. When the number of shells increases, the distance between the nucleus and the electron in the outmost shell is increasing. This means that there is less attraction between the electron in the last shell and the nucleus.

Properties of Group 1 Elements

Group 1 elements are said to be **alkali metals**. Just like other metals, groups 1 metals have physical properties and chemical properties.

Physical Properties of Group 1 Elements

- Good conductors of heat and electricity.
- Soft in nature such that they can be cut by a knife. For example: sodium.
- Low densities such that they float in water
- Shiny surfaces when freshly cut
- Compared with most metals, group 1 elements have low melting and boiling points. Boiling and melting points are also referred to as fixed points.

Chemical Properties of Group One Elements

- Burn in oxygen or air to form oxides which are soluble in water and form alkaline solution. That is why they are kept in oil to prevent them from reacting with air.
- React vigorously with water to form alkaline solution.
- React vigorously with halogens to form metal halides.

Group 2 Elements

Group 2 has some of the elements that we use every day. Compounds that contain group 2 elements are present in many food stuffs and some of the things we use in our homes. Though group two metals are reactive, they are not as reactive as group one elements. Group 2 elements change colour once exposed to air. Figure 5 below shows calcium metal.

Figure 5: A picture of calcium metal accessed from Wikimedia Creative Commons, 2010.

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Activity

Activity 4

1. Look at group 2 elements (some of which some you might be familiar with). The elements in this group are very important. Some of them are found in the food that we eat. For example think of calcium, which we find in milk. Another group 2 element is magnesium. It is found in medicine associated with indigestion. Now answer the questions that follow based on what you have learned with group 2 elements.

a) What do we call this group: group 2 elements? _____

b) How many electrons are in the outmost shell of an atom in group 2?

_____

c) What happens to the number of shells as you go down the group?

_____

d) What happens to the atomic mass as you down the group?

_____

e) What happens to the atomic number as you go down the group?

_____

f) What happens to the number of electrons as we go down the group?

_____

_____

g) What happens to the distance between the electrons in the outmost shell and the nucleus as we go down the group?

_____

_____

h) Compare the attraction between the electrons in the outer shell and the nucleus to those closer to the nucleus.

_____

_____

2. Now draw a dot diagram of the atomic structure of magnesium in the space below to verify your answers.

Compare your answers with those provided at the end of this subunit. If you score 80%, continue with the next topic. Otherwise, review this content on atomic structure and try the questions again.

Note the following points:

Note it!

- The number of electrons in the outmost shell (which is two), corresponds to the group number of the element in the periodic table.
- The number of shells corresponds to the period of the element in the periodic table.
- You should also have found that as you go down the group the atomic number, atomic mass, number of shells and the number of electrons increases.
- If the number of electrons and the number of shells increases, that means the distance of electrons in the outer shell also increases.

Properties of group 2 elements

Group 2 elements are called **alkaline earth metals**. Their physical and chemical properties are as follows.

Physical properties of group 2 elements

- Harder than those in group 1, though they can still be cut with a knife.
- Silver grey in colour when clean but tarnish quickly when left in the air due to formation of a layer of metal oxide.
- Good conductors of heat and electricity.

Chemical properties of group 2 elements

- Burn in oxygen or air to form white oxides.
- React with water but not so vigorously as group 1 to form alkaline solution.

Transition Elements

The middle block of elements between group 2 and group 3 elements are called transition metals. This block includes many of the metals that we see and use in our everyday life as compound or in their pure form. Some of these elements like copper, gold, silver and many others are used for making jewellery. These metals are grouped as transition because of the way they behave. Their properties will show that they behave in a very special way when compared to other metals. Figure 6 below shows copper metal. Copper is used for making electrical wires, ornaments, coins and many other useful things.

Figure 6: A picture of copper metal accessed from Wikimedia Creative Commons, 2001.

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Properties of Transition Group Elements

- Hard, tough and strong such that they cannot be cut by a knife like group 1 metals.
- High density. They sink in water.
- High melting point except for mercury, which is a liquid at room temperature and pressure.
- Less reactive when compared to metals from other groups.
- Form a range of brightly coloured compounds for example copper sulphate which is blue in colour.
- Good conductors of heat and electricity for example copper, iron
- Show a catalytic behaviour for example iron in Haber process and nickel in hydrogenation of vegetable oil to margarine.
- Form more than one simple ion for example, Cu^{+} in compounds like Cu_2O, Cu^{2+} in compounds like CuO, Fe^{+} in compounds like FeCl, Fe^{2+} in compounds like FeO and Fe^{3+} in compounds like $FeCl_3$.
- Do not react as quickly as group 1 and 2 with oxygen or water.

Case Study

Image from Wikimedia Commons.

Metalville is a fictional town in South Africa. The main industry in the town in gold mining. The by-product of the goldmines is large amounts of mercury which were being deposited into the lake which happened to be the main water supply for the townspeople. Mercury has toxic effects on living things. What effect do you think the mercury contamination had on the agriculture in the town? The health of the people of Metalville? The wildlife? What would be the effects of closing down the goldmine? If you were town mayor, what would you recommend?

Group 3 Elements

Group 3 also has elements that we use for different purposes. For example, some elements are used for making cooking utensils and some are used for making electrical equipment.

Activity

Activity 5

1. Look at the periodic table and answer the following questions based on group 3 elements.

a) Is aluminium a metal or non-metal? _____

b) In which group of the periodic table is aluminium? _____

c) How many electrons are in the outer shell of an atom of aluminium? _____

d) Name one use of aluminium._____

2. Draw a dot diagram of the atomic structure of aluminium in the space below to verify your answers.

Now compare your answers with the answers provided at the end of the section. As needed, review the above content to clarify any misunderstandings before continuing.

Note it!

Note the following:

Aluminium is in group 3 of the periodic table and has 3 electrons in the outer shell. From our experiences we know that aluminium is a metal and that it is used in making of cooking utensils, foil papers, aircrafts, etc.

Group 4 Elements

This group also contains some of the elements that we use in our everyday life. Some elements are used as they are and sometimes we use as compounds. Think of the food that we eat. Many compounds that we use in food products contain group 4 elements like carbon, which is present in carbohydrates

Figure 7: Carbon accessed from Wikimedia Creative Commons, 2010.

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Activity

Activity 6

1. Now that we have looked at the elements from group 1, 2 and 3, let us look at the elements from other groups.

a) Name one of the group 4 elements that you know_____

b) Is the element you have named a metal or a non-metal? _____

c) How many electrons are in the outer shell? _____

d) How many shells does it have? _____

Compare your answers with the ones given at the end of the section. Be sure you understand each answer before you continue to section 2-2. If you are having problems answering these questions, go over the above text again to understand the concepts or contact your tutor. If you are able to answer the questions, continue on.

Note the following:

Note it!

Like the other groups of elements, group 4 elements are also placed in the periodic table according to the number of electrons they have in the outer shell and the number of shells they have around the nucleus.

Group 5 Elements

Group 5 elements have 5 electrons in the outmost shell. Group 5 elements can react with metals by gaining 3 electrons from metals during **ionic bonding**. As well, group 5 elements react by sharing pairs of electrons with non-metals during **covalent bonding**. Examples of group 5 elements include nitrogen and phosphorus.

Think of the fertilizers that we use in the fields, have you ever asked yourself what fertilizer is made up of? Nitrogen and phosphorus are two elements which are very important as they are used in making fertilizers.

Activity

Activity 7

1. Look at the elements from group 5 of the periodic table and then answer the following questions:
   a) Name one element from group 5_____
   b) Is the element you named a metal or a non-metal? _____
   c) In the element you named, how many electrons are in the outer shell? _____
   d) How many shells are in a phosphorus atom? _____

2. Draw a dot diagram of the atomic structure of nitrogen to show electrons in the shell to confirm your answers in the answer space below.

Now compare your answers with the answers provided at the end of the section. Make sure you understand each answer before proceeding to the next topic.

Note the following important points:

Note it!

- Group 5 elements are non-metals and that they have five electrons in their outmost shell.
- The number of shells in each atom will depend on the number of electrons in each atom.

Group 6 Elements

This group also contains some of the elements that we use in our everyday life. Some elements are used as they are in their purest form and sometimes we use them as compounds. Think of the air that we breathe every day. Which is the most important gas that our body needs when we breathe? You will find that many of the substances that we use have some of the elements which appear in group 6.

Just like other elements, group 6 elements are placed in the periodic table by the number of electrons they have in the outmost shell and the number of shells they have around the nucleus. Group 6 elements can react both with metals and non-metals. When reacting with metals, group 6 elements gain electrons and when reacting with non-metals, they share pairs of electrons.

Activity

Activity 8

1. Look at the elements from group 6 of the periodic table and then answer
2. the following questions:
   a) Name one element from group 6_____
   b) Is the element you named a metal or a non-metal? _____
   c) In the element you named, how many electrons are in the outer shell? _____
   d) How many shells are in a sulphur atom? _____

3. Draw a dot diagram of the atomic structure of oxygen to show electrons in the shells to confirm your answers in the answer space below.

Now compare your answers with the ones given at the end of the section. Make sure you understand each answer before proceeding to the next topic. As needed, review the preceding material.

Note the following important points:

Note it!

- Group 6 elements are non-metals and they have six electrons in their outmost shell.
- The number of shells in each atom will depend on the number of electrons in each atom.

Group 7 Elements (Halogens)

This group also contains some of the elements that we use in our everyday life. Some elements are used as they are in their purest form and sometimes we use as compounds. Think of the table salt (NaCl) that we use every day! Think of the elements present in NaCl. Many compounds that we use in food products have group 7 elements in them.

Group 7 elements are coloured, and the colour deepens as you go down the group. Fluorine is pinkish in colour while chlorine is yellowish green. Liquid chlorine is shown in Figure 8. Group 7 elements are diatomic elements, which mean that they are formed when the atoms share a pair of electrons as shown in figure 9. (i.e. O_2, F_2 and Cl_2)

Figure 8: Liquid chlorine accessed from Wikimedia Creative Commons, 2010.

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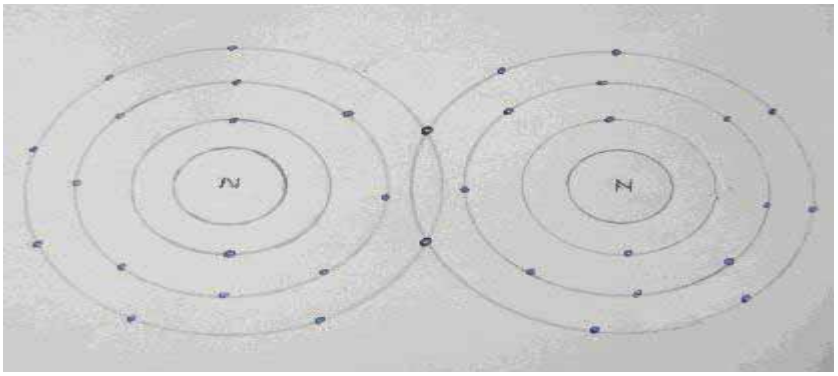


Figure 9: A diatomic element. Hand drawn by graphic designer at LDTC.

Activity

Activity 9

1. Look at the elements from group 7 of the periodic table and then answer the following questions:
   a) Name one element from group 7_____
   b) Is the element you named a metal or a non-metal? _____
   c) In the element you named, how many electrons are in the outer shell?
   _____
   d) How many shells are in a fluorine atom?
   _____

2. Draw a dot diagram of the atomic structure of fluorine to show electrons in the shell to confirm your answers in the answer space below.

Now compare your answers with the ones given at the end of the section. Again make sure you understand all the content before proceeding to the next topic. As you need, review the preceding material.

Note the following points:

Note it!

- Group 7 elements are non-metals.
- They have seven electrons in their outmost shell.
- The number of shells in each atom will depend on the number of electrons in each atom.

Properties of Group 7 Elements

Group 7 elements are called **halogens** and have their own properties especially being non-metals. The properties of this group are very different from the properties of other groups.

Physical properties

- Coloured and darken as you go down the group. For example chlorine is green, bromine is red-brown, and iodine is purple-black.
- Gradually change from is gas to liquid then to solid. For example, fluorine is a gas, chlorine is a gas, bromine is a liquid and iodine is a solid.
- Exist as diatomic molecules. For example, Cl_2, Br_2 and so on.
- Reactivity decreases as you go down the group. For example, fluorine is more reactive than chlorine, which is more reactive than bromine.

Chemical properties

- They form molecular compounds with other non-metallic elements.
- React with hydrogen to form hydrogen halides.
- React with metals to form metal halides.
- Undergo displacement reaction with a more reactive halogen. For example, chlorine will displace bromine and iodine during a chemical reaction.

$$Cl_{2(aq)} + 2KBr_{(aq)} \rightarrow 2KCl_{(aq)} + Br_{2(aq)}$$

Group 8 Elements (Noble Gases)

Group eight elements have many uses; some of which we may not be aware of. Many of these elements such as neon and argon are unreactive and are therefore used in many things like hot air balloons, light bulbs and advertising signs.

Activity

Activity 10

1

a) Name one element from group 8_____

b) Are elements in group 8 metals or non-metals?

_____

c) How many electrons are found in the outer shell of group 8 elements?

_____

Reflection

Reflection question: Is the outer shell of group 8 elements full, or does they need to gain or lose electrons? (You may need to refer back to earlier notes on electron configuration). What do you think this means in terms of its reactivity?

_____

2. Draw a dot structure of the atomic structure of helium in the space below.

Now compare your answers with the ones given at the end of the section. Again make sure you understand all the content before proceeding to the next topic. As you need, review the preceding material.

Properties of Group 8 Elements

- They are colourless gases.
- They are unreactive because of the number of electrons they have in the outmost shell. They have eight electrons in the outer shell so they do not need to gain or lose electrons.
- The shells are numbered outward from the nucleus. The maximum number of electrons found in each shell can be calculated by: $2n^2$ where "n" is the number of the shell.

Shell Number	Maximum Number of Electrons in the Shell
1	$2 \times 1^2 = 2$
2	$2 \times 2^2 = 8$
3	$2 \times 3^2 = 18$

- **The Octet Rule:**
  In general, atoms are most stable when they have 8 electrons in their outer-most shell. (Octet means 8.) The exception is the first shell which is most stable with **TWO** electrons. However, if the number of electrons in the outer shell does not make 18, the shell is considered full when it has 8 electrons until there are enough electrons to fill up the outer-most shell with 18 electrons.
- They exist as individual atoms for example, Neon (Ne)

Note the following points:

Note it!

- Metals are found in groups 1 to 3 in the periodic table while non-metals appear from group 4 to group 8 of the periodic table.
- They appear in these groups because of the number of electrons they have in outer shells.

Note it!

If you have access to the internet, please go to:
http://www.bbc.co.uk/news/science-environment-16002181.

You will read about some of the newest elements to be discovered like element 114: Flerovium or element 116: Livermorium. Do you think more elements will be discovered in the future? If you discovered an element, what would you call it?

Answers to the Activities on Atomic Structure

Activity 1

Question 1

a) 2 b) 8 c) 1 d) 3

Question 2

a) 2 b) 5 c) 2 d) 2 e) 6 f) 2

Question 3

a) 1 b) 5 c) 2 d) 6 e) 2

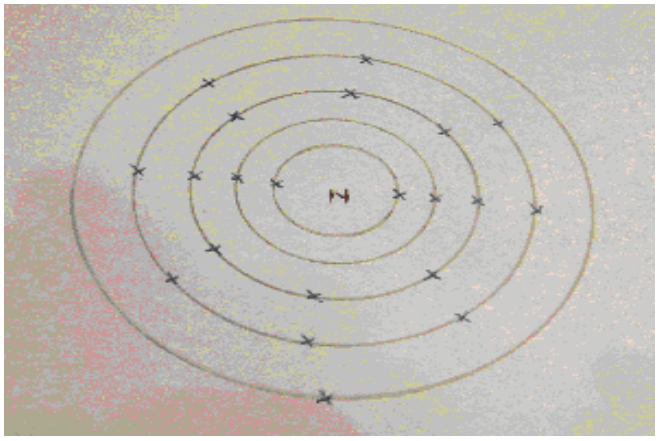
Question 4

The number of electrons in the outmost shell is the same as the group number, while the number of shells around the nucleus is the same as the period.

Activity 2

a) 19 b) 19

c) Atomic structure of element X:



d) 1. When you place the electrons in their shell there is only one electron found in the outer shell hence group 1

e) 4. When electrons are placed in their shell there are four shells surrounding the nucleus.

f) 2, 8, 8,1. The numbers show how many electrons are found in each of the four shells

g) The element in that position of the periodic table is potassium.

Activity 3

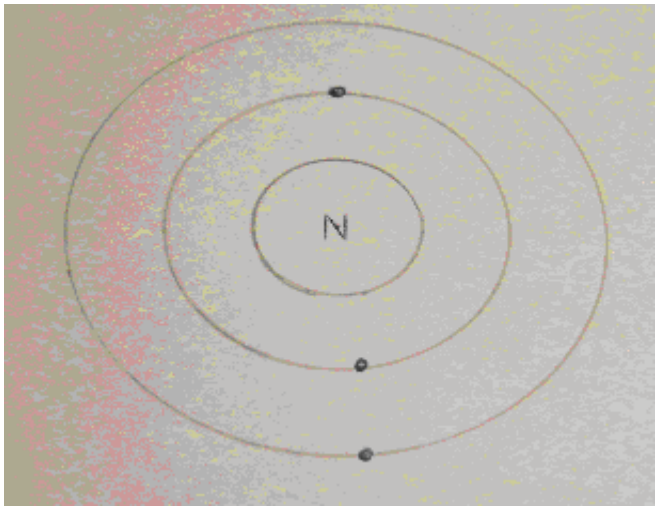
Question 1

a) Metals b) 1 c) Increases d) Increases e) It increases

f) They increase g) Increases h) Less

Question 2

Atomic structure of lithium



3. He had to keep it covered by water to prevent the phosphorus from reacting with air. As a group 1 element, phosphorus is highly reactive.

Activity 4

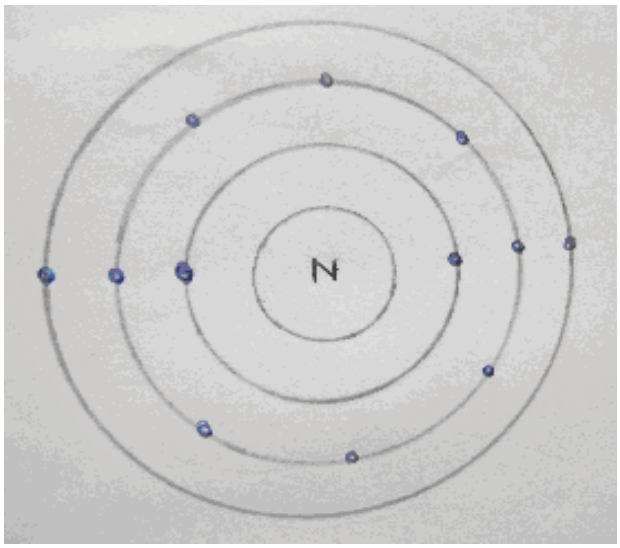
Question 1

a) Metals b) 2 c) Increases d) Increases e) Increases

f) Increases g) Increases h) Less

Question 2

Atomic structure of magnesium



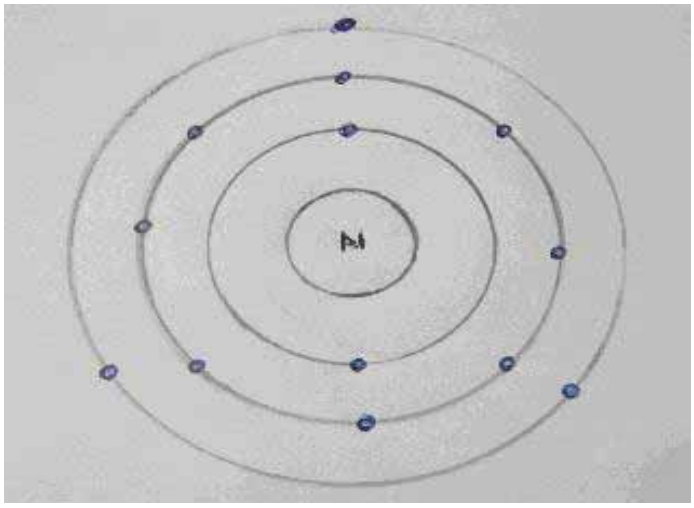
Activity 5

Question 1

a) Metal b) 3 c) 3 d) Cooking utensils, foil paper and aircraft.

Question 2

Atomic structure of Aluminium



Activity 6

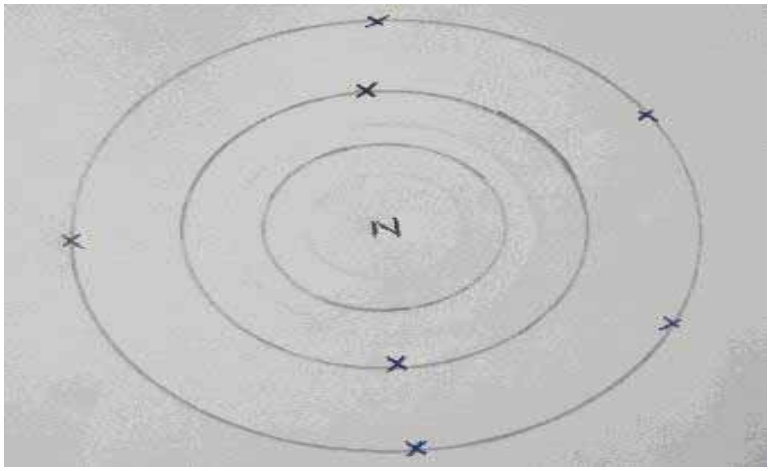
a) Carbon, silicon or tin. b) Non-metal c) 4 d) The answer will depend on the elements named in (a) for example, carbon will have 2 shells, silicon will have 3.

Activity 7

Question 1

a) Nitrogen, phosphorus or arsenic, b) Non-metal c) 5 d) The answer will depend on the element named in (a) for example, nitrogen will have two shells while phosphorus will have three shells.

Question 2

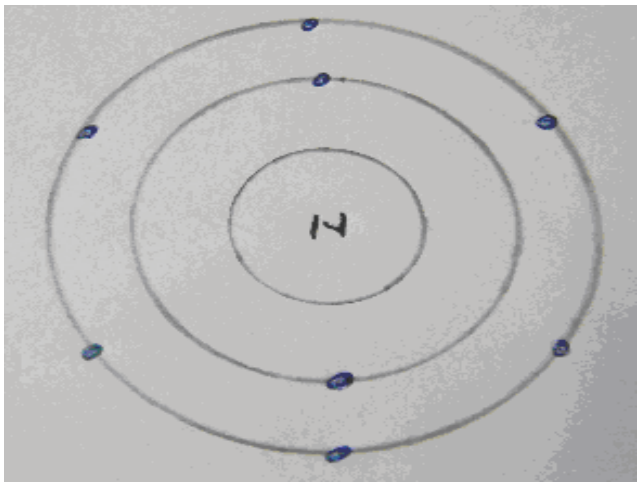


Activity 8

Question 1

a) Oxygen, sulphur or selenium, b) Non-metal c) 5 d) The answer will depend on the element named in (a) for example, oxygen will have two shells while sulphur will have three shells.

Question 2



Activity 9

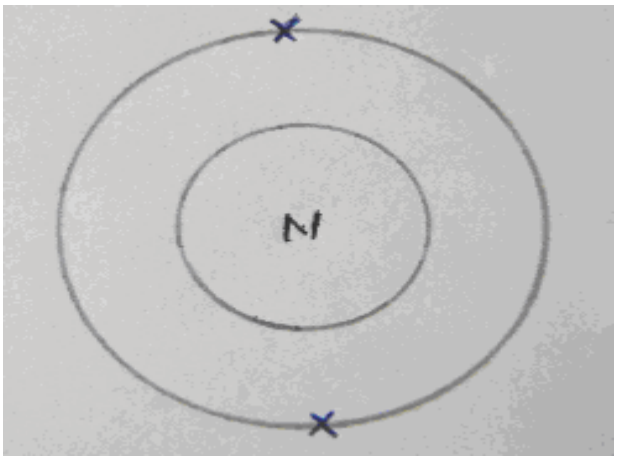
Question 1

a) Fluorine, chlorine, bromine or iodine b) Non-metals c) 7

d) 2

Question 2

Atomic structure of fluorine



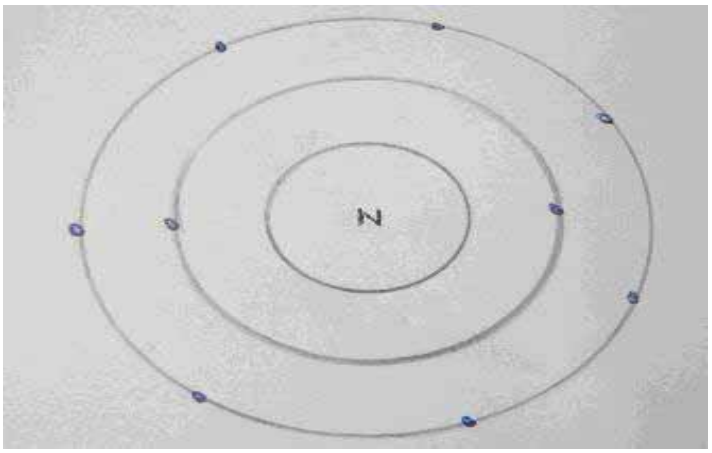
Activity 10

Question 1

a) Helium, neon or argon etc. b) Non-metal c) 8

Question 2

Atomic structure of helium



3. You should have found that group eight elements have eight electrons in the outmost shell. Group eight elements are non-metals and are called noble gases. Due to the fact that they have a full outer shell (and therefore do not need to gain or lose electrons), noble gases are very unreactive with other elements.

Section 2-2: Ionic and Covalent Bonding

At the end of section 2-2, you should be able to:

- *explain* how ions are formed by electron loss or gain.
- *describe* how molecules are formed by sharing pairs of electrons.
- *construct* dot and cross diagrams to show electron arrangement in covalent and ionic compounds.
- *differentiate* between the properties of covalent and ionic compounds.

Time

Section 2-2 has 11 pages. You should spend approximately 3-4 hours on this topic.

Elements bond in two different ways to form compounds in a chemical reaction: ionic bonding and covalent bonding. In any kind of bonding, the purpose is for each atom to have a full outer shell (2 or 8 electrons).

Ionic Bonding

Ionic bonding is the bonding that takes place between metals and non-metals. This kind of a bonding takes place when metals which have a fewer number of electrons in the outmost shell donate electrons to non-metals which have a greater number of electrons in the outer shell.

When this type of bond is formed, electrons are transferred from the metal atom to the non-metal atom during the chemical reaction. When electrons are transferred, the atoms become stable by getting full outer energy levels (eight or two electrons in the outer shell). During this kind of bonding, the atoms want to have a noble gas structure. When sodium and chlorine react together, sodium, which has 1 electron in its outer shell donates that electron to chlorine. Chlorine has seven electrons in the outer shell so now both can have eight electrons in the outer shell.

Activity

Activity 11

During a chemical reaction when sodium donates electrons to chlorine:

a) What happens to the number of electrons in the sodium atom?

_____

b) What happens to the number of protons in the sodium atom?
_____

c) What happens to the number of electrons in the chlorine atom?
_____

d) What happens to the number of protons in the chlorine atom?
_____

e) What do you expect the charge of sodium to be after an electron has been donated to chlorine? _____

f) What do you expect the charge of chlorine to be after accepting an electron from sodium? _____

Compare your answers with the ones given at the end of the section. Make sure you understand all of the content before you move to the next topic. If you get at least five right, is a good sign that you understand the material.

Further Explanation of Sodium Bonding to Chlorine

When sodium donates an electron to chlorine, the number of electrons and protons are no longer the same. The number of protons in sodium exceeds the number of electrons by 1. This means that sodium becomes positively charged while chlorine becomes negatively charged since it has more electrons than protons. After bonding, we no longer have atoms but charged ions. For example, sodium ion (Na^+) and chloride ion (Cl^-). **It is important to note that the number of protons in any atom does not change but stays the same all the time.** The protons are situated in the nucleus of the atom and can not be removed; the only particles that can be donated are electrons.

Study figures 9a and 9b and see how ionic bonding takes place between sodium and chlorine.

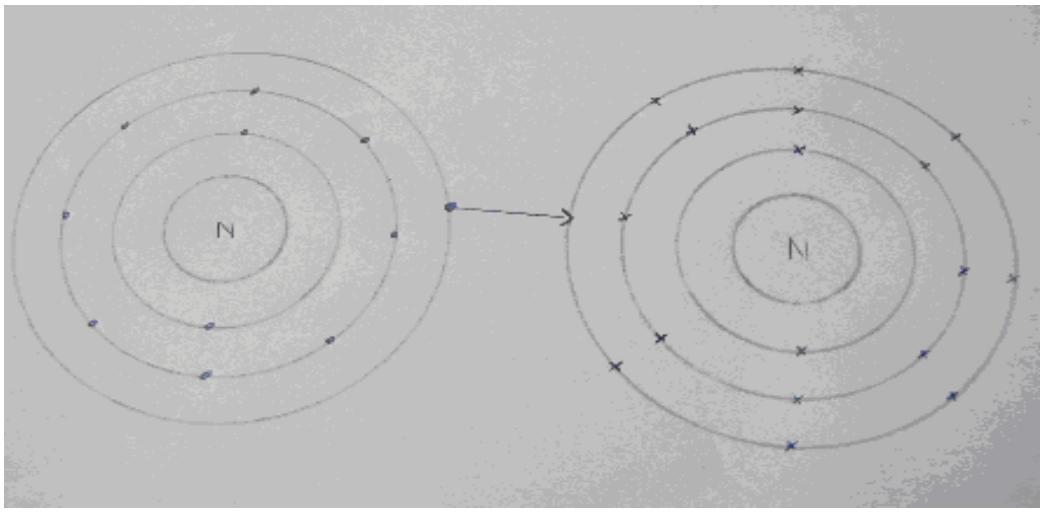


Figure 9a: An electron being donated from sodium to chlorine. Hand drawn by graphic designer at LDTC.

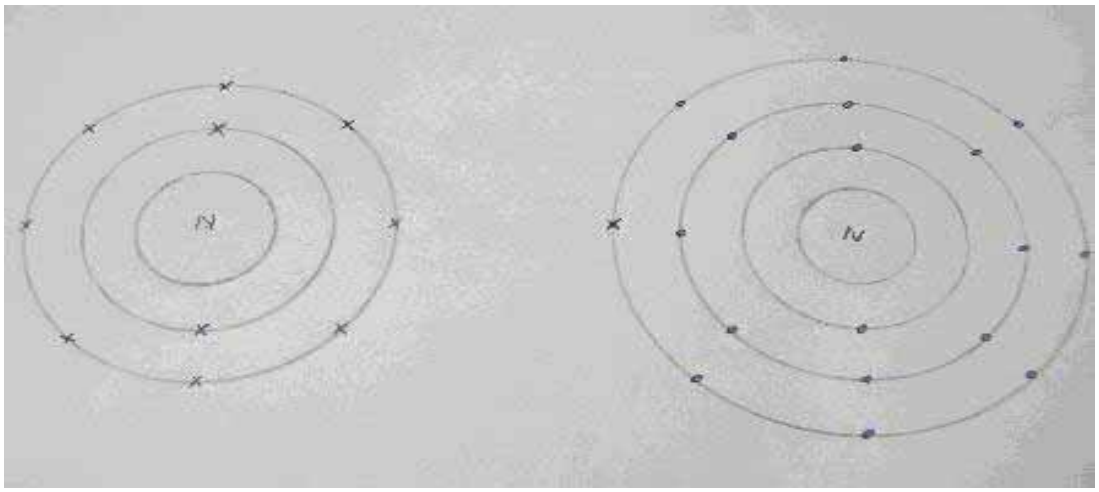


Figure 9b: Ionic bonding between sodium and chlorine. Hand drawn by graphic designer at LDTC.

The above example shows a reaction in which only one electron is donated from a metal to a non-metal. Looking at the structures, you will notice that both have eight electrons in their outer-most shell, and are in a state where they are called ions. A dot and cross diagram of the ionic-bonded NaCl shows that the sodium atom (which had one electron), has donated the electron in its outer shell to the chlorine atom. The chlorine atom (which has seven electrons) has accepted one electron from the sodium atom. We show this as a cross. There are many more ways in which electrons can be donated from a metal to a non-metal. Study the diagram below and answer the questions that follow.

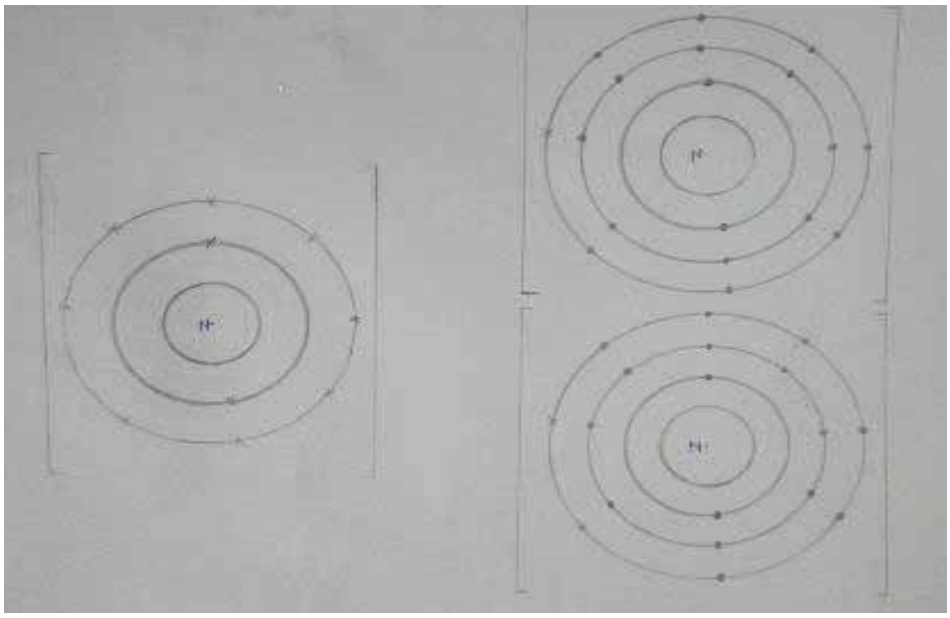


Figure 10: Ionic structure of magnesium chloride. Hand drawn by graphic designer at LDTC.

Activity

Activity 12

1. Answer these questions which are based on Figure 10:

   a) How many electrons did magnesium have in its outer shell?

   _____

   b) How many electrons did magnesium donate to the chlorine atom?

   _____

   c) For the magnesium atom to have a full outer shell, how many chlorine atoms were needed to accept the electrons? _____

   d) After donating the electrons, what is the charge of magnesium ion?

   _____

   e) After accepting electrons, what is the charge of each chlorde ion?

   _____

   f) What will be the formula of magnesium chloride?

   _____

2. Draw a dot and cross structure to show how calcium bonds with oxygen.

After you have answered all of the questions, compare your answers with the ones at the end of the section. If you scored at least five out of six on question one and drew an accurate dot structure, proceed to the next topic. Otherwise, review the content and try the activity again.

A Parallel Example:

Imagine now that calcium and fluorine will bond in the same way as magnesium and chlorine. Calcium has 2 electrons in the outer shell which have to be donated to 2 flourine atoms. The reason why we need 2 flourine atoms is because a fluorine atom needs just one electron for its outer shell to be full so a second fluorine atom is needed to accommodate a second electron from calcium. After donating 2 electrons to fluorine, calcium will have a charge of 2^+ and each of the chlorine ions will a have a charge of 1^-. Since 1 calcium atom needs 2 fluorine atoms to complete the chemical reaction, the formula for calcium fluoride will therefore be CaF_2.

Properties of Ionic Compounds

Ionic compounds have their own properties, which make them different from substances formed from other kinds of bonding:

- Solids at room temperature and pressure. For example: sodium chloride.
- Good conductors of electricity in solution or molten state. This is because they form ions which are positively and negatively charged in solution or molten state.
- Soluble in water and form ions which are positively and negatively charged. For example: magnesium chloride.
- High boiling and melting points.
- Usually hard substances.

Covalent Bonding

Covalent bonding takes place between non-metals only. This kind of a bonding takes place when non-metals (which have a larger number of electrons in the outmost shell) share electrons among themselves (non-metals). When this type of bond is formed, it results in a pair of electron being shared each time a bond is formed during the chemical reaction.

When electrons are shared, the atoms become stable by getting full outer energy levels (eight or two electrons in the outer shell). When two chlorine atoms bond together, each of the chlorine atoms share the electron in the outer shell so that both of them can have eight electrons in the outer shell. When each of the atoms shares an electron, there is a pair of electron being shared between these atoms.

Sometimes more than one pair of electrons can be shared so that there can be two or eight electrons in the outer shell. Where there is more than one pair of electrons shared (say two), then a double bond is formed. When one chlorine atom shares an electron with another chlorine atom, the number of electrons stays the same because neither atom loses anything. After bonding, we no longer have atoms but a neutral molecule.

When we show covalent bonding, dots and crosses are used to represent electrons from two different atoms. However, if the same kind of an atom is being used then the same kind of representation is used. One can use either crosses or dots. When bonding two different atoms, the representation of the electrons in the molecule should be maintained so as to show which electrons and how many electrons have been shared.

Examples of covalent bonding are shown below. They include hydrogen and carbon dioxide. These illustrations use electrons designated by coloured dots. Note that in the first case, both hydrogen atoms end up having two electrons in their shell by sharing a pair of electrons among themselves. In the other examples, carbon, oxygen and fluorine end up having eight electrons in the outer shell thereby achieving an octet by a similar sharing of electron pairs. Carbon dioxide is notable because it is a case in which two pairs of electrons (four in all) are shared between carbon and oxygen so that each of the atoms can end up having eight electrons in the outer shell. This is an example of a double covalent bond.

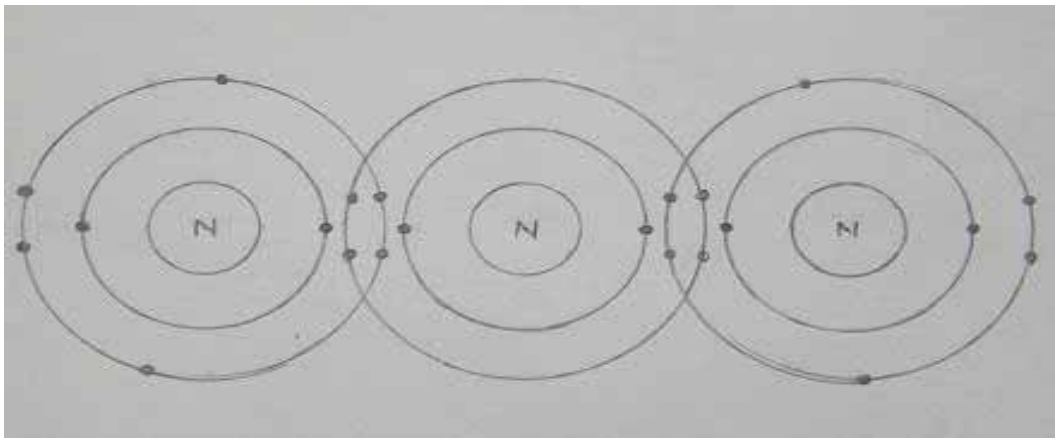


Figure 11: Covalent bonding carbon and oxygen. Hand drawn by graphic designer at LDTC.

Activity 13

Activity

1. Answer the following questions based on Figure 11:

a) How many pairs of electrons were shared between hydrogen atoms?
_____

b) How many pairs of electrons were shared between fluorine atoms?
_____

c) How many pairs of electrons were shared between carbon and oxygen?
_____

d) How many pairs of electrons were shared between carbon and fluorine?
_____

e) How many electrons are found in each atoms outer shell?

Hydrogen and hydrogen_____

Fluorine and fluorine_____

Carbon and oxygen_____

Carbon and fluorine_____

2. Draw a dot and cross diagram to show how bonding will take place between each of the following:

a) Hydrogen and oxygen

b) Hydrogen and carbon

Compare your answers with the ones given at the end of the section. Be sure you understand each answer because you are going to use some of the information learned in this topic in other units.

Important points to consider:

- In covalent bonding, each time a bond is formed it is because each of the atoms has brought an electron to be shared.
- Between any two atoms there is always a pair or more than one pair of electrons to be shared in order to make a stable compound.
- Once all the atoms have attained 8 electrons in the outer shell then there is no need for more sharing of pairs of electrons.

Properties of Covalent Compounds

Covalent compounds have their own properties, which makes them different from other substances made from other kinds of bonding.

- Gases, liquids or solids at room temperature and pressure i.e. water and carbon dioxide.
- Poor conductors of electricity as they do not form ions.
- Generally insoluble in water.
- Low boiling and melting points.

You have now completed the last section of this unit on the periodic table. In the next unit, you will be applying your knowledge of atomic structure, ionic and covalent bonding and electron shells to write chemical formulae and reactions and calculating quantities based on those reactions. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Answers to Activities on Ionic Bonding

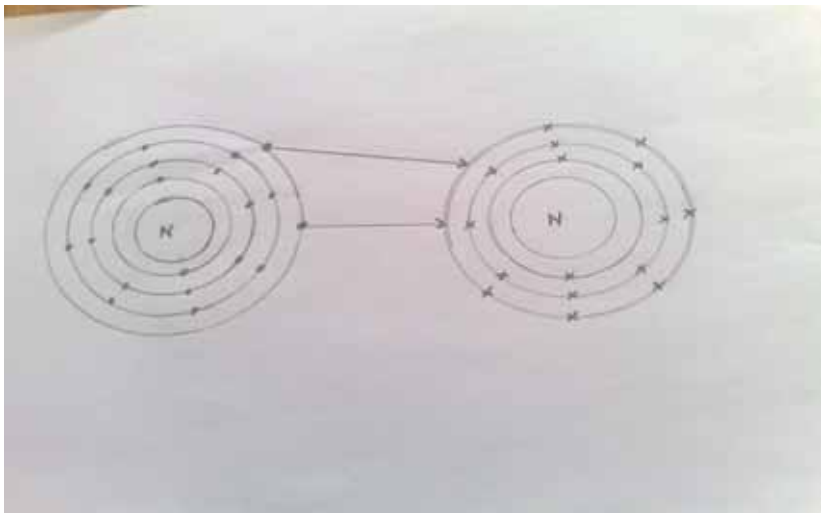
Activity 11

a. Decreases
b. Stay the same
c. Increases
d. Stay the same
e. Positive as there are more protons than electrons
f. Negative as there are more electrons than protons

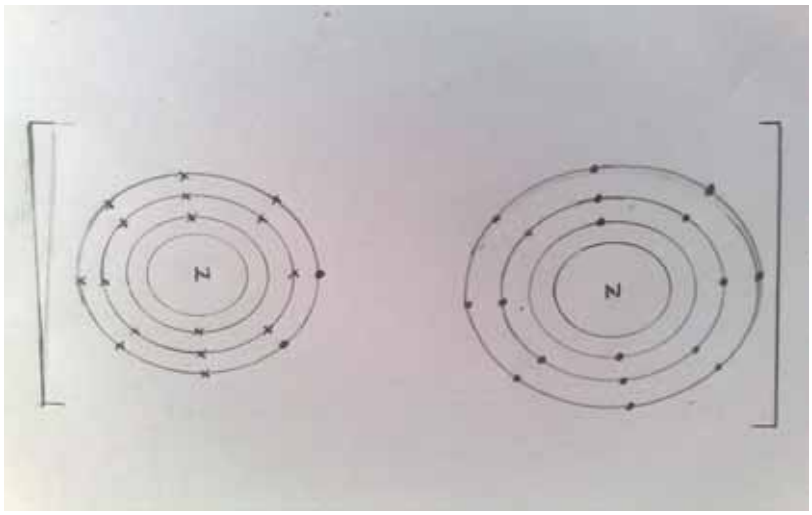
Activity 12

Question 1
a) 2 b) 2 c) 2 d) 2^+ ***e)*** 1^- ***f)*** $CaCl_2$

Question 2
Electron transfer between calcium and oxygen.



Calcium oxide ions.

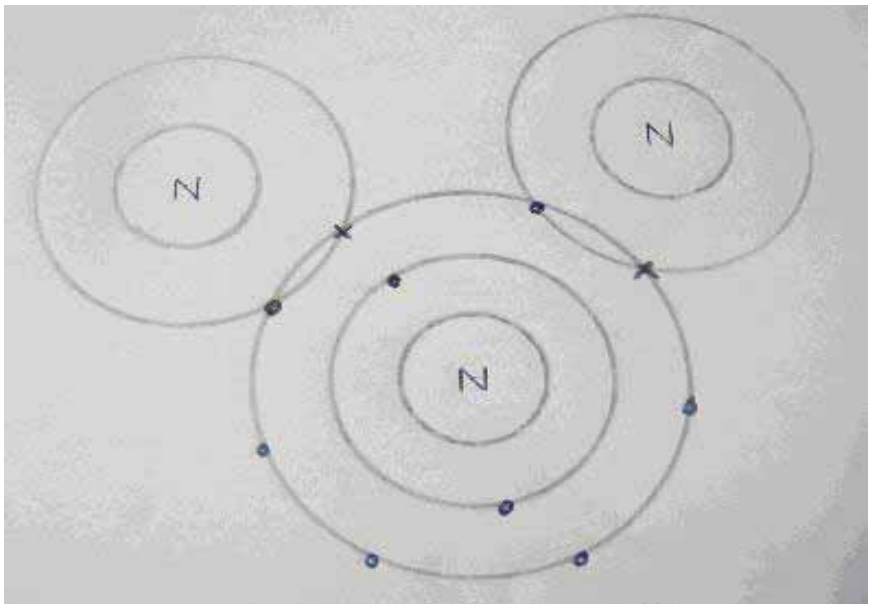


Answers to Activities on Covalent Bonding

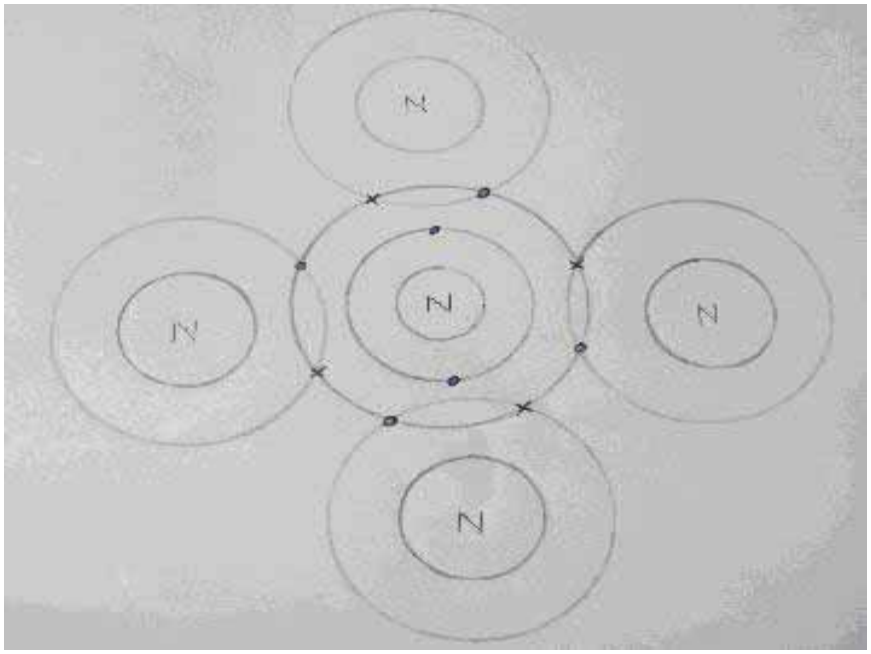
Activity 13

Question 1
a) 1 pair b) 1 pair c) 4 pairs d) 4 pairs e) hydrogen and hydrogen is 2, fluorine and fluorine is 8, carbon and oxygen is 8, carbon and fluorine is 8.

Question 2



Molecular structure of oxygen and hydrogen.



Molecular structure of hydrogen and carbon.

Unit Summary

Summary

In this unit you learned that:

- An atom has three particles: protons, neutrons and electrons.
- Protons and neutrons are situated in the nucleus of an atom while electrons are placed in the shells which are surrounding the nucleus.
- Electrons are arranged in specific number in their shells. For example, the first shell can accommodate a maximum of 2 electrons, the second shell can carry a maximum of 8 electrons and the third and fourth shell can carry a maximum of 8 electrons.
- The way electrons are arranged in an atom is called electronic configuration or electronic structure.
- Elements are classified in the periodic table by the number of electrons in the outer shell and the number of shells around the nucleus. For example, an element with 3 electrons in the outer shell and 4 shells will be found in group 3 (column 3) and period 4 (row 4).
- Elements in the same group have the same chemical and physical properties or show a trend in chemical and physical properties.
- During ionic bonding, metals donate electrons to non-metals. Since the number of electrons and protons are equal in an atom, after electron transfer metals become positively charged while non-metal become negatively charged. After atoms have donated and received electrons they are no longer called atoms but ions (positively and negatively charged ions)
- During covalent bonding (which takes place between non-metals), pairs of electrons are shared by two or more atoms thereby resulting in a molecule.
- Ionic compounds and covalent compounds have their own properties which come from the kind of bonding they have. The table below gives a summary of properties of ionic and covalent compounds

Properties of ionic compounds	Properties of covalent compounds
Usually solids at room temperature and pressure	Usually liquids or gases or solids with low fixed points.
Generally soluble in water	Generally not soluble in water but dissolve in organic solvents
Usually conduct electricity in solution or molten state	Usually do not conduct electricity
Usually hard substances	Usually soft in solid state otherwise are liquids or gases

You have completed the material for this unit on the periodic table. You should now spend some time reviewing the content in detail. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers formulae, stoichiometry and the mole concept.

Assignment 2

Assignment

Answer all the questions in this section. Make sure that you explain your answers thoroughly. When you need to draw a diagram, make them big and clear.

You should be able to complete this assignment in 60 minutes

[Total Marks:50]

1. Element Z has atomic number of 13 and atomic mass of 27.
   a) How many protons are there in element Z?_____ (1)
   b) How many neutrons are there in element Z_____ (1)
   c) How many electrons are in an atom of element Z?_____ (1)
   d) Draw the dot or cross atomic structure of element Z in the given space below. Show the numbers of the other particles and their positions, as well as the arrangement of electrons in the shells. (3)

   e) In which group of the periodic table have you placed element Z and why?_____ (3)
   f) In which period of the periodic table have you placed element Z and why?_____ (3)
   g) Show the electronic configuration of element Z_____ (2)
   h) Identify element Z from the periodic table_____ (1)

2. Elements X, Y and Z have the atomic numbers 4, 9 and 10 and are from the periodic table. Answer the following questions about these elements:

   Show the electronic configuration of:

   X _____

   Y _____

   Z _____ (6)

b. Fill in the chart for each element: (8)

Element	State at room temperature	One chemical property	Name of an element
X			
Y			
Z			

3. a) Draw the chemical structure which shows the bonding between lithium and fluorine. (3)

b) What type of bond forms between lithium and fluoride? _____ (1)

4. Complete the table below using the information given. (14)

Substance	Type of bond existing between atoms	State at room temperature and pressure	Electrical conductivity in solution or in molten state	Ions present
Aluminium Chloride				Al^{3+} and Cl^{-}
Nitrogen Oxide		gas		
Sulphur Dioxide				
Lithium Oxide			Good	

Reflection Question

5. The elements copper, silver and gold are three metals that are found naturally in their elemental state. We have found many uses for these metals such as currency and jewellery because of their durability, colours and resistance to corrosion. How would you explain the fact that these elements have such similar properties?

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 2

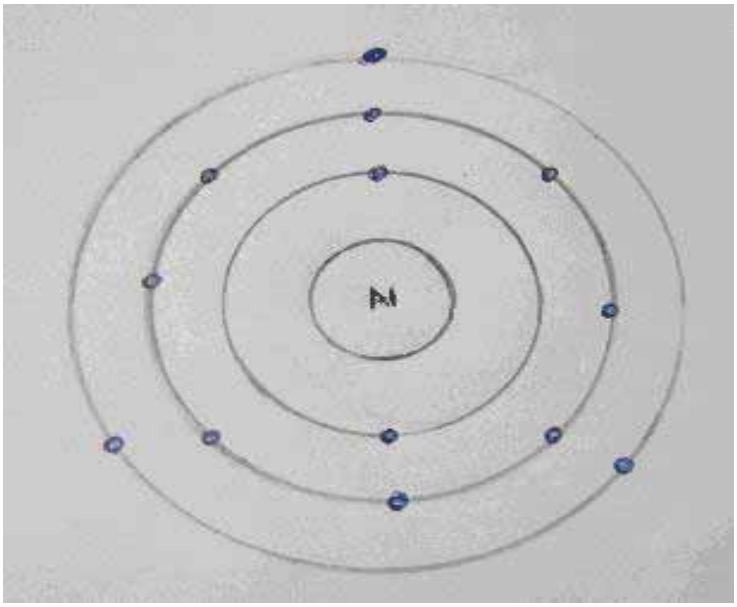
Question 1

a) 13 ***(1)***

b) 14 ***(1)***

c) 13 ***(1)***

d) Atomic structure of aluminium. ***(3)***



e) 3 ***(3)***

f) 3 ***(3)***

g) 2, 8, 3 ***(2)***

h) Aluminium. ***(1)***

Question 2

a) X-2, 2 Y- 2, 7 Z-2, 8 ***(6)***

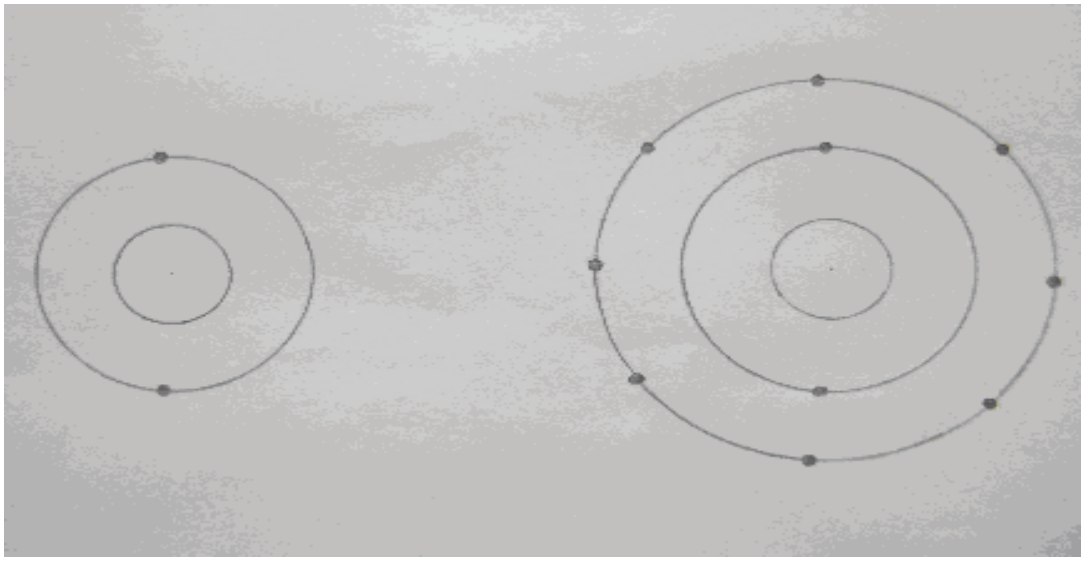
b) X- solid Y- gas Z- gas ***(3)***

c) The table below shows some of the chemical properties of elements X, Y and Z ***(5)***

X	*Y*	*Z*
• *Reacts with halogens to form metal halides* • *Forms molecular substances with other non-metals* • *Forms hydrogen halides when reacting with hydrogen*	*Forms diatomic molecules*	*Unreactive*

Question 3

a) Chemical structure of lithium fluoride *(3)*



b) Ionic bonding *(1)*

Question 4

Substance	*Type of bond existing between atoms*	*State at room temperature and pressure*	*Electrical conductivity in solution or in molten state*	*Ions present*
Aluminium Chloride	*Ionic*	*Solid*	*Good*	Al^{3+} *and* Cl^-
Nitrogen Oxide	*Covalent*	*Gas*	*Poor*	*No ions*
Sulphur Dioxide	*Covalent*	*Gas*	*Poor*	*No ions*
Lithium Oxide	*Ionic*	*Solid*	*Good*	Li^+ *and* Cl^-

One mark for each correct answer (14)

One mark for each ion

5. Copper, silver and gold are all in the same group in the period table (Group 11 of the Transition Metals). This means that they should have similar (although not identical) properties.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent chemistry course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 2

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 60 minutes.

(Total Marks:50)

1. Given that element X has atomic number of 19, an atomic mass of 39 and that it is on the periodic table:

a) How electrons, protons and neutrons are in element X? (3)

_____

b) Draw the atomic structure of element X. (2)

c) In which group of the periodic table is element X? (1)

_____

d) In which period of the periodic table is element X? (1)

_____

e) During a chemical reaction, what kind of bonding do you expect element X form? Explain your answer. (3)

_____

c) Write down two chemical properties of X. (2)

_____

2. During a chemical reaction aluminium (which has atomic number 13) reacts with oxygen (which has atomic number 8) to form aluminium oxide.

a) What kind of chemical bonding will take place between these two elements?

_____
_____ (1)

b) Draw the structure which shows how the bonding will take place between aluminium and oxygen.

(3)

c) How many aluminium atoms and oxygen atoms are needed to make a stable compound of aluminium oxide?

_____ (2)

d) Write down the ion that will be formed by aluminium during chemical bonding. _____ (1)

e) Write down 3 properties of aluminium oxide.

_____
_____
_____
_____
_____ (3)

3. Given that element Y and Z are in groups 7 and 8 of the periodic table respectively:

a) How many electrons would you expect to be in the outer shell of element Y?

_____ (1)

b) What kind of bonding would you expect element Y to form with carbon? Explain your answer.

_____
_____ (3)

c) What kind of bonding would you expect element Z to form with Y? Explain your answer.

_____
_____ (3)

d) Write down any two properties for each of the two elements.

_____
_____
_____
_____ (4)

4. The table below shows some elements A, B, C, D and E and some information about them. Using the information given in the table, fill in the missing numbers about each of the elements.

Element	Atomic number	Number of electrons	Electronic configuration	Group number
A		14	2, 8,4	
B	12			2
C	17			7
D			2, 8, 8	
E	11			

(12)

5. Discuss the following statement with reference to their chemical structures.

a) Magnesium chloride conducts electricity while carbon dioxide does not conduct electricity.

_____
_____
_____
_____ (3)

b) Fixed points of calcium fluoride and hydrogen fluoride are very different.

_____
_____
_____
_____ (2)

Chemistry

Grade 12

COL Open Schools Initiative
Lesotho

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Unit 3

Formulae, Stoichiometry and the Mole Concept

Study Skills

Before you start this unit, reflect on your learning. Ask yourself questions like: Am I flexible in adapting and applying my knowledge to new situations? Am I confident in explaining the material to someone else? Have I consulted my tutor when a concept is unclear to me? ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

Remember that in Unit 2, we discussed ionic and covalent bonding and showed that atoms can bond by losing, accepting or sharing electrons. You are now going to apply that knowledge to discover the formula of chemical compounds. The number of electrons to be given away, accepted or shared determines the formula of the compound to be formed. During a chemical reaction, different substances react in different proportions. The ratio in which atoms react in a chemical reaction is fixed. The fixed ratio of atoms taking part in a chemical reaction gives the formula of a particular substance.

Time

This unit consists of 43 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Outcomes

Study Skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Calculate* different quantities involved in chemical reactions.

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *State* the symbols of the elements and the formulae of the compounds.
- *Determine* the formulae of compounds based on charges on the ions and from relative numbers of atoms present.
- *Construct* both balanced chemical equations with state symbols and ionic equations.
- *Apply* the concept of the mole, molar mass and Avogadro's constant.
- *Solve* problems involving concentrations.
- *Calculate* the stoichiometric reacting masses and volumes of gases.

Terminology

Avogadro's law: Equal volumes of all gases measured under the same temperature and pressure contain the same number of atoms or molecules.

Concentration: The amount of substance dissolved in one cubic decimetre of water. The amount can be expressed in grams/L or in moles/L.

Empirical formula: The formula which shows the simplest ratio of atoms present in a reaction

Mole : The amount of any substance which contain 6 x 10^{23} atoms, ions or molecules of that substance. This number is called Avogadro's constant.

Relative atomic mass:	The mass of an atom compared to the mass of one-twelfth of a carbon atom or one atom of hydrogen.
Relative molecular mass:	The sum of the relative atomic masses of all the elements shown in the formula of the substance. This is usually abbreviated as RMM.

Section 3-1: Chemical Formulae

Introduction

At the end of section 3-1, you should be able to:

- *state* the symbols of the elements and the formulae of the compounds.
- *determine* the formulae of compounds based on charges on the ions and from relative numbers of atoms present.
- *construct* both balanced chemical equations with state symbols and ionic equations.

Time

Section 3-1 has 19 pages. You should spend approximately 5-6 hours on this topic.

Determining the Formulae

Elements have names and symbols which represent them. Looking at the periodic table, you will notice it is made up of symbols and/or names of elements. When we write the chemical formula of a substance, we use symbols of each of the elements in the ratio in which they react during a chemical reaction. You will remember that for a stable compound to be formed, the charge of such a compound must be zero.

Activity

Activity 1

Use the periodic table provided in Figure 1 of Unit 2 to answer the following questions:

1.

a) In which group of the periodic table is sodium? _____

b) What is the symbol for sodium? _____

c) How many electrons are in the outer shell of sodium? _____

d) Will sodium bond ionically or covalently with non-metals during a chemical reaction? _____

Why? _____

e) In which group of the periodic table is bromine? _____

f) What is the symbol for bromine? _____

g) How many electrons are in the outer shell of bromine? _____

h) Will bromine bond ionically or covalently with metals during a chemical reaction? _____

Why? _____

i) If sodium reacts with bromine, how many electrons will be donated to bromine to fill its outer shell? _____

j) How many bromine atoms are needed to accept the electrons from the outer shell of sodium? _____

k) Suggest the formula for sodium bromide: _____

2.

a) In which group of the periodic table is hydrogen? _____

b) What is the symbol for hydrogen? _____

c) How many electrons are in the outer shell of hydrogen? _____

d) Will hydrogen bond ionically or covalently with oxygen during a chemical reaction? _____

e) In which group of the periodic table is oxygen? _____

f) What is the symbol for oxygen? _____

g) How many electrons are in the outer shell of oxygen? _____

h) Will oxygen bond ionically or covalently with other non-metals during a chemical reaction? _____

i) If hydrogen reacts with oxygen how many pairs of electrons will be shared between these two elements so that each has a full outer shell? _____

j) How many atoms of each of the elements are needed to share electrons so that each atom has a full outer shell? _____

k) Suggest the formula for hydrogen oxide:_____

l) Write the balanced chemical equation for this reaction: _____

3.

Look at the periodic table and write down:

i. the symbols for each of the following.

ii. the formulae for the compounds formed when the following elements react together:

a) Magnesium and sulphur_____

b) Calcium and chlorine_____

c) Nitrogen and hydrogen_____

d) Carbon and oxygen_____

e) Aluminium and fluorine_____

f) Hydrogen and sulphur_____

g) Potassium and chloride_____

Compare your answers with the ones given at the end of the section. If you had difficulty in answering these questions go back to Unit 2 and read about bonding. You can also draw atomic structures to help you answer some of the questions. If you have forgotten about atomic structures go back to Unit 2 to remind yourself.

From the above section, we can determine the formulae of the substance by looking at the number of electrons to be shared between reacting atoms or number of electrons to be donated or accepted. You will

remember that when an atom loses or accepts an electron it becomes positively charged or negatively charged respectively. We have also seen that after bonding, the compound formed is chemically neutral. This behaviour can help us to determine the formulae of substances.

Activity

Activity 2

Answer the following questions based on the given ions of elements.

1.

a) What is the charge on a lithium ion? _____

b) Write down the symbolic formula for lithium ion: _____

c) What is the charge on a fluorine ion? _____

d) Write down the symbolic formula for a fluorine ion: _____

e) If lithium fluoride is chemically neutral, how many ions of lithium and fluorine do you need to form lithium fluoride? _____

f) Determine the formula for lithium fluoride: _____

2.

a) What is the charge on a magnesium ion? _____

b) Write down the symbolic formula for a magnesium ion: _____

c) What is the charge of chlorine ion? _____

d) Write down the symbolic formula for chlorine ion: _____

e) If magnesium chloride is chemically neutral, how many ions of magnesium and chlorine do you need to form magnesium chloride? _____

f) Determine the formula for magnesium chloride: _____

3. Determine the formula of the substance that will be formed when the following ions react together during a chemical reaction:

a) Potassium ion and sulphide ion_____

b) Calcium ion and oxide ion_____

c) Magnesium ion and chloride ion_____

d) Lithium ion and oxide_____

e) Beryllium ion and fluoride ion_____

Now compare your answers with the ones given at the end of the section. Continue with the next topic if you have scored 80% or more. For every mistake you made, determine why you answered the question incorrectly.

Help

Need more practice naming ionic compounds? If you have internet access, please go to:

http://misterguch.brinkster.net/pra_namingwkshts.html

Balancing Equations

Elements from the periodic table react in fixed ratios to form chemical compounds. The equation that shows the number or numbers of reacting substances and the number of new substances formed is called a **balanced equation.** The number of atoms in the substances reacting must be equal to the number of atoms in the substances formed.

Example:

Look at the example of an equation below:

$Mg + O_2 \longrightarrow MgO$

How many magnesium atoms do we have on the left-hand side? _____

How many magnesium atoms do we have on the right-hand side? _____

How many oxygen atoms do we have on the right-hand side? _____

How many oxygen atoms do we have on the left-hand side? _____

A balanced equation is one that has an equal number of each atom on both sides of the equation. To balance an equation, we need to insert numbers in front of each of the substances reacting until both sides have

the same number of atoms.

The above equation is can be balanced as shown below:

$2Mg + O_2 \longrightarrow 2MgO$

The number 2 is placed in front of Mg, the number 1 (though we never write it) is placed in front of O_2 and the number 2 is placed in front of MgO to balance the equation.

Activity

Activity 3

1. Let us have a look at this balanced equation and try to answer the questions that follow:

Aluminium + Oxygen → Aluminium oxide

$4Al + 3O_2 \rightarrow 2Al_2O_3$

a) How many electrons are in the outer shell of an aluminium atom? _____

b) How many electrons can be donated by an aluminium atom? _____

c) How many electrons are in the outer shell of an oxygen atom? _____

d) How many electrons can be accepted by an oxygen atom? _____

e) How many electrons will be left in the outer shell of aluminium after the outer shell of oxygen is filled with electrons? _____

f) What do you suggest could be done with electrons left in the outer shell of aluminium?

_____

g) How many aluminium atoms and oxygen atoms do you need for all shells to have eight electrons in the outer shell?

_____

h) For the reaction to be complete how many aluminium atoms do you need? _____

i) For the reaction to be complete how many oxygen atoms to you need? _____

2. During a chemical reaction, hydrogen reacts with oxygen to form water. A word equation representing the reaction is shown below:

Hydrogen + oxygen → water

Now answer the following questions:

a) Write the formula for a hydrogen molecule: _____

b) Write the formula for an oxygen molecule: _____

c) What kind of a bonding takes place between hydrogen and oxygen? _____

d) Write the chemical formula for water: _____

e) Write the chemical equation for the above reaction using chemical symbols for hydrogen, oxygen and water:
_____

f) From the equation in (e) how many atoms of oxygen will be involved in this reaction if it is to go to completion?
_____

g) How many atoms of hydrogen will be involved if the reaction was to go to completion?
_____

h) Now write a balanced chemical equation for the above reaction:_____

3. Now consider making a balanced equation from ions of beryllium reacting with ions of fluorine.

Beryllium ion + Fluorine ion → Beryllium fluoride

a) What is the charge on a beryllium ion? _____

b) Write down the formula of a beryllium ion: _____

c) What is the charge on a fluoride ion? _____

d) Write down the formula of a fluoride ion: _____

e) How many fluoride ions do you need to balance the charge on a beryllium ion? _____

f) Write down the symbolic formula for beryllium fluoride: _____

g) Write a balanced equation showing the reaction between a beryllium ion and a fluoride ion: _____

4. Let us make a balanced equation from ions of sodium reacting with ions of oxygen.

Sodium ion + Oxygen ion → Sodium oxide

a) What is the charge on a sodium ion? _____

b) Write down the formula of a sodium ion: _____

c) What is the charge on an oxygen ion? _____

d) Write down the formula of an oxygen ion: _____

e) How many sodium ions do you need to balance the charge on an oxygen ion? _____

f) Write down the symbolic formula for sodium oxide._____

g) Write a balanced equation showing the reaction between a sodium ion and an oxygen ion:_____

5. Write a balanced equation which shows the reaction between the following ions:

a) Sodium ion and sulphide ion_____

b) Calcium ion and chloride ion_____

c) Hydrogen ion and oxide ion_____

d) Aluminium ion and sulphide ion_____

e) Magnesium ion and oxide ion_____

Compare your answers with the ones given at the end of the section. Review the content as needed until you understand why each answer is correct.

Help

Need more practice balancing equations? If you have internet access, please go to:

http://education.jlab.org/elementbalancing/index.html

Important points to remember:

Note it!

- You should have found that different substances react in fixed proportion depending on their charges or the number of electrons found in the outer shell of each of the atoms.
- The equation that shows the number of substances that react and the number of substances formed in a chemical reaction is a balanced chemical reaction.

Answers to Activities on Chemical Equations

Activity 1

Question 1

a) One b) Na c) One d) Ionically e) seven f) Br

h) Seven i) Covalently j) One k) One l) NaBr

Question 2

a) One b) H c) One d) Covalently e) H2O f) O g) six

h) Covalently i) 2 pairs j) Oxygen 1, hydrogen 2 k) H_2O

m) $H_2 + O_2$ → H_2O

Question 3

a) i) Mg, S *ii) MgS*

b) i) Ca, Cl *ii) $CaCl_2$*

c) i) N, H *ii) NH_3*

d) i) C, O *ii) CO_2*

e) i) Al, F *ii) AlF_3*

f) i) H, S *ii) H_2S*

g) i) K, Cl *ii) KCl*

Activity 2

Question 1

a) $^{+}1$ b) Li^{+} c) $^{-}1$ d) F^{-1} e) Lithium 1, Fluorine 1

Question 2

a) +2 b) Mg^{2+} c) -1 d) Cl- e) Magnesium 1, Chlorine 2

f) $MgCl_2$

Question 3

a) K_2S b) CaO c) $MgCl_2$ d) Li_2O e) BeF_2

Activity 3

Question 1

a) Three b) Three c) Six d) Two e) One f) Be donated to another oxygen. g) Aluminium 2, oxygen h) Four i) Six

Question 2

a) H_2 b) O_2 c) Covalent bonding d) H_2O e) $H_2 + O_2 \rightarrow H_2O$ f) Oxygen 2 g) Hydrogen 4

h) $2H_2 + O_2 \rightarrow 2H_2O$

Question 3

a) +2 b) Be^{+2} c) -1 d) F^{-1} e) 2 f) BeF_2
g) $Be + F_2 \rightarrow BeF_2$

Question 4

a) +1 b) Na^{+1} c) -2 d) O^{2-} e) Two f) Na_2O

f) $2Na+ + O^{2-} \rightarrow Na_2O$

Question 5

a) $2Na^{+} + S^{-2} \rightarrow Na_2S$

b) $Ca^{2+} + 2Cl^{-} \rightarrow CaCl_2$

c) $2H^{+} + O^{2-} \rightarrow H_2O$

d) $2Al^{3+} + 3S^{2-} \rightarrow Al_2S_3$

e) $Mg^{2+} + O^{2-} \rightarrow MgO$

Section 3-2: The Mole Concept

Introduction

At the end of section 3-2, you should be able to:

- *apply* the concept of a mole, calculate molar mass and use the Avogadro constant to solve problems involving concentrations.
- *calculate* the stoichiometric reacting masses and volumes of gases.

Time

Section 3-2 has 23 pages. You should spend approximately 8-9 hours on this topic.

During chemical reactions, different substances react in different masses, volumes and concentrations. It is important to know how much of each

substance reacts and how much of each product is produced. To know this, we always start from balanced equations as these equations show the proportion of all the substances reacted and produced.

However, there are some cases in which we use certain chemistry laws, definitions, formulas, values or constants which have been discovered and agreed upon. Some of the constants, laws and definitions are given in the terminology section above and you may need to refer to them. Sometimes you need to rearrange the formula so that you can solve for the unknown variable (i.e. mass, concentration etc.).

Moles of Elements, Compounds and Molar Mass

The **relative atomic mass** of an element is defined as the number of times an average atom of the element is heavier than one-twelfth the mass of one atom of carbon-12. One-twelfth the mass of carbon-12 also equals the mass of one atom of hydrogen. Since the masses of atoms are compared to the mass of carbon or hydrogen, then we say they are relative atomic masses. The masses of different substances are calculated using this relationship For example; the molar mass of sodium is 23g. In 23g there are 6×10^{23} sodium atoms which means that one mole of sodium has a mass of 23g. The number of atoms in a mole (6×10^{23}) is called **Avogadro's number**.

Many substances exist as gases and from our everyday experience we know that gases are measured in volumes, masses or moles. Just like other substances, the mass of a gas is made up by the masses of the atoms making up the gas. In science, one mole of a gas at room temperature and pressure is approximately 24 dm^3. The relationship between the units for measuring gases are as follows: 1 dm^3 = 1 litre = 1000 cm^3. In other words the calculations for volumes of gases can be done in masses, moles and volumes.

To calculate the number of moles in a given mass:

$$\text{Mass (g)} \times \frac{1 \text{ mol}}{\text{molar mass of element or compound}}$$

Example 1: How many moles are there in 500 g of sodium?

$$500 \text{ g} \times \frac{1 \text{ mol}}{23 \text{ g Na}} = 21.7 \text{ moles of Na}$$

To calculate the mass of a certain number of moles:

$$\text{Number of Moles} \times \frac{\text{molar mass of element or compound}}{1 \text{ mol}}$$

Example 2: What is the mass of 21.7 moles of sodium?

$$21.7 \text{ mol} \times \frac{23 \text{ g Na}}{1 \text{ mol}} = 500 \text{ g Na}$$

Volume of a gas = number of moles x $24 dm^3$

$$\text{Number of moles} = \frac{\text{volume of gas (in } dm^3)}{24 \ dm^3}$$

Help

Many students have difficulty understanding the mole. If you have internet access, please go to:

http://www.lynchburg.net/hhs/chemistry/dozens/

You may need to contact your tutor if you are having difficulty understanding the concept of the mole.

You will need your copy of periodic table to help answer these questions.

Activity

Activity 4

1. 40 g is the mass of one mole of calcium atoms. Calculate the following:

a) The mass of 2 moles of calcium:

_____
_____
_____
_____

b) The mass of 1.5 moles of calcium:

_____
_____
_____
_____

c) The mass of ½ mole of calcium

_____
_____
_____
_____

d) The number of moles of calcium present in 100 g_____

e) The number of moles of calcium present in 8 g

f) The number of moles of calcium present in 50g _____

2. One mole of water has a mass of 18g (H_2O- H is 1g, so 2H = 2g, O = 16 so 2g + 16g = 18g). Now calculate the following:

a) The mass of 3 moles of water_____

b) The mass of 0.1 mole of water_____

c) The mass of 5 moles of water_____

d) The number of moles of water contained in 36 g_____

e) The number of moles of water contained in 4.5 g_____

f) The number of moles of water contained in 45 g_____

3. One mole of carbon dioxide has a mass of 44 g. If one mole of carbon dioxide has a volume of 24 dm^3 at room temperature and pressure (STP), calculate:

a) The volume of 3.5 moles of carbon dioxide_____

b) The volume of 0.25 moles of carbon dioxide_____

c) The number of moles present in 48 dm^3 of carbon dioxide_____

d) The number of moles contained in 12 dm^3 of carbon dioxide_____

e) The mass of carbon dioxide in 36 dm^3_____

f) The mass of carbon dioxide in 6 dm^3_____

Now compare your answers with the ones given at the end of the section. Make sure you understand all the calculations before you move to the next topic.

Remember the following important points:

Note it!

You should have found that all calculations could be done using simple ratios, but we can also come up with the formula which can be used to calculate either the number of moles of a substance from the mass or the mass of a substance from the number of moles of that substance.

Study the following formula and confirm your answers to questions 1 and 2 using these formulae.

Mass of a substance = number of moles x relative atomic/molecular mass

$$\textbf{Number of moles} = \frac{\textbf{mass of a substance}}{\textbf{relative molecular/atomic mass}}$$

Volume of a gas = number of moles x 24dm^3

$$\textbf{Number of moles} = \frac{\textbf{volume of gas (in dm}^3\textbf{)}}{\textbf{24 dm}^3}$$

4. Answer the following questions using the above formulae:

One mole of sodium has a mass of 23 g. One mole of sulphur dioxide has a mass of 64 g. Now calculate:

a) The number of moles present in 32 g of sulphur dioxide_____

b) The number of moles contained in 69 g of sodium_____

c) The mass of sodium in 2.5 moles_____

d) The mass of 1.5 moles of sulphur dioxide_____

e) The mass of ½ mole of sodium _____

f) The number of moles present in 8 g of sulphur dioxide_____

g) The volume of 0.1 mole of sulphur dioxide_____

h) The volume of 3 moles of sulphur dioxide at STP (standard temperature and pressure)_____

Compare your answers to the ones given at the end of the section. If you scored less than 80%, review the content until you understand those answers.

Note the following important points:

You should have found that to find the answers, you can use simple ratios which relate the relative atomic mass or relative molecular mass to the number of moles of a substance. The same ratio can be used when calculating the volume of gases at room temperature and pressure (STP).

Concentrations

In many reactions, the reactants which are soluble are dissolved in water to make solutions. In order for the reaction to take place in a meaningful manner, correct solution have to be made. To make a solution a certain amount of a solute must be dissolved in a certain amount of water (solvent) to make a concentration of certain strength.

Concentration is usually measured in number of moles per cubic decimetre (mol/dm^3 or mol dm^{-3}). Remember that 1 dm^3 = 1L Sometimes the concentration of a solution can be expressed by showing the number of moles in one decimetre (or L) and a capital M. For example a solution which contains two moles in one decimetre is written as 2 M. A solution which contains one mole in one decimetre is called a **molar solution**. For calculating concentration in a certain solution we use the following formulae:

$$\textbf{Concentration} = \frac{\textbf{number of moles}}{\textbf{Volume}}$$

From the formula above, find what the number of moles in a solution would be and the volume by completing the following formula:

Number of moles = _____ **x** _____

$$\textbf{Volume} = \frac{\square}{\square}$$

Compare your answers with the following:

Number of moles = Concentration x Volume

Volume = $\frac{\text{Number of moles}}{\text{Concentration}}$

(Note that $1dm^3 = 1000cm^3 = 1$ litre)

Activity 5

Activity

Use the formulae above to the answer the following questions.

1. If 20g of sodium hydroxide is dissolved in 0.25 dm^3 of water, calculate the following:

a) What is the mass of one mole of sodium hydroxide?

_____
_____
_____
_____

b) How many of moles of sodium hydroxide are in 20 g?

_____
_____
_____
_____
_____

c) Use your answer in (b) to find how many moles are present in 1 dm^3

_____
_____
_____
_____
_____

d) What will be the concentration of the solution?

_____
_____
_____
_____
_____

e) Use the formulae to confirm your answer to (d) above._____
_____
_____
_____
_____
_____

2. If a 0.125 dm^3 solution is found to contain 14 g of potassium hydroxide, calculate the following:

a) What is the relative molecular mass of potassium hydroxide?

b) How many moles of potassium hydroxide are in 14 g?

c) How many moles will be present in 1 dm^3 of the solution?

d) What will be the concentration of the solution?

e) Use the formulae to confirm your answer to (d) above.

3. If we need to prepare 200 cm^3 of a solution of magnesium oxide with a concentration of 2 M find the following:

a) The number of moles in 1 dm^3 of the solution

b) The number of moles which will be present in 200 cm^3

c) The number of moles which will be present in 200 cm^3 using the formula above to confirm your answer to (b).

d) The relative molecular mass of magnesium oxide.

e) The mass of magnesium oxide to be dissolved in 200 cm^3

Now compare your answers with the ones given at the end of the section. Be sure you understand each answer before continuing.

Note it!

Note:

You may have found that all of the calculations could be done using simple ratios. However, you can also use the formula given to come up with the answer. It is important for you to be able to use both of them.

Reacting masses

During a chemical reaction, different reactants react in certain specific moles or masses. In order to produce a certain amount of a product in a lab, you would have to know how much there is of each of the reactants to react together. If we have a balanced equation which shows the proportion of each substance (or species) in the reaction, then we will be able to calculate any substance's mass in the reaction.

When calculating the mass of any species in a reaction, we can use a simple ratio just like we did with the other examples. The most important thing in calculating the mass of a species in a reaction is to use a balanced equation where we can see the ratio of substances reacting and substances formed. When we have balanced the equation, we can then calculate the mass of each of the reactant by using the ratios. From the balanced equations, we look for the corresponding parts that we are interested in and then use them to make some calculations.

Example:

During a chemical reaction, 6 g of magnesium was burned in excess oxygen. Calculate the mass of magnesium oxide is produced (In excess here means that in was not in short supply, in other words, the amount of oxygen is not important in determining the mass of MgO produced).

Magnesium + oxygen → Magnesium oxide

$2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)}$

The following calculation shows the molar mass (the mass of 1 mole) of each substance involved in this reaction according to the above balanced equation:

2 x 24 g + 16 g x 2 → 2 x (24+16)g

48 g + 32 g → 2 x (40)g

48 g + 32 g → 80 g

We notice that 48 g of magnesium produces 80 g of magnesium oxide. Now, since 6 g of magnesium was burned we use the ratio to find out how much of the magnesium oxide will be produced:

48 g → 80 g

6 g → **x** g

$\mathbf{x} = \frac{6\text{ g} \times 80\text{ g}}{}$

48 g

x = 10 g

Study the example given above and use the same method with simple ratios to do the following activity.

Activity 6

Activity

1. Look at the following reaction and answer the questions that follow:

Carbon + Oxygen → Carbon dioxide

$C_{(s)}$ + $O_{2(g)}$ → $CO_{2(g)}$

1 mole 1mole 1mole

12 g + 32 g → 44 g

If 6 g of carbon in burned in excess oxygen, calculate:

a) The number of moles of carbon reacting_____
_____
_____
_____

b) The mass of carbon dioxide that will be formed_____
_____
_____
_____
_____

c) The volume of carbon dioxide that will be formed_____
_____
_____
_____
_____

After each question, check your answers with those at the end of the section to be sure that you are learning the concepts correctly before continuing.

2. Study the reaction below and answer the questions that follow:

Nitrogen + Hydrogen → Ammonia

$N_{2(g)}$ + $3H_{2(g)}$ → $2NH_{3(g)}$

1mole 3moles 2moles

28 g 6 g 34 g

If 7 g of nitrogen is reacted completely with hydrogen, calculate the following:

a) The number of moles of nitrogen reacting_____

b) The volume of nitrogen reacting_____

c) The mass of ammonia produced_____

d) The number of moles of ammonia produced_____

e) The volume of ammonia produced_____

3. Look at the reaction below and answer the questions that follow.

$CaCO_{3(s)}$ + $2HCl_{(g)}$ → $CaCl_{2(s)}$ + $CO_{2(g)}$ + $H_2O_{(l)}$

1mole 2moles 1mole 1mole 1mole

If 25 g of $CaCO_3$ reacted completely with 250 cm^3 of hydrochloric acid, calculate the following:

a) The relative molecular mass of HCl_____
_____
_____
_____
_____

b) The mass of hydrochloric acid present in 250 cm^3 of the solution_____
_____
_____
_____
_____

c) The number of moles of hydrochloric acid present in 250 cm^3 of solution_____
_____
_____
_____

d) The concentration of hydrochloric acid used in this reaction_____
_____
_____
_____
_____
_____

e) The number of moles of carbon dioxide produced_____
_____
_____
_____
_____

f) The volume of carbon dioxide gas produced at STP_____
_____
_____
_____
_____

g) The mass of calcium chloride produced_____

_____

_____

_____

_____

_____

_____

Compare your answers to the ones given at the end of the section. Be sure that you understand why each answer is correct before you continue.

Note it!

Important points to remember:

- Reactions can involve substances in solid form, solutions and gases.
- In all of the calculations, you can use a simple ratio once you balance the chemical equation.

Finding the Formulae

We have seen that we can determine the formula of a substance from the number of electrons to be donated and accepted by different atoms, we can also find the formula from the charges of the ions involved in the chemical reaction.

We can again find the formula from the masses of the reactants and products formed. Usually this method involves readings taken from experiments performed in the laboratory. The masses reactants and products formed are used to determine the number of moles of each of the substances reacting and formed.

Example

In an experiment, a piece of magnesium ribbon was burned in excess oxygen and the following results were obtained:

Mass of crucible before experiment	15.2 g
Mass of crucible and magnesium	15.8 g
Mass of crucible and magnesium oxide	16.2 g
Mass of magnesium (15.8 g -15.2 g)	0.6 g

Mass of magnesium oxide (16.2 g – 15.2 g) 1.0 g

Calculating the number of moles which reacted:

Magnesium $\frac{0.6\ g}{24\ g} = 0.025$ moles

Oxygen $\frac{0.4\ g}{16\ g} = 0.025$ moles

Ratio of reacting moles:

Magnesium : oxygen

0.025 0.025

1 1 (the ratio in its simplest form)

Now we need to write the empirical formula which shows the simplest ratio of the atoms present in the formula.

Empirical formula is therefore **MgO** since the ratio of magnesium to oxygen is 1 : 1

Activity

Activity 7

1. In an experiment an unknown amount of silicon was heated in excess oxygen and the following results were obtained:

Mass of crucible before experiment 17.6 g

Mass of crucible and silicon 20.4 g

Mass of crucible and silicon oxide 23.6 g

Now answer the following questions by making calculation of:

a) What is the mass of silicon that reacted? _____

b) What is the mass of oxygen which reacted? _____

c) How many moles of silicon reacted? _____

d) How many moles of oxygen reacted? _____

e) What is the simplest ratio of the number of moles which reacted?
_____

f) Suggest the formula of silicon oxide:_____

2. In an experiment, 5.4 g of aluminium reacted with 4.8 g of oxygen.

Find the answers to the following:

a) Number of moles of aluminium that reacted: _____

b) Number of moles of oxygen that reacted: _____

c) The simplest ratio of the moles of aluminium and oxygen which reacted together: _____

d) The formula for the oxide of aluminium: _____

Now compare your answers with the ones given at the end of the section. Take the time needed to ensure that you understand each answer.

Note it!

Important points to remember:

The most important thing for determining the formula from a reaction is to use the reactant masses to calculate the number of moles of each substance in the reaction and then find the simplest ratio of the moles of the atoms. The simplest ratio gives us what we call the empirical formula.

You have now completed the last section of this unit on formulae, stoichiometry and the mole concept. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Answers to Activities on Mole Concept

Activity 4

Question 1

a) 1 mole → 40 g

2mole → 2 x 40 g

=80 g

b) 1 mole → 40 g

1.5 moles → 1.5 x 40 g

=60 g

c) 1 mole → 40 g

0.5 moles → 0.5 x 40 g

= 20 g

d) 1 mole → 40 g

x moles → 100 g

$$x = \frac{100}{4} = 2.5 moles$$

e) 1 mole → 40 g

x moles → 8 g

$$x = \frac{8}{40} = 0.2 moles$$

f) 1 mole → 40 g

x moles → 50 g

$$x = \frac{50}{40} = 1.25 moles$$

Question 2

a) 1 mole → 18 g

3 moles → 3 x 18 g

= 54 g

b) 1 mole → 18 g

0.1 mole → 0.1 x 18

= 1.8 g

c) 1 mole → 18 g

5 moles → 5 x 18 g

= 90 g

d) 1 mole → 18 g

x moles → 36 g

$$x = \frac{36}{18} = 2\text{moles}$$

e) 1 mole → 18 g

x moles → 4.5 g

$$x = \frac{4.5}{18} = 0.25\text{moles}$$

f) 1 mole → 18 g

x moles → 45 g

$$x = \frac{45}{18} = 2.5\text{moles}$$

Question 3

a) 1 mole → 24 dm^3

3.5 moles → 3.5 x 24

84 dm^3

b) b)1 mole → 24 dm^3

0.25 moles → 0.25 x 24

= 6 dm^3

c) c) 1 mole → 24 dm^3

x moles → 48 dm^3

$$x = \frac{48}{24} = 2\text{moles}$$

d) d) 1 mole → 24 dm^3

x moles → 12 dm^3

$$x = \frac{12}{24} = 0.5\ \text{moles}$$

e) 1 mole → 24 dm^3

x moles → 36 dm^3

$$x = \frac{36}{24} = 1.5\text{moles}$$

f)

1 mole of carbon dioxide → 44 g

1.5 moles → 1.5 x 44

=66 g

g) 1 mole → 24 dm^3

x moles → 6 dm^3

$$x = \frac{6}{24} = 0.25\text{moles}$$

1 mole of carbon dioxide → 44 g

0.25 mole → 0.25 x 44 g

=11 g

Question 4

a) 1 mole → 64 g

x moles → 32 g

$$x = \frac{32}{64} = 0.5\text{moles}$$

b) 1 mole → 23 g

x moles → 69 g

$$x = \frac{69}{23} = 3\text{ moles}$$

c) 1 mole → 23 g

2.5 moles → 2.5 mole x 23 g = 57.5 g

d) 1 mole → 64g

1.5 moles → 1.5 x 64 = 96 g

e) 1 mole → 23 g

0.5 moles → 0.5 moles x 23 g = 11.5 g

f) 1 mole → 64 g

x moles → $\frac{1\ mole\ x\ 8g}{64g} = 0.125g$

g) 1 mole → 24 dm^3

0.1 moles → 0.1 moles x 24 dm^3 = 2.4 dm^3

h) 1 moles → 24 dm^3

3 moles → 3 moles x 24 dm^3 = 72 dm^3

Activity 5

Question 1

a) Sodium = 23

Hydrogen = 1

Oxygen = 16

Sodium hydroxide = 40 g

b) mole → 40 g

x → 20 g

$$x = \frac{1\ mole\ x\ 20g}{40g} = 0.5\ moles$$

c) 0.5 moles → 0.25 dm^3

X → 1 dm^3

$$x = \frac{0.5\ moles\ x\ 1\ dm^3}{0.25 dm^3}$$

d) 2 moles/dm^3

e) concentration= $\frac{0.5\ moles}{0.25\ dm^3}$

Question 2

a) Potassium = 39 g

Hydrogen = 1 g

Oxygen = 16 g

Potassium hydroxide = 56 g

b) 1 mole → 56 g

x moles → 14 g

$$x = \frac{1mole\ x\ 14g}{56g}\ 0.25\ moles$$

c) 0.125 dm^3 → 0.25 moles

1 dm^3 → x

$$x = \frac{1dm^3 x\ 0.25\ moles}{0.125\ dm^3} = 2\ moles$$

d) 2 moles/dm^3

e) $$concentration = \frac{0.25\ moles}{0.125 dm^3} = 2 mole/dm^3$$

Question 3

a) 2 M means 2 moles in 1dm^3

2 moles → 1000 cm^3

x moles → 200 cm^3

$$x = \frac{200 cm^3 x 2\ moles}{1000 cm^3} = 0.4\ moles$$

b) $$x = \frac{200 cm^3 x 2\ moles}{1000 cm^3} = 0.4\ moles$$

c)

magnesium = 24 g

oxygen = 16 g

magnesium oxide = 40 g

d) 40g → 1000 cm^3

x → 200 cm^3

$$x = \frac{40g\ x\ 200 cm^3}{1000 cm^3} = 8g$$

Activity 6

Question 1

a) *Moles of carbon reacting* $= \frac{6}{12} = 0.5$ *moles*

b) *Mass of carbon dioxide produced*

12 g → *44 g*

6 g → *x*

$$x = \frac{6g \times 44g}{12g} = 22g$$

c) *1 mole = 44 g*

44 g → *24 dm*^{3}

22 g → *x*

$$x = \frac{22g \times 24}{44g} = 12\ dm^3$$

Question 2

a) *1 mole of* N_2 → *28 g*

X moles N_2 → *7 g*

$$x = \frac{1mole \times 7g}{28g} = 0.25moles$$

b) 1 mole of a gas → *24 dm*^{3}

0.25 moles → *0.25 x 24 =* *6 dm*^{3}

c) 28 g of N_2 → *34 g of* NH_3

7g of N_2 → *x g of* NH_3

$$x = \frac{7g \times 34g}{28g} = 8.5moles$$

d) 1 mole of NH_3 → 17 g NH_3

x moles → 8.5 g

$$x = \frac{1\text{mole} \times 8.5\text{g}}{17\text{g}} = 0.5\text{moles}$$

e) 1 mole of a gas → 24 dm^3

0.5 moles → 0.5 moles x 24 dm^3 = 12 dm^3

Question 3

a) H = 1 g, Cl = 35.5 g so HCl = 1 g + 35.5 g = 36.5 g

b) 100 g of $CaCO_3$ → 73 g HCl

25 g $CaCO_3$ → x g HCl

$$x = \frac{25\text{g} \times 74\text{g}}{100\text{g}} = 18.25\text{g}$$

c) 1 mole → 2 moles

0.25 moles → 25x 2 moles = 0.5 moles

d) 250 ml → 0.5 moles

1000 ml → x

$$x = \frac{1000 \times 0.5}{250} = 2\text{M}$$

e) 1 mole $CaCO_3$ → 1 mole CO_2

0.25 moles 0.25 moles

f) 1 mole of a gas 24 dm^3

0.25 moles → 0.25 x 24 dm^3 = 6 dm^3

g) 1 mole $CaCl_2$ → 111 g

0.25 moles → *0.25 moles x 111g = 27.75g*

Activity 7

Question 1

a) Mass of Si = mass of crucible and Si – mass of crucible

= 20.4 g – 17.6 g = 2.8 g

b) Mass of oxygen= mass of silicon oxide – mass of crucible and Si

=23.6 g – 20.4 g = 3.2 g

c) Moles of Si = $\frac{2.8}{28} = 0.1\text{moles}$

d) Moles of oxygen = $\frac{3.2}{16} = 0.2\text{moles}$

e) Ratio of silicon to oxygen is 0.1:0.2 which simplifies to 1:2

f) SiO_2

Question 2

a)

Moles of aluminium = $\frac{5.4\text{g}}{27} = 0.2\text{ moles}$

b) Moles of oxygen = s $\frac{4.8\text{g}}{16} = 0.3\text{ moles}$

c) Ratio of moles of aluminium to oxygen = 0.2:0.3 and this simplifies to 2:3.

d) Al_2O_3

Unit Summary

Summary

In this unit you learned that:

- Elements from the periodic table react in fixed ratios to form chemical compounds.
- One mole of a gas at room temperature and pressure has an approximate volume of 24 dm^3 (STP).
- The mass of any species in a reaction can be calculated from the simple ratio of substances involved in the reaction or from the formulae as follows:

  Mass of a substance = number of moles x relative atomic/molecular mass

  $$\textbf{Number of moles} = \frac{\textbf{mass of a substance}}{\textbf{relative molecular/atomic mass}}$$

  Volume of a gas at STP = number of moles x 24 dm^3

  $$\textbf{Number of moles} = \frac{\textbf{volume of gas (in } dm^3\textbf{)}}{\textbf{24 } dm^3}$$

- The number of each of the atoms can be determined using the charges on the ions formed during a chemical reactions or the number of molecules of each of the substances reacting.

- Concentration is measured in number of moles per cubic decimetre (mol/dm^3 or mol dm^{-3}).

$$\textbf{Concentration} = \frac{\textbf{number of moles}}{\textbf{volume } (dm^3)}$$

$$\textbf{Number of moles} = \textbf{concentration x volume in } dm^3$$

- A solution which contains one mole in one decimetre is called a molar solution.

- The use of a balanced chemical equation is essential when calculating reacting masses.

- If you know the mass of at least one species in a reaction, then you can use it to calculate the mass of any other species using the molar ratio.

You have completed the material for this unit on formulae, stoichiometry and the mole concept. The next unit will build on this knowledge by looking at how specific substances have unique properties because of their chemical structure. You should now spend some time reviewing the content. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers structure and properties of substances.

Assignment 3

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 50 minutes

[Total Marks:50]

1. a) When potassium reacts with oxygen, potassium oxide is formed. Suggest the formula for potassium oxide:

_____ (2)

b) Predict the formula of the substance formed when Na^{+} and O^{2-} react together during a chemical reaction?

_____
_____
_____
_____ (2)

2. Write a balanced equation for the following reactions:

a) Carbon + Oxygen → Carbon dioxide

_____
_____
_____ (2)

b) Calcium + Sulphur → Calcium sulphide

_____
_____ (2)

3. Use the periodic table to help you calculate the following:

a) The mass of 0.1 mole of calcium fluoride (3)

b) The number of moles present in 4 g of magnesium sulphide

(3)

c) The volume of 4. 4g of carbon dioxide measured at room temperature and pressure. (5)

4.

a) If 100 ml of copper oxide (CuO) solution is found to contain 16 g of copper oxide, what is the concentration of the solution? (5)

b) If we need to prepare 250 ml of a molar solution of sodium chloride (NaCl), how much sodium should be dissolved? (5)

5. If 8 g of sulphur is completely oxidized during a chemical reaction, calculate the following:

a) The mass of sulphur dioxide produced (4)

b) The number of moles of sulphur dioxide formed (4)

c) The volume of sulphur dioxide measured at room temperature and pressure (3)

6. In an experiment, 'Malonya heated an unknown amount of copper in excess oxygen to produce a black powder of copper oxide. In that experiment, the following results were obtained:

Mass of crucible	14.2g
Mass of crucible and copper	27.0g
Mass of crucible and copper oxide	30.2g

Use the information given to provide the formula for copper oxide:

(10)

Reflection Question

7. Hydrogen sulphide (H_2S) is a smelly compound that gives eggs its characteristic smell. Based on this information, can you say that elemental sulphur (S_8) is smelly as well?

Compare your answers against the ones given below. Allot the marks as given in the marking guide. Review every section where you made a mistake.

Answers to Assignment 3

Question 1

a) K_2O *(2)*

b) Na_2O *(2)*

Question 2

a) $C + O_2 \rightarrow CO_2$ *(2)*

b) $Ca + S \rightarrow CaS$ *(2)*

Question 3

a) *1 mole of* $CaF_2 \rightarrow$ *78 g*

0.1 moles $\rightarrow$ *xg*

x = 78 g x 0.1 moles = 7.8 g *(3)*

b) *RMM of MgS = 56 g*

4 g = 4/56 moles = 1/14 moles *(3)*

c) *Volume of 1 mole of a gas (44 g of CO_2)= 24 dm^3*

4.4 g of CO_2 = 4.4/44 = 0.1 mole

0.1 mole = 0.1 mole x 24 dm^3 =2.4 dm^3 (5)

Question 4

a) *100 ml contains 16 g of CuO*

$$1000\ ml \rightarrow \frac{16\ g \times 1000\ ml}{100\ ml} = 2\ M \quad (5)$$

b) *Molar solution is 1 mole (59 g of NaCl) in 1000 ml*

xg → 250 ml

$$xg = \frac{59\ g \times 250\ ml}{1000\ ml} = 14.75\ g \quad (5)$$

Question 5

a) $S + O_2 \rightarrow SO_2$

32 g → 64 g

8 g → xg

$$xg = \frac{8\ g \times 64\ g}{32\ g} = 16\ g \quad (4)$$

b) *1 mole of SO_2 = 64 g*

x moles = 16 g

$$x\ moles = \frac{1\ mole \times 16\ g}{64\ g} = 0.25\ moles \quad (4)$$

c) *1 mole of a gas = 24 dm^3*

0.25 moles = x dm^3

x dm^3 = 0.25 moles x 24 dm^3 = 6 dm^3 (3)

Question 6

a) Mass of Cu = mass of crucible and Cu – mass of crucible

= 27.0 g – 14.2 g = 12.8 g

b) Mass of oxygen= mass of copper oxide – mass of crucible and Cu = 30.2 g – 27.0 g = 3.2 g

c) Moles of Cu = $\frac{12.8\ g}{64\ g}$ *= 0.2 moles*

d) Moles of oxygen = $\frac{3.2}{16} = 0.2\text{moles}$

e) Ratio of copper to oxygen is 0.2:0.2 which simplifies to 1:1

f) CuO *(10)*

7. No, you cannot say that. Compounds have unique characteristics independent of the elements within them. Elemental sulphur in fact has a very unnoticeable smell.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent chemistry course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 3

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 60 minutes.

(Total Marks:50)

1.

a) Write the formula for the following substances:

Magnesium iodide and potassium sulphide (2)

b) Predict the formula of the substance that will be formed when Fe^{3+} and Cl^- react together. (2)

2. Use the periodic table to help you do the following calculations:

a) The mass of 0.75 moles of potassium chloride (3)

b) The number of moles present in 69g of nitrogen dioxide (3)

c) The mass of 6 dm^3 of chlorine gas (4)

3. Write a balanced equation for the following reactions:

a) Sodium + Fluorine → Sodium fluoride (2)

b) Sulphur + Oxygen → Sulphur dioxide (2)

4.

a) If 28 g of calcium carbonate (CaO) is dissolved in 200 ml of water, what will be the concentration of the solution? (5)

b) If we need to prepare 500ml of a 2M solution of zinc oxide (ZnO), how much of the zinc oxide should be dissolved? (5)

5.

If 7 g of silicon is reacted completely with oxygen in a chemical reaction, calculate the following:

a) The number of moles of oxygen that reacted. (4)

b) The volume of silicon dioxide produced. (4)

c) The mass of silicon dioxide that was produced. (4)

6. In an experiment, an unknown amount of carbon was burned in oxygen until the reaction was complete. The measurements of different items were taken and the results were recorded as follows:

Mass of crucible	15.6 g
Mass of crucible and carbon	18.6 g
Mass of crucible and copper oxide	26.6 g

Use the information given to provide the formula for carbon dioxide (10)

Chemistry

Grade 12

COL Open Schools Initiative
Lesotho

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Unit 4

Structure and Properties of Substances

Study Skills

Are you having difficulties staying motivated and completing tasks? Motivation is the number one challenge that self-directed learners face. Try creating a schedule and setting goals for yourself. Reward yourself when you meet your goals. Regular contact with your tutor also helps you to stay motivated. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

Have you ever asked yourself what the things around you are made of? All of the things around us are made of small particles. Particles form substances that can be seen and touched, and those that cannot be seen or touched. All of the materials around us are different in their structure and behaviour.

In order to understand this unit, you should have studied Unit 2 (Periodic Table) thoroughly. The ideas that you learn in this unit will help you to understand upcoming the units on Chemical Reactions, Carbon and Carbonates and Alkanes and Macromolecules.

Time

This unit consists of 37 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. You should focus on those skills while studying this unit.

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Describe* the structure and properties of different substances.

Study Skills

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Describe* the states of matter and their relationship to the kinetic particle theory.
- *Describe* the particle arrangement in solids, liquids and gases
- *Define* elements, compounds and mixtures.
- *Describe* the difference between metals and non-metals.
- *Explain* why different metals and alloys are used for different purposes in industry.
- *Place* metals in their order of reactivity.

Terminology

Alloy:	A mixture of two or more metals mixed by thoroughly melting them together.
Compound:	A substance which is made up of two or more different elements chemically combined together in a fixed ratio.
Element:	A substance that is made up of just one kind of atom.
Mixture:	A substance which is made up of two or more different substances physically combined together in no fixed ratio.

Section 4-1: Particles in matter

Introduction

At the end of section 4-1, you should be able to describe the particulate nature of matter and their relationship to kinetic theory of particles.

Time

Section 4-1 has 6 pages. You should spend approximately 1 hour on this topic.

Particle Arrangement in Solids, Liquids and Gases

Look at the things around you. You will find that they are in different forms in nature. For example, you see smoke from fire, water from the tap and bricks for making houses. Think about what might make them different. All of the things around us are made of matter. Matter is made up of small particles called atoms or molecules. These particles are held by strong electric forces. When many of these particles are held together, the result is the things around you.

We have different substances around us because of the arrangement of particles in them. The arrangement of particles in substances has brought about three states of matter. In each of the three states of matter, the arrangement of particles is different which creates differences in their properties. Note that there are empty spaces between the particles of matter that are very large compared to the particles themselves.

Activity 1

1. Look at the following substances and try to classify them in Table 1 into three different groups using your own classification system. As you classify the substances, you need to look at one feature which is common to all substances in that group. At the top of each column, write the heading for the group of substances you have classified together.

Activity

Stone, sugar, oil, air, wood, water, steam, petrol, carbon dioxide and iron

Table 1

Now compare your answers with the ones in Table 2 at the end of the section. Continue on if you can comfortably classify objects as being

either a solid, liquid, or gas.

2. Give two other examples of substances of each state of matter.

Solids: _____and_____

Liquids: _____and_____

Gases _____and_____

I hope you managed to find examples of substances you have classified together. Now compare your answers with the ones at the end of the section. If your examples do not fit the definitions of the corresponding state of matter, review the above content.

Note it!

Important points to remember:

All of the above substances can be classified into solids, liquids or gases. Is there any other state of matter that you can think of?

There is one other type of state that we are not going to cover: plasma. Plasma is a state of matter that is similar to a gas, but the particles are ionized. Plasma is found in dense stars. Most substances in the universe can be classified as solids, liquids or gases. These are the three states of matter that we shall be talking about when we refer to matter.

We have three states matter for all matter because of the particle arrangement which differs in each of the states. Let us have a look at how the particles are arranged in each form:

Solids

In solids, the particles are closely arranged to one another forming the pattern shown in Figure 1. The particles have a strong force of attraction between them such that they do not move freely, but vibrate about a fixed position. The particle arrangement and the force of attraction between the particles results in the solid having a definite shape. Let us look at the particle arrangement in a solid. Notice that the particles are arranged in a pattern and that it has a fixed shape.

Figure 1: Particle arrangement in a solid. Hand drawn by graphic designer at LDTC.

Liquids

In liquids, the particles are still closely packed to one another but are free to move around each other in all directions. As the particles move in any direction, they collide with one another. The particles have a force of attraction between them though not as strong as in the case of solids. The arrangement and force of attraction between particles in a liquid result in liquids taking the shape of the container. Let us look at the particle arrangement in liquids shown in Figure 2:

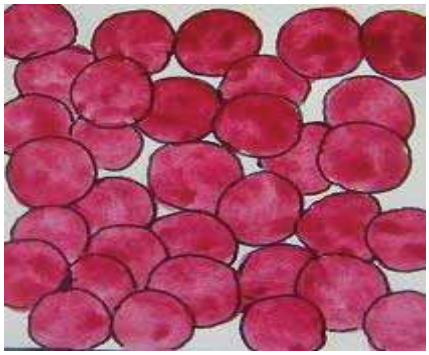

Figure 2: particle arrangement in a liquid. Hand drawn by graphic designer at LDTC.

Gases

In gases, the particles are far apart from each other and they move freely in all the direction because there is no significant force of attraction between the particles. The particles move in all the direction at high speed and collide with one another and the wall of the container. The force of attraction, which is very little, and the random arrangement of particles results in gases taking the shape of the container. Look at the particle arrangement of gases as shown in Figure 3. Note the distances between the particles and the directions they can move in as compared to liquids and gases.

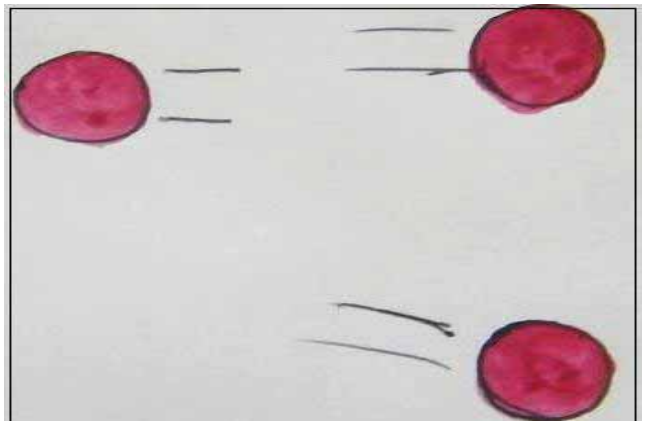

Figure 3: particle arrangement in a gas. Hand drawn by graphic designer at LDTC.

Group Activity

If you have access to the internet, try this online activity with another person.
http://phet.colorado.edu/en/simulation/states-of-matter

If you do not have access to the internet, try making models of the particles in a solid, liquid and gas using things you can find around the home (i.e. beads or rice).

Activity 2

Activity

Answer the following questions based on the discussion given above and the diagrams:

a) Describe how the movement of particles differs in each of the three states of matter:

_____

_____

_____

_____

b) Compare the force of attraction between particles in each of the three states of matter.

_____

_____

_____

_____

_____

c) Compare the shapes and volumes of solids, liquids and gases of the same number of particles.

_____

_____

_____

_____

_____

Now compare your answers with the ones given at the end of the section. Before proceeding, be sure you understand all of the differences between solids, liquids and gases.

Note it!

Key points to remember:

The key points to remember in section 4-1 on particles in matter are:

- In solids, the particles are closely arranged to one another and are so close that they form a pattern. The particles in solids have a fixed shape.
- In liquids, the particles are still closely packed to one another but are free to move around each other in all directions. The particles in liquids take the shape of the container.
- In gases, the particles are far apart from each other and they move freely in all directions. The particles in gases take the shape of the container.

Answers to the Activities on Particles in Matter

Activity 1

Question 1

Table 2

Solids	***Liquids***	***Gases***
Stone	***Oil***	***Air***
Sugar	***Water***	***Steam***
Wood	***Petrol***	***Carbon dioxide***
Iron		

Any examples are acceptable as long as they fall under the correct state of matter. For example:

Solids: ***Bread and coal***

Liquids: ***Milk and juice***

Gases: ***Steam and oxygen in the air***

Activity 2

a) ***Particles in solids vibrate about a fixed point because of a strong force of attraction between particles. Particles in liquids move freely around each other because the force of attraction is not as great as in solids. Particles in gases move freely in all directions because there is an insignificant force of attraction between the particles.***

b) ***Solids have a fixed shape and fixed volume.***

Liquids take the shape of a container and have fixed volume.

Gases take the shape of a container and do not have a fixed volume.

Gases do not have a fixed volume because the particles are always in motion moving in all directions. The only volume that we can talk about is the volume of the container.

Section 4-2: Change of State of Matter

Introduction

At the end of section 4-2, you should be able to describe the particle arrangement in solids, liquids and gases and their ability to interchange.

Time

Section 4-2 has 8 pages. You should spend approximately 2 hours on this topic.

During the winter it snows in Lesotho. What happens to the snow on the mountains as the sun shines?

When you boil water in a kettle, recall what comes out from the spout of the kettle.

Snow melting and liquid water changing to steam show a change of state of matter. Now let us have a look of change of state of matter in detail.

Change of States of Matter

When heat is applied to matter, the particles gain kinetic energy and move with an increased speed. **The higher the temperature, the faster the speed of the particles.**

Let us see what happens in the case of each of the states of matter when

heat is applied. In Figure 4, we see three states of matter of the same substance. In the first diagram, the substance is in solid form, in the second diagram it is in liquid form while in the third diagram it is in gas form. This change may be a result of applying heat which gives kinetic energy to particles resulting in the particles moving away from each other, hence these states of matter.

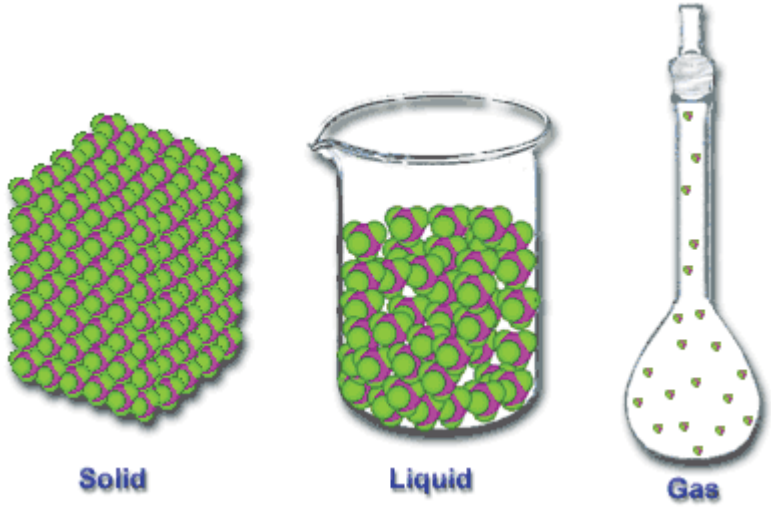

Figure 4: Molecular structure of the three states of matter accessed from Creative Commons, 2010.

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Reflection

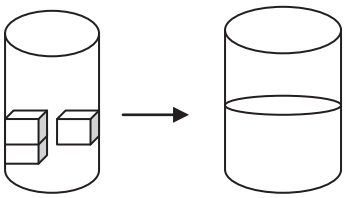
Solids

When heat is applied to a solid, the particles start to vibrate faster thereby pushing each other. If the temperature is increased enough, the force of attraction between particles becomes weak and the particles start to move freely. When the particles begin to move freely, the state of matter changes. This change in state of matter is usually into a liquid. However, in some cases a solid can change directly into a gas. Changing from a solid directly into a gas is called **sublimation**. Can you think of any examples of sublimation in your own environment? You may have mothballs in your closet. These are small balls of chemical pesticide that prevent mould or moth larvae from damaging clothing. Mothballs sublimate directly from a solid to a chemical vapour.

Activity 2

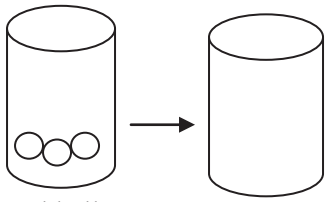
Activity

Study the figures below and answer the questions that follow.



Ice cubes

Figure 5



Mothballs

Figure 6

a) What will happen to the ice cubes if heat is applied to them?
_____

b) What will be the change (more or less) in speed of particles as heat is applied to the particles?
_____

c) In Figure 5, which state of matter does ice change to when the particles start to move freely?_____

d) What do we call the point at which the solid changes its state?
_____

e) In figure 6, if mothballs are placed in a container and left for some months, what will happen to the mothballs?
_____
_____

f) What do we call the process by which the solid changes into a gas? _____

Compare your answers with those at the end of the section. Be sure that you understand each answer before continuing. If you have any misunderstandings, review the above content.

It is important to remember:

Note it!

Solids can change to two different states of matter which are liquids and gases.

The **process** by which a solid changes into a liquid is called **melting**.

The **point** at which a solid changes to a liquid state is called the **melting point**.

The **process** by which a solid changes into a gas is called **sublimation**.

The **point** at which a solid changes to a gas is also called the **melting point**.

Liquids

When heat is applied to a liquid, the particles gain kinetic energy and start to move at a higher speed thereby colliding with one another. In the process of moving and colliding, some particles escape from the surface of the liquid and form a new state of matter: a gas.

Activity 3

Activity

Study Figures 7 and 8 below and answer the questions that follow:

Figure 7: A kettle boiling. Hand drawn by graphic designer at LDTC.

1.

a) In Figure 7, what will happen to water if heat is applied to it?
_____

b) What will be the change in speed of particles (faster or slower) in the kettle as heat is applied?
_____

c) Which state does water change to when it is heated to its boiling point? _____

d) What do we call the **point** at which the liquid changes into a new a gas? _____

e) What do we call the **process** in which a liquid turns into a gas?
_____

Note it!

Figure 8: Ice cubes. Hand drawn by graphic designer at LDTC.

2.

a) In Figure 8, what will happen to water as it is cooled?

_____

b) What will be the change in speed of particles (faster or slower) as water is cooled?

_____

c) Into what state does water change when cooled?

_____

d) What do we call the **point** at which the liquid changes into a solid? _____

e) What do we call the **process** by which a liquid changes into a solid? _____

Now compare your results with the ones given at the end of the section. When you can comfortably answer all of the questions, continue on.

Key points to remember are:

- Liquids can change to two different states: gases or solids.
- The *process* by which liquids change to gases is called **evaporation**.
- The *point* at which liquids change to a gaseous state is called **boiling point**.

- The *process* by which the liquids change to solid is called **freezing**.
- The *point* at which liquids changes their state to solid is called the **freezing point**.

Tip

To help recall terms associated with weather, think about common expressions. For example, when it's too cold we say its freezing.

Gases

When heat is applied to a gas, the molecules of gas gain kinetic energy and move at a higher rate of speed. Since there is no significant force holding the particles together, the particles move in all directions colliding with the walls of the container and some even escape into the atmosphere if the container is not completely sealed.

Figure 9: Condensation from Wikimedia Creative Commons, 2010.

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Activity 4

Activity

a) In Figure 9, what will happen to steam as it is cooled?

_____

b) What will be the change in speed (faster or slower) of particles as steam is cooled?

_____

c) In Figure 9, into which state does steam change when it is cooled?

_____

d) What do we call the process by which the gas changes into a liquid? _____

e) What state do you think the contents of fire a extinguisher are in?

_____

f) Into what state do you think the contents of a fire extinguisher turn into when in operation?

_____

g) What do we call the process by which a gas turns into a solid?

_____

Note it!

Check your performance against the given solutions at the end of the section. Continue if you are satisfied with your ability to answer the questions. If not, review the above content and try the activity again.

Reflection

Think you know how to easily identify what state something is in? What state do you think milk is in?

Milk actually consists of two separate phases: solid butterfat globules dispersed within a water-based solution. Milk is known as a colloid. Colloids can be composed of solids, liquids or gases and any combination thereof. Can you find an example of another colloid?

Key points to remember:

- Gases can change to two different states: liquids or solids.
- The process by which gases change to liquid when cooled is called **condensation**.
- The process by which gases change to solid is called **sublimation**.
- Liquids can change to a solid by **freezing**. Gases can change to a solid by **evaporation**.
- Solids can change to liquids by **melting**. Gases by can change to liquids by **sublimation**.

Activity

Create a flow diagram using the following terms: melting, freezing, evaporation, condensation, sublimation, solid, liquid and gas. Use your diagram as a study aid!

The figure below summarises what we have discussed, showing all the processes involved and giving examples of what happens in real life.

From Figure 10 we learn that:

A liquid can change to a solid by freezing. A gas can change to a solid by evaporation.

Solids can change to liquids by melting.

Gases can change to liquids by sublimation. However, there are examples of solids changing directly into a gas (sublimation). For example, moth balls are solid and change directly into a gas. Carbon dioxide in fire extinguishers (which is a gas) turns into a solid when it is sprayed. Ice can form directly from water vapour (clouds) and ice can change directly into water vapour (clouds). Gases can change to solids by sublimation and gases by condensation.

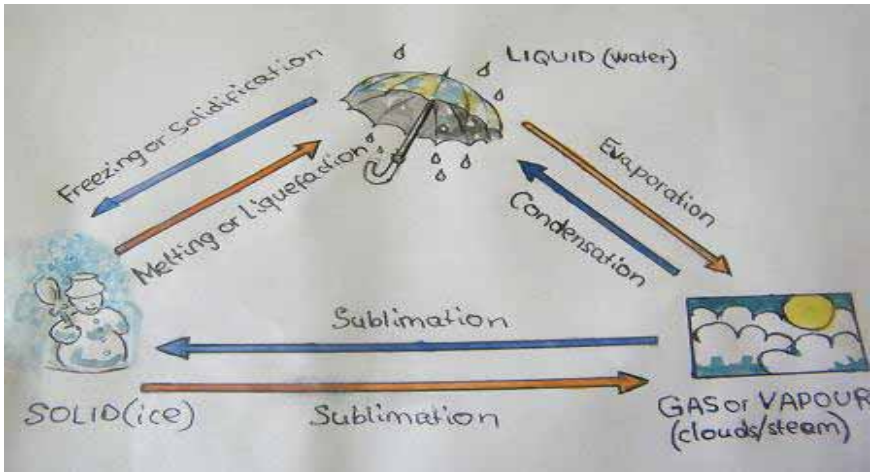


Figure 10: a cycle showing changes in states of matter. Hand drawn by graphic designer at LDTC.

The figure shows a cycle in changes of matter. Each of the changes is two-way in that it shows that a particular state of matter can change into two different states of matter under different processes.

Answers to Activities on Changes in States of Matter

Activity 2

a) *Melt*
b) *Particles will move faster*
c) *Liquid*
d) *Melting point*
e) *Change into a gas*
f) *Sublimation*

Activity 3

Question 1

a) *Evaporate*
b) *Particles will move faster*
c) *Gaseous form*
d) *Boiling point*
e) *Evaporation*

Question 2

a) *Solidifies*
b) *Particles will move slowly/vibrate*
c) *solid*
d) *Freezing point*
e) *Freezing or solidification*

Activity 4

a) *Liquid*
b) *Condensation*
c) *Gas*
d) *Solid*
e) *Sublimation*

Section 4-3: Elements, Compounds and Mixtures

Introduction

At the end of section 4-3, you should be able to define elements, compounds and mixtures.

Section 4-3 has 3 pages. You should spend approximately 30 minutes on this topic.

Time

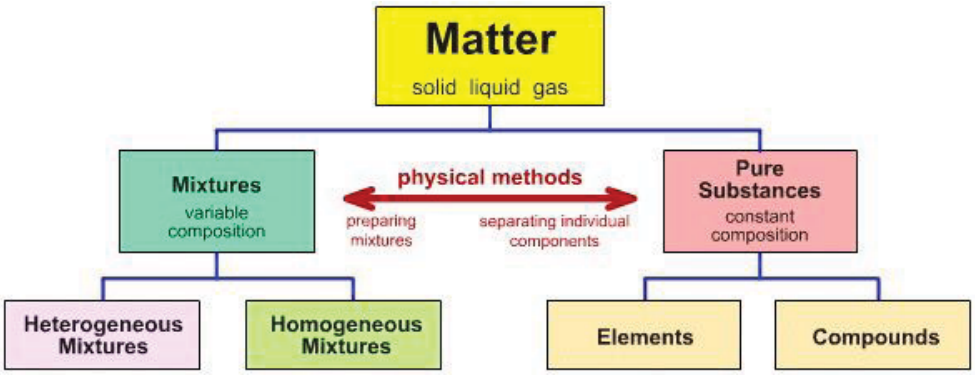
Look at the things around you. Which substances can you identify as elements? Compounds? Mixtures?

Every day we see and use different substances. These substances are different because of their chemical structures.

Elements, Compounds, Mixtures and their Properties

All of the substances around us are different in structure, formation, state and composition. In Unit 2, you learned that different elements from the periodic table can react together by bonding ionically or covalently to form new substances. In life, we form new substances with desirable properties by combining existing substances. Each of the substances we have around us has a unique composition which makes them different from each other.

The following diagram will help illustrate the connections between different classifications of matter. Note that in Unit 1, you learned about different types of mixtures.



Activity 5

Activity

Look at *chemical formula of* the following substances to answer the questions that will follow:

Nitrogen gas (N_2), ammonium chloride (NH_4Cl) and sodium chloride (NaCl) solution.

a) How many kinds of atoms are in nitrogen gas?
_____

b) How many kinds of atoms are in ammonium chloride?
_____

c) How many kinds of atoms are in sodium chloride?
_____

d) What kind of bonding has taken place between the in atoms forming nitrogen gas?
_____

e) What kind of bonding has taken place between the atoms in ammonium chloride? _____

f) What kind of bonding has taken place between sodium chloride and water? _____

Now compare your answers with the ones at the end of the section. If you were not able to answer questions d, e, and f, review Unit 2 to remind yourself about ionic and covalent bonding and how they happen.

Note it!

Note that some substances contain only one kind of atom (i.e. N_2 only contains nitrogen,). Others contain more than one kind of atom which are combined together during a chemical reaction (ammonium chloride, NH_4Cl) while others are *separated into ions* (sodium chloride solution).

Let us have a look at the definition and examples of elements, compounds and mixtures.

Element: A substance which is made up of just one basic kind of atom, for example hydrogen gas (H_2), sodium metal (Na) and so on. All elements found in nature and those that are man-made are classified in the periodic table of elements.

Compound: A substance which is made up by chemically combining two or more elements together in a fixed ratio. For example: sodium chloride (NaCl), carbon dioxide (CO_2) and so on. The properties of a compound are different from the properties of the substances making up the compound. *Chemical means are used to separate the substances making up a compound.*

Mixture: A substance which is made up by physically combining two or

more substances together in any ratio. For example: sand and rocks or air (air is a mixture of many gases, the most prevalent being oxygen and nitrogen). The properties of mixtures are those of individual substance making up the mixture. When separating the components of a mixture, physical means are used.

Activity 6

Activity

Classify the following substances into elements, compounds and mixtures in Table 3 below as per the headings given. It might help you to classify them if you to write the formula of those you know.

Ammonia gas, sugar and sand, oxygen gas, copper sulphate, potassium oxide, sulphur dioxide, chlorine gas, iron, zinc, water and cooking oil, salt solution.

Table 3

Elements	Compounds	Mixtures

Check your performance against the table given at the end of the section. Continue if you are satisfied with your ability to classify substances. If not, review the above content and try the activity again.

Note it!

Key Points to Remember:

From the above discussion we have learned that:

- Elements are made up of one kind of an atom, for example copper.
- Compounds are made up of two or more elements combined together chemically. For example: calcium carbonate is made from calcium, carbon and oxygen.
- Compounds have atoms in a fixed ratio. For example: calcium carbonate ($CaCO_3$).
- Mixtures are made up of two or more substances combined together physically.

- Mixtures do not have atoms in a fixed ratio. For example: sodium chloride solution (any amount of sodium chloride and water).
- The properties of the mixture are those of the individual substances making up the mixture.
- The components of a compound can be separated by chemical means.
- The components of a mixture can be separated by physical means.

Answers to the Activities on Elements, Compounds and Mixtures

Activity 5

a) One

b) Three

c) Four

d) Covalent

e) Ionic bonding

f) No bond

Activity 6

Table 4

Elements	*Compounds*	*Mixtures*
Chlorine	*Copper sulphate*	*Water and oil*
Oxygen	*Ammonia gas*	*Sugar and sand*
Iron	*Potassium oxide*	*Salt solution*
Zinc	*Sulphur dioxide*	

You should have found that all substances that have been formed by a combination of different elements from the periodic table either by ionic bonding or covalent bonding are compounds, those that have only one kind of atom are elements and the ones made by combining different substances in any ratio are mixtures.

Section 4-4: Metals and Non-metals

Introduction

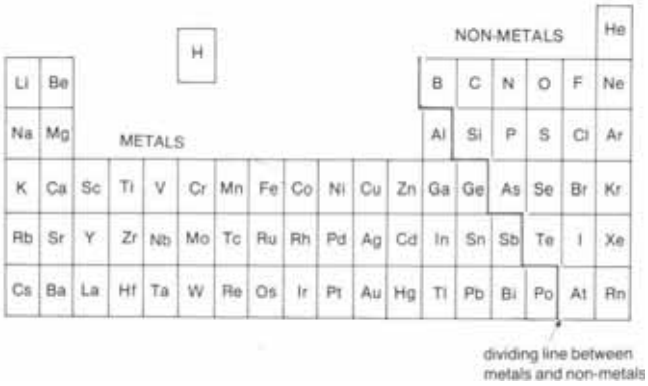
At the end of section 4-4 you should be able to describe the difference between metals and non-metals. You should also be able to explain why different metals and alloys are used for different purposes in industry.

Section 4-4has 10 pages. You should spend approximately 2 hours on this topic.

Time

Metals, Non-metals, Alloys and their Properties

The periodic table of elements is classified into metals and non-metals. Metals and non-metals have their own properties. The individual properties of each metal and non-metal make them different in their behaviour and usage. From Unit 2, we have already learned that metals react with non-metals during ionic bonding while non-metals will react together during covalent bonding. We also looked at the properties of ionic compounds and covalent compounds in Unit 2.



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The elements on the left of the "staircase" are considered metals. Those elements on the right of the "staircase" are considered non-metals. Hydrogen is a special case: sometimes it acts as a metal, and other times it acts as a non-metal. Most often, it acts as a non-metal.

Activity

Activity 7

Let us have a look at the following substances and answer the questions that follow. You may use the periodic table in Unit 2 to help you answer some of the questions. You can also use the ideas learned on change of state of matter to help you answer the questions.

Iron, bromine, copper, oxygen and sulphur.

1) At room temperature and pressure, in what state are the following substances?

a) Iron _____

b) Bromine _____

c) Copper _____

d) Oxygen _____

e) Sulphur _____

2) Are the following elements classified as a metal or a non-metal?

a) Iron _____

b) Bromine _____

c) Copper _____

d) Oxygen _____

e) Sulphur _____

3) Complete Table 5 below to show the properties of metals and non-metals:

Table 5

	Metals	Non-metals
a)	Solid at room temperature and pressure, except for mercury which is a liquid.	Solid, liquid or gas at room temperature and pressure.
b)	Can be hammered into sheets (malleable)	
c)	Can be drawn into wires (ductile)	
d)		Poor conductors of electricity
e)	High density	
f)		Poor conductors of heat

g)		Do not produce a ringing sound (not sonorous)
h)	Can have shiny surfaces	

Now compare your answers with those given at the end of this section 4-4. Continue if you understand the physical properties of metals and non-metals.

Different metals are used in everyday life because of their properties which are explained in the above text. Some metals are very reactive while some are unreactive. From the periodic table, we also learned that metals can react with non-metals to form different ionic compounds some of which are used in our everyday lives. For example, the table salt that we use is sodium chloride.

Metals that are reactive react with water, air and many other things around us. This behaviour makes different metals useful for different purposes. Sometimes we have to change the properties of metals by mixing them with other metals or non-metals so that they can be used for other things. There are so many objects around us which are made of metals. To confirm this, look at the things surrounding you and note where various metals have been used.

Activity

Activity 8

1. Write the uses of the following metals:

a) Copper _____

b) Aluminium _____

c) Iron _____

d) Gold _____

e) Silver _____

Compare your answers to the ones provided at the end of this section.

Alloys

Alloys are mixtures of two or more metals combined together by heating at a very high temperature. Figure 11 below shows the alloys bronze and brass.

Figure 11: A picture of brass and bronze (alloys). Picture taken at LDTC.

When metals are mixed, the properties of each of metal mixed changes, so a mixture with a required property can be made in this manner. Many metals are useful but most of them are most useful when they are alloys. Sometimes non-metals are also used in the making of an alloy. An example of non-metal which is used is carbon in the making of steel. A certain percentage of each of the components of an alloy is added and this will produce a unique alloy with specific properties. Examples of alloys are given below:

Brass- (70% copper and 30% zinc): it used in musical instruments.

Bronze- (95% copper and 5% tin): it is used in statues, coins and ornaments.

Stainless steel- (70% iron, 20% chromium and 10% nickel): it is used in making cutlery and kitchen sinks.

Solder- (70% tin and 30% lead): it is used in joining metallic substances.

Metals

From the periodic table we learned that metals are found in groups one, two, three and transition group. We also learned that as we move down a group, the distance between the electron in the outer most shell and the nucleus increases thereby making the force of attraction between the electron in the outer shell and the nucleus smaller. When the force between the electron in the outer shell and the nucleus decreases, it becomes easier for the electron in the outer shell to be donated to other elements. This behaviour makes some metals more reactive than others.

Some metals are so reactive that they cannot be found in their natural state, but they can be found in their **ores**. An ore is an impure metal (or aggregate of minerals). The less reactive metals can be found in their natural form. Examples are silver, gold and copper. The more reactive metals have to be extracted from their ores. For example: iron, sodium and so on. Because of their reactivity, different metals have to be extracted in different ways. Iron is extracted by reduction from its ore, while metals like and potassium and sodium are extracted by electrolysis.

In chemical reactions, the more reactive metal displaces the less reactive metal in a compound to form a stable compound. For example, if calcium reacts with magnesium chloride, calcium chloride and magnesium will be formed because since calcium appears above magnesium in the reactivity series. This reaction is known as a displacement reaction because calcium displaces magnesium. The reactive series shows the most reactive metals followed by the least reactive metals. It helps us to predict the outcome of chemical reactions.

The table below show how each of the metals react with dilute acid, oxygen and water. The reactions of metals with these three substances help us to put the metals in their order of reactivity. The order of reactivity also helps us to predict which metal will displace which in a given reaction.

Table 6 shows the order of reactivity of metals.

Table 6: Reactivity series of metals

Metals	Reaction with dilute acid	Reaction with oxygen	Reaction with water
Potassium(k) Sodium (Na)	Reacts vigorously with decreasing vigour as go down	Burns vigorously	Reacts vigorously with decreasing vigour with cold water
Calcium (Ca) Magnesium (Mg)		Burns to form oxide with decreasing vigour	Reacts with steam with decreasing vigour
Aluminium (Al)			
Zinc (Zn)			
Iron (Fe)			
Lead (Pb)		Reacts slowly to form the oxide	Does not react with cold water or steam
Copper (Cu)	Does not react with dilute acids		
Silver (Ag)		Does not react at all	
Gold (Au)			

Activity 9

Activity

1. Predict whether a reaction will take place or not:
   a) Copper + calcium chloride _____
   b) Aluminium oxide + magnesium _____
   c) Calcium + potassium nitrate _____
   d) Silver chloride + iron _____

e) Iron sulphate + sodium _____

2. Metals X and Y were reacted with a solution of calcium chloride and the following results were observed:

There was no reaction between metal X and calcium chloride.

There was a reaction taking place between metal Y and calcium chloride.

a) What could X be? _____

b) What could Y be? _____

Now compare your results with ones given at the end of this section 4-4. If you encountered problems with the questions, refer to table 8 showing the reactivity of metals and try to find out where you went wrong. Remember that a metal that appears above the other in the series can displace it in a chemical reaction.

Note it!

Key Points to Remember:

- Metals which are very reactive are found as compounds in nature while those which are less reactive are found as natural elements.

Metals and non-metals have the following properties:

	Metals	*Non-metals*
a)	*Solids at room temperature and pressure except for mercury which is a liquid.*	*Solids, liquids or gases at room temperature and pressure.*
b)	*Can be hammered into sheets (malleable)*	*Are not malleable*
c)	*Can be drawn into wires (ductile)*	*Cannot be drawn into wires (not ductile)*
d)	*Good conductors of electricity*	*Poor conductors of electricity*
e)	*High density*	*Low density*
f)	*Good conductors of heat*	*Poor conductors of heat*
g)	*Produces a ringing sound (sonorous)*	*Do not produce a ringing sound (not sonorous)*
h)	*Can have shiny surfaces*	*Have dull surface*

- Alloys are mixtures of two metals combined by heating. The mixture of two or more metals change the properties of each of the metals combined together.

A reactivity series shows the order of reactivity of different metals. Metals are listing in decreasing order or reactivity with more reactive are placed at the top of the reactivity series while the least reactive metals are placed at the bottom.

The more reactive metal displaces the less reactive in a chemical reaction.

Answers to the Activities on Metals, Non-metals and Alloys

Activity 7

Question 1

- ***a) Iron – solid***
- ***b) Bromine – liquid***
- ***c) Copper – solid***
- ***d) Oxygen – gas***
- ***e) Sulphur - solid***

Question 2

- ***a) Iron – metal***
- ***b) Bromine – non-metal***
- ***c) Copper – metal***
- ***d) Oxygen – non-metal***
- **e)** ***Sulphur – non-metal***

Question 3

Table 6: properties of metals and non-metals

	Metals	*Non-metals*
a)	*Solids at room temperature and pressure except for mercury which is a liquid.*	*Solids, liquids or gases at room temperature and pressure.*
b)	*Can be hammered into sheets (malleable)*	*Are not malleable*
c)	*Can be drawn into wires (ductile)*	*Cannot be drawn into wires (not ductile)*
d)	*Good conductors of electricity*	*Poor conductors of electricity*
e)	*High density*	*Low density*
f)	*Good conductors of heat*	*Poor conductors of heat*
g)	*Produces a ringing sound (sonorous)*	*Do not produce a ringing sound (not sonorous)*
h)	*Can have shiny surfaces*	*Have dull surface*

Activity 8

Question 1

a) Copper – electrical appliances, ornaments and jewellery.

b) Aluminium – cooking utensils, aeroplanes and cans.

c) Iron – roofing material, nails, fencing wire, cookware and cutlery.

d) Gold – jewellery and ornaments and specially minted coins.

e) Silver – jewellery and ornaments and specially minted coins.

You may have noticed that different metals are used for different purposes depending on their strength, how they look, the ease at which they are found in nature and other important properties which are either chemical or physical.

Activity 9

Question 1

a) No reaction

b) Displacement reaction

c) No reaction

d) Displacement reaction

e) Displacement reaction

You should also have noticed that there will be a displacement of the least reactive metal by the most reactive metal. There is no reaction when the most reactive metal has already formed a stable compound.

Question 2

a) Potassium and sodium as they are above calcium in the reactive series.

b) Any metal below calcium for example magnesium, aluminium and so on.

Extraction of Iron from its Ore

Metals are found in different forms in nature due to their reactivity. Some metals are found as compounds while some are found in their elemental form. The position of each of the metals in the reactivity series determines how it can be extracted.

Iron is not found as a natural metal so it is extracted from its ore Haematite (Fe_2O_3) or Magnetite (Fe_3O_4). Iron ore (Fe_2O_3), limestone ($CaCO_3$) and coke (C) are fed into a blast furnace as shown in Figure 12 below:

Figure 12: A picture of a blast furnace. Hand drawn by graphic designer at LDTC.

Hot air is then blown into the bottom of the blast furnace. When the carbon in coke contacts hot air, it is oxidised into carbon dioxide:

Coke + air →Carbon dioxide

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$

The carbon dioxide rises up the blast furnace and as it does, there is a

lack of oxygen drawn up the chamber. As a result, the carbon dioxide that comes into contact with hot coke is reduced into carbon monoxide:

Carbon dioxide + coke → Carbon monoxide

$CO_{2(g)} + C_{(s)} \rightarrow 2\ CO_{(g)}$

When calcium carbonate is heated, it thermally decomposes into calcium oxide and carbon dioxide. The carbon dioxide undergoes the same reaction as above where it combines with the carbon in coke and is reduced into carbon monoxide.

Calcium Carbonate → Calcium Oxide + carbon dioxide

$CaCO_{3(s)} \rightarrow CaO_{(s)} + CO_{2(g)}$

Carbon dioxide + coke → Carbon monoxide

$CO_{2(g)} + C_{(s)} \rightarrow 2\ CO_{(g)}$

When carbon monoxide is abundant, it reduces iron oxide into iron and carbon dioxide. Carbon dioxide continues to be reduced into carbon monoxide and the reaction continues.

Iron oxide + carbon monoxide → Iron + carbon dioxide

$Fe_2O_{3(s)} + CO_{(g)} \rightarrow Fe_{(s)} + CO_{2(g)}$

When calcium carbonate is decomposed by heat, calcium oxide is formed. Calcium oxide reacts with acidic impurities like silicon oxide to form calcium silicate.

Calcium oxide + silicon oxide → Calcium silicate

$CaO_{(s)} + SiO_{2(s)} \rightarrow CaSiO_{3(s)}$

Iron has high density. As a result, as it forms it runs down to the bottom of the blast furnace. Calcium silicate is less dense than iron. As it also runs down the blast furnace, it floats on top of iron. Calcium silicate and other impurities are now called slag. The blast furnace has two outlets at the bottom, the top one is for tapping off slag while the bottom one is for tapping off hot iron.

The iron formed from this reaction is not pure since the ore has been dug from the ground. It contains impurities like sulphur, silicon, carbon and others. This impure iron is called 'pig' or wrought iron. In order to remove impurities, hot air is blown through the iron. The impurities are oxidized and bubble out as acidic gases.

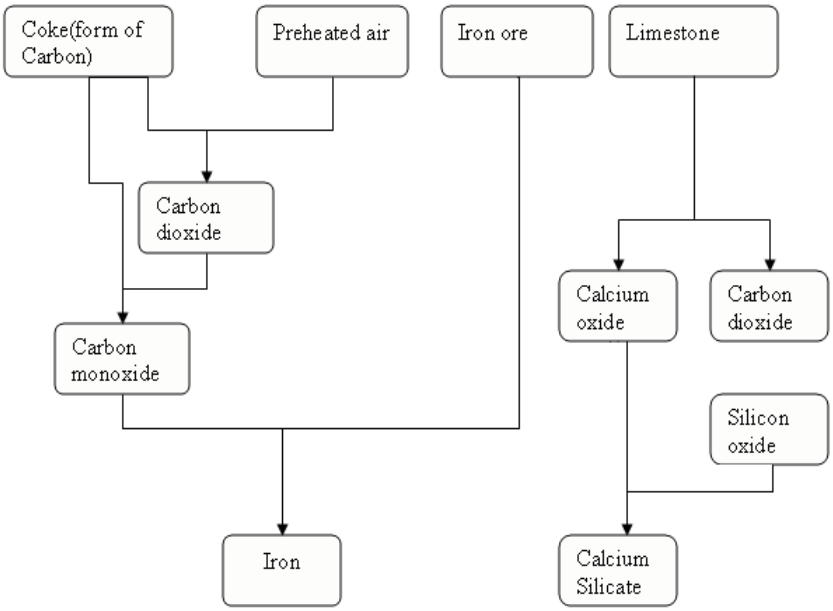
Note it!

Based on the above discussion, note that:

- Iron is extracted from its ore (haematite or magnetite).
- Three materials are fed into the blast furnace: iron ore, coke and limestone.
- Hot air oxidises coke to carbon dioxide which is then reduced to carbon monoxide due to a shortage of oxygen coming up the blast furnace.

- Carbon monoxide reduces iron oxide to iron.
- Calcium carbonate is thermally decomposed into calcium oxide and carbon dioxide.
- Calcium oxide reacts with acidic impurities like silicon dioxide to form calcium silicate.

A summary of the reactions taking place in the blast furnace:



In the extraction of iron, a reaction takes place as substances are put into the blast furnace and heated. A similar reaction is used in the manufacturing of lime. This will be covered in the Unit 7 which discusses carbon and carbonates.

Unit Summary

Summary

In this unit you learned about many important points regarding matter, and its characteristics in different instances.

Important points about matter:

Important points about matter:

- Matter is made up of particles which are classified into three states: solids, liquids and gases.
- Particles are moving all the time. In the three states of matter they move in the following manner: Particles in solids vibrate about a fixed point because of the strong force of attraction between particles. Particles in liquids move freely around each other because the force of attraction between particles is minimal. Particles in gases move freely in all the directions because there is no force of attraction between the particles.
- Solids have a fixed shape and fixed volume. Liquids also have a fixed volume but take the shape of the container they are in. Gases take the shape of the container they are in, but do not have a fixed volume.

The effect of heat on particles:

- When heat is applied to a solid, the particles start to vibrate faster thereby pushing at each other. If the temperature is high, the force of attraction between particles becomes weak and the particles start to move freely. When the particles move freely, the state of matter changes to liquid.
- When heat is applied to a liquid, the particles gain kinetic energy and start to move at a higher speed resulting in some particles escaping from the surface of the liquid and forming a new state of matter.
- When heat is applied to a gas, the molecules gain kinetic energy and move at a higher rate of speed in all directions. Some even escape into the atmosphere.

Changes of states of matter are as follows:

- Gases can change to two different states which are liquids or solids.
- The process by which gases change to liquid when cooled is called **condensation**.
- The process by which the gases change to solid is called **sublimation**.
- Liquids can change to solids by **freezing,** or to gases by **evaporation**.
- Solids can change to liquids by **melting,** or to gases by **sublimation.**

- Metals which are very reactive are found as compounds in nature while those which are less reactive are found as pure elements.

Metals and non-metals have the following properties:

	Metals	*Non-metals*
a)	*Solids at room temperature and pressure except for mercury which is a liquid.*	*Solids, liquids or gases at room temperature and pressure.*
b)	*Can be hammered into sheets (malleable)*	*Are not malleable*
c)	*Can be drawn into wires (ductile)*	*Cannot be drawn into wires (not ductile)*
d)	*Good conductors of electricity*	*Poor conductors of electricity*
e)	*High density*	*Low density*
f)	*Good conductors of heat*	*Poor conductors of heat*
g)	*Produces a ringing sound (sonorous)*	*Do not produce a ringing sound (not sonorous)*
h)	*Can have shiny surfaces*	*Have dull surface*

- Alloys are mixtures of two metals combined by heating. The mixture of two or more metals change the properties of each of

the metals combined together.

- A reactivity series shows the order of reactivity of different metals. Metals which are more reactive are placed at the top of the reactivity series while the least reactive metals are placed at the bottom with the very least reactive as the last one.
- The more reactive metal displaces the less reactive in a chemical reaction.

Important points about elements, compounds and mixtures:

- Elements are made up of one kind of an atom, for example carbon.
- Compounds are made up of two or more elements combined together chemically. For example: sodium chloride (sodium and chlorine). Compounds have atoms in a fixed ratio for example calcium carbonate ($CaCO_3$) The properties of the compounds are different from those of the elements making up the compound. The components of a compound can be separated by chemical means.
- Mixtures are made up of two or more substances combined together physically. Mixtures do not have atoms in a fixed ratio for example sodium chloride solution (any amount of sodium chloride and water). The properties of the mixture are those of the individual substances making up the mixture. The components of a mixture can be separated by physical means.

Important points about extraction of iron:

- Iron is extracted from its ore: haematite or magnetite.
- Three materials are fed into the blast furnace: iron ore, coke and limestone
- Hot air oxidises coke to carbon dioxide which is then reduced to carbon monoxide due to a lack of oxygen fed up into the blast furnace.
- Carbon monoxide reduces iron oxide to iron.
- Calcium carbonate is thermally decomposed into calcium oxide and carbon dioxide.
- Calcium oxide reacts with acidic impurities like silicon dioxide to form calcium silicate.

You have completed the material for this unit on the Structure and Properties of Substances. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Once you have completed the assessment, proceed to the next unit. It covers chemical reactions.

Assignment 4

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 60 minutes

[Total Marks:50]

1.

a) Name three states of matter.

_____
_____
_____ (3)

b) Explain with a diagram how particles in a gas are arranged._____
_____
_____
_____
_____ (4)

c) Name two changes of state of a matter that gases undergo and explain how they come about.

_____
_____
_____ (4)

d) Explain what happens to the particles in a solid when heat is applied.

_____
_____
_____
_____(5)

e) Explain with examples the difference between an element and a compound.

_____
_____
_____
_____
_____
_____
_____(4)

2. Predict as to whether the following reaction will take place or not. Where the reaction is possible, write a balanced equation which shows

the reaction (refer to unit three to remind yourself about balancing equation).

a) Magnesium chloride + zinc

_____
_____
_____

b) Iron sulphate + aluminium_____
_____
_____

c) Calcium fluoride + sodium_____

_____
_____ (7)

3.

a) Give two uses each of the following metals: (4)

(i) copper

_____
_____
_____
_____

(ii) gold

_____
_____

b) Suggest how each of the metals in (a) could be extracted.

_____
_____
_____
_____
_____ (4)

c) Define an alloy

_____
_____
_____
_____ (2)

c) Name one alloy and give its use

_____
_____
_____
_____ (2)

4.

a) State the use of each of the following substances in a blast furnace. (3)

(i) Oxygen

(ii) Carbon monoxide

(iii) Silicon dioxide

b) Write a balanced equations for each of the reactions in part a) (6)

c) Describe how the impurities from iron are removed? (2)

5. Molise wonders if it is possible to store a silver spoon safely in a zinc nitrate solution, or will the spoon be oxidized by the zinc through the following reaction:

$$Ag_{(s)} + Zn(NO_3)_{2\,(aq)} \rightarrow 2AgNO_{3\,(aq)} + Zn_{(s)}$$

What would you tell Molise? Could he store the spoon safely in a zinc nitrate solution? Why or why not? (5)

_____
_____
_____

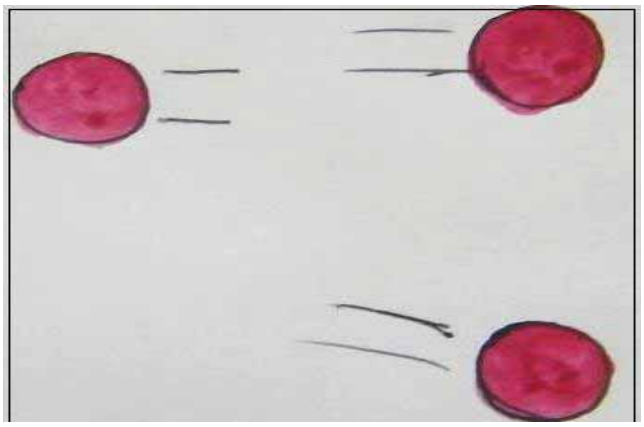
Now mark your assignment using the marking guide given below. Based on your results and the recommendation that you should aim for 80% (since concepts from this unit will help you in other units), determine how much you should study before attempting the assessment.

Answers to Assignment 4

Question 1

a) Solids, liquids and gases. (3)

b) ***The particles in a gas are far apart from each other, they move freely in all the direction because there is no force of attraction between the particles. The particles move in all directions at high speed and collide with one another and the wall of the container. (4)***



c) Condensation- when the temperature is decreased and the particles turn into a liquid. Sublimation- when the temperature decreases and the particles turn into a solid state. (4)

d) The particles are closely arranged to one another and are so close that they form a pattern. When heated, the particles gain kinetic energy and start to vibrate faster. The force of attraction becomes less and particles loosen up and start to move in all directions. That is when they become liquid. (5)

e) An element is made up of one kind of an atom. For example: oxygen. A compound is made by chemically combining two or more atoms together. (4)

Question 2

a) No reaction (1)

b) Reaction possible – $FeSO_4 + Al \rightarrow Al_2(SO4)_3 + Fe$ (3)

c) *Reaction possible – $CaF_2 + 2Na \rightarrow 2NaF + Ca$* (3)

Question 3

a) *Copper – ornaments and electrical wires.* (4)

b) *Gold - jewellery and galvanising.*

c) *Copper and gold are found as elements in nature* (4)

d) *An alloy is a mixture of metals or a metal and non-metal.* (2)

e) *Brass- it used in musical instruments.*

f) *Bronze- it is used in statues, coins and ornaments.*

g) *Stainless steel- it is used in making cutlery and kitchen sinks.*

h) *Solder- it is used in joining metallic substances.*

Question 4

a) *State the use of each of the following substances in the blast furnace.* (3)

i. *Oxygen oxidises carbon into carbon dioxide.*

ii. *Carbon monoxide reduces iron oxide into iron and carbon dioxide.*

iii. *Silicon dioxide reacts with calcium oxide to form calcium silicate.*

b) *Write a balanced equations for the each of the reactions in part a):* (6)

i. $C + O_2 \rightarrow CO_2$

ii. $3CO + Fe2O_3 \rightarrow 2Fe + 3CO_2$

iii. $SiO_2 + CaO \rightarrow CaSiO_3$

c) *The impurities are removed by bubbling oxygen in iron. The non-metals will react with oxygen to form acidic oxides.* (2)

Question 5

Since silver is below zinc on the chart, silver metal will not be oxidized by zinc. You could tell Molise that it would be safe to store the silver spoon in the zinc nitrate solution, it will not be corroded.

Assessment 4

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 60 minutes.

(Total Marks:50)

1.

a) Explain with the aid of a diagram how particles in a solid are arranged.

(4)

b) Explain what happens to the particles of a liquid when heat is applied. (5)

c) What are the two states of matter that a solid undergo at different temperatures and explain how each come about. (4)

d) Give two properties each of metals and non-metals giving examples in each case. (6)

2. Predict as to whether the following reaction will take place or not. Where the reaction is possible, write a balanced equation which shows the reaction. (7)

a) Magnesium chloride + zinc

b) Iron sulphate + aluminium

c) Calcium fluoride + sodium

3.

a) Give two uses each of the following metals:

(i) Silver (ii) iron (4)

b) Suggest how each of the metals in (a) could be extracted. (4)

c) Why do we make alloys? (3)

d) Name one alloy and give its use. (2)

4. In manufacturing iron from its ore, three materials are fed into the blast furnace and are heated at a high temperature.

a) Name the three materials. (3)

b) Which is the first reaction in the blast furnace? (2)

c) Which substance is responsible for the reduction of iron ore? (1)

d) Write a balanced equation that shows the reduction of iron. (2)

e) What do we call the substance that floats on top of iron at the bottom of the blast furnace?

f) List two uses of iron. (2)

Chemistry

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 5

Chemical Reactions

Study Skills

When you are reading and making your own notes, here are some good tips:

1. Only highlight/underline things when you have read the entire paragraph or section. That way you will only highlight the most important points.

2. Make sure that you create your own set of notes that are in your own words. Copying something that you do not understand is of little value!

Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.

Introduction

2008 Beijing Olympics accessed from Wikimedia Creative Commons, 2010.

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In 7th century China, the Chinese developed many different kinds of fireworks with a variety of effects and colour. Gunpowder, charcoal and sulphur were packed into a bamboo tube and ignited. The chemical reaction causes a powerful explosion accompanied by beautiful colours.

In the previous unit, we looked at the structure and properties of substances. You learned that substances can change back and forth between states. What do you get when you burn a piece of paper? Is the product(s) similar or different to the paper you burnt? After burning paper, do you think it is possible to get the paper back?

There are two kinds of changes: physical change and chemical change. We have discussed some physical changes in Unit 4. These are the changes that involve dissolving, crystallisation, boiling and freezing. The difference between physical and chemical changes is that physical changes are easy to reverse. For example, liquid water is produced by melting ice cubes. The change can easily be reversed by putting that melted water back into the freezer! Chemical changes can make it difficult to get the products back. Burning is one example of a chemical change. This unit deals mostly with chemical changes.

Time

This unit consists of 36 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Describe* the behaviour and characteristics of different chemical reactions.

Study Skills

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

- *Describe* characteristics of exothermic and endothermic reactions.
- *Explain* how different factors affect the rate of chemical reactions.
- *Define* oxidation and reduction in terms of oxygen/hydrogen and gain/loss of electrons.
- *Describe* acids and bases in terms of their ions and properties.
- *Classify* oxides using their characteristics.
- *Describe* a method of preparing, separating and purifying a salt from given substances.

Terminology

Acid:	A substance that donates hydrogen ions (protons) or accepts electrons. Acids react with bases.
Alkalis:	A basic ionic salt of an alkali metal or an alkaline earth metal element. A base that dissolves in water.
Amphoteric oxide:	Oxide that behaves as both an acidic oxide and a basic oxide.
Base:	A substance that accepts hydrogen ions (protons) or donates electrons. Bases react with acids.
Endothermic reaction:	A chemical reaction that absorbs heat energy from the surroundings.
Exothermic reaction:	A chemical reaction that gives off heat energy.
Neutralisation reaction:	A chemical reaction between acids and bases that produces salt and water.
Oxidation:	The loss of electrons by a molecule, atom or ion.
Reduction:	The gain of electrons by a molecule, atom or ion.
Reactants:	The starting substances in a chemical reaction.
Products:	The new substances formed in a chemical reaction.

Section 5-1: Production of Energy

Time

Section 5-1 has 3 pages. You should spend approximately 40 minutes on this topic.

Burning

Burning is one example of a chemical reaction. An example of burning is shown in figure 1 below. In this figure we see methane gas burning. Methane is one gas that we use for cooking.

Figure 1: Natural gas burning accessed from Flickr (Creative Commons), 2010.

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The equation below shows the chemical reaction that takes place in Figure 1.

$$\text{Methane} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water}$$

$$CH_4 + O_2 \longrightarrow CO_2 + H_2O$$

Chemical equation for burning methane.

The products are carbon dioxide and water. The other product that is not shown in the equation is heat.

Burning is sometimes called **combustion**. It is a chemical reaction between oxygen which is found in the atmosphere and other elements. In a chemical reaction, one or more new substances are formed. In the equation above, oxygen is reacting with a natural gas or methane (CH_4). The fuel burning in Figure 2 is wood. As with methane, wood also burns in a chemical reaction. The burning of wood produces carbon dioxide, water and heat that is being used to braai the meat.

Activity 1

Activity

Study the illustration in Figure 2:

Figure 2: Wood burning accessed from Wikimedia Creative Commons, 2010.

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Another fuel that burns is coal. Coal and wood contain a certain amount of carbon. Concentrating only on the reaction between carbon and oxygen:

1.

a) In your home, how do you make fire? _____

b) When you bring your hand close to the fire what do you feel?

_____

_____

c) What do you use the heat from the fire for?

_____

_____

_____

d) Write down the chemical equation for the reaction in figure 2.

_____

_____

_____

_____

Compare your answers with those at the end of the section. Be sure that you understand the answer before continuing. If you have any misunderstanding, review this content and try the activity again.

The other fuel that burns in oxygen is hydrogen. Hydrogen burns in oxygen to produce water and heat energy. As a result, hydrogen is used as fuel in space shuttles. It burns in the engine to produce energy that is used to move the space shuttle. The chemical equation for the reaction in the engine is:

$$2H_2 + O_2 \longrightarrow 2H_2O + heat$$

Answers to activities

Activity 1

1 a) Fire can be made from wood, coal, gas or paper.

b) You feel heat

c) Fire is usually used for cooking, warming ourselves and lighting.

d) The equation for the chemical reaction in Figure 2 is:

$$C + O_2 \Rightarrow CO_2$$

Section 5-2: Endothermic and Exothermic Reactions

At the end of this section 5-2, you should be able to:

- *Describe* characteristics of exothermic and endothermic reactions.

Time

Section 5-1 has 3 pages. You should spend approximately 40 minutes on this topic.

Exothermic Reactions

Burning reactions give off heat energy. In some families, gas stoves, paraffin stoves or spirit stoves are used. The heat that is given off during the reaction is used for cooking food. A reaction that gives off heat energy is called an **exothermic reaction**.

Endothermic reactions

In some reactions, heat is absorbed into the system and the surroundings become cool. Chemical reactions in which energy is taken in from the surroundings are called endothermic reactions.

Bond Breaking and Bond Formation

In a chemical reaction, a new substance is formed. This can happen as a result of two or more atoms bonding together or when bonds are broken to form new substances. We know that compounds and molecules are substances in which atoms have bonded covalently or ionically. Consider the two reactions which are shown below:

$CaCO_3$ + heat => CO_2 + CaO

C + O_2 => **CO_2** + heat

During the chemical reaction, calcium carbonate has been thermally decomposed or broken down into calcium oxide and carbon dioxide. By 'thermally decomposing, we mean that heat energy was used to break the bonds in the compound. The energy that is used to break down the bonds is not released to the atmosphere but absorbed from the source. Sometimes an endothermic reaction takes heat from its surrounding and as a result, the surroundings become cool. This is what happens in endothermic reactions.

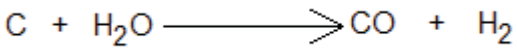
Looking at the second reaction, we see that a new compound was formed and heat energy was given off. On the other hand, when a new substance is formed at least one new bond has been formed. When a bond is formed, energy is given off. This is what happens in exothermic reactions.

In reality, the bond breaking and bond formation processes occur at the same time. We have discussed them separately in this unit to simplify the concepts.

Activity

Activity 3

The equation below shows a reaction between carbon and steam:



Ntsu realised that the first stage of the reaction is the bond of bonds in the reactants and the second stage is the formation of new bonds. Also, he noticed that in this reaction, the energy required to break the bonds is 924 kJ and the energy released when new bonds are formed is 787 kJ.

1.

a) Is this an endothermic or exothermic reaction?

_____

b) What was the change in energy? _____

c) Do you think the temperature increased or decreased during the reaction?

_____

_____

_____

Compare your answers with those at the end of the section.

In exothermic reactions, more energy is given off when making new bonds than was supplied to break the old bonds. The extra energy is released into the surroundings.

If more energy is required to break the bonds than the energy released in bond formation, the surroundings becomes cooler. These are endothermic reactions.

Answers to Activities on Endothermic and Exothermic Reactions

Activity 2

a) The reaction is endothermic.

b) The change in energy of the system was 137 kJ.

c) Heat was not given off- the mixture became cooler. The temperature dropped because more heat energy was needed to break the bonds than the energy released during bond formation.

Section 5-3: The Rate of Chemical Reactions

At the end of section 5-3, you should be able to:

- *Explain* how different factors affect the rate of chemical reactions.

Time

Section 5-3 has 3 pages. You should spend approximately 40 minutes on this topic.

Factors that affect the rate of chemical reactions

Some reactions take a long time to go to completion whereas others take a short time to complete. This means the reaction can be slow or fast and these words, fast and slow, both describe the reaction rate. There are different factors that affect reaction rates. These are concentration, surface area, catalysts, temperature, pressure and light.

Concentration

At home, if you put two teaspoons of sugar in one cup half-filled with water and in another one you put five teaspoons of sugar also half-filled with water, which one will have a higher concentration of sugar? In your home, you may have also seen concentrated drink mix. Before you drink it, you need to add water to the powder or concentrate. Adding water to the drink powder is called dilution. This means there are more particles of the drink mix in concentrated drink than in dilute drink. We also have concentrated chemicals and dilute chemicals. In concentrated chemicals, there are more particles of the substance in solution. The concentration of a solution is usually given in number of moles present per litre of a solution. This was discussed in Unit 3.

Activity

Activity 4

Khauhelo performed the following experiments as illustrated in Figures 3 and 4.

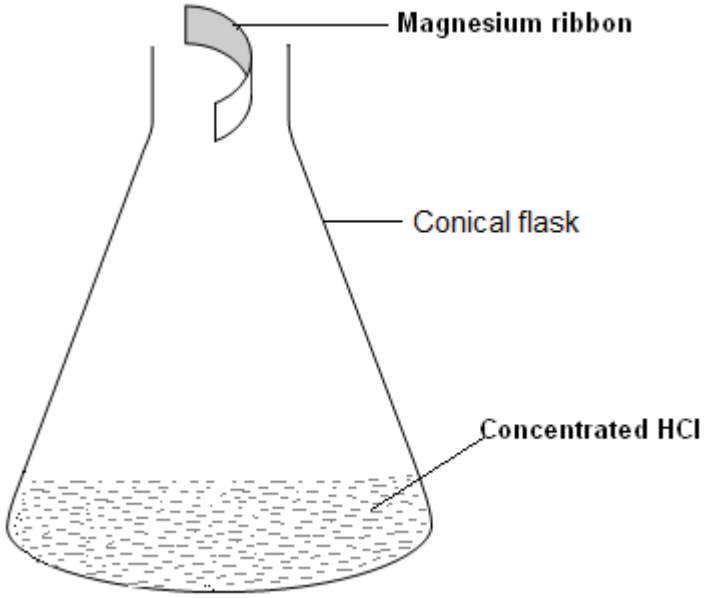


Figure 3: Reaction between concentrated HCl and magnesium. Hand drawing, 2010.

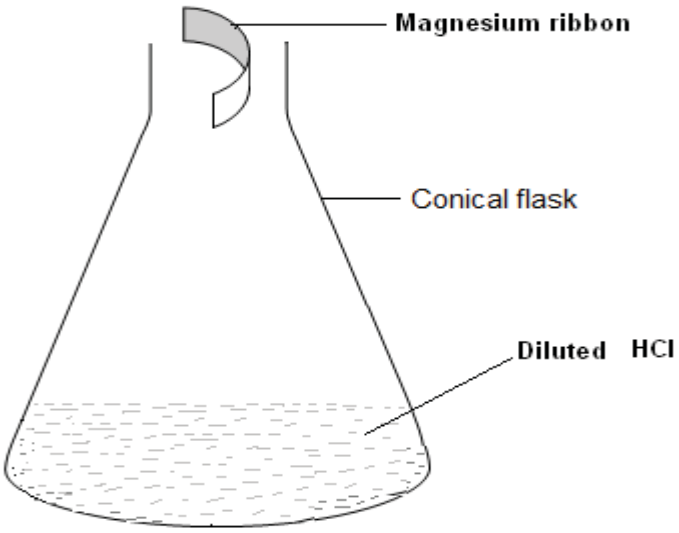


Figure 4: Reaction between diluted HCl and magnesium. Hand drawing, 2010.

- In both experiments, she used a magnesium ribbon of the same size.
- In the first experiment, she used concentrated hydrochloric acid and in the second she used diluted hydrochloric acid.
- She dropped the magnesium ribbon into acid. As the reaction started, some bubbles were observed.
- When she dropped the magnesium into the flask, she also started the clock to measure the time taken for each reaction. She could tell when the reaction was complete when the bubbles stopped.
- In the concentrated HCl, the reaction took 25 seconds and in the dilute HCl it took 60 seconds.

a) Between the two which reaction was faster?

_____

b) What is the effect of concentration in this reaction?

_____
_____
_____
_____
_____
_____

Compare your answers with those at the end of the section.

Surface Area

Have you ever wondered why dogs, cats or even human beings curl up in winter and uncurl in summer when they are in their sleeping positions? In our everyday lives we use powdered substances and lump substances. An example of the substances we use are powdered soaps and bar soaps, sugar blocks, sugar granules and icing sugar, coarse and fine table salt and many more. When using these substances which state do you prefer and why?

Activity

Activity 5

Khauhelo continued with the experiments, but this time she kept the concentration constant. She used diluted hydrochloric acid in both experiments. In one experiment she used magnesium ribbon and on the other she used magnesium powder. Refer to Figures 5 and 6.

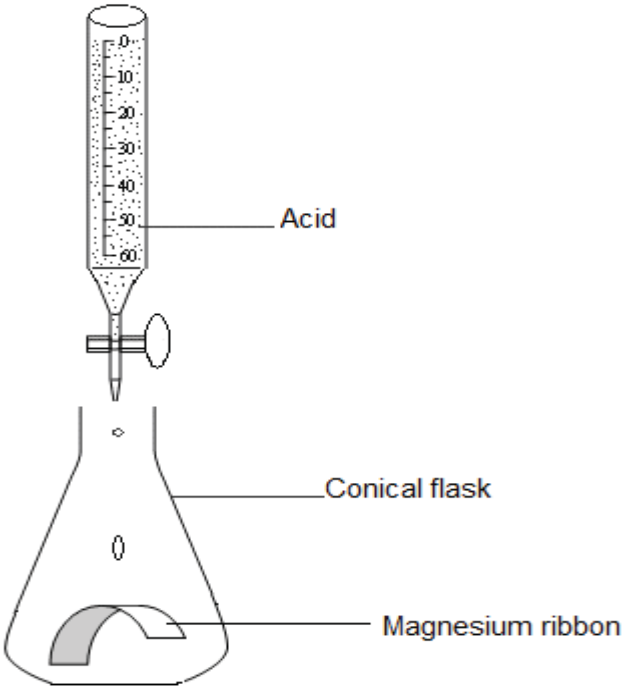


Figure 5: Reaction between HCl and magnesium ribbon. Hand drawn, 2010.

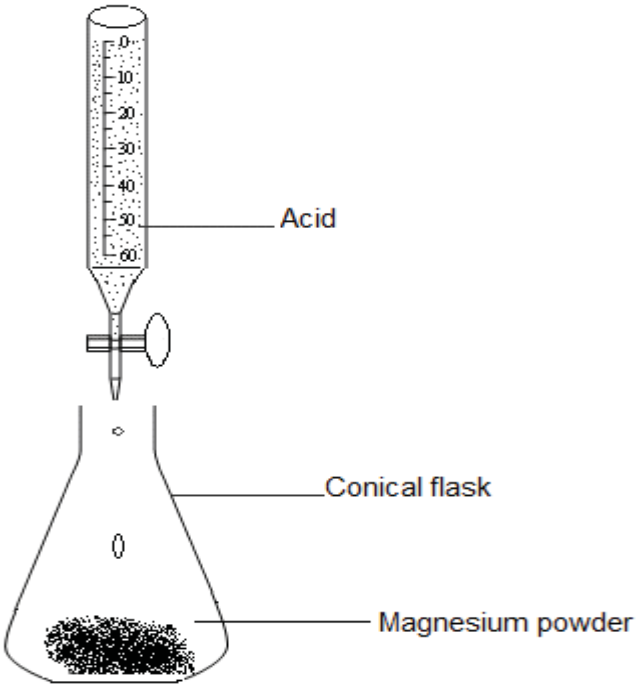


Figure 6: Reaction between HCl and magnesium powder. Hand drawn, 2010.

Khauhelo realised that in her experiment, the reaction of magnesium ribbon with acid took 75 seconds and the acid with magnesium powder took 40 seconds to react.

1.

a) Between magnesium ribbon and powder which has a larger surface area?
_____

b) Between the two, which reaction was faster? _____

c) What is the effect of surface area on the rate of a chemical reaction?
_____
_____
_____

Compare your answers with those at the end of the section.

The rate of chemical reaction is higher in the reaction of magnesium powder with acid compared to that of magnesium ribbon with acid. This is because in the powder, there is more surface area and hence many particles are exposed to the acid at a time.

Catalysts

A catalyst is any substance which speeds up the rate of a chemical reaction but remain chemically unchanged at the end of the reaction. When chemicals are mixed, particles in the mixture move and collide with each other. When the collisions are successful, the chemical reaction occurs. A catalyst provides a chance for more successful collisions because in the presence of a catalyst, reactants require less energy (i.e. a lower temperature) to occur than if the catalyst was not there. There are many reactions which make use of a catalyst; an example is preparation of oxygen which is shown in the equation below:

Hydrogen peroxide $_{+}$ Manganese dioxide => Oxygen + water + Manganese dioxide

$$2H_2O_2 + MnO_2 \rightarrow O_2 + H_2O + MnO_2$$

Reflection

Where else have you heard about catalysts? In the human body, catalysts are very important for allowing many biochemical reactions occur at lower temperatures (i.e. body temperatures). If we did not have catalysts in our bodies, we would not be able to survive!

Temperature

Temperature is one factor which affects the rate of a chemical reaction. If you were to dissolve 5 tablespoons of sugar in water, what would you do to make it dissolve faster? Yes, you would use hot water. What happens when you put ice cream near hot surfaces or in the sun? Yes, it melts.

When magnesium reacts with water, bubbles of gas are seen. Taelo conducted an experiment to check whether there was any difference between the reaction of magnesium with cold water and magnesium with hot water. In one beaker the water was heated as shown in Figure 7.

Figure 7: Apparatus for heating water. Photo by Molise Nhlapo at Lesotho College of Education Chemistry Laboratory.

When the water boiled, he added magnesium powder and observed the changes.

On the other beaker he poured cold water and added magnesium powder then also observed the changes.

Activity

Activity 6

a) In which reaction do you think bubbles will produced at a faster rate?
_____

b) In which reaction will the magnesium particles move the fastest?
_____

c) What is the name of the energy that causes movement of particles?
_____

d) What caused the particles to move faster in one of the reactions?
_____

Now compare you answers with the ones given at the end of section 5-3.

When heat is applied to chemicals reacting together, particles gain kinetic energy and start to move faster (Refer to unit 4). Heat therefore increases the rate of chemical reaction. When a substance is hot, particles in it move faster. This causes the particles to collide more and this increases the reaction rate.

Light

Some reactions are sped up or started by light. Such reactions include photosynthesis and photography. In photosynthesis, the light that starts the process (from the sun) is absorbed by chlorophyll molecules found in plants. In

photography, silver salts, silver chloride, silver bromide and silver iodide coating the film are sensitive to light at different levels. In this case, light speeds up the change from silver salts to silver.

Answers to Activities on the Rate of Chemical Reactions

Activity 5

In the concentrated hydrochloric acid, the reaction took less time than in the diluted acid. This shows that if the chemicals are concentrated, the rate of the chemical reactions increases. On the other hand, if the chemicals are diluted, the rate decreases.

Activity 6

a) More bubbles will be produced in the heated reaction.

b) The particles will move faster in the heated reaction.

c) Kinetic energy.

d) Heat energy

Section 5-4: Oxidation and Reduction Reactions

There are 5 pages on this section.

At the end of section 5-4 you should be able to:

- *Define* oxidation and reduction in terms of oxygen/hydrogen and gain/loss of electrons.

Time

Section 5-4 has 5 pages. You should spend approximately 1 hour on this topic.

Oxidation Reactions

Consider the following reactions:

1. $2H_2 + O_2 \longrightarrow 2H_2O$

2. $C + O_2 \longrightarrow 2CO_2$

Both reactions are called oxidation reactions. In reaction 1, hydrogen has been oxidised to form water and in reaction 2, carbon has been oxidised to form carbon dioxide.

Activity

Activity 7

Using the information above, define oxidation.

_____

_____

_____

_____

Compare your answer with the one at the end of the section.

In both of the above reactions, oxygen has been added to the other reactant. Therefore, these reactions are called oxidation reactions because oxygen has been added.

More About Oxidation

In Unit 2, you studied the structure of an atom. There are atoms with less than four electrons in the outer shell, such as elements in groups 1, 2 and 3.

For example, consider the following atomic structures:

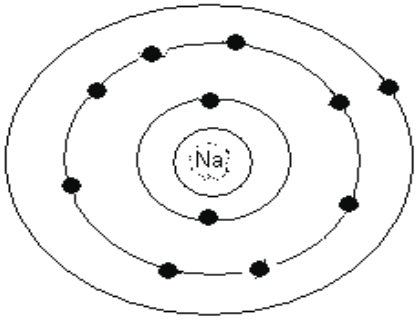


Figure 8: Sodium atom has one electron in the outer shell. Hand drawn by graphic designer at LDTC.

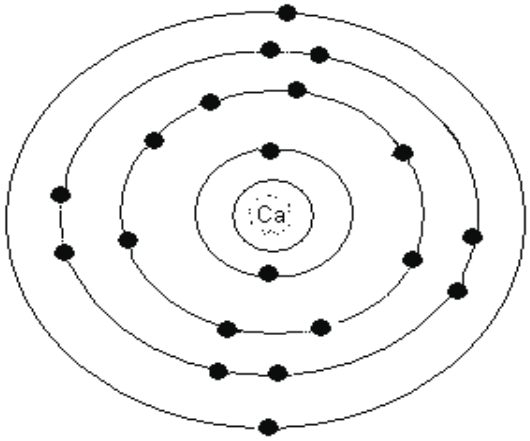


Figure 9: Calcium atom has two electrons in the outer shell. Hand drawn by graphic designer at LDTC.

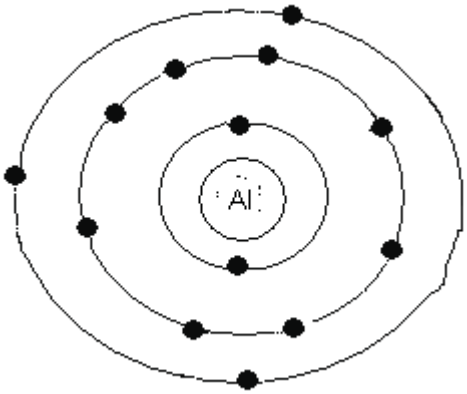


Figure 10: Aluminium atom has three electrons in the outer shell. Hand drawn by graphic designer at LDTC.

When the elements in these groups react, they lose electrons in the outer shell.

Atoms		Ions		Electrons
Na	$\longrightarrow$	Na^+	+	e^-
Ca	$\longrightarrow$	Ca^{2+}	+	$2e^-$
Al	$\longrightarrow$	Al^{3+}	+	$3e^-$

The loss of electrons by substances is called **oxidation.** The substance that has lost an electron or electrons has been oxidised.

Reduction Reactions

Activity

Activity 8

Consider the reactions below:

$F_2 + H_2 \rightarrow 2HF$

$CuO + H_2 \rightarrow Cu + H_2O$

1. Focus on the CuO. At the end of the reaction, what has happened to CuO?

   _____
   _____
   _____

2. Focusing on fluorine, what has been done to fluorine to form hydrogen fluoride?

   _____
   _____
   _____

3. From the explanation of the process in 1 and 2, predict the definition of reduction in terms of oxygen and hydrogen.

   _____
   _____
   _____

Compare your answers with those at the end of the section.

In this reaction, oxygen has been removed from the compound CuO (copper oxide). In other words, copper has been reduced. This is why reduction is defined as removal oxygen.

Reduction in Terms of Electron Transfer

Some atoms have more than four electrons in the outer shell, for example, elements in groups 5, 6 and 7.

Consider the examples below:

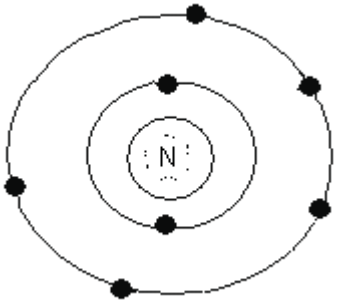


Figure 11: Nitrogen has five electrons in the outer shell. Hand drawn by graphic designer at LDTC.

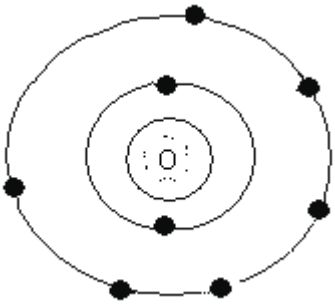


Figure 12: Oxygen has six electrons in the outer shell. Hand drawn by graphic designer at LDTC.

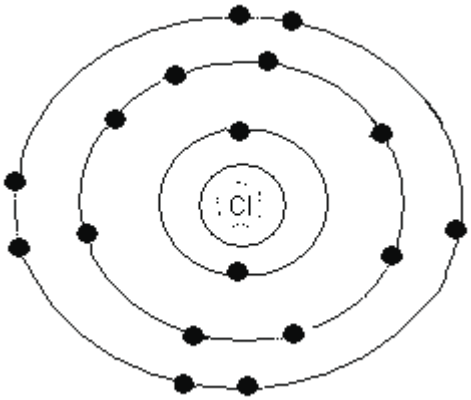


Figure 13: Chlorine atom has seven electrons in the outer shell. Hand drawn by graphic designer at LDTC.

During a chemical reaction, these atoms do not give away their electrons, but gain electrons from other atoms.

Atoms		Electrons		Ions
N	+	$3e^-$	⟶	N^{3-}
O	+	$2e^-$	⟶	O^{2-}
Cl	+	e^-	⟶	Cl^-

The gain of electrons by a substance is called **reduction**. We say a substance has been reduced.

Answers to Activities on Oxidation and Reduction Reactions

Activity 7

Oxidation is the addition of oxygen

Activity 8

1. ***CuO has lost oxygen atom, oxygen has been removed from the CuO compound, Cu has been reduced.***
2. ***Reduction is the removal of oxygen, and the gain of electrons.***

Section 5-5: Types of Oxides

At the end of section 5-5 you should be able to:

- *Classify* oxides using their characteristics.

Time

Section 5-5 has 3 pages. You should spend approximately 40 minutes on this topic.

Oxygen reacts with metals and non-metals to form oxygen compounds. The compounds of oxygen and metals or non-metals are called oxides.

Activity

Activity 9

Ntombi performed the following experiment to find the properties of different oxides:

Experiment 1

1. She burnt two metals: calcium and magnesium in oxygen.
2. She then dissolved each oxide formed in water.
3. She tested each solution with the litmus paper.

Experiment 2

1. She burnt sulphur in oxygen.
2. She dipped the litmus paper into water.
3. She then held the damp litmus paper over burning sulphur.

Results

Experiment 1

Both solutions of magnesium oxide and calcium oxide turned the red litmus paper blue.

Experiment 2

The damp blue litmus paper turned red.

Solutions of magnesium oxide and calcium oxide turn red litmus paper blue.

1. What does this tell you about oxides?

   _____
   _____
   _____

2. Why did Ntombi dip litmus paper in water before putting it over sulphur dioxide?

   _____
   _____
   _____

3. Sulphur oxide solution turns blue litmus paper red. What does this tell you about sulphur oxides?

   _____
   _____
   _____
   _____

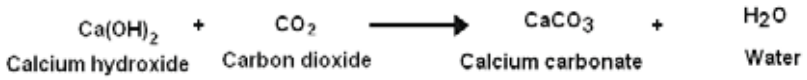
Compare your answers with those at the end of the section.

There are four types of oxides:

- Acidic oxides
- Basic oxides
- Neutral oxides
- Amphoteric oxides

Acidic Oxides

Sulphur dioxide forms an acidic solution. This is an example of acidic oxides. Acidic oxides are formed from non-metals and are usually gases like carbon dioxide and nitrogen dioxide. When these oxides are dissolved in water they form acidic solutions. These oxides react with bases to produce salt and water. The equation below shows an example of a reaction. In this case the salt produced is calcium carbonate:



Basic Oxides

Basic oxides dissolve in water to form alkaline solutions. They are oxides of metals. They react with acids to form salt and water. Refer to the equation below showing the reaction:

Neutral Oxides

Neutral oxides do not have any effect on litmus paper and the universal indicator remains green. They do not react with acids or alkalis. An example of a neutral oxide is water, H_2O.

Amphoteric Oxides

These are oxides of less reactive metals such as zinc and aluminium. Amphoteric oxides act as acidic oxides and also as basic oxides. That means they react with acids to form salt and water and they also react with bases to form salt and water.

Answers to Activities on Types of Oxides

Activity 9

Magnesium oxide and calcium oxide turn litmus paper blue; this shows that they are basic.

The water in the litmus paper dissolved sulphur dioxide and the solution turns litmus paper red. This shows that sulphur oxides are acidic.

Section 5-6: Acids and Bases

At the end of section 5-6, you should be able to:

- *Describe* acids and bases in terms of their ions and properties.

Time

Section 5-6 has 4 pages. You should spend approximately 40 minutes on this topic.

Solutions can be classified into acidic, basic or neutral solutions. We test whether a solution is acidic, basic or neutral by using indicators.

Indicators

Indicators are substances that change colours in different solutions. They can be in liquid form or in a paper form. The most common indicators used in chemistry are litmus paper (red and blue) and universal indicators.

Litmus paper

Blue litmus paper changes to red in acidic solutions while red litmus paper remains red in acidic solutions. The effect of acidic solution on litmus paper is shown in Figure 14.

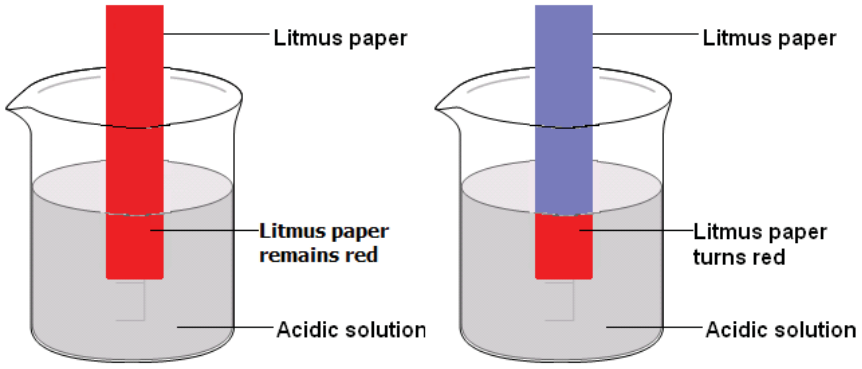


Figure 14: Litmus paper turning red in acidic solutions accessed from Wikimedia Creative Commons, 2010.

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Blue litmus paper remains blue in basic solutions where red litmus paper changes to blue in basic solutions.

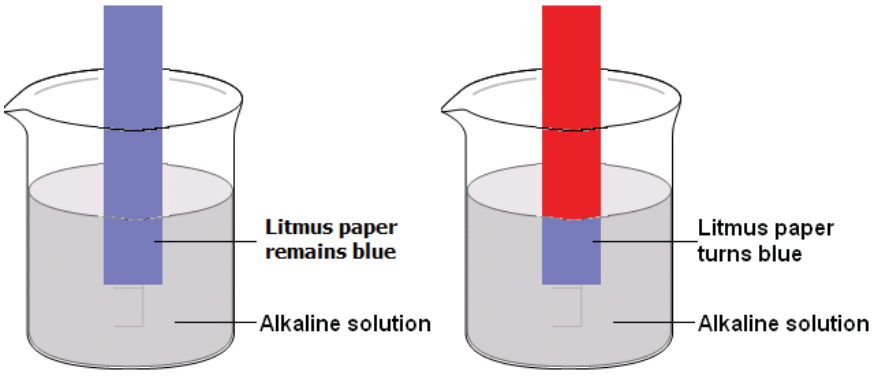

Figure 15: Litmus paper turns blue in basic solutions accessed from Wikimedia Creative Commons, 2010.

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Universal Indicator

A universal indicator is in both paper and solution form. It has many colours it changes to in different solutions. In acidic solutions, a universal indicator changes from red to orange to yellow as shown in Figure 16. The colour changes with strength of the acid. A very strong acid will turn a universal indicator red and a weak acid turn a universal indicator yellow. Any acid which is in between will have a colour between these two colours as shown in the strip.

Figure 16: Part of universal indicator showing colour changes in acidic solutions accessed from Wikimedia Creative Commons, 2010.

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In neutral solutions, the universal indicator changes to green colour.

Figure 17: Universal indicator turns green in neutral solutions accessed from Wikimedia Creative Commons, 2010.

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In basic solutions, the universal indicator changes from greenish blue to blue to purple. The colour changes with strength of the base. A very strong base will turn a universal indicator purple and a weak acid turn a universal indicator blue. Any base which is in between will have a colour between these two colours as shown in the strip.

Figure 18: Part of universal indicator showing colour changes in basic solutions accessed from Wikimedia Creative Commons, 2010.

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The diagram below illustrates the colour range in the universal indicator paper.

Figure 19: Range of colours in the universal indicator paper accessed from Wikimedia Creative Commons, 2010.

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Other indicators

Other indicators that can be used to test the solutions in the following:

Indicator	Colour in acidic solution	Colour in alkaline solution
Methyl orange	red	orange
Phenolphthalein	colourless	pink
Litmus	red	blue

Table adapted from Wikimedia Creative Commons, 2010.

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Acids

Acids contain hydrogen atoms (protons). When acids dissolve in water, they form hydrogen ions (H^+) as the only positive ion in the solution. Consider the following examples of acids

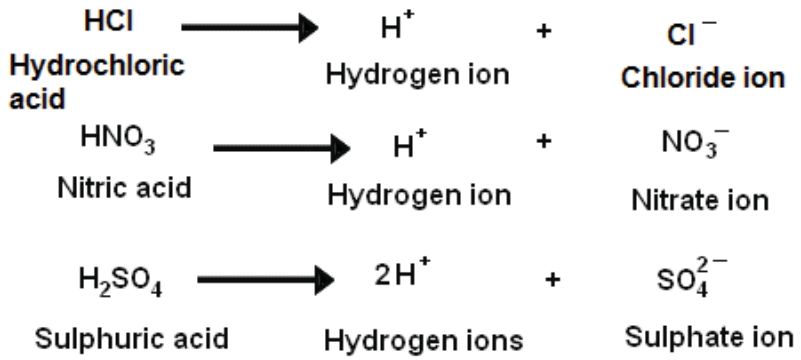


Figure 20: Ionization of hydrochloric acid, nitric acid and sulphuric acid.

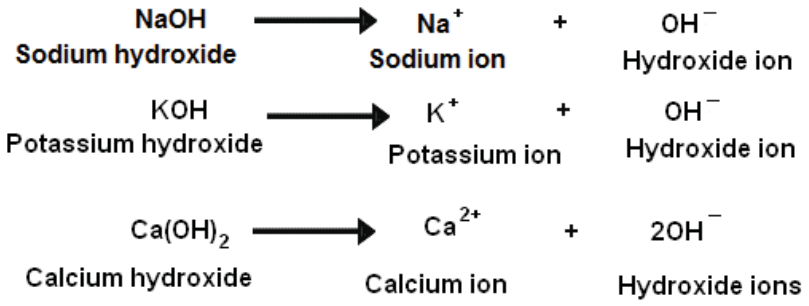
The hydrogen ions are responsible for the properties of acids.

Bases

A base is a proton acceptor. Metal oxides react with water to form bases. Metal oxides react with an acid to form salt and water. The product will no longer change litmus paper to red.

Some bases dissolve in water while others do not dissolve (are insoluble) in water. Bases that dissolve (are soluble) in water are called alkalis. Alkalis dissolve in water to form hydroxide ions (OH^-) as the only negative ion in solution.

Consider the following examples of alkalis:



The hydroxide ions are responsible for the properties of alkalis in solutions.

Section 5-7: Salts

At the end of section 5-7, you should be able to:

Describe a method of preparing, separating and purifying a salt from given substances.

Time

Section 5-7 has 6 pages. You should spend approximately 1.5 hours on this topic.

Preparation of Salts

From your previous study of chemistry you have learned that there are some chemical reactions that produce salt as one of the products.

1. Acid and a base

An acid reacts with a base to produce salt and water. The reaction is called neutralisation. This is because the acid loses its acidic properties while the base loses its basicity. Both of them become neutral.

Acid + base → salt + water

Acid + metal oxide ⟶ salt + water

Acid + metal hydroxide ⟶ salt + water

Examples:

a) $CaO + 2HCl \rightarrow CaCl_2 + H_2O$

b) $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$

2. Metals and acid

Metals react with acids to form salt and hydrogen. Metals which are very reactive are more likely to react with water to produce salt and hydrogen although the reaction is explosive. (Refer to Unit 4). These are metals like sodium, potassium and calcium which appear high in the reactivity series. Metals like magnesium, aluminium, zinc, iron and tin can react with acids to form salt and hydrogen. This is one method which is also used in the laboratory preparation of hydrogen.

Metal + acid ⟶ salt + hydrogen

Metal + water ⟶ salt + hydrogen

For example:

a) $Mg + 2HCl \rightarrow MgCl_2 + H_2$

b) $Ca + 2H2O \rightarrow Ca(OH)_2 + H_2$

3. Carbonates and Acid

Carbonates and acids can react to form salt, carbon dioxide and water. This method is also used in the laboratory preparation of carbon dioxide.

For example:

$CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O$

All of these reactions can be used to prepare salts. But some of the reactants are scarce and it would be more costly to use them. For example, metals are extracted in a costly manner and it would be very expensive to use metal reactions to prepare salts.

The chemical reaction that is mostly used in the school laboratories is the acid + metal hydroxide. Metal hydroxides are sometimes referred to as alkaline solutions. An alkali is defined as a soluble base. Other bases are insoluble in water. For example, CuO is a base but it is not an alkali because it is not soluble in water.

When preparing salts using alkalis and acids, the challenge is to use the required amount of acid and alkali. If the amounts of reactants do not balance, the salt produced will be impure. To make sure that the required amount of reactants is used, an indicator is added to the mixture to determine the required amounts.

The flow chart below shows the steps followed in preparation of salts in the school laboratory. When preparing a soluble salt:

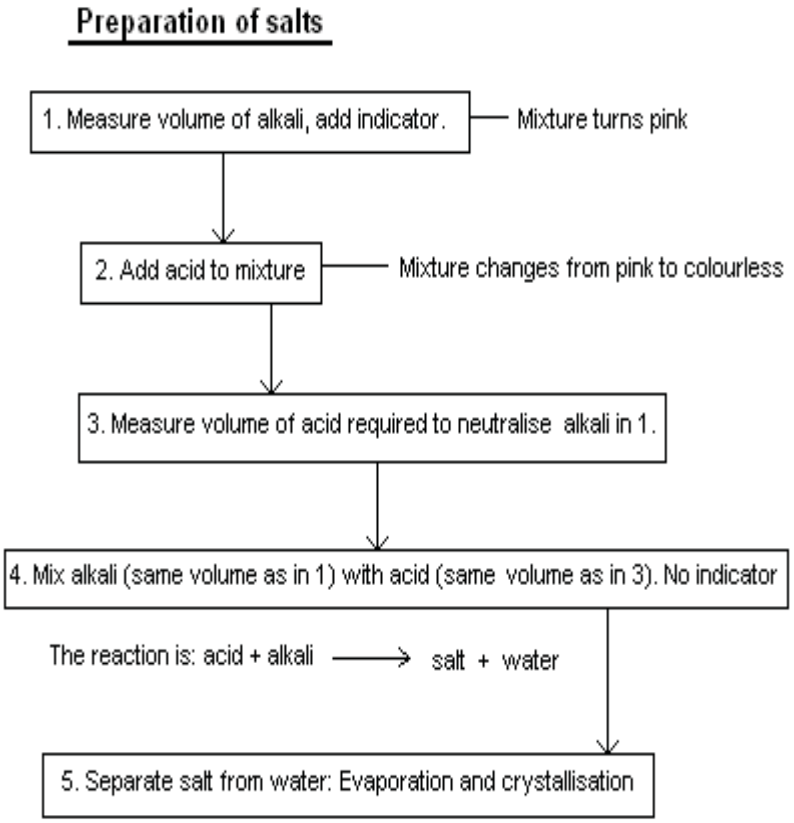


Figure 20: Flow chart showing preparations of salt.

The following illustrations demonstrate some steps in the process:

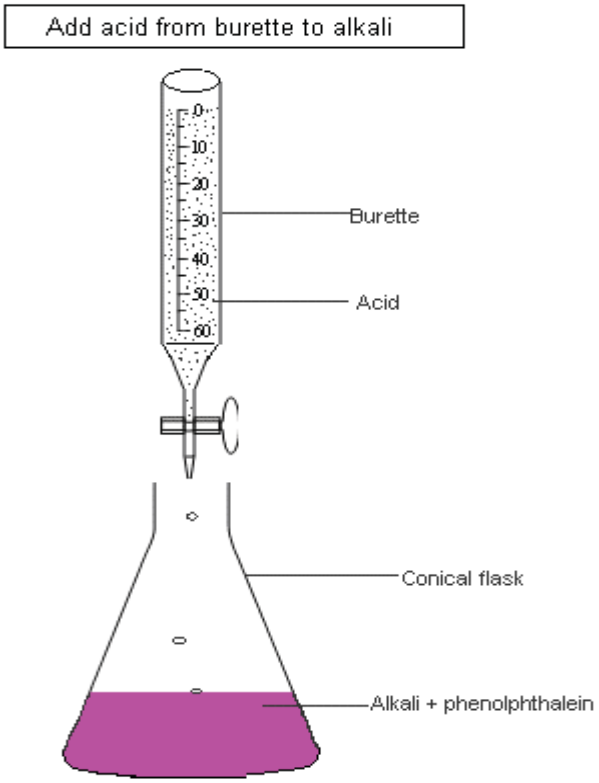


Figure 21: Titration reaction accessed from Wikimedia Creative Commons, 2010.

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This is the first step in which the chemist determines the amount of acid to be mixed with the alkali. The tap of the burette controls the acid out of the burette. The indicator phenolphthalein is in the alkali substance. This indicator is pink in basic conditions, and colourless in acidic conditions. When the colour is about to change to colourless, the acid is poured in drops until the last drop when the alkali changes to colourless.

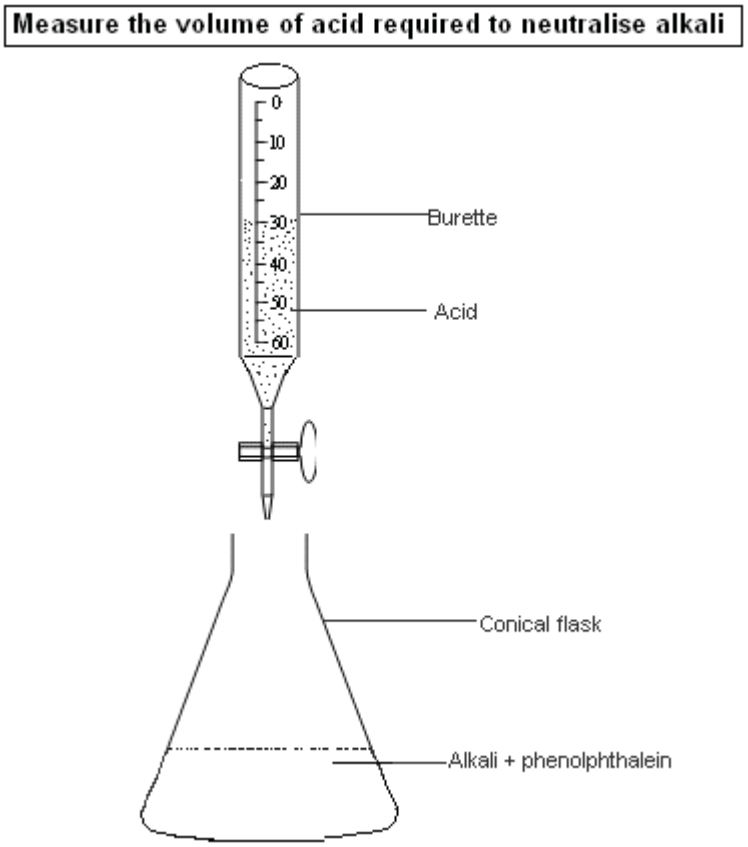

Figure 22: Volume of acid used in titration accessed from Wikimedia Creative Commons, 2010.

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From the reading of the burette in Figure 22, the volume of acid required to neutralise the alkali in the conical flask is 30 cm^3 or 30 ml.

After the volume of acid and alkali required in preparing the salt is established, the next step is to mix the fresh acid and alkali to prepare the salt.

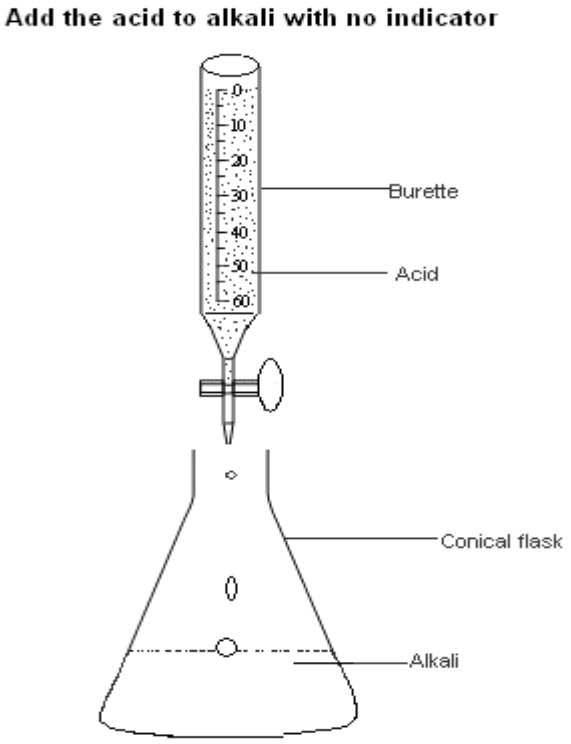

Figure 23: Preparation of salt accessed from Wikimedia Creative Commons, 2010.

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The alkali without the indicator is mixed with the measured volume of acid (Figure 23 shows 30 cm^3 has been measured, in that case 30 cm^3 would be added to the known volume of alkali).

Separation of Salt from Water

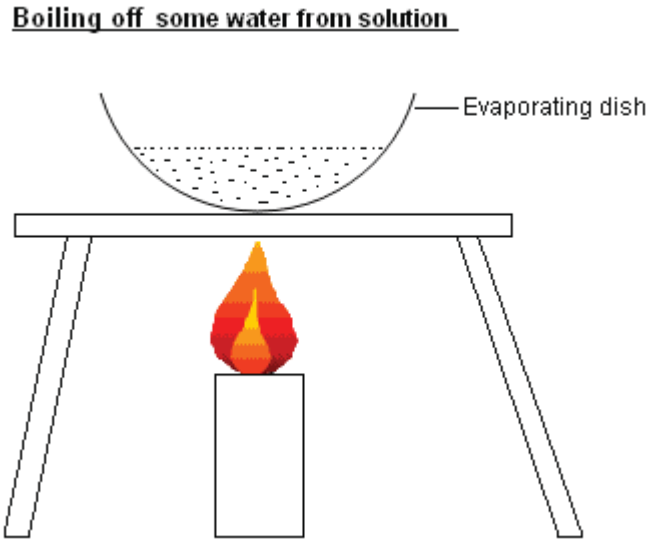


Figure 24: Apparatus for boiling off some water. Hand drawn by graphic designer at LDTC.

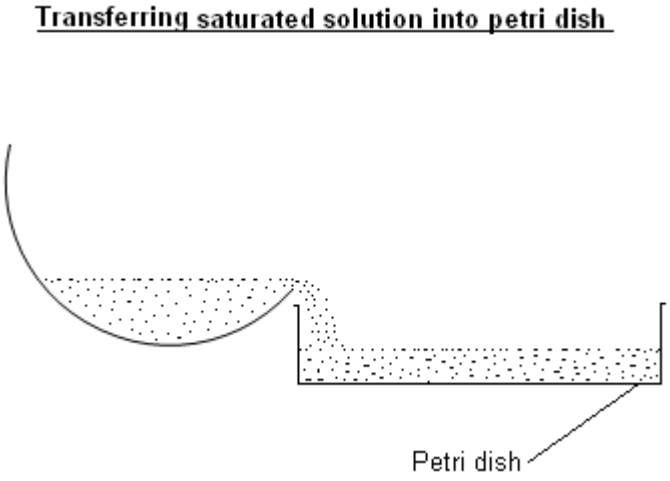


Figure 25: Transferring solution for evaporation. Hand drawn by graphic designer at LDTC.

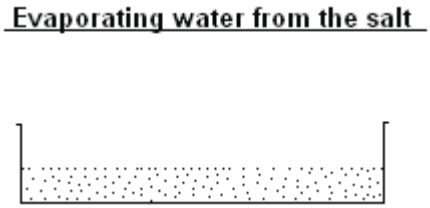


Figure 26: Evaporation of water. Hand drawn by graphic designer at LDTC.

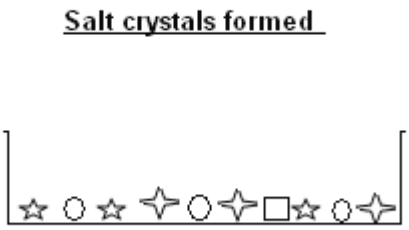
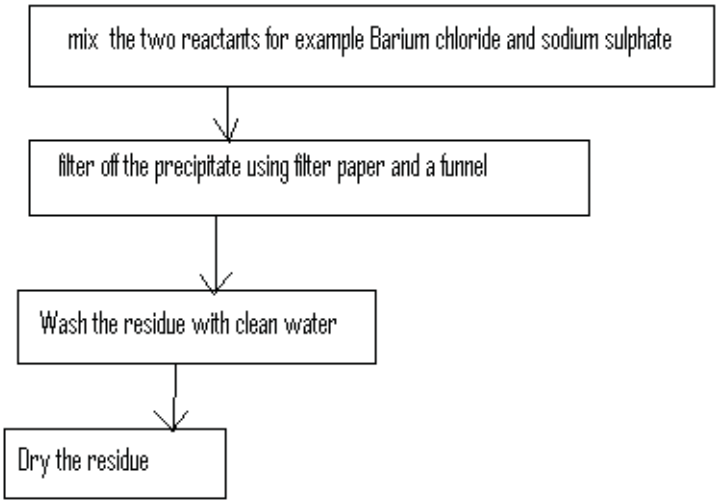


Figure 27: Salt crystals. Hand drawn by graphic designer at LDTC.

Precipitation Method of Preparing Salts

When preparing an insoluble salt, **precipitation** method is used. This method is called precipitation because the product formed is a precipitate. The above method cannot be used as it applies to substances which form crystals. The steps followed are as follows:



You have completed the material for Unit 5 on chemical reactions. You should now spend some time reviewing the content in detail. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit where you will begin to learn how the way chemicals interact with each other creates and influences our atmosphere and environment.

Unit Summary

Summary

In this unit, you learned that exothermic reactions give off heat energy to the surroundings. Most of these reactions involve burning or combustion where bonds are formed. Endothermic reactions on the other hand absorb heat from the surroundings. During and after endothermic reaction, the surroundings become cool. In these reactions, the energy is used to break chemical bonds.

You have also learned that there are different factors that affect the rate of chemical reactions. These include temperature, a catalyst, surface area and concentration. These factors can make the chemical reactions go faster or slower.

The other thing learned from this unit is that oxidation can be described as addition of oxygen or removal of hydrogen and reduction as addition of hydrogen or removal of oxygen. These terms can also be described in terms of gain and loss of electrons. Oxidation is the loss of electrons by a substance whereas reduction is the gain of electrons.

You learned that acids donate the hydrogen ion, H^+, and turn blue litmus paper red. The universal indicator shows a range of colours in acids from red for strong acids to yellow for weak acids. On the other hand, alkalis which are soluble bases produce hydroxide ions, OH^-, in solutions and change red litmus paper blue while a universal indicator changes to blue-green for weak alkalis, blue and purple for strong alkalis. Acids and bases react together in a neutralisation reaction to produce salt and water. These reactions are used both in the school laboratories and in industry to prepare salts. When the reaction is complete, the salt is separated from water by using boiling, evaporation and crystallisation.

You have learned that oxides can be classified as acidic oxides, basic oxides, neutral and amphoteric oxides.

Assignment 5

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:30]

1. Name the salt that will be produced from:

a) The reaction of hydrochloric acid [HCl] and sodium hydroxide [NaOH]. (1)

b) The reaction of nitric acid [HNO_3] and calcium hydroxide [$Ca(OH)_2$]. (1)

c) The reaction between sulphuric acid [H_2SO_4] and magnesium hydroxide [$Mg(OH)_2$]. (1)

2. What will be the colour of the indicator in the following solutions:

Indicator	Solution				
	Strong acid	Weak acid	Neutral solution	Weak alkali	Strong alkali
Litmus paper					
Universal indicator					

(10)

3.

a) Define the following terms:

(i) Oxidation (2)

(ii) Reduction (2)

b) Between metals and non-metals, which substances are likely to be oxidised? (1)

4. Which of the following processes are exothermic or endothermic:

a) Burning wood (1)

b) Photosynthesis (1)

c) Cooking porridge (1)

5.

a) Mention any three factors that affect the rate of chemical reactions. (3)

b) Say whether the situations in the following chemical reactions increase or decrease the rate of chemical reaction:

i) Calcium carbonate reacts with hydrochloric acid (HCl), calcium carbonate is ground-up. (1)

ii) Magnesium reacts with nitric acid (HNO3), nitric acid is diluted. (1)

iii) Copper reacts with HCl, then HCl is heated. (1)

6. Oxides A, B and C were each dissolved in water and the solutions were tested using litmus paper and a universal indicator.

The table below shows the results:

Oxide	Litmus paper	Universal indicator
A	No change	Green
B	Red	Yellow
C	Blue	Purple

Classify the oxides A, B and C. (3)

Case study

7. You are working as a chemical consultant at an industrial plant that produces magnesium sulphate from the reaction between solid magnesium and liquid sulphuric acid. The director of the industrial plant has brought you in to figure out how to increase the amount of sulphate they can produce (in other words, increase the reaction rate). What would your final report say?

_____
_____
_____
_____(5)

Answers to Assignment 5

1.

(a) Sodium chloride (NaCl)

(b) Calcium nitrate [$Ca(NO_3)_2$]

(c) Magnesium sulphate ($MgSO_4$)

2.

Indicator	*Solution*				
	Strong acid	*Weak acid*	*Neutral solution*	*Weak alkali*	*Strong alkali*
Litmus paper	*Red*	*Red*	*No change*	*Blue*	*Blue*
Universal indicator	*Red*	*Yellow*	*Green*	*Green-blue*	*Purple*

3.

(a)

(i) Oxidation is the addition of oxygen or removal of hydrogen or loss of electron (s)

(ii) Reduction is the removal of oxygen or addition of hydrogen or gain of electron (s)

(b) Metals are likely to be oxidised.

4.

(a) Burning wood is exothermic

(b) Photosynthesis is an endothermic reaction

(c) Cooking porridge is endothermic reaction

5.

(a) Factors that affect the rate of chemical change are:

Temperature, a catalyst, concentration, surface area and light.

(b)

(i) When calcium carbonate reacts with hydrochloric acid and calcium carbonate is ground-up, the rate increases.

(ii) When magnesium reacts with nitric acid and nitric acid is diluted, the rate of chemical reaction decreases.

(iii) When copper reacts with HCl and HCl is heated, the rate increases.

6. A – Neutral oxide,

B – Acidic oxide,

C – Basic oxide.

Assessment 5

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 60 minutes.

(Total Marks:34)

1. State the factor that is responsible for the following process:

   (a) Explosion by fine flour dust in a flour mill. (1)

   (b) Milk taking a longer time to go sour in a fridge. (1)

   (c) Fire burning fast and well in chopped wood. (1)

2. Say whether the following better describe exothermic or exothermic reaction:

   (a) Bond breaking (1)

(b) Release of heat energy to the surroundings (1)

(c) Absorbing heat energy from the surroundings (1)

(d) Bond formation (1)

3. Which of the following reactions is oxidation and which is reduction:

(a) $Na \longrightarrow Na^{+} + e$

(b) $Cl + e \longrightarrow Cl^{-}$

(c) $Al \longrightarrow Al^{3+} + 3e$

(d) $S + 2e \longrightarrow S^{2-}$

(e) $Fe \longrightarrow Fe^{2+} + 2e$

(5)

4. Define the following terms and give an example of each:

   (a) Base (3)

   (b) Alkali (3)

   (c) Indicator (3)

5. State the acid and or the alkali that can be used to produce the following salt:

   (a) Magnesium chloride, $MgCl_2$ (2)

   (b) Potassium nitrate, KNO_3 (2)

6. Define the following terms and give an example of each:

   (a) Amphoteric oxide (3)

   (b) Basic oxide (3)

   (c) Acidic oxide (3)

Chemistry

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 6

Atmosphere and Environment

Study Skills

Do you find it difficult or distracted to study at home? Make sure to establish a study routine that your family members are aware of. Organize your environment, and plan for the unpredictable! Disruptions are a natural part of life-don't get angry, study when and where you can and just do a little bit at a time. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

You know that air and water are essential to our survival. Is the air and water around you clean? Some of the activities we do in everyday life affect the environment we live in. Air and water are affected by some of the things we produce. For example, some people burn tyres during festive seasons. As the tires emit smoke, it goes into the air making it dirty. Others dump oil into the water and make the water we drink dirty.

In this unit, you will learn about the components of the atmosphere and environment and how to make the environment clean. We are also going to look at the properties of the gases found in the atmosphere, their uses and effects.

Time

This unit consists of 23 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. They are a guide to what you should focus on while studying this unit.

Outcomes

Study Skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Describe* the composition and behaviour of the atmosphere and the environment.

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *State* the composition of clean air.
- *Describe* the formation and uses of oxygen.
- *Name* common pollutants of air and their sources and effects.
- *Discuss* the purification of water.
- *Describe* the formation and uses of hydrogen.
- *Describe* the formation and uses of carbon dioxide.
- *Describe* the uses of nitrogen in plant life.
- *Discuss* the Haber process.

Terminology

Aerosols:	Tiny particles released from cars, trucks and other smokestacks. They include sulphates and carbon.
Catalyst:	A substance that increases the rate of chemical reaction but is not consumed.
Combustion:	Reaction with oxygen to produce carbon dioxide and water. Also known as burning.
Corrosion::	Breaking of a material into its component atoms.
Dry ice:	Solid carbon dioxide.
Fractional distillation:	Method of separating a mixture of solutes with boiling points close to each other.
Galvanizing:	Covering iron metal with zinc metal.
Liquid air:	Air that has been cooled to very low temperatures so that it has condensed to a liquid.

Smog: Mixture of smoke and fog in air.

Sublimation: The change from solid to gas or gas to solid with no change to liquid.

Section 6-1: Air

By the end of section 6-1, you should be able to:

- *state* the composition of air.
- *describe* the formation of oxygen, hydrogen and carbon dioxide.
- *describe* the uses of these gases.

Time

Section 6-1 has 3 pages. You should spend approximately 40 minutes on this topic.

Air is one mixture which is found around us in the whole world. Although air is a mixture, its composition in terms of the amount of gases found in it is known. Air as a mixture contains gases which are essential for the lives of animals and plants. Other gases which are found in air also have their own importance.

The Atmosphere

The atmosphere of the earth is made up of layers with different conditions. Figure 1 below illustrates the layers of the atmosphere as: troposphere, stratosphere, mesosphere, thermosphere and the exosphere.

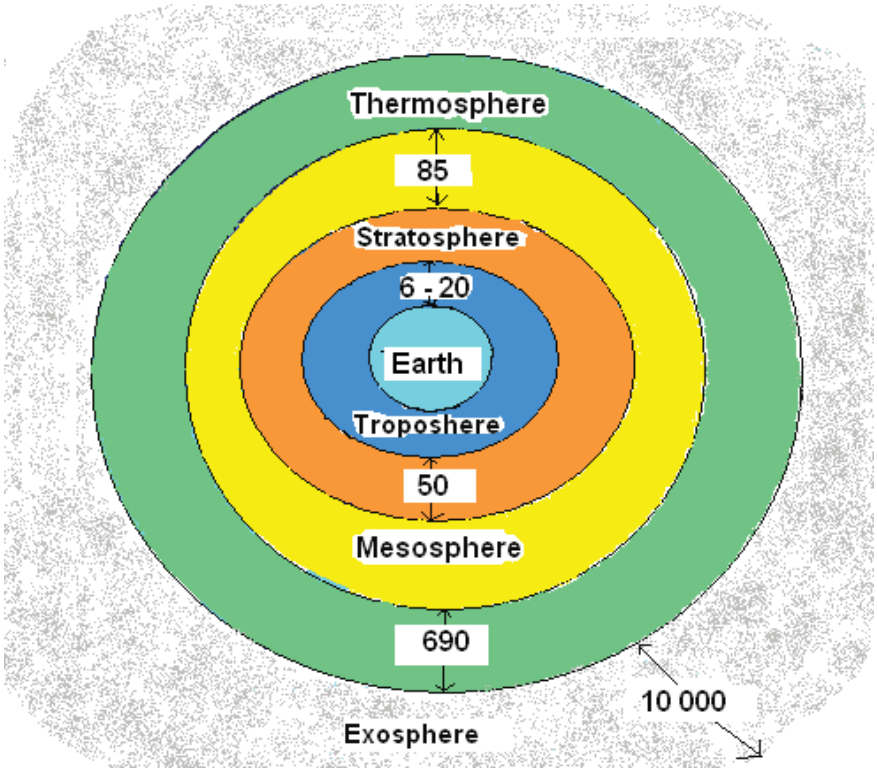

Figure 1: Layers of the atmosphere measured in km, (not drawn to scale). Hand drawn by graphic designer at LDTC.

Objects on Earth

There are many objects around you that you can see. These include people, animals, stones and plants. There are also some things that you do not see, but you know exist. For example, there are different gases around you. Sometimes you may smell gases but do not see them. The mixture of different gases in the atmosphere is called air.

Figure 2: Environment with living and non-living things accessed from Creative Commons, 2010.

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Activity

Composition of Air

Activity 1

1. What is the most abundant gas that is found in the air you require for respiration?

_____

_____

2. What is the most abundant gas that is found in the air you breathe out?

_____

_____

Check the answers at the end of the section.

Animals take in oxygen and produce carbon dioxide during respiration. During photosynthesis, plants take in carbon dioxide to produce carbohydrates and oxygen. Both oxygen and carbon dioxide are found in the atmosphere. The gases that make up air include nitrogen, oxygen, carbon dioxide, inert gases and some other gases such as water vapour. If a sample of air is taken from the troposphere the composition of air would be similar to the one shown in Table 1 below:

Table 1: Composition of Air

Component	Symbol	Percent of Volume
Nitrogen	N_2	79%
Oxygen	O_2	20%
Noble gases	Ar, He	1%
Carbon dioxide	CO_2	
Water vapour	H_2O	

Section 6-2: Formation of Gases and their Uses

The different gases in the atmosphere are used in various ways. For example, oxygen is used by humans for burning things and by all animals

for respiration. Hydrogen is used as fuel for jets while carbon dioxide is used as a fire extinguisher.

By the end of section 6-2, you should be able to

- *Describe* the formation and uses of oxygen.

Time

Section 6-2 has 6 pages. You should spend approximately 1 hour on this topic.

Oxygen

Oxygen forms 20% of the atmosphere as shown in Table 1. Sometimes oxygen has to be used in its purest form and therefore needs to be separated from air by fractional distillation. Small amounts of oxygen can be prepared in the laboratory from hydrogen peroxide using manganese dioxide as a catalyst. The equation below shows a catalytic decomposition of hydrogen peroxide:

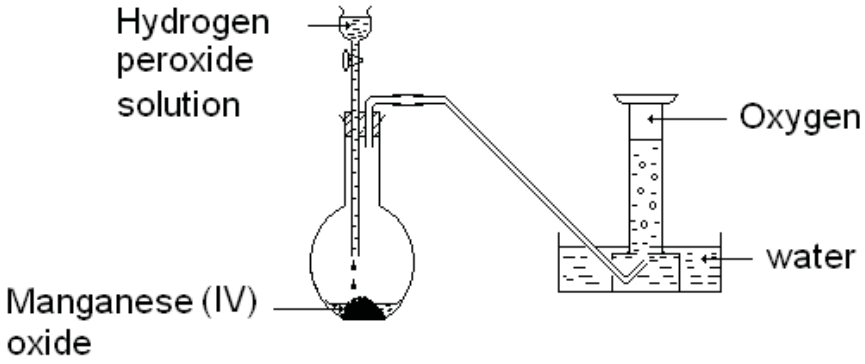

Figure 2: Preparation of oxygen from hydrogen peroxide accessed from Wikimedia Creative Commons, 2010.

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The reaction is: $\mathbf{H_2O_2 + MnO_2 \rightarrow H_2O + O_2 + MnO_2}$

Properties of Oxygen:

a) It is a colourless gas

b) It is odourless

c) It supports burning

d) It is slightly soluble in water

Test for Oxygen:

When a glowing splinter is introduced into a gas jar containing oxygen, it rekindles/burns again

Uses of oxygen

Respiration

Oxygen is essential for respiration. Animals breathe in oxygen that is needed for cell respiration. Some people have difficulty in breathing oxygen for respiration. Figure 4 shows an oxygen tent used in hospitals to supply oxygen to patients. Figure 5 shows an astronaut carrying oxygen to the moon to help them breathe. Figure 6 illustrates a diver carrying oxygen gas in a tank for breathing under water.

Figure 3: Oxygen tent accessed from Wikimedia Creative Commons, 2010.

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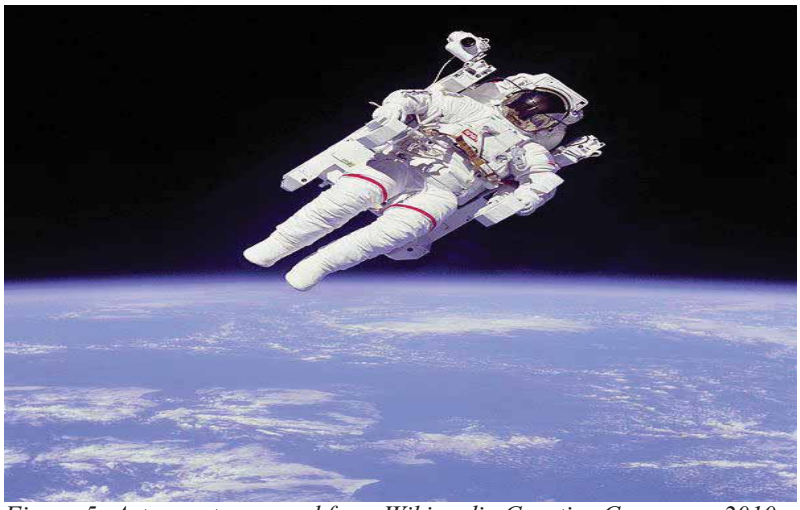

Figure 5: Astronaut accessed from Wikimedia Creative Commons, 2010.

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Figure 6: Deep sea diver with oxygen tank accessed from Wikimedia Creative Commons, 2010.

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Burning

Oxygen supports burning. It reacts with other substances to produce different oxides. Figure 7 shows a diagram where methane is burning. In this case oxygen is reacting with methane (CH_4) to give carbon dioxide and water.

Figure 7: Methane burning accessed from Flickr, 2010.

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Fuel burns in oxygen to produce heat and light.

Welding

Acetylene burning in oxygen produces enough heat to melt and combine metals, as shown in Figure 8.

Figure 8: Welding torch accessed from Wikimedia Creative Commons, 2010.

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Formation of Carbon Dioxide

Carbon dioxide is a gas found in the atmosphere. This gas has many uses in everyday life. Carbon dioxide can be prepared in the laboratory using a metal carbonate and acid. Below is a diagram which shows how carbon dioxide can be prepared in the laboratory.

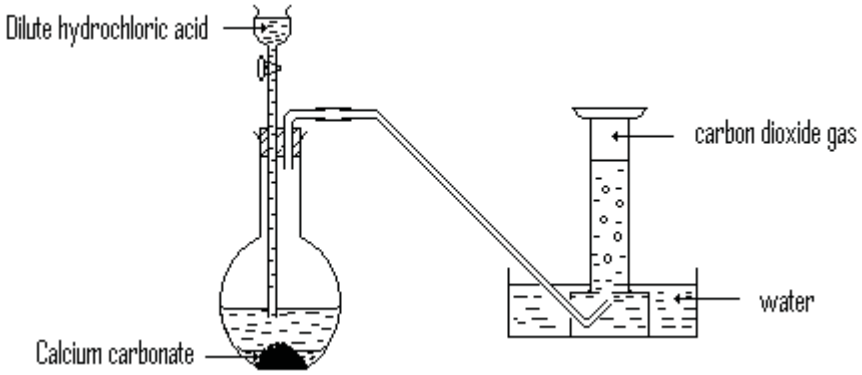


Figure 9: Preparation of carbon dioxide using calcium carbonate and dilute hydrochloric acid.

Properties of Carbon Dioxide

a) Colourless

b) Odourless

c) Slightly soluble in water

d) Turns a blue litmus paper pink

Test for Carbon Dioxide

a) Bubble carbon dioxide in lime water, lime water will turn cloudy

b) Introduce a burning splint into a gas jar containing carbon dioxide; the flame will be put out.

Uses of Carbon Dioxide

a) As fire extinguisher

b) In fizzy drinks

c) In photosynthesis

d) In refrigeration

e) To decorate stage with fumes

Reflection

Due to global increases in carbon dioxide emissions from burning fuels such as oil, natural gas and diesel, the Earth has seen global temperature increases and global climate change in the past 50 years. This is due to what is called the Green House Effect. Carbon dioxide and other greenhouse gases trap sunlight in the atmosphere, making it warmer. The effects of global warming can be seen in the disappearance of Arctic ice, glaciers and mountains snows, destruction of coral reefs and an increase in extreme weather events.

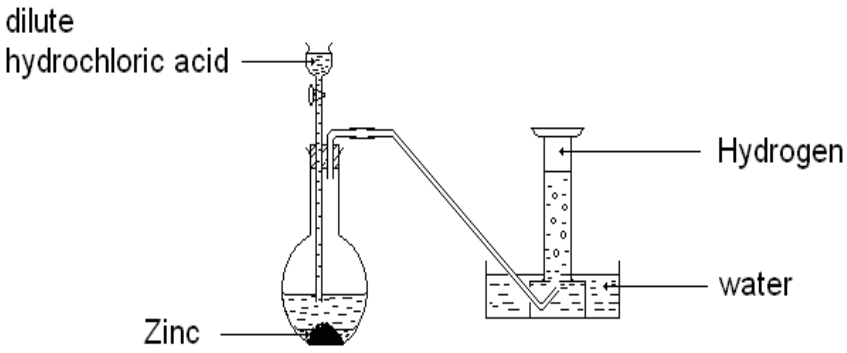
Read more here:
http://news.nationalgeographic.com/news/2004/12/1206_041206_global_warming.html

Formation of Hydrogen

Hydrogen does not form part of the atmosphere. However, hydrogen is an important gas which is used in many chemical reactions. Water is made of hydrogen and oxygen. Large amounts of hydrogen can be produced from water. There are different ways in which water can be broken down to yield hydrogen. We are going to discuss three methods of producing hydrogen.

Laboratory Preparation of Hydrogen

Metals react with acids to form salt and hydrogen (Unit 5). In the laboratory, metals like magnesium, aluminium, zinc react with acids to form hydrogen gas. The gas is collected using downward displacement of water. The equation below shows how hydrogen can be prepared in laboratory.



$$Zn + 2HCl \rightarrow ZnCl_2 + H_2$$

Using Carbon to Form Hydrogen

Water reacts with carbon to produce hydrogen and carbon monoxide. For this reaction to occur at a high rate, heat is provided. Figure 10 shows how this process occurs.

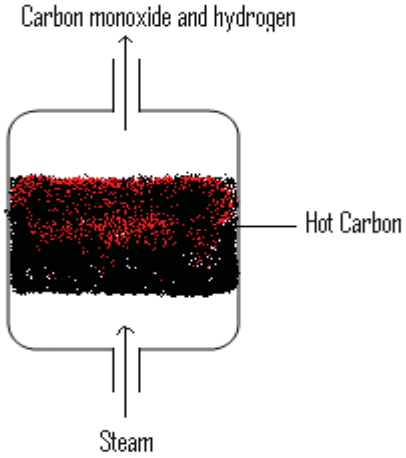


Figure 40: Production of hydrogen from carbon and water (Hand drawn).

Using Hydrocarbons to Form Hydrogen

Water can react with hydrocarbons to give hydrogen and carbon monoxide. This reaction needs both heat and a catalyst (nickel) to occur at a high rate. The following equations show examples of this reaction:

$$C_2H_8 + 2H_2O \xrightarrow[Ni]{heat} 2CO + 6H_2$$

$$C_8H_{16} + 8H_2O \xrightarrow[Ni]{heat} 8CO + 16H_2$$

Properties of Hydrogen:

a) It is colourless

b) It is odourless

c) It is insoluble in water

A Test for Hydrogen:

When a burning splint is introduced into a gas jar containing hydrogen, a burning splint is put out with a 'pop' sound.

Uses of Hydrogen

Hydrogen is used in industry for the manufacturing of ammonia. This process will be discussed later.

Hydrogen reacts with unsaturated hydrocarbons such as alkenes and alkynes. This reaction changes liquid hydrocarbons to solid hydrocarbons. For example oil can be changed into margarine.

Hydrogen is also used as a fuel. The reaction between hydrogen and oxygen produces heat energy.

Hydrogen is used in the production of organic compounds such as ethanol.

Nitrogen

Nitrogen forms a large percentage of air. Nitrogen is therefore found by distilling air. Nitrogen is used to make many important chemicals which are used in many ways.

Uses of Nitrogen

Fertilisers

Nitrogen compounds are needed to make proteins in plants. Therefore, nitrogen is used to make fertilisers. Examples of fertilisers that contain nitrogen are NPK fertilisers. The symbol NPK shows elements that are contained in this fertiliser and it stands for Nitrogen, Phosphorus and

Kalium (potassium). Fertilisers contain minerals that plants need to grow fast and healthy.

Ammonia

- Ammonia is gas that is produced from the reaction between hydrogen and nitrogen in a Haber process. Nitrogen is taken from the air while hydrogen is from methane and steam. Another way of producing hydrogen is by heating water using coke (C). During the Haber process, hydrogen and nitrogen are passed over iron catalyst at high pressure and temperature.

$$3H_2 + N_2 \longleftrightarrow 2NH_3$$

Ammonia is a very important gas because it is used for making fertilisers and many household chemicals that are used for cleaning.

Production of Ammonia

Ammonia cannot be found in large quantities naturally, therefore, the best option is to produce it.

Figure 11 shows the steps in the production of ammonia:

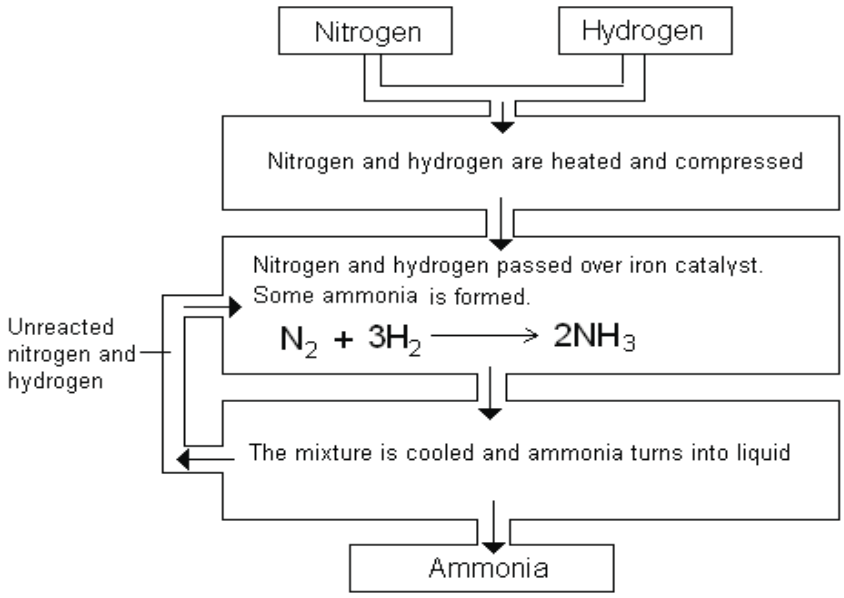


Figure 51: Production of ammonia (Hand drawn).

Through the fractional distillation of air, hydrogen is obtained from hydrocarbons (e.g. reaction of methane and steam). The production of ammonia in large quantities in industry is called the Haber process.

Activity 2

Activity

1. Fill in the table below with missing terms;

Preparation of	Reaction	Products	Balanced equation
Hydrogen	---------- + sulphuric acid	Magnesium sulphate	----- + ------ → MgSO4 + H_2
Oxygen	----------+----------	Oxygen + water	------+------ → O_2 + H_2O
Ammonia	_____+_____	Ammonia	N_2 + H_2 → NH_3

2. a) How do you test for hydrogen gas?

   b) Name a catalyst used in the preparation of nickel.

   c) Name one of the uses for carbon dioxide.

Answers to Activities Formation of Gases and their Uses

Activity 1

1. ***We breathe in oxygen and it is used for respiration.***
2. ***The gas that is in large quantity from exhaled air is carbon dioxide.***

Activity 3

1.

Preparation of	Reaction	Products	Balanced equation
Hydrogen	Magnesium + sulphuric acid	Magnesium sulphate + hydrogen gas	-Mg + H_2SO_4----- -=> $MgSO_4$ + H_2
Oxygen	-hydrogen peroxide and manganese dioxide as a catalyst-	Oxygen + water	- H_2O_2+MnO_2=>O_2 + H_2O + MnO_2
Ammonia	Nitrogen + Hydrogen	Ammonia	N_2 + 3H_2=> 2NH_3

2 a) Introduce a burning splint into a gas jar containing hydrogen and a "pop" sound will be heard.

b) Nickel

c) Photosynthesis, fire extinguisher, carbonated drinks, refrigerator or decorating stages.

Section 6-3: Air Pollution

Time

Section 6-3 has 5 pages. You should spend approximately 1 hour on this topic.

Activity 2

Activity

Mamello is cleaning her surroundings and she finds tyres and plastics and she burns them. The smoke from the fire goes into the atmosphere.

Suggest any problems that may be caused by the smoke from burning tyres and plastics to plants and animals.

_____

_____

Compare your answers with those at the end of the section.

The composition of air shows the gases that are in clean air. Sometimes there are other substances that may be found in the air. These substances make air unclean. Unclean air is called polluted air and the other substances are called air pollutants. Figure 17 shows one of the causes of air pollution.

Figure 62: Gas waste from industry accessed from Wikimedia Creative Commons, 2010.

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Air pollutants come mainly from burning: coal, gas, petrol, diesel, plastics or tyres. The smoke from burning these substances produces different gases and some of them are harmful to plants and animals:

- Carbon dioxide (CO_2) is produced when burning carbon-containing substances (fossil fuels). For example, carbon dioxide can be produced when burning coal, wood or any organic substance. When carbon dioxide has been produced from burning the mentioned substances, it goes into the atmosphere where it reacts with rain to form carbonic acid. The equation show how carbonic acid is formed:

  $$CO_2 + H_2O \rightarrow H_2CO_3$$

  Carbon dioxide has also been found to cause greenhouse effect which is the result of carbon dioxide building up in the air which subsequently traps heat from the sun in the atmosphere. This results in and increase in the temperature of the Earth.

- Sulphur dioxide (SO_2) is produced from burning substances which contain sulphur like petrol, coal and tyres. The sulphur dioxide produced goes into the atmosphere where it reacts with water to form acid rain. This equation shows how acid rain is formed:

  $$SO_2 + H_2O \rightarrow H_2SO_3$$

- Nitrogen oxides (NO, NO_2, N_2O) are produced from burning coal, petrol or diesel. Nitrogen in air reacts with oxygen at high temperatures. The inhalation of oxides produced causes death, faintness, and a rapid burning and swelling of the tissues of the throat and respiratory track. Headache, dizziness and fatigue are also results of these pollutants.

- Lead oxide (PbO) is produced when burning leaded petrol. The fumes produced from burning the leaded petrol harms the lungs and respiratory track.

Effects of Air Pollution

Activity

Activity 3

One source of air pollution may produce many pollutants. Each pollutant causes different problems.

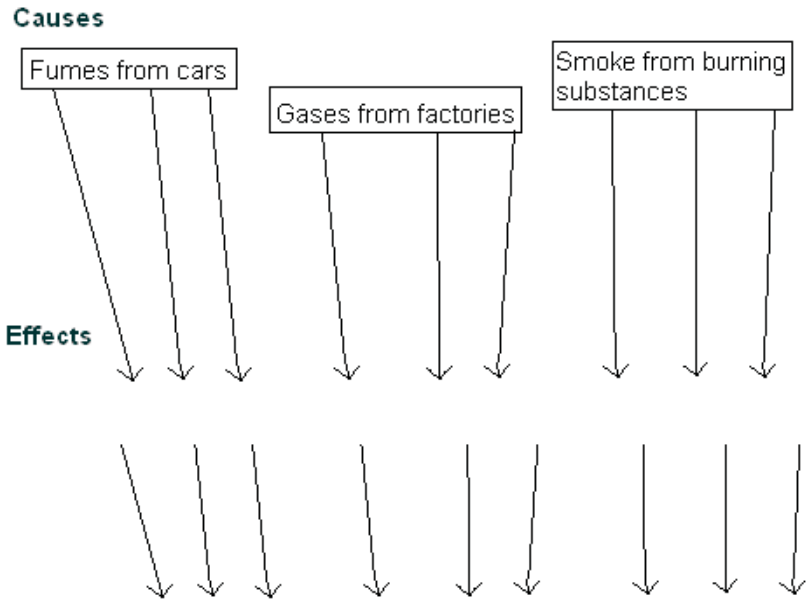
1. Some of the causes of air pollution are cars, factories and burning substances. Name some of the pollutants resulting from the above causes:

   _____
   _____
   _____
   _____

2. State the effects of these sources of air pollution in the space provided._____

   _____
   _____
   _____
   _____

Causes and effects of air pollution



Compare your answers with those at the end of the section.

People have no alternative but to breathe in the air around them whether polluted or not. The sources of air pollution produce gases such as carbon dioxide, carbon monoxide, sulphur oxide, nitrogen oxides, lead oxide and dust. These pollutants have harmful effects on human lungs especially elderly, young and sick people whose lungs are weak. Most of these pollutants are odourless and cannot be seen.

Reflection

Activity 4

What are the sources of air pollution in your area? Make a list. Think of a project to advise your community leaders on how to reduce air pollution in your area. You may want to discuss this with your friends and family.

Compare your answers with those at the end of the section.

Answers to Activities on Air Pollution

Activity 2

Some gases are dangerous to animals, buildings and plants. Animals breathe in oxygen from the air. If the air is polluted, air taken in by animals will have less oxygen as part of the air will be pollutants. The acid in the rain will also react with materials in the buildings and cause corrosion. The acid will also destroy the plants.

Plants get destroyed by acid rain and too much heat. Too much carbon dioxide will result in greenhouse effect and acid rain. Polluted air such as nitrogen oxides and sulphur dioxide result cause acid rain which kills plants.

Activity 3

1. ***Sulphur dioxide, carbon dioxide and oxides of nitrogen.***

2. ***Acid rain and smog in the atmosphere.***

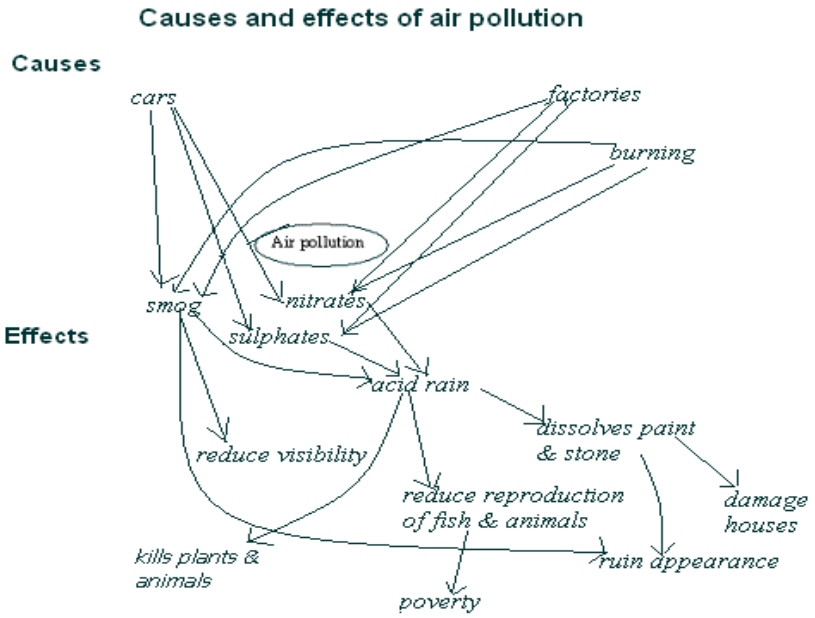


Figure 13: Causes and effects of air pollution. Hand drawn by graphic designer at LDTC.

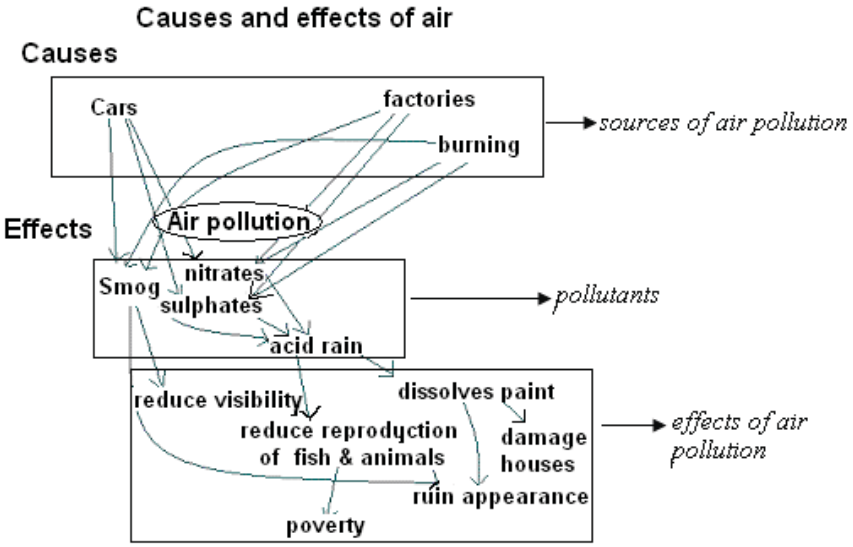


Figure 14: Causes and effects of air pollution. Hand drawn by graphic designer at LDTC.

Activity 4

The activities that can be done to reduce air pollution include:

Avoid burning of plastics, tyres and other toxic substances. Some of these substances can be re-cycled.

Encourage use of public transport and bicycles.

Encourage use of unleaded petrol.

Therefore, you could design a project based on these activities. For example, a campaign to inform the community about the dangers of burning tyres and the use of leaded petrol or a project about making valuable objects from plastics, cans or paper depending on which waste product is problematic in your area.

Section 6-4: Water Pollution and Treatment

Time

Section 6-4 has 3 pages. You should spend approximately 30 minutes on this topic.

Water Pollution

Note it!

Activity 5

Study Figure 15 below. It is reported that people living near this river throw objects into the water. The objects thrown include; dirty water after washing their clothes, empty tins after using tin foods.

Figure 75: Polluted water accessed from Wikimedia Creative Commons, 2010.

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Imagine yourself living down-stream and you have no other source of water. How would you treat (purify) the water?

_____
_____
_____
_____
_____

Compare your answers with those at the end of the section.

Water pollutants are normally called impurities. Some people put impurities in clean water. They urinate and throw rubbish in sources of drinking water. Some rubbish contains chemicals which are harmful compounds. Impurities include cans, organic matter (i.e. paraffin), bacteria and viruses. If you drink this water you will probably get sick.

Water Treatment

Our drinking water comes from rivers, lakes, reservoirs and wells. To be used as drinking water, it has to be treated. Figure 16 demonstrates the steps followed in the treatment of water.

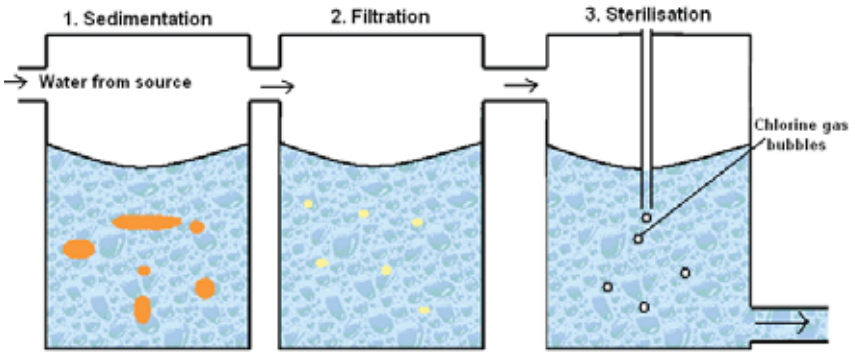

Figure 168: Water treatment process accessed from Wikimedia Creative Commons, 2010.

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Stage 1

Big solid particles are removed from the water. Most of the particles are gravel and plant remains.

Stage 2

This is where small particles from plants and dead animals are filtered out. In this case sand filters are used. Sand filters have four layers that trap the impurities: stony layer, coarse layer, fine layer and very fine layer of sand to trap the impurities.

Stage 3

Chlorine is added to kill all bacteria and viruses. Lime is also added to adjust the pH of chlorinated water.

Answers to Activities on Water Pollution and Treatment

Activity 5

You can boil and filter it. Boiling will kill the bacteria and filtration will remove the solid particles. Some people dig wells on the river bend in the sand and use the water. This water may be clean from particles but may not free from bacteria.

Unit Summary

Summary

In this unit you learned that:

- The atmosphere is made of five different layers: troposphere, stratosphere, mesosphere, thermosphere and the exosphere. The layer closest to the earth is troposphere. The atmosphere contains varying amounts of pollution.

- Clean air is composed of the following gases with the corresponding percentages by volume: nitrogen = 79, oxygen = 20, carbon dioxide and inert gases = 1. Clean air is essential for plant and animal life.

- The different gases in the atmosphere are used in various ways. Oxygen is used by humans for burning things and by all animals for respiration. Oxygen can be provided to enable people to temporarily live in environments where there is no oxygen.

- Both hydrogen and nitrogen are used in the production of ammonia gas in the Haber process. Ammonia is used in the production of fertilisers which are essential for plant growth. The nitrogen used in the Haber process is obtained from the air by fractional distillation. Hydrogen can be produced by the reaction of methane with steam. Another way of producing hydrogen is by heating water using coke. During the Haber process, hydrogen and nitrogen are passed over an iron catalyst in high pressure and temperature.

- The main sources of air pollution are the burning of fuel like petrol and diesel and emissions from factories. Polluted air contains gases that are harmful plants and animals. These gases include sulphur dioxide, nitrogen oxides and carbon monoxide. Sulphur and nitrogen oxides result in acid rain which kills plants and small animals. Carbon monoxide is very poisonous and can kill a person.

- There are three main steps in the purification of water. The first two steps, sedimentation and filtration, are concerned with physical separation of particles in water. The third, sterilisation, deals with killing bacteria and viruses that can be in water.

Assignment 6

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:28]

1. How is nitrogen important in plant growth?

   _____
   _____
   _____(1)

2.

   (a) What are the two gases with the largest volume in air?_____
   _____
   _____ (2)

   (b) State the percentage of oxygen in air.

   _____
   _____
   _____
   _____(1)

3. List two uses of each of the following gases:

   (a) Oxygen,_____
   _____
   _____
   _____ (2)

   (b) Hydrogen

   _____
   _____
   _____
   _____ (2)

   (c) Nitrogen._____
   _____
   _____
   _____ (2)

4.

(a) What are the reactants in the production of ammonia?_____
_____
_____
_____ (2)

(b) What is the name given to the process of ammonia production?_____
_____ (1)

(c) Write down the chemical reaction for the production of ammonia._____
_____ (2)

(d) State the conditions needed for the production of ammonia.
_____
_____
_____(2)

5. List the steps in the water treatment process. Explain the purpose of each step.
_____
_____
_____
_____
_____
_____ (6)

6. Nitrogen oxides and sulphur dioxide are common pollutants of air.

(a) State the source of nitrogen oxides and sulphur dioxide.
_____
_____
_____
_____(4)

(b) State the common effect of sulphur dioxide and nitrogen oxides:_____
_____
_____
_____ (1)

Assignment 6 Solutions

1. ***Nitrogen forms compounds that are needed by plants to make proteins.***

2.

   (a) Nitrogen and oxygen.

   (b) Oxygen = 20%.

3.

   (a) Oxygen uses – in hospitals by patients, by divers, by astronauts, for welding and for metal extraction.

   (b) Hydrogen uses – for ammonia production and for making fertilisers.

   (c) Nitrogen uses – for ammonia production and for making fertilisers.

4.

   (a) Nitrogen and hydrogen.

   (b) Haber process.

   (c) $N_2 + H_2 \rightarrow 2NH_3$

   (d) High pressure and high temperature.

5. ***Sedimentation – to remove big particles from the water.***

   Filtration – to remove fine particles from the water.

   Sterilisation – such as chlorination, to kill all bacteria and viruses in water.

6. ***a) Nitrogen oxides – from burning of diesel, petrol and coal.***

   Sulphur dioxide – from burning of petrol and coal.

   b) They both produce acid rain which can damage buildings and kill plants.

Assessment 6

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 50 minutes.

(Total Marks:28)

1. Air contains a mixture of gases. Identify the gases described below:

   a) One gas in the mixture will allows things to burn in it._____
   _____
   _____ (1)

   b) A gas which makes up 79% of the air.
   _____
   _____
   _____ (1)

2.

   a) Explain how nitrogen and hydrogen gas are obtained for the production of ammonia.
   _____
   _____
   _____
   _____ (2)

   b) What is the importance of ammonia?_____
   _____
   _____
   _____ (1)

3. State whether the following statements are true or false.

   a) It is not possible to purify water that has bacteria in it._____ (1)

b) Hydrogen forms part of the atmospheric air._____ (1)

c) Carbon dioxide is highly soluble in water._____ (1)

4. Nitrogen is one of the gases present in clean air.

(a) Name any other two gases present in clean atmosphere._____
_____ (2)

(b) What percentage by volume do other gases, other than nitrogen, share?_____ (2)

5. Mokhehle identified some air pollutants as lead compounds and sulphur dioxide.

(a) What is the source of each pollutant?
_____
_____ (2)

(b) State the harmful effect of each pollutant:
_____
_____ (2)

6. Nitrogen and hydrogen are the main reactants in the Haber process.

(a) What is the source of each gas?
_____
_____
_____(2)

(b) What is the main product of this process?
_____
_____
_____ (1)

(c) State two uses of nitrogen:
_____
_____ (2)

7. Give any two uses of oxygen:

_____
_____ (2)

8. You are asked to survey a new water source for the town you live in.

   (a) What would you be looking for to determine if the water was safe to drink?

   _____
   _____ (1)

   (b) There may be living organisms in the water.

      (i) List any two types of living organisms that pollute water._____
      _____ (2)

      (ii) How are they treated?

      _____
      _____ (1)

9. Hydrocarbons are involved in both the formation and uses of hydrogen.

   (a) State how hydrogen is produced from hydrocarbons:

   _____
   _____
   _____ (2)

   (b) Describe the use of hydrogen that involves hydrocarbons.

   _____
   _____
   _____ (2)

Chemistry

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 7

The Chemistry of Carbon and Carbonates

Study Skills

The best way to remember information is to associate it with an example from your own life or to something that you have learned in the past. When it comes to recalling the information for the test, it will become much easier! ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In the previous unit (Unit 6: Atmosphere and the Environment), you learned about the composition of air and the problems that arise when it becomes polluted. In Unit 7, you will be looking at Carbon. Carbon is a very important element that is found in most substances in life. Most of the substances found in nature are composed mainly of carbon. The importance of carbon can be seen in compounds formed by carbon, which form a special branch of chemistry called organic chemistry. Another importance of carbon is found in carbonates which have their own special properties. One of those properties is the tendency of carbonates to thermally decompose to form oxides of carbonates and carbon dioxide.

Time

This unit consists of 16 pages and will take you approximately 10 hours or 1.5 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Spend a moment reading the following learning outcomes. They are what you should focus on while studying this unit.

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Discuss* the composition and characteristics of organic compounds.

Outcomes

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Name* the allotropes of carbon.
- *Relate* the structures of diamond and graphite to their uses.
- *Describe* how lime is manufactured.
- *State* the uses of lime, slaked lime and calcium carbonate.

Study Skills

Terminology

Allotropy:	When an element exists in more than one form in the same state.
Lime:	Calcium oxide.
Lime stone:	Calcium carbonate.
Slaked lime:	Calcium hydroxide.

Section 7-1: The Chemistry of Carbon

Introduction

At the end of section 7-1, you should be able to name the allotropes of carbon and relate the structure of carbon allotropes to their uses.

Section 7-1 has 6 pages. You should spend approximately 1 hour on this topic.

Time

Carbon is an important element that is found in many substances found in nature. Just think of substances like the food that we eat, fuel used for cooking and in motor vehicles, stainless steel kitchen utensil and so on. Have you ever wondered what they are made of or what elements are present in them? Carbon is one of the elements that are found in these substances.

Allotropes of Carbon

Carbon is a non-metal that exists in nature in more than one physical form in the same state: a solid. An element that shows this behaviour is said to show

allotropy, while each of those forms are called allotropes. The two allotropes of carbon are diamond and graphite.

There are many elements in the periodic table that show this behaviour. Some examples are iron, carbon, tin and sulphur.

Activity

Activity 1

1. Fill in the table to show the characteristics of each substance. Then, write one use for each substance.

Table 1: Properties of Carbon

	Shiny or Dull?	Use(s)
Diamond		
Pencil		
Carbon electrodes		
Charcoal		

I hope you managed to come up with some uses of carbon, especially the ones that we use in our daily lives. If not, do not worry. You will learn more about carbon and its allotropes in the next unit.

Compare your answers with the ones given at the end of the section to see how well you did. While comparing, note how the substances are the same element yet they differ in so many ways.

Structures and Properties of Graphite and Diamond

Graphite and diamond have different structures because of different bonding between carbon atoms. The difference in the structure of carbon results in the two allotropes having different physical properties.

Graphite

Graphite has a layer structure where the atoms all lie in a plane, and are only weakly bonded to the graphite sheets above and below. Between these layers are weak forces of attraction (called van der Waals forces) and so the layers can slide over each other easily. With only three electrons being shared, there are spare (delocalized) electrons that form electron clouds between layers. These delocalised electrons are the ones responsible for conducting electricity.

Help

Need more information on van der Waals forces?
Please go to: http://antoine.frostburg.edu/chem/senese/101/liquids/faq/h-bonding-vs-london-forces.shtml

Figure 1 below shows the layered structure of graphite, the arrangement of atoms in each layer and the way the layers are spaced. Study the diagram and answer the questions that follow.

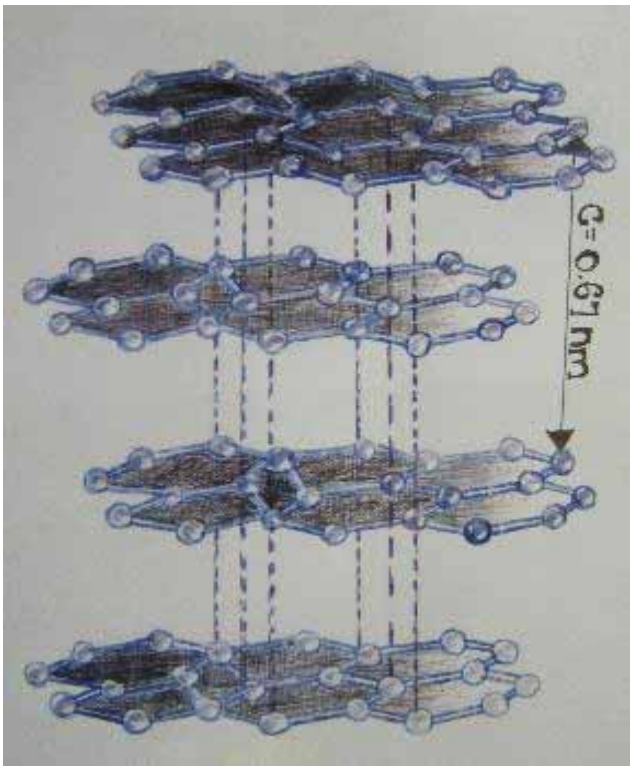

Figure 1 Structure of graphite. Hand drawn by graphic designer at LDTC.

Activity

Activity 2

1. How many pairs of electrons have been shared within 1 graphite layer between the carbon atoms of the graphite structure?

_____
_____
_____
_____

2. Describe the structure of graphite.

_____
_____
_____

3. Which part of a pencil is responsible for the black colour left on paper by a pencil?

_____
_____
_____

4. Why do you think pencil lead is so weak and easy to break?

_____

Now compare your answers with the ones given at the end of the section. Continue in the unit when you understand that graphite has a sheet-like structure where the atoms all lie in a plane and are only weakly bonded to the graphite sheets above and below.

Note it!

Important points to remember:

Graphite has a layer structure where the carbon atoms all lie in a plane and are only weakly bonded to the graphite sheets above and below. Within each layer, each carbon atom is bonded to three other carbon atoms by strong covalent bonds. Each layer is therefore a giant molecule. Between these layers are weak forces of attraction (van der Waals' forces) and so the layers can slide over each other easily. This behaviour of weak layers which can slide over each other is made use of in the lead in a pencil. With only three electrons being shared, there are spare (delocalized) electrons that form electron clouds between layers. It is because of these spare electrons that graphite is able to conduct electricity.

Physical properties of graphite and its uses

Properties	**Uses**
Dark grey shiny solid	Pencils
Soft material with slippery feel	Lubricant
Conducts electricity	Electrodes as it conducts electricity

Diamond

The picture below shows the structure of diamond. Looking at the structure carefully, one can see that the bonds between the carbon atoms form hexagons while the carbon atoms themselves form tetrahedrons. Study the diagram and answer the questions that follow.

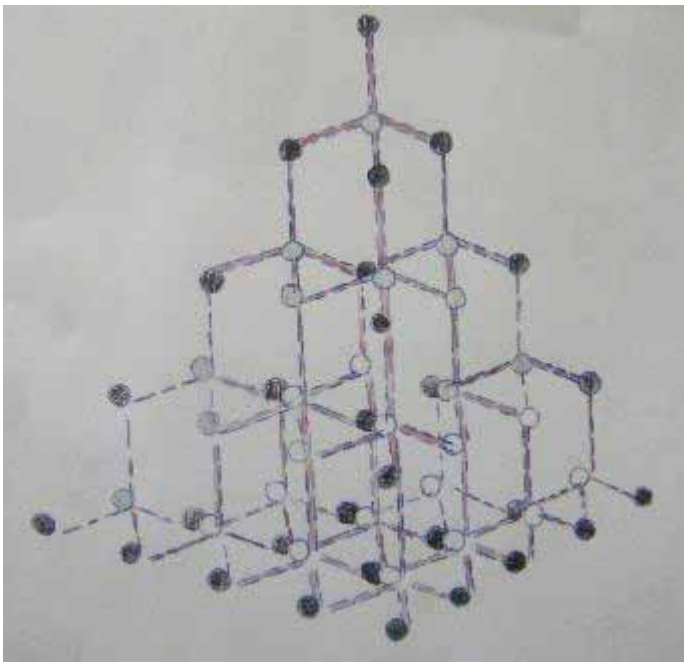

Figure 2 Structure of diamond. Hand drawn by graphic designer at LDTC.

Reading

What makes diamonds sparkle?

Light normally travels at 186,000 miles/s, but a diamond is so dense that it slows the light to less than half that speed. The unique optical properties of diamonds were not fully understood until comparatively recently. If you have access to the internet, read more at:

http://www.pbs.org/wgbh/nova/physics/diamond-science.html

Image from Wikimedia Creative Commons, 2010.

Activity

Activity 3

a) How many pairs of electrons have been shared between carbon atoms in the structure?

_____

b) Describe the structure of diamond.

_____

_____

_____

c) Which part of the structure do you think is responsible for the glittering property of diamond?

_____

_____

_____

Now compare your answers with the ones given end of the section. If you have any misunderstandings, review this content or contact your tutor.

Answers to the Activities on Allotropes of Carbon

Activity 1

Question 1

	Shiny or Dull?	***Use(s)***
Diamond	***shiny***	***Making jewellery*** ***Glass cutters*** ***Drill bits***
Pencil	***dull***	***Making pencil lead*** ***Making lubricants***
Carbon electrodes	***dull***	***For conducting electricity***
Charcoal	***dull***	***For cooking***

Activity 2

1) Three pairs in the layer and another bond going to the second layer.

2) There are layers of carbon atoms which are in the form of hexagons connected together. The carbons share 3 pairs of electrons. In addition, there is a bond which connects the carbon atoms from the top layer to the ones below it.

3) The layers which slide on top of one another due to weak bonds between the layers.

4) Due to the weak van der Waals bonds between its sheets, graphite is quite weak and brittle.

Activity 3

Question 1

a) Four pairs.

b) Many tetrahedrons joined together to form a large structure.

c) The tetrahedral shape formed by carbons.

Important points to remember:

Note it!

In diamonds, each of the carbon atoms is covalently bonded to four other carbons. The carbons form a giant structure which is tetrahedral in shape. This kind of bonding gives a very rigid three-dimensional structure and is responsible for extreme hardness of diamond. Since diamonds are the hardest known substance, diamonds are used for cutting other hard materials such as glass. Since there are no free electrons moving around (delocalized electrons) diamond does not conduct electricity. Diamond can be manufactured by heating graphite to about 300^0C at a very high pressure.

Physical properties of diamond and its uses

Properties	Uses
A colourless transparent crystal which sparkles in light	Jewellery
The hardest known substance	Drill bits, glass cutters, diamond-studded saws and polishers
Does not have delocalised electrons	Does not conduct electricity

Section 7-2: Manufacturing Lime

Introduction

At the end of section 7-2, you should be able to describe how lime is manufactured and also be able to state the uses of lime, limestone and slaked lime.

Time

Section 7-2 has 4 pages. You should spend approximately 1 hour on this topic.

Manufacturing Lime and Uses of Calcium and Calcium Compounds

Calcium is an element that forms many compounds that are very useful in our everyday lives. Some of these compounds are found in nature while some calcium substances are made by combining existing compounds. The most important calcium compound found in nature is calcium carbonate from which many other calcium compounds are formed.

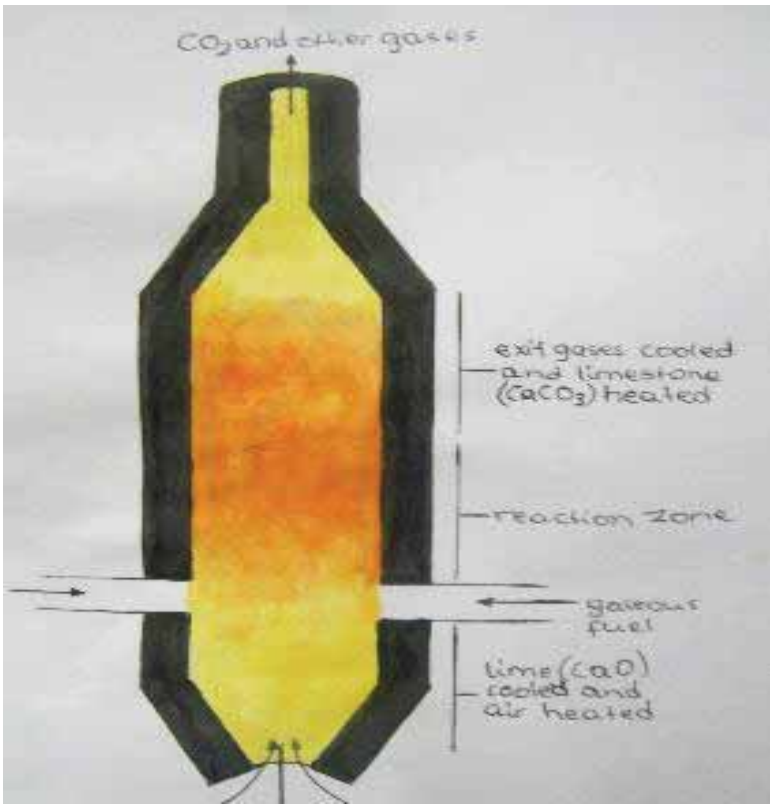

Figure 3 A lime kiln. Hand drawn by graphic designer at LDTC.

Calcium oxide (lime) is manufactured by thermal decomposition (breaking down by heat) of calcium carbonate (limestone) in a large structure called a lime kiln. Calcium carbonate is fed into the kiln and then fuel burned near the bottom of the kiln is used to generate heat to decompose calcium carbonate. The fuel, which can be coal or wood or even gas, heats up calcium carbonate at the reaction zone. When calcium carbonate is heated to a high temperature, it decomposes into calcium oxide and carbon dioxide. The calcium oxide falls down the kiln and is

cooled by air. The carbon dioxide produced moves up the chamber together with other gases and is released into the atmosphere.

$$CaCO_3 \quad \Leftrightarrow \quad CaO + CO_2$$

The reaction can go in either direction depending on factors like temperature and pressure.

The above reaction can be summarised in this steps:

Step 1- Fuel (coal, wood or gas) is put at the bottom of the kiln.

Step 2- Calcium carbonate is put on top of the fuel.

Step 3- The fuel is burned which decomposes calcium carbonate into calcium oxide and oxygen.

Step 4- Calcium oxide is collected at the bottom of the kiln while carbon is released through the top of the kiln.

Calcium Compounds and Their Uses

Calcium is in position three in the reactivity series, which means it is one of the more reactive metals. Since calcium is so reactive, it forms stable compounds like calcium carbonate which is found in nature. Calcium carbonate can be decomposed by heat to form calcium oxide from which we can form calcium hydroxide. Compounds of calcium are given different names. We use the following terms for the above calcium compounds:

Native name	**Chemical name**	**Chemical formula**
Limestone	Calcium carbonate	$CaCO_3$
Lime	Calcium oxide	CaO
Slaked lime	Calcium hydroxide	$Ca(OH)_2$

The above substances have many uses. Think of how many of the above substances you have used, the reason for using them and where they have been used. The uses of these substances are given in the following table.

Name of a compound	**Uses of a compound**
Calcium carbonate	• *for making chalk,* • *for making cement*
Calcium oxide	• *for making glass*

	• *for neutralising acidic soil* • *as a drying agent in industry* • *improves drainage of clay soil which contains large amounts of clay*
Calcium hydroxide	• *for making bleaching powder* • *to reduce acidity of soil* • *for purifying water* • *for making glass*

Activity 4

Activity

a) Name two calcium compounds.

_____

_____

b) Name the uses of the calcium compounds you have named in (a) above.

_____

_____

_____

c) Why do you think calcium is found as a compound and not as an element in nature?

_____

_____

_____

Now compare your answers with the ones given below. If you get less than 80% right then review this section again.

Answers to the Activity on Uses of Some Calcium Compounds

Activity 4

a) Calcium carbonate, calcium oxide and calcium hydroxide.

b) Calcium carbonate- used for writing on a chalk board and making cement.

Calcium Oxide- used for making glass, neutralising acidic soil, as a drying agent in industry, and for improving drainage of clay soil which contain large amounts of clay.

Calcium hydroxide- used for making bleaching powder, reducing the acidity of soil, purifying water and in glass manufacture.

c) Calcium is very reactive which is why it is found in its compounds.

You have now completed the last section of this unit on carbon and carbonates. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Unit Summary

Summary

In this unit you learned that :

- Carbon is present in many compounds that are found in nature.
- Carbon can also be found in nature in different forms. This behaviour of carbon is called allotropy.
- The allotropes of carbon are diamond and graphite.

  Diamond has a giant tetrahedral structure which is very strong due to the kind of bonding which exists between carbon atoms. This kind of bonding result in diamond having unique properties and uses.

Physical properties of diamond and its uses

Properties	Uses
A colourless transparent crystal which sparkles in light	Jewellery
A very hard substance	Drill bits, glass cutters, diamond-studded saws and polishers
Does not have delocalised electrons	Does not conduct electricity

Graphite has a hexagonal structure that forms layers. Between the layers are weak Van der Waal bonds which can easily break. This kind of bonding, which exists between carbon atoms, results in graphite having unique properties and uses.

Physical properties of graphite and its uses

Properties	Uses
Dark grey shiny solid	Pencils
Soft material with slippery feel	Lubricant
Conducts electricity	Electrodes as it conducts electricity

- Lime is manufactured by the thermal decomposition of calcium carbonate.
- Calcium oxide is used for making glass, to neutralise acidic soil, as a drying agent in industries and to improve drainage in soil that contains large amounts of clay.
- Calcium carbonate is used for making chalk and cement.
- Calcium hydroxide is used for making bleaching powder, to reduce acidity in soil, purifying water and manufacturing glass.

You have completed the material for the unit on carbon and carbonates. Spend some time now and review the entire content of this unit. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers organic chemistry. In organic chemistry you are going to see how carbon can form many other compounds covalently.

Assignment 7

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 40 minutes

[Total Marks:25]

1) Using your knowledge of the structure of diamond and graphite to explain the following:

a) Graphite is used in making pencils._____
_____
_____ (3)

b) Graphite conducts electricity but diamond does not._____
_____
_____
_____ (3)

c) Diamond is an extremely hard substance.
_____
_____
_____ (3)

2) Name the allotropes of carbon and write down 3 properties for each allotrope by filling the table provided below.

a)		
b)		
c)		

(8)

3) Lime is manufactured by the thermal decomposition of calcium carbonate. What is meant by thermal decomposition? Write down the equation which shows the reaction.
_____
_____
_____ (4)

4) Which factors can affect the formation of lime during its manufacturing?

_____
_____
_____ (2)

5) Limestone is one calcium compound found in nature. Give two uses of calcium carbonate:

_____
_____
_____
_____
_____ (2)

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 7

Question 1

a) The layers are able to slide over one another leaving a black substance which is used in writing. (3)

b) The delocalised electrons in graphite form a cloud of such electrons which is responsible for conducting electricity.(3)

c) Because of the tetrahedral structure that is formed, diamond is very hard.(3)

Question 2

Diamond and graphite
(2)

Graphite	*Diamond*
Soft	*Hard*
Good conductor of electricity	*Not a good conductor of electricity*
Dull in colour	*Shiny*

(8)

Question 3

The breaking down of calcium carbonate due to heating in which calcium oxide and carbon dioxide are formed. (2)

$CaCO_3$ *(s)* ➔ $CaO(s) + CO_{2(g)}$
(2)

Question 4

Temperature and pressure
(2)

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent chemistry course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 7

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 60 minutes.

(Total Marks:40)

1.

a) Define the term 'allotropy'

_____
_____
_____
_____
_____ (2)

b) Name two uses of graphite and two uses of diamond.

_____
_____
_____
_____
_____ (4)

c) Describe the uses for graphite and diamond in terms of their structures.

_____
_____
_____
_____
_____
_____ (6)

2.

Describe the structure of graphite and explain how it contributes towards its uses.

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____ (10)

3.

a) Explain how lime is manufactured from limestone. Mention the reactants, products, and how the reaction takes place.

_____
_____
_____
_____
_____
_____
_____
_____
_____ (10)

b) Write an equation showing the decomposition of limestone in forming lime.

_____
_____(2)

c) Give two uses each of the following substances: (6)

Calcium carbonate_____

_____
_____
_____

Calcium hydroxide_____

_____
_____
_____

Calcium oxide _____

_____
_____

Chemistry

Grade 12

COL Open Schools Initiative
Lesotho

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Unit 8

Micromolecules

Study Skills

Studies have shown that just simply memorizing information works in the short-term, but over the long term, it is not an effective study strategy. Try making a mind-map: a visual representation of how ideas are connected. Start by writing down a central idea, and then write all of the important ideas and vocabulary around it. Draw lines to show where ideas are connected and on the line write how they are connected. This makes a great study tool! ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

Image accessed from Wikimedia Creative Commons, 2010.

Have you ever wondered what gives carrots their bright orange colour?

Beta-carotene is a naturally-occurring pigment responsible for the bright orange colour of carrots (I guess it's not hard to see where its name comes from!). Beta-carotene has an extremely important role in relation to vitamin A, the vitamin that is essential for our eyes. Vitamin A is an alcohol (a molecule containing an -OH group) whose structure is exactly one half of that of beta-carotene.

As you saw in Unit 7, most of the substances that we use in our everyday lives contain carbon molecules. Examples substances that contain carbon include the food that we eat, the fuel that we use for cooking, the fuel used by cars as well as many other substances. The question that we have to ask ourselves is what makes these substances different if they all contain carbon? The answer lies in the chemical structure of each group. In this unit we are going to learn how the arrangement of different atoms in a substance or micromolecule can change its properties.

In order to understand this unit, you should have studied Unit 2 thoroughly. This unit will also help you to understand Unit 9.

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Discuss* the composition and characteristics of organic compounds.

Study Skills

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Name* and draw the structures of unbranched alkanes, alkenes, alcohols and acids.
- *Describe* the physical and chemical properties of alkanes, alkenes, alcohols and acids.
- *Differentiate* between cracking and polymerisation.
- *Name* the uses of petroleum fractions, ethanol and polymers.

Terminology

Alkane: A hydrocarbon which only has single bonds (saturated) and has the general formula $C_nH_{(2n+2)}$.

Alkene: A hydrocarbon which has one double bond and has the general formula C_nH2_n.

Cracking: A process by which a large molecule is broken down to form small useful molecules.

Esterification: A process in which an organic acid reacts with an alcohol to form an ester.

Hydrocarbon: A substance which is made up of carbon and hydrogen only.

Monomer A small molecule which is joined together repeatedly to form a large molecule called a polymer.

Polymerisation: A process by which monomers are joined together to form a large molecule called a polymer

Section 8-1: Alkanes

Have you ever wondered what the LPG written on our gas cylinders means or where substances like the gas we use for cooking comes from?

There is a large group of substances which consist of carbon as the main element. In these substances, carbon has been bonded to other elements by covalent bonding which you studied in Unit 2. This group of substances form a branch of science called **organic chemistry**.

Alkanes form one group of such substances and have their own properties that make them different from other substances. At the end of section 7-1, you should be able to draw and name alkanes. You should also be able describe their physical and chemical properties.

Time

Section 8-1 has 7 pages. You should spend approximately 1 hour on this topic.

Molecular Structures and Physical Properties of Alkanes

Alkanes form a group of substances which are made up of a carbon and hydrogen backbone. Just think of how many substances we can form by covalently bonding carbon and hydrogen atoms! An example is shown in Figure 1. Because of this composition, alkanes are called hydrocarbons. In their structure, carbon atoms are bonded to other atoms covalently by four single bonds. In forming members of this group, there is an increase in the number of carbon atoms bonded to each other and hydrogen atoms bonded to carbon atoms. Since four single bonds around a carbon atom makes its outermost shell full in such a way that no other atoms can be added, alkanes are said to be **saturated**.

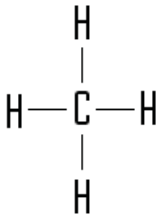

Figure 1: Representation of a methane molecule.

Alkanes are named by the number of carbon atoms present in their main structure and the common ending which is ***-ane.*** The prefixes that are used are as follows:

Number of carbon atoms	**Prefix**	**Suffix**
1	Meth	-ane
2	Eth	-ane
3	Prop	-ane
4	But	-ane

And so on…

Activity

Activity 1

a) How many carbon atoms are in an ethane molecule?

_____

b) For a stable compound to be formed, how many electrons should be in the outermost shell of

Carbon? _____

Hydrogen? _____

c) If carbon atoms are going to share just one pair of electrons between them, how many electrons will remain unshared in each carbon atom? _____

d) How many hydrogen atoms are needed to share electrons such that both carbon atoms have their outermost shells full?

_____

e) Draw the structure of the ethane:

f) Draw the structure of propane:

g) Give the general formula for the molecular structure of an alkane. _____

Compare your answers with the ones given at the end of the section. If you score 6 or more out of 7, continue with the next topic. Otherwise, review the content on alkanes and try the questions again.

Note that all atoms have their outermost shell full when a stable compound is formed and the carbon atoms are bonded to hydrogen by single bonds. If you look at the structure of alkanes, there is a pattern in the number of carbon and hydrogen atoms present in a molecule. Each time a new alkane is formed, for every increase of one carbon atom there is an increase of two hydrogen atoms. This increase gives a general formula which is:

$$C_nH_{(2n+2)}$$

Note it!

Note the following points:

- Members of the alkane group have similar trend in their physical and chemical properties. A group of substances which have a trend in their physical properties and have similar chemical properties are called a **homologous series**.

Do you still remember what atomic molecular mass of a substance is? Do you remember the change in state of group 7 elements as you go down the group (Unit 2)? We see that the increase in mass of these substances increase the amount of energy needed to break bonds within the substance.

Let's have a look at the physical properties of some alkanes:

Table 1: Physical properties of alkanes.

Name of alkane	Formula of alkane	Melting point °C	Boiling point °C	State at room temperature and pressure
Methane	CH_4	-182	-162	Gas
Ethane	C_2H_6	-183	-89	Gas
Propane	C_3H_8	-188	-42	Gas
Butane	C_4H_{10}	-138	-0.5	Gas
Pentane	C_5H_{12}	-130	36	Liquid

Activity 2

Activity

1. Study the table above and answer the following questions:

a) What happens to the boiling points of alkanes as the number of carbon atoms increases?

_____

b) What happens to the state at room temperature and pressure of alkanes as the number of carbon atoms increases?

_____

c) From the pattern in the table you can see that when the number of carbon atoms increases, there is a change in state as you go down the table. As more carbon atoms are added, the molar mass and therefore the density of increases. Predict the state of the twentieth member of the alkane group at room temperature and pressure.

_____

d) Write the molecular formula of the seventeenth member of the alkane group.

_____

Compare your answers with the ones given at the end of the section. Be sure you understand each answer before you continue to the next section.

In summary, by looking at the table one can see that as number of carbon atoms increases, the boiling point and melting point increases. The state at room temperature and pressure also changes from gas to liquid as we increase the number of carbons. Consequently, one can expect that there will also be a change from liquid to solid when the molecule is large enough (i.e. paraffin wax).

Chemical Properties of Alkanes

Alkanes, like other compounds, undergo chemical reactions even though they are very unreactive. Most of the reactions involving alkanes are very useful. A description of such reactions is given below.

Oxidation Reaction

Do you still remember the definition of "oxidation" given in Unit 5? Alkanes burn in oxygen as shown in the equation below:

$$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O + \text{heat}$$

This reaction gives off a lot of heat, as well as carbon dioxide and water. Because of this behaviour, alkanes are used as fuels for cooking in schools and homes. Examples of gases used as fuels are methane (known as natural gas), propane and butane. These gases

are compressed under high pressure to form liquefied petroleum gas (LPG). Normally, LPG is sold in cylinders as shown in Figure 2.

Figure 2: Liquefied petroleum gas (LPG) in cylinders accessed from Wikimedia Creative Commons, 2005.

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Substitution Reaction

When a player is injured in football or netball, the coach can substitute another player. Can you think of what substitution in chemical reactions would mean?

Alkanes react with halogens in order to form new substances (Look back at Unit 2 if you need to remind yourself about the properties of halogens). This reaction takes place when hydrogen is substituted by a halogen to form a halogenoalkane and hydrohalogen. This substitution reaction may be represented as follows:

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

Many of the compounds formed by alkanes with halogens have been found to be very useful. Some of the useful substances are chloroform ($CHCl_3$-see Figure 3), which is used as an anaesthetic and dichloromethane (CH_2Cl_2), which is used as a solvent.

Figure 3: A test-tube of Chloroform accessed from Wikimedia Creative Commons, 2009.

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Test for an alkane

Bubble an alkane in a test tube containing bromine solution which is brown in colour. No colour change is observed because the brown colour of bromine remains unchanged.

Important points to remember:

Note it!

- Alkanes are hydrocarbons that are generally unreactive. This is due to the fact that they are saturated. The only way they can react is by substituting atoms that are already in their structure or breaking up completely.
- Alkanes are named by the number of carbon atoms present in their main structure.
- Alkanes have single bonds throughout their structure; that is why they are said to be saturated.
- The longer the chain the higher the boiling point. This is brought about by the fact there are more bonds to be broken before there can be a state change from liquid to gas.
- Alkanes form a homologous series. This means there is a pattern in their chemical and physical behaviour.
- Alkanes burn in oxygen to form carbon dioxide and water. These reactions release a large amount of heat. Remember bond formation, which you learned about in Unit 5.
- Alkanes undergo a substitution reaction with halogens to form halogenoalkanes.

Activity

Activity 3

a) Give one use of alkanes:

_____

b) What is meant by the term homologous series?

_____

c) What kind of a reaction do alkanes undergo with halogens?

_____

d) Write a balanced equation showing the reaction between ethane and fluorine.

_____

e) Why are alkanes used as fuels?

_____

f) Write a balanced equation which shows the reaction between methane and oxygen.

_____

Now compare your answers with the ones given at the end of the section. If you have at least 5 correct, continue to the following section on Alkenes. Otherwise, review this topic again.

Answers to Activities on Alkanes

Activity 1

a)	***2***	***This is based on the definition of ethane.***
b)	***Carbon: 8***	***8 is determined by the number of electrons in the outermost shell of an atom when it is full (Octet rule).***
	Hydrogen: 2	***2 is determined by the first shell which can accommodate only 2 electrons for it to be full.***
c)	***Three***	***It is 3 because carbon has 4 electrons in the outermost shell, so if it shares one electron then 3 electrons are left unshared***
d)	***Six***	***It is 6 because each carbon atom can share 3 electrons with 3 hydrogen atoms. Since there are two carbons that makes a total of 6 hydrogen atoms.***

e) The molecular structure of ethane is shown in Figure 4.

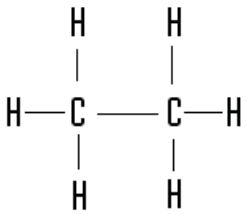


Figure 4: Molecular structure of Ethane.

f) The molecular structure of propane is shown in Figure 5.

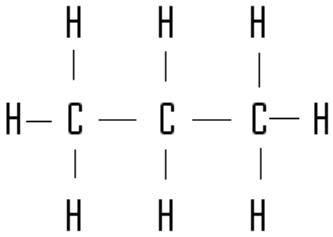


Figure 5: Molecular structure of Propane.

g) $C_nH_{(2n+2)}$

Activity 2

a) The boiling point increases. This is because the number of bonds in the molecule increases and so more energy is required in the form of heat to break the bonds (boil).

b) The state eventually changes from gas to liquid with the increase in number of carbon atoms and the increase in density,

c) Solid. The mass increases as the number of carbon atoms and therefore the density increases, so this leads to a solid state in members with 16 or more carbon atoms.

d) $C_{17}H_{36}$ *Since the number of hydrogen atoms is determined by the general formula of 2n+2; 2 x 17 + 2 = 36.*

Activity 3

a) Alkanes are used as fuels.

b) A group of substances which have similar properties or show a trend in their behaviour.

c) They undergo a substitution reaction.

d) $C_2H_6 + F_2 \rightarrow C_2H_5F + HF$

e) ***Alkanes are used as fuel because they produce a lot of heat when burned in oxygen.***

f) $CH_4 + O_2 \rightarrow CO_2 + H_2O + heat$

That concludes section 8-1 on alkanes. Go back to the beginning of the section and carry out a quick review of the content before moving on to the next one.

Section 8-2: Alkenes

In the previous section we looked at a group of hydrocarbons called alkanes. Can you think of other ways in which carbon and hydrogen can be covalently bonded to form a different group of hydrocarbons?

In this unit you will learn about another group of hydrocarbons called alkenes.

By the end of section 8-2, you should be able to draw and name different alkenes. You should also be able describe their physical and chemical properties.

Time

Section 8-2 has 7 pages. You should spend approximately 1 hour on this topic.

Molecular Structures and Physical Properties of Alkenes

Alkenes also form a group of substances which are made up of carbon and hydrogen atoms only. Because of this composition, alkenes are also called hydrocarbons. In their structure, there is a pair of carbon atoms which are bonded by a double bond (refer to Unit 2 if you need to review what you learned about double bonds). This pair of carbon atoms is linked to other atoms covalently by four single bonds as shown in Figure 6, which shows the alkene known as butene.

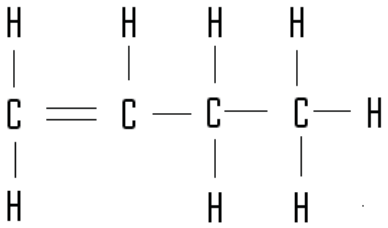


Figure 6: Molecular structure of Butene.

When we add carbon atoms to members of this group, we give each new hydrocarbon a unique name. However, we use the same prefixes as the alkanes. Since there is a double bond which can allow other atoms to bond with the two carbons which were bonded by a double bond, alkenes are said to be **unsaturated**.

Just like alkanes, alkenes are named by the number of carbon atoms present in their structure and the common ending which is ***-ene.*** The prefixes that are used are as follows:

Number of carbon atoms	**Prefix**	**Suffix**
1	*Not possible, since a minimum of two carbon atoms is required to form an alkene.*	
2	Eth	-ene
3	Prop	-ene
4	But	-ene

And so on…

Activity

Activity 4

a) How many carbon atoms are in ethene? _____

b) For a stable compound to form, how many electrons should be in the outermost shell of carbon? _____ Hydrogen? _____

c) If two carbon atoms are going to share just two pairs of electrons between them how many electrons will remain unshared in each carbon atom? _____

d) In ethane, how many hydrogen atoms are needed to share electrons such that the carbon atoms have their outermost shells full?_____

e) Draw the structure of ethene:

f) Draw the structure of propene:

g) Give the general formula for the molecular structure of alkenes:

_____

Now compare your answers with the ones given at the end of the section. If you have 6 or 7 out of 7 correct, continue to the next section. If you have 5 or less correct, review this content before continuing.

Note it!

Note the following important points:

- All of the atoms in an alkene molecule have their outermost shell full when a stable molecule is formed. There is a pair of double-bonded carbon atoms, while the other carbon atoms are linked with single bonds.
- There is a trend in physical and chemical properties of alkenes. They therefore form a homologous group.
- Because of their similar structures, alkenes have a general formula which can be used to find the formula of any other member if the number of carbon atoms present in that molecule is known. The general formula of alkenes is:

  C_nH_{2n}

  Where n is the number of carbon atoms present in the molecule.

  For example, octene will have the molecular structure of C_8H_{16}.

Let's have a look at the physical properties of some alkenes:

Table 2: Physical properties of alkenes

Name of alkene	Formula of alkene	Melting Point in ^0C	Boiling Point in ^0C	State at room temperature and atmospheric pressure
Ethene	C_2H_4	-169	-104	Gas
Propene	C_3H_6	-185	-47	Gas
Butene	C_4H_8	-184	-6	Gas

Activity

Activity 5

Study the table above and answer the following questions:

a) What happens to the boiling points of alkenes as the number of carbon atoms increases?

_____

_____

b) Write the molecular formula of the alkenes group member with 20 carbon atoms.

_____

Now compare your answers with the ones given at the end of the section. If you answered both questions correctly, continue to the next section. Otherwise go back and read the text and then attempt them again.

Note it!

Take note of the following important points:

From the table one can see that as number of carbon atoms increases, the properties of the substance formed are affected. For example, the boiling point increases. The state of alkenes at room temperature and pressure also changes from gases to liquids and then to solids as the number of carbon atoms increase. These characteristics are the result of the increasing mass and therefore the density of the molecules as carbon atoms are added and new members of the group are formed.

Chemical Properties of Alkenes

Like alkanes, alkenes undergo chemical reactions though they are more reactive. Which part of the alkene structure plays an important role in its reactions?

Yes, alkenes are more reactive because of the presence of a double bond. Most of the reactions involving alkenes are very useful. A description of some reactions is given below.

Oxidation reaction

When Alkenes burn in oxygen, the give off heat as well as carbon dioxide and water. This reaction requires more oxygen than the comparable reaction of alkanes with oxygen.

$$C_2H_4\,(g) + 3O_2\,(g) \rightarrow 2CO_2(g) + 2H_2O(g)$$

Hydrogenation

Alkenes react with hydrogen in the presence of a catalyst (see Unit 6 if you need to remind yourself of the definition of a catalyst). Typically nickel or platinum are used as catalysts in reactions at controlled temperatures (150 – 300 °C) to form an alkane. During this reaction, the double bond is broken and two hydrogen atoms are attached to each carbon atom that was involved in the double bond. This reaction is shown in Figure 7.

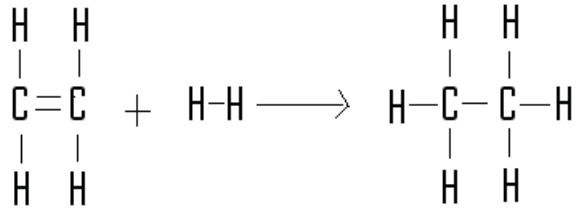


Figure 7: Hydrogenation reaction

The hydrogenation reaction can be written as:

$$C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$$

Addition reaction

Alkenes undergo an addition reaction with water and halogens to form alcohols and halogenoalkanes respectively as shown in Figure 8. The addition reaction between ethene and water takes place in the presence of a catalyst (phosphoric acid). The reaction is reversible, so control is exercised over the temperature (around 300 °C) and pressure (60atm) of the reaction vessel in order to ensure maximum production of ethanol.

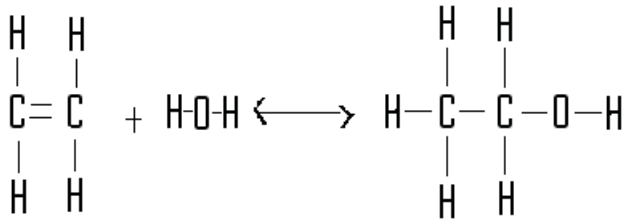


Figure 8: Ethene reacting with water to form an alcohol.

The addition reaction of alkenes with a solution of bromine to produce dibromoethane as shown in Figure 9 below is used as a test

for alkenes. Do you still remember the colour of bromine, which was stated in Unit 2? When testing for alkenes, the alkene is bubbled in a solution of bromine water and the brown colour from bromine fades away as the bromine is used up as a reactant, leaving a colourless solution.

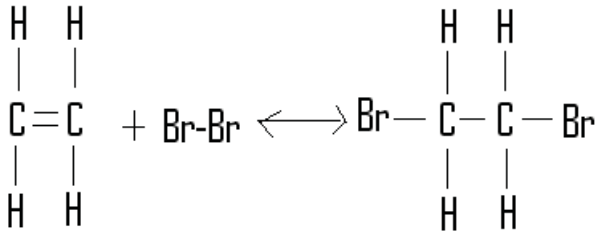


Figure 9: Ethene reacting with bromine in an addition reaction.

The reaction showing how addition takes place between propene and bromine is shown below:

$$C_3H_6 + Br_2 \rightarrow C_3H_6Br_2$$

Note it!

Important points to remember:

- Alkenes are reactive hydrocarbons. This is due to the presence of a double bond which can be broken to accommodate new atoms in the structure that is being newly formed.
- Alkenes are named by the number of carbon atoms present in their structure.
- Alkenes have one double bond between two carbon atoms and then single bonds between the remaining carbon and hydrogen atoms.
- Alkenes form a homologous series. This means there is a pattern in their chemical and physical behaviour.
- Alkenes burn in oxygen to form carbon dioxide and water. This reaction also releases heat.
- Alkenes undergo addition reaction with halogens through breaking double bond to form halogenoalkanes.

Activity 6

Activity

1.

a) Alkenes are said to be unsaturated. Explain what this statement means._____
_____
_____
_____

b) Name two substances produced during the burning of alkenes:
_____
_____
_____
_____

c) Write down what you would see when propene is bubbled in a test tube containing bromine water.
_____
_____
_____
_____

d) What kind of reaction will take place between ethene and chlorine?
_____
_____
_____
_____

e) Write the molecular formula of the ninth member of the alkene group:
_____

Now compare your answers with the ones given below. If you correctly answered all the questions, continue to the next section. Otherwise go back and read the text and then attempt them again.

Answers to Activities on Alkenes

Activity 4

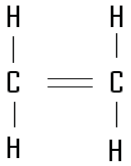
a) 2. This is based on the definition of ethane.

b) Carbon: 8. 8 is determined by the number of electrons in the outermost shell of an atom when full (octet). Hydrogen: 2, 2 is determined by the first shell which can accommodate only 2 electrons for it to be full.

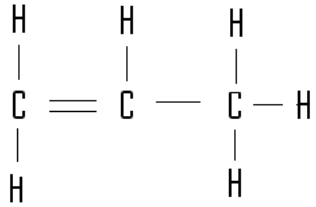
c) Two. It is 2 because carbon has 4 electrons in the outermost shell so if it shares two electrons, then 2 electrons are left unshared.

d) Four. It is 4 because each carbon atom can share 2 electrons with 2 hydrogen atoms. Since there are two carbons that makes a total of 4 hydrogen atoms.

e) Molecular structure of ethane:



f) Molecular structure of propene:



g) The general formula for alkenes: C_nH_{2n}

Activity 5

a) The boiling point increases because there is an increases in the number of bonds in the molecule. It takes more energy to break the bonds to allow for boiling.

b) $C_{20}H_{40}$

Activity 6

Question 1

a) Other substances can be added to alkene where the double bond will be broken to accommodate the new atom which will then be attached to the carbon chain.

b) Water and carbon dioxide. These are the only possible products looking at the reactants.

c) ***The brown colour will disappear and will turn colourless. This is because bromine (which is brown) is one of the reactants so this is an indication that it has reacted.***

d) ***Addition reaction because alkenes have a double bond which can be broken to accommodate other atoms during a chemical reaction.***

e) C_9H_{18}

Section 8-3: Alcohols

When you see the word alcohols what is the first thing that comes to your mind? Alcohols are very important in our everyday lives. We use alcohols for different purposes. What are two uses of alcohols that you know?

1. _____

2. _____

Compare your ideas to the following. You may have thought of the same uses or different ones.

Alcohol can be used:

- To sterilise wounds
- To remove stains from clothing
- As a fuel
- As a drink to enjoy
- And many more.

At end of section 8-3, you should be able to draw and name different alcohols. You should also be able describe their physical and chemical properties.

Time

Section 8-3 has 7 pages. You should spend approximately 1 hour on this topic.

Molecular Structures and Chemical Properties of Alcohols

Alcohols form a group of substances which are made up of carbon, hydrogen and oxygen atoms. The oxygen is bonded on one side to a

carbon atom and on the other side to a hydrogen atom. Because of this composition, alcohols have what we call a **functional group** of –OH which is responsible for all the characteristics of this group.

In their structure, carbon atoms are bonded to each other covalently by four single bonds. Other atoms bonded to carbons are also bonded covalently by single bonds as displayed in Figure 10.

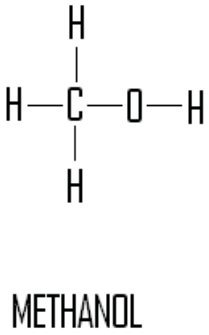


Figure 10: Molecular structure of methanol.

In forming members of this group, when there is an increase in the number of carbon atoms bonded to each other, there is an increase of the number of hydrogen atoms bonded to carbon atoms. The functional group then bonds with one of the carbon atoms along the chain to form an alcohol.

Just like alkanes and alkenes, alcohols are named by the number of carbon atoms present in their structure and the common ending which is ***-anol.*** The prefixes that are used are as follows:

Number of carbon atoms	**Prefix**	**Suffix**
1	Meth	-anol
2	Eth	-anol
3	Prop	-anol
4	But	-anol

And so on…

Activity

Activity 7

a) How many carbon atoms are in ethanol?

_____

b) For oxygen to have a full outer shell, how many pairs of electrons should it share with other atoms in the structure of ethanol? _____

c) If the oxygen atom is going to share just one pair of electrons with carbon, how many electrons are left unshared?

_____

d) How many hydrogen atoms are needed to share electrons with oxygen so that the oxygen atom has its outermost shell full? _____

e) Draw the structure of ethanol:

f) Draw the structure of propanol:

g) Give the general formula for the molecular structure of an alcohol:_____

Now compare your answers with the ones given at the end of the section. If you get 6 or more correct then move on to the next section. Otherwise review the section and attempt them again.

Note it!

Note the following important points:

- When stable alcohols are formed, atoms have their outermost shells full.
- The carbon atoms in alcohol are bonded to hydrogen and oxygen by single bonds.
- There is a pattern in the number of carbon, hydrogen atoms and the functional group -OH present in the structure of an alcohol.
- Members of the alcohol group display a trend in their physical and chemical properties. Therefore, they form a homologous series.
- Because of their similar structure, alcohols have the general formula:

  $C_nH_{(2n+1)}OH$

  This formula can be used to find the formula of any other member if the number of carbon atoms present in that molecule is known.

For example heptanol will have the molecular structure $C_7H_{15}OH$.

Let's have a look at the physical properties of some alcohols:

Table 5: Physical properties of alcohols

Name of alcohol	Formula of alcohol	Melting point °C	Boiling point °C
Methanol	CH_3OH	-94	64
Ethanol	C_2H_5OH	-117	78
Propanol	C_3H_7OH	-126	97
Butanol	C_4H_9OH	-138	117

Activity

Activity 8

Study the table above and answer the following questions:

a) What happens to the melting points of alcohols as the number of carbon atoms increases?

_____

b) What happens to the boiling points of alcohols as the number of carbon atoms increases?

_____

c) What do you think is the state of the first three members of the alcohol group at room temperature and pressure?

_____

d) Write the molecular formula of the pentanol:

_____

Now compare your answers with the ones given at the end of the section. If you got 3 or more correct then move to the next section. Otherwise review the section and attempt them again.

Note it!

Note the following points:

Looking at the table one can see that as number of carbon atoms increases, the properties of the substance formed is affected. For example, the boiling point increases.

Chemical Properties of Alcohols

Alcohols, like other compounds undergo chemical reactions. Most of the reactions involving alcohols are very useful, ethanol being the most important alcohol in the group as it used for many things. A description of some reactions is given below.

Oxidation Reaction

Alcohols burn in oxygen to give off a lot of heat, carbon dioxide and water. Because of this characteristic, alcohols are used as fuels for cooking, especially in camping stoves where they are usually referred to as spirits. Some countries use a mixture of petrol and ethanol as fuel in cars. In Figure 11 below, a clean blue flame is produced from burning ethanol.

Figure 11: Burning Ethanol in a spirit stove accessed from Wikimedia Creative Commons, 2004.

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The chemical reaction when alcohol is burned is represented in the following chemical equation:

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O + \text{heat}$$

Oxidation of Alcohols

Alcohols can be oxidised by using strong oxidising agents to form organic acids. Sometimes oxygen can react with an alcohol naturally in the presence of bacteria to produce ethanoic acid. In this reaction,

the first product is aldehyde as shown in Figure 12, which is further oxidised into an acid.

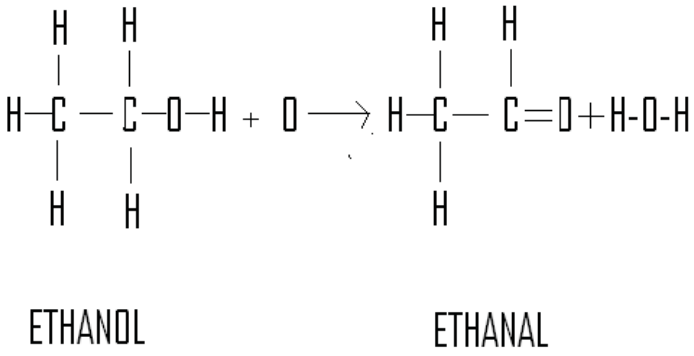


Figure 12: Ethanol reacting with oxygen.

For example, ethanol is oxidised into ethanal, then into ethanoic acid. The equation which shows this reaction is shown below.

$CH_3CH_2OH + O_2 \Rightarrow CH_3CHO + H_2O$

$CH_3CHO + O_2 \Rightarrow CH_3COOH$

Esterification

Alcohols will react with carboxylic acids in the presence of a few drops of sulphuric acid to form esters, as shown in Figure 13. The reaction is a typical reaction where a substance containing the hydroxyl ion (-OH) will react with a substance containing hydrogen ion (+H) to form salt and water. In this case, the reaction is called esterification. The equation showing esterification is shown below:

$CH_3CH_2OH + CH_3COOH \Rightarrow CH_3COOCH_2CH_3 + H_2O$

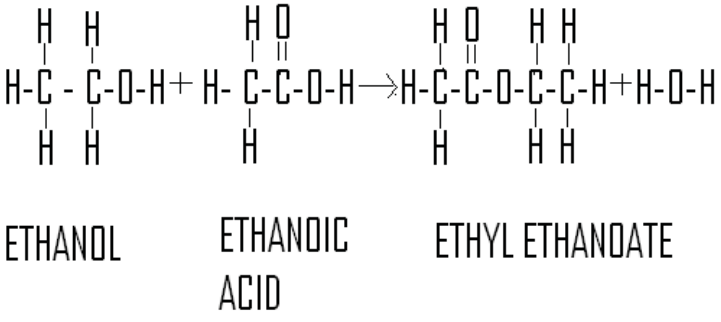


Figure 13: Ethanol reacting with ethanoic acid.

Esters have a very pleasant smell and are used in making some of the food flavourings and perfumes. Some esters occur naturally in oils, fats, fruits and flowers.

Some Uses of Alcohols

As was mentioned earlier, alcohols can be used for a variety of things. In particular, ethanol is used:

- As a fuel
- As a food flavouring agent
- As a solvent
- As a disinfectant

Important points to remember about alcohols:

Note it!

- Alcohols have a functional group of –OH. Looking at the functional group, one can notice that alcohols behave like the bases that were studied in Unit 5.
- Alcohols are named by the number of carbon atoms present in their structure.
- Alcohols have one carbon atom bonded to an oxygen atom by a single bond, while there are single bonds between the remaining carbon and hydrogen atoms.
- Alcohols form a homologous series. This means there is a pattern in their chemical and physical behaviour.
- Alcohols burn in oxygen to form carbon dioxide, water and a lot of heat.
- Alcohols react with oxygen to form organic acids.
- Alcohols react with organic acids to form esters. This reaction resembles the neutralisation reactions that were studied in Unit 5.

Answers to Activities on Alcohols

Activity 7

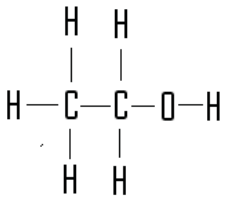
a) 2, this is based on the definition of ethanol

b) 2, 2 is determined by the number of electrons in the outermost shell of an atom when full (octet) since oxygen has 6 electrons in the outermost shell it has a shortage of two.

c) 1, since it had 6 so if it shares one electron then one will be left unshared.

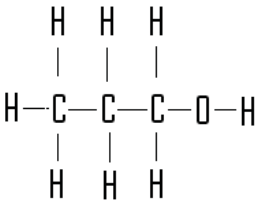
d) One, so that the outermost shell is full

e) Molecular structure of ethanol



ETHANOL

f) Molecular structure of propanol



PROPANOL

g) $C_nH_{2n+1}OH$

Activity 8

a) Melting point increases, due to the fact that the molecular mass has increased.

b) Boiling point increases due to the fact that the number of chemical bonds that need to be broken to achieve boiling has increased.

c) Liquids.

d) $C_5H_{11}OH$

Section 8-4: Acids

Do you still remember the definition of an acid? (Go back to Unit 5 if you need to review). Can you think of different acids that you know? Some common acids are found in the kitchen where they are used to prepare and flavour food. What do the acids you use in the kitchen taste like? Look at the labels on canned food and drinks and you will find that acids of different kinds have been used as preservatives.

At the end of section 8-4, you should be able draw and name different acids. You should also be able describe their physical and chemical properties.

Time

Section 8-4 has 6 pages. You should spend approximately 1 hour on this topic.

Molecular Structures and Chemical Properties of Acids

Carboxylic acids form another large group of organic compounds. The organic acids are made up of a carbon chain with hydrogen atoms attached to the carbons, except for just one carbon atom from which two oxygen atoms are attached, one with a double bond while the other with a single bond and a hydrogen atom attached to it (Figure 14). This structure makes organic acids have a functional group of –COOH.

Example of an organic acid:

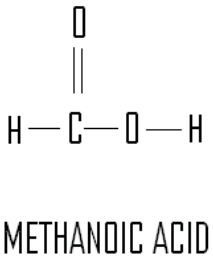


Figure 14: Methanoic acid or Formic acid.

In forming members of this group, there is an increase in the number of carbon atoms bonded to each other and hydrogen atoms bonded to carbon atoms. The functional group also bonds with one of the carbon atoms to form this group.

Acids, just like all other organic substances we have looked at so far, are named by the number of carbon atoms present in their structure and the common ending which is ***-anoic acid.*** The prefixes that are used are as follows:

Number of carbon atoms	Prefix	Suffix
1	Meth	-anoic acid
2	Eth	-anoic acid
3	Prop	-anoic acid
4	But	-anoic acid

And so on…

Activity

Activity 9

a) How many carbon atoms are in ethanoic acid ?
_____

b) For carbon and oxygen to have full outermost shells, how many pairs of electrons should they share with other atoms?
Carbon _____ Oxygen _____

c) If in the carbon chain one oxygen atoms shares two pairs of electrons with carbon and another oxygen shares one pair of electron, how many electrons are shared between the carbon atoms?_____

d) Draw the structure of ethanoic acid:

e) Draw the structure of propanoic acid:

f) Give the general formula for the molecular structure of acids
_____

Now compare your answers with the ones given at the end of the section. If you got 7 or more correct, then move to the next section. Otherwise review the section and attempt them again.

Note it!

Note the following important points:

- When stable organic acids are formed, atoms have their outermost shells full.
- The carbon atoms are all bonded to hydrogen and oxygen by single bonds except a single carbon atom, which bonds with oxygen by a double bond and with a single bond to another oxygen atom.
- There is a pattern in the number of carbon atoms, hydrogen atoms and the functional group -COOH present in a molecular structure of organic acids.
- Members of the organic acid group have a trend in their physical and chemical properties and therefore form a homologous series.
- Because of their similar structure, acids have the general formula:

$$C_nH_{(2n-1)}COOH$$

  - The general formula can be used to find the formula of any other member if the number of carbon atoms present in that molecule is known.

  For example, hexanoic acid has the molecular structure $C_5H_{11}COOH$.

Let's have a look at the physical properties of some acids:

Table 6: Physical properties of carboxylic acids

Name of acid	Formula of acid	Melting point °C	Boiling point °C
Methanoic acid	HCOOH	9	101
Ethanoic acid	CH_3COOH	17	118
Propanoic acid	C_2H_5COOH	-21	141
Butanoic acid	C_3H_7COOH	-138	163

Activity

Activity 10

Study the table above and answer the following questions:

a) What happens to the boiling points of acids as the number of carbon atoms increases? _____

b) What is the state of the carboxylic acids at room temperature and pressure?

_____

c) Write the molecular formula of the octanoic acid:

_____

Now compare your answers with the ones given at the end of the section. If you got every question correct, then move to the next section. Otherwise review the section and attempt them again.

Looking at the table one can see that as number of carbon atoms increases, the properties of the substance formed is affected. For example, the boiling point increases.

Chemical Properties of Organic Acids

Organic acids are said to be weak acids. Do you remember what a weak acid means?

Like other acids, organic acids undergo the same chemical reactions that inorganic acids undergo. Do you remember what happens when inorganic acids react with metals? With carbonates? With alkalis? (If not, review these topics from Unit 5).

Most of the reactions involving acids are very useful, especially the esterification reaction which was briefly outlined under alcohols. The description of these reactions is given below.

Esterifaction

Esters have a very sweet pleasant smell as mentioned earlier. Naturally-occurring esters are found in fruits and flowers. An ester is a product of the reaction of an acid (usually organic) and an alcohol; the hydrogen of the acid is replaced by an alkyl group. This reaction is similar to what happens between inorganic acids and alkalis.

Esters mainly result from the condensation (a reaction that removed water from the reactants) of a carboxylic acid and an alcohol, a process referred to as *esterification*. This reaction can be catalyzed by the presence of H^+ ions. Sulphuric acid (H_2SO_4) is often used as a catalyst for this reaction.

Esters are named as derivatives of the carboxylic acid from which they are formed. Condensation of ethanoic acid with methanol will produce methyl ethanoate. As stated earlier the ending of the acid -anoic is changed to -anoate, much as if the ester were a salt of the acid.

Esterification reactions are generally easily reversible by the addition of water; the reverse reaction is called the hydrolysis of the ester and proceeds in the presence of aqueous base. An example of the esterification reaction between ethanol and ethanoic acid, which produces ethyl ethanoate, is shown in Figure 15.

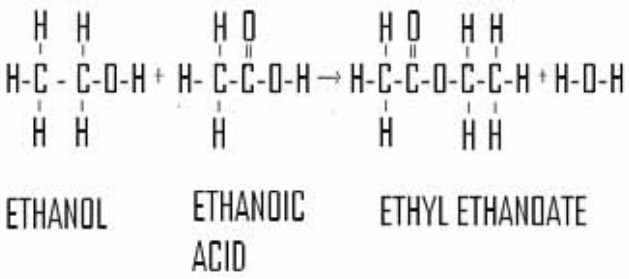


Figure 15: Esterification reaction.

The chemical equation for the esterification reaction above is:

$$CH_3CH_2OH + CH_3COOH \rightarrow CH_3COOCH_2CH_3 + H_2O$$

Note it!

Note the following important about organic acids:

- Acids have a functional group of –COOH. The H in the functional group is the responsible for the H^+ behaviour of the acid.
- Acids are named by the number of carbon atoms present in their structure.
- Acids have one carbon atom bonded to an oxygen atom by a double bond, and another oxygen atom bonded to carbon by a single bond. The remaining carbon and hydrogen atoms are linked by single bonds.
- Acids form a homologous series. This means there is a pattern in their chemical and physical behaviour.
- Alcohols react with organic acids to form esters.

Answers to Activities on Acids

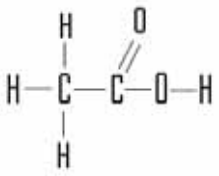
Activity 9

a) 2, this is based on the definition of ethanoic acid.

b) Carbon – 4 Oxygen – 2, is determined by the number of electrons in the outermost shell of an atom when full (octet).

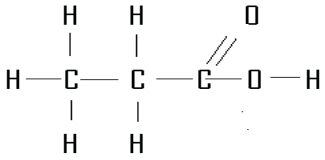
c) 2

d)



ETHANOIC ACID

e)



PROPANOIC ACID

f) $C_nH_{2n-1}COOH$

Activity 10

a) The boiling point increases due to the fact that the number of bonds that need to be broken before boiling can be achieved has increased.

b) Liquids.

c) $C_7H_{15}COOH$

Section 8-5: Cracking and Polymerisation

You have seen many things crack in life: a drinking glass, an egg shell, walls, our teeth, ceramic tiles and so on. What is the end result when something has cracked? What we usually see is that it will break into small pieces. Sometimes we crack something on purpose because we want those small pieces for a good reason.

At the end of section 8-5, you should be able to differentiate between cracking and polymerisation.

Time

Section 8-5 has 4 pages. You should spend approximately 40 minutes on this topic.

Cracking

In chemistry, cracking means breaking up of large (long chain) alkane molecules to form small (short chain) molecules of alkanes and alkenes. This is shown in Figure 16. Cracking can take place at a high temperature and pressure, or at a lower temperature and pressure in the presence of a catalyst.

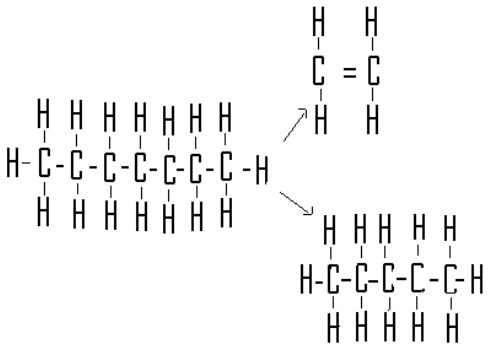


Figure 16: Cracking of Heptane.

Cracking is very important because it allows scientists to turn less useful molecules into more useful alkane and alkene molecules. The production of alkenes in cracking is very important as alkenes are very and can be reacted with other substances to produce more useful substances such as alkanes, like ethane or propane with smaller carbon chains. Cracking can be done in the laboratory using very simple apparatus in which kerosene can be broken down into ethene gas and ethylene gas.

Polymerization

Look around you and find out how many things are made up of plastic material. Have you ever wondered where plastic comes from? Have you noticed that plastics are different and can be used for different things?

From your own experience, write down three properties of plastics.

a) _____

b) _____

c) _____

Some characteristics of plastics include:

- They are good insulators, which mean they do not conduct electricity; think of the plastic tubing used to surround the wiring in our homes.
- They burn easily. An example is a plastic shopping bag.
- They are very unreactive. This means that food does not pick up any chemical flavours or odours when wrapped in plastic.
- Plastics are poor conductors of heat. Just think of the plastic ware that we use in the kitchen.
- They are light in weight. Again, think of plastic shopping bags.
- They are strong. Plastic pipes are commonly used for plumbing in the home.
- They are flexible and return to their original shape after deformation. Most new cars have plastic bumpers because they do not show dents after minor crashes.
- Plastics can be easily moulded into many different shapes; this is why so many toys are now made out of plastic.

Sometimes we need to produce a large molecule by joining small molecules together. The small molecules that are joined together may be of the same kind or be different. Small molecules called monomers are used to form large molecules called polymers. The process by which monomers react together to form polyymers is called: **polymerisation**. So polymerisation can be defined as the process by which small molecules are joined together to form a large molecule.

Since the molecules are added together, this process is called: addition polymerisation. Substances which undergo addition polymerisation have a double bond. This means that alkenes are suitable for this kind of process. Polymerisation is very important as it produces polymers which are very useful. For example, ethene molecules joined together in the presence of a catalyst produces poly(ethene). This reaction is shown in Figure 17 below:

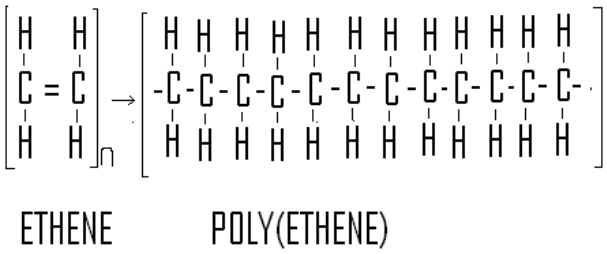


Figure 17: Polymerisation reaction to produce Poly(ethene).

Poly(ethene) is a substance which is tough, durable, easily moulded into different shapes, is an insulator and does not corrode. Poly(ethene) is used for making plastic bags, bowls, buckets, bottles and so on. Figure 18 below shows some of the products made from plastic.

Figure 18: Some examples of things made from plastic accessed from Wikimedia Creative Commons, 2006.

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Note it!

Important points to remember:

- **Cracking** means breaking up of large (long chain) alkane molecules to form small (short chain) molecules of alkanes and alkenes.
- **Polymerisation** is a process by which small molecules, called monomers, are combined together in the presence of a catalyst to form a large molecule called a polymer.

Section 8-6: Fractional Distillation of Petroleum Oil

In our everyday lives we use oils for different purposes: cooking, fuelling truck, lubricating moving parts, moisturising our skin and so on. Have you ever wondered where these oils come from and what makes them so different?

In section 8-6, you will learn about the fractions or substances that can be made from the distillation of crude oil and what these substances can be used for.

At the end of section 8-6, you should be able to list the uses of the different fractions of petroleum oil.

Time

Section 8-6 has 3 pages. You should spend approximately 40 minutes on this topic.

Petroleum oil

Petroleum oil is a mixture of different substances which come from decayed organic matter that is usually trapped in underground deposits. Since crude oil is a liquid, the best way to separate the substances is by using fractional distillation. If you need to remind yourself of how the distillation process works, go back to Unit 1 of the course for some quick review.

In fractional distillation, a substance with a low boiling point is collected first, followed by the one with the next lowest boiling point. Each of the collected substances is called a fraction. The substances which are collected first are the ones with low density. From their structures, one can see that the substances which are collected first have the shortest carbon chains. The fractions that are collected are used for many important things such as fuel for cooking, for cars, buses, aeroplanes, ships and many more objects.

Activity

Activity 12

Study Figure 19 below and answer the questions that follow:

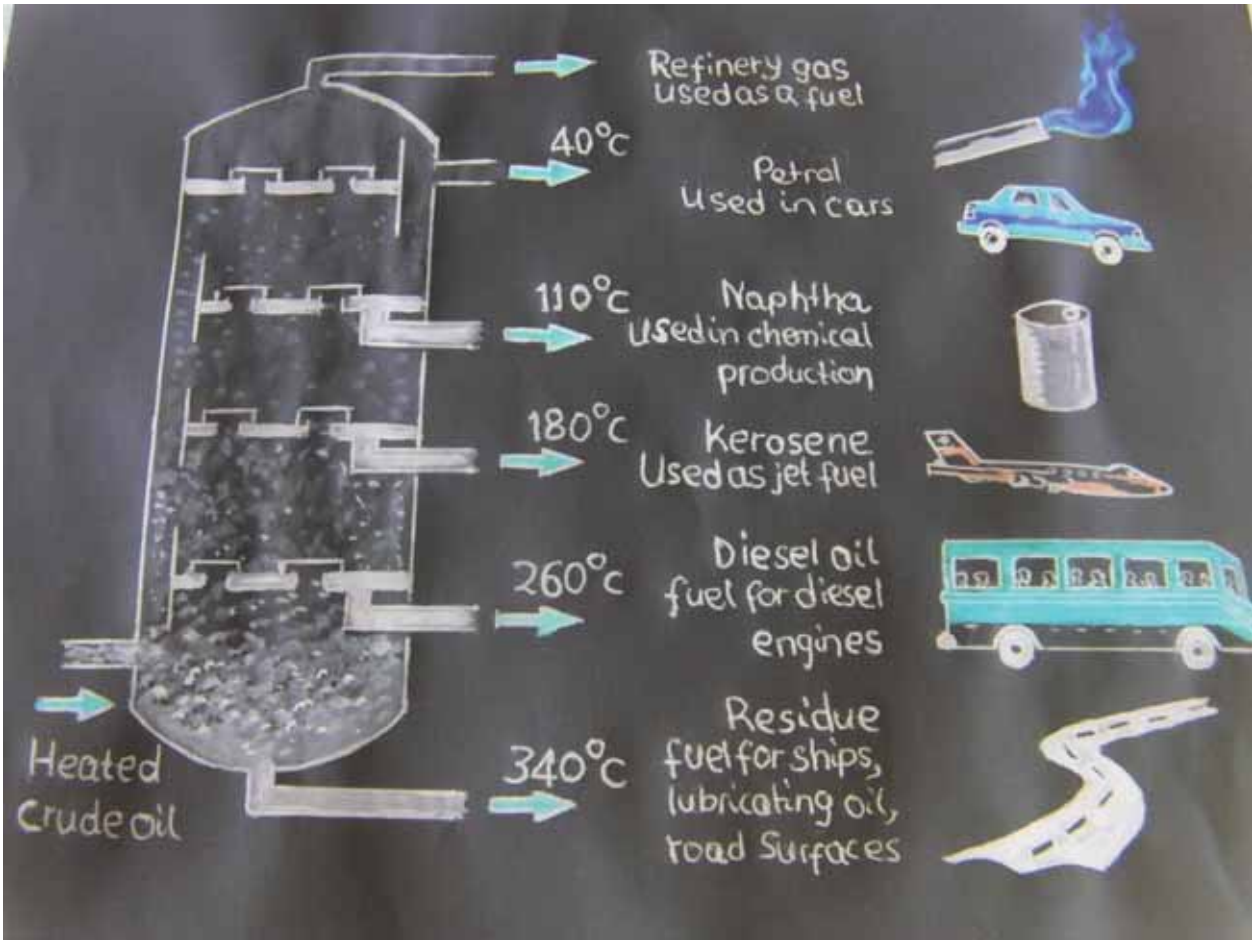


Figure 19: Fractional distillation of crude oil.

1.

a) Name one fraction that is used for cooking in homes:

_____

b) Give the name of the fuel used by cars:

_____

c) Which has the highest boiling point between kerosene and petrol? _____

d) Which has the highest density between diesel and naptha?

_____

e) Name two uses of the residue:

_____

_____

_____

f) Wax is one fractions resulting from this process. Where would you place wax and why?

_____

_____

_____

g) What happens to the ease of burning of the substances as you go down the fractions in the diagram?

_____

h) Which fraction burns easily between petrol and residue?

_____

i) There is one common use for most of the fractions collected during fractional distillation. What is it?

_____

_____

Now compare your answers with the ones given below. If you get 7 correct then you will have performed well.

Answers to Activities on Fractional Distillation

Activity 12

a) Propane or butane because they are lighter.
b) Petrol.
c) Kerosene.
d) Diesel.
e) Lubricant, in road making or as a fuel for ships.
f) I would place under residue because of its density.
g) It decreases. Compare candle wax and the gas that we use in the kitchen for cooking.
h) Petrol.
i) Used as a fuel. This will either be for vehicles or at home.

Note it!

Some important points to remember:

- Petroleum is made up of hydrocarbons.
- Petroleum is a mixture of different substances.
- Substances that form petroleum are called fractions as they form part of a whole just like in mathematics.
- Fractions with the lowest boiling points are collected first, as they will be the ones eliminated first.
- The density of the fractions increases as one goes down the fractional distillation chamber.
- The ease of burning decreases as one goes down the chamber.
- Members with the longest carbon chain are denser and are found at the bottom of the chamber.
- Most fractions are used as fuels.

You have completed the material for the unit on micromolecules, including alkanes, alkenes, alcohols, acids and the fractional distillation

of crude oil. Now spend some time reviewing the content.

Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers against those provided and clarify any misunderstandings that you have.

After reviewing the concepts again, your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit on large or macromolecules.

Unit Summary

Summary

In this unit you learned about organic chemistry, especially hydrocarbons, alcohols and carboxylic acids. These are some of the **important points to remember:**

ALKANES- general formula C_nH_{2n+2}

- Alkanes are hydrocarbons which are generally unreactive.
- Alkanes are named by the number of carbon atoms present in their structure.
- Alkanes have single bonds throughout their structure; that is why they are said to be saturated.
- The longer the chain, the higher the boiling points.
- Alkanes form homologous series.
- Alkanes burn in oxygen to form carbon dioxide and water.
- Alkanes undergo a substitution reaction with halogens to form halogenoalkanes.

ALKENES- general formula C_nH_{2n}

- Alkenes are hydrocarbons which are reactive.
- Alkenes are named by the number of carbon atoms present in their structure.
- Alkenes have one pair of double-bonded carbon atoms, while the remaining carbon and hydrogen atoms are linked by single bonds.
- Alkenes form a homologous series.
- Alkenes burn in oxygen to form carbon dioxide and water.
- Alkenes undergo an addition reaction with halogens to form halogenoalkanes.

ALCOHOLS- general formula $CnH_{2n+1}OH$

- Alcohols have a functional group of –OH.
- Alcohols are named by the number of carbon atoms present in their structure.
- Alcohols have one carbon atom bonded to an oxygen atom by a single bond. The remaining carbon and hydrogen atoms have single bonds.
- Alcohols form a homologous series.
- Alcohols burn in oxygen to form carbon dioxide and water.
- Alcohols react with oxygen to form organic acids.
- Alcohols react with organic acids to form esters.

ACIDS – general formula $C_nH_{2n-1}COOH$

- Acids have a functional group of –COOH.

- Acids are named by the number of carbon atoms present in their structure.
- Acids have one carbon atom bonded to an oxygen atom by a double bond, and another oxygen atom bonded to a carbon atom by a single bond. The remaining carbon and hydrogen atoms have single bonds.
- Acids form a homologous series.
- Acids react with alcohols to form esters

CRACKING AND POLYMERISATION

- Cracking is the term used in chemistry for the breaking up of large (long chain) alkane molecules to form small (short chain) molecules of alkanes and alkenes.
- Polymerisation is the process by which small molecules (monomers) are joined together to form a large molecule (polymer).

FRACTIONAL DISTILLATION OF PETROLEUM OIL

- Petroleum is a mixture of hydrocarbons.
- Substances obtained from the distillation of petroleum are called fractions.
- Fractions with the lowest boiling points are collected first.
- The density of the fractions increases as one goes down the fractional distillation chamber.
- The ease of burning decreases as one goes down the chamber.
- Members with the longest carbon chain are denser and are found at the bottom of the chamber.
- Most fractions are used as fuels.

The knowledge you gained from this unit will be used again in the next one, where we will be looking at the formation of micro- and macro-molecules. These processes will involve some of the functional groups you have learned about here.

Assignment 8

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 50 minutes

[Total Marks:50]

1. Explain the following statements:

a) Ethane is a saturated hydrocarbon.

_____

_____

_____ (3)

b) Ethene can undergo an addition reaction.

_____

_____

_____ (2)

2. Give **two** example of each of the following groups of substances:
   a) Alkenes (2)
   b) Carboxylic acids (2)
   c) Alcohols (2)
3. Ethanol is an important alcohol.
   a) Name two reactions that ethanol undergoes: (2)
   b) Write balanced equations for the reactions you named in (a) above. (4)
   c) Name two uses of alcohols: (2)
4. Describe the following processes and give an example produced in each case and its use.
   - Polymerisation (4)
   - Esterification (4)
   - Cracking (4)
5. Show the molecular structure of the following molecules:
   - Methanioc acid (3)
   - Butanol (3)
   - Pentene (2)

6. During fractional distillation of petroleum oil, different fractions are collected at different temperatures and at different points of the fractionating column.

   a) Name any three fractions which are collected from this process. (3)

   b) Name one use each of the fractions you have named above. (3)

   c) From the fractions you have named above, list them in order of flammability? (3)

   d) Name two uses for the residue of the fractional distillation of crude oil. (2)

Answers to Assignment 8

1) a) Ethane is saturated because it has single bonds throughout its structure.

b) Ethene can undergo an addition reaction because it has a double bond.

2) a) Alkenes: ethane, propene, butene, pentene etc

b) Methanoic acid, ethanoic acid, propanoic acid, butanoic acid etc

c) Methanol, ethanol, propanol, butanol etc

3. a) Ethanol can undergo oxidation reaction and esterification.

b) Any two balanced reactions for example:

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O + heat$$

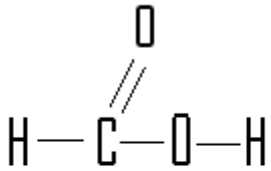
$$CH_3CH_2OH + CH_3COOH \rightarrow CH_3COOCH_2CH_3 + H_2O$$

c) Two uses of alcohol for example:

- ***As a fuel***
- ***As a food flavouring agent***
- ***As a solvent***
- ***As a disinfectant***

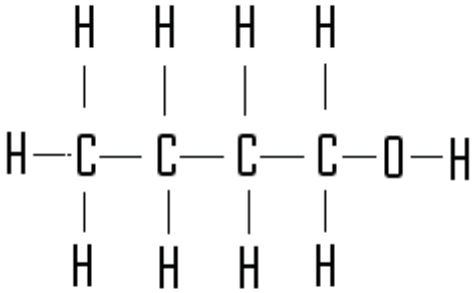
4. Polymerisation: Polymerisation is the process by which small molecules are joined together to form a large molecule for example ethene to form polyethene.

5. Methanoic acid



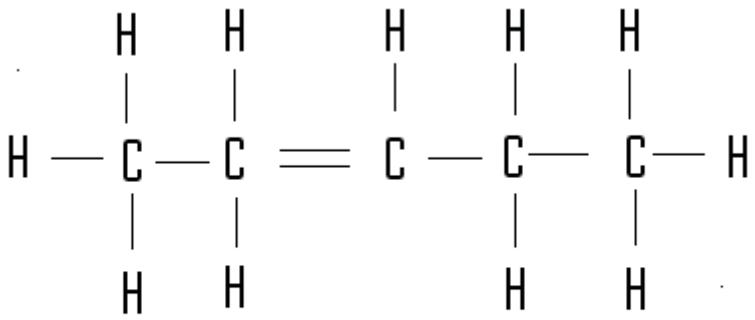
Methanoic acid

Butanol



Butanol

Pentene



Pentene

6. a) Names of fractions (any three of the following):

Refinery gases, petrol, naptha, kerosene, diesel or residue.

b) Uses of the fractions:

refinery gases-domestic fuel

petrol- fuel for cars

naptha- chemical production

diesel- for diesel engines for example buses tractors etc

residue- fuel for ship

c) Refinery is more flammable, then petrol, followed by naptha, kerosene and then diesel.

d) Fuels for ships, lubricating oil and for road surfaces.

Assessment 8

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 50 minutes.

(Total Marks:50)

1. Explain the following statements:

a) Ethane undergoes a substitution reaction.

_____
_____
_____
_____ (3)

b Ethene is unsaturated

_____
_____
_____
_____ (2)

2 Give two examples each of the following groups of substances:

a) Alkanes
(2)

b) Alkenes
(2)

c) Esters
(2)

3. Ethene is an alkene.

a) Name two reactions that ethene undergoes:
(2)

b) Write balanced equations for the reactions you named in (a) above:
(4)

4. Describe the following processes and give an example produced in each case and its use.

   a) Hydrogenation (4)

   b) Addition reaction (4)

   c) Oxidation
   (4)

5. Show the molecular structure of the following molecules:

   a) Pentane
   (3)

   b) Methanol
   (3)

   c) Butanoic acid
   (2)

6. During fractional distillation of petroleum oil, different fractions are collected at different temperatures and different points of the fractionating column.

   a) What happens to the density of the fractions as you go down the fractionating column?
   (3)

b) Name one use each of the following:

Naptha, kerosene and diesel.
(3)

c) What happens to the boiling points of the fractions as you go down the fractionating column?
(3)

d) Both diesel and petrol are used as fuels in buses and cars. Which one burns faster? State the reason why.
(2)

Chemistry

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 9

Macromolecules

Study Skills

Thinking creatively enables you to approach problems with an openness to alternatives. Strategies to improve you creative thinking include: looking at challenges in new or unusual ways, visualizing problems and solutions, make connections between ideas, learn from an experience when you failed and practice! ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In the last unit, you learned about micromolecules. In this unit, we are going to focus on big molecules and their uses. Big molecules or long-chain molecules are known as **macromolecules**. There are artificial and natural macromolecules and both of them are very important in our lives.

Molecules are particles that have their atoms covalently bonded. For example, oxygen gas (diatomic) and water are molecules. The bond between an oxygen atom and another oxygen atom in diatomic oxygen is a covalent bond. Also, the bond between an oxygen atom and a hydrogen atom in water (H_2O) is a covalent bond. A covalent bond is a bond that forms between two non-metals in which electrons are shared.

Time

This unit consists of 37 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Outcomes

Course Outcomes:

As in Unit 8, when you have completed this unit, you should be comfortable with being able to:

- *Discuss* the composition and characteristics of organic compounds.

Study Skills

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Describe* proteins, fats and carbohydrates as natural polymers and their uses.
- *Describe* hydrolysis of proteins, fats and carbohydrates.
- *Explain* how nylon and terylene are formed as synthetic polymers.

Terminology

Polymer:	Large molecules (macromolecules) that are made of many small molecules.
Monomer:	A molecule that is joined together with another to form a large molecule (macromolecule). Some macromolecules are made from different monomer molecules.
Hydrolysis:	The chemical breakdown of a molecule due to a reaction with water.
Polymerisation:	When small molecules (monomers) join together to form polymers.

Section 9-1: Synthetic Polymers

By the end of section 9-1, you should be able to:

- e*xplain* how nylon and terylene are formed as synthetic polymers.

Time

Section 9-1 has 17 pages. You should spend approximately 3-4 hours on this topic.

Different Families of Hydrocarbons

You should review the unit on micromolecules before you continue with this section.

Activity

Activity 1

In this activity you are going to review the different families of hydrocarbons you discussed in Unit 8-Micromolecules.

1. Describe the structure of each of the following:

   a) Alkane:

   _____
   _____

   b) Alkene:

   _____
   _____

   c) Alcohol:

   _____
   _____

2. Draw the structure of each of the following compounds:

   a) Ethane:

   b) Ethene:

   c) Ethanol:

d) Ethanoic acid:

e) Ethylamide:

Compare your answers with those at the end of the section. Review the related content for any questions that you missed.

You may not be familiar with the last two families, the carboxylic acids and the amides.

Carboxylic acids have a –COOH group called a carboxylic acid group. Ethanoic acid has two carbon atoms and one acid group. Some compounds have more than one acid group. An example of this is Benzene-1,4-dicarboxylic acid.

An amine has an amide group ($-NH_2$) attached to it. Ethylamide has two carbon atoms and one amide group.

The two families are illustrated in Figures 1 and 2:

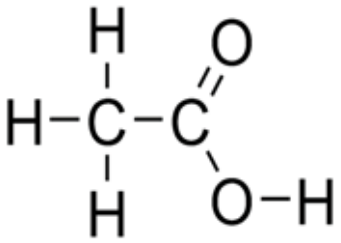


Figure 1: Ethanoic acid. Hand drawn by graphic designer at LDTC.

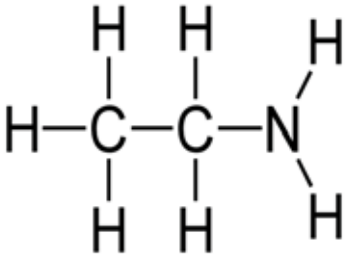


Figure 2: Ethylamide. Hand drawn by graphic designer at LDTC.

Addition Polymerisation

Activity

Activity 2

In this activity we are going to look at how macromolecules are formed. Consider the ethene molecule in Figure 3 below:

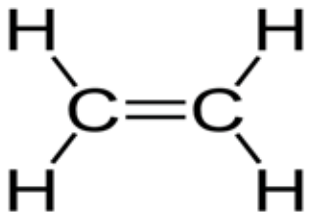


Figure 3: Ethene. Hand drawn by graphic designer at LDTC.

1. What happens when one ethene molecule reacts with another ethene molecule?

_____
_____

2. What is/are the product(s) when two ethene molecules react?

_____
_____

3. How many products do you think will be formed when 20 ethene molecules react?

_____
_____

After completing the questions, compare your answers to the correct answers at the end of the section. Take the time needed to understand each answer before continuing.

I hope you managed to get the answers to Activity 2 and the idea of how ethene molecules react together. However, if you did not get the idea please review the content before continuing.

Macromolecules

Macromolecules (long-chained molecules) are made from smaller molecules reacting and combining called **monomers**.

From Activity 2 above, the monomer is ethene. When many ethene monomers combine, a polymer called polyethene is formed.

Long-chained molecules such as polyethene may be made up of chain of several thousands of monomers, therefore, it becomes difficult to draw the structure of a whole molecule on one page. However, chemists have addressed this by using a general representation (structure), where n

represent any number (like in Algebra) of molecules of the monomer. The general representation (structure) of polyethene is shown in Figure 4.

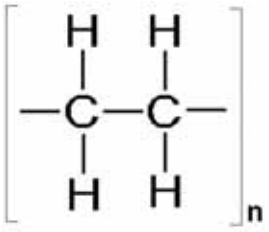


Figure 4: A general representation of polyethene molecule. Hand drawn by graphic designer at LDTC.

The type of reaction where one ethene molecule/monomer is added to another molecule to form a long chain molecule is called addition polymerisation. The polymer formed is called polyethene as mentioned earlier.

Polyethene is not a natural substance. It is man-made. In other words,

polyethene is a synthetic polymer. Polyethene is a plastic used to make plastic bags and plastic bottles among other things.

There are different types of plastics. Polyethene is just one of the many types. Other atoms can be added to ethene to make different plastics. For example, a different plastic is made when chlorine is added to polyethene to form polychloroethene.

Now, let us look at the next member of the group after ethane: propene. We will also look at the polymers that can be formed.

Polypropene

Similar to ethene in Activity 2, here the monomer is propene. When many propene molecules combine, the polymer polypropene (Figure 5) is formed. Polypropene (like polyethene) is a plastic. However, polypropene is stronger than polyethene. Therefore, it is used to make buckets, chairs, crates, fibres and rope.

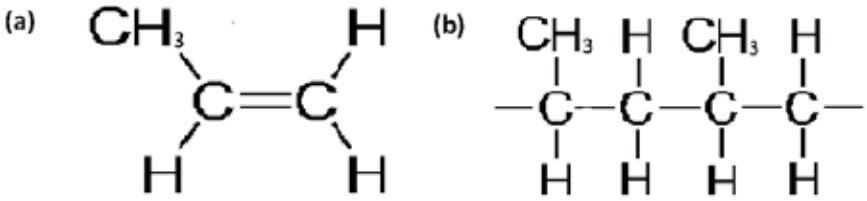


Figure 5: Polypropene.

Activity

Activity 3

(a) In your own words, give the definition of addition polymerisation.

_____
_____
_____
_____

(b) A polymerisation reaction takes place and the following polymer is formed:

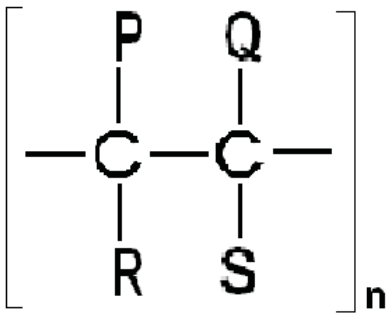


Figure 6: General polymer.

Note: P, Q, R, S could represent a number of different atoms or combinations of atoms. For example: H, F, Cl or CH_3.

i. Give the structural formula of the monomer of this polymer.

ii. In which group of organic compounds does this monomer belong?

_____

iii. What type of polymerisation reaction has taken place to combine the monomers to form this polymer?

_____

Compare your answers to those given at the end of the section. Note that it is important to understand this concept. If you do not understand it, review the above content and try the activity again.

You have seen what happens when ethene is added to another ethene molecule. Addition polymerisation occurs. In addition polymerisation, large molecules are made by combining identical smaller molecules. These smaller molecules (monomers) always contain an unsaturated bond which is the one making the monomers reactive. This is **not** the only way polymerisation occurs.

Now, let us look at another type of polymerisation reaction.

Condensation Polymerisation

There are some polymers which form in a different way to addition polymers. This way will be introduced by illustration in Example 1.

Example 1

Look at the structures of ethanoic acid and ethylamide in Figure 7. Think about which bonds will be broken for the reaction to take place.

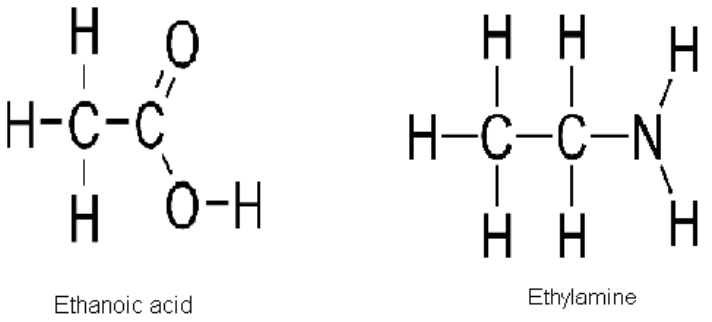
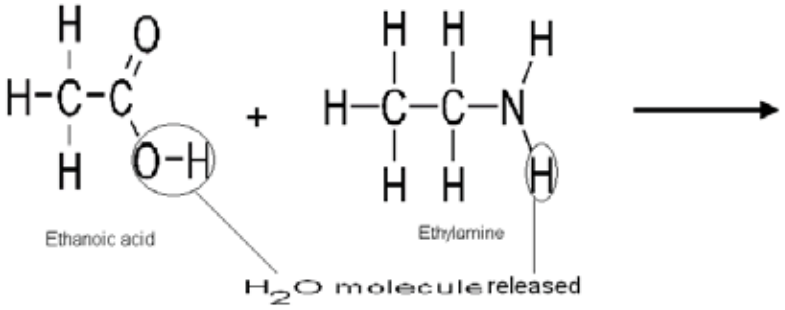


Figure 7: Ethanoic acid and Ethylamine

Compare your answer to the reaction of the carboxylic acid and the amine in Figure 8.



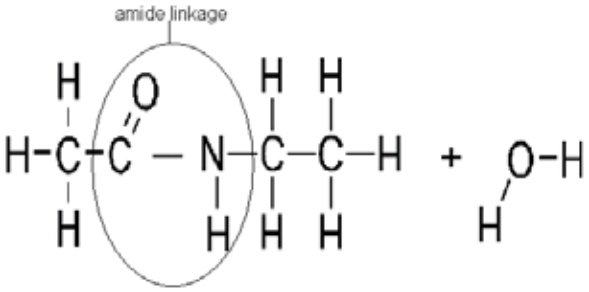


Figure 8: Ethanoic acid and Ethylamine react (a) to form a molecule of an amide and a molecule of water

The reaction in Figure 8 produces water as one of the products. This is probably why it has the name condensation. However, you should be careful -the smaller molecule produced is not always water, it depends on the combining monomers.

Points to note from Example 1 are:

Note it!

- The two monomers are not identical.
- The monomers have different functional groups. For the carboxylic acid (ethanoic acid), it is –COOH. For the amine (ethylamine), it is -NH_2 as shown in F7 and 8.
- If the two substances are added together, there will be a reaction between the two different functional groups.
- There are two products formed; one is a bigger molecule the other is a smaller molecule. Refer to Figure 8 above.
- If the smaller molecule is water; the –OH part is from the acid and the –H part is from the amine. Refer to Figure 8.

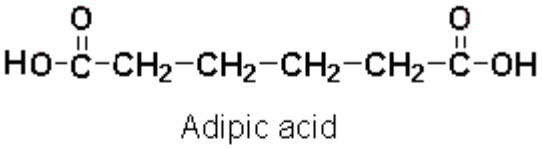
Remember the –OH is from the acid and the –H from the amine. These two combine to form H_2O. The reaction is called a condensation reaction. Again, in a condensation reaction, -OH is from the acid and -H is from the amine.

Now let us put the ideas into action.

Activity 4

Activity

1. Look at the two molecules below. The first one is an acid and the second one is an amine. Notice that they both have their family groups at **both ends**.



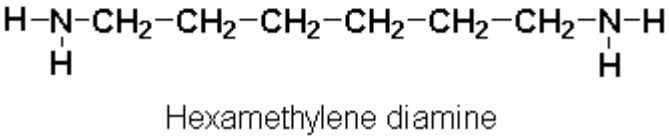
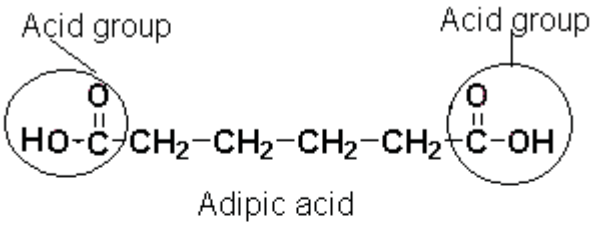


Figure 9: Adipic acid and hexamethylene diamine. Hand drawn by graphic designer at LDTC.

2. The following illustration shows the acid group and amine group.



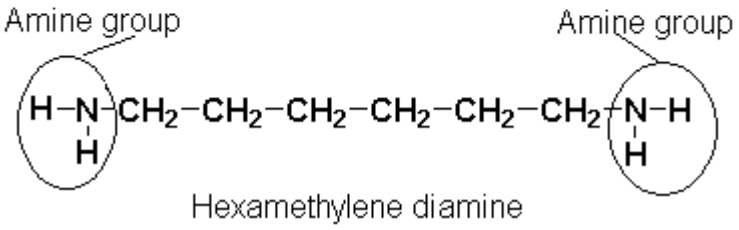


Figure 10: Family groups in adipic acid and hexamethylene diamine. Hand drawn by graphic designer at LDTC.

Hexamethylene diamine contains two amine groups, that is why it is called diamine (di = 2, so diamine = 2 amines). The adipic acid is also a diacid because it contains two acid groups.

3. Use the idea discussed in Example 1 to combine the acid and the amine. Show your work using the structures provided in Figure 10.

4. Draw the structure of the product that will be formed if you add another adipic acid molecule to the answer in 3.

5. Draw the structure of the product that will be formed if you add another diamine molecule to the answer in 4.

Compare your answers with those at the end of the section. Be sure you understand how diacids and diamines combine before continuing.

If more amine molecules and acid molecules are joined together in this reaction, a macromolecule (a very big molecule) will be formed. The macromolecule that will be formed is called a **polyamide**. The common name for this polyamide in the above reaction is nylon. This type of reaction is called **condensation polymerisation**. In chemistry, a condensation reaction is a chemical reaction where two molecules combine to form one large molecule and a smaller molecule (usually water molecule) is removed. In this case the big molecule formed is nylon (which is a polyamide) and water (a small molecule) is released. In reactions where water is released, the reaction is called a **dehydration reaction.**

Reflection

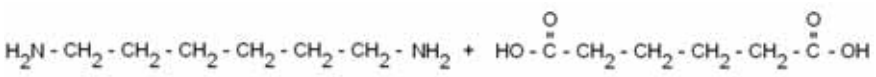
Nylon was first produced on February 28, 1935 by Wallace Carothers at DuPont's research facility. It's original use was to replace silk in the production of parachutes in WWII. Can you find thinks in your everyday life that are made of nylon? What are some other synthetic fabrics?

Why are we concerned about these kinds of reactions? Our interest is due to the evidence that most biological reactions are condensation reactions. Moreover, there are other interesting common polymers which form by the same condensation polymerisation. Examples of these other polymers include polyesters and polyamides (as Activity 4 illustrates). There are many synthetic polyesters and polyamides materials, which are made artificially by chemists. However, they are now part of our lives as they are used more and more in the clothing industry and other industries. Since the chemical industry is quite a big area by itself, we will only look at examples not the whole area. We will look at the common polyamide nylon and the common polyester terylene in the following section.

Formation of Synthetic Polymers

Nylon

Nylon is a polymer formed from the reaction of an amine monomer (1,6-diaminohexane) and an acid monomer (1,6-hexanedioic acid, an adipic acid).



1,6-diaminohexane
(hexanemethylene diamine)

1,6-hexanedioic acid
(adipic acid)

Figure 11: An amine monomer and an acid monomer.

1. The amine has two reactive groups. What are the reactive groups?

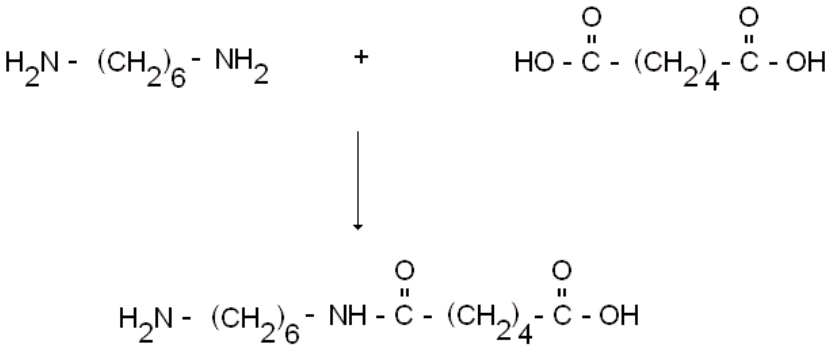
_____

2. The acid has two reactive groups as well. What are the reactive groups on the acid? Hint: there is one at each end.

_____

Compare your answer to Figure 11 above and then continue to the simplified equation in Figure 12 below.

The simplified equation for the reaction is given in Figure 12 below:



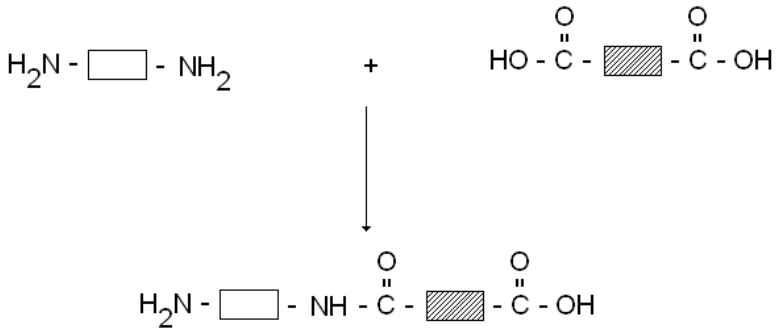
where

$(CH_2)_6$ = $- CH_2 - CH_2 - CH_2 - CH_2 - CH_2 - CH_2 -$

$(CH_2)_4$ = $- CH_2 - CH_2 - CH_2 - CH_2 -$

Figure 12: simplified equation of nylon formation.

The above equation can be further simplified by writing it as in Figure 13 below:



where the boxes represent the following:

$\square$ = $(CH_2)_6$ = $- CH_2 - CH_2 - CH_2 - CH_2 - CH_2 - CH_2 -$

$\blacksquare$ = $(CH_2)_4$ = $- CH_2 - CH_2 - CH_2 - CH_2 -$

Figure 13: The box represantation of nylon formation.

The bond that forms between the two monomers is called an amide **linkage**. The amide linkage forms between the nitrogen atom in the amine monomer and the carbon atom of the carbonyl group of the carboxylic acid. In the process, a water molecule is released as shown in Figure 14 below.

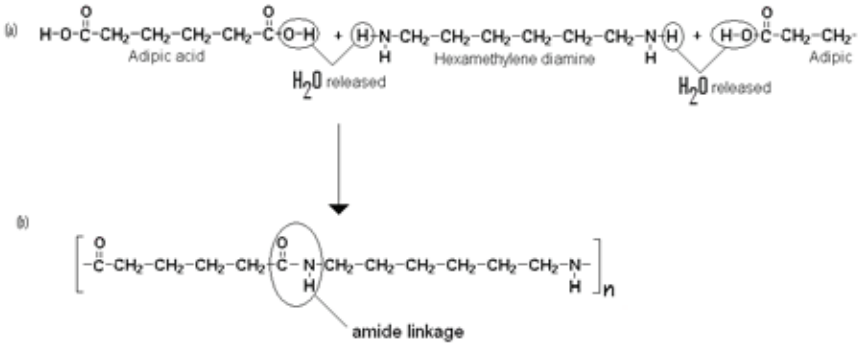


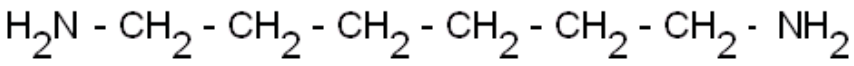
Figure 14: An acid and an amine (a) combine to form a part of a nylon polymer (b).

Now it is you turn to use the ideas from figure 10 to do the following activity:

Activity 5

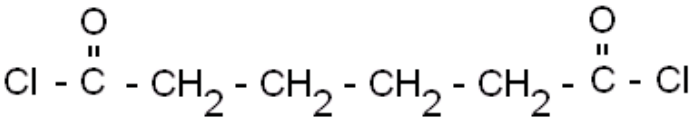
Activity

a) Draw structure of the polymer molecule and by-product formed by joining the monomer molecules shown in Figure 15 below.



1,6-hexane diamine

and



1,6- hexane dioyl chloride

Figure 15: The monomer molecules.

b) Is the reaction a condensation reaction or addition polymerisation? Give a reason to support your answer.

_____
_____
_____
_____
_____

c) Draw the linkage in the structure in (a). Give the name of the linkage.

Name of linkage is _____

d) Is there any small molecule formed? Name it.

_____
_____
_____
_____

Check your performance against the given solutions at the end of the section. Continue if you are satisfied with your ability to answer the questions. If not, review the above content and try the activity again.

Uses and Properties of Nylon

Nylon fibres are very strong and resistant. They are stronger than natural fibres such as cotton. These properties make nylon ideal for the following uses.

- Threads
- Ropes
- Shirts, tights and other clothing (figure 16 below)
- Carpets
- Fishing nets, fishing line and guitar strings
- Shoes
- Toothbrushes bristles
- Machine parts such as gear wheels
- Electrical equipment insulation
- Equipment cases

Figure 16: Nylon socks in shoes accessed from Wikimedia Creative Commons, 2010.

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We have looked at polyamides up to this stage. More will be studied in more advanced courses. Let us look at polyester (terylene).

Terylene

Terylene (or Dacron) is a polymer (polyester) formed from the reaction between a dioic acid (benzene-1,4-dicarboxylic acid or terephthalic acid) and a diol (1,2-ethanediol or ethylene glycol). It will make our understanding easier to look at an example.

Example:

1. Look at the following molecules:

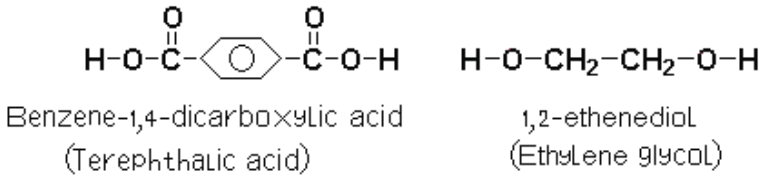


Figure 17 : Terephthalic acid and ethylene glycol

2. Show how condensation polymerisation occurs between the two molecules. Also clearly show how water is formed. Hint: note that instead of an amine we have an alcohol. The ideas previously covered relate to this.

Compare your answers with the following solution.

In the reaction, a hydrogen atom is lost from the alcohol and a hydroxyl group is lost from the carboxylic acid. The hydrogen atom and hydroxyl group combine together to form one water molecule which is released during the condensation reaction as in Figure 8. The bond forms between the oxygen of the diol and the carbon of the carbonyl group of the carboxylic acid. This bond is called an **ester linkage**. One of the products of the reaction is terylene (polyester). Polyesters are a group of polymers that contain the ester functional group in their main carbon chain.

Now focus on the reaction in Figure 14 below to see what is meant by the above text.

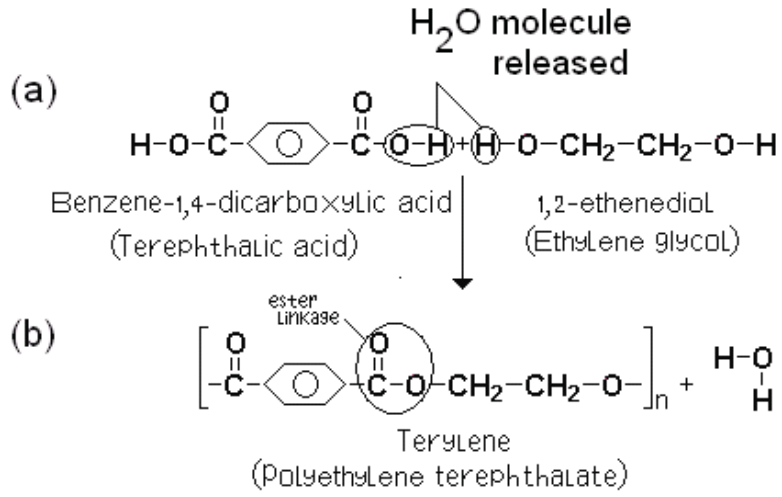


Figure 18 : An acid monomer and an alcohol monomer react (a) to form a molecule of the polyester (terylene) (b).

Let us slow down and notice that:

1. The acid end of one molecule is joined to the alcohol end of another molecule to form a bond as shown in Figure 18.

2. The bond formed between the acid and the alcohol is called an ester linkage.

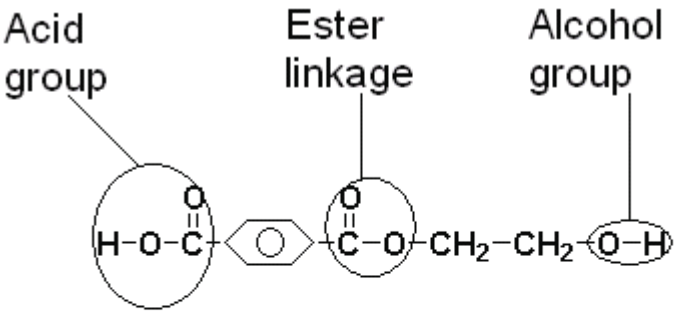


Figure 19 : The ester linkage, shown with the acid group and the alcohol group

From what we have done up to now, we can tie ideas together so that we can form a general picture (statement).

Many molecules of terephthalic acid and ethylene glycol molecules react to produce a long chain with many ester linkages. This polymer is called **polyester.** Its common name is **terylene.** The diagram in Figure 20 below shows a simplified structure of this reaction. Note that the boxes represent chains of hydrocarbons and n represents any number.

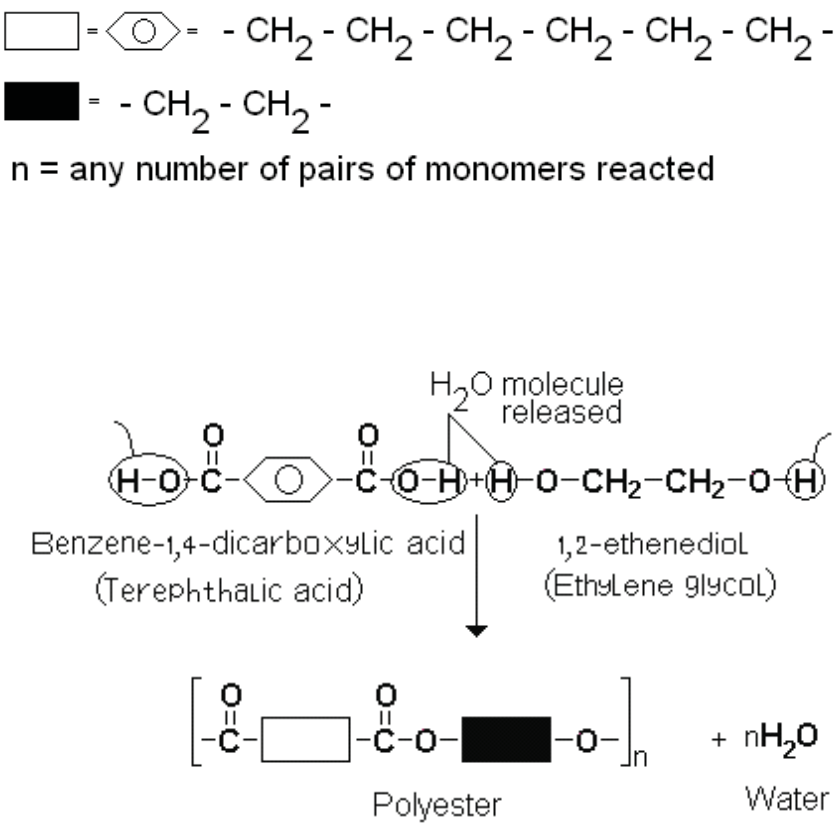


Figure 20 : Esterification

In general, polyester is a polymer (a chain of repeating units) in which the individual units are held together by ester linkages. Polyester is used for a variety of things.

Uses and Properties of Terylene

Terylene fibres are very strong. They are not easily attacked by insects, need little or no ironing and when pure do not absorb water to any great extent. These properties make terylene ideal for the following uses:

- Clothing such as crimplene materials. These materials are normally mixed with cotton to make shirts (polyester and cotton).
- Suits (usually mixed with wool as their texture is similar).
- Drip-dry clothing, trousers with permanent creases.

- Curtains.
- Sleeping bags.
- Sails and parachutes.
- Conveyor belts and safety belts.
- Moulded plastics such as drink bottles.
- Fishing line.

Key points to remember:

Note it!

The key points to remember in this section on synthetic polymers are:

1. A monomer is a small molecule that can join to other monomers to form large and long molecules (polymers).
2. A polymer is a large molecule made by joining many smaller molecules together (monomers).
3. Polymerisation is the process of forming very large and long molecules (polymers) by joining small molecules (monomers) to each other.
4. In addition polymerisation, the small molecules (called monomers) have a double bond between two carbon atoms. The double bond is used to join one molecule to the next. The large molecule formed is called an addition polymer.
5. In condensation polymerisation, the small molecules release atoms to free some bonds so that the link to the next molecule is possible. The atoms lost (from the monomers) form a small molecule such as water (or hydrogen chloride or ammonia). The large molecule formed is called a condensation polymer.
6. Polyethene (or polyethylene PVC) is an example of an addition polymer.
7. Nylon (polyamide) and terylene (polyester) are examples of condensation polymers.
8. Nylon and terylene are also examples of synthetic polymers.
9. Monomers in nylon are joined by amide linkages. Monomers in Ttrylene are joined by ester linkages.

We have looked synthetic polymers, we will next look at natural polymers: polyamides (example is proteins) and polyesters (example is fats). We will also look at carbohydrates.

Answers to Activities on Synthetic Polymers

Activity 1

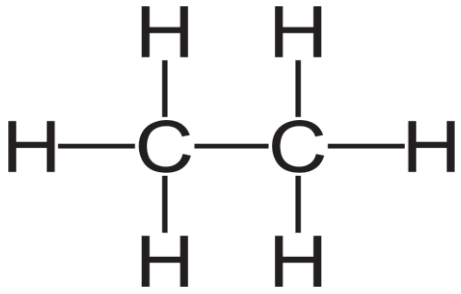
1.

a) Ethane is a compound of carbon atoms and hydrogen atoms (hydrocarbon) made up of two carbon atoms and six hydrogen atoms joined by single bonds.

b) Ethene is a hydrocarbon that consists of two carbon atoms joined by a double bond and four hydrogen atoms.

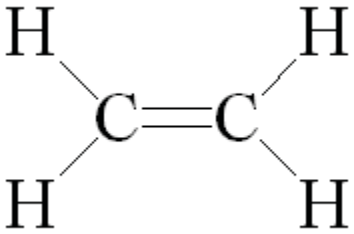
c) Ethanol is an alcohol with two carbon atoms. All hydrocarbons that contain a –OH group (hydroxyl group) are called alcohols.

2.



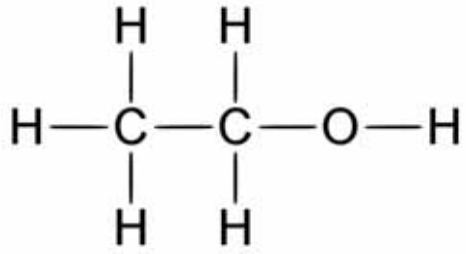
a)

Figure 21: Ethane.



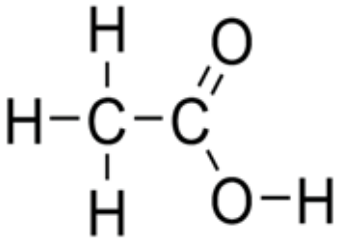
b)

Figure 22: ***Ethene.***



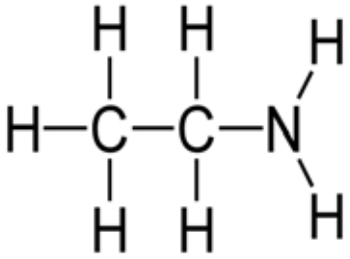
c)

Figure 23: Ethanol.



d)

Figure 24: Ethanoic acid.



e)

Figure 25: Ethylamide.

Activity 2

1. *When two ethene molecules react, a double bond breaks and the two molecules bond to each other. This results in the formation of butane.*

2. *When two ethene molecules react, a hydrocarbon with no double bonds, called butane is formed. Refer to Figure 26.*

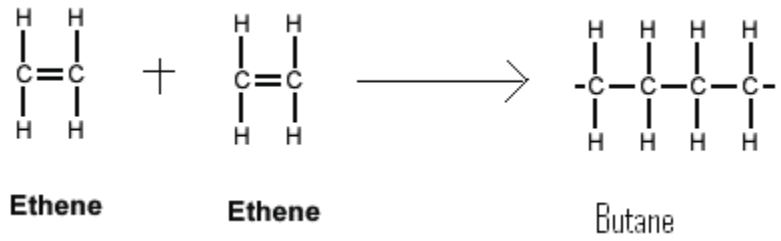


Figure26: *Addition of two ethene molecules produce butane.*

3. *When 20 ethene molecules react, there is only one product formed. A long-chained hydrocarbon with 40 carbon atoms.*

Activity 3

(a) Addition Polymerisation: when small unsaturated molecules (monomers) join together to form saturated polymersNo atoms are lost or gained for bonds to form between the monomers.

(b) i. Look at the structure of the repeating unit in the polymer to determine the monomer.

The monomer is:

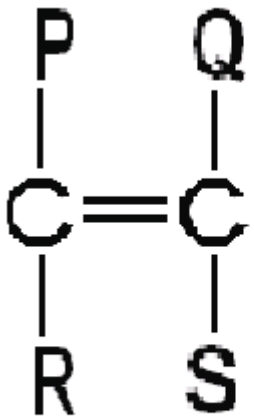


Figure 27: A monomer

ii. Look at the atoms and bonds in the monomer to determine which group of organic compounds it belongs to.

The monomer has a double bond between two carbon atoms. The monomer must be an alkene.

iii. Determine the type of polymerisation reaction.

In this activity, unsaturated monomers combine to form saturated polymer. No atoms are lost or gained in order for the bonds between monomers to form, they are simply added to each other. This is addition reaction polymerisation.

Activity 4

<u>The first step</u>

Remove –OH from the acid and –H from the amine as shown in figure 28.

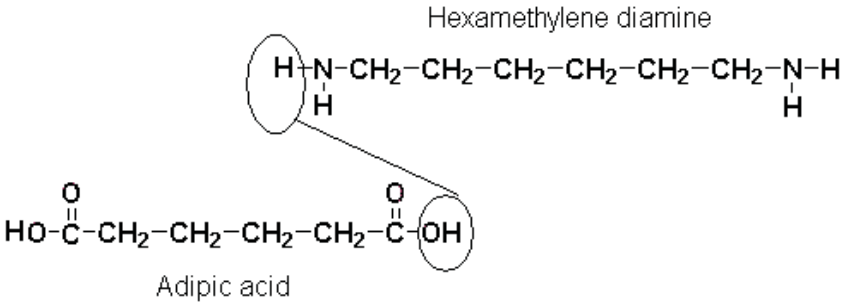


Figure 28: Dehydration in adipic acid and hexamethylene diamine reaction.

<u>The second step</u>

Join the acid to the amine to form a bigger molecule as shown in figure 29.

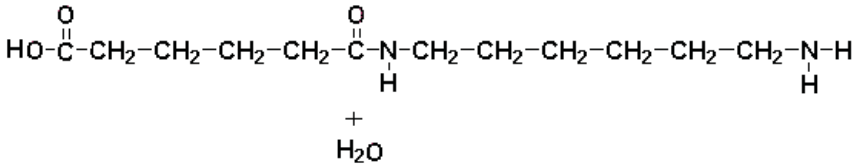


Figure 29: Products of adipic acid and hexamethylene diamine reaction.

If adipic acid is added to the product, the following molecule will be produced as shown in Figure 30. Notice that the carbon chain in both the amide and acid have been shortened, but it is still the same number of carbon atoms as in adipic acid and amine.

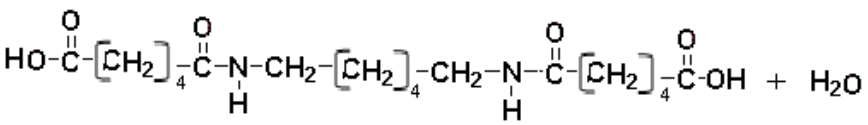


Figure 30: Products of hexamethylene diamine and two molecules of adipic acid.

If another amine is added to the product, it will be attached to the acid group. One molecule of water will also be released. Refer to figure 31 below:

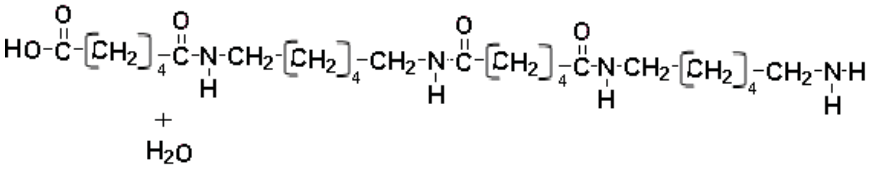


Figure 31: Products of two molecules of adipic acid and two of hexamethylene diamine.

Activity 5

a)

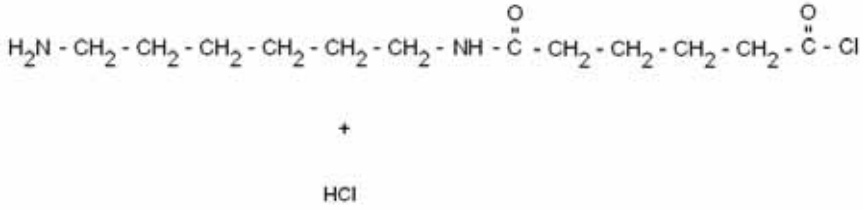
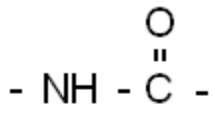


Figure 32: part of a polymer and a small molecule.

b)

This is condensation polymerisation because one large molecule is formed and a smaller molecule of HCl is released.

c)



or

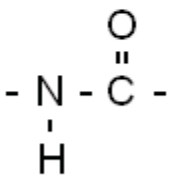


Figure 33: An amide linkage.

Name of the linkage is amide linkage.

d)

Yes there is a small molecule released. The name is hydrogen chloride or hydrochloric acid (HCl).

Example 2

Terephthalic acid falls under a family of <u>acids.</u>

Ethylene glycol falls under <u>alcohols.</u>

As in the case of condensation polymerisation of adipic acid and ethylamide, now the –OH group is from the acid and the –H group is from the alcohol. Refer to Figure 34 below.

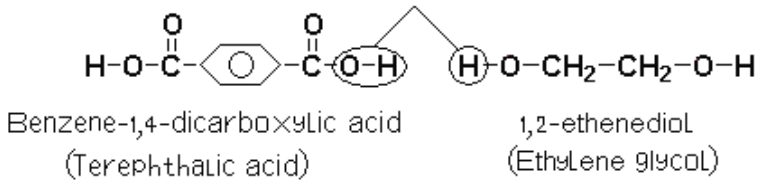


Figure 34: Dehydration of Terephthalic acid and ethylene glycol reaction.

The ends, where the –OH group and –H are removed are now joined to form a long chain. Figure 35 shows the product after the reaction:

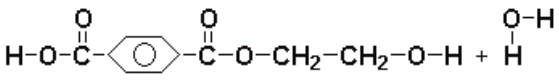


Figure 35: Condensation polymerisation of terephthalic acid and ethylene glycol.

Section 9-2: Natural Polymers

At the end of section 9-2, you should be able to:

- *describe* proteins, fats and carbohydrates as natural polymers.

Time

Section 9-2 has 8 pages. You should spend approximately 1.5 hours on this topic.

Proteins

Macromolecules are also found in animals and plants. One example of natural macromolecules are proteins. Proteins are formed naturally from amino acids (monomers). Proteins build up and replace the tissues and cells in your body. Your body uses the protein you eat to make the proteins including haemoglobin. Haemoglobin is the part of red blood cells that carries oxygen to every part of your body.

Single cell anaemia is a genetic disease in which red blood cells form an abnormal crescent shape. This is caused by an abnormal type of haemoglobin. The symptoms of this disease include fatigue, rapid heart rate, paleness and strokes: all because the abnormal haemoglobin cannot properly carry oxygen to cells. If you have access to the internet, try this virtual lab: http://k12education.uams.edu/scvlab/

Activity

Activity 6

1. Look at the structure of an amino acid:

The letter R represents other atoms attached.

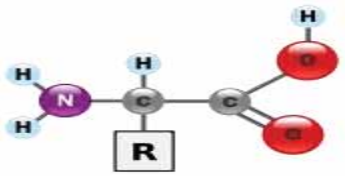


Figure 4: Amino acid structure accessed from Wikimedia Creative Commons, 2010.

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2. If polymerisation occurs using amino acid as a monomer, would addition or condensation polymerisations be more likely to happen? Why?

_____
_____
_____
_____

3. Show how a condensation reaction between two amino acid molecules occurs.

4. From what you have learnt from polymerisation reactions earlier in this unit, what do you think is the name of the polymer produced from a carboxylic acid and an amine?

_____

Compare your answers with those at the end of the section. For further reinforcement read the following paragraph on amino acids.

Amino Acids

Amino acids have a carboxylic acid group on one end and an amine group on the other end. There are no alcohol groups. One amino acid is both an acid and an amine. When two amino acid molecules combine, the amine end is joined to the acid end. Many amino acid molecules can react like this to form a macromolecule called a polyamide. Refer to Figure 37 below:

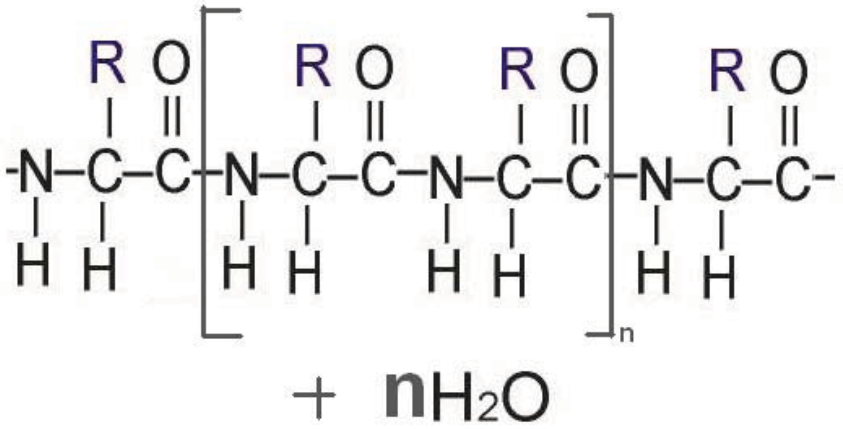

Figure 5: Proteins are polyamides.

Fats

The other group of natural macromolecules are fats. Fats are made by the condensation reaction between a molecule with an alcohol group (-OH) and another molecule with acid group (-COOH). Fats play a vital role in maintaining healthy skin and hair, insulating body organs against shock and maintaining body temperature. In chemistry, fats are used to make soap.

Activity

Activity 7

1. Describe how a polyester molecule is made. Which two molecules combine to form a polyester macromolecule?

   _____

   _____

2. Draw an ester linkage in the space provided below:

3. Show how one molecule can be produced from the four molecules below. Use the space that follows the diagrams.

   Hint: there should be three ester linkages. Each acid attaches itself to one alcohol group of glycerol.

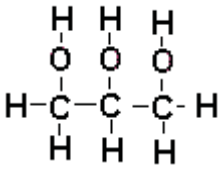

Figure 6: Glycerol.

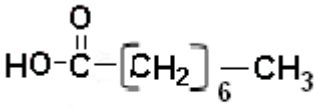

Figure 7: Acid.

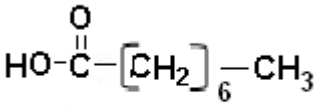

Figure 40: Acid.

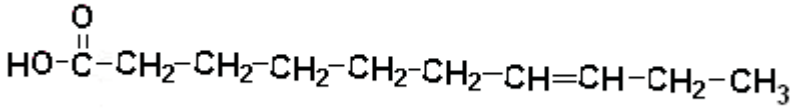

Figure 41: Acid with a double bond.

Compare your answers with those at the end of the section. Review as needed and continue after you have gained the idea of how fats form naturally.

Carbohydrates

All compounds which contain carbon, hydrogen and oxygen atoms are called carbohydrates. Examples of such compounds are sugar, cellulose and starch. Like proteins and fats, carbohydrates are also formed by condensation polymerisation. The bonds between carbohydrate monomers are known as glycosidic linkages. Carbohydrates are found in foods high in starch and they are the source of energy in living things.

Activity

Activity 8

Figure 42 shows two molecules of sugar.

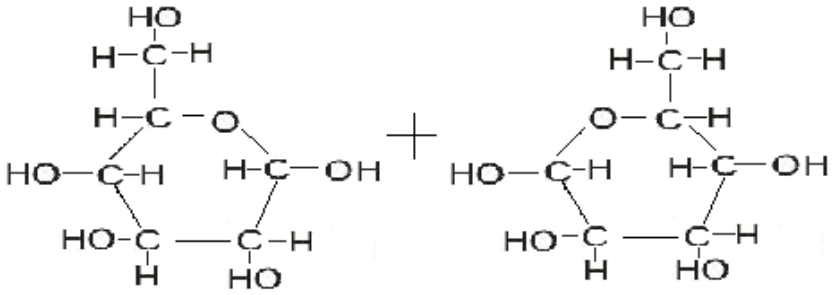

Figure 42: Sugar molecules. Hand drawn by graphic designer at LDTC.

Predict how the dehydration reaction (condensation polymerisation reaction) will occur to form linkages between sugar molecules.

_____

_____

_____

_____

Compare your answer with the suggested ones at the end of the section. Remember to spend time on questions you got wrong to gain more understanding before moving on to the next idea.

Imagine the product formed when two sugar molecules react to produce one molecule.

The sugar molecules combine naturally to produce starch. Figure 43 illustrates a linkage found in the carbohydrates. Notice that I have only shown one bond, but more bonds can be formed.

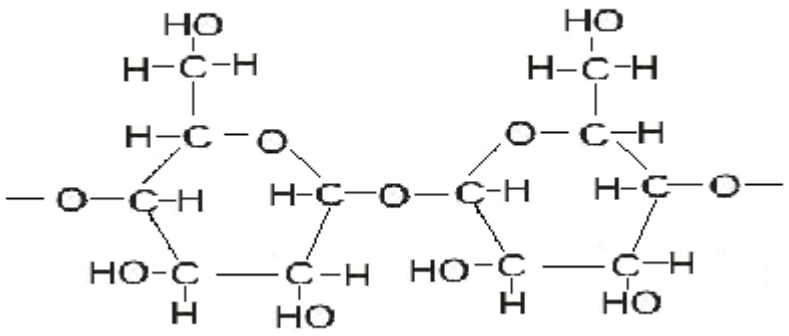

Figure 43: Condensation polymerisation of carbohydrates. Hand drawn by graphic designer at LDTC.

Uses of Natural Polymers

The natural polymers discussed above are food types. You have already learned about food types and their uses in your body in your biology lessons. Figures 44 and 45 show food samples where you can obtain proteins, fats, carbohydrates and other food types.

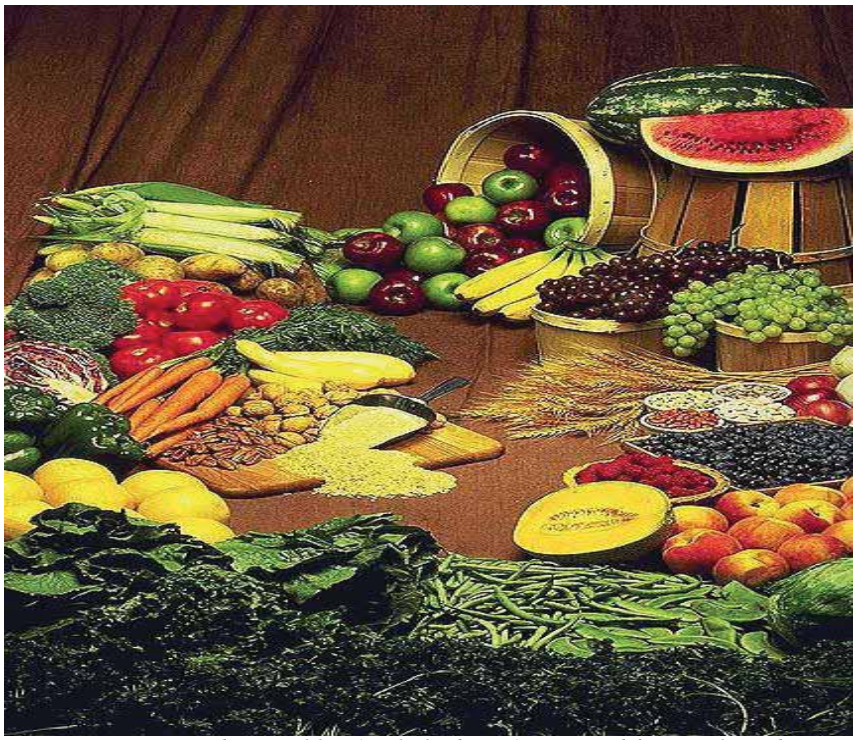

Figure 8: Fruits and vegetables (carbohydrates) accessed from Wikimedia Creative Commons, 2010.

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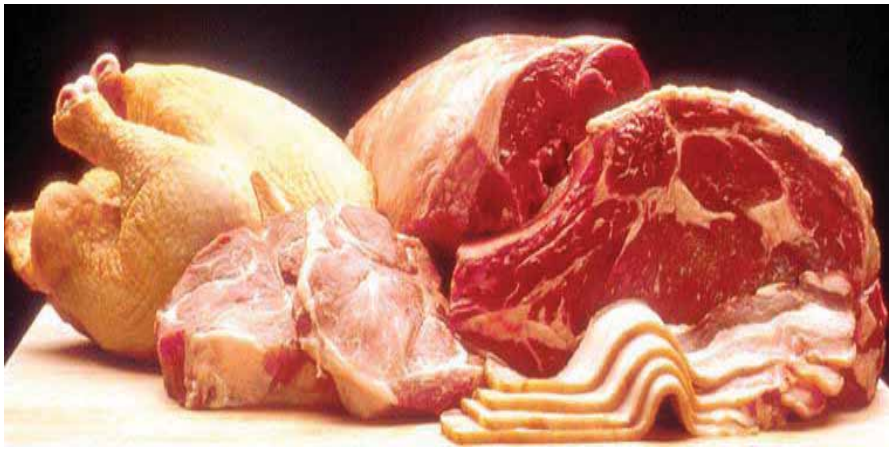

Figure 9: Meat (proteins and fats) accessed from Wikimedia Creative Commons, 2010.

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Hydrolysis of Natural Polymers

Activity 8

Activity

1. Copper (II) sulphate solution is blue in colour. When the solution is heated, the solution becomes white and water vapour is given off. What is common between this reaction and condensation polymerisation?

   _____
   _____
   _____

2. When water is added to the white compound, it turns blue again. This is the reverse reaction of heating blue copper (II) sulphate solution. What is the reverse reaction of condensation polymerisation?

   _____
   _____
   _____

Compare your answers with those at the end of the section. Be sure that you understand each answer before continuing. If you have any misunderstandings, review this content and work through the activity again.

During condensation polymerisation, water is given off as another product. The reverse reaction can also occur. Proteins, fats and carbohydrates can react with water if an acid is added to speed up the reaction and the reactants are boiled. This type of reaction where water is added is called **hydrolysis.** The products of each reaction are given below:

- Proteins can be hydrolysed to give amino acids.
- Fats can be broken down to acids and alcohol.
- Starch (a carbohydrate) can be hydrolysed to simple sugars.

There are other ways that hydrolysis occurs. For example, the hydrolysis of fats using sodium hydroxide yields soap.

Key points to remember:

Note it!

The key points to remember in section 9-2 on natural polymers are:

1. Carbohydrates, proteins and fats are natural macromolecules. They are also main constituents of food.
2. Proteins have the same monomer to monomer linkages (amide linkages) as nylon but their monomer units are different.

3. Fats have the same monomer to monomer linkages (ester linkages) as terylene but with different monomer units.

4. Hydrolysis of :

    a. Proteins in acidic conditions produce amino acids which you use to build up your body tissues, hair and nails.

    b. Carbohydrates produce glucose which you use for energy.

    c. Fats produce fatty acids and glycerol. These are stored as new fats under the skin and around internal organs until they are needed for energy.

You have now completed the last section of this unit on macromolecules. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Answers to Activities on Natural Polymers

Activity 6

2. The most favourable reaction to occur is condensation polymerisation. You may think that addition is possible as it occurs in an unsaturated carbohydrate where a double breaks and creates a room for another monomer to be added. In this case, the monomer is saturated; you may think that a double bond in the acid group between oxygen and carbon can provide room for addition polymerisation. This is not what happens, as you have realised when adipic acid reacts with an amide to produce a polyamide. Adipic acid also reacts with hexanol to produce polyester.

The reaction that occurs in this case is condensation polymerisation. Refer to formation of polyamide and polyester.

3. The –OH from the acid group and the –H from the amine group break from different amino acid molecules. They then join and form water.

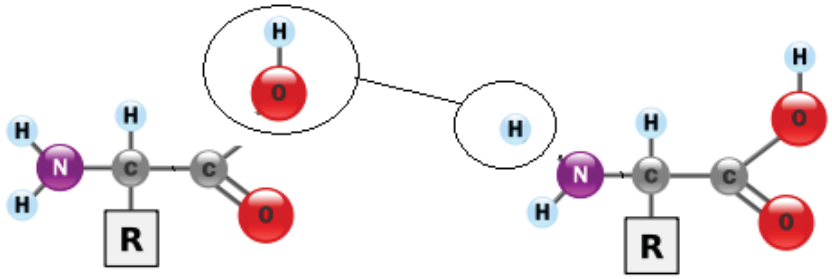

Figure 10: A water molecule is formed from -OH and H. ***Hand drawn by graphic designer at LDTC.***

The two molecules combine to form a longer molecule as shown in Figure 47.

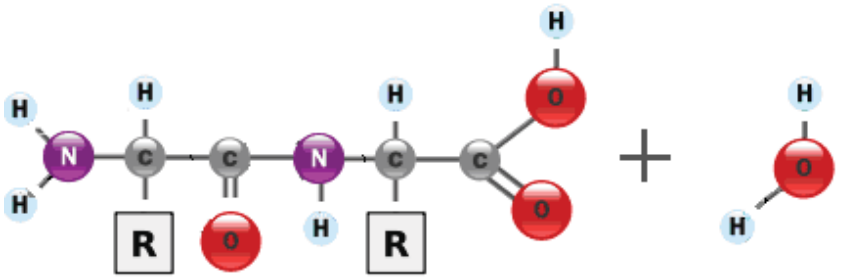

Figure 11: Reaction of two amino acids. ***Hand drawn by graphic designer at LDTC.***

Activity 7

1. ***A polyester is produced by an acid and an alcohol.***
2. ***The diagram showing an ester linkage:***

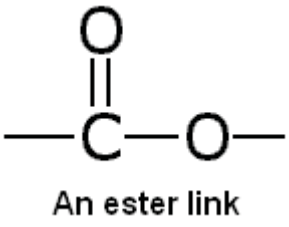

Figure 12*: An ester link.* ***Hand drawn by graphic designer at LDTC.***

3. *A diagram showing a tri-ester.*

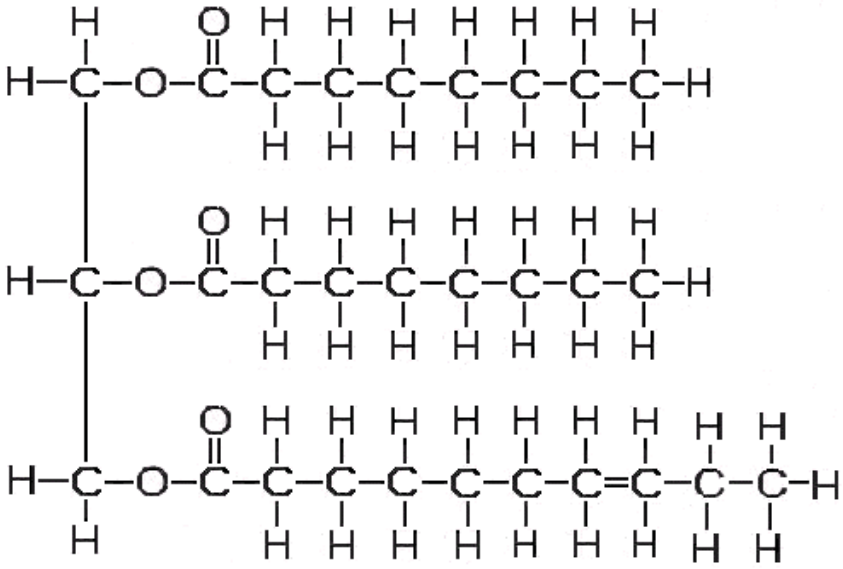

Figure 49: A tri-ester

Activity 6 is challenging. The idea you use is the same as in terylene production. You have to make sure that each alcohol group is attached to an acid group of another molecule. The product is given in Figure 49. Note that the linkage (ester linkage) is the same as the one in terylene. This is how fats are formed naturally. Fats are also known as triglycerides because they are composed of three fatty acids attached to one glycerol backbone.

Activity 8

Reaction between two sugar molecules:

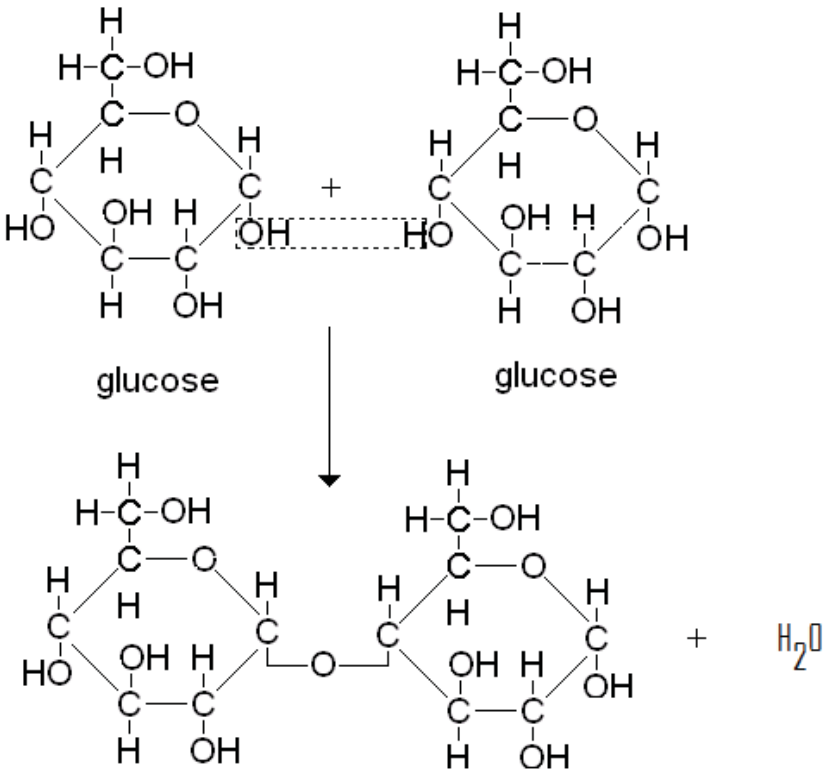

Figure 50 : Polymerisation of carbohydrates

Activity 9

1. ***In both reactions, water is given off.***
2. ***The reverse reaction of condensation polymerisation is addition of water to the product or hydrolysis.***

Unit Summary

Summary

In this unit you learned that:

- Macromolecules are divided into natural macromolecules and man-made macromolecules.
- Man-made macromolecules are also called synthetic polymers. These include polyethene, polyamide (commonly known as nylon) and polyester (also known as terylene).
- Polyethene is made from ethene monomers in a reaction called addition polymerisation. This polymer is used for making plastic.
- Polyamide is made carboxylic acid and amine groups as monomers. In this reaction, water is produced as the other product; hence it is called condensation polymerisation.
- Polyester is made from carboxylic acid and alcohol units. The reaction also produces water as another product and it is called condensation polymerisation.
- Natural polymers or macromolecules are found in plants and animals in the form of fats, proteins and carbohydrates. These are mostly found in food products that are essential in our health.
- Proteins are made from amino acid monomers and the reaction produces linkages similar to those found in nylon.
- Fats are made from carboxylic acids and alcohols. Fats are natural polyesters.
- The natural macromolecules can be hydrolysed back to their monomers.

You have completed the material for this unit on macromolecules. You should now spend some time reviewing the content in detail. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit.

Assignment 9

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 20 minutes

[Total Marks:18]

1. Define the following terms:

   a) Addition polymerisation (1)

   _____
   _____
   _____

   b) Hydrolysis (1)

   _____
   _____
   _____

   c) Condensation polymerisation (1)

   _____
   _____
   _____

2. Give the scientific names of the following synthetic polymers:

   (a) Nylon (1)

   _____

   (b) Terylene (1)

   _____

3. Polymers are produced from monomers.

   (a) Draw each part of a polymer molecule formed by joining the three monomer molecules shown in Figure 51 below.

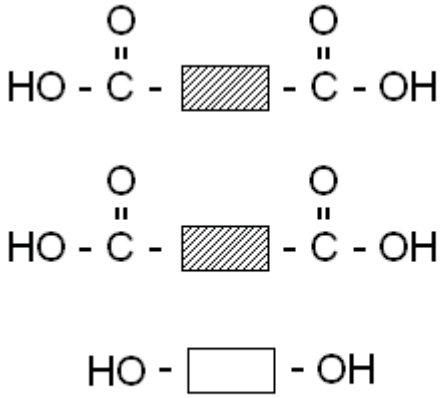

Figure 51 : Monomer molecules.

(2)

(b) When terylene is produced as a result of a condensation polymerisation, some small molecules of another compound are formed.

Name this compound:

_____ (1)

(c) Give two uses of terylene:

_____
_____ (2)

4. Give the monomer for each of the following macromolecules:

a) Protein (1)

_____

b) Nylon (1)

_____

c) Starch (1)

_____

d) Terylene (1)

_____

5. What is the monomer in the following natural polymers?

(a) Proteins (1)

_____

(b) Fats (1)

_____

6. What is the name of the linkage between monomers of:

a) Polyethene (1)

_____

b) Fats (1)

_____

Reflection Question

7. Which do you think would be more viscous (resistance to flow): a polymer made of long molecular strands or one made of short molecular strands? Why?

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 9

1.

a) Addition polymerisation is the reaction between two or more monomers forming one product.

b) Hydrolysis is the breaking down of a substance through reaction with water.

c) Condensation polymerisation is a reaction between two different monomers giving a macromolecule and water.

2. Scientific names:

(a) Nylon – polyamide

(b) Terylene – polyester

3.

(a)

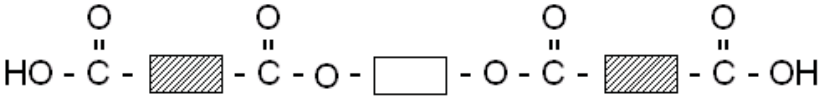

Figure 52: Polymer molecule.

(b) Water.

(c) Make clothing and moulded plastics such as drink bottles (or any other two from the list given above).

4. Monomers

a) Proteins = amino acids

b) Nylon = carboxylic acid and an amide

c) Starch = sugar

d) Terylene = carboxylic acid and an alcohol

5. Monomers:

(a) Proteins – amino acids

(b) Fats – alcohol and carboxylic acids

6. Linkages

a) Polyethene = single carbon – carbon bonds

b) Fats = ester linkages

7. Long molecular strands = more viscous. This is because there is a greater chance of the long strands becoming tangled together.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent chemistry course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 9

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

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

(Total Marks:12)

1. What is esterification? (2)

2. What is the difference between addition polymerisation and condensation polymerisation? (2)

3. The structure of a polyamide is shown in Figure 53 below.

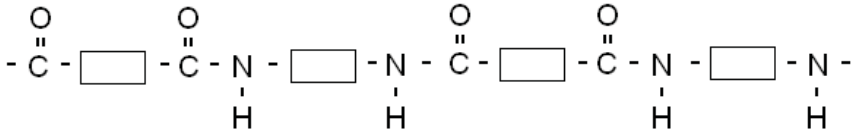

Figure 53: Structure of a polyamide.

Draw a pair of monomers which will form the structure in Figure 53 above: (2)

Monomer 1

Monomer 2

4. Starch is a carbohydrate formed in plants. It is used for energy storage. (2)

   a) What is the other product produced in the process of starch production? (1)

   b) What is the link between the monomers of starch known as? (1)

5. What is formed when the following are hydrolysed?

   a) Fats (1)

   b) Proteins (1)

COURSE MATERIAL

Physics

Grade 12

COL Open Schools Initiative
Lesotho

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‘MamochetaMakara	Team Leader
‘MaseitlhekoRamakau-Moima	Subject Master
‘MapholeMarake	Subject Master
‘MalerotholiLetsoela	Subject Master
Molise Nhlapo	Subject Master
SekelekeleHeqoa	Subject Master
HapeSetloboko	Artist
MonahengMohale	Member of Country Management Committee

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About the Course

The materials for Grade 12 Physics have been produced by the Commonwealth of Learning's COL Open Schools Initiative. All **Error! No text of specified style in document.**s produced by the COL COL Open Schools Initiative are structured in the same way, as outlined below.

How the Error! No text of specified style in document. 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 need to know before starting the course
- 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:

- How to improve your study skills
- Where you can get help
- How to complete course assignments and assessments
- How to find your way around the course using the margin icons
- What is included in each unit

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

The Course Content

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

- An introduction to the unit content
- Unit outcomes
- New terminology
- Core content of the unit with a variety of learning activities
- A unit summary
- Assignments and/or assessments

Resources

If you are interested in learning more about this subject, we provide you with a list of additional resources at the end of this **Error! No text of specified style in document.**; these may be books, articles or websites.

Your Comments

After completing Grade 12 Physics, we would appreciate it if you could take a few moments to give us your feedback on any aspect of this course. Your feedback might include comments on things such as:

- Content and structure
- Reading materials and resources
- Assignments
- Assessments
- Duration
- Support (assigned tutors, technical help, etc.)

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

Course Overview

Welcome to Grade 12 Physics

These materials form part of the Physical Science Course that is designed to prepare students for the Cambridge Overseas School Certificate examination. Units 1 to 9 of the overall course are devoted to chemistry, while the remaining units cover aspects of physics.

Units 10 – 26 deal with concepts in physics and their application to situations you are likely to encounter in everyday life. They are designed to meet the requirements of the national Grade 12 syllabi in many nations across the Commonwealth. They should thus provide a sound foundation for learners who wish to further their education in any field of study for which physics is a prerequisite.

Is This Course For You?

This course is intended for open and distance learners who wish to acquire knowledge and understanding of physical sciences. In order to cope with these course materials, you must have passed mathematics and science at the Junior Secondary Certificate or Grade 10 level. This course is designed as a two year course examinable at the end of the two years in November by the University of Cambridge through the Examinations Council of Lesotho.

These units on physics are intended to:

- Enhance your scientific skills, including: measurement, interpretation, application, accuracy and precision.
- Broaden your knowledge and acquaint you with scientific concepts.
- Develop attitudes relevant to science and physics such as:
    - Objectivity
    - Integrity
    - Enquiry
    - Initiative
    - Inventiveness

Course Outcomes

Outcomes

Upon completion of Units 10 – 26 of the Grade 12 Physical Science course, you will be able to:

- *Measure* physical quantities.
- *Give* the correct SI units of the different physical quantities.
- *Solve* problems which involve physical forces, such as energy, light, magnetism and electricity.
- *Describe* matter and its related physical processes.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.
- *Analyse* experimental data.
- *Apply* correctly various formulae which relate the different physics concepts and theories to the world around us.

Timeframe

How long?

Students at conventional schools in Lesotho normally take two years to prepare themselves for the Cambridge Overseas School Certificate examination in Physical Science. This is equivalent to six or seven hours per week for 40 weeks per year over two years, a total of roughly 500 study hours.

However, those who register with an open school often have to make time for their studies while fulfilling other responsibilities at home or at work. For this reason, a more flexible study schedule may be necessary. Nevertheless, it is essential that you create a timetable for yourself. If you do not set aside time on a regular basis to work through these materials, you may not be able to complete the course.

Study Skills

As an adult learner, your approach to learning will be different from that of your school days. You can choose what you want to study, you may be motivated by personal and/or professional goals and you will have to find time for your studies while coping with other responsibilities at home or at work.

Essentially you will need to take control of your learning environment. You should consider a number of issues that can affect your performance including how to manage your time, how to set goals or how to manage stress. You may also need to re-acquaint yourself with 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*. That is the time you dedicate to your learning and the environment in which you engage in that learning.

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/

  This "how-to-study" website is dedicated to information on study skills. You will find links to resources on study preparation (a list of nine essentials for a good study place), taking notes, and strategies for reading text books, using reference sources and coping with test anxiety.

- http://www.ucc.vt.edu/stdysk/stdyhlp.html

  This is the website of the Virginia Tech Division of Student Affairs. You will find links to resources on time scheduling (including a "where does time go?" link), a study skills checklist, basic concentration techniques, control of the study environment, note taking, how to read essays for analysis and memory skills ("remembering").

- http://www.howtostudy.org/resources.php

  This is another "how-to-study" website 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 and 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 something similar in the address pane of your web browser.

Learning Approaches

Part of taking control of your learning environment involves being mindful of your learning approach to the material. When this course was developed, a specific learning approach was kept in mind. It is helpful if you take the same approach when doing your own self-study!

The *Nine Events of Instruction* was developed by Robert Gagné and is a framework for your own learning (adapted from edutechwiki):

1. **Gain attention**: when a new situation, problem or information is presented, how can you relate it to your own life? What questions can you ask? This will help motivate you to learn more.

2. **Describe the goal**: Refer to the course and unit outline. These are the goals you wish to accomplish by the end of the unit/course. How can you use this knowledge in future units, in other courses or in your day-to-day life?

3. **Stimulate recall of prior knowledge:** pay attention to where we tell you how new information relates to information you have already learned. Ideas that you learn in this course are connected. By recognizing those connections, you will remember and understand things more easily.

4. **Present the material to be learned:** Pictures, diagrams, and examples throughout the course will help aid you in learning.

5. **Provide guidance for learning:** Icons in the margins will help you to identify the type of activity you should be doing to learn. Please see the Margin Icons section (p. 10) in the course overview for more information.

6. **Elicit performance "practice":** It is very important that you perform the self-assessment activities. Try to do those activities without referring to the answers until you have completed as much as you can. This will help tell you what you need to study more.

7. **Provide informative feedback:** Both the answers to the self-assessments and your tutor's feedback will help with this, but it means nothing if you do not learn from it. Take time to understand why you were incorrect. This may involve follow-up with your tutor!

8. **Assess performance test:** This will help you understand whether or not you have learned the content.

9. **Enhance retention and transfer:** Can you solve similar problems in new situations? Try teaching the information to someone else!

Good luck!

Need Help?

Help

As you study Grade 12 Physics, you may encounter academic and social issues that hinder your progress. For example, you may have questions or need help to make sense of the materials. To help you overcome some of these problems, the Lesotho Distance Teaching Centre (LDTC) established a Student Advice Section, whose main objective is to offer you counselling before, during and after the course. Whenever you come across an issue that impedes your studies, you should write or call the LDTC office, where someone will assist you:

Address: The Director

Lesotho Distance Teaching Centre

P.O. Box 781

Maseru

Tel: + 266 22316961

Fax: +266 22310245

Email ldtc@ymail.com

LDTC also has offices in five other districts. These offices are housed in the Ministry of Education and Training's District Resource Centres and are manned by LDTC officers. All services provided by the head office in Maseru are available in the districts. In this way, if you live in one of these districts you do not have to travel to Maseru to get study materials and other services. Please feel free to drop into these Resource Centres any time between 8:00 and 4:30 p.m. to get advice or help with any problems relating to your studies, assignments, face-to-face sessions or end of course examinations. The districts are:

Qacha's-Nek (Tel. +266 22950702)

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Since LDTC uses print as its main medium of instruction, you will receive information through letters, leaflets, pamphlets and booklets. But you too must write whenever you have information or news to share.

From time to time, tutorials will also be arranged so that you can get advice and assistance on any points of confusion. A schedule listing the dates of these tutorials will be given to you when you register.

Physics Resources

Help

If you have access to the internet, there are a plethora of excellent physics resources out there that include videos, animations, games and different explanations of the ideas you will be introduced to in this course. Please make sure to take advantage of the following resources as you work through the course.

http://phet.colorado.edu/

Physics simulations and virtual labs.

http://www.howstuffworks.com/

A general source of good explanations of physical phenomenon.

http://www.physicsclassroom.com/

Physics tutorials and worksheets.

Assignments

Assignments

The Grade 12 Physics course has 17 units that are going to be bound together into workbooks. At the end of each workbook you will be expected to do a self-marked assignment. The aim of these assignments is to test how well you have studied and understood the contents of each workbook. After completing such assignments, check your work against the model answers provided. If you did not get at least 80% of them correct, go back through the unit and study the material carefully before trying the assignment again. Please read your workbooks and answer the assignment questions in the set order. Following the logical order will enhance your comprehension and help you to complete your work on time.

Your tutors are here to help! If you need help, please attend the face-to-face tutorials held by the tutors. During these sessions you are given the chance to meet your tutors and to get immediate answers to all your questions. The tutorials also afford you a chance to meet and interact with other learners. If you still have some difficulty understanding the material, ask your tutor at the next scheduled meeting.

Assessments

Assessments

In addition to the assignment, each unit also includes an assessment to test your understanding of the content. The time you should take to complete the assessment is shown at the top of each paper, as well as the total marks available and the marks for each question.

When you finish each assessment, please submit it to the Student Advice Section at LDTC Head Office. You may do this through the post or drop it at the office if you live nearby. LDTC engages teachers (tutors) on a part-time basis to mark these assessments and assist you. Each assessment has a cover sheet on which you can seek an explanation of any part you could not understand. The tutors will answer all of your queries and give you feedback on your assessment. The deadlines for submitting these assignments will be provided by your tutor at the first meeting each year. Feedback will be provided to you about two weeks after the submission dates.

Getting Around the Course

Margin Icons

While working through this **Error! No text of specified style in document.** you will notice that little pictures or icons appear frequently in the left-hand margin. 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 **Error! No text of specified style in document.**. A complete set of these icons is shown below. We suggest that you familiarize yourself with the icons and their meaning before starting your studies.

Activity	Assessment	Assignment	Case study
Discussion	Group activity	Help	Note it!
Outcomes	Reading	Reflection	Study skills
Summary	Terminology	Time	Tip

Unit 10

Measurement of Physical Quantities

Study Skills

Tips for preparing to take a test:

-begin reviewing early
-conduct short daily review sessions
review with a group
-contact your tutor with questions and
-study in small chunks.

Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.

Introduction

This is one of the most important topics in physics because physics is all about measurement of the physical quantities. In our everyday life we are concerned about how far a certain object is, how tall, how heavy, how long it is and many more. This topic will help us answer these questions.

Time

This unit consists of 37 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a minute to read the following learning outcomes. They are your guide as to what you should particularly focus on while working through this unit.

Outcomes

Study skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Measure* physical quantities.
- *Give* the correct SI units of the different physical quantities.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.
- *Analyse* experimental data.
- *Apply* correctly various formulae which relate the different physics concepts and theories to the world around us.

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Give* correct SI unit for each physical quantity measured.
- *Convert* SI units.
- *Measure* basic quantities using suitable instruments.
- *Perform* and describe an experiment to determine period of a pendulum.
- *Calculate* the period and frequency of a pendulum.

Terminology

Physical quantity: A quantity that can be measured and consists of a numerical magnitude and a unit.

Oscillation: One complete to-and-fro movement of a pendulum.

Section 10-1: SI Units

Physical Quantities

In physics, we have many physical quantities. For example: length, time, mass, speed, volume, current, temperature and density. A **physical quantity** is a quantity that can be measured and consists of a numerical magnitude and a unit.

Some of these quantities are base quantities (assumed to be independent) and some are derived or come from the base quantities. Many of these quantities are inter-related. The International System of Units universally abbreviated (SI) is the modern metric system of measurement. Each physical quantity has its own SI unit.

By the end of section 10-1, you should be able to state the correct SI unit for each physical quantity measured.

Section 10-1 has 6 pages. You should spend approximately 1 hour on this topic.

Time

Now let us look at the base quantities and their SI units.

SI Base Quantities and Units

The SI is founded on seven *SI base units* for seven *base quantities*, as given in Table 1,1:

Table 1. 1 SI base units

Physical quantity	Unit	Symbol
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
temperature	degrees Celsius	$°C$
amount of substance	mole	Mol
luminous intensity	candela	Cd

SI derived units

The *derived quantities* are defined in terms of the seven base quantities via a system of quantity equations. Examples of such SI derived units are given in Table 1.2:

Table 1.2 Examples of SI derived units

Derived quantity	Unit	Symbol
Area	square meter	m^2
Volume	cubic meter	m^3
speed, velocity	meter per second	m/s
Acceleration	meter per second squared	m/s^2
Density	kilogram per cubic meter	kg/m^3

Note it!

NOTE:

10 mm = 1 cm

1 000 mm = 1 m

100 cm = 1 m

1 000 m = 1 km

Activity 1

Fill in the following table. The first one has been done for you.

Table 1.3

Activity

Physical quantity	Relation with base quantity
Area	length x width
Volume	
Speed	
Density	

Check for correct answers on at end of section 10-1. Make sure you get them all correct before moving on. Refer to your Grade 10 mathematics if you encounter any problems.

SI Prefixes

When we are measuring quantities which are very big or very small, we often add prefixes to the name of the units. These prefixes are multiples or decimals of ten. Table 1.4 below show some of these prefixes:

Table 1: Some prefixes of SI units

Factor	Name/Prefix	Symbol
one tenth 10^{-1}	Deci	d
one hundredth 10^{-2}	Centi	c
one thousandth 10^{-3}	Milli	m
one millionth 10^{-6}	Micro	μ
one thousand times 10^{3}	Kilo	K
one million times 10^{6}	Mega	M

Note it!

NOTE:

One millimetre (mm) equals one thousandth of a metre $1 \text{ mm} = 10^{-3}$ m

One kilometre (km) equals one thousand metres $1 \text{ km} = 10^{3}$ m

One microsecond (μs) is one millionth of a second $1 \text{ μs} = 10^{-6}$ s

Example:

This example will help us learn how to change from larger units to smaller units.

A block of concrete is 0.4 m long. What is its length in:

a) mm?

Solution:

This is how we solve the problem.

10^{-3} m = 1 mm

0.4m = ? mm

When setting up the ratio, the units you do not want (m) must cancel each other in the numerator and denominator and you should be left with the units you want (mm) in the numerator:

0.4m = $\frac{0.4m \times 1mm}{10^{-3}m}$

= (0.4 x 10^3) mm

Based on math you should have previously learned, 10^{-3} in the denominator is equal to 10^3 in the numerator.

= (0.4 x 1 000) mm

= 400 mm

Activity

b) cm

Solution: 0.4m = $\frac{0.4m \times 100\ cm}{1m}$

In this case again, the units you do not want (m) cancel each other in the numerator and denominator and you should be left with the units you want (cm).

= (0.4 x 10^2) cm

= (0.4 x 100) cm

= 40 cm

c) km

Solution: 0.4m = $\frac{0.4\ m \times 1\ km}{1000\ m}$

In this one again, the units you do not want (m) should cancel in the numerator and denominator.

= 0.0004 km

Activity 2

1. How many millimetres are there in:

a) 4.4 cm?

_____
_____
_____
_____

b) 2.2 m?

_____
_____
_____
_____

2. Convert the following lengths to metres.

a) 27 mm

_____
_____
_____
_____

b) 2 000 cm

_____
_____
_____
_____

c) 65 km

_____
_____
_____
_____

Look up the correct answers to this activity at the end of section 10-1. Once you understand the answer to each question, continue on. If needed, review the above content.

Key points to remember:

Note it!

The key points to remember in this section on SI units are:

- Different physical quantities have different SI units. For example, the SI units of length are metres (m), time are seconds (s) and so on.

In the next section, we are going to learn how to measure length as an example of a physical quantity.

Answers to Activities on SI Units

Activity 1

Table 1.3:

Physical quantity	*Relation with base quantity*
area	*length x breadth*
volume	*length x breadth x height*
speed	$\frac{\text{distance}}{\text{time}}$
density	$\frac{\text{mass}}{\text{volume}}$

Activity 2

1. How many millimetres are there in:

a) 4.4 cm?

Solution: $4.4\ cm = (4.4 \times 10)\ mm$

$= (4.4 \times 10)\ mm$

$= 44\ mm$

b) 2.2 m

Solution: $2.2\ m = (2.2 \times 10^{3})\ mm$

$= (2.2 \times 1\,000)\ mm$

$= 2\,200\ mm$

2. Convert the following lengths to metres.

a) 27 mm

Solution: $27\ mm = (27 \times 10^{-3})\ m$

$= \frac{27}{10^{3}}\ m$

$= \frac{27}{1000}\ m$

$= 0.027\ m$

b) 2 000 cm

Solution: $2\,000\ cm = (2\,000 \times 10^{-2})\ m$

$= \frac{2000}{10^{2}}\ m$

$= \frac{2000}{100}\ m$

$= 20\ m$

c) 65 km

Solution: *65 km = (65 x 1 000) m*

= 65 000 m

Activity

Section 10-2: Measurement of Length

Introduction

Length is one of the important physical quantities in our everyday life, so in this section we are going to learn more about it.

By the end of section 10-2, you should be able to:

- *Measure* length using the appropriate instrument.

Time

Section 10-2 has 15 pages. You should spend approximately 2-3 hours on this topic.

In every day conversation, we often talk of a long dress or a short dress, tall buildings or long distances and so on.

What is one tool we use to determine how short or how long something is?

_____

___

A ruler is one of the tools used to measure length. Other tools include a measuring tape, square ...

Length is the distance between two points.

In the previous section, you learned that the SI units of length are metres (m)

Activity 3

Figure 1 shows how to place a pencil on the ruler when measuring its length.

1. State which letter gives the correct length:

_____

_____

2. Explain why the other letters give wrong lengths:

_____
_____
_____
_____
_____

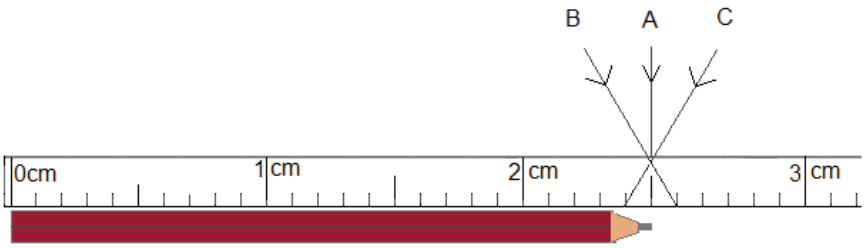

Figure 1 measuring the length of a pencil.

Compare your answers to those provided at the end of section 10-2. Take the time needed to understand the explanations.

How to Read a Ruler

- Place the zero of the ruler at the beginning of the object you are measuring.
- Read the length by looking perpendicularly to the ruler in order to avoid a parallax error.
- The ruler gives lengths correct to one decimal place. That is it gives lengths in centimetres and millimetres.

Vernier Callipers

Activity

The vernier calliper, as shown in Figures 2(a) and 2(b), is another instrument that is used to measure length. It is more accurate than a ruler. A ruler gives the length in one decimal place but the vernier calliper gives the length in two decimal places.

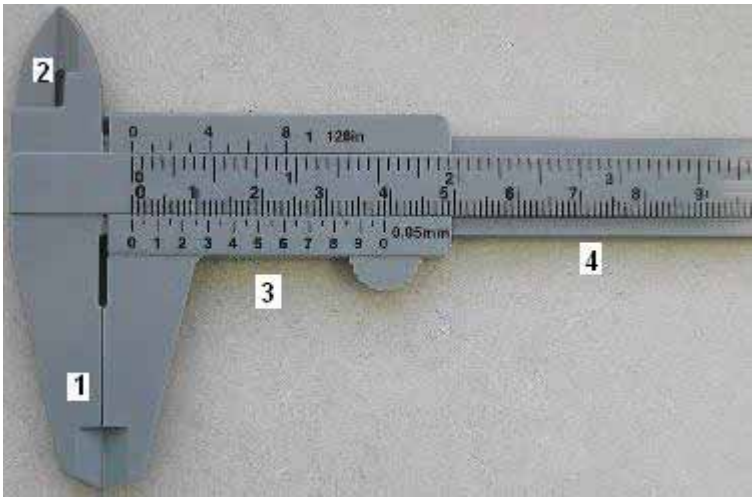

Figure 2(a): Vernier callipers accessed from Creative Commons, 2010.

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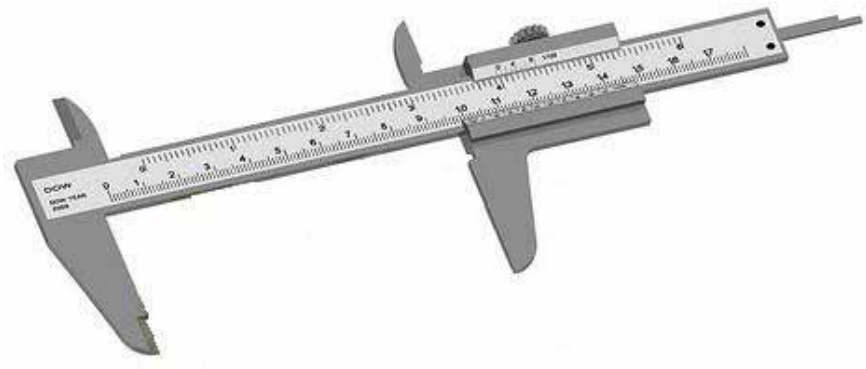

Figure 2(b): Vernier calliper accessed from Creative Commons, 2010.

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Note the parts of a vernier caliper. The following refer to the labels on Figure 2(a):

1. **Outside jaws:** used to measure external diameter or width of an object
2. **Inside jaws:** used to measure internal diameter of an object
3. **Vernier:** gives measurements up to two decimal places (in cm)
4. **Main scale:** gives measurements of up to one decimal place (in cm)

The vernier calliper is used to measure small lengths like the inside diameter of a bottle opening. In order to measure the inside diameter the inside jaws are put inside the bottle opening and for the outside diameter the bottle opening is placed between the outside jaws.

The vernier calliper has two scales. They are the vernier scale and the main scale.

The main scale

The main scale works in the same way as the ruler. It has both the centimetre and the millimetre scale.

The vernier scale

The vernier scale has a 9 mm scale which is divided into 10 equal divisions.

Vernier Scale

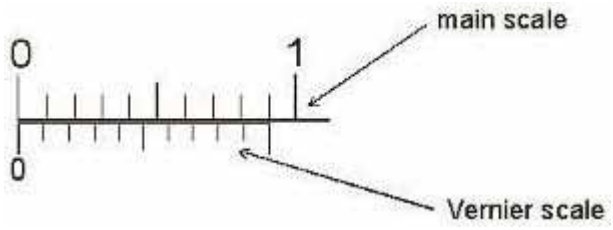

Figure 2(c): The vernier scale. Hand drawn by graphic designer at LDTC.

How many millimetres is one division on the vernier scale?

_____

I hope you determined that one division $= \frac{1}{10}$ mm = 0.1mm.

Let us now find out how we use a vernier calliper.

Using a Vernier Calliper

To measure the diameter of an object, put the object between the jaws of the calliper as shown in the *Figure* 3a:

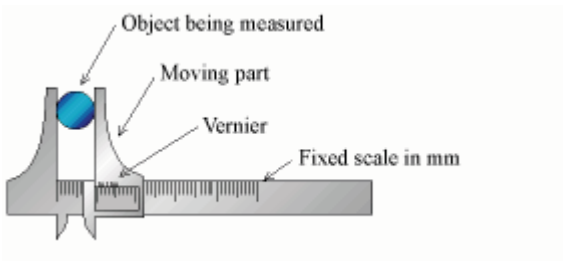

Figure 3a Measuring the diameter with a vernier calliper accessed from Wikimedia Creative Commons, 2010.

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NOTE

In Figures 3b, 3c, and 3d, the bottom scale is the main scale, sometimes called the fixed scale, and the scale on top is the vernier scale. The lines that enclose the ball represent the outside jaws.

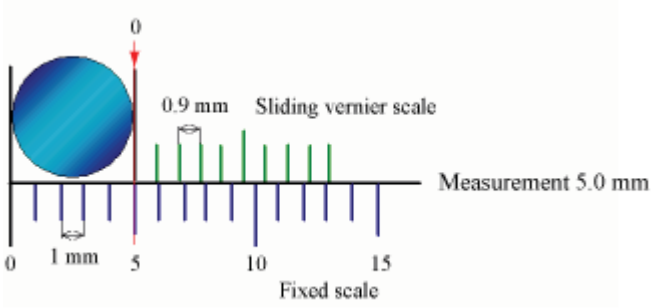

Figure 3(b): Using the vernier calliper to measure diameter of ball. Hand drawn by graphic designer at LDTC.

As shown in Figure 3b, the zero of the vernier aligns with 5 mm on the main scale, hence why the diameter of the ball is 5.0 mm.

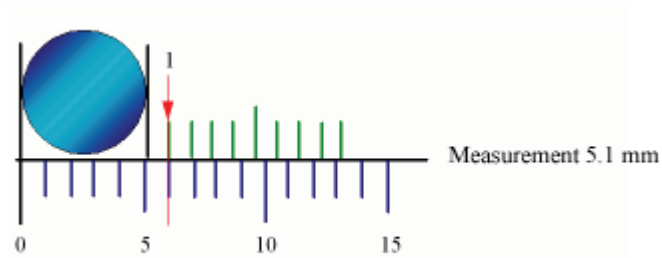

Figure 3(c) Reading the vernier scale. Hand drawn by graphic designer at LDTC.

When you look closely at Figure 3(c), you will notice that the zero of the vernier scale does not exactly align with the 5 mm line on the main scale, but the first division on the vernier does align with the marking on the main scale. So we take 1 as the vernier scale reading.

Diameter of the ball in mm

= main scale reading + 0.1 x vernier scale reading

= 5 mm + 0.1 x 1

= 5 mm + 0.1

= 5.1 mm

Activity

Diameter in cm

Remember from SI units that

1 cm = 10 mm

So

$$5.1\text{mm} = \frac{5.1\text{mm} \times 1\text{cm}}{10\text{mm}}$$

$$= \frac{5.1}{10}\text{cm}$$

= 0.51cm

Activity 4

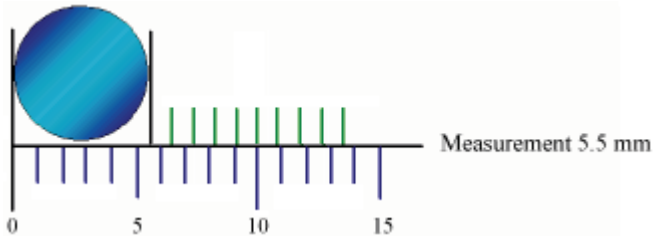

Figure 3(d): Measuring the diameter of a ball.

Following how we got the diameter of the ball in Figure 3c, describe how the diameter of the ball in Figure 3(d) is 5.5 m:

_____

_____

_____

_____

_____

I hope you were able to give the reason. Now compare your answer to the one given at the end of section 10-2. As needed, review the above content.

Note it!

Take note that:

The **main scale reading** is given by the sleeve reading which appears before the zero on the vernier.

The vernier reading is given by the vernier mark which makes a straight line with the mark on the main scale.

Activity 5

Write the length shown by the vernier scale in Figure 4 in millimetres:

_____
_____
_____
_____
_____

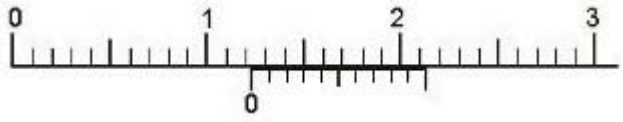

Figure 4: Reading the vernier scale. Hand drawn by graphic designer at LDTC.

Compare your answer to the one given at the end of section 10-2. If you made an error, review the above content and then clarify any misunderstandings.

Activity

Remember that:

- SI units of length are meters.
- When using the vernier calipers:
  Length = main scale reading + vernier reading.
- Vernier calipers give the reading in two decimal places when the length is measured in cm.

Help

Need more help understanding how to read a vernier caliper?

If you have internet access, please go to:
http://youtu.be/Vz40xmrdhyY

Micrometer Screw Gauge

This is another instrument which is used to measure length.

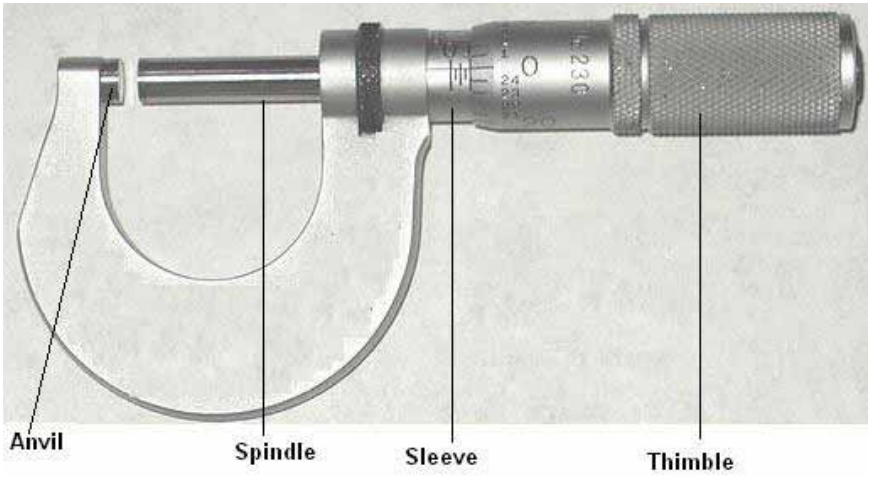

Figure 5: Micrometer screw gauge accessed from Creative Commons, 2010.

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A micrometer is another instrument that is used to measure length. It is used to accurately measure very small lengths like the diameter of a wire or the diameter of a ball bearing and so on.

A micrometer gives lengths (in cm) correct to three significant figures as opposed to a vernier caliper which gives lengths (in cm) to two decimal places.

The spindle is screwed to the thimble. When the ratchet turns the spindle also turns. The distance the spindle moves during one revolution is called the **pitch**. It is equal to 0.5mm.

Steps to follow when measuring length using a micrometer

- Clean the object to remove dust as it may give incorrect readings.
- Put the object between the anvil and spindle.
- Turn the ratchet until the object is softly held between the anvil and the spindle.
- Now take note of the readings.

How to Read the Micrometer

The micrometer has two scales:

The **sleeve scale** or the main scale is on the sleeve. The horizontal line on the sleeve is called the **datum line**.

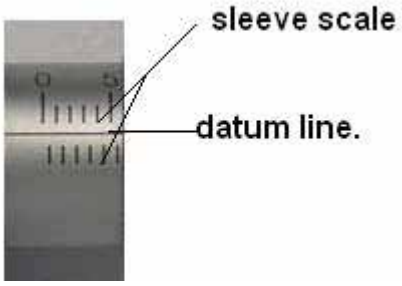

Figure 5: A Sleeve scale.

The sleeve scale reading is graduated in millimeters. Each division above the datum line is equal to 1 millimeter and below the datum line each division is equal to 0.5 millimeters which is the pitch of the spindle.

The **thimble scale** is on the thimble. There are 50 equal divisions on the thimble scale.

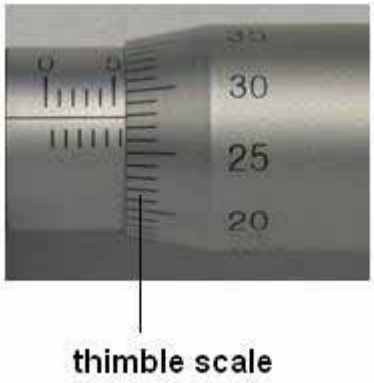

Figure 6: Thimble scale.

Reflection

- If the zero of the thimble scale is on the datum line, the zero of the thimble scale will be back on the datum line after one revolution.
- The thimble scale is divided into 50 equal divisions. If the ratchet is turned such that the zero of the thimble scale returns to the datum line, it would have turned through $\frac{1}{50}$ of a revolution.

After one revolution, the anvil and the spindle open up to 0.5mm. So this means that one division on the ratchet is equal to:

$\frac{1}{50}$ X 0.5mm = 0.01mm

OR

$\frac{1}{50}$ X 0.05 = 0.001cm

Example 1

The reading shown by the micrometer in Figure 7 is:

Sleeve reading + 0.01 x thimble reading

= 5.5 mm + 0.01 x 28

=5.5 mm + 0.28

=5.78 mm

The same length can also be changed into centimeters. So let us see how to convert from mm to cm.

$$\text{In cm} = \frac{5.78\text{mm} \times 1\text{cm}}{10\text{mm}}$$

$$= \frac{5.78}{10}\ \text{cm}$$

$$= 0.578\text{cm}$$

Figure 7: Micrometer screw gauge accessed from Wikimedia Creative Commons, 2010.

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I hope you were able to follow all the steps in the example above.

If not go through the example again to make sure that you understand everything.

Figure 8: A Micrometer screw gauge accessed from Wikimedia Creative Commons, 2001.

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Note it!

Points to remember:

- Read and write the main scale reading either in cm or mm.
- Write what each division on the thimble scale represents, that is, if you take readings in:

  mm, one division = 0.01mm

  cm, one division = 0.001cm

Activity 6

Write the length (in mm) shown by the micrometer in Figure 9:

Activity

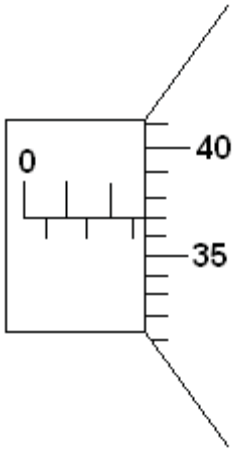

Figure 9: Reading the main and thimble scale of the micrometer. Hand drawn by graphic designer at LDTC.

I hope this was a good learning experience.

You will find the answers at the end of section 10-2. Compare your answers to those provided. Be sure that you can read the values shown on a micrometer before continuing.

Key points to remember:

Note it!

The key points to remember in section 10-2 are:

- SI units of length are meters.
- When using the vernier calipers:
  - Length = main scale reading + vernier reading.
- Vernier calipers give the reading in two decimal places when the length is measured in cm.
- When using the micrometer screw gauge:
- Length = Sleeve reading + 0.01 x thimble reading.
- Micrometer screw gauge give readings in three decimal places when the length is measured in cm.

In the next subunit we are going to learn how to measure time using appropiate instruments.

Answers to Activities on Measurement of Length

Activity 1

1. *Letter A*
2. *Letter A shows the eyes positioned vertically above the tip of the pencil. Letters B and C show the eyes looking from an angle, so they give the reading either smaller or larger than the actual length. The difference between the readings of letter A and B gives what is called parallax error.*

Activity 4

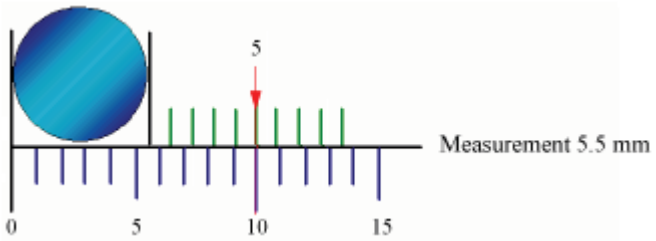

Figure 10: Highlight of the 5.5 mm reading. Hand drawn by graphic designer at LDTC.

The vernier reading, as shown in Figure 10 is the 5th mark which aligns with the mark on the main scale.

Diameter = main scale reading + 0.1 x vernier scale reading

= 5 mm + 0.1 x 5

= 5 mm + 0.5

= 5.5 mm

Activity 5

Length = Main scale reading + 0.1 x vernier reading

=12 mm + 0.1 x 3

=12 mm + 0.3

=12.3 mm

Activity 6

Length in mm = main scale reading + 0.01 x thimble reading

= 2.5mm + 0.01 x 37

$= 2.5mm + 0.37$

$= 2.87mm$

Section 10-3: Measurement of Time

Introduction

Time is one of the physical quantities which affect our lives directly, so in this unit we are going to learn more about time.

By the end of section 10-3, you should be able to

- Measure time using different clocks and a pendulum

Time

Section 10-3 has 11 pages. You should spend approximately 2 hours on this topic.

Time is one of the most important quantities that need to be measured in the world. Measurement of time helps regulate events. Imagine how difficult life would be without being able to measure time.

Time is measured from a variety of clocks and watches. This variety provides a wide range of time intervals that require measurement for different purposes starting from the smallest to the biggest time intervals. For example: time taken by a 100 m runner or a plane flying from one country to the other.

Figures 11, 12, and13 show widely used clocks and watches for measuring time.

Figure 11: Pendulum clock accessed from Wikimedia Creative Commons, 2010.

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Figure 12: Wrist watch accessed from Wikimedia Creative Commons, 2010.

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Figure 13: Alarm clock accessed from Wikimedia Creative Commons, 2010.

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Time is measured in years, months, days, hours, minutes and seconds. There are units of time which are bigger than the year and far smaller than the second, but the **SI unit of time is the second.**

Activity 9

Activity

The following table shows the relationship between some units of time. Fill in the gaps. Others have been done for you.

1 millisecond(ms) = 1/1000sec	0.001 sec
1 microsecond(μs) = 1/1 000 000sec	0.000001sec
1 nanosecond(ns) = 1/1 000 000 000sec	0.000000001sec
_____ second	1 minute
_____ minute	1 hour
_____ hours	1 day
_____ days	1 week

_____ weeks (approximately)	1 month
_____ months	1 year
10 years	_____
100 years	_____

I hope most or all of these are familiar, if they are not, then go through the table again to make sure that you understand them.

Time measuring instruments (clocks or watches) whether digital or analogue, ancient or modern make use of devices which have constantly repetitive motions called **oscillations or vibrations.**

In digital clocks and watches, the oscillations are produced by a tiny quartz crystal. A pendulum clock is controlled by a **swinging pendulum** which shall be our focal point in this unit.

Now let's study a pendulum and its use in the measurement of time!

The Pendulum

A simple pendulum is described as a small heavy body suspended by a light string which is inextensible.

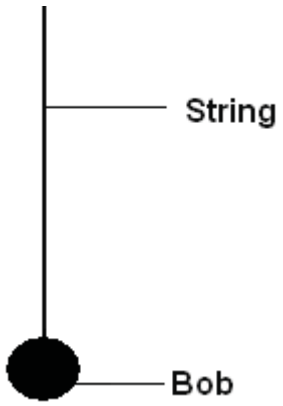


Figure 14: A pendulum (Hand drawn), 2010.

It is important to familiarise yourself with the following terms as they shall be used often throughout the study of the pendulum.

Clarification of terms

- One complete to-and-fro movement of the pendulum is called an **oscillation or vibration**.

Figure 15 Shows an oscillation.

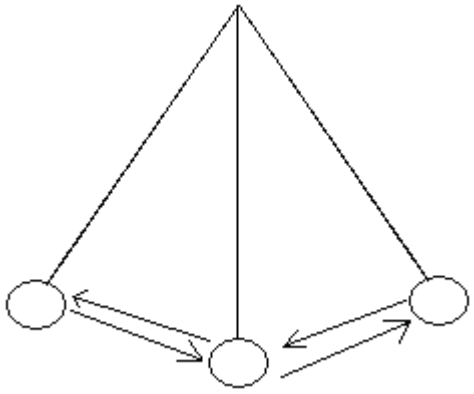


Figure 15: A swinging pendulum (Hand drawn), 2010.

- The number of complete oscillations made per second is the **frequency (f).** The unit of frequency is the **Hertz (Hz)**.

- The time taken to complete an oscillation or vibration is called the **period** and is denoted with the letter T, and

  T = 1/f where f is the frequency

- The maximum displacement of the pendulum from its rest position is called the **amplitude**, as shown in Figure 16.

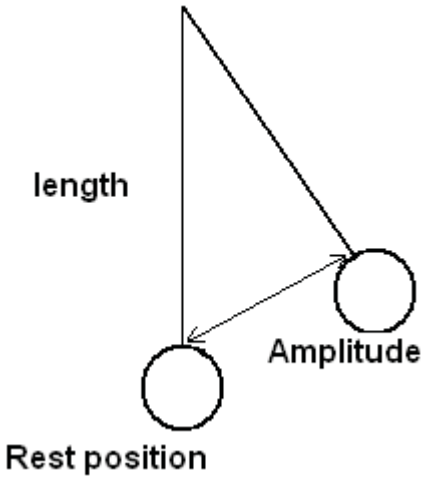


Figure 16: Amplitude of a pendulum (Hand drawn), 2010.

- The distance from the point of suspension to the centre of gravity of the bob is the **length** of the pendulum and is denoted with the letter ***l***.

Activity 10

Activity

Now let's make a pendulum! You will need the following materials:

- A thread which does not stretch.
- A small metal sphere, like a marble (called a bob) with a hole through its diameter.
- A stop watch (you may be able to use your cell phone for this).
- A metre-rule

Set up the experiment as shown by Figure 17 below.

Note

The thread should be inserted inside the hole in the bob. Then fasten a knot on the other side to stop the thread from running out of the bob**.**

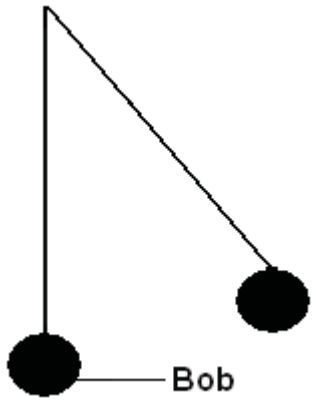


Figure 17: Measuring the period of a pendulum (Hand drawn), 2010.

Procedure 1

- After hanging the bob by the thread, measure the length of the thread using the metre rule.
- Give the pendulum bob a small displacement and set it into motion.
- Time 20 oscillations using a stopwatch and record the time ***t*** for 20 oscillations. Fill this data into the chart below.
- Now calculate the period **T** of the pendulum. Refer to clarification of terms above to remind yourself of what **T** is.

- Repeat the experiment with a different length (increased) of the pendulum
- Calculate **T** for both lengths.

T= time (t) for twenty oscillations/20

Number of oscillations	Length (l)	Time (t)	Period (T)

Procedure 2

- For the same length of the pendulum repeat the experiment and calculate T again.
- Repeat experiment again, this time keep the length of the pendulum constant and vary the amplitude over a few degrees

Number of oscillations	Length (l)	Time (t)	Period (T)

With respect to amplitude, what do you observe?

_____
_____

Compare your observations to those at the end of the section 10-3.

WHAT HAVE WE JUST LEARNED?

- The time taken for the pendulum to swing to-and-fro is constant provided that the pendulum length stays the same.
- As the pendulum length increases, the time taken for the pendulum to swing to-and-fro increases.

Pendulum Clocks

Pendulum clocks make use of this regularity of the period to measure time intervals! Incredible isn't it? We will apply this principle in the following example. Refer to Figure 18.

Example

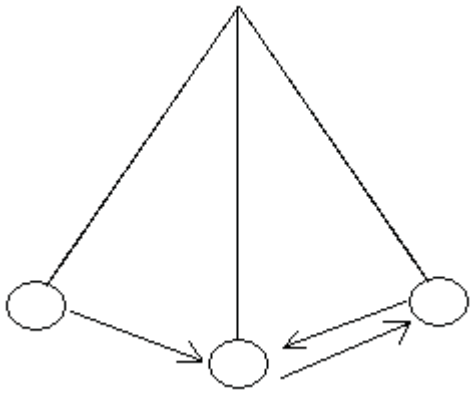


Figure 18: An oscillating pendulum (Hand drawn), 2010.

A pendulum oscillates between the positions as shown in the diagram. It takes 1.5 s to move through these positions. What is the period of the pendulum?

Solution

The period is the time taken for one complete to-and-fro movement of the pendulum Since the pendulum in the diagram above moves to and fro half way through the backward movement, it follows that

T = 2s

Activity 11

Activity

i) The period of a pendulum is 0.2 s, how many complete oscillations are made in 1 s?

_____
_____
_____
_____
_____

ii) A pendulum takes 20 seconds to make 50 oscillations, what is its period?

_____
_____
_____
_____
_____

iii) A pendulum of period 0.5 makes 30 oscillations. How much time does it take?

_____
_____
_____
_____
_____

Now compare your answers to those given at the end of section 10-3. Be sure that you understand how to do each calculation.

Help

Need more help with understanding pendulums? If you have access to the internet, please go to:

http://phet.colorado.edu/en/simulation/pendulum-lab

Key points to remember:

The key points to remember in this section on measurement of time are:

Note it!

- The number of complete oscillations made per second is the **frequency (f).** The unit of frequency is the **Hertz (Hz).**
- The time taken to complete an oscillation or vibration is called the **period** and is denoted with the letter **T** and

  $T = 1/f$ where f is the frequency

- The maximum displacement of the pendulum from its rest position is called the **amplitude.**

You have now completed the last section of this unit on the measurement of physical quantities. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Answers to Activities on Measurement of Time

Activity 9

1 millisecond(ms) = 1/1000 sec	*0.001 sec*
1 microsecond(μs) = 1/1000 000 sec	*0.000001 sec*
1 nanosecond(ns) = 1/1000000000sec	*0.000000001 sec*
60 sec	*1 minute*
60 min	*1 hour*
24 hrs	*1 day*
7 days	*1 week*
4 weeks	*1 month*
12 months	*1 year*
10 years	*Decade*
100 years	*Century*

Activity 10

You should have observed that varying the length of the pendulum also varies the periodic time. T increases with increasing length.

You should have also observed that T remains the same when the amplitude is varied over a few degrees.

Activity 11

(i) Number of complete oscillations made in 1 sec is the frequency; frequency and period are related by the formula:

$$T = 1/f$$

Therefore, f = 1 / T

f = 1/ 0.2 s

= 5 Hz

ii) T = 50 oscillations/20 seconds = 2.5 Hz

iii) t = 30 oscillations / 0.5 Hz

= 60 seconds

Unit Summary

Summary

This summary gives you the important points you should have learned in this unit.

In this unit you learned that:

- Most scientific measurements are stated in SI units.
- Prefixes are often used to denote very big or very small quantities.
- The SI unit of length is the metre (m).
- Vernier callipers measure lengths accurately up to 0.01 cm.
- Micrometers measure accurately up to 0.001 cm.
- The time for one complete swing of a pendulum is its period.
- The period of oscillation increases with the length of the pendulum.

You have completed the material for this unit on the measurement of physical quantities. You should now spend some time reviewing the content in detail. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit where you will put into practice scientific measurement in studying speed, velocity and acceleration.

Assignment 10

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:19]

1. Fill the SI units in the table below: (4)

Physical quantity	**SI Unit**
Length	
Mass	
Temperature	
Time	

2. What are these lengths in metres? (3)

   a) 300 mm

   _____
   _____
   _____
   _____
   _____

   b) 43 cm

   _____
   _____
   _____
   _____
   _____

   c) 12 km

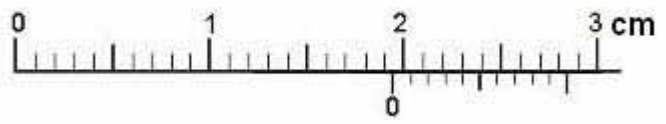
   _____
   _____
   _____

3. Name the instrument which is more accurate among a rule, vernier callipers and micrometer screw gauge. (1)

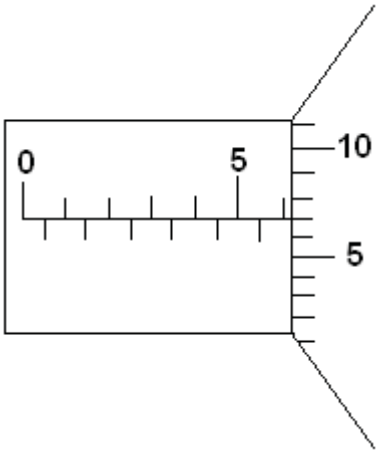
Give a reason for your choice. (1)

4. Write the lengths shown by the instruments below. (4)

a)



b)



5. i) Explain the terms frequency and period of a pendulum. (2)

frequency

_____

_____

period

_____

_____

(ii) Calculate the period of the pendulum of frequency 3Hz. (2)

_____

_____

_____

(iii) Calculate the frequency of a pendulum which has a period of 0.8 seconds. (2)

_____

_____

_____

_____

Reflection Question

6. If we double the frequency of a swinging pendulum, what happens to its period?

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Solutions to Assignment 10

1.

Physical quantity	***SI Unit***
Length	***m***
Mass	***kg***

Temperature	*°C*
Time	*S*

2. *a) 300 mm* = *(300 x 10^{-3}) m*

= $(\frac{300}{1000})$ *m*

= $(\frac{3}{10})$ *m*

= *0.3 m*

b) 43 cm = *(43 x 10^{-2}) m*

= $(\frac{43}{100})$ *m*

= *0.43 m*

c) 12 km = *(12 x 10^{3}) m*

= *(12 x 1 000) m*

= *12 000 m*

3. Micrometers are more accurate because they can measure accurately up to 0.001 cm.

4. a) Reading = sleeve reading+ 0.01 x vernier reading

1.9cm + 0.01 x 4

1.9cm + 0.04

1.94cm

b) Reading = main scale reading +0.01 x thimble reading

6mm + 0.01 x 7

6mm + 0.07

6.07mm

5. *(i) frequency refers to the number of oscillations made per second*

Period is the time taken to complete one oscillation

(i) $T = 1 / f$

$= 1 / 3Hz$

$= 0.33sec$

$Frequency = 1 / 0.8sac$

$= 1.25\ Hz$

6. The period will decrease (It will be half of what it was before).

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physics course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 10

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

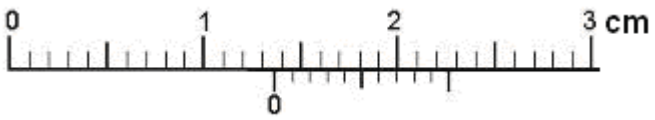
Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

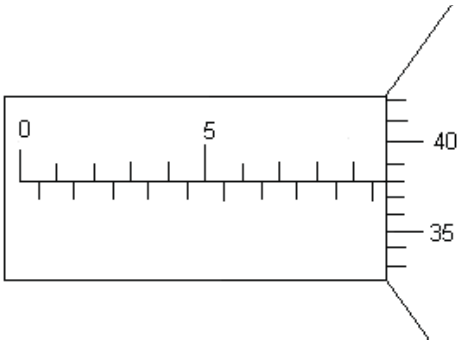
(Total Marks:14)

1. The pages of a book are numbered 1 to 200 and each leaf is 0.10 mm thick. If each cover is 0.20 mm thick, what is the thickness of the book? (2)
2. Rewrite the following measurements in the units suggested. (3)
   a) 840 mm in m
   b) 4.5 μs in s
   c) 7.2 km in mm
3. Which instrument will accurately measure the thickness of one page of a book? Explain your answer. (1)
4. Write the readings shown by the following instruments. (4)

   a)



   b)



5. a) A pendulum clock has a period of 0.3 Hz. Find the total number of oscillations if it takes 10 seconds to complete them. (2)

   b) Find the frequency of a pendulum of period 0.1 s. (2)

Physics

Grade 12

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Unit 11

Speed, Velocity and Acceleration

Study Skills

Discover your key productivity periods and places. Morning, afternoon or evening? Find spaces where you can be the most focused and productive. Prioritize these for your most difficult study challenges. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

Hello again! I hope you are enjoying learning physics. In the previous unit, you learned about measurement, SI units, and measuring length and time. In this unit, you are going to learn about speed, velocity and acceleration. You will also come across the graphical analysis of motion as well as the motion of free falling bodies.

Time

This unit consists of 32 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Let us begin by focussing on the learning outcomes as they help you focus on the important parts of the unit.

Outcomes

Study Skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Measure* physical quantities.
- *Give* the correct SI units of the different physical quantities.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.
- *Analyse* experimental data.
- *Apply* correctly various formulae which relate the different physics concepts and theories to the world around us.

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Define and differentiate* between distance and displacement; speed and velocity.
- *Define* acceleration.
- *Calculate* velocity, displacement and acceleration using equations of motion.
- *Analyse* motion graphically.
- *Describe* motion of free falling bodies.

Terminology

Displacement:	The change in position from the starting point in a given direction.
Speed:	The distance travelled per given time.
Velocity:	The distance travelled per given time in a given direction.
Acceleration:	Change in velocity per given time

Section 11-1: Distance and Displacement

Introduction

By the end of section 11-1, you should be able to define distance and displacement and differentiate between the two.

Time

Section 11-1 has 3 pages. You should spend approximately 30 minutes on this topic.

Activity

Activity 1

1. Point A represents Mpho's home and point B represents the school. Line AB represents the pathway Mpho could take to school if she walked along a straight street.

A ---------- B

a) Measure the length of **line** AB: _____

b) If 1 cm on the line represents 1 km, what is the distance between Mpho's home and the school in km?

_____

_____

c) What distance does Mpho travel to and from school every day?

_____

2. The school is due East of Mpho's home. The distance between Mpho's home and the school is 6.7 km.

a) When Mpho returns home after school, does she travel the same distance as when she went to school?

_____

_____

b) What direction does Mpho walk after school?

_____

Check your performance against the given solutions at the end of section 11-1. Continue if you are satisfied with your ability to answer the questions.

Note it!

Remember:

- DISTANCE is the length between two points.
- Distance increases whenever the object is moving, whether it is moving forward or backward. So this means that Mpho walks a total distance of 13.4 km every day to and from school.

When Mpho goes to school, she walks due East and when she returns, she walks due West. When the distance moved has direction, there is displacement.

DISPLACEMENT is defined as the change in position from the starting point in a given direction.

SCALAR QUANTITY: A quantity that has magnitude only (i.e. 15 km).

VECTOR QUANTITY: A quantity that has magnitude and direction (i.e. 15 km North).

Activity

Activity 2

Between displacement and distance, which one is a vector and which one is a scalar? Displacement _____

Distance _____

Answers are provided at the end of section 11-1. Be sure you understand why the answers are correct before you continue to the next topic. Let us move forward.

Key Points to Remember:

Note it!

The key points to remember in this section on distance and displacement are:

- Distance is a scalar quantity because it has the magnitude only.
- Displacement is a vector quantity because it has both magnitude and direction.

In the next section we are going to learn how to calculate velocity and acceleration using distance.

Answers to Activities on Distance and Displacement:

Activity 1

1. a) AB = 6.7 cm

b) Distance between Mpho's home and the school = 6.7 km since 1 cm represent 1 km then 6.7 cm is equivalent to 6.7 km [This should have an explanation of the calculation].

c) Distance to and from school = 6.7 km + 6.7 km = 13.4 km

2. a) Yes, Mpho travels the same distance to and from school.

b) West

Activity 2

Displacement	***vector***
Distance	***scalar***

Section 11-2: Velocity and Acceleration

Velocity and acceleration are important concepts in motion.

By the end of section 11-2, you should be able to:

- *define* velocity and acceleration
- *differentiate* between them
- *calculate* velocity and acceleration.

Time

Section 11-2 has 6 pages. You should spend approximately 1 hour on this topic.

Example 1

A boy walks to school which is 500 m from his home. When he is 200 m from his home, he remembered that he forgot his pen. He then goes back home to get his pen and then runs to school.

a) What is the total distance moved by the boy?

_____

b) What is the total displacement?

_____

Solutions:

a) Total distance = 200 m + 200 m + 500 m

= 900 m.

200 m is the distance he walked before he saw that he forgot his pen.

200 m is the distance he walked back to collect his pen.

500 m is the distance he walked from home to school.

b) Total displacement = 200 m – 200 m + 500 m

= 500 m.

The first 200 m is the distance he walked before he realised that he had forgotten his pen.

When he went back to take the pen, he walked another 200 m. We subtract it because it is the distance in the backward direction.

500 m is the distance from his home to school, so we add it because it is the forward distance.

Remember that displacement is the distance in a given direction, so when the car moves back it is moving in the opposite direction. The last 40 k m of the journey to point B and the 40 km of the journey from point C to D cancel out. That is the reason why displacement is 60 km.

I hope you are following along well! Let us now move on.

Speed and Velocity

In physics, speed is described as the distance travelled per unit time.

In Unit 10 you learned about the SI unit. I hope you remember that the SI unit of speed is metres per second (m/s or ms^{-1}).

There are other units of speed. There are bigger units such as kilometres per hour (km/h or kmh^{-1}) and smaller units such as millimetres per second (*mm/s or* mms^{-1}).

Example 2

If a car took 2 hours to move from point A to point B and points A and B are 100 km apart, at what speed was it moving?

Solution 1:

$$\text{Speed} = \frac{\textit{distance travelled}}{\textit{time taken}} = \frac{100km}{2hrs}$$

= 50 km/h

This means that the car on average covers a distance of 50 km in 1 hour.

2. If the two points A and B are two towns with a lot of traffic between them, would the car move with the same speed from the start of its journey to the end? Explain.

_____
_____
_____
_____

Compare your answer to the following:

Solution 2

The car would not maintain the same speed throughout this journey, because of traffic constraints. At some points the driver would need to apply the brakes and slow down, and at other points increase the speed.

Therefore; we talk about average speed.

Average speed = $\frac{total\ distance\ travelled}{total\ time\ taken}$

Activity

Activity 3

This activity will help us understand average speed better.

John and Teboho are athletes. Both of them participate in a 100 m race. John took 10 seconds and Teboho took 15 seconds to run the same race.

a) What is the average speed of John?

_____
_____
_____

b) What is the average speed of Teboho?

_____
_____
_____

c) Why do we talk of their average speed and not just their speed?

_____
_____

Compare your answers with those at the end of section 11-2. Review the related content for any question that you missed.

Note it!

This is what we have learned so far:

- Speed is the distance moved per unit time. It measures how fast or slow the object is moving.
- Average speed is the total distance travelled per total time taken.
- The SI units of speed are m/s. The other way of writing it is ms^{-1}. Speed is also measured in km/h which is also written as kmh^{-1}.
- Speed is a scalar quantity.

We are now going to look at the differences between speed and velocity.

In Activity 3, we calculated displacement. If the car took 2 hours to move from point **A** to **C** then we talk of velocity and not speed. *Velocity* is the distance travelled per unit time in a given direction.

In activity 3 displacement of the car is 60 km.

So velocity = $\frac{60\ km}{2h}$ = 3 km/h from point A to C (direction given)

Just like with speed we also talk of average velocity, which is the total distance travelled per unit time in the stated direction.

The differences between speed and velocity are:

- Velocity is described as the distance travelled per unit time in the stated direction.
- Average velocity is described as the total distance travelled per unit time in the stated direction.
- The SI unit of velocity is m/s, and it is also measured in km/h.
- Velocity is a vector quantity.

Activity

Activity 4

1. If a runner takes 8 s to run an 80 m race, what is his average speed?

   _____
   _____

2. Is there any period in his race when he runs faster or slower than his average speed? Explain your answer.

   _____
   _____
   _____

3. Is it possible to run around a curved race course at constant velocity? Explain.

_____
_____
_____

Compare your answers to those given at the end of section 11-2. Note that it is important to understand this concept. If you do not understand it, review the above content and try the activity again.

We have learned what velocity is, so we are now going to learn what acceleration is and how it happens.

When an object starts to move from rest, it starts with a low velocity and gradually its velocity increases.

ACCELERATION is the change in velocity per given time.

$$\text{Acceleration} = \frac{change\ in\ velocity}{time\ taken\ for\ the\ change}$$

Remember the unit for velocity is m/s

So the unit for acceleration is $= \frac{m}{s*s} = \frac{m}{s^2}$

Example 3

A car which starts from rest and achieves a velocity of 25 m/s in 10 s experiences an acceleration of:

SOLUTION:

Initial (starting) velocity = 0 m/s

Final velocity = 25 m/s

Time = 10 s

$$\text{Acceleration} = \frac{25-0}{10} = \frac{25m/s}{10s} = 2.5\ m/s^2$$

NOTE

Note it!

- An object whose velocity is increasing has a positive acceleration.
- An object which moves with the same velocity has an acceleration of $0 m/s^2$.
- An object whose velocity is decreasing is said to have negative acceleration, and it is said to be decelerating.

Example 4

A toy car moving with the velocity of 2 m/s comes to rest after 5 s. What is the acceleration of the car?

Initial velocity = 2 m/s

Final velocity = 0 m/s

Time = 5 s

Acceleration = $\frac{0-2}{5} = \frac{-2m}{5s^2}$ = - 0.4 m/s^2

The acceleration is negative because the velocity is decreasing. So the toy car is decelerating (or it simply slows down until it stops).

Note it!

NOTE

- Acceleration is a vector quantity.
- Acceleration is positive when velocity is increasing.
- Acceleration is negative when velocity is decreasing and it is called deceleration.

Answers to Activities on Velocity and Acceleration

Activity 3

a) Average speed of John $= \frac{total\ distance\ travelled}{total\ time\ taken}$

$= \frac{100m}{10s}$

= 10m/s

b) Average speed of Teboho $= \frac{total\ distance\ travelled}{total\ time\ taken}$

= 100/15

= 6.66m/s

= 6.7m/s

c) Because the speed of the athletes changes during the race.

Answers to Activity 4

1. Average speed $= \frac{total\ distance\ travelled}{total\ time\ taken}$

$= \frac{80m}{8s}$

= 10m/s

2. Yes, because when the athlete begins the race, he or she runs with a high speed but towards the end of the race the athlete is tired and the speed changes.

3. No. When the athlete runs around a curve, the direction in which he or she is running changes. Therefore, speed in the original direction reduces. Remember that velocity is defined as the distance travelled per given time in a given direction.

Section 11-3: Velocity vs. Time graphs

Motion can also be represented graphically. By the end of section 11-3, you should be able to draw motion graphs to show how velocity of a moving object differs with time.

Activity

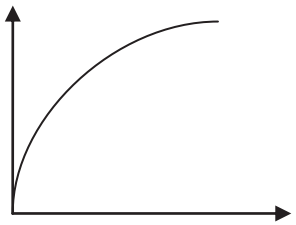
If you have access to the internet, please go to: http://phet.colorado.edu/en/simulation/moving-man to experiment with changing the velocity, position and acceleration of a man. What happens when acceleration is 0? What happens when there is a negative acceleration? A positive acceleration? Make sure to click on the charts tab to see a graphical representation of motion.

Activity

Activity 5

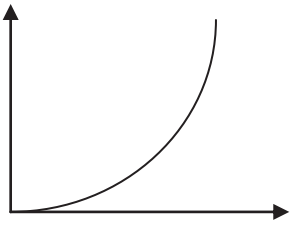
Study the following displacement-time graphs and describe/explain the motion represented by each of them.

(a) Displacement (m)



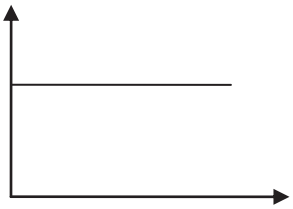
Time (s)

(b) Displacement (m)



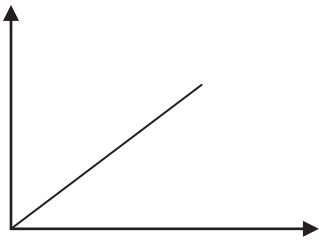
Time (s)

(c) Displacement (m)



Time (s)

(d) Velocity (m)



Time (s)

a) _____

_____

b) _____

_____

c) _____

_____

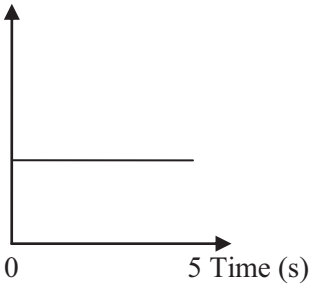
d) _____

_____

Compare your answers with those at the end of section 11-3. If you got them all correct, proceed to the next section. If you made any errors, be sure you understand the answers before continuing. Can you replicate the motion of the above graphs using the moving man simulation?

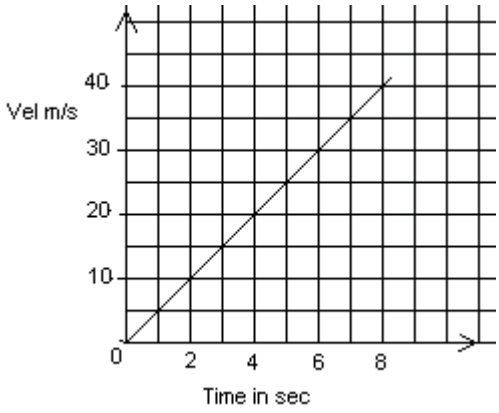
Let us now study the following graphs which show the motion of a toy car for 5 seconds:

a) Velocity (m/s)



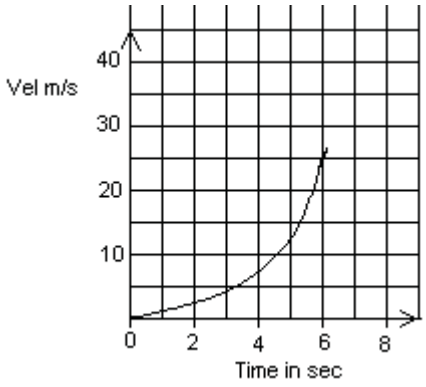
- Velocity is the same throughout the period of 5 seconds.
- The car is moving with **constant velocity**.

b)



- Velocity is increasing at the same rate throughout the period of 6 seconds.
- The car is moving with ***constant acceleration***.

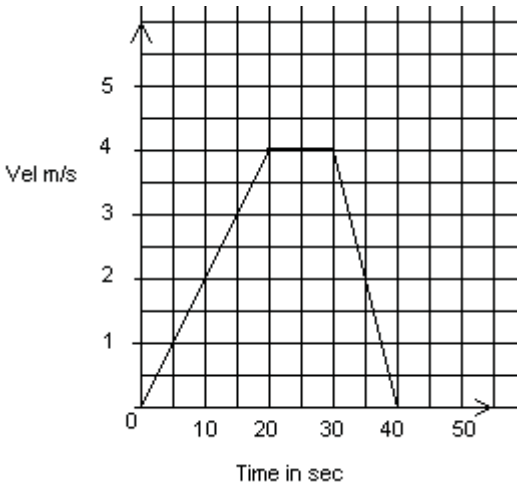
c)



- The velocity is increasing very slowly at the beginning of the journey.
- Velocity increases fast towards the end of the journey.
- The car is moving with ***non-uniform acceleration***.

Example 5:

The velocity-time graph shows the motion of a toy car.



1. Describe the motion of the car during the period of 40 seconds.

   _____
   _____
   _____

2. Calculate the acceleration of the car during the first 20 seconds.

   _____
   _____
   _____
   _____

3. Calculate the deceleration of the car.

   _____
   _____

Solution:

1. The car accelerated during the first 20 seconds, it then moved with constant velocity of 4 m/s for 10 seconds and then decelerated until it came to rest during the last 10 seconds.

2. Acceleration $= \frac{final\ velocity - initial\ velocity}{total\ time\ taken}$

$$= \frac{(4 - 0)\ m/s}{20\ s} = \frac{4\ m/s}{20s}$$

$$= 0.2\ m/s$$

3. Deceleration $= \frac{final\ velovity - initial\ velocity}{total\ time\ taken}$

$$= \frac{(0-4)\ m/s}{10\ s}$$

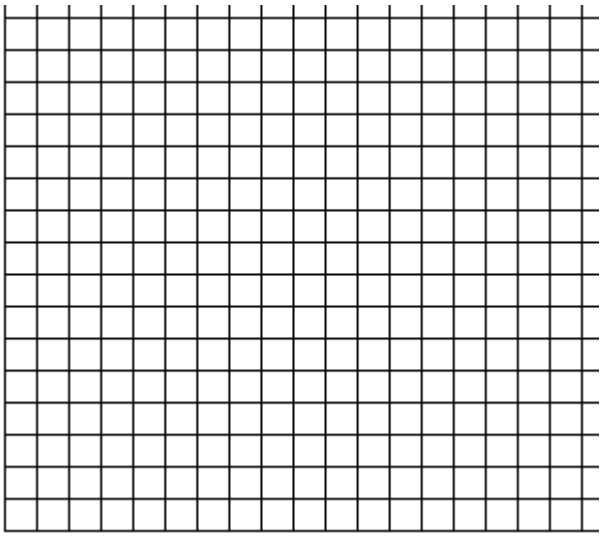
$$= -\ 0.4\ m/s$$

Activity

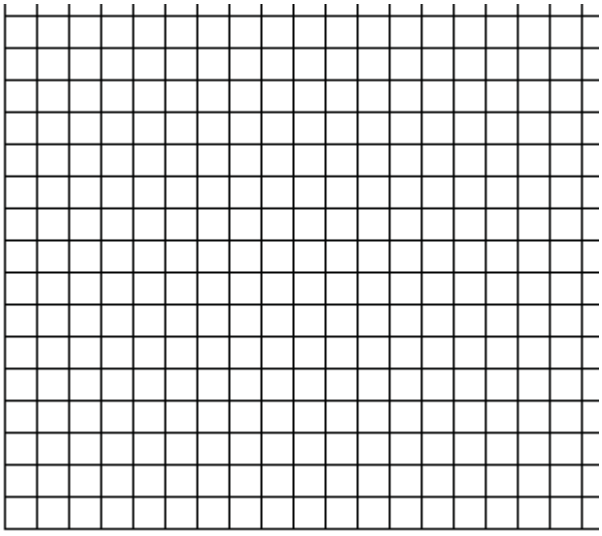
Activity 6

1. Sketch the graph representing the following motions. Make sure to label the X and Y axes with titles and units.

   a) A car accelerates from rest for 5 seconds up to a maximum velocity of 20 m/s. It then moves with a constant velocity of 20 m/s for another 6 seconds.



   b) A car moves with a constant velocity of 15 m/s for 10 seconds and then comes to rest with a uniform deceleration for 5 sec.



2. Calculate acceleration of graphs 1 (a) and (b).

(a) _____

_____

_____

_____

_____

(b) _____

_____

_____

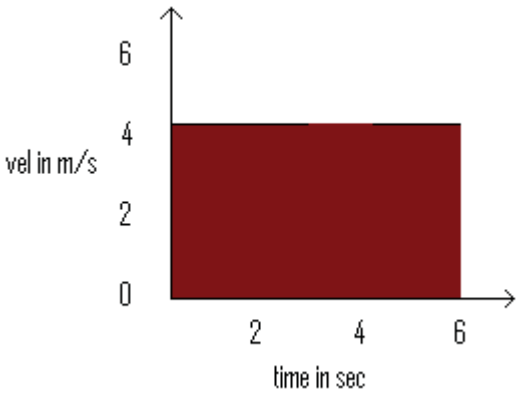
_____

_____

Compare your answers with those at the end of section 11-3. If you got them all correct, proceed to the next section. If you had problems drawing motion graphs take sometime to practice before moving onto the next section

Area Under a Velocity-Time Graph

The graph below is the velocity-time graph for a body moving with constant velocity of 4 m/s in 6 seconds.



Draw a vertical line from 6 s to the horizontal line, what shape does the graph make with time axis?

_____

Remember that;

- Velocity = $\frac{\text{distance travelled in the given direction}}{\text{time taken}}$

When we multiply both sides of the equation by the time taken we find that:

Distance travelled = velocity x time taken

Remember again that:

Area of a rectangle = length x width

In this case, the length is on the time-axis, so the units of length are seconds. The width is on the velocity-axis, so the units of width are m/s.

- Area of the region under the graph = 5 s x 4 m/s

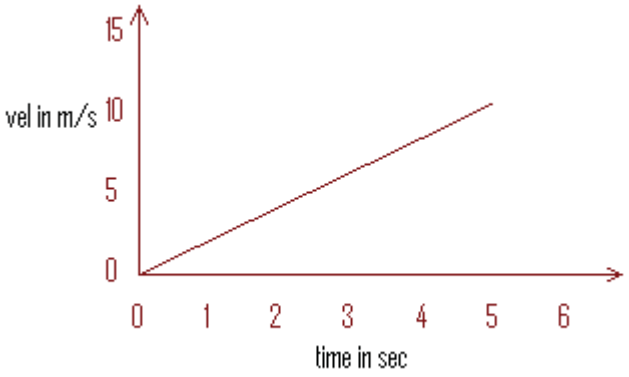
  = 20 m

- When we check the units of area we find that they are the units of length. So we conclude that distance under the velocity-time graph is numerically equal to the area under the graph.

Activity

Activity 7

1) The graph below is the velocity-time graph for a body moving with constant acceleration.



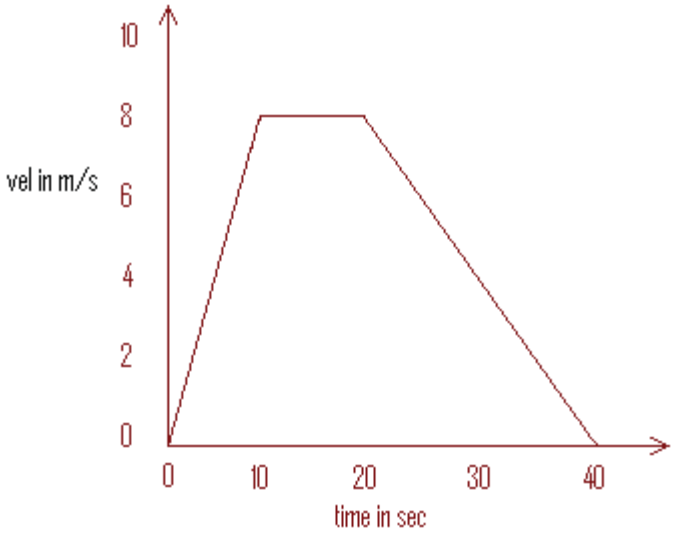
a) What shape is the region under the graph?

_____

b) Calculate the distance travelled by the body in the 5 seconds journey:

_____
_____
_____
_____
_____

2) The graph below is of the car which moved for 40 seconds.



Calculate:

a) The distance moved during:

i. The first 10 seconds

_____
_____
_____
_____

ii. The next 10 seconds

_____
_____
_____
_____

iii. The last 20 seconds

_____
_____
_____
_____

b) Find the total distance moved during the whole journey

_____
_____
_____
_____
_____

Compare your answers with those at the end of section 11-3. Be sure that you understand each answer before continuing. If you have any misunderstandings, review this content and work through the activity again.

Key Points to Remember:

Note it!

The key points to remember in section 11-3 on drawing motion graphs are:

- Time is labelled on the horizontal axis while the distance, velocity and acceleration are labelled on the vertical axis.
- Different motions can be represented graphically.

Answers to Activities on Velocity vs. Time Graphs

Activity 5

(a) Graph (a) – object is moving with decreasing velocity. This is known because over time the change in displacement decreases.

(b) Graph (b) – object is moving with increasing velocity. This is known because over time there is an increase in change in displacement.

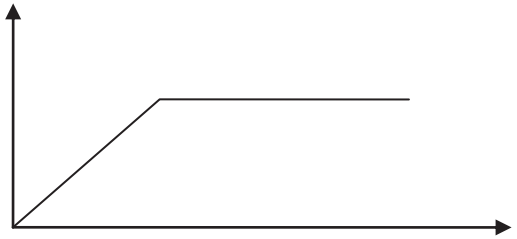
(c) Graph (c) – object is at rest.

(d) Graph (d) – object is moving with uniform/constant velocity.

Activity 6

1. (a)

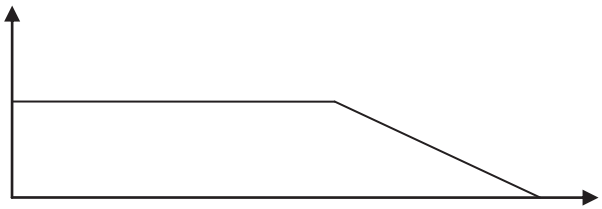
Velocity (m/s)



5 11 Time (s)

1. (b)

Velocity (m/s)



10 15 Time (s)

2. (a)

Initial velocity = 0 m/s

Final velocity = 20 m/s

Time taken = 5 s

$$\textit{Acceleration} = \frac{20m/s - 0m/s}{5s}$$

$$= \frac{20m/s}{5s}$$

$$= 4\ m/s^2$$

(b)

Initial velocity = 15m/s

Final velocity = 0m/s

Time =5 s

$$\textit{Acceleration} = \frac{0m/s - 15m/s}{5s}$$

$$= \frac{-15m/s}{5s}$$

$$= -3\ m/s^2$$

Activity 7

1) ***a) When we draw a vertical line from 5 s on the time-axis to the graph, we get a triangle.***

b) Distance moved = ½ x 5 s x 10 m/s

= 25 m

2) ***a) Remember that the distance travelled is numerically equal to the area under the graph.***

i. ***Distance = ½ x base x height***

= ½ x 10 s x 8 m/s

= 40 m

ii. ***When we draw another vertical line from 15 s on the time-axis we get a rectangle.***

So distance = 10 s x 8 m/s

=80 m

iii. ***The remaining region is a triangle,***

So the distance = ½ x 2 0s x 8 m/s

= 80 m

b) We get the total distance by adding all the distances, that is

40 m + 80 m + 80 m =200 m

Section 11-4: Free falling bodies

We have learned how to describe and represent motion of moving objects. By the end of this subunit, you should be able to describe the motion of freely falling objects.

Example

Think about the following events and answer the questions that follow:

1. A feather falling from a tree.

   i. Does the feather fall directly downwards or does it move in a zigzag motion?

   _____
   _____

   ii. If it does not move directly downwards, what do you think causes this?

   _____
   _____
   _____

2. A peach falling from a tree.

   Answer questions i) and ii) about this event. Write your answers on the spaces below

   i. _____
   _____
   _____

   ii. _____
   _____
   _____
   _____

Solution

Let us now check whether you answered them correctly.

1.

   i. A feather does not fall freely, it moves in a zigzag motion.

   ii. This is because of the air which is trying to push the feather upwards. We call it air resistance.

2.

   i. The peach moves directly downwards.

   ii. The second question does not apply because the peach moves directly downwards.

The question you are probably asking yourselves is; why is there a difference in the way these objects fall?

Let us now look at this in detail.

All objects near the surface of the earth are pulled downwards by the force of gravity, which is denoted by letter g. Gravitational force makes objects accelerate downwards at the rate of 10 m/s^2.

When an object has more mass, gravity acts more on it than an object which has less mass.

This is because the force of gravity determines the weight of an object.

Weight = mass x acceleration due to gravity

W = m x g

A stone whose mass is 0.5 kg has a weight of:

$$W = 0.5kg \times 10 \frac{m}{s^2}$$

$$= 5\ N$$

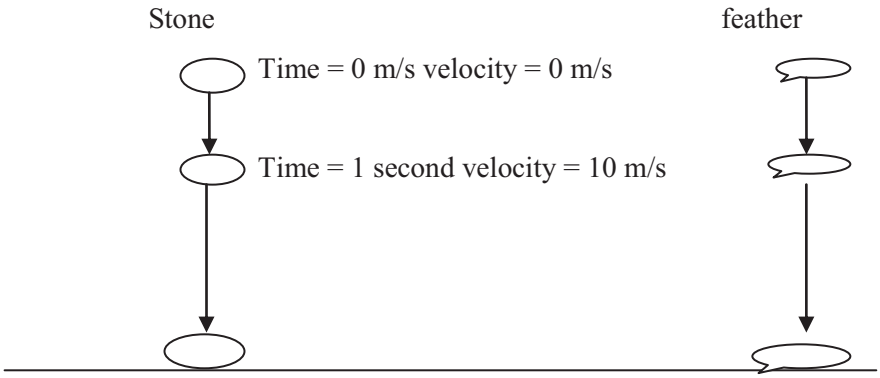
Prediction of how a stone and feather fall in a vacuum

Imagine that a stone and feather are hanging suspended in a sealed container that has had all of the air pumped out. If the stone and feather are released at the same time, predict which object, if any, will reach the bottom of the container before the other.

_____

Analyze your answer based on the following demonstration.

Demonstration of how a stone and feather fall in a vacuum

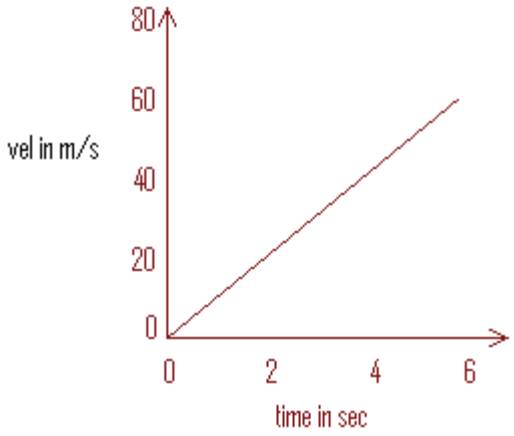


These diagrams show a stone and a feather falling in a vacuum. After every 1 second the velocity increases by 10 m/s. So this means that they are accelerating downwards at the rate of 10 m/s.^{2}

The first pair of arrows is short showing that the total displacement covered in 1 second is small.

The second pair of arrows is long showing that the total displacement covered in 1second is long.

This is what happens in free fall. The velocity time graph for free fall, in a vacuum, looks like this.



From the graph we see that at time 0 seconds, the object was not moving so velocity is 0 m/s. After 1 second velocity has increased by 10 m/s, after 2 second velocity is 20 m/s and so on.

Key Points to Remember:

Note it!

The key points to remember in this subunit on free falling bodies are:

- Objects falling in a vacuum fall with the same constant acceleration.

You have now completed the last section of this unit on speed, velocity and acceleration. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Unit Summary

Summary

We have learned many new concepts in this unit. Take some time to go through the summary to help you recall what you learned.

In this unit you learned:

- Distance is a scalar quantity while displacement is a vector quantity.
- Displacement is the change in position from a starting point in a given direction.
- Speed is the change in distance per given time while velocity is the change in displacement per given time.
- Average speed = $\frac{total\ distance\ travelled}{total\ time\ taken}$
- Speed is a scalar quantity while velocity is a vector quantity.
- Average velocity = $\frac{total\ displacement\ travelled}{total\ time\ taken}$
- The SI unit of speed and velocity is meters per second, m/s.
- The total displacement/distance travelled by an object can be found by calculating the area under the velocity time graph.
- Acceleration is the change in velocity per unit time.
- Acceleration = $\frac{final\ velocity - initial\ velocity}{total\ time\ taken}$
- Area under the velocity-time graph is numerically equal to the distance travelled by the object.
- When velocity increases, acceleration is positive.
- When velocity of an object decreases, acceleration is negative and the object is said to be decelerating.
- Freely falling objects fall with a uniform acceleration of 10 m/s^2

You have completed the material for this unit on speed, velocity and acceleration. You should now spend some time reviewing the content in detail. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit.

Assignment 11

Assignment

Answer all the questions in the assignment.

You should be able to complete this assignment in 30 minutes. This is very important because when you write final examinations, you will be given a maximum time in which you must complete the exam.

[Total Marks:21]

Multiple choice questions (5 marks)

1. A body moving along a straight line at 20 m/s decelerates at the rate of 4 m/s^2. After 2 seconds its speed will be equal to:

A - 8 m/s

B 12 m/s

C 16 m/s

D - 12 m/s

2. An object moving with a speed of 5 m/s comes to rest 10 s after the brakes are applied. What is the initial velocity?

A 0 m/s

B 5 m/s

C 15 m/s

D 50 m/s

3. A body moving along a straight line at 40 m/s undergoes an acceleration of 4 m/s^2. After 10 seconds its speed will be:

A 20 m/s

B 28 m/s

C 16 m/s

D 80 m/s

4. When an object is moving with uniform velocity, what is its acceleration?

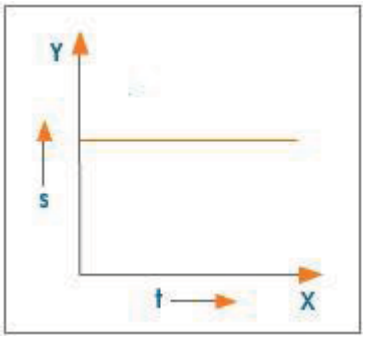
A Zero

B Uniform

C Non-uniform

D Negative

5. What does the following S (distance) – t (time) graph indicate?



A Uniform speed

B Body at rest

C Non- uniform speed

D Variable speed

Structured questions (16)

1. An athlete runs a 200m race in 20 seconds. Find her average speed.(2)

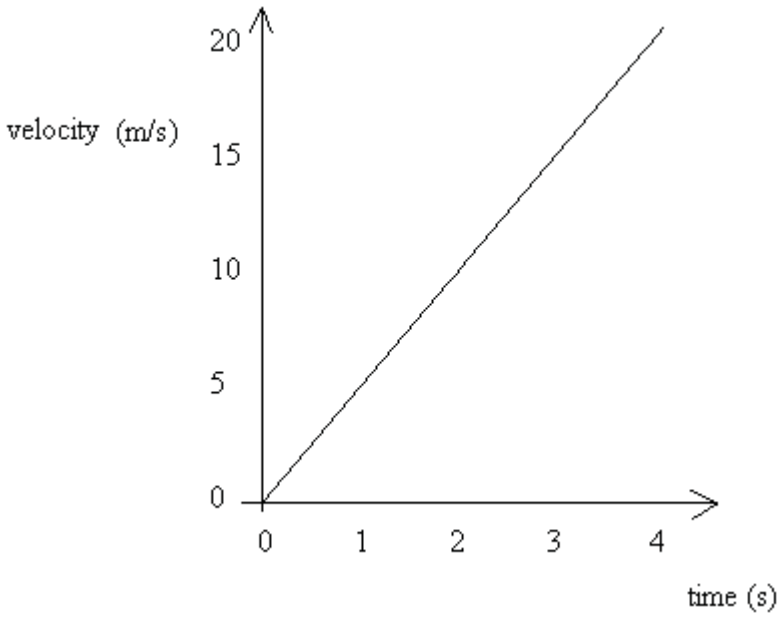
2. A car is moving along the curved road of distance 20 km for 0.5 hours; find the velocity of the car. (2)

3. An athlete moved with a velocity of 25 $^{m}/_{s}$ for 10 seconds and then comes to rest after the next 5 seconds. Find:

   i. Acceleration during the first 10 seconds of the journey. (2)

   ii. Acceleration during the last 5 seconds of the journey (2)

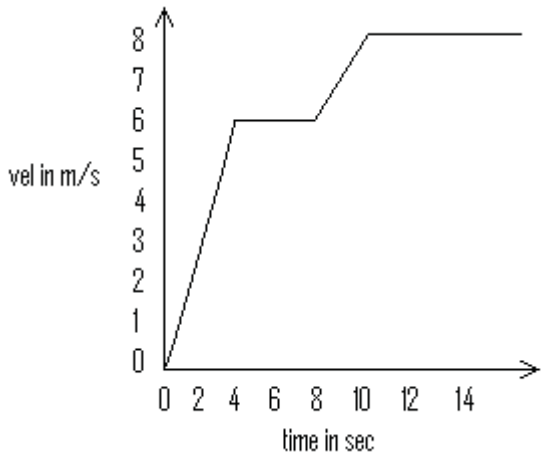
4. The graph below is for a ball falling freely in a vacuum.



   a) Calculate the area under the graph. (2)

   b) Calculate the distance moved by the ball during the 20 seconds of its fall. (1)

5. The graph below shows the motion of an object.



a) Explain how the object moves when the time is

i. 0 to 4 s

_____
_____
_____(1)

ii. 4 s to 8 s

_____
_____
_____(1)

b) Calculate the total distance moved by the object during the 14 seconds of its journey. (3)

_____
_____
_____
_____
_____
_____

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to the Assignment 11

Answers to multiple choice questions

1. ***D***
2. ***B***
3. ***D***
4. ***A***
5. ***B***

Answers to Structured Questions

1. $\textit{Average speed} = \frac{\textit{total distance travelled}}{\textit{total time taken}}$

$$= \frac{200\text{m}}{20\text{s}}$$

$$= 10\ m/s$$

2. $\textit{Velocity} = \frac{\textit{total displacement travelled}}{\textit{total time taken}}$

$$= \frac{20km}{0.5h}$$

$$= 40\ km/h$$

3. *i) Initial velocity = 0 m/s*

Final velocity = 25 m/s

Time = 10 s

$$\textit{Acceleration} = \frac{\textit{final velocity} - \textit{initial velocity}}{\textit{total time taken}}$$

$$= \frac{25m/s - 0m/s}{10s}$$

$$= \frac{25m/s}{10s}$$

$$= 2.5\ m/s^2$$

ii) Initial velocity = 25 m/s

Final velocity = 0 m/s

Time = 5 s

$$\textit{Acceleration} = \frac{0m/s - 25m/s}{5s}$$

$$= \frac{-25m/s}{5s}$$

$= -5\ m/s^2$

4. *a) i) From 0 to 4 s the body is accelerating with uniform acceleration of 1.5 m/s^2*

ii) From 4 to 8 s the body moved with constant velocity of 6 m/s

b) From 0 to 4 s the shape under the graph is a triangle, so:

Distance = ½ x 4s x 6m/s
=12 m

From 4 to 8 s the graph forms a rectangle with the horizontal.
So the distance moved during this period = 6 s x 4 m/s
= 24 m

From 8 to 12 s the area under the graph is a trapezium, so the distance = ½ (6 m/s + 8 m/s) x 2 s
= ½ x 14 m/s x 2 s
= 14 m

From 12 to 14 s the distance = 8 m/s x 4 s
= 32 m

The total distance moved by the object = 12 m + 24 m + 14 m + 32 m
= 82 m

This is the end of the assignment. Based on the fact that you should get 80%, you are now in the position to know if you are ready to move on to the assessment. If not, go through the concepts of the unit which gave you problems and then do the assessment.

Assessment 11

Assessment

The assessment prepares you for the final examination, so put maximum effort into it. You should get 80% to be sure that you are fully prepared.

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:22)

In section A (Marks: 5)

Write the letter of the correct answer only.

In section B, you are advised to show all the necessary working and to write in full sentences.

SECTION A: Multiple choice questions

1. What is the SI unit of speed?

A km/h

B m/s

C m/min

D km/s

2. What is the distance covered by a car in 5 h if it is moving with a speed of 35 km/h?

A 175 km

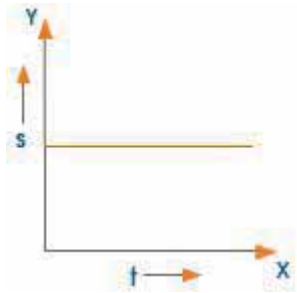
B 150 km

C 7 km

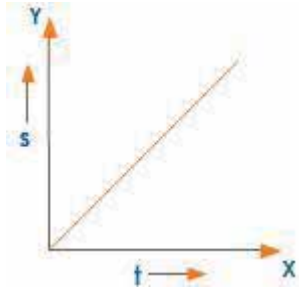
D 1750 km

3. The S-t (distance – time) graph for uniform speed is

A.



B.



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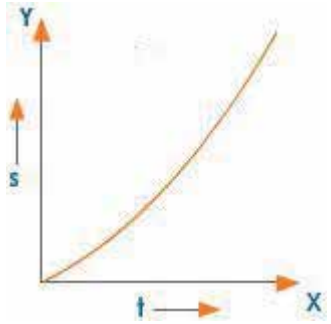
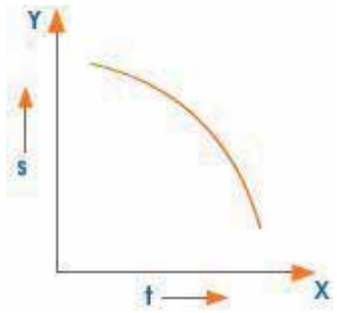


D.



4. Displacement is a _____ quantity.

A scalar

B vector

C derived

D linear

5. The area under the speed-time graph gives the _____.

A distance

B velocity

C time

D acceleration

SECTION B (Marks 17)

1. Find the average velocity of an athlete who runs 1500 m in 4 minutes in m/s. (2)
2. A car accelerates uniformly from 5 m/s to 13 m/s in 4 s. What is the acceleration of the car? (2)
3. The acceleration due to gravity is 10 m/s^2. If an object has been falling freely from rest for 5 seconds, what is its velocity? (2)
4. Two cyclists, A and B, start a race. A accelerates for the first 5 seconds, until his velocity reaches 12 m/s, after which he travels with constant velocity for another 5 seconds. B accelerates for the first 10 seconds, until his velocity reaches 15 m/s, after which he travels with constant velocity for 5 seconds.
    a) Sketch the velocity-time graphs for the two cyclists. (6)
    b) Calculate the distance travelled by both cyclists in the first 10 s. (4)
    c) Who is in the lead after 10 s? (1)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 12

Forces

Study Skills

When reading difficult material, try the "look-away method". Periodically look away from the text and ask yourself questions relating to the text. Try to respond in your own words. Mark down what you do not understand and review later. You may understand it after reading more content. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In this unit we are going to study force. The unit defines force, studies the different types of force and most importantly carries out an in-depth study on the effect that forces have on the motion of stationery and moving object. In unit 14, you will be exposed to the turning effect of a force which will consider concepts like the moment of a force and stability.

Time

This unit consists of 30 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Outcomes

Study Skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Solve* problems which involve physical forces, such as energy, light, magnetism and electricity.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.
- *Analyse* experimental data.

  Apply correctly various formulae which relate the different physics concepts and theories to the world around us.

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Define and add* force.
- *Describe* different types of force.
- *Describe* the effect of force on an object.
- *State* Newton's laws of motion.
- *Solve* problems relating to Newton's first and second laws.
- *Describe* the effect of friction force on motion.
- *Plot, analyse and interpret* an extension load graph.

Terminology

Force:	A push or a pull.
Resultant/net force:	An unbalanced force.
Friction force:	A force which opposes motion.
Centripetal force:	Is the force that causes a body to follow a curved path.

Section 12-1: Defining Force

Introduction

At the end of section 12-1, you should be able to define force, add forces, describe different types of force and describe the effect of force on an object.

Time

Section 12-1 has 6 pages. You should spend approximately 1 hour on this topic.

What is a force?

From your own daily experiences, how do you define force? Fill in your answer in the space provided.

_____

___

In science, force has something to do with pushing or pulling.

Force may therefore simply be described as a push or pull.

Indeed it is! Whenever we apply force, we either push or pull.

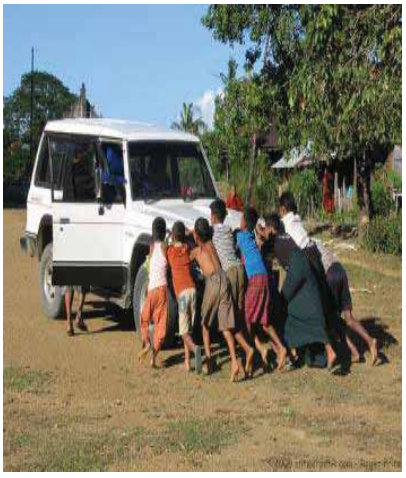

Figure 1: Pushing and Pulling accessed from Wikimedia Creative Commons, 2011.

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Think of other activities you carry out where you need to apply force and then you will find that either way there is a pull or a push, sometimes both!

Look at the picture in Figure 2. When an arrow is fired from the bow, which force is involved, push, pull or both?

_____

Figure 2: Which force? Image accessed from Creative Commons.

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Compare your answer to the following:

The string was initially pulled back. However, when fired, the string pushes the arrow forward.

The SI unit of force is the newton (N). To measure force, a spring balanced is used. Figure 3 shows you a typical spring balance.

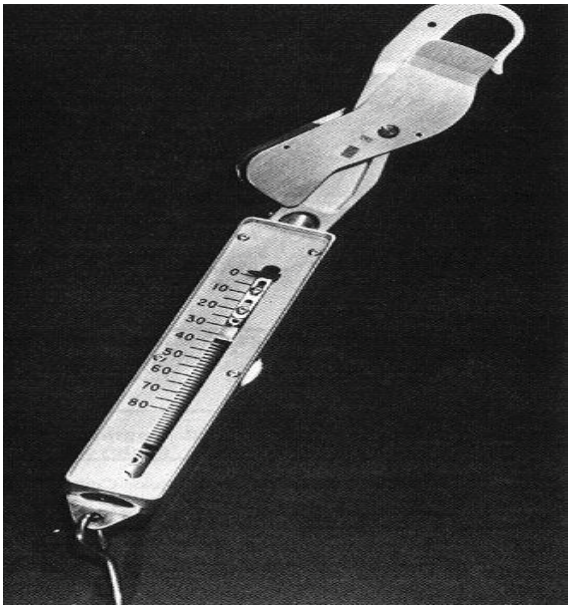

Figure 3 - A spring balance accessed from Wikimedia Creative Commons, 2011.

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Force is a vector quantity. This means that force is described in terms of its magnitude (size) and direction. To understand better what this means, let us look at addition of forces.

Adding Forces

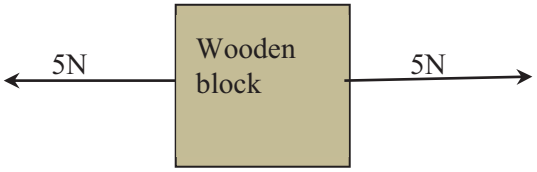
When forces are added, it is not only the size of the force which is considered, but also the direction in which the force is acting. **Remember force is a vector quantity.**

Activity

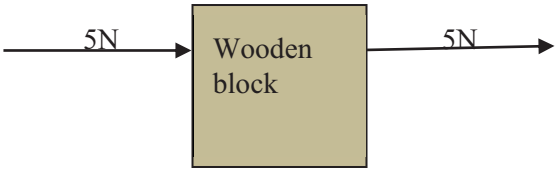
Activity 1

Study the following diagrams:

(i)



(ii)



(i) The two 5N forces are pulling on the wooden block in **OPPOSITE,** not **DIFFERENT** directions. What is the effective force acting on the block?

_____

(ii) There are two 5N forces acting on a block. One is pulling on the block and the other is pushing in the **same direction.** What is the effective force acting on the block?

_____

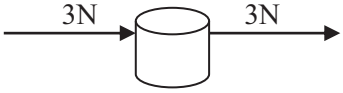
After completing Activity 1, compare your answers to the correct answers given at the end of section 12-1. Note the detailed feedback. Make sure you understand the answers before moving on to Activity 2.

Activity

Activity 2

Calculate the **resultant** or **net** force in each of the following cases in Table 1 below.

Table 1: Resultant force

Forces acting on a body	NET FORCE	Direction of net force
(i)		
(ii)		
(iii) 		

Compare your answers with those at the end of section 12-1. Review the related content for any answer that you missed.

Types of Forces

There are different types of force, the most common of which are listed and described briefly below. Some other forces will be discussed in the Turning Effect of Force unit.

(i) **Friction** – is a force which opposes motion. For every moving body friction force exists between two surfaces in contact and will always act opposite to the direction of motion. Imagine a student pushing a box full of books on the floor from one corner to the next corner in a classroom. Friction is the force that will oppose the pushing and make it difficult for the box to move easily.

(ii) **Weight** – pull of the Earth on objects on its surface.

(iii) **Tension** – force experienced by stretched objects (like springs, rubber bands and so on).

(iv) **Magnetic** – force exerted by magnets on other magnets when they repel (push) or attract (pull) each other. This force can also exist between magnets on magnetic objects (i.e. a magnet on a fridge).

(v) **Electric** - attraction or repulsion between electric charges.

Effect of a Force

When several forces or a single force is applied on an object, several changes may occur on the object to which the force is being applied.

A push or pull on objects may cause them to:

- Change in size and shape
- Change their state of motion
- Change their direction of movement
- Produce a turning effect

Activity

Activity 3

Think of an object or situation in which applying a force will cause a change in:

(i) Shape or size of the object _____

(ii) State of motion of the object

_____

(iii) Direction of movement of the object

_____

Compare your answers with those at the end of section 12-1. Be sure that you understand each answer before continuing. If you have any misunderstandings, review this content and work through the activity again. Some of these effects will be discussed in the topics to follow while others will be dealt with in other units.

Note it!

Key Points to Remember:

The key points to remember in section 12-1 on defining force are:

- A force is a pull or push
- Forces can change the size and hence the shape of some objects such as a spring. Sometimes the shape or size may become permanently changed.

The next section will deal with the effects of balanced and unbalanced forces on object.

Activity

If you have access to the internet, take this short quiz on identifying types of forces:

http://www.neok12.com/diagram/Types-of-Forces-01.htm

Answers to Activities on Defining Force

Activity 1

You should have found that in:

(i) The effective force acting on the block is 0 since the two equal forces are acting opposite each other and therefore their effect cancels out.

But in:

(ii) The effective force acting on the block is 10N since the two forces are acting in the same direction.

The effective force referred to above is sometimes called the resultant or net force.

To calculate the resultant force: if forces acting in a straight line are working in the same direction, we simply add them together.

5N+ 5N = 10N (Resultant Force)

But if forces acting in a straight line are working in opposite directions we simply subtract them

5N- 5N = 0 (Resultant Force)

Activity 2

(i)	***7N – 7N = 0***	***No direction***
(ii)	***7N – 3N = 4N***	***Right***
(iii)	***3N + 3N = 6N***	***Right***

Activity 3

(i) ***Stretching a rubber band***

(ii) ***Applying brakes on a moving car***

(iii) ***Turning the steering wheel of a moving car***

Section 12-2: Balanced and Unbalanced Forces

Introduction

At the end of section 12-2, you should be able to state Newton's three laws of motion and solve problems relating to Newton's first and second laws of motion.

Think about a fast moving car which suddenly comes to a halt. Passengers may be lurched forward. This is an effect of applying a force on an object. Newton's laws of motion deal with the effects of different forces to different objects in motion.

Section 12-2 has 8 pages. You should spend approximately 1.5 hours on this topic.

Time

Newton's Laws of Motion

Isaac Newton summed up the basic principles of motion in relation to force in three laws.

We shall therefore discuss these laws and their applications.

Newton's First Law of Motion

Every object continues in its state of rest or uniform motion in a straight line unless an external force acts on it.

In simple terms what this means is, if an object is placed in a certain position and let to rest, it will remain in that resting position unless there is a force that compels it to behave otherwise. Make sense?

In the same manner, a moving object/body such as a moving car in Figure 4 will continue moving in a straight line unless it is stopped or made to change its direction by external forces.

Figure 4: A moving car accessed from Creative Commons, 2011.

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Forces acting on such objects/bodies which continue doing what they are doing are balanced.

Reflection

If an object in motion tends to stay in motion, then when does a rolling ball eventually stop rolling?

Things eventually come to rest due to a force opposing motion called **friction**. You will learn more about friction in section 12-3.

Newton's Second Law of Motion

Unlike the first law, the second law of motion talks about the motion of a body when it being acted upon by a force and it states that:

The resultant/effective force acting on the body is equal to the product of the mass and acceleration of the body, and the direction of this resultant force is the same as the body's acceleration.

The following equation summarises the second law:

F = ma

Where F is the **resultant force or effective force** acting on the body in N

m is the mass in kg

a is the acceleration m/s^2

Let us now explain the second law Newton.

From Newton's first law we learnt that when forces acting on a body are balanced (meaning there is no resultant force), then the body stays either or rest or continues to move in a straight line.

Now the question that we need to ask ourselves is what happens to a body if the forces acting on it are unbalanced? (Meaning there is a resultant force.)

Example

A toy sports car shown in Figure 5 has a mass of 100 kg and is acted upon by forces as shown in the diagram below.

Figure 5: A toy sports car accessed from Creative Commons, 2011.

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Read the following questions and study the corresponding answers that are provided below.

Questions

(i) What name is given to the force which opposes the motion of the car?

(ii) What is the resultant force acting on the car?

(iii) In which direction will the car move?

(iv) Calculate the magnitude of the acceleration of the car.

(v) If the effective force is doubled, what happens to the acceleration of the car?

(vi) If the mass of the car is doubled what is the magnitude of the acceleration?

Solution

(i) *The force which acts against the direction of the car is friction.*

(ii) *Resultant force = 15N – 5N = 10N*

(iii) *The body will move towards the left which is the direction of the resultant force.*

(iv) *From second law f = ma*

Therefore a = f/m

a = 10N/100kg

= 0.1m/s^2

(v) *double the effective force*

2x 10N = 20N

a = 20N/100kg (remember the mass is constant!)

a = 0.2m/s^2

(vi) *double the mass*

2 x100kg = 200kg

a = 10N/200kg (remember the effective force is constant!)

a = 0.05m/s^2

Note it!

NOTE:

- The body will accelerate when there is a resultant force.
- Doubling the resultant force doubles the acceleration.
- Doubling the mass halves the acceleration.

This means that:

$$a \propto F$$

and

$$a \propto \frac{1}{m}$$

$$\therefore a \propto \frac{F}{m}$$

To make the proportion an equation, we use a constant k.

So the equation is:

$$ka = \frac{F}{m}$$

$$\Rightarrow F = kma$$

Where *k* is the constant of proportionality and is equal to 1 and so we can write

$$F = ma$$

Remember! The force F which produces the acceleration a is the resultant force or net force.

Example

All of the forces which are acting on the train in Figure 6 below are balanced, such that the resultant force is zero. The train is moving. Think about what this suggests about the motion of the train.

Figure 6: A train accessed from Wikimedia Creative Commons, 2001.

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Solution

Since all the forces acting on the train are balanced, the net force is zero and therefore the acceleration is also zero. But zero acceleration does not imply the train is stationery. It is simply means it is moving with a ***constant velocity.***

In equation form when:

F = ma and 'f' is zero then 'a' is also zero!

When the forces acting on a body are balanced, the body may either be stationery or moving with a constant velocity.

Activity

Activity 4

1. What will happen when two equal and opposite forces act on:

a) A stationery object?

_____

_____

b) A moving object?

_____

_____

2. Calculate:

(a) The resultant force acting when a 2 kg body accelerates at 5 m/s^2

_____

_____

_____

(b) The mass of an object whose acceleration is 2.5 m/s^2 on which a 10N net force is effective.

_____

_____

_____

(c) What can you say about the motion of a body in which the backward force is greater than the forward force as illustrated in Figure 7 below?

_____

_____

_____

Note: The length of an arrow represents the magnitude of force.

Figure 7: Moving object accessed from Creative Commons, 2011.

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3. If a wildebeest were chasing you, its enormous mass would be very threatening but if you zigzagged, then its great mass would be to your advantage. Explain why.

_____
_____
_____

After you attempted all questions, compare your answers with the correct answers provided at the end of section 12-2. If you do not understand the solutions, review the above content and try the activity again.

Newton's Third Law of Motion

- The third law of motion states that, **for every action there is an equal and opposite reaction.**

The law tells us that forces exist in pairs; namely **action and reaction.**

The distinction between action and reaction is purely arbitrary: any one of the two forces can be considered an action, in which case the other (corresponding) force automatically becomes its associated reaction.

Figure 8: Newton's third law of motion accessed from Flickr, 2011.

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With reference to Figure 8 above, what this law means is that when a book exerts a force on the table (**action)** which is a downward force, the table in turn exerts **an equal** and **opposite** upward force on the book (**reaction**).

It is important to realise that the action and reaction forces act on different bodies:

Book on table (action) and table on book (reaction).

Activity

If you have access to the internet, please go to:

http://phet.colorado.edu/en/simulation/forces-1d

And try the simulation on Forces in 1 Dimension. Does it require more force to push a book or a crate? Which object has a greater force of friction to overcome? What happens when you increase the applied force?

If you do not have access to the internet, find a heavy object and a light object. Answer the questions above.

Note it!

Key Points to Remember:

The key points to remember in this subunit on balanced and unbalanced forces are:

- Forces obey Newton's laws of motion when they are balanced or unbalanced.
- When multiple forces act on a body and their effect cancels and the net force is zero, forces are then said to be balanced. **When forces acting on a body are balanced,** then the body is either **stationery or moving with a constant speed**
- Newton's first law of motion states that every object continues in its state of rest or uniform motion in a straight line unless an external force acts on it.
- Newton's second law of motion states that the resultant/effective force acting on the body is equal to the product of the mass and acceleration of the body, and the direction of this resultant force is the same as the body's acceleration. In equation form **F = ma.**
- The third law of motion states that, **for every action there is an equal and opposite reaction.**

In section 12-3, we are going to see how the motion of objects is also affected by the force of friction.

Answers to Activities on Balanced and Unbalanced Forces

Activity 4

1.

(i) It will remain at rest

(ii) It will move with a constant velocity

2.

(a) F = ma

$F = 2\ kg \times 5\ m/s^2$

$F = 10N$

(b) m = F/a

$= 10N/2.5\ m/s^2$

$= 4\ kg$

(a) Forward force – backward force will give a negative resultant force and hence a negative acceleration. Negative acceleration suggests a body is decelerating.

3. Since the acceleration of an object is indirectly proportional to its mass, the larger the object, the smaller the acceleration. In other words, you would be able to accelerate much faster than a wildebeest!

Section 12-3: Friction

Introduction

At the end of section 12-3, you should be able to describe the effect of friction force on motion.

Imagine worn out car tyres travelling on a slippery road after a heavy rain. This is a recipe for an accident. Having good tyres can reduce car accidents since good tyres can provide enough frictional force to hold a car on the road even when the road is slippery.

Section 12-3 has 4 pages. You should spend approximately 40 minutes on this topic.

Time

What is Friction?

Friction was briefly described above as a type of force.

Simply explained, **friction** is a force which exists between surfaces which are in contact and act against the motion of a body. When a body moves in one direction, friction acts in the direction opposite to that of the moving body.

The arrow on the left in Figure 9 below represents the direction of action of friction force and the arrow on the right represents the direction of the motion of the bus.

Error! Reference source not found.

Figure 9: Direction of friction accessed from Creative Commons, 2011.

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Friction sounds like an irritation doesn't it? Well, that could be argued because friction has its good and bad side.

Let us now explore the two sides of frictional force.

Friction as a Useful Force

The amount of friction that exists between two surfaces in contact depends on the **roughness or smoothness** of the bodies. The rougher the surface, the higher the frictional force is. The smoother the surface, the lower the frictional force is.

Think of walking on a smooth surface like a polished floor, as in the woman in Figure 10 below!

Figure 10: Woman walking on a polished floor accessed from Creative Commons, 2001.

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On such surfaces we are most likely to slip and fall, right?

Why are we cautioned in some places that the floor is wet?

Is it generally easier or more difficult to walk on these surfaces? It is difficult because they are slippery!

We can therefore conclude that where friction is small, it difficult to walk because then we are more likely to slip and fall.

Why? For a simple reason, friction provides a grip between our shoes and the ground and prevents us from slipping.

Take a moment to think about this:

Without friction, objects on surfaces that are not perfectly horizontal would slide downwards and eventually fall off of the edge.

Some Other Useful Applications of Friction Force

- Friction force is used in the braking system of automobiles.
- Screws, nails and bolts are held in place by the force of friction.
- Treads on car tyres also provide friction which prevents cars from slipping.

Friction as a Problem

While friction is highly useful in some situations, in others it is problematic, and needs to be reduced.

What happens when you rub your hands together?

They become warm!

Friction causes moving objects to heat up and this may be problematic where heating up is not required as in car engines. Friction therefore reduces the efficiency of machinery as some of the energy is wasted in the form of heat energy. Friction also causes parts to wear out, for example a car tyre may become worn out after a lot of driving.

Reducing friction

To overcome friction where it may cause problems, oil is supplied to moving parts to provide **lubrication** which greatly reduces friction force.

Another method of reducing friction is by mounting moving parts on **rollers or ball bearings**. This reduces contact between moving parts and therefore highly reduces friction.

Making moving parts **very smooth** as possible also reduces friction.

Separating surfaces by an **air cushion** reduces friction too! A **hovercraft** (**air-cushion vehicle**, **ACV**) is a craft capable of travelling over surfaces while supported by a cushion of slow moving, high-pressure air which is ejected against the surface below. Because they are supported by a cushion of air, hovercraft are unique among all other forms of ground transportation in their ability to travel equally well over land, ice and water.

Figure 11: A hovercraft accessed from Wikimedia Creative Commons, 2011.

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Activity

Activity 5

Answer the following questions by filling in the spaces provided.

1. What happens when tyres are worn out?

_____

_____

2. List three useful applications of friction. Try to think of examples that were not mentioned previously.

_____

_____

_____

After completing the two questions, compare your answers to the correct answers at the end of section 12-3. Take the time needed to understand each answer before continuing.

Note it!

Key Points to Remember:

The key points to remember in this section on friction are:

- Friction is the force that opposes motion.
- Friction can be both useful and harmful as in treads on tyres and producing heat in car engines.

In the next section we are going to look at how a force can deform elastic materials.

Activity

If you have access to the internent, please go to:

http://phet.colorado.edu/sims/friction/friction_en.html
for a simulation on friction. What happens as you rub the two books together?

Answers to Activities on Friction

Activity 5

1. ***When tyres are worn out, they lose their grip and there is less friction between them and the road. Accidents can easily happen, especially on slippery roads, as in roads when it is raining.***

2.

a) Friction force is used in the braking system of automobiles, motorcycles and bicycles.

b) Screws, nails and bolts are held in place by friction force.

c) Treads on car tyres also provide friction which prevents cars from slipping.

d) Rubbing your hands together to create heat to make your hands warm.

e) Using a sander or sandpaper to smooth wooden surfaces such as a table top.

f) Mixing hard powders together with objects that you want polished. After repeated mixing (sometimes days or weeks) the objects can become smoothly polished.

g) Using a nail file to smoothen the edge of a fingernail.

h) Using a whetting stone to sharpen knives.

i) Using a grinding stone to sharpen axes.

Section 12-4: Deformation

Introduction

At the end of section 12-4, you should be able to plot, analyse and interpret an extension load graph. In our daily lives we use elastic materials such as rubber bands to hold wads of money together and on clothing to make clothes fit. This is because elastic materials can stretch back and forth. In this section we are going to see how they stretch and how they can eventually be destroyed and not stretch back to their original length.

Time

Section 12-4 has 7 pages. You should spend approximately 1 hour on this topic.

Stretching a Spring

At the beginning of this unit, it was mentioned that one of the effects which a force may have on objects is to change its size and shape. Under this section we shall explore this effect using a spring balance as an object on which a force is acting.

When a spring is stretched, a force is applied on the spring and the effect of this application is an increase in the length of the spring!

The force used to stretch the spring to a new length is called the **stretching force.**

The difference between the stretched length and the original length of the spring is called the **extension.**

Activity 6

Activity

We shall therefore investigate the relationship between the stretching force and the extension using the apparatus shown in Figure 12. If you do not have the use of known masses from a school laboratory, you can use objects of known mass such as a bag of sugar or salt.

If you have access to the internet, you can use the following simulator:
http://phet.colorado.edu/sims/mass-spring-lab/mass-spring-lab_en.html

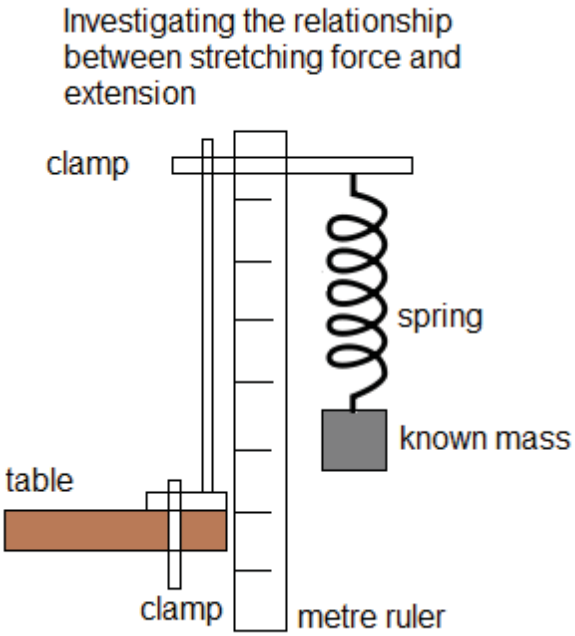


Figure 12: Hooke's Law (Hand drawn), 2011.

Procedure

a) Stretch the spring in stages by hanging standard masses of 50 g, 100 g, 150 g, 200 g and 250 g to the end of the spring as shown in Figure 12.

b) Each time, record the total mass, the length of the spring before hanging the mass, and the new length of the spring after being stretched by hanging the mass.

c) Record the results in Table 2. When filling in the table you have to calculate the stretching force = mg. Since mass is measured in grams, you need to convert it to kilograms before multiplying by g as 10 m/s^2 and the extension of the spring $x_2 - x_1$.

Table 2: Hooke's Law

Stage	Mass (g)	Force = mg (N)	Original length x_1 (cm)	New length x_2 (cm)	Extension $x_2 - x_1$ (cm)
1	50g				
2	100g				
3	150g				
4	200g				
5	250g				

Compare your table with the table given below that show typical results that can be expected from this experiment.

Table 3: Hooke's Law

stage	Mass (g)	Force = mg (N)	Original length x_1 (cm)	New length x_2 (cm)	Extension $x_1 - x_2$ (cm)
1	50g	0.5	5	6	1
2	100g	1	5	7	2
3	150g	1.5	5	8	3
4	200g	2	5	9	4
5	250g	2.5	7	17	10

d) Plot a graph of extension against the stretching force (load) using the results you obtained in Table 2 in the space provided below.

Compare your graph to the graph plotted in Figure 13 for the results of Table 3.

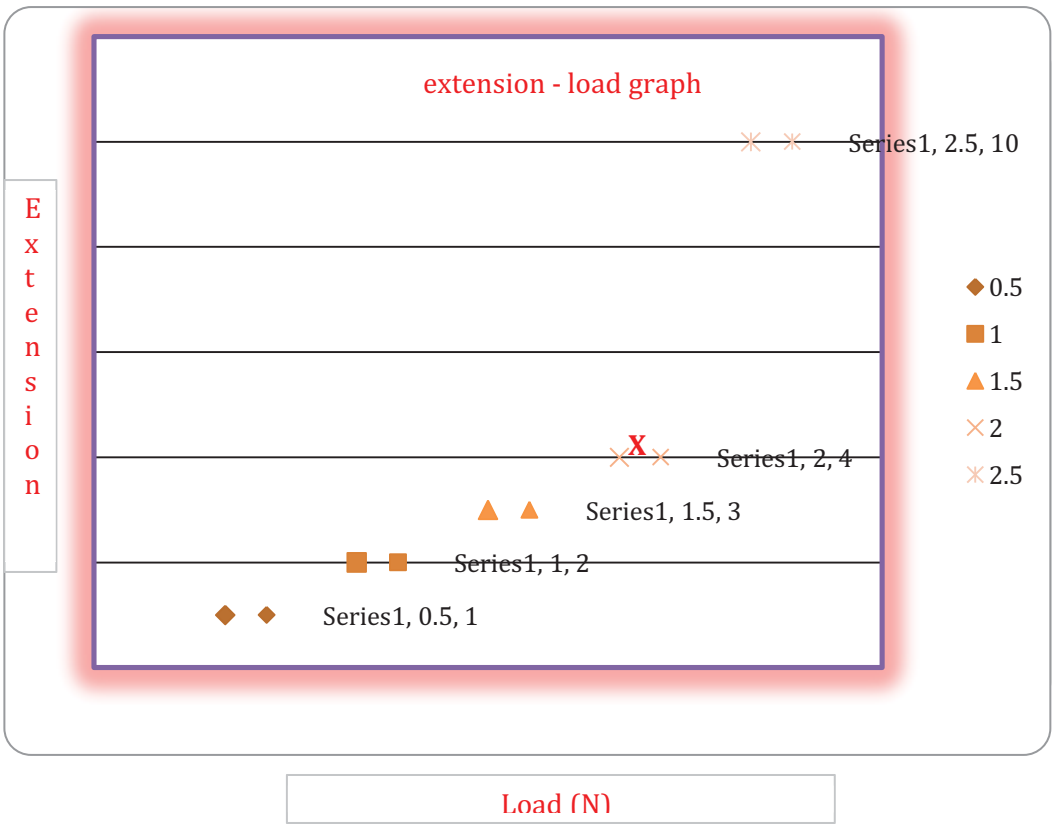


Figure 13: Extension – load graph

Conclusions:

1. The graph is a straight line passing through the origin, except beyond point X. What does the straight line proportion of the graph suggest?

-

_____
___

Compare your answer to the following:

A straight line suggests that the **stretching force is directly proportional to the extension**

F α e

F = ke where k is the force constant of the spring

Check the following from the graph:

2. If you double the stretching force what happens to the extension?

_____

_____

Compare your answers with the following correct answers.

Doubling the stretching force doubles the extension

For example; 0.5N x 2 = 1N 1 cm x 2 = 2 cm

3. If you divide the stretching force by the corresponding extension, what type of result can you expect?

_____

_____

Compare your answers with the following:

Dividing the stretching force by the corresponding extension always gives the same result.

For example;

0.5N / 1cm = 0.5N/cm

1N / 2cm = 0.5N/cm

1.5N / 3cm = 0.5N/cm

For the above spring, 0.5N/cm is the force constant of the spring, that means every 0.5N produces a 1 cm extension.

The direct proportionality between the extension of the spring and the stretching force is called **Hooke's law**. It was a scientist named Robert Hook who discovered this relationship and hence it is named after him.

4. What happens beyond point X?

_____

_____

Compare your answers with the following:

Beyond this point, the graph takes a different shape and there is no longer a direct proportional relationship between the extension and the stretching force.

At point X, the spring is said to have reached its **elastic limit,** beyond which it becomes permanently stretched **(it gets deformed)** and it no longer returns to its original length.

Example

For the spring used above, what extension would be produced by a 5N force if the elastic limit is not exceeded?

Solution

$e = F/k, \quad e = 5N/0.5 \quad = 10cm$

Activity

Activity 7

1. A stretching force of 25N on a spring produces an extension of 2.5 cm. Assume that the limit of proportionality has not been reached and find the following:

   a) The extension produced if a force of 15N is applied.

   _____
   _____
   _____

   b) The force required to stretch the spring by 3.5 cm.

   _____
   _____
   _____
   _____

Compare the correct answers provided at the end of section 12-4. Be sure you understand how the calculations are done before you continue.

Key Points to Remember:

Note it!

The key points to remember in this section on deformation are:

- For an elastic object, the stretching force is proportional to the extension of the object, provided the limit of proportionality is not exceeded.

You have now completed the last section of this unit on force. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Answers to Activities on Deformation

Activity 7

1. *Given: Stretching force, F = 25 N*

   Extension, e = 2.5 cm

By Hooke's Law $F = ke$

$25\ N = k\ (2.5\ cm)$

Therefore, $k = 25N/2.5\ cm$

$= 10\ N/cm$

a) *Let the extension produced be e1 by the stretching force F1 = 15 N.*

Then, $F1 = ke_1$

Therefore $e_1 = \frac{F1}{k}$

$= \frac{15\ N}{10}$

$= 1.5\ cm$

b) *Let the stretching force be F2 that produces the extension* $e_2 = 3.5\ cm$.

Then, $F2 = ke2$

$= 10 \times 3.5\ cm$

$= 35\ N$

Unit Summary

Summary

In this unit you learned that there are different types of forces, each of which has a vital role that it plays in our lives even if we sometimes do not notice it. We have learned that:

- Forces can change the size and hence the shape of some objects such as a spring. Sometimes the shape or size may become permanently changed.
- Forces obey Newton's laws of motion when they are balanced or unbalanced.
- When multiple forces act on a body and their effect cancels and the net force is zero, forces are then said to be balanced. **When forces acting on a body are balanced** then the body is either **stationery or moving with a constant speed**
- Newton's first law of motion states that every object continues in its state of rest or uniform motion in a straight line unless an external force acts on it.
- Newton's second law of motion states that the resultant/effective force acting on the body is equal to the product of the mass and acceleration of the body, and the direction of this resultant force is the same as the body's acceleration. In equation form **F = ma.**
- The third law of motion states that, **for every action there is an equal and opposite reaction.**
- Friction is the force that opposes motion.
- For an elastic object, the stretching force is proportional to the extension of the object, provided the limit of proportionality is not exceeded.

You have completed the material for this unit on force. After reviewing the content, try the assignment and check your answers with those provided and clarify your misunderstandings (if any). The final step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers Mass, Weight, and Density.

Assignment 12

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:36]

1. Why is force referred to as a vector and not a scalar?

   _____
   _____
   _____(1)

2. State and explain the name of the force which produces acceleration:

   _____
   _____
   _____(2)

3. What happens to a body when the forces acting on it are balanced? Unbalanced?

   _____
   _____
   _____
   _____(2)

4. State Hooke's law:

   _____
   _____
   _____(1)

5. What happens to a spring when it has stretched beyond its limit of proportionality?

   _____
   _____
   _____(1)

6. Calculate the **resultant** or **net** force in each of the following cases in table 1 below. (3)

Forces acting on a body	NET FORCE	Direction of net force
(i) 12N ← ● → 12N		
(ii) 6N ← ● → 14N		
(iii) 6N → ● → 6N		

7. Calculate:

(a) The resultant force acting when a 4 kg body accelerates at 10 m/s^2

_____
_____
_____
_____
_____ (2)

(b) The mass of an object whose acceleration is 5 m/s^2 on which a 20N net force is effective.

_____
_____
_____
_____
_____ (2)

8. List three ways in which friction can be reduced.

_____
_____
_____
_____ (3)

9. A stretching force of 75N on a spring produces an extension of 7.5 cm. Assume that the limit of proportionality has not been reached and find the following:

   a) The extension produced if a force of 30N is applied.

   _____
   _____
   _____
   _____
   _____
   _____ (3)

   b) The force required to stretch the spring by 10.5 cm.

   _____
   _____
   _____
   _____
   _____
   _____ (3)

10. In a spring experiment, the following results were obtained:

Load (N)	Length of Spring (mm)	Extension of Spring (mm)
0	30	0
2	46	16
4		32
6		48

8		64
10		80
12		96
14		112

a) Complete the table. (3)

b) What is the length of the spring when it is unstretched?

_____
_____ (1)

c) Plot a graph of load against extension using the data in the completed table on the space provided below. (5)

d) What load would give an extension on 72 mm? Use the graph.

_____
_____ (1)

e) What would be the spring length be if the load was 7N? Use the graph.

_____
_____ (1)

11. As you sit in your chair and study your physics (presuming that you do), the force of gravity acts downward upon your body. The *reaction force* to the force of the Earth pulling you downward is ___. (1)

a. the force of the chair pushing you upward
b. the force of the floor pushing your chair upward
c. the force of the Earth pushing you upward
d. the force of air molecules pushing you upwards
e. the force of your body pulling the Earth upwards
f. ... nonsense! Gravity is a field force and there is no such reaction force.

12. Which of the following are **always true** of an object that is at equilibrium? Include all that apply. (1)

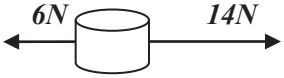
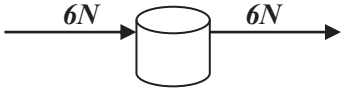
a. All the forces acting upon the object are equal.
b. The object is at rest.
c. The object is moving and moving with a constant velocity.
d. The object has an acceleration of zero.
e. There is no change in the object's velocity.
f. The sum of all the forces is 0 N.
g. All the forces acting upon an object are *balanced.*

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 12

1. *It has both magnitude and direction (1)*
2. *Resultant/net force, it is the unbalanced force which produces acceleration (2)*
3. *When forces are balanced, the body is stationery or moving with a constant velocity (2)*
4. *Stretching force is directly proportional to the extension (1)*
5. *It becomes permanently stretched (deformed)/ it does not return to its original length and shape (1)*

6. *(3)*

Forces acting on a body	*NET FORCE*	*Direction of net force*
(i)	*0N*	*No direction*
(ii) 	*8N*	*To the right*
(iii) 	*12N*	*To the right*

7. *(a)* $F = ma$

$F = 4kg \times 10m/s^2$

$F = 40N$ *(2)*

(b) $m = F/a$

$= 20N/5m/s^2$

$= 4kg$ *(2)*

8. *Three ways in which friction can be reduced: choose three of the following (3)*
   - *a) Lubrication*
   - *b) Putting moving parts on rollers or ball bearings e.g. a gas heater on four wheels*
   - *c) Making moving parts very smooth*
   - *d) Separating surfaces by an air cushion*

9. *Given: Stretching force, F = 75 N*

Extension,	*e*	=	*7.5 cm*
By Hooke's Law	*F*	=	*ke*
	75 N	=	*k (7.5 cm)*
Therefore,	*k*	=	*75N/7.5 cm*
		=	*10 N/cm*

a) Let the extension produced be e_1 by the stretching force F1 = 75 N.

Then,	*F1*	=	*ke_1*
Therefore e_1	=	$\frac{F1}{k}$	
	=	$\frac{75\ N}{10}$	
	=	*7.5 cm (3)*	

b) Let the stretching force be F2 that produces the extension e_2 = 10.5 cm.

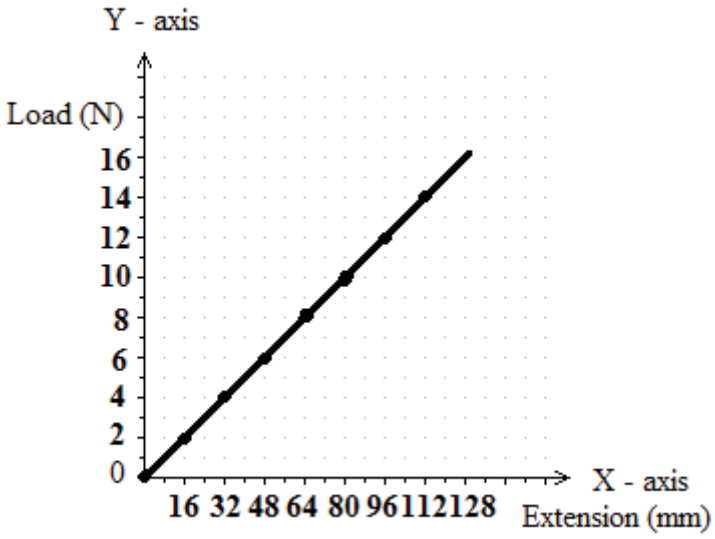
Then,	*F2*	=	*ke_2*
	=	*10 x 10.5 cm*	
	=	*105 N (2)*	

10. a) (3)

Load (N)	*Length of spring (mm)*	*Extension of spring (mm)*
0	*30*	*0*
2	*46*	*16*
4	*62*	*32*
6	*78*	*48*
8	*94*	*64*
10	*110*	*80*
12	*126*	*96*
14	*142*	*112*

b) The length of the spring when unstretched is 30 mm. (1)

c) Graph of load against extension:



c) 9 N

d) 56 mm

11. Answer: E

The most common wrong answer is a - the force of the chair pushing you upward. As you sit in your chair, the chair is indeed pushing you upward but this is not the reaction force to the force of the Earth pulling you downward. The chair pushing you upward is the reaction force to you sitting on it and pushing the chair downward. To determine the action-reaction force pairs if given a statement of the form object A pulls X-ward on object B, simply take the subject and the object in the sentence and switch their places and then change the direction to the opposite direction (so the reaction force is object B pulls object A in the opposite direction of X). So if the Earth pulls you downward, then the reaction force is you pull the Earth upward.

12. **Answer: DEFG**

These (DEFG) statements are always true. Statements ABC might be true but are not always true.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physics course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 12

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 50 minutes.

(Total Marks:46)

Multiple choice questions (1 mark each)

1. Several effects are possible when a force is applied on a body. Which of the following effects is not possible?
   a. The speed of the object increases
   b. The objects changes direction of movement
   c. The mass of the object increases
   d. The length of the object increases
2. Which one of the following quantities is not a force
   a. Weight
   b. Centripetal
   c. Friction
   d. Length
3. What is the resultant force in the following diagram:

   a. 12N to the right
   b. 12N to the left
   c. 2N to the left
   d. 2N to the right

4. What is the acceleration of a body of mass 2kg moving on a frictionless surface with a forward force of 10N?
   a. $8m/s^2$
   b. $12m/s^2$
   c. $20m/s^2$
   d. $5m/s^2$
5. Calculate the size of a force that will produce an extension of 5cm on a spring whose force constant is 2N/cm
   a. 10N
   b. 20N
   c. 30N
   d. 40N
   e. 50N

Structured questions

1. (a) Define force (1)
   (b) State any three effects of force on objects (3)
   (c) State and briefly describe any two types of forces that you have learn about (4)

2. (a) State the three laws of motion of Isaac Newton (3)
   (b)
   (i) Calculate the acceleration of body of mass 50kg that is pushed with a 110N force when there is no friction (3)
   (ii) What resultant force acts on a body moving with a constant velocity? (2)

3. (a) Fill in the following table to show two positive and two negative impacts of friction force (4)

Negative effects	Positive effects
1.	1.
2.	2.

(a) State two ways in which friction force may be sufficiently reduced when it is not wanted (2)

4. When a force of 100N is hung on a spring an extension of 10 cm is produced. Assuming that the limit of proportionality has not been exceeded, find:

(i) The force required to produce an extension of 2 cm (2)

(ii) The extension produced when a 70N weight is hung on the spring (2)

(iii) Explain the limit of proportionality (1)

5. Describe the motion of a body which is moving with the same speed but a changing velocity. Mention the name of the net force which causes this body to accelerate and hence state its direction. (3)

6. In a spring experiment, the following results were obtained:

Load (N)	Length of spring (mm)	Extension of spring (mm)
0	50	
1	58	
2	66	
3	74	
4	82	
5	90	
6	102	
7	125	

a) Copy and complete the table. (3)

b) What is the length of the spring when it is unstretched? (1)

c) Plot a graph of load against extension using the data in the completed table. (5)

d) Mark the elastic limit on your graph. (1)

e) What load would give an extension on 20 mm? (1)

f) What would be the spring length of 3.5N? (1)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 13

Mass, Weight and Density

Study Skills

Some of the words you are learning in this course, you may already know, but many of them will be new to you. To help remember them, try to use them every day in a sentence or think of examples when you define them. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In this unit we are going to learn the differences between weight and mass. We will explain that mass is not weight even though in our everyday language, we treat them as the same thing. We will also find that the volume of different objects in order to be able to do density calculations. Experiments to find density will be described thoroughly to enable you to conduct them at home through some improvising. This is needed since you may not have access to the apparatus that you would normally use in the laboratory.

Time

This unit consists of 39 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. You should focus on those skills while studying this unit.

Outcomes

Study skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Measure* physical quantities.
- *Give* the correct SI units of the different physical quantities.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.
- *Analyse* experimental data.
- *Apply* correctly various formulae which relate the different physics concepts and theories to the world around us.

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Define* mass and weight.
- *Differentiate* between mass and weight.
- *Calculate* mass and weight given the acceleration due to gravity.
- *Describe* inertia as a property of mass.
- *Measure and calculate* volume.
- *Calculate* the density of solids and liquids.
- *Describe* experiments to determine density of irregularly shaped solids.
- *Analyse* data regarding experiments that determine the density of irregularly shaped solids.

Terminology

Density:	The relative mass or "heaviness" of an object within a constant volume.
Gravitational field:	The space around an object in which it exerts gravitational pull.
Gravitational field strength:	The acceleration an object will experience within that gravitational field.
Inertia:	The reluctance of an object to start moving if it stationary and its reluctance to stop moving if it is in motion.
Mass:	The amount of matter in an object.
Volume:	Amount of space occupied by an object.
Weight:	The force exerted on an object due to gravity.

Section 13-1: Mass and Weight

Introduction

By the end of section 13-1, you should be able to define mass and weight, differentiate between mass and weight, calculate mass and weight given acceleration due to gravity and describe inertia as a property of mass.

Time

Section 13-1 has 19 pages. You should spend approximately 5-6 hours on this topic.

Mass

A person will say: "I want to go weigh myself. I think I am gaining weight". Is this person really gaining weight? What about mass? How are these two different? Let us start first by explaining mass.

Your mother can ask you to go to a shop to buy her a 50 kg packet of bread flour. This 50 kg of bread flour will be the same mass regardless of which shop you buy it from.

The mass of an object is a measure of the amount of matter is in it.

This mass will only depend on how atoms are arranged in the object and the size of those atoms. This means the mass of an object is its basic property and therefore cannot be changed by the location, shape or speed of the object.

To illustrate this further, the 50 kg of flour will remain 50 kg whether it is in a bag, taken out and put into a bucket or even put in a box. The shape of the container does not affect the mass. If you buy the flour from a shop in town and carry it home in a speeding taxi, it will still be 50 kg. That means the location and the speed of the taxi does not affect it.

Remember, mass is a basic quantity which is measured in kilograms (kg), as explained in Unit 10 on measurement. This is the SI unit of mass. Larger masses can be measured in tonnes, while small masses can be measured in grams (g). Even small masses are measured in milligrams (mg).

- 1 tonne = 1000 kg
- 1 g = 10^{-3} kg which the same as 1 g = $\frac{1}{1000}$ kg
- 1 mg = 10^{-3} g or $\frac{1}{1\,000}$ g

What Do You Use to Measure Mass?

In most school laboratories, mass is measured by a beam balance and or an electronic balance. Otherwise there are a variety of other balances that can be used. The images shown in Figures 1a and 1b show a triple beam balance that is used in some laboratories.

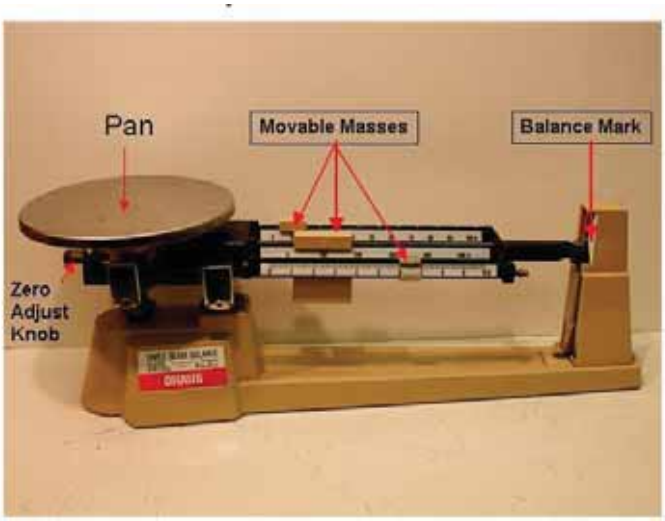

Figure 1a: A Triple Beam Balance accessed from Creative Commons, 2011.

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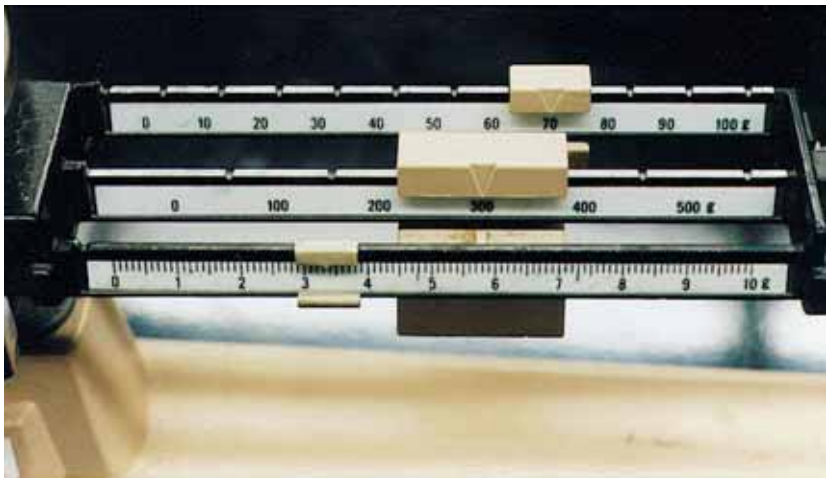

Figure 1b – Triple Beam balance accessed from Creative Commons, 2011

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When you want to find the mass of an object, you must empty the pan and set it to read 0.00 g. There is a little knob under the pan which you can screw in or out to set the balance to 0.00 g on the triple beam balance shown in Figure 1a. If you were to put a can of soda onto the pan and slide the movable masses on the beams until the beams are balanced, you would get the following results:

Rear beam reads…… 70 g
Middle beam reads ..... 300 g
Front beam reads.....3.34 g

The mass of the soda..... 373.34 g

Because of the sliding masses, the beam balances are also called sliding mass balances.

Figure 1c: Electronic top pan balance accessed from Wikimedia Creative Commons, 2011.

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How do you use the electronic top pan balance shown in Figure 1c?

You take any substance you want to measure and put it on the electronic balance and read its mass directly from the screen provided. **You should see this for yourself.** Please visit a nearby clinic and politely ask a nurse to show you how they measure the mass of a baby. She/he will put the baby completely naked onto the balance and the mass will appear on the screen. Unfortunately, not all clinics have electronic balances. Ask the nurse to show you what they use.

There is a variety of other balances including bathroom and kitchen scales, some of which are shown below in figures 1d, 1e, 1f and 1g. Do not despair if you are not familiar with them. These images are intended to give you a good idea of other types of balances.

Figure 1d: Electronic bathroom scale accessed from Creative Commons, 2011.

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Figure 1e: Mechanical bathroom scale accessed from Creative Commons, 2011.

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Figure 1f: Mechanical kitchen scale accessed from Creative Commons, 2011.

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Figure 1g: Electronic kitchen scale accessed from Creative Commons, 2011.

So, how is mass different from weight?

Weight

Let us refresh our memories a little bit. Acceleration due to gravity *(g)* causes all objects to fall towards the centre of the earth. This happens as a result of the force of attraction between the earth and the falling object. Refer to Unit 11 for more details.

Suppose we were to let a body of mass *m* fall. It will move towards the centre of the earth with an acceleration of *g*. If we use the equation **force = mass x acceleration (f = ma)**, as discussed in Unit 12, we can then see that the body is acted upon by a force of *mg* for falling bodies towards the centre of the earth. This force of gravity acting on the object is known as its weight. So:

Weight = mass x acceleration due to gravity

$W = mg$ where W = weight in Newtons (N)

m =mass in kilograms (kg)

g = acceleration due to gravity (m/s^2)

The weight of an object is the force of gravity acting on the object.

As we can see, weight is a force; therefore its SI unit is the Newton (N) like all the other forces. Weight is measured in physics laboratories using a spring balance. Figure 2 below shows you the spring balance.

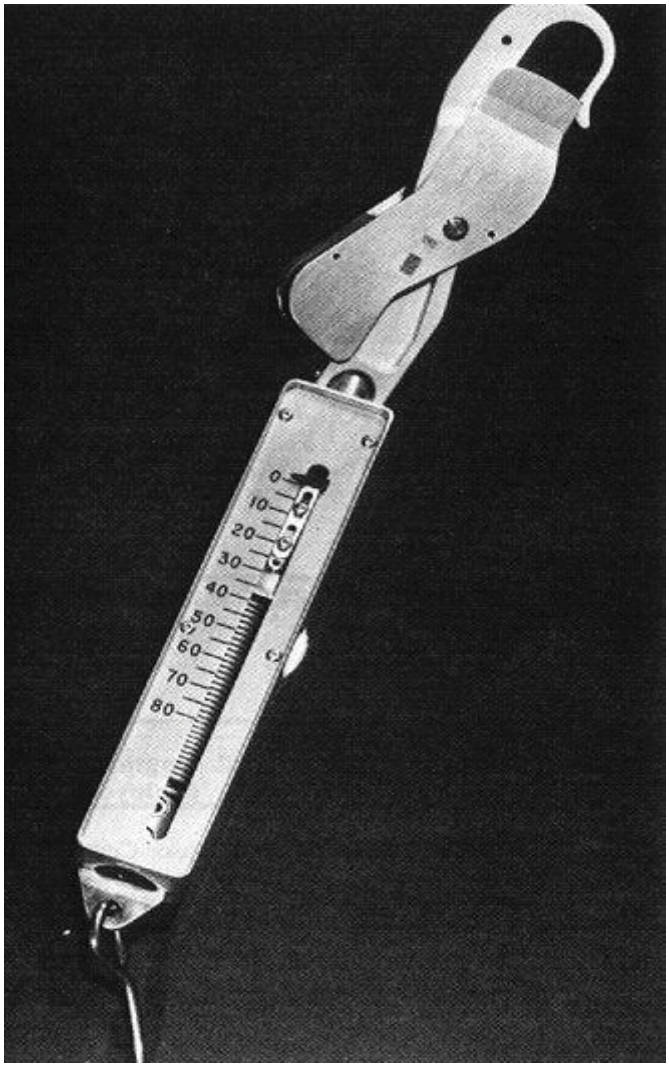

Figure 2 - A spring balance accessed from Wikimedia Creative Commons, 2011.

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Example:

The acceleration due to gravity on Earth is approximately 10 m/s^2.

1. If a book has a mass of 1.5 kg, how much is its weight?

2. What is the mass of a lady whose weight is 450N?

Solutions:

1. *Weight of book W* = *mg*

= *1.5 kg x 10 m/s^2*

= *15N*

2. *mg* = W

$m = \frac{W}{g}$

$$= \frac{450N}{10m/s^2}$$

$$= 45 \text{ kg}$$

From the example above, we calculated the weight of the book to be 15N.

If the same book could be taken to the surface of the moon, would its weight would be more than 15N, the same or less than 15N?

_____

The book would weigh less than 15N because gravity on the moon (g) is less than gravity on Earth. On Earth, gravity is roughly 10 m/s^2, on the surface of the moon (g) is about one sixth of the gravity on Earth!

Compared to the moon, the Earth's mass is larger than the moon's mass. Therefore the Earth has a greater gravitational pull on objects.

Example

1. What would the weight of the same book on the surface of the moon be? Let us calculate it.

Solution

$W = mg$

$= 1.5 \text{ kg } x \frac{1}{6} x \text{ } 10 \text{ m/s}^2$

$= 2.5N$

Does mass of an object change based on its location? Take a moment to think about this.

Reflection

2. What would the mass of the book be on the moon?

_____

Solution:

The mass of the object would not change. It would still be 1.5 kg.

Note it!

NOTE:

Unlike mass which does not change due to location, weight can change. It depends on the strength of gravitational pull of the surface on which a body is.

There you have it! This is the major difference between mass and weight.

Solve the following problems to get more practice. The correct answers will be provided at the end of section 13-1.

Activity 1

Activity

1. Calculate the weight of a man who has a mass of 100 kg:

a) On the Earth where g = 10m/s^2

b) On the moon where g = 1.6m/s^2

2. A bag of flour has a weight of 600N on the moon, how much is its mass?

3. What is the mass of an object that has a weight of 115 N on the moon?

4. Calculate the weight of a car with a mass of 1500 kg on Earth.

5. If an astronaut's mass is 80 kg on Earth, what would it be on the moon?

Compare your answers to the ones given at the end of section 13-1. As needed, review the content above to be sure you understand each answer before you continue.

Gravitational Field and Field Strength

Let us now consider that Earth is surrounded by a gravitational field. Objects that are in this field will experience a force pulling it towards the centre of the Earth. This force will be stronger on the surface of the Earth and will get weaker the further the object is away.

The gravitational field strength near the Earth's surface is approximately 10 N/kg. This value can be found by dividing the weight of any object by its mass.

$$\text{Gravitational field strength} = \frac{weight}{mass}$$

Since we already know that

Weight = mass x acceleration due to gravity

It follows then that the gravitational field strength (in N/kg) must be equal to the acceleration due to gravity, *g* (in m/s^2).

Therefore, weight = mass x gravitational field strength

Example:

The acceleration due to gravity near the surface of the moon is 1.6 m/s^2

(a) What is the gravitational field strength?

(b) What is the weight of an astronaut on the moon if his mass is 80 kg?

Solution:

(a) gravitational field strength = acceleration due to gravity

= 1.6 N/kg

(b) Weight = mg

= 80 kg x 1.6 m/s^2

= 128N

Inertia

Look at Figure 3. It shows various boulders with different masses.

Figure 3 – Boulders accessed from Creative Commons, 2011.

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Activity

If you were to push the bolders, which ones will move more easily and which ones will be harder to push?

_____

_____

Compare your answers with the following:

It will be easier to push the smaller boulders as they have less mass.

All objects have inertia. The inertia of an object is the reluctance of the object to start moving if it is stationary and its reluctance to stop moving if it is in motion.

All objects have this reluctance - but do some objects have more of a tendency to resist changes than others?

Absolutely yes! The tendency of an object to resist changes in its state of motion varies with mass. **The more inertia an object has, the more mass it has. A more massive object has a greater tendency to resist changes in its state of rest or motion.**

Activity 2

Figure 4: Vehicle hitting another vehicle accessed from Wikimedia Creative Commons, 2011.

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1. As shown, in Figure 4, suppose a vehicle carrying passengers was moving at a fixed rate and it suddenly ran into another vehicle. What would happen to the passengers?

Base your answer on inertia and refer to Figure 4.

_____

_____

_____

_____

2. In a different scenario, suppose you are riding in the passenger seat of a car moving straight ahead, when suddenly the driver makes a quick left turn. What happens to you?

_____

_____

The following is for questions 3 and 4.

Figures 5a and 5b show two identical looking bricks, one brick is made of light-weight plastic and the other brick is made of heavy-weight plastic.

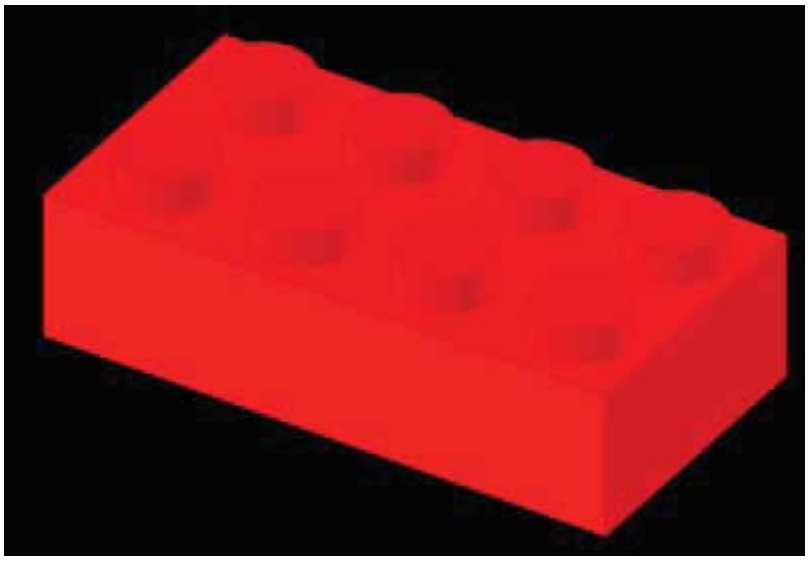

Figure 5a - Plastic brick (light-weight plastic) accessed from Creative Commons, 2011.

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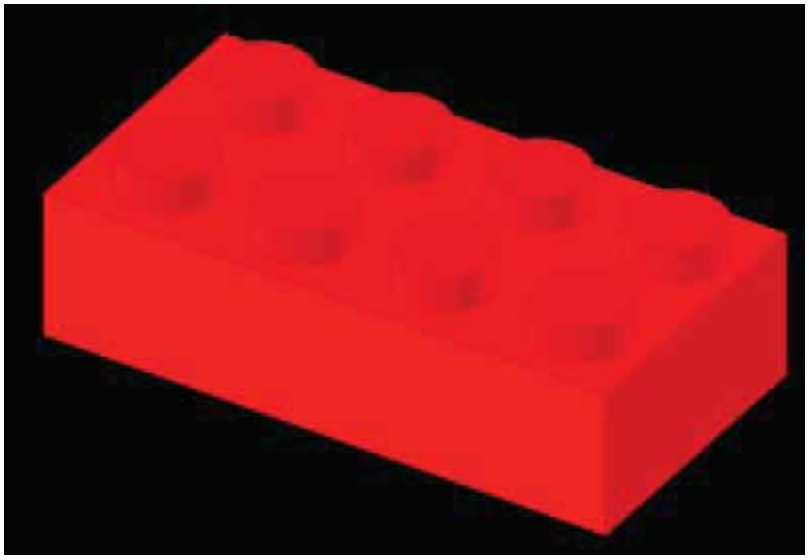

Figure 5b - Plastic brick (heavy-weight plastic) accessed from Wikimedia Creative Commons, 2011.

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3. If you put the two bricks on a table at rest and could not lift them, how could you tell which brick had more mass?

_____
_____
_____
_____

4. Now suppose you were on the moon with the same two bricks. If you pushed them the same way, how would your results change?

_____
_____
_____
_____

Compare your answers with the correct answers at the end of section 13-1. Be sure you understand the answers before continuing.

Create a table that summarises the differences between mass and weight:

Mass	Weight

Compare and contrast your table to the following:

Table 4.1: Differences between mass and weight

Mass	Weight
• The amount of matter in an object. • Is measured in kilograms (kg) and other related units. • Is measured by a beam balance or electronic balance. • Is constant regardless of place, location or speed. • Has only magnitude but no direction; a scalar quantity.	• The force of gravity acting on an object. • Is measured in Newtons (N). • Is measured by a spring balance. • Changes when there are differences in gravitational force. • Has both magnitude and direction; a vector quantity (this was covered in Unit 11.)

Activity

Activity 3

1. An astronaut and his spacesuit have a total mass of 120 kg. What will be his:

(a) Weight on Earth?

_____
_____
_____
_____

(b) Mass on the moon?

_____
_____
_____
_____

(c) Weight on the moon?

_____
_____
_____
_____

2. The acceleration due to gravity on Earth is 10 m/s^2.

(a) What is the gravitational field strength?

_____
_____

(b) What is the mass of an object on earth which has a weight of 200N?

_____
_____
_____
_____

Compare your answers to those provided at the end section 13-1. I hope you got them all correct. Spend enough time to ensure you fully understand each answer. Once you can confidently answer the questions, continue to the next section, which covers density.

Answers to Activities on Mass and Weight

For the following solutions, check that you have the correct units. Correct units are an important part of the solution.

Activity 1:

Mass, m = 100 kg

(a) On earth g_e = $10m/s^2$

Weight on Earth W_e = mg

= 100 kg x 10 m/s^2

= 1000N

(b) On the moon g_m = $1.6\ m/s^2$

Weight on the moon W_m = 100 kg x $1.6\ m/s^2$

= 160N

1. W = 600N

g = 10 N/kg

m = $\frac{w}{g}$

= $\frac{600N}{10N/kg}$

= 60 kg

2. W = 115N

g = 1.6 m/s2

m = $\frac{w}{g}$

= $\frac{115N}{1.6m/s^2}$

= 71.86 kg

3. W = mg

= 1500 kg × 10 m/s^2

= *15,000N*

4. *Mass is independent of location, so the astronaut's mass on the Moon is the same as the astronaut's mass on the Earth.*

   Therefore:

   Astronaut's mass on the moon = Astronaut's mass on Earth

   = 80 kg

Activity 2:

1. *Two outcomes will be seen:*

The car will be abruptly stopped. Even though its motion will have stopped, it will continue ploughing into the brick wall rather than bouncing off it due to inertia.

People or objects inside the vehicle will also continue to move forward, straight into the dashboard or windscreen in response to inertia (seat belts and airbags help protect people.)

2. *The entire vehicle, you and everything else inside the vehicle is still responding to inertia and therefore "wants" to move forward even as the car is turning to the left.*

3. *You could give the bricks an identical push in an effort to change their state of motion. The brick which offers the least resistance is the brick with the least inertia and therefore the brick with the least mass.*

4. *The bricks will offer the same resistance on Earth because the mass of an object does not change.*

Activity 3

1. *Mass, m = 120 kg*

   On Earth, g_e = 10 N/kg

   On moon g_m = 1.6 N/kg

   (a) Weight on Earth W_e = mg_e

   = 120 kg x 10 N/kg

   = 1,200N

(b) Mass on moon = *120 kg (unchanged)*

(c) Weight on moon W_m = mg_m

= *120 kg x 1.6 N/kg*

= *192N*

2. (a) Gravitational field strength due to gravity = *Acceleration*

= *10 N/kg*

(b) m = *W/g*

= *200 N/10 N/kg*

= *20 kg*

Section 13-2: Density

Introduction

By the end of section 13-2, you should be able to measure and calculate volume, calculate density of solids and liquids and describe and analyse data on experiments to determine the density of irregularly shaped solids.

Time

Section 13-2 has 16 pages. You should spend approximately 5-6 hours on this topic.

Density

The density of an object is defined as its mass per unit volume.

Density = $\frac{mass}{volume}$

In our everyday life we encounter different substances. We will say some are heavier than others and yet when we look at them they may seem the same.

Reflection

Think about the same size bag filled with two different materials such as flour and feathers. Which one is heavier?

_____

Compare your answer with the following:

The same bag is heavier when filled with flour than with feathers! If an object with the same dimensions as another is heavier, the heavier object has more density.

We say the two objects are occupying the same amount of space or **volume** but have different densities. We therefore describe **volume as the amount of space occupied by an object.** Remember, mass is the amount of matter in an object.

Therefore:

$\rho = \frac{m}{V}$ where ρ = density of the object in kg/m^3

m = mass of the object in kg

V = volume of the object in m^3

The SI unit of density is kilogram per cubic metre (kg/m^3). Another unit is also gram per cubic centimetre (g/cm^3). Remember, for this course, we are assuming that volume is measured in m^3 or cm^3 and mass in kg or g.

Reflection

Around 250 B.C., the Greek mathematician Archimedes was given the task of determining if the king's crown was actually made of pure gold. The king had given a chunk of gold to the goldsmith, but suspected that the goldsmith had made mixed in some silver and kept some pure gold for himself. Legend has it that Archimedes arrived at a method of determining what the crown was made of when we lowered himself into a bath tub. He noticed that the water level in the tub rose as his body entered the tub. He was able to show that the volume of water displaced by his body was equal to the volume of his body. **How do you think Archimedes was able to apply this knowledge to the king's problem?**

Archimedes was able to determine the density of the crown by lowering it into water. He divided the mass of the object by the volume of water it displaced (mass/volume = density) and compared this to a pure sample of gold. After performing his test, Archimedes discovered that silver had indeed been used.

The method discovered by Archimedes can be used to find the density of different substances. We can carry out these experiments in the laboratory. At home, you can improvise with the apparatus described below.

Activity

Activity 4

Experiment 1: To determine the density of a liquid.

Apparatus needed:

- Beaker or a jug with calibrations (gradations).
- Balance such as a baby scale at a clinic or a kitchen scale.

If you do not have these apparatus, but you have access to the internet, please use the simulation: http://phet.colorado.edu/sims/density-and-buoyancy/density_en.html

Procedure:

1. Find the mass of a clean, dry beaker or jug (m_1).

   The mass is ……

   If you do not have a balance: Let m_1 = 20 g

2. Fill the beaker or jug with a volume (V) of water.

   The volume is ……...

   If you do not have a beaker or jug: Let V = 50 cm^3

   Figures 6a and 6b are aimed at helping you to be able to use the instruments that are used to measure volume of a liquid.

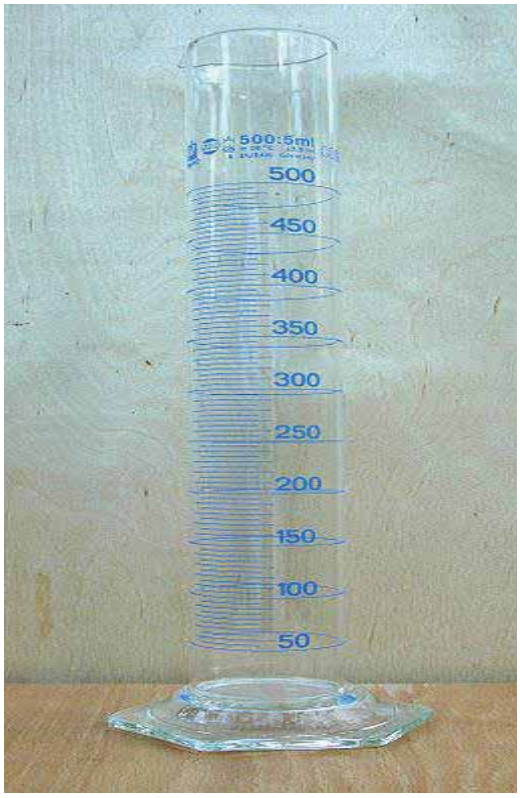

Figure 6a - Graduated measuring cylinder accessed from Wikimedia Creative Commons, 2011.

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a. Keep the measuring cylinder **vertical**.

b. Place your eyes **level** with the surface of the liquid.

c. Read to the **lower** surface of the meniscus (A meniscus is the curve at the surface of the liquid).

The beakers seen in figure 6b are found in a laboratory. They are similar to a jug that you can use at home for your experiment.

Figure 6b – Beakers of different sizes accessed from Wikimedia Creative Commons, 2011.

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Remember: ml = cm^3, therefore if your jug gives its volume in ml it the same as cm^3. Also when reading the volume of the liquid, make sure that the eye is level with the base of the meniscus of the liquid.

3. Find the mass of the jug and the water (m_2).

   The mass is ……

   If you do not have a balance: Let $m_2 = 25$ g

Calculation: If the masses are measured in g, and the volume in cm^3, then the density of the liquid

$$\rho = \frac{m_2 - m_1}{V} \text{ g/cm}^3$$

Based on your calculation, the density of water is:

_____

_____

_____

Solution: Compare your value to the solution below.

If you used the given values:

$$= \frac{25g - 20g}{50cm^3}$$

$$= \frac{5g}{50cm^3}$$

= 1 g/cm^3

Your value should be approximately 1 g/cm^3. If you have found a value that is not approximately 1 g/cm^3, what could have caused this?

_____
_____
_____

The value could be different due to experimental error. Experimental error is a normal occurrence in scientific studies. All we can do is try to minimize it and explain what the sources might be. Try doing the experiment until you get a value close to 1 cm^3.

Example:

An empty measuring cylinder has a mass of 200 g. A liquid is poured into the measuring cylinder until the level is at the 80 cm^3 mark. The total mass is now 272 g. What is the density of the liquid in g/cm^3?

Solution:

Mass of the liquid m = m_2 - m_1

= 272 g - 200 g

= 72 g

Volume V = 80 cm^3

Density ρ = $\frac{m}{V}$

= $\frac{72g}{80cm^3}$

= 0.9 g/cm^3

Activity 5

Now, please answer the questions below.

Activity

1. The mass of an empty measuring cylinder is 60.0 g. When 30 cm^3 of oil is poured into it, the total mass is 87.6 g. What is the density of the oil?

   _____
   _____
   _____
   _____
   _____

2. The mass of an empty graduated cylinder is 70 grams. When it is filled with 50 ml of liquid its mass is 120 grams.
   (a) What is the mass of just the liquid?
   (b) What is the density of the liquid?

_____
_____
_____
_____
_____

How did it go? Go to the end of section 13-2 to check if you got each question right. If you got all of them correct, proceed to the next section. If you got any wrong, be sure you understand why before you continue.

Activity 6

Experiment 2a: To determine the density of a regularly-shaped object.

The table below show the densities of some common substances. For the three experiments that you have to carry out, use this table to predict the densities of the three objects that you will use. After carrying out the experiments, use the given examples to compare your calculated values with your predictions.

Activity

Table 4.2: Densities of some common substances

Substance	Density (g/cm^3)
Air	0.0013
Feathers	0.0025
Wood (Oak)	0.6 – 0.9
Ice	0.92
Water	1.00
Bricks	1.84
Aluminium	2.70
Steel	7.80
Silver	10.50

Apparatus needed:

- vernier callipers (**refer to Unit 10)** or ruler
- balance (e.g. kitchen scale, beam balance
- electronic top pan balance etc)
- different regularly shaped objects (e.g. a cuboid – use a book, a cylinder – use a soft drink can and a sphere – use a tennis ball).

Cuboid

Procedure: 1. Find the mass, *m,* using the balance.

2. Determine the volume by taking appropriate measurements and then calculating the volume as follows: (You can use your book for this.)

Measure the length, breadth and height by using a ruler or a pair of vernier callipers as explained in Unit 10 on measurement of length. *If needed, go back to the unit and remind yourself.*

Based on your measurements and the table above, write down your prediction of the density of your object: ……

V = lbh

For the figure below depth = breadth

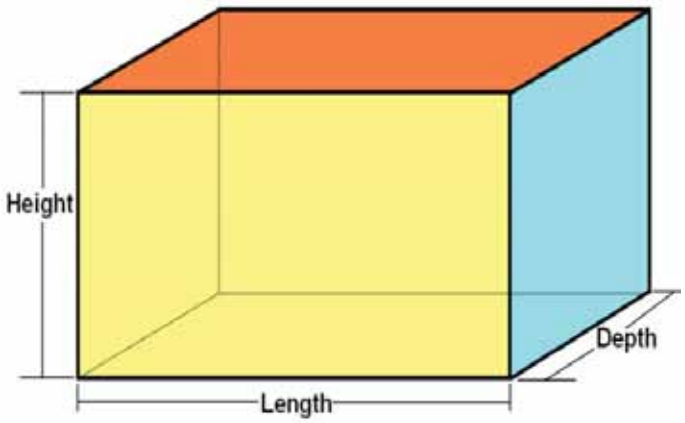

Figure 7(a): A cuboid accessed from Wikimedia Creative Commons, 2011.

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Calculation: If the mass is in g and the volume in cm^3, then

Density $\rho = \frac{m}{V}$ g/cm^3

$= \frac{m}{V} \times 1\,000$ kg/m^3

What is the density of your cuboid? As needed, follow the example below as a model for your own calculations.

_____

_____

_____

Think about how your calculated value compares with your predicted value. See if your next prediction can be as close or closer to the actual value.

Example:

1. A block of concrete 0.4 m long, 0.3 m wide and 0.1 m high has a density of 2,500 kg/m^3. Calculate it's mass.

Solution:

Given: *Length of concrete block (l)* = *0.4 m*

Breadth of concrete block (b) = *0.3 m*

Height of concrete block (h) = *0.1 m*

Density of concrete block = *2,500 kg/m^3*

Volume of the concrete block = *lbh*

= *0.4 m x 0.3 m x 0.1 m*

= *0.012 m^3*

By definition $\rho = \frac{m}{V}$

Therefore $m = \rho V$

= *2,500 kg/m^3 x 0.012 m^3*

Cylinder

Procedure:

1. Find the mass, *m,* using the balance.

2. Determine the volume by taking the appropriate measurements and then calculating the volume as follows: (You can use a soft drink can such as Coke©.)

Measure the diameter and the height.

Based on your measurements and the table above, write down your prediction of the density of your object: ……

$V = \left[\frac{\pi d^2}{4}\right]h$

$= \pi r^2 h$

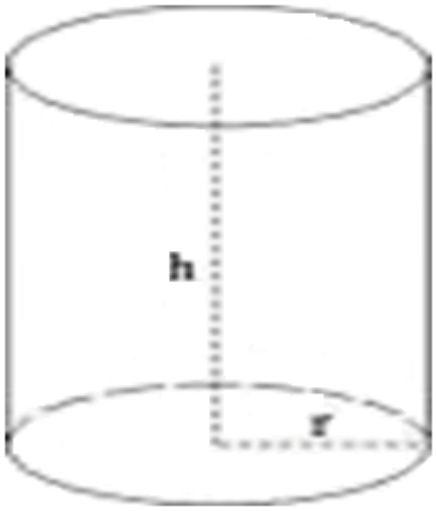

Figure 7(b): A cylinder accessed from Wikimedia Creative Commons, 2011.

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Calculation: If the mass is in g and the volume in cm^3, then:

$$\text{Density } \rho = \frac{m}{V} \text{ g/cm}^3$$

$$= \frac{m}{V} \times 1\,000 \text{ kg/m}^3$$

What is the density of your cylinder? As needed, follow the example below as a model for your own calculations.

_____

_____

_____

Think about how your calculated value compares with your predicted value. See if your next prediction can be as close or closer to the actual value.

Example: $\pi = 3.14$

2. (a) Find the volume of a cylindrical canister with radius 7 cm and height 12 cm.

   (b) Calculate its density if the mass is 75 g.

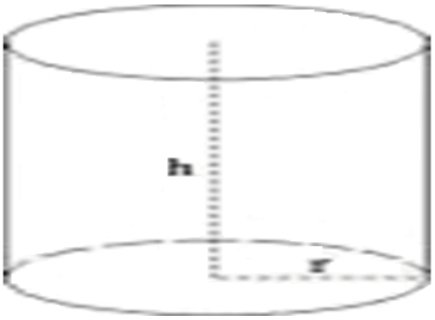

Figure 7(b): A cylinder accessed from Wikimedia Creative Commons, 2011.

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Solution:

(a) V = $\pi r^2 h$
= 3.14 x 7 cm x 7 cm x 12 cm
= 1,846.32 cm^3

(b) $\rho = \frac{m}{V}$

$= \frac{75g}{1846.32cm^3}$

= 0.041 g/cm^3

Sphere

Procedure:

1. Find the mass, *m,* using the balance.

2. Determine the volume by taking the appropriate measurements and then calculating the volume as follows: (You can use a tennis ball or an orange.)

   Measure the diameter with a pair of vernier calipers together with a ruler.

Based on your measurements and the table above, write down your prediction of the density of your object: ……

$$V = \frac{4}{3}\pi\left[\frac{d}{2}\right]^3$$

$$= \frac{4}{3}\pi r^3$$

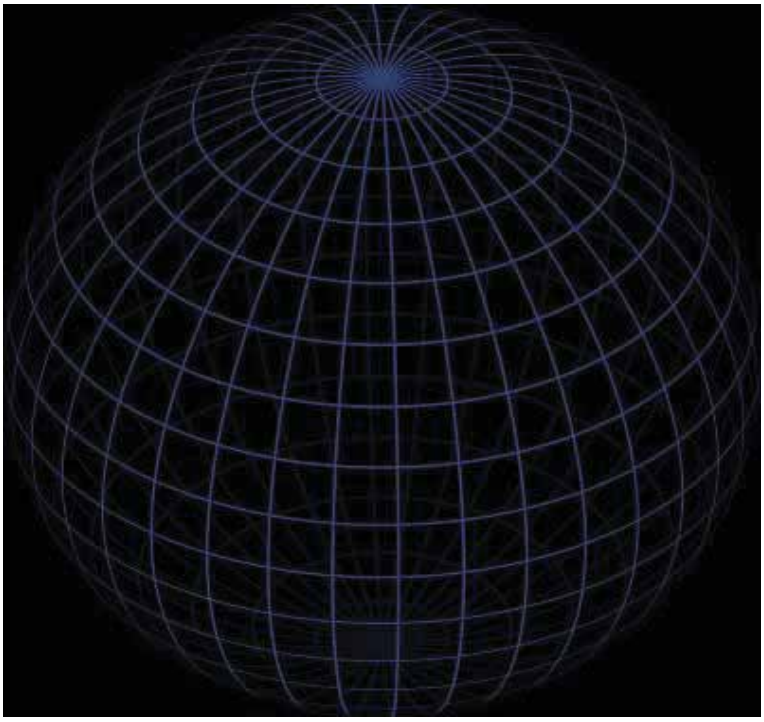

Figure 7(c): A sphere accessed from Wikimedia Creative Commons, 2011.

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Calculation: If the mass is in g and the volume in cm^3, then

$$\text{Density } \rho = \frac{m}{V} \text{ g/cm}^3$$

$$= \frac{m}{V} \; x \; 1\,000 \text{ kg/m}^3$$

What is the density of your sphere? As needed, follow the example below as a model for your own calculations.

_____

_____

_____

Compare your calculated value to your predicted value. I hope the two values are similar.

Example: π = 3.14

(a) What is the volume of a sphere with radius of 5 cm?

(b) Calculate its density if its mass is 50 g.

Solution:

(a) Given radius r of sphere = *5cm*

Volume of sphere V = $\frac{4}{3}\pi r^3$

= $\frac{4}{3}$ *x 3.14 x 5cm x 5cm x5cm*

= *523.33 cm*^{3}

(b) $\rho = \frac{m}{V}$

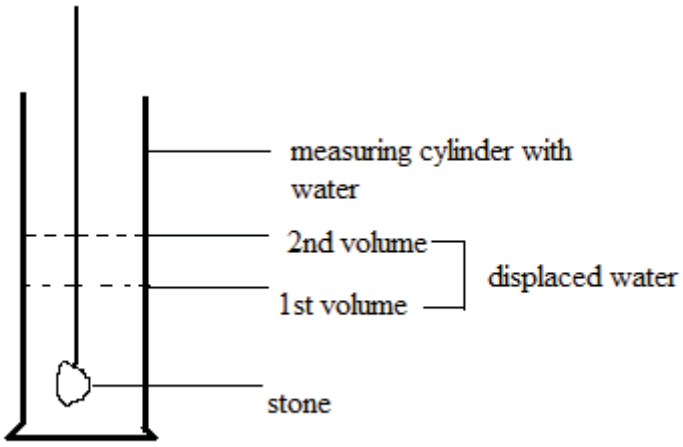
$= \frac{50g}{523.33cm^3}$

= *0.096 g/cm3*

Activity 7

Experiment 3: To determine the density of an irregularly-shaped object.

For this experiment refer to Figure 8 below to carry out the instructions.



Activity

Figure 8: Determining the density of an irregularly-shaped object (method 1) (Hand drawn), 2011.

Apparatus needed:

- measuring jug
- water
- stone

Procedure:

1. Find a stone that can fit into your measuring jug in your surroundings.
2. Find the mass, *m,* of the stone using a balance.
3. Tie the stone with a piece of wool/thread.
4. Take a measuring jug and fill it with water up to a certain level.
5. Take the reading of the volume of the water at that level.
6. Slowly lower the tied stone into the measuring jug filled with water.
7. Take the reading of the next level of water.

Calculation: Calculate the difference between the two readings.

Volume of the stone = 2nd reading – 1st reading

(volume of water and stone) - (volume of water only)

Remember that our measuring jugs at home will have millimetres (ml) as the units which are the same as cubic centimetres (cm^3).

Then:

Density ρ = $\frac{m}{v}$ g/cm^3

= $\frac{m}{v}$ x 1 000 kg/m^3

Example:

A measuring cylinder is filled with water to the level of 25 cm^3. A stone of mass 85 g is then tied with a piece of threat and slowly lowered into the jug. The water level rises to 45 cm^3. What is the density of the stone?

Solution:

Mass of stone = 85 g

Volume of the stone = 2nd reading - 1st reading

$= \quad 45\ cm^3 \quad - \quad 25\ cm^3$

$= \quad 10\ cm^3$

Density $\rho \quad = \quad \frac{m}{V}\ g/cm^3$

$= \quad \frac{85g}{10cm^3}$

$= \quad 8.5\ g/cm^3$

Alternatively, you can use displacement can method as shown in Figure 9 below to measure the volume of an irregularly shaped object.

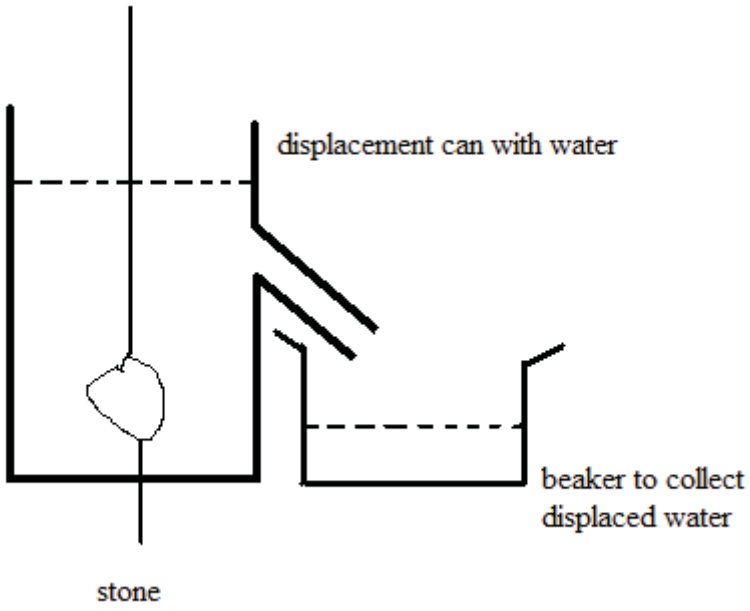


Figure 9: Volume of an irregular-solid using the displacement can method (Hand drawn), 2011.

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Procedure:

1. Take a displacement can and fill it with water.
2. Then take an empty beaker and place it under spout.
3. Carefully lower your irregular solid into the water in the displacement can.
4. Collect the water that overflows into the beaker.
5. Take the water from the beaker and pour it into a measuring cylinder to find its volume. The volume of the displaced water equals the volume of the irregular solid.

Activity

Activity 8

1. An alloy is made by mixing 360 g of copper, of density 9 g/cm^3, with 80 g of iron, of density 8 g/cm^3. Find the density of the alloy, assuming the volume of each metal used does not change during the mixing.

_____
_____
_____
_____
_____
_____

Compare the density you calculated to the answer at the end of section 12-2. Be sure you understand how to do the calculation before continuing.

Answers to Activities on Density

Activity 5

1. ***Mass of oil m*** $= m_2 - m_1$

$= 87.6g - 60.0\ g$

$= 27.6\ g$

Volume V $= 30\ cm^3$

Density $\rho = \frac{m}{V}\ g/cm^3$

$= \frac{27.6g}{30cm^3}$

$= 0.92\ g/cm^3$

2. ***(a) Mass of cylinder alone*** $m_1 = 70\ g$

Mass of cylinder + liquid $m_2 = 120\ g$

Mass of liquid $= m_2 - m_1$

$= 120\ g - 70\ g$

$= 50\ g$

(b) Volume of liquid $= 50\ ml$

$= 50\ cm^3$

Density of liquid $\rho = \frac{m}{V}$

$= \frac{50g}{50cm^3}$

$= 1\ g/cm^3$

Activity 8

1. First, we have to find the volume of copper and the volume of iron.

$$\text{Volume of copper} = \frac{360g}{9g/cm^3}$$

$$= 40cm^3$$

$$\text{Volume of iron} = \frac{80g}{8g/cm^3}$$

$$= 10\ cm^3$$

$$\text{Total volume} = 40\ cm^3 + 10\ cm^3$$

$$= 50\ cm^3$$

$$\text{Total mass} = 360\ g + 80\ g$$

$$= 440\ g$$

$$\text{Density of alloy } \rho = \frac{m}{V}$$

$$= \frac{440g}{50cm^3}$$

$$= 8.8\ g/cm^3$$

Unit Summary

Summary

In this unit you learned:

- Mass is the amount of matter in an object. Mass does not change with location. The SI unit of mass is kilograms.
- Weight is the force of gravity acting on an object. Weight changes from place to place, depending on the force of gravity acting upon it. Its SI unit is the Newton.
- Volume is the amount of space an object occupies. SI unit is the cubic metre.
- How to measure and calculate volume.
- Experiments can be done to determine the density of solids and liquids.
- Density can be calculated as mass per unit volume.

You have completed the material for this unit on mass, weight, and density. After reviewing the content, try the assignment and compare your answers to those provided. As needed, clarify any misunderstandings you have. The last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers the turning effect of forces.

Assignment 13

Assignment

Answer all the questions that follow. Please show your work.

You should be able to complete this assignment in 30 minutes

[Total Marks:15]

Section A Multiple-Choice Questions

1. When using a measuring cylinder one precaution to take is to:

   A. Check for the zero error.

   B. Look at the meniscus from below the level of the water surface.

   C. Obtain more readings by looking from more than one direction.

   D. Position the eye in line with the base of the meniscus. (2)

2. The mass of an empty measuring cylinder is 60 g. When 30 cm^3 of olive oil is poured into it, the total mass is 87.6 g. The density of olive oil in g/cm^3 is:

   A. 0.34

   B. 0.92

   C. 1.09

   D. 2.00 (2)

3. A rock on the moon has a mass of 0.5 kg. It is brought to the Earth where the gravitational field is stronger. On Earth, the rock will have:

   A. Less mass and less weight.

   B. Less mass and the same weight.

   C. The same mass and the same weight.

   D. The same mass and more weight. (2)

Section B Structured Questions

1. The mass of a liquid is 0.8 kg and its volume is 0.0005 m^3. What is the density of the liquid in kg/m^3? (2)
2. The density of a solid is 4 g/cm^3. What is the volume of 200 g of the solid? (2)
3. An irregular-shaped solid is lowered gently until completely immersed in a liquid (of density 1.2 g/cm^3) in a displacement can. The mass of the liquid which overflowed is 180 g.

   (a) What is the volume of the irregularly-shaped solid? (2)

   (b) What is the mass of the solid if its density is 3.0 g/cm^3? (3)

Answers to Assignment 13

For scoring on each question, give yourself 1 mark for the correct answers and the rest of the marks for the proportional amount of correct work that you showed.

Section A Multiple-Choice Questions

1. *D*
2. *B*

$m_1 = 60\ g,\ m_2 = 87.6\ g$

$V = 30\ cm^3$

$$\text{Density } \rho = \frac{m}{V}$$

$$= \frac{m2-m1}{V}$$

$$= \frac{87.6g-60g}{30cm3}$$

$$= 0.92\ g/cm^3$$

3. *D*

Section B Structured Questions

1. *Mass m* $= 0.8\ kg$

Volume V $= 0.005\ m^3$

$$\text{Density } \rho = \frac{m}{V}$$

$$= \frac{0.8kg}{0.005m^3}$$

$$= 160\ kg/m^3 \quad (2)$$

2. *Density* $\rho = 4\ g/cm^3$

Mass m $= 200\ g$

$$\text{Volume } V = \frac{m}{\rho}$$

$$= \frac{200g}{4g/cm^3}$$

$$= 50\ cm^3 \quad (2)$$

3. *(a) Volume of overflowed liquid V_l = volume of solid V_s.*

Density of overflowed liquid $\rho_l = 1.2\ g/cm^3$

Mass of overflowed liquid m_l = 180 g

Therefore:

Volume of overflowed liquid V_l = $\frac{m_l}{\rho l}$

= $\frac{180g}{1.2g/cm^3}$

= $150\ cm^3$

Volume of irregularly shaped solid Vs = $150\ cm^3$ **(2)**

(b) Volume of irregular solid Vs = $150\ cm^3$

Density of irregular solid ρ_s = $3\ g/cm^3$

Mass of irregular solid m_s = $V_s\rho_s$

= $150\ cm^3 \times 3\ g/cm^3$

= 450 g *(3)*

Assessment 13

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes. Show all of your work for full marks.

(Total Marks:25)

Section A Multiple-Choice Questions (2 marks each)

1. The amount of matter in an object is its:

A Weight

B Mass

C Volume

D Density

2. A graduated cylinder is used to measure:

A Weight

B Mass

C Volume

D Density

3. If we use the use grams (g) for mass and cubic centimetres (cm^3) for volume, then the units for density will be:

A g

B cm^3

C $g\text{-}cm^3$

D g/cm^3

4. The mass of an object on mass is 6 kg. On the moon the mass will be:

A 6 kg

B 0 kg

C 1 kg

D 3 kg

5. A cube has a side of 5 cm. It has a mass of 250 g. The density of the cube is:

A 50 g/cm^3

B 2.0 g/cm^3

C 5. 0 g/cm^3

D 20 g/cm^3

Section B Structured Questions

1. The mass of a solid is 1000 g and its volume is 400 cm^3. What is the density of the solid in g/cm^3? (2)
2. A concrete slab 1.0 m by 0.5 m by 0.1 m has a mass of 120 kg. What is the density of concrete? (2)
3. What is the volume of a sphere of radius 10 cm? Take π = 3.14 (2)
4. Describe how you would measure the density of an irregularly-shaped solid by means of an experiment. Your explanation should have diagrams. (6)
5. A measuring cylinder contains 100 cm^3 of water. An irregularly-shaped object of mass 70 g is lowered into the cylinder. Given that the density of the object is 7.0 g/cm^3 and that it is completely immersed, calculate the new reading on the measuring cylinder. (3)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

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Unit 14

Turning Effect of Forces

Study Skills

Tips on Avoiding Stress:

Taking self-directed classes can be very enjoyable, but also stressful at times. To avoid stress:

Be organized and prepared
Make time for fun and relaxation
Stay positive
Eat healthy food and exercise
Go to sleep at a regular time

Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.

Introduction

Have you ever asked yourself why it is easy to open a gate? Why it is easy to move heavy objects with a wheel burrow? Why it is easy to fasten a bold and nut with a long spanner? Why a racing car is less likely to over- turn compared to an ordinary car? This unit will help us understand why these things happen.

Time

This unit consists of 31 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. You should focus on those skills while studying this unit.

Outcomes

Study skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Measure* physical quantities.
- *Give* the correct SI units of the different physical quantities.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.
- *Analyse* experimental data.
- *Apply* correctly various formulae which relate the different physics concepts and theories to the world around us.

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Calculate* the moment of a force.
- *Describe* the principle of moments for a body in equilibrium.
- *Solve* problems on moments.
- *Determine* the centre of mass of a plane lamina experimentally.
- *Identify and describe* different forms of stability.

Terminology

Moments:	The turning effect of a force.
Pivot:	The point where the system turns.
Lever:	A rigid bar pivoted on a fixed point and used to transmit force, as in raising or moving a weight at one end by pushing down on the other.
Centre of mass:	The point on the object where the entire mass appear to concentrate.
Stability:	The body's ability to maintain its original position.

Section 14-1: Moments

Introduction

In Unit 3 we learned that force is defined as a push, a pull, a twist, a squeeze and so on. You also learned that force can produce a motion and it can stop a moving object. For example, when brakes are applied to a moving vehicle, that object will stop. Remember that the state of motion of the object will change only when the applied force is greater than the opposing force applied by the object.

By the end of section 14-1, you should be able to:

- *Define* moment of a force.
- *Perform* calculations of moment.
- *State* the principle of moments.
- *Perform* calculations of the principle of moments.

Time

Section 14-1 has 12 pages. You should spend approximately 2 hours on this topic.

Definition of a Moment

In Unit 3 we learned that force is defined as a push, a pull, a twist, a squeeze and so on. You also learned that force can produce a motion and it can stop a moving object. For example, when brakes are applied to a moving vehicle it will stop. Remember that the state of motion of the object will change only when the applied force is greater than the opposing force applied by the object.

1. When you open a door, at which point do you apply the force?

   _____

2. What does this force do to the door?

   _____

3. You are given a sealed tin of paint and a screw driver, and then you are asked to open it. How will you open the tin?

   _____
   _____
   _____

These are some of the things you do every day, so I hope you managed to answer the questions.

Compare your answers with those given below:

When you open a door, you apply the force at the door knob. The force results in the turning of the hinge of the door.

When opening a tin of paint, you put the screw driver or a knife between the lid and the tin. Then you apply the downward force to the knife or screw driver. The force applied results in the turning of the lid and eventually the whole lid will open.

- In the two examples we have just discussed, we have seen that the applied force at the door knob and at the end of the screw driver results in turning at the point away from where the force was applied.
- **Moment of a force** is defined as the turning effect of the force.
- Moment is also referred to as **torque**.

Activity

Activity 1 - Experiment

Look for two tightly sealed identical tins. If they are not identical, the results may vary.

Reflection

Do you think it will be easier to open the cans with a short lever or a long lever? Why do you think this?

1. Open one of the tins with a short screwdriver or knife as shown in Figure 1a. If you use the knife, it must be very strong.
2. Open the second one with a longer screwdriver or knife, as shown in Figure 1b.
3. Was it easier using a short screwdriver or a long one?

_____

_____

Figure 1a: Opening a paint tin with a short screwdriver. Photo taken at the Lesotho College of Education Chemistry Laboratory, 2010.

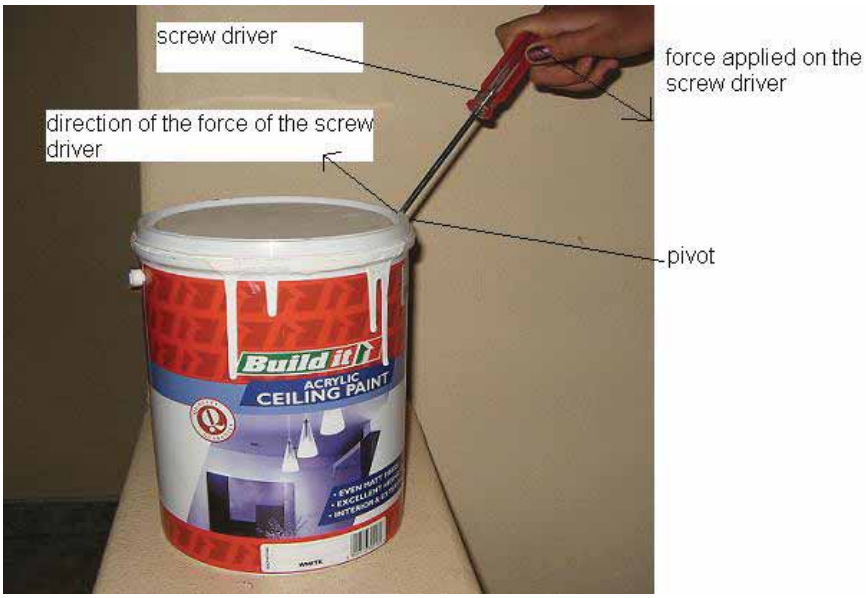


Figure 1b: Opening a paint tin with a long screwdriver. Photo taken at the Lesotho College of Education Chemistry Laboratory, 2010.

I hope you did the activity and you were able to feel the difference while using screwdrivers of different lengths.

I hope you realised that while using a long screwdriver, you apply less force than when the screwdriver is short.

- The object on which the force is applied is called a lever.
- In our example, the screwdriver is the lever.
- Moment of a force depends on the perpendicular distance from the pivot to the point where the force is applied.

In Figure 1b, the long screwdriver is used and a small downward force results in a large force exerted on the lid by the screwdriver.

In Figure 1a, the screwdriver is short and therefore, a lot of force needs to be applied downward so that the upward force is large enough to open the lid.

Moment = force x distance

Remember that the unit for force is Newton (N).

The distance must be in meters (m).

So the unit for moment is Newton meter (Nm).

Example 1

If the short screw driver is 10 cm long and a force of 2N is applied at the end of the screwdriver, calculate the moment of the force in Figure 1a.

If the long screw driver is 15 cm long and the force of 2N is also applied at the end of the screwdriver, calculate its moment in Figure 1b.

Solution

First, change centimetres to meters.

10 cm = 10/100 = 0.1 m

The moment in a) = force x distance

= 2N x 0.1m

= 0.2 Nm

The moment in b) = force x distance

= 2N x 0.15 m

= 0.30 Nm

A moment of 0.2 is less than 0.3. This tells us that when the same amount of force is applied on both levers, the lid turns through a longer distance while using the long lever than when using the short one.

Note it!

NOTE:

- The force applied in both cases is 2N.
- However, the turning of the lid using a larger screwdriver is larger than the turning of the lid using a shorter screwdriver.
- We conclude that: moment depends on the size of the force applied and the distance of that force from the pivot.
- The longer the distance, the larger the moment. The shorter the distance, the smaller the moment.

Activity

Activity 2

A force of 10N is applied to a wrench to tighten a nut. The length of the wrench is 0.2 m. What is the moment exerted when the force acts at:

i. The end of the wrench? This is shown in Figure 2.

ii. The middle of the wrench?

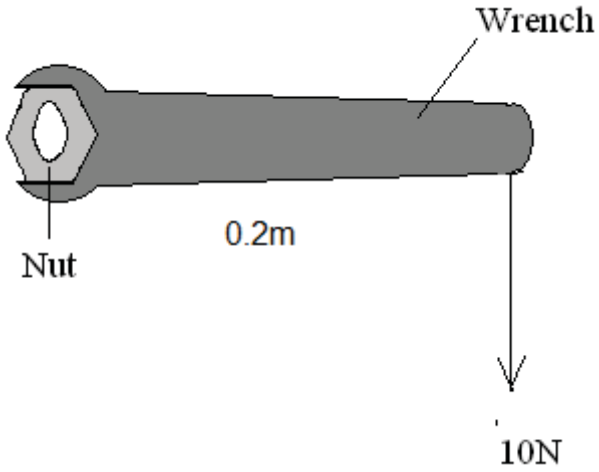


Figure 2 Force applied to the end of a wrench. Photo taken at the Lesotho College of Education Chemistry Laboratory, 2010.

I hope you enjoyed doing the activity. Compare your answers with those at the end of section 14-1. Be sure you understand each answer before continuing to the next activity.

Activity

Activity 3

In this activity we are going to verify the principle of moments.

You will need a kitchen scale, two small stones of obviously unequal mass, a 30 cm ruler, a nail and strings.

The nail will serve as a pivot.

- Using a kitchen scale, measure the mass of each stone and write their values in the space below.

Figure 3a: A larger stone on the kitchen scale: 86 g. Photo taken at the Lesotho College of Education Chemistry Laboratory, 2010.

Figure 3b: A smaller stone on the kitchen scale: 28g. Photo taken at the Lesotho College of Education Chemistry Laboratory, 2010.

_____

_____

- Calculate the weight of each stone.

_____

_____

_____
_____
_____
_____

- Take a ruler and make a small hole in it with a nail at the 15cm mark as shown in Figure 4.
- Make a small hole with a nail on the wooden stand and suspend the ruler such that it rests horizontally as shown in Figure 4.
- If the ruler does not balance, put used chewing gum on the side which is tilted upwards. Vary the amount of gum until the ruler balances.
- On either side of the ruler suspend the each stone by fastening each of them with a small string of the same length.
- Adjust their positions until the ruler rests horizontally again.
- Record the distance of each stone from the pivot (the point where the ruler is suspended). Distance d1 = _____

  Distance d2 = _____

Figure 4: A smaller stone 5 cm from the pivot and larger stone 14.7 cm from the pivot suspended on either side of the ruler. Photo taken at the Lesotho College of Education Chemistry Laboratory, 2010.

- Calculate the moment of the smaller stone on the right of the pivot:

  _____
  _____
  _____
  _____

- Calculate the moment of the larger stone on the left of the pivot:

  _____
  _____
  _____
  _____

- What can you conclude about the clockwise and anticlockwise moments?

  _____
  _____
  _____
  _____

I hope you enjoyed doing the activity. Compare your answers with those at the end of section 14-1. In particular, be sure that you understand the conclusion before continuing.

The above activity illustrates the **principle of moments.**

It states that:

When a body is in equilibrium, the sum of anticlockwise moments about the balance point is equal to the sum of clockwise moments about the same point.

Example 2

1. A meter rule is supported at its centre. It is balanced by two weights: A and B as shown in Figure 5. If weights A and B are 30N and 20N respectively, find the distance of weight B from the pivot if A is 20 cm from the pivot.

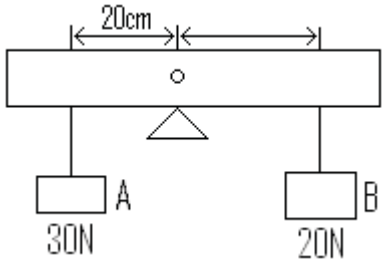


Figure 5: principle of moments (Hand drawn), 2010.

2. Two objects A and B are suspended on the ruler on either side of the balance point. Object A has a mass 5 kg and it is 20 cm from the balance point. If object B is 25 cm from the balance point find its mass.

Solution

1. Anticlockwise moment = clockwise moment

Weight x distance = weight x distance

30 N x 20 cm = 20 N x d

Distance = 600Ncm =20N x d

When we divide both sides of the equation by 20 N we get:

= 30 cm

2. Weight of A = mass x gravity

= 5 kg x 10 N/kg

=50 N

Anticlockwise moment = clockwise moment

50 N x 20 cm = W x 25 cm

1000 N cm = W x 25 cm (dividing both sides by 25 cm we get)

W = 40 N

Weight of object B = 40 N

Remember weight = mass x gravitational pull

40 N = mass x 10N/kg

Dividing both sides by 10 N/kg we get:

Mass = 4 kg

Activity

Activity 4

1. Figure 6 shows the arrangement of two weights suspended on either side of the ruler.

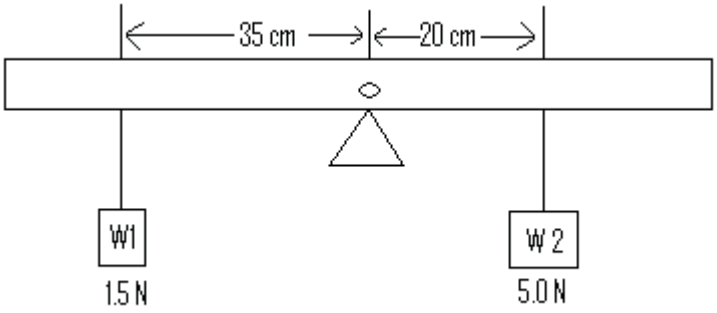


Figure 6: Two weights suspended on either side of the centre of a ruler (Hand drawn), 2010.

Where: $d_1 = 35$ cm, $d_2 = 20$ cm

$W_1 = 1.5$ N, $W_2 = 5$N

i) Calculate the moment of weight W_1 and weight W_2.

_____
_____
_____
_____

ii) Which side of the ruler will go down?

_____

2. The board shown in Figure 7 is hinged at A and supported by a vertical rope at B, 3.0 m from A. A boy weighing 600 N stands at the end D of the board, which is 4.0 m from the hinge. Neglecting the weight of the board, calculate the force F on the rope.

_____
_____
_____
_____
_____
_____

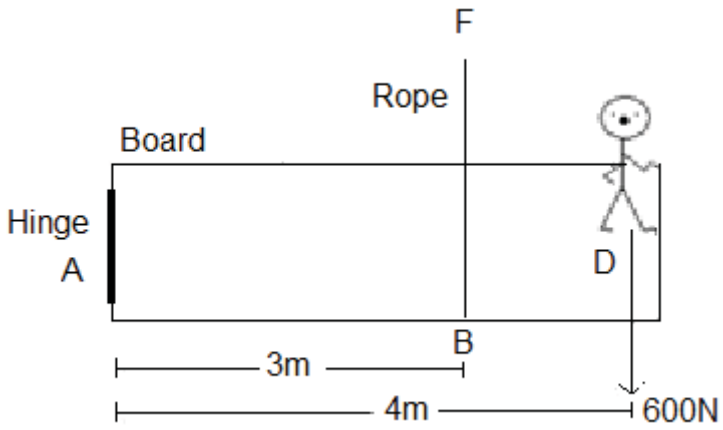


Figure 7: A hinged board (Hand drawn), 2010.

Make sure you attempt all of the questions before moving on. Compare your answers with those at the end of the section 14-1. Take the time needed to ensure you understand each calculation.

Let us recall what we have discussed so far:

- Moment is the measure of the turning effect of the force.
- Moment depends on the force applied and the distance it is from the pivot.
- The principle of moments states that: the sum of the clockwise moments about a point is equal to the sum of the anticlockwise moments about the same point.
- The units of moments are Newton metres (Nm).

Answers to Activities on Moments

Activity 2

i) ***Moment = force x distance***

= 10N x 0.2m

= 2.0 Nm

ii) ***Moment = force x distance***

= 10 N x 0.1m

=1 Nm

Activity 3

Mass of small stone = 55 g = 0.055 kg

Weight of the small stone = 0.055 kg x 10 ms^{-2} = 0.55N

Mass of the large stone = 110 g = 0.11 kg

Weight of the large stone = 0.110 kg x 10 ms^{-2} = 1.1N

Moment of the small stone = weight x distance

= 0.55N x 0.12 m

= 0.066 Nm

Moment of the large stone = 1.1N x 0.06 m

= 0.066 Nm

Anticlockwise moment = Clockwise moment

Activity 4

1.

i. Moment of A = Weight x distance

= 1.5N x 35 cm

= 52.5 Ncm

Moment of B = weight x distance

= 5 N x 20 cm

= 100 Ncm

ii. Side B will go down because the moment on B is more than the moment on A.

2.

Clockwise moment = anticlockwise moment

$$600N \times 4m = F \times 3m$$

$$\frac{2400\ Nm}{3m} = \frac{Fx3m}{3\ m}$$

$$800\ N = F$$

$$F = 800\ N$$

Section 14-2: Centre of Mass

Introduction

Centre of mass is one of the physical concepts that make life possible. It enables objects to balance.

In section 14-2 we are going to:

- *Determine* the centre of mass experimentally.

Time

Section 14-2 has 9 pages. You should spend approximately 1.5 hours on this topic.

Reflection

Take a 30 cm ruler and balance it on your middle finger. Why are you able to make the ruler balance? What actions make the ruler fall off your finger?

All bodies are made up of many particles. The weight of a body is due to the attraction of the Earth on all these particles. There is one point on the object where the entire weight seems to act. This point is called the **centre of mass.**

For a regularly shaped object like a uniform ruler, the centre of mass is at the centre of the object.

Figure 8 shows a uniform ruler supported at the centre. The ruler is uniform because it is made of the same material and its thickness is the same throughout the length of the ruler.

The gravitational force on either side of the ruler is the same so the ruler balances.

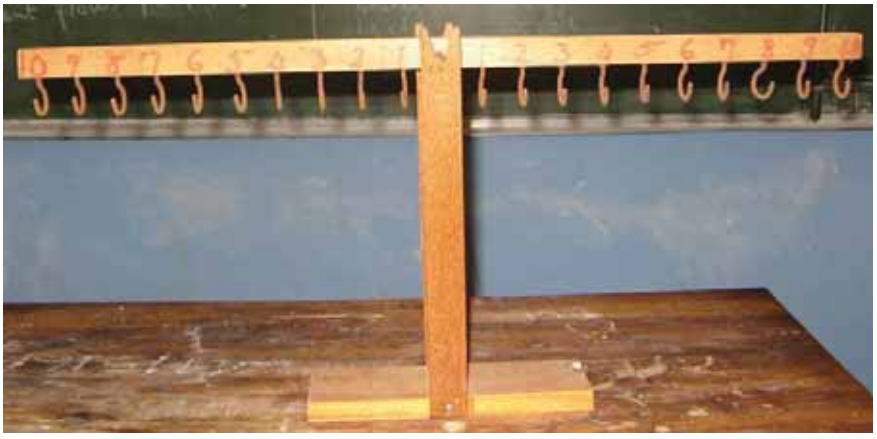


Figure 8: A ruler at equilibrium. Photo taken at the Lesotho College of Education Chemistry Laboratory, 2010.

The ruler is said to be at equilibrium because the gravitational pull on either side of the pivot is the same.

Activity

Activity 5

The ruler is now supported at a point away from its centre of mass.

1. Draw a diagram on the space below to show how a 1 m ruler will rest when the ruler is pivoted at the 70 cm mark.

2. Explain why the ruler will rest the way it does:

_____

_____

_____

Make sure that you have confidently done the experiment. Then compare your answers with those at the end of section 14-2.

Activity

Activity 6 - Experiment

In this activity we are going to find the centre of mass of an irregularly shaped object.

Collect the following materials:

- Irregularly shaped cardboard (which is also called a plane lamina)
- A nail
- A string with a mass fixed on one end (this is called a plumb line)

Now do the following steps:

Note:

Instead of mounting the nail on the wall, I have mounted the nail on the horizontal clamp fixed on the vertical stand.

1. On the edges of the cardboard make the holes A, B, and C as shown in Figure 9.

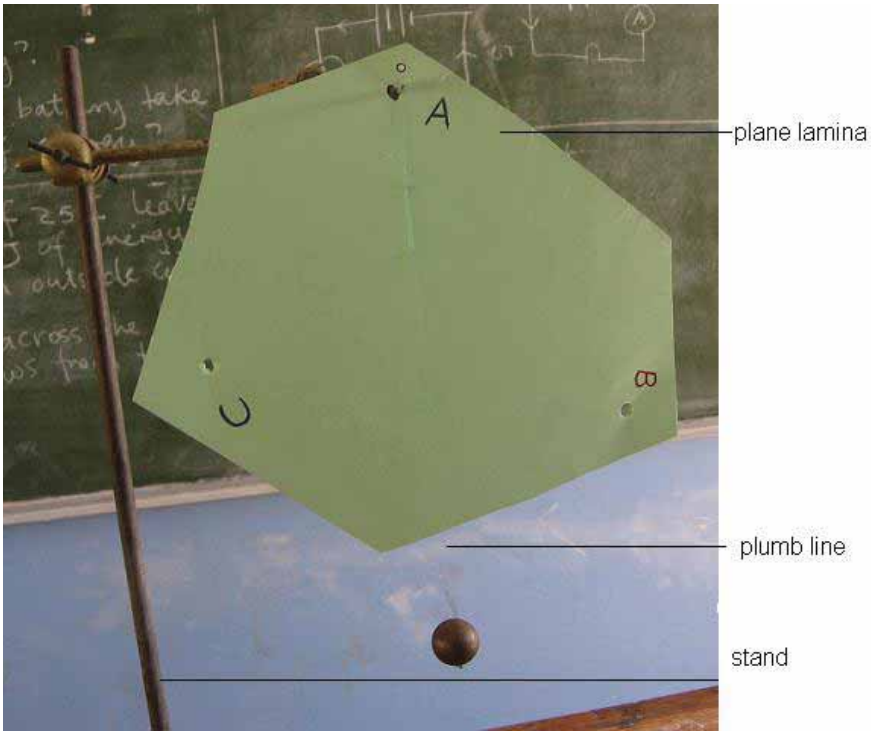


Figure 9: Arrangements of materials when finding the centre of mass of a plane lamina. Photo taken at the Lesotho College of Education Chemistry Laboratory, 2010.

2. Put the nail into the wall.
3. Put the cardboard on the nail using hole "A". Attach the plumb line to the nail in front of the card. Let it swing until it is still.
4. Draw a straight line on the card along the plumb line.
5. Repeat steps 3 and 4 with the other two holes.

What do you notice?

_____

Compare your answer with the one at the end of section 14-2.

Remember that:

The **centre of mass** is the point on the object where the entire mass of the object seems to act.

I hope you are asking yourselves why we are doing this and why it is important?

Let us now find out how the centre of mass principle affects things.

Activity

Activity 7 - Experiment

A box is a regularly-shaped object so its centre of mass is at the centre.

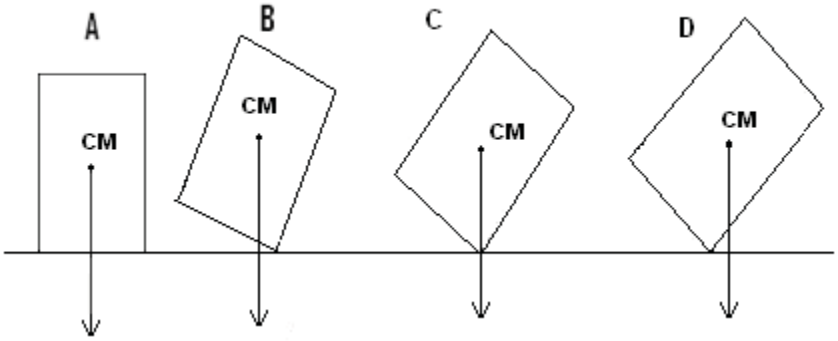


Figure 10: The centre of mass of a box (Hand drawn), 2010.

In A, the box rests flat on its base. The arrow shows the direction of gravitational pull from the centre of mass (CM).

1. If you tilted the box at a small angle, as in B, the gravitational pull acts within the base of the box as shown by the arrow. Would the box topple over or would it return to its original position?

   _____

2. What would happen to the box if you increase its angle of tilt to be greater than that at position C?

   _____

   _____

Before comparing your answers with those at the end of section 14-2, verify your answers by doing the same thing with any rectangular-shaped box that you have.

At position B, the box returned to its original position because the centre of mass acts within the base of the box. But at position C, the box can either topple over or fall back to its original position because the centre of mass acts at the vertex of the box. At position D, the box topples over because this time the centre of mass is now acting outside the base.

Activity

Activity 8

Figure 11 shows the positions of a box. The arrows show the direction of the gravitational pull.

1. Explain what happens to the box at positions:

a) B

_____
_____
_____
_____

b) C

_____
_____
_____
_____

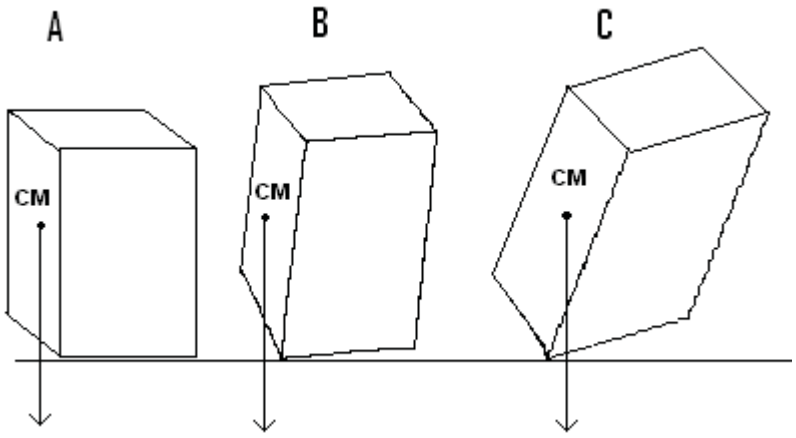


Figure 11: Centre of mass of a box (Hand drawn), 2010.

2. Explain what happens when we fix a slab of wood inside the base of the box as shown on Figure 12.

_____
_____
_____
_____
_____

Before comparing your answers with those at the end of section 14-2, verify your answers by doing the same activity with a box that has something heavy that fits tightly in the bottom.

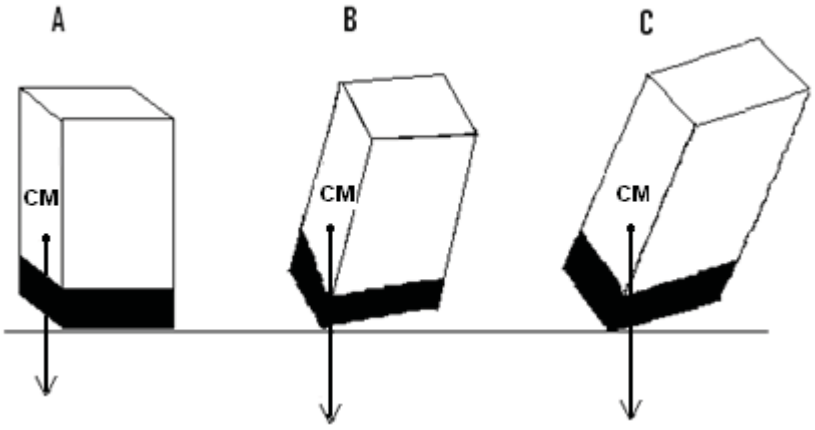


Figure 12: Centre of mass of a box with a heavy object fixed inside the base (Hand drawn), 2010.

Activity

Activity 9

Now, let's consider how the position of the box affects the centre of mass. In Figure 13, will box "A" or box "B" have a lower centre of mass, given both boxes are empty?

_____

Why?

_____

_____

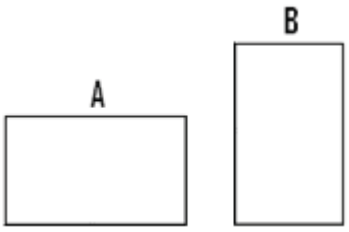


Figure 13: Centre of mass position (Hand drawn), 2010.

Once you have answers, compare your answers with those at the end of section 14-2.

Activity

Activity 10

Let us now place the empty box such that the longer side is the base and then tilt it as before.

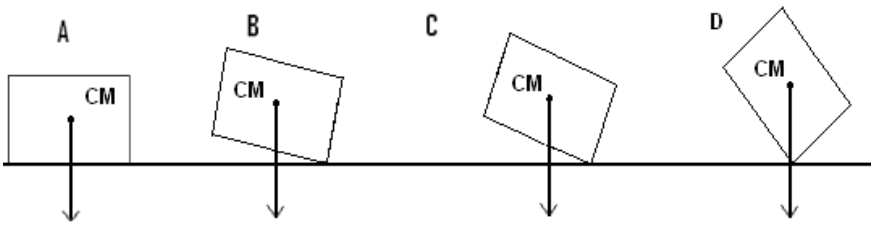


Figure 14: The effect of the base area on the stability of an object (Hand drawn), 2010.

Study Figure 14. Note that the centre of mass is now closer to the base.

Is the box on its side harder or easier to topple? _____

Why?

_____

_____

Compare your answers with those at the end of section 14-2.

Centre of Mass Summary

Note it!

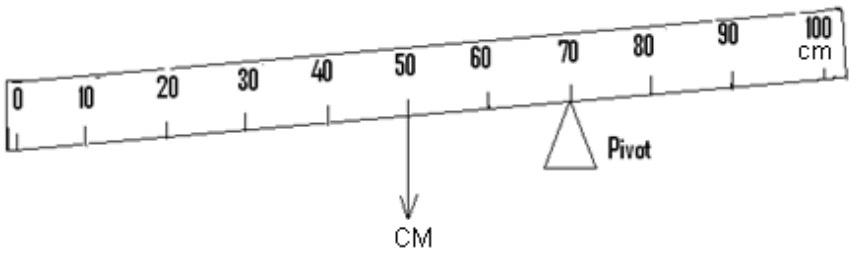
Let us recall what we have done so far:

- Centre of mass was previously called the centre of gravity.
- The centre of mass is the point on the object where the entire mass of the object appears to act.
- For symmetrical objects, the centre of mass is at the centre of the object.
- When the surface area of the base is large the object does not topple over easily.
- The weight of the base lowers the centre of mass and as a result the object does not topple over easily.

Answers to Activities on Centre of Mass

Activity 5

1.



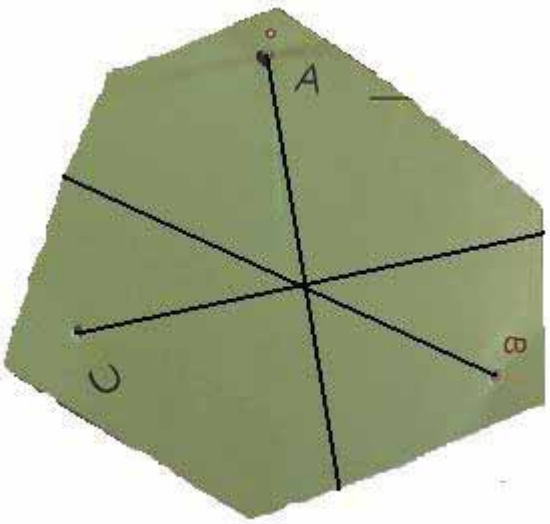
2. ***The ruler will topple to the left of the pivot because there is more mass and therefore more weight than on the right of the support.***

   Therefore, the centre of mass of the ruler lies on the left side of the pivot. There is more gravitational pull on the left than on the right side of the ruler.

Activity 6

You should have found that all the three lines cross at one point.

The point where the lines cross is called the <u>centre of mass</u>.



Activity 7

1. ***The box will return to its original position.***
2. ***The box will topple over.***

Activity 8

1.

a) ***In B, the box is tilted with a small angle and the centre of mass falls within the base as shown by the arrow. So the box returns to position A.***

b) ***In C, the angle of tilt is increased and the centre of mass falls outside the base so the box topples over.***

2. ***Remember that the centre of mass is the point where the entire mass of the object appears to concentrate. So when a heavy object is fixed in the base of the box, there is more mass towards the base hence the centre of mass is lowered. Therefore, the box topples over when tilted at a small angle.***

At B the box returns to position A, because its centre of mass is within the base of the box

Activity 9

Box "A" has a lower centre of mass because the centre of mass of a regularly-shaped object is at the centre of the object, as shown in Figure 15 below.

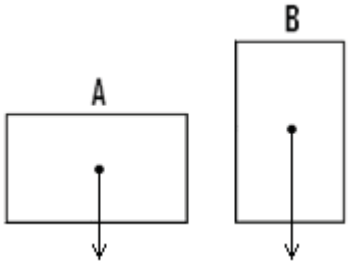


Figure 15: Centre of mass comparison (Hand drawn), 2010.

Activity 10

A box on its side is harder to topple.

In both B and C the centre of mass falls within the base of the box, so the box does not topple over. It must be tilted at a large angle in order to topple over, as shown in D. This is because the centre of mass of the box is close to the base of the box.

Section 14-3: Stability

Introduction

Some objects are easily displaced while others are not.

In section 14-3 we are going to:

- Identify and describe different types of stability.

Time

Section 14-3 has 4 pages. You should spend approximately 30 minutes on this topic.

Activity

Activity 1 1

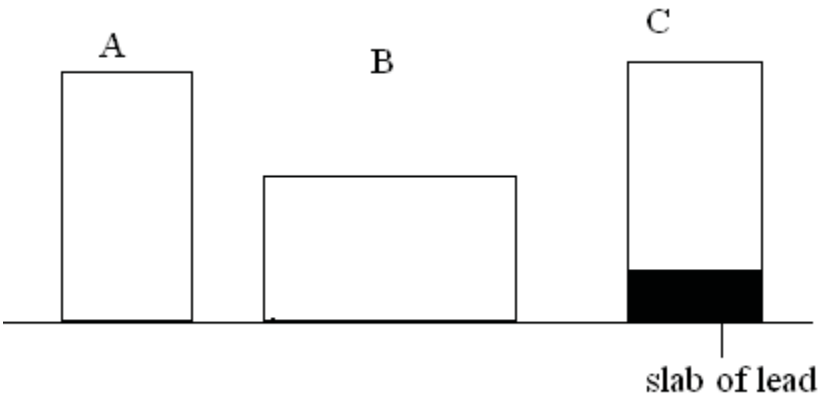


Figure 16: Comparing the centre of mass of three similar boxes (Hand drawn), 2010.

Figure 16 above shows three boxes put on a table. Box A and B are identical, but A is placed with its small side as the base and B is placed with its long side as the base. In box C, a slab of lead is fixed inside the box. All of the boxes are the same size.

a) What does the slab of lead do to the centre of mass of box C?

_____

_____

_____

b) Between box A and C, explain which box is more likely to topple over when the same amount of force is applied on the top left of each box.

_____
_____
_____
_____

c) Between B and C, explain which one needs a larger angle of tilt in order for it to topple over.

_____
_____
_____
_____

Compare your answers to those given at the end of section 14-3. Be sure you understand the explanations before you continue.

Stability is defined as the body's ability to maintain its original position. In Activity 11 above, box B is more stable than the other two boxes because the centre of mass is near the base of the box and the surface area of the base is larger than area of the other two.

Kinds of Equilibrium

Three kinds of equilibrium fundamentally exist. They are: stable equilibrium, unstable equilibrium and neutral equilibrium.

1. **Stable equilibrium** is when the body returns to its original position after being displaced. For example, in an inverted funnel as shown in Figure 17, the centre of mass is close to the base. So when a small horizontal push is applied on the narrow edge of the funnel, the funnel does not fall. Instead it returns to its original position.

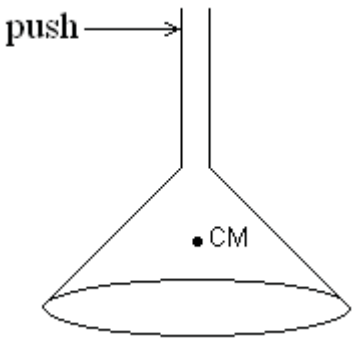


Figure 17: Inverted funnel (Hand drawn), 2010.

2. **Unstable equilibrium** exists when the body continues to move away from its original position after being displaced. For example, in a funnel balanced upright on its narrow tip as shown in Figure 18, the centre of mass is far from the base. So, a small push will topple the funnel.

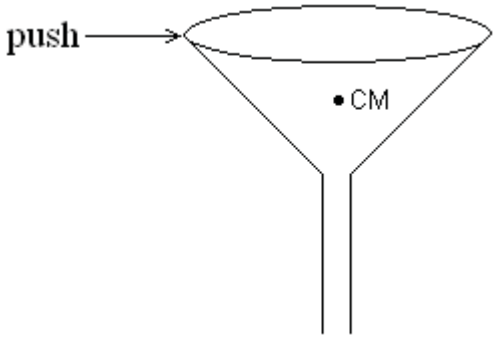


Figure 18: Upright funnel (Hand drawn), 2010.

3. **Neutral equilibrium** exists wherever the body is displaced. For example, in a funnel lying horizontally on its side as shown in Figure 19, when a small push is applied on the funnel, it simply rolls. It does not topple or return to its original position.

Figure 19: Horizontal funnel. Photo taken at the Lesotho College of Education Chemistry Laboratory, 2010.

Stability Summary

The key points to remember about stability are:

- There are three types of stability:
- **Stable equilibrium** is when the body returns to its original position after being displaced.
- **Unstable equilibrium** exists when the body continues to move away from its original position after being displaced.
- **Neutral equilibrium** exists wherever the body is displaced. It does not topple or return to its original position.

You have now completed the last section of this unit on the turning effect of forces. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Answers to Activities on Stability

Activity 11

a) The slab of lead lowers the centre of mass of the box.

b) Box A is more likely to topple over because its centre of mass is higher than in box C.

c) When placed with its long side as the base, the centre of mass of the box is next to the base. So the box will topple over when tilted through a large angle.

Unit Summary

Summary

Go through the summary to make sure that you remember everything you have learned in this unit.

In this unit you learned:

- Moment is the turning effect of a force.
- Moments depend on the force applied and the perpendicular distance from the pivot.
- Moment = force x perpendicular distance to the pivot.
- The units of moments are Newton meters.
- The principle of moments states that: The sum of the anticlockwise moments equals the sum of the clockwise moments about the same point.
- Pivot is the supporting point at which turning takes place.
- Centre of mass, formally called the centre of gravity, is the point on the object where the entire mass of the object appears to concentrate. When the centre of mass is near the base, the object is less likely to topple over when tilted. But when the centre of mass is far from the base, the object topples over more easily.
- When there is more mass on the base, the centre of mass lowers and the object does not topple over as easily.
- Stability is the body's ability to maintain its original position.
- The stability of an object is determined by the position of its centre of mass.
- The three kinds of equilibrium are: stable equilibrium, unstable equilibrium and neutral equilibrium.

This is the end of the unit, take a deep breath and ask yourself if you have thoroughly learned the content in this unit. If you feel confident that you have learned it well, then you are ready to do the assignment on the next page. If you do not feel confident, then go through the points you think need more attention before doing the assignment.

Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers work, energy, and power.

Assignment 14

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:18]

1. Define the moment of a force. (1)

_____
_____
_____

2. What does the moment of a force depend on? (2)

_____
_____

3. A man moves a boulder with a metal rod as shown on Figure 20. He applies a force of 50N 1.5 m away from the pivot. Calculate the moment of the applied force. (3)

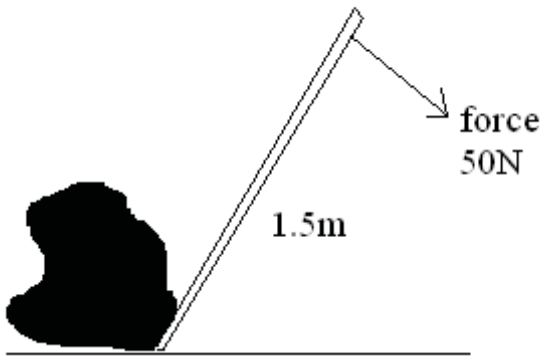


Figure 20

_____
_____
_____
_____
_____
_____

4. Figure 21 shows a uniform plank pivoted off centre but maintained in equilibrium by an object of weight 4 N.

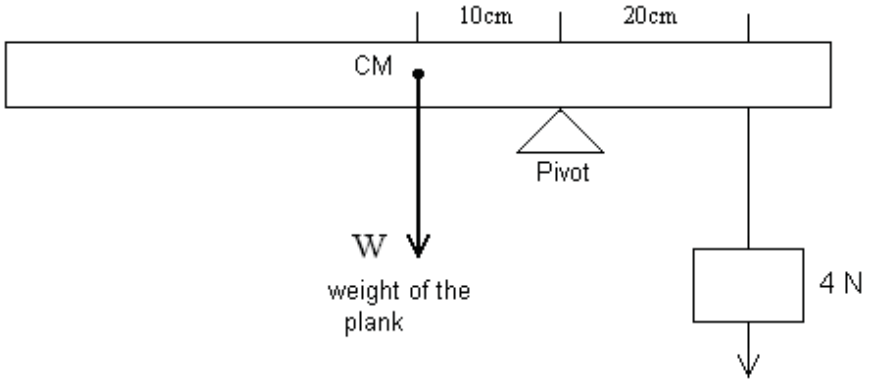


Figure 21

a. What is the weight of the plank? (4)

b. Calculate the mass of the plank. (2)

5. With the help of diagrams, explain how you will increase the stability of an object. (6)

Compare your answers with those below. Take time to ensure you understand each solution.

Answers to Assignment 14

1. ***Moment is the measure of the turning effect of a force.***
2. ***Moment of a force depends on the perpendicular distance and the size of the applied force.***
3. ***Moment = force x distance***

   = 50N x 1.5 m

   = 75.0 Nm
4.

   a) The system is in equilibrium. So the sum of the clockwise moments equals the sum of the anticlockwise moments.

   $F_1d_1 = F_2\ d_2$

   Remember that weight of an object equals the gravitational pull on that object, so weight (W) = force (F_1).

   If d_1 is the distance of the centre of the ruler from the pivot, then d_1 =10cm = 0.1m

   If d_2 is the distance of the applied force from the pivot, then d_2=20 cm =0.2 m

   $F_2 = 4N$

   So $Wd_1 = F_2d_2$

   W x 0.1 m = 4N x 0.2 m When we divide both sides of the equation by 0.1 m we get:

   $$W = \frac{0.8Nm}{0.1m}$$

   $$= 8N$$

   The weight of the ruler is 8N.

   b)Weight =mass x gravitational pull

   8N = mass x $^{10N}/_{kg}$ ***(when we divide both sides by 10 N/kg we get:***

   $$\text{Mass (M)} = \frac{8N\ kg}{10N}$$

   $$= 0.8\ kg$$

   The mass of the ruler is 0.8 kg.
5. ***When the box is put with its short side as the base as in Figure 21, it falls easily when tilted.***

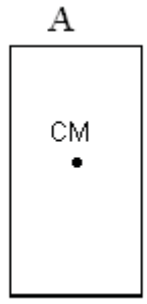


Figure 21: Upright box (Hand drawn), 2010.

When the same box is put with its long side as the base as Figure 22 shows, it becomes more stable than in A because its centre of mass is lowered.

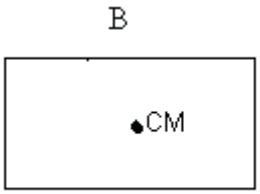


Figure 22: Box on its side (Hand drawn), 2010.

To make this box more stable, put something heavy in the base of the box as figures 23 and 24 C and D show. The heavy slab lowers the centre of mass and makes it even more stable than in B.

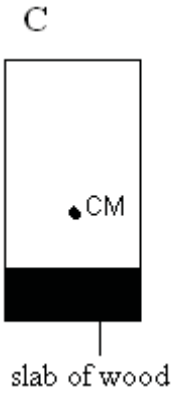


Figure 23: Upright box with a slab (Hand drawn), 2010.

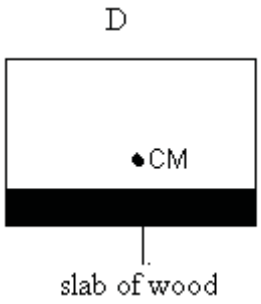


Figure 24: Box on its side with a slab (Hand drawn), 2010.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physics course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 14

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:22)

1. State the principle of moments. (1)
2. Define the centre of mass. (1)
3. Explain why a bucket half filled with water is more stable than an empty bucket. (2)
4. Describe an experiment you would do to determine the centre of mass of a plane lamina. (10)
5. Figure 25 shows a simplified diagram of a claw hammer being used to pull a nail out of wood.

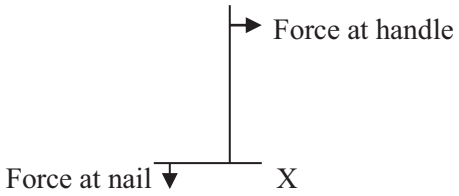


Figure 25

a) Explain why the force at the nail is greater than the force exerted at the handle of the hammer. (2)

b) When the nail has been pulled out a short distance, point X of the hammer touches the wood. Point X is then the pivot. Describe and explain how this changes the force that needs to be exerted at the handle of the hammer. (2)

6. Figure 26 shows a uniform metre rule weighing 3.0N pivoted on a wedge placed under the 40 cm mark and carrying a weight of 7.0N hanging from the 10 cm mark. The rule is kept horizontal by a weight W hanging from the 100 cm end. Calculate the value of the weight W. (4)

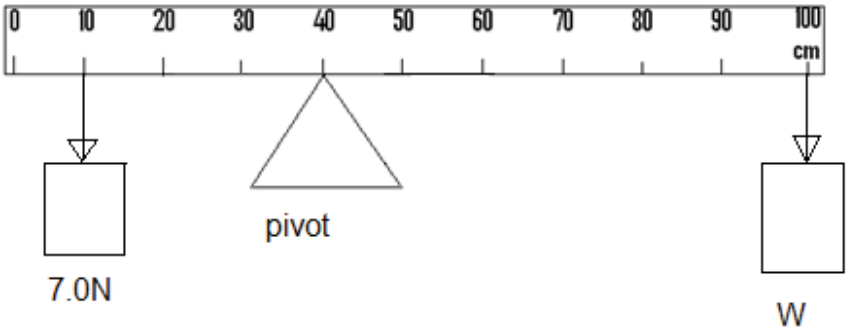


Figure 26: Arrangement showing the principle of moments (Hand drawn), 2010.

Physics

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 15

Work, Energy and Power

Study Skills

Do you know someone who has taken Physics 12 before? Get input from former students of the course. Find out where the easy spots and the hard spots are. Ask previous learners where they thought "if only I had known that . . .". ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In this unit we explore the concept of energy. It is a known fact that without energy, most processes would not take place, either in your body or in practical processes. It is therefore important to understand where energy comes from, what its different forms are and how it can be preserved for future use. Work and power are two other quantities which are closely related to energy and shall also be looked into in this unit.

Time

This unit consists of 30 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. You should focus on those skills while studying this unit.

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.
- *Analyse* experimental data.
- *Apply* correctly various formulae which relate the different physics concepts and theories to the world around us.

Study skills

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Identify* different sources of energy.
- *Describe* different forms of energy conversions and conservation.
- *Calculate* kinetic energy, potential energy and the work done using appropriate formulae.
- *Calculate* the power dissipated.

Terminology

Work:	Force applied through a distance.
Energy:	Ability to do work.
Power:	Rate at which work is done or energy transferred.
Kinetic energy:	Energy a body has because of its motion.
Potential energy :	Energy a body has because of its condition or position.

Section 15-1: Work

Introduction

By the end of section 15-1, you should be able to define work and calculate work done.

Time

There are 4 pages on the topic of work. You should spend approximately 20 minutes on this topic.

What is work?

If somebody asked you what work was, what would you say?

_____

_____

Compare your answer to the following:

You may think of your mother or father's occupation or possibly household chores like washing or cleaning the house as work.

In science however, work has a different meaning from its use in ordinary conversation. **Work is done when a force applied to an object results in the object moving**.

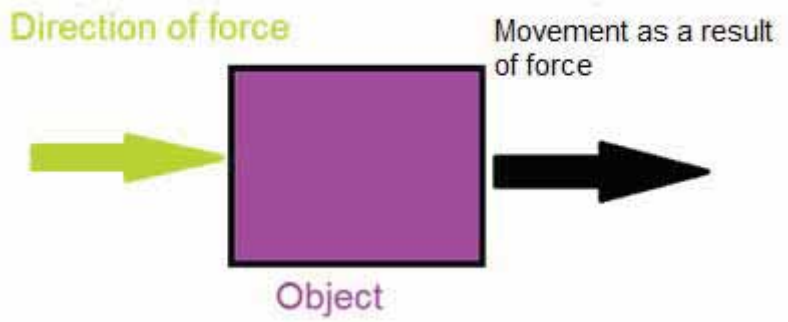

Figure 1: Work done. Image created by Lesotho College of Education Chemistry Laboratory, 2010.

What does this mean? It means if a force is applied to a stationary object but the object does not move, then work has not been done. Work will be done if and only if a force produces **motion**.

If you were to push with all your strength on the side of a brick building, is work being done?

Reflection

If you said "No", you would be correct. Work is not being done on the building because the building does not move (unless you have the strength of Superman!).

Activity 1

Activity

With reference to the definition of work provided above, look at the following pictures and say whether work is being done.

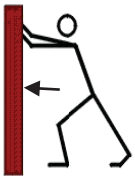

Figure 2: Man pushing on the wall and the wall remains stationery (Hand drawn), 2010.

(a) In Figure 2, is work being done? ……..

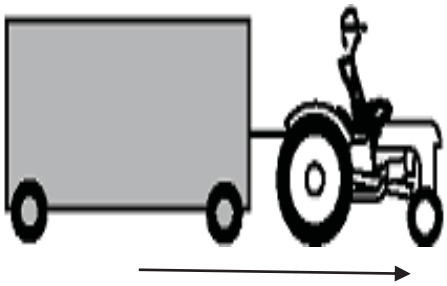

Figure 3: Tractor pulling on the carrier and it moves in the direction of the force (Hand drawn), 2010.

(b) In Figure 3, is work being done? ……..

Compare your answers with the correct answers at the end of section 15-1. Be sure you understand the answers to both questions before moving on.

In equation form:

Work = force applied x distance moved.

In symbols:

W= Fs

Where:

- **W** is the work done in joules (which is the SI unit of work)
- **F** is the force applied in Newtons and
- **s** is the distance moved in meters.

1 joule = 1 newton x 1 metre. In symbols 1 J = 1 Nm

Larger units are the kilojoules (kJ) and the megajoules (MJ)

1 kJ = 1000 J

1 MJ = 1 000 000 J

EXAMPLES*:*

1. How much work is done when a 50 kg box is moved by applying a 20N force on the box through a 200 cm distance?
2. How much work is done when a school bag with wheels full of books is pulled a horizontal distance of 0.6 m by a constant force of 30N?

SOLUTION:

1. $W = Fs$
   $= 20N \times 200cm/100$
   $= 20 \times 2$
   $= 40J$

Reflection

Why does the 200 cm distance have to be divided by 100?

Distance must be expressed in metres when calculating work done.

2. $W = Fs$
   $= 30\ N \times 0.6\ m$
   $= 18\ J$

Activity 2

Calculate work done when

(a) A block of mass of 200 kg is pulled across a floor using a 50N force and it moves through a 3 m distance.

_____
_____
_____
_____
_____

(b) A 100 g box of matches is pushed using 1N of force through 50 cm.

_____
_____
_____
_____
_____

Activity

Compare your answers to the correct answers provided at the end of section 15-1. Be sure that you can do the calculations before proceeding.

Key Points to Remember:

The key points to remember in this section on work are:

- Work is done only when a force causes motion.
- W = Fs

Where: W is the work done in joules (which is the SI unit of work)

F is the force applied in Newtons and

s is the distance moved in meters.

Note it!

The next section with deal with energy, its relationship with work and its conversions.

Answers to Activities on Work

Activity 1

(a) Work is not done when the stickman pushes on the wall since the wall does not move when the stickman exerts a force on it.

(b) Work is done by the tractor since the force exerted by the tractor on the carrier causes it to move and cover some distance.

Activity 2

(a) Work done = force x distance

= 50N x 3 m

= 150J

(b) Work done = force x distance

= 1N x 0.5 m

= 0.5J Note: 50 cm was changed into 0.5 m.

Section 15-2: Energy

Introduction

By the end of section 15-2, you should be able to identify different sources and forms of energy, calculate kinetic energy and potential energy and describe the different forms of energy conversions and conservation.

Time

There are 17 pages on the topic of energy. You should spend approximately 4-5 hours on this topic.

What is Energy?

Energy is described as the ability to do work. Anything that is able to do work (as defined above) does so because it possesses energy. Energy therefore like work is measured in joules (J).

Where does energy come from?

We often say "I don't have the energy to …." or "I had a lot of energy this morning and I did …" We get energy from the food that we eat.

But where does food get the energy it contains from?

Let's think of a simple breakfast meal and analyse it in the table that follows:

Soft porridge with milk, egg, slice of bread, a cup of tea

Food	**Made/come from**	**Feeds on?**	**Which gets the energy from?**
Soft porridge	Sorghum		Sun
Milk	Cow	Grass	Sun
Egg	Chicken	Maize	Sun
Bread	Wheat		Sun
Tea	Tea leaves		Sun

What can you conclude from the table in terms of the major source of energy?

_____

_____

_____

Compare your answer to the following:

The major source of energy is the sun.

Different Energy Sources

Solar energy

The main source of energy used on Earth is the **sun**. The sun's energy is referred to as **solar** energy. The sun gives out energy in the form of **electromagnetic waves** in enormous quantities.

You will learn more about electromagnetic waves in Unit 19!

Other sources of energy are nuclear, fuels, wind, hydropower, tidal and geothermal.

Nuclear energy

Nuclear energy is the energy stored within the nucleus of some radioactive atoms. It released when these nuclei combine (**nuclear fusion)** or split **(nuclear fission)** in a nuclear reactor. These processes release thermal energy in vast quantities.

The energy released this way may be used among other things in the generation of electricity and in the making of atomic bombs.

Nuclear energy will be dealt with in depth under the unit on radioactivity (Unit 26).

Fuel energy

Fuel energy is the energy which is stored in fuels such as oil, coal or natural gas. These are formed from the remains of dead plants and animals. The energy stored in this form is also referred to as **chemical energy**.

Chemical energy is released when these fuels are burnt (chemical process). Although food is not a fuel, it is also a store of chemical energy which is released during chemical processes which take place in the body.

Wind energy

This is the energy derived from wind when it turns giant windmills which in turn drive electrical generators. Wind energy may also be used to pump water or set sailing ships in motion. Use of wind energy is however limited, as production of wind is also dependent on other weather elements.

Geothermal energy

Geothermal energy is the natural heat energy of the Earth. It is stored in hot molten rock deep in the Earth's crust. This energy may be used in the production of electricity if this heat is used to produce steam which turns the turbine of the generator. It is a highly technical and very expensive source of energy to put into practice.

Hydroelectric energy

Water stored in a dam at a higher level is allowed to flow to a lower level where it is used to drive a turbine. This turns the generator which produces electricity.

Activity

Activity 3

Look at the energy sources as shown in Figure 4 below.

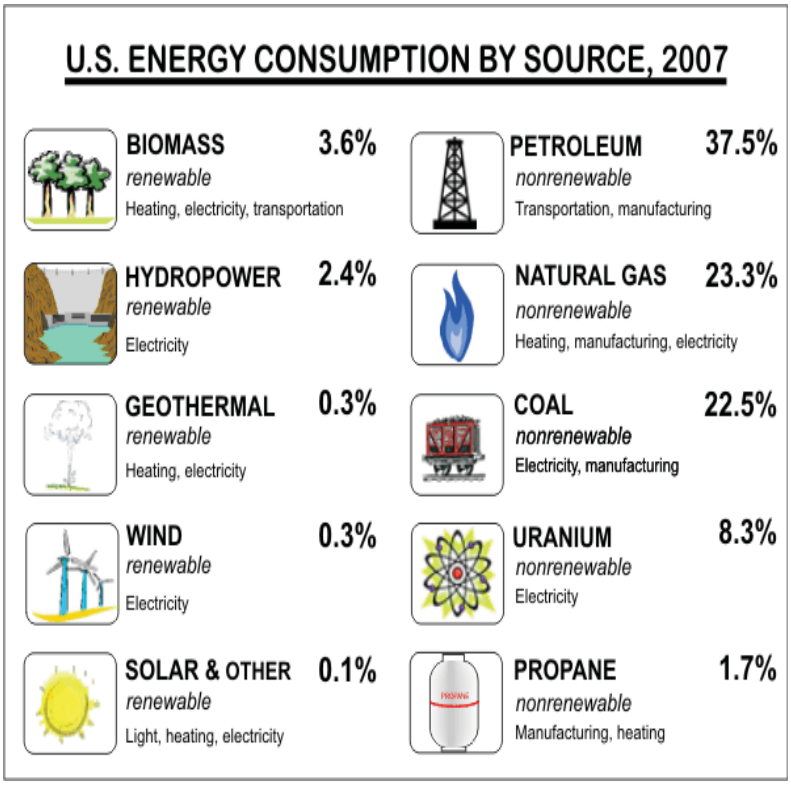

Figure 4: Sources of energy accessed from Creative Commons, 2010.

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(a) List sources of energy that are:

i) Natural

_____
_____
_____
_____

ii) Artificial

_____
_____
_____
_____

b) The energy sources in the left column are renewable and the sources in the right column are non- renewable. Using that information as a guideline, what are renewable and non-renewable energy sources?

_____
_____
_____
_____

You will find the correct answers at the end of section 15-2. Compare them to your own and move on after analyzing each one.

Reading

Learn more about energy sources here:
http://www.eia.gov/kids/energy.cfm?page=2

Energy not only comes from different sources but also comes in many different **forms**. The energy sources discussed above may also be described as forms of energy.

Different Forms of Energy

Heat energy, sometimes referred to as thermal energy, is the energy which is transferred from one place to another owing to a temperature difference between them. Heat energy is transferred through three main processes namely conduction, convection and radiation. See Unit 16 for more details.

Electrical energy is the energy associated with the current in electrical appliances, an electric drill, power tools and immersion heaters and is produced by energy transfers at power stations.

Sound energy

Sound energy is the energy possessed by anything that produces sound.

Light energy

Light energy is the energy possessed by anything that produces light.

Mechanical energy

Mechanical energy is divided into two types: **potential energy** and **kinetic energy.**

1. Potential energy

Potential energy is possessed by objects which have been moved to a position in which they can do work if released. Simply put, it is the energy which a body has because of its **condition** or **position**. These could be:

- raised objects (because of their position)
- compressed and stretched springs (because of their condition)

Stretched and compressed objects are said to possess **elastic potential energy** and raised objects possess **gravitational potential energy.**

Activity

Activity 4

Look at the following pictures:

Figure 5: People riding a roller coaster accessed from Flickr, 2010.

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a) Does the object in Figure 5 possess elastic potential or gravitational potential energy?

_____

Figure 6: Stretched bow and arrow accessed from Flickr, 2010.

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b) Does the object in the picture possess elastic potential or gravitational potential energy?

_____

Compare your answers to the correct answers provided at the end of section 15-2. Continue if you are satisfied with your ability to answer the questions. If not, review the above content and try the activity again.

Calculating Gravitational Potential Energy

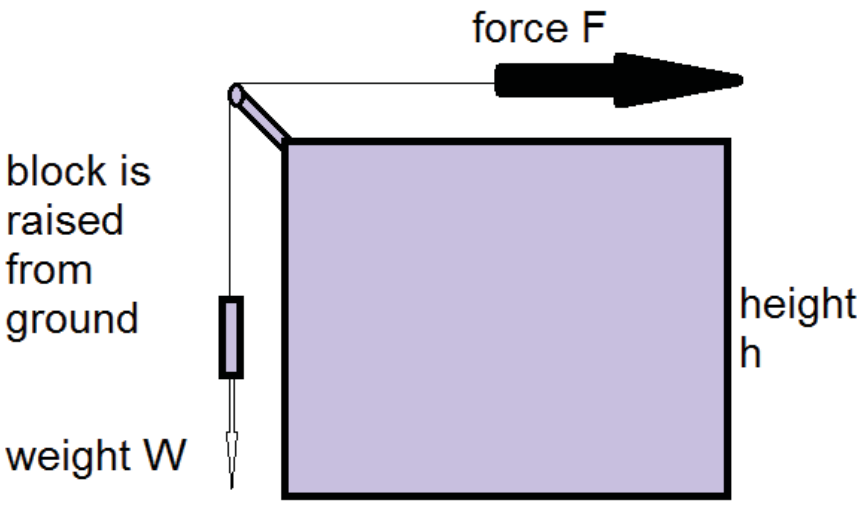


Figure 7: Work done in raising an object (Hand drawn), 2010.

When the block shown in the picture is raised from the ground, work is done.

What is the formula for work done?

_____

Compare your answer to the following:

Work is a force applied through a distance. The formula is: W= Fs

So when the block is raised, it is lifted through a vertical height ***h*** the force **F** which is used to lift the block is equal to the weight ***w*** of the block.

The amount of work done in lifting the block is therefore:

Work done = weight (N) x height (m).

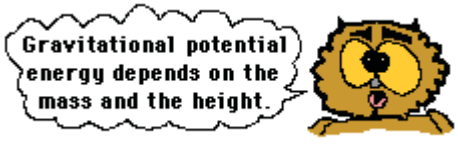
But the weight of the block is ***w = mg*** *(If you need to, refer to Unit 13 to review this).*

Where:

m is the mass of the object in Kg and ***g*** is the acceleration due to gravity in m/s^2.

The work done in lifting the object is therefore W = ***mgh.*** This work done is also equal to the gravitational potential energy gained by the object when it is lifted.

Gravitational potential energy, G.P.E = mgh in (joules)



Worked example:

What is the gravitational potential energy gained by a box of mass 10 kg that is lifted on to a table which is 2 m in height? Assume g is10 m/s^2.

Solution:

G.P.E. = mgh

= 10 kg x 10 m/s^{-2} x 2 m

= 200 J

When dealing with problems involving potential energy, only the vertical height is considered.

Activity

Activity 5

Work out the following problems: Assume *g* is 10 m/s^2

a) What is the potential energy of a body of mass 10 kg which is raised to a vertical height of 2 m?

_____
_____
_____
_____

b) A body on top of a hill possesses a gravitational potential energy of 200 J. If its mass is 5 kg, to what height is the body raised?

_____
_____
_____
_____

Compare your answers with the correct answers at the end of section 15-2. Take the time needed to understand each calculation before continuing.

2. Kinetic energy

Kinetic energy is another form of mechanical energy. It is the energy which a body possesses because of its motion. Any moving body has kinetic energy. The faster the body moves, the more kinetic energy it has.

Figure 8: Moving objects accessed from Wikimedia Creative Commons, 2010.

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All moving bodies have kinetic energy

Calculating kinetic energy

The equation that defines kinetic **K.E = 1/2*mv*^{2}.**

Where

- ***m*** is the mass of the moving object in kg and
- ***v*** is the velocity of the object in m/s

Kinetic energy is also measured in joules and it is equal to the amount of work done when the object is moving.

Note it!

Worked example:

What is the kinetic energy of an elephant of mass 1000 kg moving at a velocity of 2 m/s?

Solution:

= 1/2 x 1000 kg x (2 m/s)^2

= 1/2 x 1000 kg x 4 m/s^2

= 2000 J

Kinetic energy depends on the square of velocity (v^2).

An elephant of the same mass moving at three times the velocity will have nine times the kinetic energy.

Let's work it out!

K.E = 1/2*mv*^{2}

=1/2 x 1000 kg x (4m/s) ^{2}

= 1/2 x 1000 kg x 16

= 8000 J

Activity

Activity 6

(a) Energy comes in many different forms; mention three that you've learned about.

_____

_____

_____

(b) Which two forms of energy are mechanical? State the formula of each.

_____

_____

After attempting both questions, compare your answers to the correct answers provided at the end of section 15-2. Be sure that you understand each answer before continuing. If you have any misunderstandings, review this content and work through the activity again.

Energy Conservation and Conversions

Energy is needed for many purposes, and can be changed from one form to another.

For the following situation, think about the questions asked, but do not write down the answers as no spaces are provided. The questions are answered in subsequent paragraphs.

- The man in Figure 9 needs energy to be able to work on the computer. Where does he get his energy from?
- The computer also needs energy for it to operate. What form of energy?
- He also needs other forms of energy to allow him to work comfortably on the computer. Which could these be?

Figure 9: A man working on a computer accessed from Creative Commons, 2010.

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Let us now try to figure it out.

He **gets** chemical energy from the food he has eaten. The food in turn got energy from the sun (solar energy). The sun is the main source of energy in the food chain. Even if the man has eaten meat say from a cow, the cow had also eaten grass which is a plant getting energy from the sun.

The computer **utilises** electrical energy, and produces light energy and other forms of energy such as sound and kinetic energy.

The following are then the energy conversions for the man in Figure 9.

a) Solar energy ➔ Chemical energy ➔ Kinetic energy

(Solar energy is from the sun, chemical energy from food eaten and kinetic energy from his moving fingers as he types).

b) Electrical energy ➔ [Light + Sound + Kinetic] energy

(Electrical energy can be from water. For example, electricity produced in the Katse/Muela project.)

(Light can be produced by the monitor of the computer, sound and kinetic energies from the fan of the computer).

The energy conversions lead us to the principle of conservation of energy that states that:

Energy may not be created or destroyed in any process, it may only change from one form to another, but the total amount remains constant.

Consider the following examples:

- A bulb converts electrical energy to heat energy and light energy.
- A paraffin heater converts chemical energy to heat and light energies.

Do you see that in each case the original energy is not used up, it just changes from one form to another? Energy is conserved (preserved) and converted (changed from one form to another).

That's the principle of conservation of energy!

Activity

Activity 7

Hydropower generation

Look at the following diagram to state the energy conversions involved.

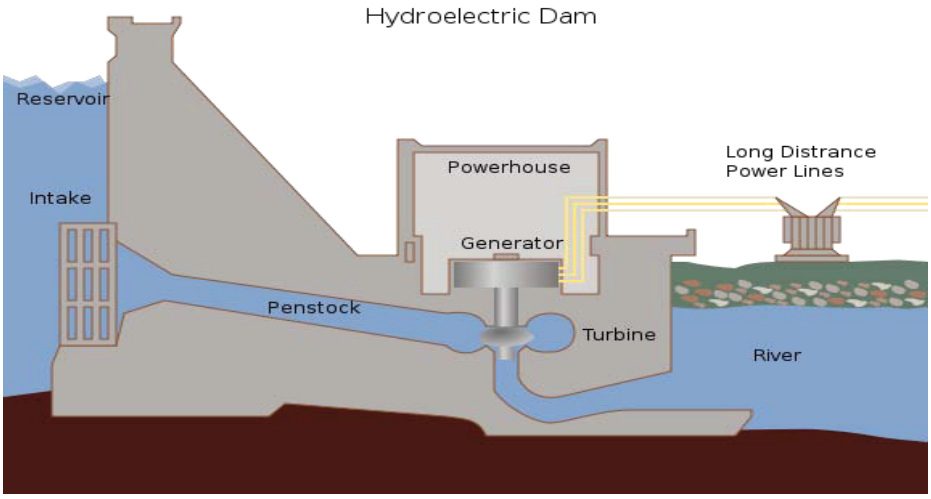

Figure 10: A hydroelectric Dam accessed from Wikimedia Creative Commons, 2010.

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Water in the reservoir has gravitational potential energy which is converted to: (a) _____ when the turbine turns.

The turbine is connected to the generator which produces

(b) _____ energy.

This energy is then carried by power lines to our homes and offices where it is converted to various forms of energy such as:

(c) _____ and

(d) _____ and

(e) _____ energy.

After filling up the blank spaces, compare your answers to the ones provided at the end of section 15-2.

Kinetic and Potential Energy Conversions and Conservations

The stone in Figure 11 has zero potential energy at position A. It only has G.P.E. and not kinetic energy after it is raised to level B.

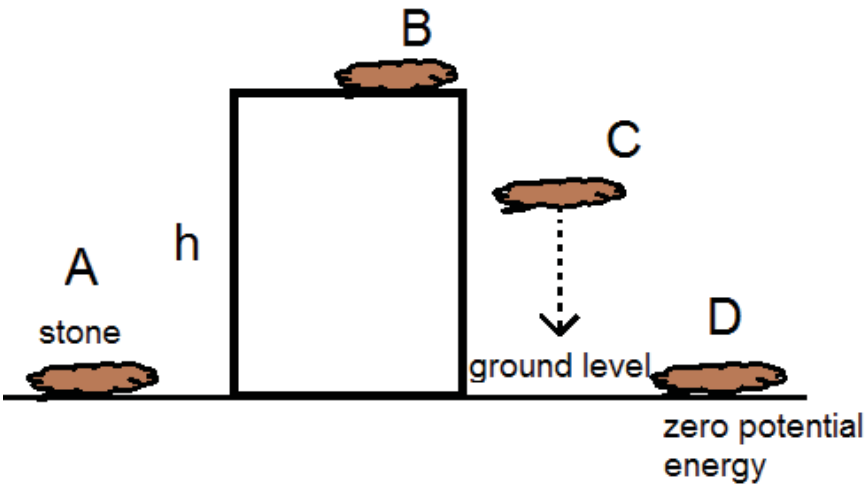

Figure 11: Energy conversions of a raised and falling stone (Hand drawn), 2010.

If it is released and falls from B to position C part of its G.P.E. is converted to K.E. (because it is moving) and other forms of energy such as sound energy and heat energy. Just before it hits the ground, its potential energy is converted mostly into K.E and other forms of energy. At D it has zero potential energy; all its potential energy is converted into other forms (sound, a little heat due to the friction of the stone travelling through the air, and light can be generated if sparks are made).

If the air resistance is ignored, when the same object is falling all the G.P.E is converted into K.E only. It gains K.E at the expense of potential energy;

In fact, the potential energy lost is equal to the kinetic energy gained.

The reverse process also applies in the same manner. When an object is raised and is given an initial velocity with which it moves upwards, the amount of its kinetic energy lost where it stops rising is equal to the potential energy gained.

When all frictional forces are ignored **loss in P.E = gain in K.E**, but the total energy remains the same! Study Figure 12 to ensure you understand why the total energy remains the same.

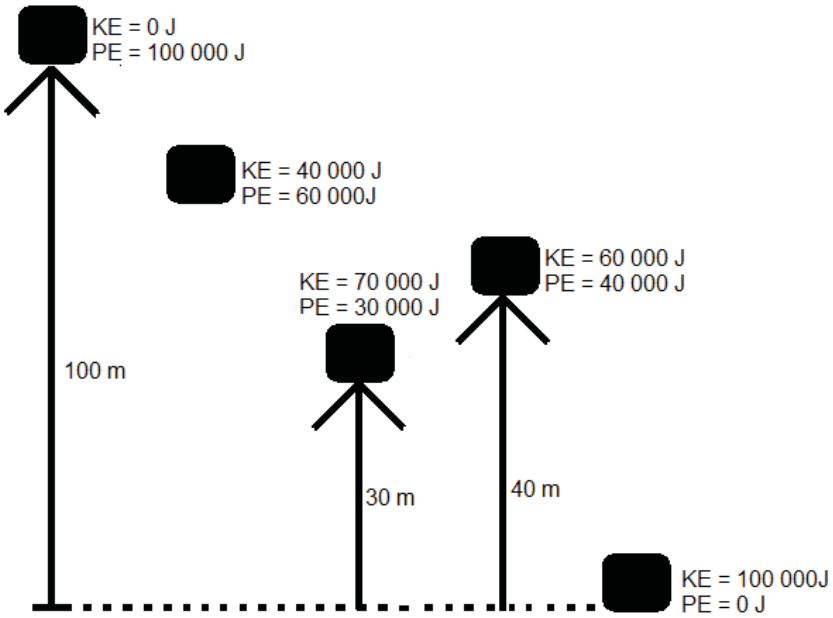

Figure 12: Energy conversions given negligible air resistance (Hand drawn), 2010.

Example

A stone of mass 2 kg is thrown vertically upwards with an initial velocity v of 50 m/s to a height of 100 m where it stops momentarily before it comes down. Ignoring air resistance and knowing *g* is 10 m/s^2, calculate:

(i) The potential energy gained by the stone at 100 m above the ground surface.

(ii) The potential and kinetic energies of the stone mid-way through the 100 m height (50 m).

(iii) The initial velocity of stone as it was thrown.

Solution

(i) $G.P.E = mgh$

$= 2\ kg \times 10\ m/s^2 \times 100\ m$

$= 1000\ J$

(ii) *Mid-way through G.P.E gained = K.E lost*

$2\ kg \times 10\ m/s^2 \times 50\ m = K.E$

$1000\ J$

(iii) *K.E at the start = G.P.E at the top*

$1/2mv^2 = 2000\ J$

$1/\cancel{2} \times \cancel{2}\ kg \times v^2 = 2000\ J$

Make v^2 the subject of the formula

$V^2 = 2000\ J$

$V = \sqrt{2000}$

$V = 44.72\ m/s$

Activity

Activity 8

1. A package of mass 5 kg is thrown vertically upwards with an initial velocity 100 m/s to a height of 200 m where it stops momentarily before coming back down. Ignore air resistance assume g = 10 m/s^2, calculate:

    a) The potential energy gained by the stone at a 200 m height above the ground surface.

    b) The potential and kinetic energies of the stone mid- way through the 200 m height.

    c) The initial velocity of stone as it was thrown.

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2. Just as the principle of conservation states: energy lost = energy gained but the total amount of energy remains _____.

Compare your answers with those given at the end of section 15-2. Review as needed until you understand the answer to each question.

Activity

If you have access to the internet, please got to:

http://phet.colorado.edu/en/simulation/energy-skate-park

Click on the "bar graph" button to view the changing potential and kinetic energy levels. What happens when you make the track less steep? Steeper? Change the mass of the skater?

Key Points to Remember:

The key points to remember in this section on energy are:

- Work done = energy converted from one form to another.
- The different forms of energy are heat, sound, light, electrical, potential and kinetic energies. They can be converted from one form into another.
- Kinetic energy K.E = $1/2mv^2$
- Gravitational potential energy G.P.E = *mgh*

The next section deals with power which is directly related to both work and energy.

Note it!

Answers to Activities on Energy

Activity 1

a) i) Natural sources – biomass, hydropower, geothermal, wind, solar, natural gas, coal and uranium.

ii) Artificial sources – petroleum and propane.

b) Renewable sources of energy are those that can be regenerated and non-renewable sources are those which run a risk of getting all used up with time.

Activity 4

a) Elastic potential energy

b) Gravitational potential energy

Activity 5

(a) Potential energy mgh = 10 kg x 2 m x 10 m/s^2

= 200 J

(b) Height (h) = G.P.E/g x m

= 200 J/ 10 m/s^2 x 5 kg

= 4 m

Activity 6

(a) Sound, heat, light, electrical etc.

(b) Potential energy = mgh

Kinetic energy = $1/2mv^2$

Activity 7

a) Kinetic energy

b) Electrical energy

c) Light energy from a bulb/globe.

d) Sound energy from a radio/television/video player.

e) Heat energy from a stove/iron/heater.

They can be other forms of energy in homes other than the ones listed above; e.g. kinetic energy from a fan. Refer to your tutor for those you may have mentioned but not listed here.

Answers to Activity 8

a) G.P.E = mgh

= 5 kg x 10 m/s^2 x 200 m

= 10,000 J

(i) Mid-way through G.P.E gained = K.E lost

5 kg x 10 m/s^2 x 200 m = K.E

10,000J

(ii) K.E at the start = G.P.E at the top

½ mv^2 = 2,000 J

$1/\cancel{2}$ x $\cancel{2}$kg x v^2 = 2,000 J

Make v^2 the subject of the formula

V^2 = 2,000 J

V = $\sqrt{2000}$

V = 44.72 m/s

Section 15-3: Power

Introduction

By the end of section 15-3, you should be able to calculate power.

Time

There are 3 pages on the topic of power. You should spend approximately 20 minutes on this topic.

What is Power?

Refers to the rate at which work is done or the rate at which energy is transferred from one form to another.

Look at Figure 12 and say which of the two men would you consider to be more powerful?

The obvious choice would be the muscular one!

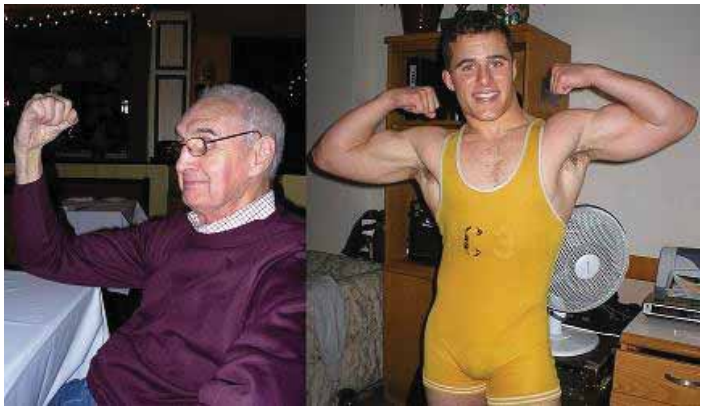

Figure 12: Two men accessed from Flickr, 2010.

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In science, power is not about the build of a body but about how fast work can be done or energy can be transferred. So, the stronger person can only qualify as more powerful if he or she meets this condition.

In equation form:

power = work done/ time taken

OR

energy transfer/time taken

In symbols:

P=W/t where:

- **P** is power in watts

- **W** is the work done or energy transferred in joules and
- **t** is time in seconds

i.e. 1W = 1J/s

Other units of power are the kilowatt (kW) and the megawatt (MW)

1Kw = 1000W

1MW = 1000 000W

Example

An electric motor lifts 200 kg of water from a well 100 m deep to the surface in 5 seconds. How powerful is the motor? Assume g is 10 ms^{-1}.

Solution

P = W/t, but **W = Fs**

Therefore P = Fs/t and F = *mg*

P = mg x s/t

P = 200 kg x 10 m/s^2 x 100 m/ 5 seconds

= 200000/5

= 40,000 W or 40 kW

Activity 9

Measuring your own power

Measure your own power by carrying out these simple steps. You will need:

- A measuring tape
- Scale (from your home or a nearby clinic or any other from which you can measure your mass).
- A stop clock/watch. For this your can use your cell phone if it has this accessory.

Activity

Procedure

- Measure your mass.
- Using the tape measure, find the height of a flight of stairs. (Note: measure the vertical height in meters).
- By yourself or with someone's help, use the stop watch to record the time for which it takes you to run up the stairs. You can repeat this and take the average of the two times recorded (remember it has to be in seconds!)

Doing the calculations

Your power is the amount of work you do when you climb the stairs divided by the average time taken (let's call it *t*).

Work done = your weight x vertical height of the stairs (let's call it *h*)

Your weight = your mass (let's call it *m*) x 10 m/s^2
(which is the value of *g*)

Your power = 10 *m* x *h/t*

How much power did you exert? Express it in watts.

_____

_____

_____

Compare your answer to the following sample:

Suppose your mass m = *50 kg*

Then your weight W = *50 kg x 10 m/s2*

= *500N*

Now imagine climbing a flight of stairs 50 m high.

Then work done = *your weight x the height*

= *500N x 50 m*

= *25,000 J*

Suppose it took you 60 seconds to climb the stairs

Then your power P = $\frac{work\ done}{time\ taken}$

= $\frac{25\,000 J}{60\ s}$

= *416. 67 W*

You should be aware that your power may change slightly from time to time depending on the amount of time you take to run up the stairs.

Note it!

Key Point to Remember:

The key point to remember in this section on power is:

- Power P = W/t

You have now completed the last section of this unit on work, energy and power. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Unit Summary

Summary

In this unit you learned about energy and its different forms. The major source of which is the sun. All other energy sources are in one way or the other related to the sun. You also learned about work and power as described in science which is different from the way in which these concepts are dealt with in everyday language. It is important to distinguish scientific concepts from everyday use of language; they may sound the same but they have different meanings!

It is also crucial to remember formulae and match every quantity with its correct SI unit.

You should be able to:

- Relate work done to force and distance (W = Fs).
- Show that work done = energy converted from one form to another.
- Describe and express qualitative understanding of different energy forms and their conversions.
- Relate kinetic energy to mass and velocity (K.E = $1/2mv^2$).
- Relate G.P.E to mass, gravity and height (G.P.E = *mgh*).
- Relate power to work done and energy transferred (P = w/t).

You have completed the material for this unit on work, energy and power. Spend some time reviewing the content. Once you are confident that you know the material, try the assignment. Check your answers with those provided and clarify your misunderstandings (if any). Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers the transfer of thermal energy.

Assignment 15

Assignment

For all questions where necessary, assume $g = 10$ m/s^2 and all frictional forces are negligible.

Answer all the questions that follow. You should be able to complete this assignment in 30 minutes. Please show all of your work for full marks.

[Total Marks:20]

1. **Multiple choice questions (1 mark each)**

(a) When a catapult is stretched, what form of energy does it possess?

A Potential

B Kinetic

C Heat

D Sound

(b) A block of wood has 100 J of potential energy at the top of a 50 m high ground. What is its mass?

A 0.2 kg

B 0.5 kg

C 1 kg

D 20 kg

(c) The block of wood in (b) above is accidentally dropped to the ground. What is velocity just before it hits the ground?

A 316 m/s

B 31.6 m/s

C 3.16 m/s

D 3160 m/s

(d) What energy changes occur when a moving car is suddenly brought to rest by its brakes?

A. Kinetic energy to potential energy.

B. Potential energy to kinetic energy.

C. Kinetic energy to heat and sound energies.

D. Potential energy to heat and sound energies.

(e) How much power is exerted by a girl of mass 50 kg running up a flight of stairs of vertical height 10 m in 5 s?

A 1000 W

B 100 W

C 2000 W

D 200 W

Structured Questions

1. Write the name (NOT SYMBOL) of the correct SI unit for each of the following: (6)

   a) mass _____

   b) weight _____

   c) force _____

   d) work _____

   e) energy _____

   f) power _____

2. State the principle of conservation of energy: (2)

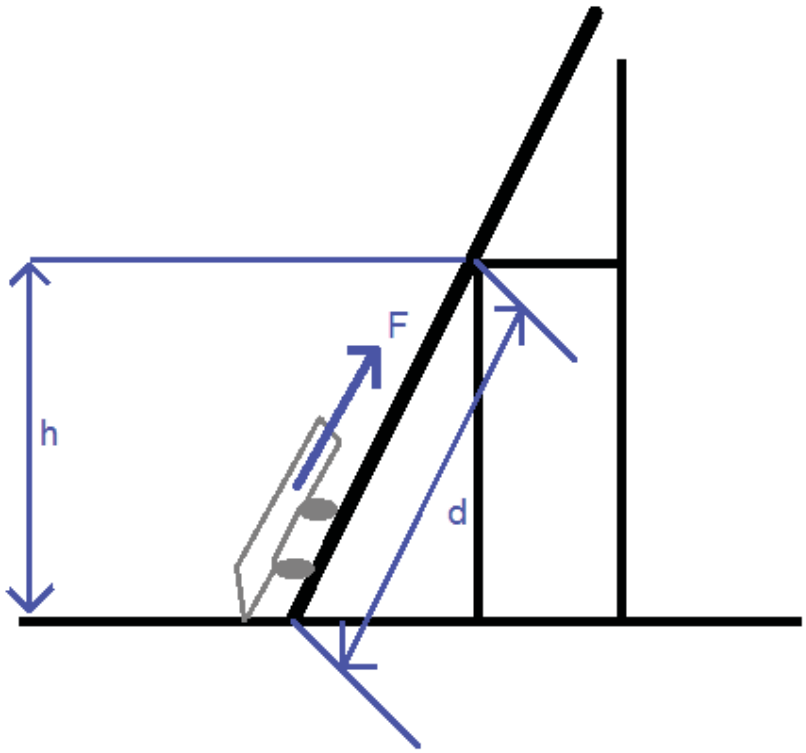
3. (a) Name the energy transfers which take place when: (3)

   (i) An electric heater is on.

   (ii) You run up a flight of stairs.

   (iii) A spring is compressed.

   (b) A cart is pulled at a constant speed along an inclined plane to the top of a ledge. If the mass of the cart is 3.0 kg and the height of the ledge is 0.45 meters, then what is the potential energy of the cart at the height of the seat? (2)



c) What is the potential energy of a 10 kg body at a 200 m height? What is its kinetic energy just before it hits the ground when it falls from the peak? (2)

Compare your answers with those below. For any question you get wrong, review the related content in this unit.

Answers to Assignment 15:

Multiple choice questions (1 mark each)

(a) Potential

(b) 0.2 kg

GPE = mgh

Therefore m $= \frac{GPE}{gh}$

$= \frac{100J}{10\ x\ 50}$

$= 0.2\ kg$

(c) 31.6m/s

GPE = KE

KE $= \frac{1}{2}mv^2$

Therefore $v^2 = \frac{2KE}{m}$

$v^2 = \frac{2\ x\ 100J}{0.2\ kg}$

$v^2 = 1\ 000$

$v = \sqrt{1000}$

$v = 31.6\ m/s$

(d) Kinetic to heat and sound.

(e) 1000 W

$m = 50\ kg$

Then the girl's weight W $= 50\ kg\ x\ 10\ m/s2$

$= 500\ N$

For running up a flight of stairs 10 m high,

Work done = *the girl's weight x the height*

$= 500\ N\ x\ 10\ m$

$= 5\ 000\ J$

Suppose it took you 60 seconds to climb the stairs

Then your power P $= \frac{work\ done}{time\ taken}$

$= \frac{5\ 000J}{5\ s}$

$= 1\ 000\ W$

Structured questions

1.

(i) mass – kilogram

(ii) weight – newton

(iii) force – newton

(iv) energy – joules

(v) work – newton meters or joules

(vi) power – watt (1 mark each)

2. *Energy cannot be created or destroyed, it just changes from one form to another but the total amount remains the same (2)*

3. *(a)*

(i) Electrical to heat and light (1)

(ii) Chemical to kinetic to gravitational potential (1)

(iii) Kinetic energy to elastic potential energy (1)

(b) 13.5 J (2)

(c) G.P.E = 20 000 J

K.E = 63.25 m/s (2)

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 15

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes. Please show all your work.

(Total Marks:25)

1. Define the following quantities and give the formula of each:

   (i) Work (2)

   (ii) Energy (2)

   (iii) Power (2)

2. A man pushes a case with a mass of 50 kg across a floor at a constant speed of 50 m/s. He exerts a force of 100N.

(a) How much work did the man do? (2)

(b) Give the energy conversions that take place as work is done by the man when pushing the case. (2)

(c) What power does the man exert in 3 s? (2)

3. A water stream travels at 7 m/s and reaches a hydropower station where it turns a generator. A mass of 800 kg passes through the generator every second.

   (a) What is the kinetic energy of the water which arrives at the generator? (2)

   (b) From what height was the water flowing, if all the gravitational potential energy was converted to kinetic energy? (2)

4. A car of mass 1500 kg moves at 8 m/s.

(a) Calculate the kinetic energy of the car (2)

(b) If the engine of the car is switched off, to what height could the car rise up a hill before coming to rest if there is no energy loss due to friction? (2)

(c) Into what form has the kinetic energy been transformed when the car has come to rest on the hill? (2)

5. State the energy conversions which take place in a hydropower station. (3)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 16

Transfer of Thermal Energy

Study Skills

Do you have trouble concentrating? Break-up the content of study by mixing up subjects and building in variety and interest and removing boredom. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

You can't see thermal energy, but you can see evidence of heat transfer. You might see the air shimmering over a heater (**convection**), put your hand on a warm spoon that's been sitting in a hot cup of tea (**conduction**) or note that the sun shine feels warm on your skin (**radiation**). In this unit, you will find out about all the three forms of heat transfer.

Time

This unit consists of 40 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. You should focus on those skills while studying this unit.

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

Describe matter and its related physical processes.

Study Skills

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Describe* how heat transfer occurs in solids in molecular terms.
- *Describe* convection in fluids.

- *Explain* how heat is transferred by radiation.
- *Distinguish* between good and bad emitters and good and bad absorbers of infra red radiation.
- *Identify and explain* some of the everyday applications and consequences of conduction, convection and radiation.

Terminology

Molecules:	Groups of atoms.
Thermal energy:	The kind of energy that is caused by heat.
Conduction:	The flow of heat through a solid.
Convection:	The transfer of heat through a fluid by the actual movement of the heated material itself by convection currents.
Radiation:	The transfer of heat by electromagnetic waves.
Electromagnetic spectrum:	The electromagnetic spectrum describes the range of electromagnetic waves placed in order of increasing frequency.

Section 16-1: Molecular Model of the Three States of Matter

Introduction

At the end of section 16-1, you should be able to describe the three states of matter in molecular terms.

Time

There are 5 pages on the topic of the molecular model and three states of matter. You should spend approximately 30 minutes on this topic.

Three States of Matter

There are three states of matter: solids, liquids and gases. Scientists have devised a model that explains the properties of these states. This model assumes that matter is made up of a large number of tiny particles called **atoms** or groups of atoms called **molecules** (refer to Unit 2). These particles are in continuous motion and they are too small to be seen by the naked human eye.

Try to imagine these particles as small balls, such as marbles. They are in constant movement. The hotter they are the faster they move. Now let us look at what happens in each state.

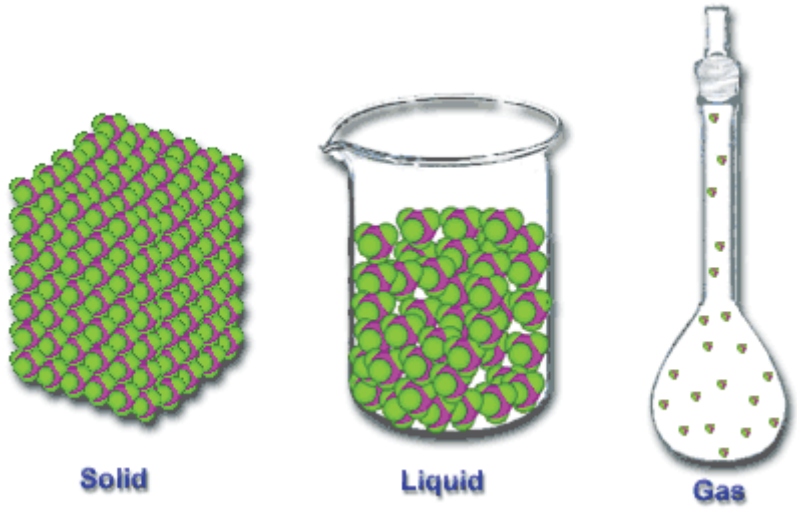

Figure 1: Molecular structure of the three states of matter accessed from Creative Commons, 2010.

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Solids:

In a solid, the particles are arranged close together in a regular pattern, touching each other.

The molecules attract each other with a strong force and the force holds them in fixed positions. This makes the molecules only able to vibrate around their fixed positions.

Think of an overcrowded class with students sitting in threes at one desk touching one another in a classroom. Everyone sits in his/her place. They represent molecules in a solid. As the teacher is teaching them they do not swap places, but will only move a bit.

Note it!

NOTE:

- Solids keep their shape and volume because the molecules in them cannot change places.
- They cannot be compressed since the molecules are arranged close together, they cannot be squashed any closer.
- When a solid is heated, the molecules gain energy and vibrate more.

Let us go back to our example of students in a classroom. Imagine that it is winter and the students are cold. They will sit closely to one another to keep their warmth. As the day progresses, they become heated up and will start to shuffle more and have more motion as in solids.

Liquids:

In a liquid, the molecules are not arranged in a regular pattern and are slightly farther apart (refer to Figure 1 above).

The molecules still have forces between them, but they are not held in fixed positions. The molecules are therefore moving among one another all the time and they can change places.

Let us think about our learners, but now in a science laboratory carrying out an experiment. They will be sitting quite close to one another, but they will also be moving around, changing places as they carry out some errands such as collecting apparatus and materials to be used, opening gas outlets and collecting water from taps found in the lab. They may often bump into each other at these times. This is typical of what happens in a liquid.

Note it!

NOTE:

- Liquids flow since their molecules can move past each other.
- Liquids will take the shape of a container since their molecules are always moving around and changing places.
- Liquids keep their volume; the forces holding them together make it difficult for the molecules to escape from the liquid.
- Liquids are extremely hard to compress as the molecules are so close together and there is little space between them.
- When a liquid is heated, the molecules gain energy and move about more vigorously.

Gases:

In a gas, the molecules are far apart (refer to Figure 1 above).

In gases, the molecules are moving very quickly in different directions. There is no pattern and they are changing places all the time. The forces holding the molecules together are so small that they can be ignored, they are negligible.

Now our learners have finished with the experiments in the laboratory and it is break time. They all go their separate ways, some to the toilet, some back to their classroom and others to the playground. They spread out around the school like a gas.

Note it!

NOTE:

- Gases flow since their molecules are always changing places with each other.
- Gases fill and take the shape of a container since they are moving very fast and there are no forces to stop them from flying apart.
- Gases can be compressed as they can easily be squeezed together because their molecules are so far apart.

Reflection

If you have access to the internet, please go to:
http://phet.colorado.edu/en/simulation/states-of-matter-basics

What happens to the molecules when you change from a solid to a liquid to a gas?

Reflection:

How are you doing so far? I do hope you are not encountering any problems. Let us take a moment to think about this:

Why is it easier to walk through air than water?

_____

_____

Reflection

Compare your answer to the following:

It is easier to walk through air because its particles are so far apart and they are moving freely.

What about water and a wall? Which one can you go through?

Water of course! Note that the differences have to do with their molecular models.

Activity 1

Try and answer the following questions on your own without referring to the content above to see if you understand the molecular model of matter.

Explain the following in terms of the molecular model of matter:

Activity 1

1. Why is it difficult to compress a solid?

_____

_____

_____

_____

2. Why are solids unable to flow?

_____

_____

_____

_____

3. Why are gases relatively easy to compress?

_____

_____

_____

_____

4. Why do liquids have a fixed volume but not a fixed shape?

_____
_____
_____
_____

5. Fill in the following table to compare solids, liquids and gases.

Solids	Liquids	Gases
Have fixed shape		**Has no fixed shape**
	Flows	**Flows**
	Keep their volume	

Compare your answers to the correct answers provided at the end of this section. Continue on if you understand each answer. If not, review the above content before continuing.

Note it!

The key points to remember in this section are:

- In a solid, the particles are arranged close together in a regular pattern, touching each other.
- In a liquid, the molecules are not arranged in a regular pattern and are slightly farther apart.
- In a gas, the molecules are far apart.

In the subsequent sections we are going to find out how the arrangement of particles aid heat transfer.

Answers to Activities on Molecular Models of the Three States of Matter

Activity 1

1. ***It is difficult to compress a solid because the molecules in a solid are arranged close together and so they cannot be squashed any closer together.***
2. ***Solids are unable to flow because the molecules in them cannot change places.***

3. ***Gases are relatively easy to compress because they can easily be squeezed together since their molecules are so far apart.***
4. ***Liquids have a fixed volume the forces holding them together make it difficult for the molecules to escape from the liquid. Liquids do not have a fixed shape because their molecules are always moving around and changing places.***
5.

Solids	**Liquids**	**Gases**
Have fixed shape	Takes shape of the container	**Has no fixed shape**
Does not flow	**Flows**	**Flows**
Have fixed volume	**Keep their volume**	No fixed volume

Section 16-2: Conduction

Introduction

At the end of section 16-2, you should be able to describe heat transfer occurring in solids in molecular terms.

Time

There are 5 pages on the topic of conduction. You should spend approximately 60 minutes on this topic.

Heat Transfer

In simple language, heat is warmth and transfer means movement or travelling. Heat is given off when an object's thermal energy is transferred. **Thermal Energy** is the kind of energy that is related to and/or caused by heat. When thermal energy is applied to a substance, the *velocity* of the *molecules* which makes up the substance *increases* and it gets *warmer*.

In the simplest of terms, heat transfer is concerned with only two things:

- **Temperature**, and
- **Flow of heat**.

Temperature represents the amount of thermal energy available, while the flow of heat represents the movement of thermal energy from place to place.

Reflection

If you have access to the internet, please go to:
http://phet.colorado.edu/en/simulation/states-of-matter-basics

What happens to the solid, liquid and gas when you increase the temperature of the system? What happens when you cool the system?

Thermal energy can be transferred in three ways: by *conduction*, by *convection* and by *radiation*.

We now know that the molecules of any object are constantly moving. If they become hotter, they gain more kinetic energy and move faster and farther apart. Suppose you have two objects that are at different temperatures and you place them next to each other (in thermal contact with one another) what do you think will happen?

There will be a transfer of thermal energy from the object at a higher temperature *(hot object)* to the object at a lower temperature *(cold object)* until they are at the same temperature. The objects are then said to be in thermal equilibrium. *How does this happen?*

This happens because the hot object contains molecules that have higher kinetic energy. When the hot object is in contact with the cold object, the group of molecules in the hot object lose kinetic energy by slowing down whereas the molecules in the cold object gain energy by speeding up. The transfer of energy stops when the molecules of both objects have the same average kinetic energy.

What is Conduction?

Conduction is the flow of heat through a solid.

Suppose you are walking on a hot sidewalk barefooted, the concrete will warm or even burn your feet. This happens through conduction.

Ok! *How?* When a warmer object (**in this case the sidewalk**) comes into contact with a cooler object with slowly moving molecules (**your bare feet**), the faster molecules bump into the slower ones. This makes the slower molecules move faster until they are moving at the same speed as the fast ones.

Remember, the two objects must always be in contact for conduction to happen. Figure 4 shows what happens to the molecules of two objects in contact during conduction.

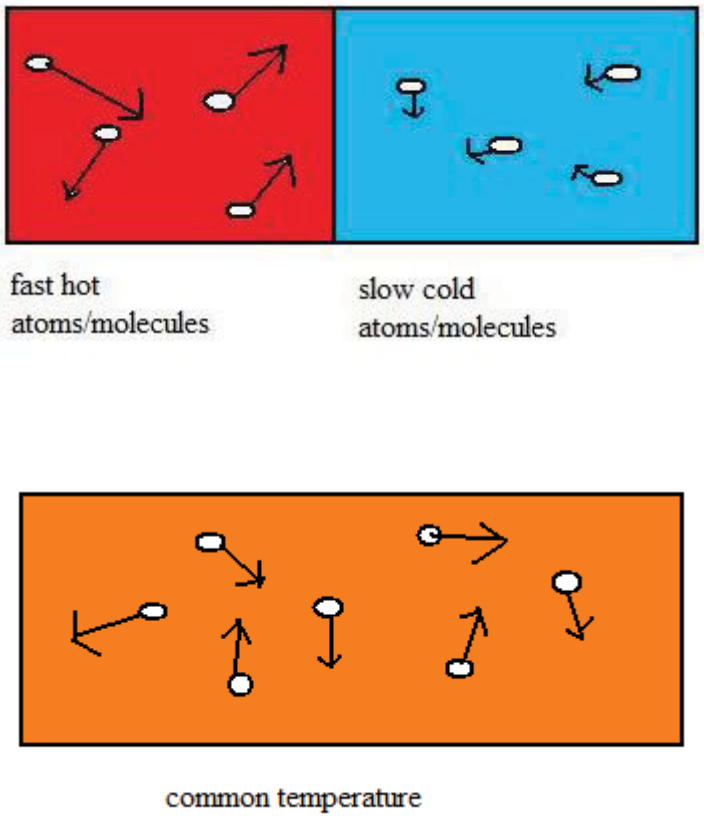

Figure 4: Heat transfer by conduction. Hand drawn by graphic designer at LDTC.

Note it!

NOTE:

- Conduction happens when two solids of different average kinetic energy are in thermal contact.
- All molecules vibrate, but the vibration increases when they are heated.
- Heat spreads by conduction when molecules **increase their vibrations** and pass this energy on to nearby objects.

Reflection

If you have access to the internet, please go to:

http://www.hk-phy.org/contextual/heat/hea/condu02_e.html

and watch the animation of conduction.

Different materials transfer heat by conduction at different rates. *How can we show this in an experiment?* Let's understand something first.

You have just made yourself a nice cup of hot coffee and you stir it with a metal spoon. Gradually the spoon becomes hot. Wow! Heat has passed throughout the spoon by conduction.

If you had the laboratory at your disposal, this is the experiment you would carry out:

Activity 2

Activity 2

Experiment 1: Comparing Conducting Powers

Apparatus needed:

- Short lengths of four different metals – aluminium rod, brass rod, copper rod and iron rod
- Hot water in a container
- Matches and wax

Procedure: Fix a match to one end of each rod using a little melted wax.

Heat the opposite end of the rods in the hot water.

Observation: When the temperatures of the opposite ends reach the melting points of wax, the matches drop off.

Reflection

Take some time to explain in your own words how you think you could use this information to determine which material conduced heat the fastest.

Conclusion: The time taken by each bit of wax to melt and drop off its match will tell you which material conducted heat the fastest. In this case, the match on copper falls first showing it is the best conductor, followed by aluminium, brass and then iron.

This is an experiment you can carry out in the laboratory. You and I both know that you may not have access to a lab. So does it mean there is nothing you can do? No way! Try this at home!

Find yourself a similar-sized metal spoon, wooden spoon, and plastic spoon or any other kitchen utensils you may have to **compare heat conducting powers**. Place all of them in a container filled with boiling water such that they all reach the bottom of the container and their ends are at least 3 cm out of the water. After 30 seconds, carefully touch the ends of each.

Which one is the hottest?

_____

Compare your answer to the following:

You should discover that the ends of the metal utensils felt the hottest.

Why did the metal utensil feel hottest?

_____

Compare your answer to the following:

Metal utensils feel the hottest because they conduct heat better than non-metals.

Try this activity again but use only metal objects. Examples of metal objects you could use are a metal spoon, a nail, a small piece of a sheet of corrugated iron sheet or any that you have at home. Dab each utensil with cold margarine on top. Which metal loses its margarine first?

_____

Assuming all metals are good conductors, why does margarine on the different metals melt at different times?

_____
_____
_____
_____

Compare your answer to the following:

Look at each utensil's handle thickness and length as well as its surface area for clues. Keep in mind that some metals conduct heat better than others do.

So it could be that the metal that loses its margarine first is the widest of all the metals you have or the shortest. It may also have been at a warmer place than others. Maybe you took the nail from a shady spot and the spoon from a pot with some hot food.

Note it!

This is what it comes down to:

- Metals are good conductors of heat. Examples are copper, aluminium and iron.
- Heat is conducted faster through a metal object if it has a large cross-section area, is short or has a larger temperature difference between its ends.
- Non-metals are bad conductors of heat. Examples are wood, paper and plastics.

Why are Metals and Non-Metals Different?

All solids, metals and non-metals are made up atoms and/or groups of atoms, or molecules. However, metals have many free electrons

that are able to move randomly between molecules. Non-metals on the other hand have very few of these free electrons.

In metals, the **free electrons** carry the heat energy faster than the molecular vibrations and transfer it by **colliding with other electrons** and the molecules themselves.

Because of this, metals are good conductors of heat.

Too much information! Let's refresh by answering the following questions.

Activity 3

1. Define conduction.

   _____
   _____
   _____

2. Suppose you have bought yourself a set of three knives made of the same material, width and thickness but with different lengths. You then dab them each with the same amount of margarine and place them in a basin of hot water. Which knife will melt the margarine first and why? The longest knife, the medium length knife or the shortest knife?

   _____
   _____
   _____
   _____

Activity 3

Compare your answers to the correct ones at the end of this section. If you made an error be sure you fully understand the correct answer before continuing on.

Note it!

The key points to remember in this section are:

- Conduction is the flow of heat through a solid.
- Different materials transfer heat by conduction at different rates.

You have learned about how conduction transfers thermal energy. The next section covers convection, another way that thermal energy is transferred.

Answers to Activities on Conduction

Activity 3

1. ***Conduction is the flow of heat through a solid.***

2. ***Given the knives are otherwise identical, the shortest knife will melt the margarine first because heat travels through a smaller distance.***

Section 16-3: Convection

Introduction

At the end of this section, you should be able to describe convection in fluids.

Time

There are 3 pages on the topic of convection. You should spend approximately 30 minutes on this topic.

What is Convection?

Convection is the transfer of heat through a fluid by the actual movement of the heated material itself by convection currents.

Any substance that flows is a fluid. Examples are water, milk, tea and **soft porridge.** Although they cannot be seen in most cases, gases, such as air, air fresheners etc. are also fluids.

What happens to water in a pot when it is heated over a fire?

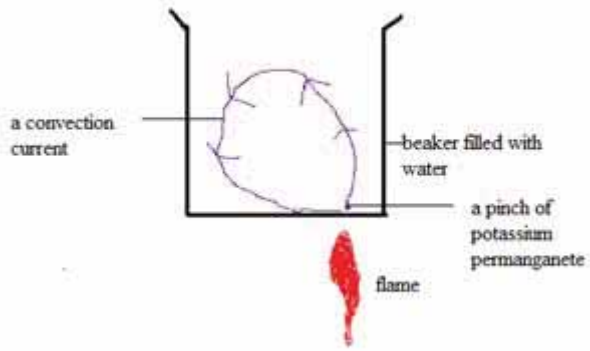

Figure 5:Heat transfer by convection. Hand drawn by graphic designer at LDTC.

Reflection

The water at the bottom of the pot heats up first. This causes it to expand. After expansion, the heated water will have a lower density i.e. it becomes lighter. Why?

Let's take a little trip down memory lane to Unit 13 and remember density.

$$Density = \frac{mass}{volume}$$

We should remember that the mass of a substance does not change, so the mass of the heated water remains the same. When it expands, it occupies more space meaning the volume becomes greater. The end result therefore will be a lower density.

Back to convection!

The warmed water now has a lower density than the water around it, so what happens?

It is lighter, so it rises up through the cooler, dense water. The water cools at the top of the pot (where it is exposed to air), and hence has more density. It sinks down to the bottom to occupy the space of the lighter heated water. This up and down movement continues until all of the water is at an equal temperature.

Streams of warm moving fluids are called convection currents. In this case, the movement of the heated water will be our convection current.

Reflection

If you have access to the internet, please go to:

http://www.hk-phy.org/contextual/heat/hea/conve03_e.html

and watch the animation of convection.

How can we show convection experimentally?

Activity 4

Experiment 2: Convection in Liquids

Apparatus needed:

- Bunsen burner (use any source of fire or a stove)
- Beaker (use a pot)
- Water
- Matches
- Tube (use a drinking straw)

Activity 4

- Potassium permanganate (Potassium permanganate is the purple coloured powder 'makhona tsohle' that you buy at streets markets for simple remedies.

Procedure:

Light the bunsen burner/stove with a match.

Fill the beaker/pot with water and place it on the burning fire of the burner/stove.

Drop a few crystals of potassium permanganate down the tube/drinking straw to the bottom of the beaker/pot and remove the straw. What do you notice?

_____
_____
_____
_____

Activity 5

Compare your observations with the following:

Observations:

When the tube/drinking straw is removed, purple streaks of water rise upwards and fan outwards.

Reflection

Take some time to explain in your own words what you are seeing using your knowledge about convection.

Conclusion:

The purple streaks are showing a convection current as the lighter heated water rises up and the cooler denser water at the top takes its place.

As air is also a fluid, the same thing happens to it. For example, if heated, air decreases in density. The surrounding air is **cooler and denser**. This makes it heavier, so it falls beneath the hot air, forcing the hot air upwards. Wind patterns are large scale convection currents in the atmosphere. If there is a warmer spot on Earth, convection currents are set up resulting in wind as the air circulates. Can you think of other situations where convection currents may be observed?

Activity 5

1. What is the cause of convection currents?

_____
_____
_____

2. Why is the heating element of an electric kettle located near the bottom of the kettle?

_____
_____
_____

Compare your answers with those provided at the end of this section. If you had both answers right, continue on. If not, review the content first and try the activity questions again.

Note it!

The key points to remember in this section are:

- Convection is the transfer of heat through a fluid by the actual movement of the heated material itself by convection currents.
- Streams of warm moving fluids are called convection currents.

You have learned about how convection transfers thermal energy. The next section covers radiation, the third way that thermal energy is transferred.

Answers to Activities on Convection

Activity 5

1. ***Convection currents are caused by changes in density within the fluid.***
2. ***The heating element of an electric kettle is placed near its bottom to allow for convection currents. The water at the bottom will become heated up first, be less dense, rise and be replaced by the cold, more dense water at the top of the kettle.***

Section 16-4: Radiation

Introduction

At the end of this section, you should be able to explain how heat is transferred by radiation and distinguish between good and bad absorbers and good and bad emitters of infrared radiation.

Time

There are 8 pages on the topic of radiation. You should spend approximately 1.5 hours on this topic.

What is Radiation?

Radiation is the transfer of heat by electromagnetic waves.

Experiencing radiation:

Please carry out the following activities to get an idea about radiation.

a. Move outside to a location that is shady, maybe under a bunch of trees. Stand there for some time, two/three minutes. What do you feel? Is it hot? Is it cool or is it cold? Can you feel your body absorbing the sun's energy and heat?

b. Now go to a sunny location. Again stand there for two/three minutes. What you feel? Is it hot? Is it cool or is it cold? Can you feel your body absorbing the sun's energy and heat? How do you feel?

c. What is happening to you?

d. You have experienced "radiation" or the method by which the sun's energy reaches the earth. **The sun's energy travels in waves.** When you felt the sun's warmth, you were feeling the sun's energy or waves touching and warming up your "surface."

The Electromagnetic Spectrum

The **electromagnetic spectrum** describes the range of electromagnetic waves placed in order of increasing frequency.

These waves are vibrations of electric and magnetic fields that pass through space. All electromagnetic waves travel at the same speed - the speed of light. They differ in the amount of energy they transfer, called electromagnetic radiation. **Refer to Unit 19 – Light.**

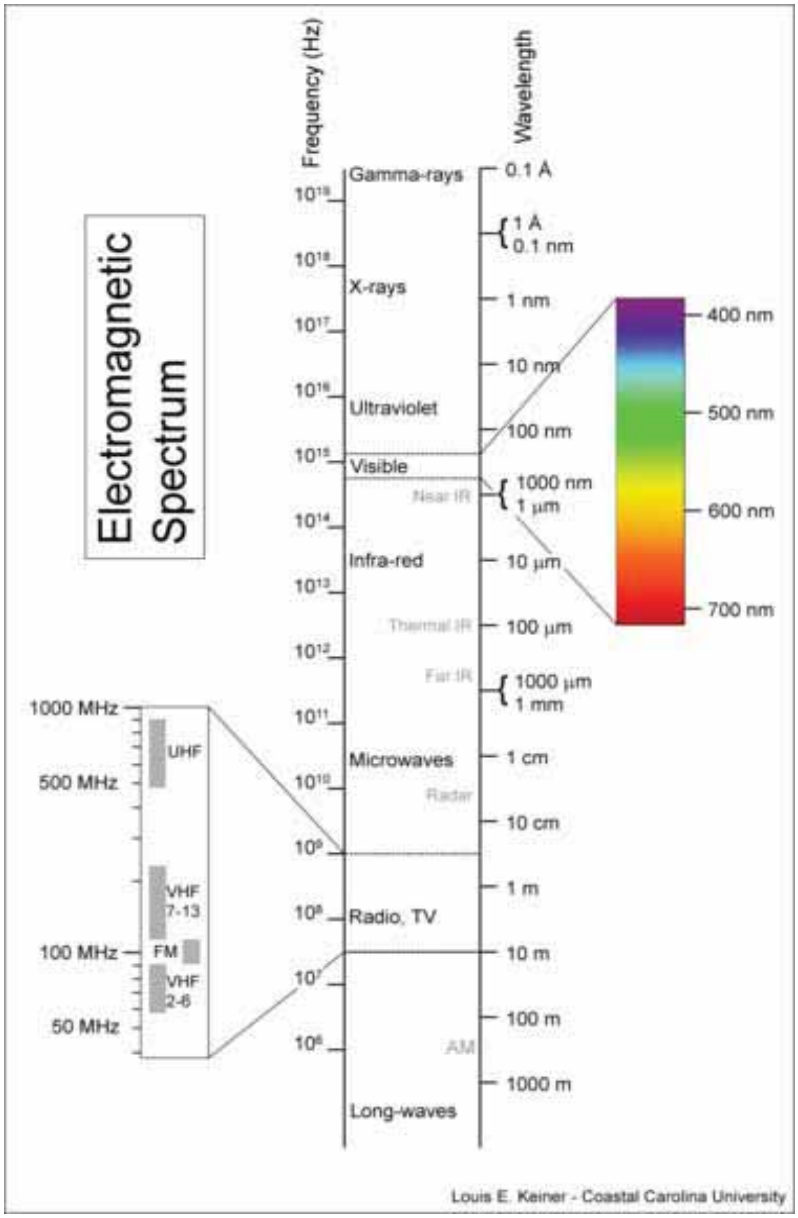

Figure 6: Electromagnetic Spectrum accessed from Wikimedia Creative Commons, 2011.

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Figure 6 above shows all parts of the whole electromagnetic spectrum which infrared radiation is only a small part of.

We have already mentioned that heat energy can be transferred by radiation. This is the infrared radiation that forms part of the electromagnetic spectrum. It has the following features:

- Heat radiation consists of infrared waves.
- Infrared waves travel at the speed of light.
- Heat radiation can go in any direction, even through a vacuum.

- Heat reaches us from the sun by infrared radiation.

Reflection

If you have access to the internet, please go to:

http://www.hk-phy.org/contextual/heat/hea/radia03_e.html

and learn about radiation and the greenhouse effect.

Activity 6

Figure 7 below show us another source of infrared radiation other than the sun.

Figure 7: A radiant heater accessed from Flickr.

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Absorption and Emission of Infrared radiation

Infrared radiation is absorbed by all objects and surfaces. It is also emitted by all objects and surfaces. But, they all do it differently.

We have good absorbers and bad absorbers of the radiation. We also have good emitters and bad emitters. How do we know which is which? Let us try to carry out the following experiments to find out.

Activity 6

Experiment 3: Comparing the Absorption of Radiation Between Tin That is Shiny/White and Tin that is Painted Black/Dark/Dull.

Apparatus/materials:

- Two tin surfaces
- Black paint
- Bunsen burner/candle
- Wax
- 2 coins that are the same size

Procedure:

Take two tin surfaces and paint one of them black and the leave the other one shiny. Note that you can equally compare a black tin surface to a white tin surface.

Stick the coin on the outside edge of each surface using melted wax.

Place a Bunsen flame/candle flame midway between the lids as shown by Figure 8 below.

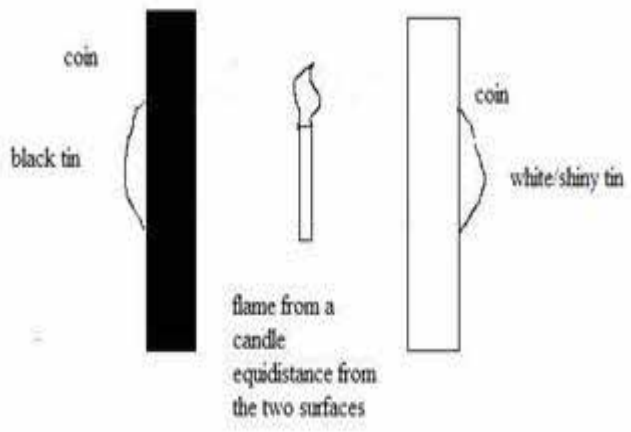

Figure 8: Radiation from a flame. Hand drawn by graphic designer at LDTC.

Does the coin on the black or shiny surface fall first?

_____
_____
_____

Compare your observation to the following:

Observations:

The wax on the blackened surface will melt in a shorter time and the coin on that surface will fall first.

On the other hand, the shiny surface remains fairly cool and the wax on it stays un-melted. The coin does not fall off.

What can you conclude from these observations?

_____
_____
_____

Compare your conclusion to the following:

Conclusion: This experiment shows that a black/dark/dull surface is a better absorber of radiation than a shiny/white surface.

In general good absorbers are also good emitters and bad absorbers are bad emitters. Let us look at the next experiment to prove this.

Activity 7

Experiment 4: The Emission of Radiation by a Black/Dark/Dull Coloured Surface and a Shiny or White Surface.

Apparatus/materials:

- Two cups of the same material: one black/dark/dull coloured and the other shiny or white
- Boiling water

Activity 7

Figure 9:Emission of radiation. Hand drawn by graphic designer at LDTC.

Procedure: Fill the two cups with boiling water.

Place your hands on both of them. What do you feel in each cup?

After ten seconds, place one hand around each cup. Which one feels hotter?

_____

_____

Take some time to explain what you are seeing in your own words.

Activity 8

Compare your observations to the following:

Observations:	You will feel that the black cup radiates more heat than the white one. The black cup will feel hotter to the touch.
Conclusion:	Black, dark, or dull coloured surfaces are better emitters of radiation than shiny/white surfaces. Shiny/white surfaces are good reflectors.

Activity 9

Activity 8

Answer the following questions by filling in the spaces provided.

1. List three properties of infrared radiation.

   _____
   _____
   _____

2. What is radiation?

   _____
   _____
   _____

Compare your answers to correct answers given at the end of the section. Ensure that you understand each answer before continuing.

Activity 9

The following questions address the three ways of transferring heat.

1. What are the three ways of heat transfer?

2. Explain the role played by the free electrons in good conductors of heat.

3. How is heat transferred from one place to another by convection?

4. Describe how you could find out whether a black pot of cold water or a silvered pot warms up first when heated up.

Compare your answers to the correct answers provided at the end of this section. Be sure you understand the correct answer for each question before you proceed.

Note it!

The key points to remember in this section are:

- Radiation is the transfer of heat by electromagnetic waves.
- A black/dark/dull surface is a better absorber of radiation than a shiny/white surface.
- Black, dark or dull coloured surfaces are better emitters of radiation than shiny/white surfaces. Shiny/white surfaces are good reflectors.

You have learned about how radiation transfers thermal energy. The next section covers practical applications of the transfer of thermal energy.

Answers to Activities on Radiation

Activity 8

1. ***Three properties of infrared radiation are:***
   a) ***It travels at the speed of light.***
   b) ***It can be absorbed and emitted by different objects/surfaces.***
   c) ***It can go in any direction, even through a vacuum.***
2. ***Radiation is the transfer of heat by electromagnetic waves.***

Answers to Activity 9

1. ***The three ways of heat transfer are conduction, convection and radiation.***
2. ***In metals, the free electrons carry the heat energy faster than the molecular vibrations and transfer it by colliding with other electrons and the molecules.***
3. ***If a fluid is heated, it decreases in density. The surrounding fluid is cooler and denser. This makes it heavier, so it falls beneath the hot fluid, forcing it upwards. This forms convection current.***
4. ***I can take a black pot and a silvered pot and fill them both with cold water. Then I can stick a coin on the outside of each pot using melted wax. Then I would heat them over the same amount of heat. The one which the coin falls off of first is the better absorber.***

Section 16-5: Consequences and Everyday Applications of Energy Transfer

Introduction

At the end of this section, you should be able to identify and explain some of the everyday applications and consequences of conduction, convection and radiation.

Time

There are 14 pages on the topic of consequences and everyday applications of energy transfer. You should spend approximately 4-5 hours on this topic.

Consequences of Conduction

1. **Trapping air to use as insulation**

   Birds use feathers to trap air, some mammals such as cats and polar bears have fur to trap air. How does this relate to heat conduction?

   _____
   _____
   _____

   Compare your answer to the following:

   Air is a very good insulator of heat (a poor conductor). Trapping it with feathers or fur will minimise loss from the animals' warm bodies to the colder surroundings.

   Human beings use clothes to trap air because the hair on our bodies is very sparse.

2. **Different sensations from good and bad conductors of heat**

   Walking on a marble/tiled floor feels colder than a walking on a carpet. Why do you think this is? The marble is a good conductor compared to the carpet. Our feet are normally warmer than both and so the heat will be conducted from our feet. The marble/tile being the better conductor take the heat away from the feet faster, hence will feel colder.

   If you are entering a house and it is winter, the metal door knob will feel colder than the wooden part of the door. Think about why that is.

   The difference is because metal is a better conductor of heat than wood.

Applications of Conduction

Uses of good conductors of heat

1. Cooking utensils, kettles, saucepans and boilers that involve direct heating are normally made of aluminium or stainless steel. Figure 9 shows some pots made of aluminium.

Figure 10(a): Cooking pots accessed from Flickr, 2011.

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2. Soldering iron rods as shown by figure 10(b) are made of iron, but the ***tip is made of copper*** because copper is a much better conductor of heat than iron.

Figure 9(b): Soldering iron rod accessed from Wikimedia Creative Commons, 2011.

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What is a soldering iron? What are they used for? The Concise Oxford Dictionary offers us the following definitions:

Solder: a low-melting alloy, especially one based on lead and tin used for joining less fusible metals.

Fusible: when one thing **fuses** with another or when two things **fuse** or **are fused** together, they are joined together to form a single thing. So some metals are less **fusible**. That means they cannot be easily joined together.

Soldering iron: an electrical tool for melting and applying solder.

Uses of poor conductors of heat

1. Handles of utensils such as saucepans, kettles, teapots, irons and soldering irons are often made of wood or plastics. That way the hot utensil can be picked up without burning our hands. The spoon for eating shown in figure 11 (a) show a handle made of plastic.

Figure 11(a): A spoon accessed from Flickr, 2011.

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2. Table mats are usually made of cork or other non-conductors so that hot kitchenware can be placed on them without damaging the table-top. Figure 11(b) shows a table mat.

Figure 10 (b): A table mat accessed from Flickr, 2011.

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Sawdust is used to provide warm flooring for farm animals such as pigs and chicks because of its good insulating property. Figure 11(c) below shows a pig lying on a saw dust floor.

Figure 11(c): Sawdust accessed from Flickr, 2011.

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Wooden spoons are very useful for stirring or scooping hot soup and/or food that have just been cooked. Figure 11(d) shows a wooden spoon used to stir red currant jelly.

Figure 10 (d): Wooden serving spoon accessed from Flickr, 2011.

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3. Woollen blankets or clothes are used to keep people warm on cold and chilly days. Figure 11(e) shows a variety of woollen blankets.

Figure 11(e): Woolen blankets accessed from Flickr, 2011.

Consequences of Convection

1. Formation of land and sea breezes

During the day, the heat radiation from the sun causes the land surface to become warmer than the sea surface. This causes the air above the heated surface of the land to warm up faster and therefore to rise. As a result, the relatively colder air above the surface of the sea moves towards the land to replace the hotter air. This movement of air from the sea to the land forms a sea breeze.

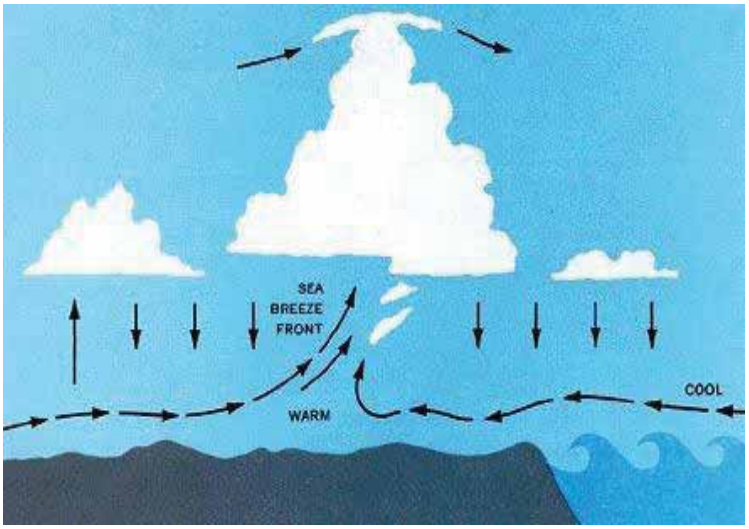

Figure 12: Sea breeze accessed from Wikimedia Creative Commons, 2011.

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At night, the land cools faster than the water in the sea. Therefore, the air above the surface of the sea is hotter than the air above the land surface. As a result, a reverse convection is set up as the warm air above the surface of the sea rises and colder air from the land moves in to replace the warm air. This sets up a land breeze.

2. Convection currents in a room

Whenever a group of people enter a room, convection currents are set up. The heat generated by bodily processes such as breathing causes the air near the body to be heated up by conduction. The warm air being less dense rises while the colder, denser air above the person sinks. This sets up a convection current.

3. Convection currents in a pond

During the beginning of winter, the air above the surface of a pond is cooler than the water in the pond. The upper layers of water therefore lose heat to the air and become denser than the water below them. The colder water sinks down while the warmer water below rises up. This sets up convection currents.

Applications of Convection

1. Household hot-water systems

Figure 13(a): A solar hot water system accessed from Flickr, 2011.

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The working principle of the household hot water system that is based on the convection in liquids is as follows:

Water is heated by gas burners or by solar energy in the boiler. The hot water expands and becomes less dense. It then rises and flows into the upper half of the cylinder, where it is used first.

To replace the hot water, cold water from the cistern falls into the lower half of the cylinder and then into the boiler. It is then heated and rises. Figure 13(a) shows a solar hot water system.

2. Electric kettles

Figure 13(b): An electric kettle accessed from Wikimedia Creative Commons, 2011.

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The heating coil of an electric kettle, figure 13(b), is always placed at the bottom of the kettle. When the power is switched on, the water near the heating coil gets heated up, expands and becomes less dense. The heated water therefore rises while the cooler regions in the upper part of the body of water descend to replace the heated water.

3. Air-conditioners

Figure 13(c): An air conditioner accessed from Flickr, 2011.

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An air-conditioner is always installed near to the ceiling of a room as shown in figure 13(c).

The rotary fan inside an air conditioner forces cool dry air out into the room. The cool air, being denser, sinks while the

warm air below, being less dense, rises and is drawn into the air conditioner where it is cooled. In this way, the air is recirculated and the temperature of the air falls to the value preset on the thermostat.

4. **Refrigerators**

Figure 12 (e): A refrigerator accessed from Flickr, 2011.

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Refrigerators work in very much the same way as air conditioners. The freezing unit is placed at the top to cool the air so that the cold air being denser sinks while the warm air at the bottom rises. This sets up convection currents inside the cabinet which help to cool the contents inside. Figure 13(e) is a typical refrigerator that is used at home.

Consequences of Radiation

1. **Colour and texture of clothing**

   On sunny days, wearing dull black clothes will be much more uncomfortable than wearing shiny, white clothes due to the large amount of the radiant heat absorbed.

2. **Skin cancer**

   With the damage done to the ozone layer in the atmosphere, human beings are increasingly exposed to harmful radiation from the sun. The ultraviolet radiation from the sun is one of the causes of skin cancer.

Applications of Radiation

1. Vacuum/thermos flasks

Figure 14(a): A vacuum flask accessed from Wikimedia Creative Commons, 2011.

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Figure 14(a) shows a typical vacuum flask that can be bought from a shop.

For the vacuum flask, the vacuum prevents heat to be transferred by conduction in either direction. This helps to keep hot fluids hot and cold fluids cold. The outer shiny wall reflects radiant energy coming from the surroundings. The inner walls of the flask are silvered to reflect radiant energy back to the fluid.

Conduction through the trapped air above the liquid is minimal as air is a poor conductor of heat. The stopper is normally made of plastic which is also a poor conductor of heat.

2. Teapots

Figure 14(b): A teapot accessed from Flickr, 2011.

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Since shiny surfaces are bad emitters of radiation, shiny teapots can keep tea warmer than a black teapot for a longer period. Moreover, since shiny surfaces are bad absorbers of radiation, shiny containers can keep a cold liquid cooler for a longer time than black containers. Figure 14(b) shows a shiny teapot that can keep tea hot for a longer period.

3. The greenhouse

Figure 14(c): A greenhouse accessed from Flickr, 2011.

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The greenhouse, as shown in figure 14(c), traps heat to help certain plants grow better. When the sun is shining, infra-red

radiation from the sun passes through the glass of the greenhouse and is absorbed by the soil and plants inside. The soil and the plants therefore become warmer and they emit infra-red radiation of longer wavelengths. These longer wavelengths of radiation are unable to pass through the glass and so heat is trapped inside the greenhouse. This causes the temperature inside the greenhouse to rise and this is good for plant growth. Where else have you seen the greenhouse effect? That is right, global greenhouse effects.

Activity 10

1. An aluminium pot is filled with water then covered with a metal lid. The pot is then put on a burning flame of a gas stove. What are the processes of heat transfer in:

a) Heating the base of the pot where it is contact with the fire.

_____
_____

b) Distributing the heat through the water?

_____
_____

2. A young child is given some hot soft porridge in an enamel drinking cup. She drops the cup when her fingers touch its handle which is also made of enamel.

a) Why did she drop the cup?

_____
_____

Activity 10

b) How could this be prevented?

_____
_____

Compare your answers with those below. If you understand all of the concepts, continue on. Otherwise, review the section.

You have learned about practical applications of the transfer of thermal energy. You should now proceed to the unit summary.

Answers to Activities on Consequences and Everyday Applications of Energy Transfer

Activity 10

1. a) Conduction

b) Convection

2. ***a) Heat from the enamel cup was transferred to her hand and she was burned.***

   b) The cup handle could be covered with a non-conductor such as plastic or cork so that when the child touches the cup, she will not be burned.

Unit Summary

Summary

In this unit you learned that:

- Heat is conducted by vibrating molecules that are in close contact with each other. Metals are good conductors because they have free electrons. Liquid and gases are poor conductors.
- Convection is the transmission of heat from one place to another by the movement of the heated molecules. It occurs in fluids, liquids and gases. Convection currents happen due to density changes in the fluids. The hot less-dense fluid rises and the cold more-dense fluid sinks to take its place.
- Heat transfer by radiation happens by electromagnetic waves. Black/dark/ dull coloured surfaces are good emitters and good absorbers of radiation. Shiny/white surfaces are poor emitters and absorbers of radiation.
- A vacuum flask minimises both conduction and convection and reduces radiation.
- Everyday applications of heat transfer include cooking utensils, refrigerators and vacuum flasks. Everyday consequences include the formation of sea and land breeze and skin cancer.

You have completed the material for this unit on the transfer of thermal energy. You should now review the content of the entire unit. Once you are sure that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It addresses thermal properties.

Assignment 16

Assignment 16

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:13]

1. Explain convection in your own words.

_____
_____
_____ (2)

2. Give two everyday examples of heat transfer by radiation.

_____
_____
_____ (2)

3. Name two uses of good conductors of heat.

_____
_____
_____ (2)

4. Name any three applications of convection.

_____
_____
_____ (2)

5. Explain how a vacuum flask reduces heat transfer in order to maintain the temperature of a liquid.

_____
_____
_____ (2)

6. Which teapot will keep tea hot longer, a light shiny one or a dull dark one?

_____
_____ (1)

7. Why are houses in hot countries often painted white?

_____
_____
_____ (2)

Reflection Question

8. In desert regions that are hot in the day and cold at night, the walls of homes are often made of very thick mud. Why do you think people use this thick construction?

Compare your answers to those provided below. Particularly note any mistakes that you made and spend the time needed to understand how to fix those mistakes.

Answers to Assignment 16

1. ***Convection is the transfer of heat through a fluid by the actual movement of the heated material itself by convection currents.(2)***
2. ***Two everyday examples of heat transfer by radiation are: getting heat from the sun and from a heater. (2)***
3. ***Two uses of poor conductors of heat are: handles of utensils such as saucepans and woollen blankets or clothes being used to keep people warm on cold and chilly days. (2)***
4. ***Three of the many applications of convection are: (3)***
    - ***Household hot-water systems***
    - ***Electric kettles***
    - ***Refrigerators***
5. ***The vacuum in a vacuum flask is used to reduce heat transfer by both conduction and convection.(2)***
6. ***The light shiny cup will keep tea hot for the longest time.(1)***
7. ***Because white surfaces are poor absorbers of radiation, so a lot of heat will not be absorbed by the houses.(2)***
8. ***If the walls are thick, this keeps the air in the home warm at night because heat conduction from warmer inside to cooler outside is slowed. In the day, conduction is slowed from the warmer outside to the cooler inside.***

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physical science course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 16

Assessment 16

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes. Please show all of your work.

(Total Marks:25)

Section A Multiple-Choice Questions

1. According to the simple kinetic theory, how is heat transferred from the hot end of an iron rod to the cold end? The molecules from the hot end:

A) move to the cold end.

B) vibrate more and pass on the energy to the neighbouring molecules.

C) send out infrared radiation to the cold end.

D) move from place to place, collide with colder molecules and pass on the energy to them. (1)

2. Woollen clothing is effective at keeping us warm because**:**

A) the air trapped in the wool acts as an insulator.

B) heat loss by convection and radiation is prevented.

C) wool is a bad radiator and a good absorber of heat.

D) wool can retain high temperatures. (1)

3. In a hot water tank, the heating element should be placed at the bottom because:

A) conduction cannot take place when the heater is at the top of the tank.

B) the heated water will rise and form a convection current.

C) radiant heat travels faster in upward direction.

D) the heater must be covered by water at all times. (1)

4. In a vacuum flask, the vacuum prevents heat transfer by:

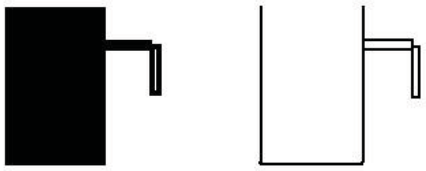
A) radiation only.

B) conduction only.

C) convection only.

D) conduction and convection. (1)

5. In the following experimental set-up, equal volumes of hot water were poured into two containers. The temperature of both containers and contents were the same. After ten minutes, the temperature of container S was found to be lower than that of container T.



5. This shows that S is a better ……..... of heat than T.

A) conductor

B) absorber

C) radiator

D) conductor and absorber (1)

Section B Structured Questions

1. State the three ways by which heat is transferred. (3)

2. Describe an experiment to distinguish between a good and bad conductor of heat. (5)

3. What are convection currents? (2)

4. Describe an experiment to illustrate convection in liquids. (5)

5. Describe a simple experiment to demonstrate that good radiators of heat are also good absorbers of heat. (5)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 17

Thermal Properties

Study Skills

Plan the length of your study period by the amount of material you have decided to cover, not by the clock. (Often the clock is one of the most serious distracters.)
Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.

Introduction

We often argue about how cold or hot the weather is. Words such as warm or cool are also used. In this unit we are going to learn how to be more accurate when talking about temperature of objects.

Time

This unit consists of 30 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Describe* matter and its related physical processes.

Outcomes

Upon completion of this unit you will be able to:

- *Describe* the order of magnitude of expansion of solids, liquids and gases.
- *Explain* how a physical property may be used to measure temperature.
- *Describe* how to calibrate a thermometer.
- *Distinguish* between sensitivity, range and linearity of thermometers.
- *Describe* the structure and action of laboratory thermometers, clinical and thermocouple thermometers.
- *Distinguish* between processes of boiling, evaporation, melting, solidification and condensation.

Study Skills

Terminology

Boiling:	The change of state from liquid to gas.
Calibrate:	Giving a scale to something like a thermometer.
Condensation:	The change of state from solid to liquid.
Freezing:	The change of state from liquid to solid.
Lower fixed point:	The temperature of pure melting ice at standard atmospheric pressure.
Melting:	The change of state from solid to liquid.
Temperature:	The measure of coldness or hotness of a substance.
Thermometer:	An instrument that is used to measure temperature.
Upper fixed point:	The temperature of the steam of boiling water at the standard atmospheric pressure.

Section 17-1: Expansion of Solids, Liquids and Gases

Introduction

In Unit 16, you learned about the three states of matter, the arrangement of particles within each of them and how the particles behave when heated. This section will build on those concepts.

This section will help you understand why certain things happen, like why you should not pour boiling water in glass and why you should not fill water to the brim when it is going to be put in the freezer.

By the end of this section, you should be able to describe the order of magnitude of expansion of solids, liquids and gases.

Time

There are 5 pages on the topic of expansion of solids, liquids and gases. You should spend approximately 1 hour on this topic.

Activity

Activity 1

Describe how the particles are arranged in each case:

Solids

_____

_____

_____

_____

Liquids

Gases

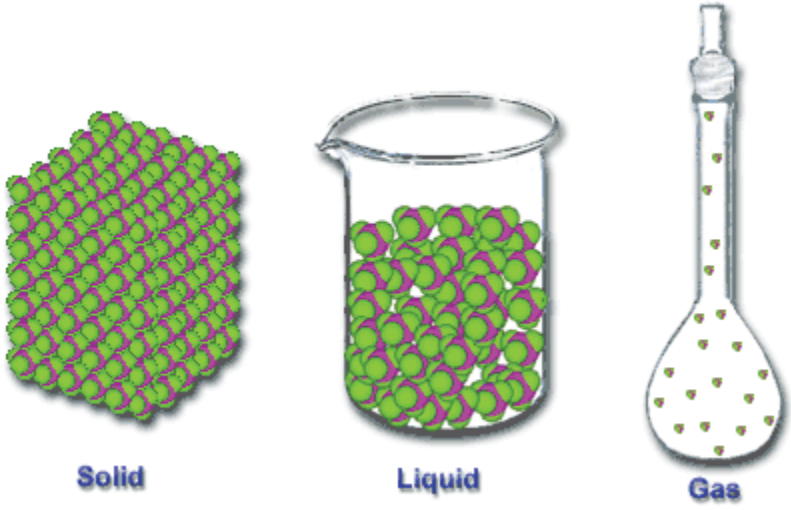

Figure 1: Molecular structure of the three states of matter accessed from Creative Commons, 2011.

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Compare your answers to those given at the end of the section. Be sure to understand the differences between how particles are arranged in solids, liquids and gases before continuing.

Activity

Activity 2

In this activity, we are going to compare the expansion of liquids and gases.

Figure 2 shows two flasks. One flask contains water and the other contains air. Each flask is held in a bath of boiling water by a stand.

If you can get these apparatus, arrange them like in Figure 2.

Water and cotton wool in the glass tubes are at the same level.

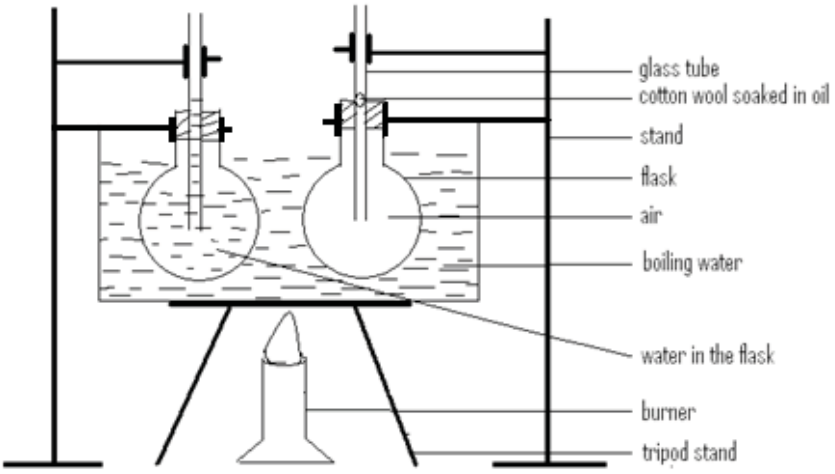

Figure 2: Expansion of liquids and gases. Hand drawn by graphic designer at LDTC.

After 10 minutes, the level of water in the glass tube increased and the level of cotton wool in the other glass tube has also increased as shown in Figure 3 below.

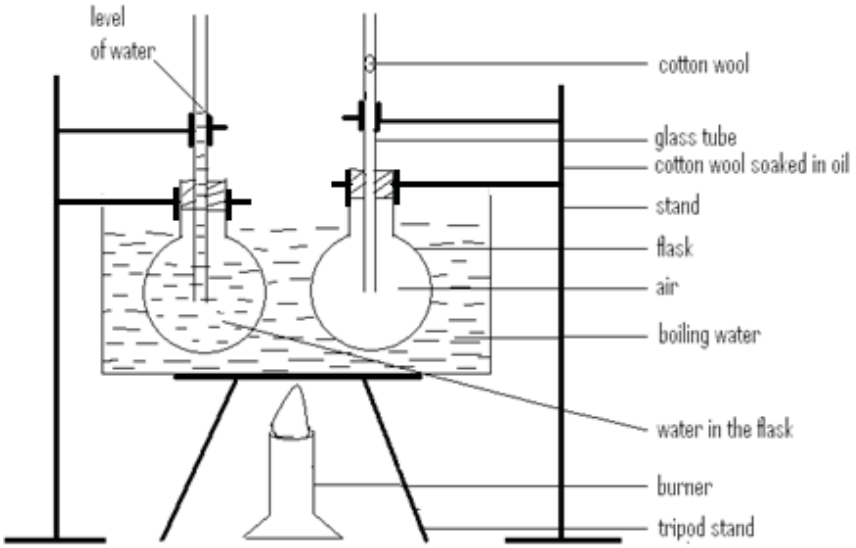

Figure 3(a): Expansion of liquids and gases. Hand drawn by graphic designer at LDTC.

1. Explain why the level of the water and cotton wool increased.

   _____
   _____
   _____

Explain why the levels of the water and cotton wool are not the same.

_____
_____
_____
_____
_____

2. Now turn off the burner, remove the stand and the bath of boiling water. Explain what happens to the level of water and cotton plug as the flasks cool.

   (If you are not able to do the experiment, predict what you think will happen to the level of water and cotton plug as the flask cools.)

_____
_____
_____
_____
_____

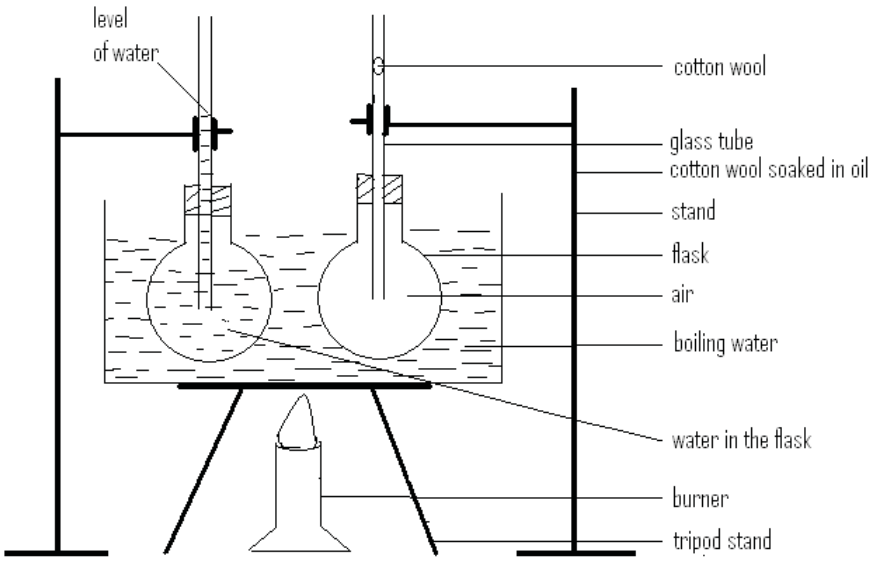

Figure 3(b): Expansion of liquids and gases. Hand drawn by graphic designer at LDTC.

Compare your answers to those that are given at the end of this section Be sure that you understand each answer before continuing.

You should have learned that liquids and gases expand when heated and contract when cooled.

Gases expand more than liquids. This is why the level of the cotton plug is higher than the level of water.

Expansion occurs when the particles gain heat energy and then vibrate more and move further away from one another.

Liquids – The particles are not closely packed and so there are spaces between the particles as shown in Figure 1. When heated, the particles gain kinetic energy and they vibrate. As they vibrate they occupy more space than before they gained kinetic energy.

Gases – The particles are very far apart from each other, so when they gain kinetic energy, they have large space to occupy hence why they vibrate more than liquids.

Activity

Activity 3

Compare the expansion of solids to that of liquids and gases:

_____
_____
_____
_____
_____
_____
_____

Compare your answers to those given at the end of this section. Take the time needed to understand each answer before you continue.

Note it!

Note:

Expansion and contraction are **physical properties** of matter.

Physical properties are the characteristics or qualities that something has. Examples are conductivity, reactivity, ductility, solubility and many more.

Answers to Activities on Expansion of Solids, Liquids and Gases.

Activity 1

In solids, the particles are very close to each other.

In liquids, the particles are loosely packed. That is they are not as close to each other as in solids.

In gases, the particles are very far apart from each other.

Activity 2

1. ***When water is heated, the particles gain kinetic energy and start to vibrate. The same thing happens to gas particles. In gases the particles vibrate more than in both liquids and solids.***
2. ***Gases expand more than liquids; this is why the level of the cotton plug is higher than that of the water.***
3. ***When the flasks cool, the level of water decreases and the cotton plug also goes down. This is because solids, liquids and gases contract when cooled.***

Activity 3

The spaces between the solid particles are very small, so when the particles gain kinetic energy they do not have as much space as the particles of liquids and gases. So the expansion in solids is very small compared to that of liquids and gases.

Section 17-2: Measurement of Temperature

Introduction

We often argue about the temperature outside. Why do we argue over this issue? It is because we are not being exact or because we are not using any instrument to measure how cold or hot things are.

By the end of this section you should be able to:

- *Describe* the structure and action of laboratory thermometers, clinical and thermocouple thermometers.
- *Describe* how to calibrate a thermometer.
- *Distinguish* between sensitivity, range and linearity of thermometers.

Time

There are 13 pages on the topic of measurement of temperature. You should spend approximately 5-6 hours on this topic.

Activity 4

Activity

1. Which instrument could be used to measure how cold or hot tea is?

   _____

2. You must have heard people arguing about the weather, one complaining that it is hot and another one saying it is not hot, it is warm. What does this tell you about using our body to judge how hot or cold it is?

   _____
   _____
   _____
   _____

3. What is temperature?

   _____
   _____
   _____

I hope you answered the questions correctly! Compare your answers to those given below.

Thermometers

A thermometer is an instrument used to measure temperature. In this unit we are going to study two types of thermometers: the liquid in glass thermometer and the thermocouple thermometer.

Remember that temperature is the measure of the coldness or hotness of a substance.

Liquid in glass thermometer

Mercury used to be the commonly used liquid in thermometers, but because it was discovered to be poisonous mercury thermometers are being phased out. So **coloured alcohol** is now commonly used in liquid-in-glass thermometers, as shown in Figure 4.

Figure 4: Laboratory thermometer accessed from Flickr, 2011.

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Activity

Activity 5

1. What do you think the advantages and disadvantages of using alcohol instead of mercury in thermometers are?

   For example:

   Advantage of using mercury:

   It can be seen clearly through glass because it has colour.

Disadvantage of using alcohol:

It cannot be seen clearly because it is colourless, so it needs to be coloured.

a) _____

b) _____

c) _____

2. What would be the disadvantage of using a colourless liquid in a thermometer?

_____

How did you find the questions? Compare your answers with those given at the end of the section. Again, be sure you understand the advantages and disadvantages of the different types of thermometers before you continue further.

Activity

Activity 6

Calibrating a Thermometer

Do not be scared by the word calibrate, it simply means giving a scale.

We are going to learn how a thermometer is calibrated. Is this not interesting? There are steps followed when calibrating a thermometer.

We will not do the calibration with a mercury thermometer because mercury is poisonous if it is swallowed or if the vapours are inhaled.

If you have access to a thermometer, recalibrate it by doing the following steps:

1. Half fill a beaker with crushed ice
2. Add enough water to cover the ice but not so much water that the ice floats.
3. Thoroughly stir the ice water mixture.
4. Insert the thermometer into a rubber stopper with a slit hole.
5. Use a ring stand and clamp to suspend the thermometer in the ice water as shown in Figure 5.

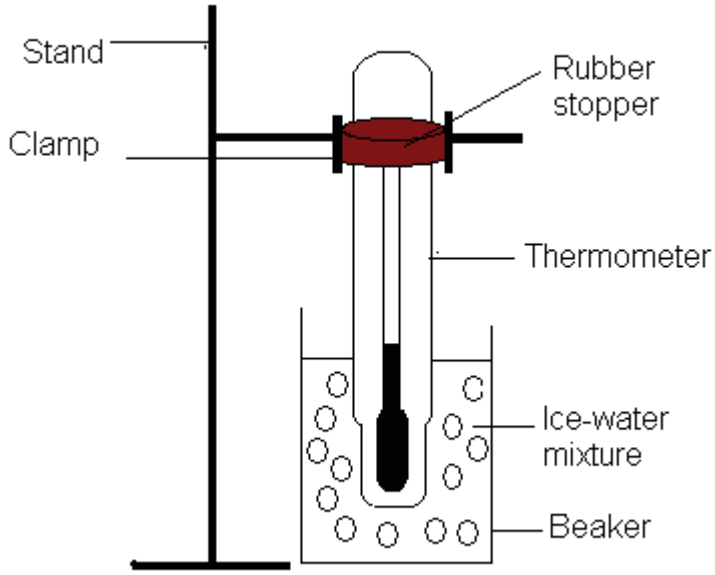

Figure 6: Calibrating a thermometer at the freezing point of water or lower fixed point. Hand drawn by graphic designer at LDTC.

6. Wait 3 minutes for the temperature of the liquid in the thermometer to stabilise. Then make a marking where the meniscus is.
7. With the thermometer still clamped, suspend it over boiling water such that the bulb is immersed in the steam of boiling water as in Figure 6.

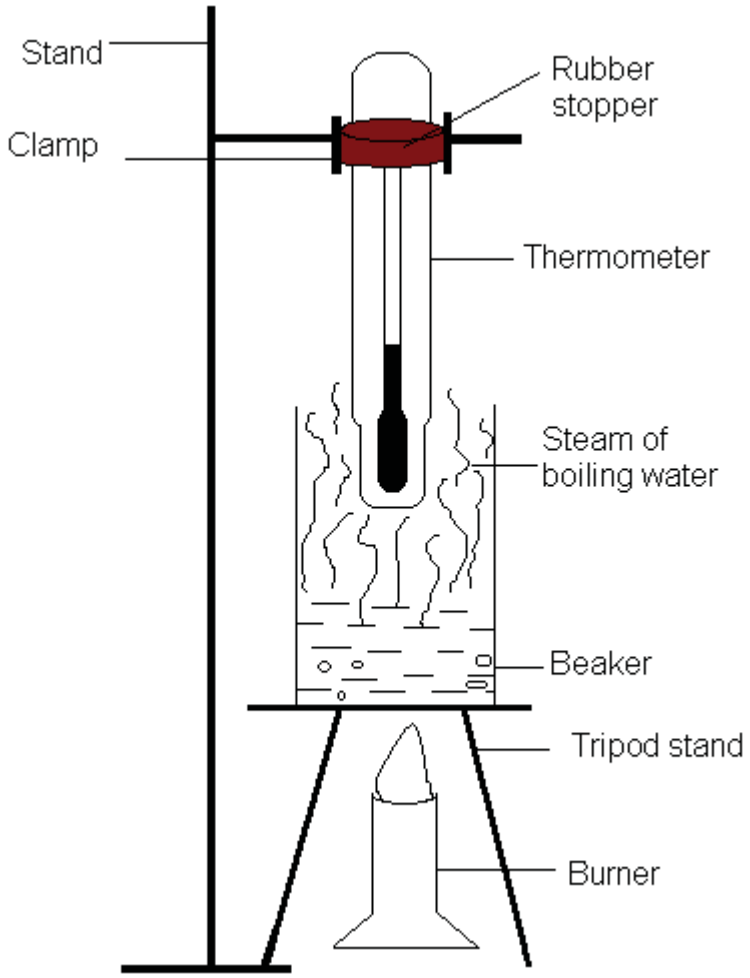

Figure 7: Calibrating a thermometer at the boiling point of water or upper fixed point. Hand drawn by graphic designer at LDTC.

8. Allow the temperature of the liquid in the thermometer to stabilise for 3 minutes then mark it.
9. Now divide the space between the freezing point and boiling point into 100 equal divisions. Each division is 1^0 C.
10. Now the thermometer has a calibrated scale.

Activity

Activity 7

1. If you were going to do scientific experiments requiring temperatures to be measured at places whose temperatures range from -20 C to 10 C, which liquid would you use when making your own thermometer? Give reasons why you will use that liquid.

_____
_____
_____
_____

2. Two alcohol-in-glass laboratory thermometers are shown in Figure 8. Table 1 shows the different features of these two thermometers.

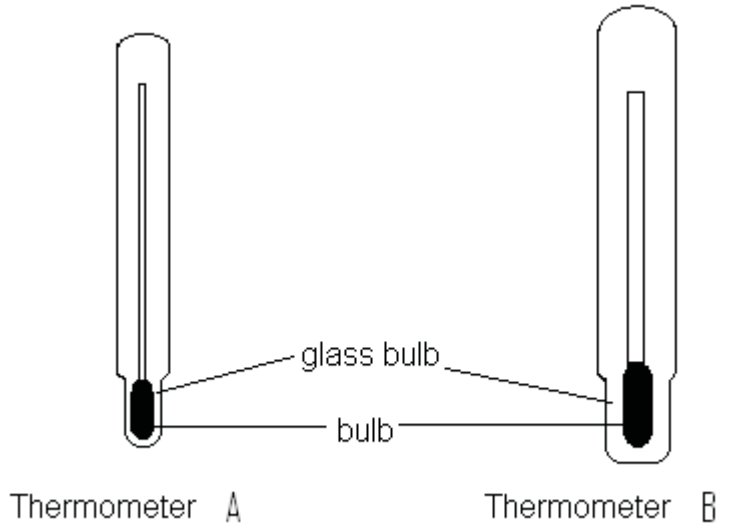

Figure 8: Two thermometers. Hand drawn by graphic designer at LDTC.

Table 1: The features of thermometer A and B

Thermometer A	Thermometer B
Thin glass bulb.	Thick glass bulb.
Narrow capillary tube.	Thick capillary tube.
Small volume of liquid in the bulb.	Large volume of liquid in the bulb.

a) What is the advantage of having a thin glass bulb?

_____
_____
_____
_____

b) What is the advantage of a narrow capillary tube over the wide capillary tube?

_____
_____
_____
_____

c) Which thermometer is more sensitive to temperature changes?

_____

I hope you were able to answer the questions. Now compare your answers to those given at the end of the section. Be sure you understand the differences in the thermometers before continuing.

Clinical Thermometer

Figure 8 shows another type of a liquid in glass thermometer called a clinical thermometer.

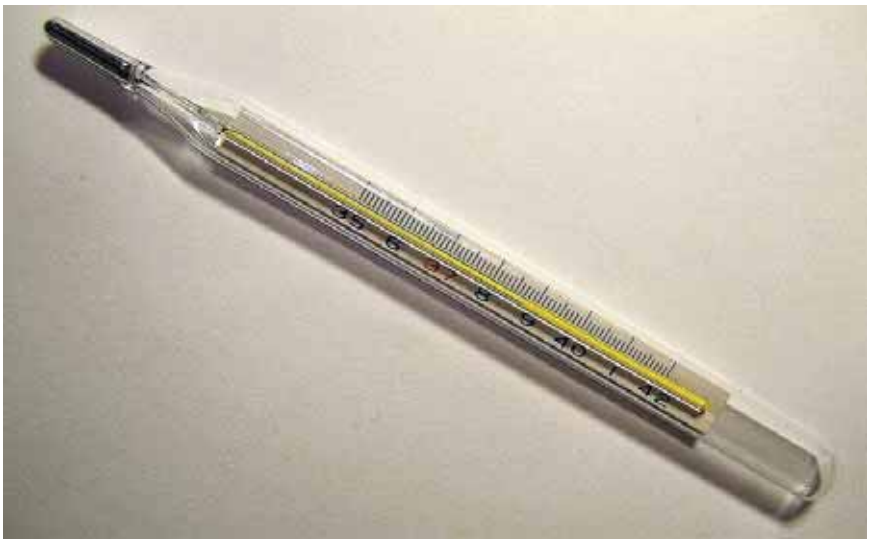

Figure 9: Clinical Thermometer accessed from Wikimedia Creative Commons, 2011.

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Activity

Activity 8

Referring to Figures 8 and 9, write the differences between a clinical thermometer and laboratory thermometer in the table below:

Laboratory thermometer	Clinical thermometer

I hope you managed to complete the table. Compare your answers to those given at the end of the section. Continue when you are clear about the differences between the two thermometers.

Thermocouple Thermometer

Imagine you are to measure temperatures above 100^0C like the temperature in an oven. Do you think a liquid in glass thermometer will work?

In this section, we will learn how temperatures higher than 100^0C are measured.

A thermocouple thermometer is a sensitive instrument used to measure very high temperatures like the melting point of metals. Rather than directly measuring temperature, a galvanometer actually measures voltage or potential difference. You will learn more about it when doing the unit about electricity.

As shown in Figure 10, two copper wires are connected to a galvanometer and the two ends are connected by an iron wire.

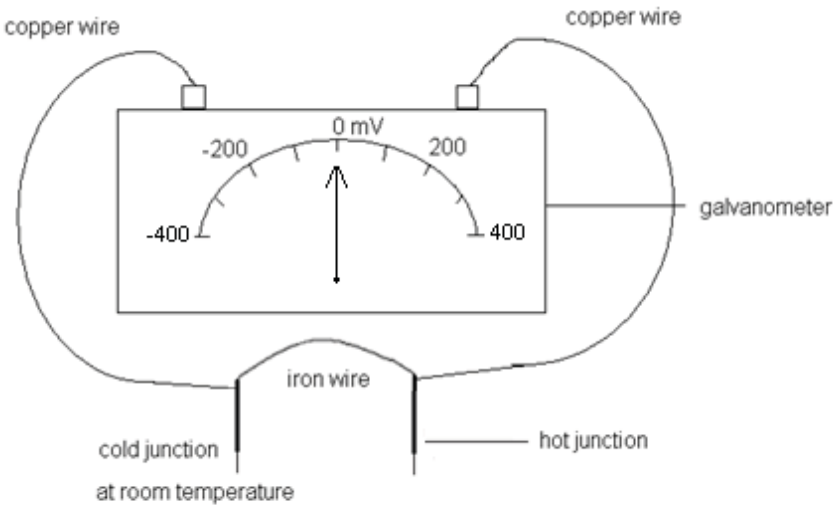


Figure 10: Thermocouple thermometer. Hand drawn by graphic designer at LDTC.

How the Thermocouple Thermometer Works

When both junctions of the thermocouple thermometer are at the same temperature (i.e. room temperature) the galvanometer needle reads 0 mV. But when the hot junction is placed in a temperature higher than room temperature (i.e. boiling water) a voltage is produced.

Higher temperature differences between the junctions produce higher voltages.

The temperature range that a thermocouple thermometer can measure depends on the wires used. If the wires have very high melting points, then they can measure high temperatures before they melt.

Generally thermocouple thermometers operate over very wide temperatures, from -200 to about 2000^0 C.

It can also be used to measure rapidly changing temperatures because it responds quickly to changes in temperature.

Calibrating the Thermocouple Thermometer

Put the hot junction in the steam of boiling water and the cold junction in ice water and then record the meter reading. If the galvanometer reads 200 mV, it means that 200 mV corresponds to 100 degrees Celsius.

NOTE:

Although, thermocouple thermometers are used to measure very high and very low temperatures, we calibrate them with ice water and boiling water because ice water and boiling water are easily created and provide known reference points.

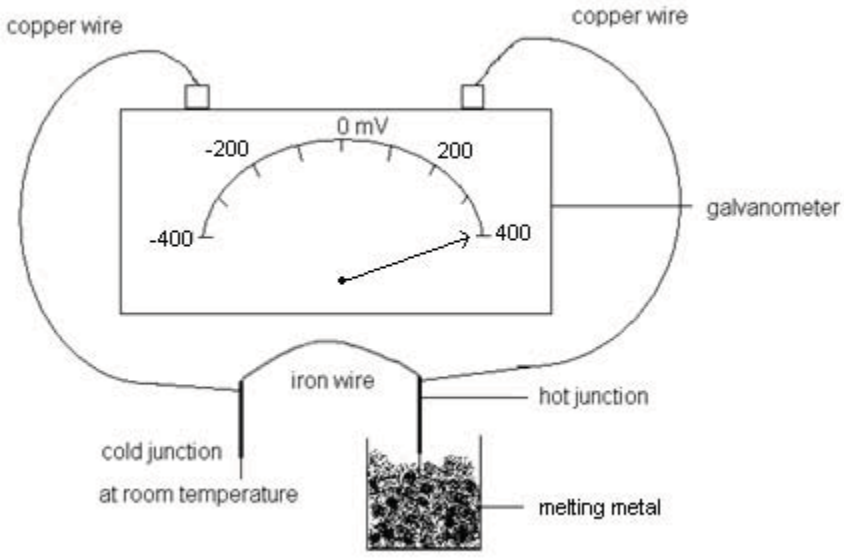


Figure 11: Using the thermocouple thermometer. Hand drawn by graphic designer at LDTC.

Example 1

When we put the hot junction of the thermocouple thermometer in the melting metal, whose temperature is 2000 C, and the cold junction is at room temperature, the thermocouple reads 100 mV. This means that a temperature difference of 2000 C (if the room temperature is ignored or if the cold junction is in ice water) it is equivalent to 100 mV. What is the temperature of the melting metal if the thermocouple reads 20 mV?

Solution 1

If 100 mV corresponds to 2000 C

Then 20 mV corresponds to X C

Or

$$\frac{2000}{100} = \frac{x}{20}$$

Remember that in mathematics, to find the temperature of the water in which the hot junction sits, which is represented as X, we cross multiply.

That is $\frac{20mV\ x2000\ C}{100mV}$

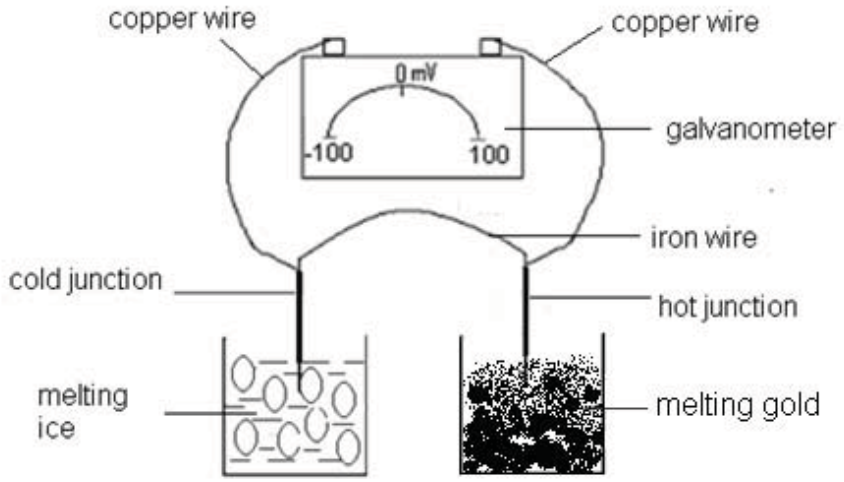
$= 400\ C$

The temperature of the melting metal is 400 C.

Activity

Activity 9

When one junction of a thermocouple thermometer is put in melting gold, whose melting point is 1050 C and the cold junction is put in melting ice, the galvanometer needle deflects to 105 mV.



a) When calibrating a thermocouple thermometer, what is the 105 mV called?

_____

b) How much in degrees Celsius is 105 mV equal to?

_____

c) The hot junction of the same thermocouple thermometer is then put in a melting solid of unknown temperature and the galvanometer needle deflects to 210 mV, what is the temperature of the melting solid?

_____

_____

_____

I hope you managed to answer the questions correctly. Compare your answers to those given at the end of the section. Before continuing, be sure you can apply calibration readings to calculate an actual temperature. If you cannot do this, review the above content.

Summary of your learning

Write a short summary of what you have learnt so far

a. _____
_____

b. _____
_____

c. _____
_____

d. _____
_____

e. _____
_____

Compare your summary to the one below. As needed, modify your summary.

- Temperature is the measure of how cold or how hot a substance is.
- A thermometer is an instrument used to measure temperature.
- The physical properties used to measure temperature in a liquid-in-glass thermometer are expansion and contraction. The thermometry liquids expand when heated and contract when cooled. Alcohol and mercury expand uniformly when heated. That is they have linear expansivity.
- The physical property used to measure temperature in a thermocouple thermometer is voltage or electromotive force.
- Two types of liquid in glass thermometers are: the laboratory thermometer and the clinical thermometer.
- A laboratory thermometer has a longer scale than a clinical thermometer.
- A clinical thermometer is more sensitive than a laboratory thermometer; it responds faster to temperature changes.
- A clinical thermometer has a constriction while the laboratory thermometer does not have a constriction.
- Expansion is a physical property used to measure temperature in the liquid- in- glass thermometer.

- Lower fixed point is the temperature of melting ice at standard atmospheric pressure.
- Upper fixed point is the temperature of steam of boiling water at standard atmospheric pressure.

Answers to Activities on Measuring of Temperature

Activity 4

1. ***Thermometer.***
2. ***Our bodies do not all respond the same way to temperature, so they can not accurately measure how hot or how cold something is.***
3. ***Temperature is the measure of how cold or how hot a substance is.***

Activity 5

1.

Table 1 – Advantages and Disadvantages of Mercury and Alcohol

Mercury	***Alcohol***
Droplets do not form on glass.	***Droplets form on the walls of glass.***
It boils at a very high temperature of 357 C, so it will not boil before the desired temperature is reached.	***Boils at 78 C, so if it is used to measure temperatures above 78, it will boil before the desired temperature is reached.***
Freezes at a temperature of -39 C. If it is used to measure temperatures lower than -39 C it will freeze before the desired temperature is reached.	***Freezes at -115 C. This is an advantage because it can measure very low temperatures than mercury.***

2. The disadvantage of using a colourless liquid is that it will not be seen easily because the glass that is used to make thermometers is also colourless.

Activity 7

1. ***Alcohol would be a good choice because it freezes at a very low temperature of -11 C. So alcohol will not freeze while the scientist is still working.***

2.

a) Heat transfer through a small glass bulb is faster than through a thick glass bulb.

a) When the capillary tube is thin, a small expansion or contraction of mercury is detected.

b) Thermometer A is more sensitive.

Activity 8

Laboratory thermometer	*Clinical thermometer*
Has a long scale, from -5 C to 100 C.	*Has a short scale from 35 C to 42 C.*
Does not have a constriction.	*It has a constriction, which stops mercury from going back into the bulb when the thermometer is taken from the human body to take the reading.*
Has a thicker capillary tube.	*Has a narrower capillary tube.*
Has a thicker bulb.	*Has a thinner bulb.*

Activity 9

a) 75 mV is the upper fixed point.

b) 105 mV corresponds to the temperature of melting gold. It is 1050 ^{o}C.

c) 105 mV corresponds to 1050 ^{o}C, that is;

105 mV_____1050 ^{O} C

210 m _____?

So when we multiply 210 mV by 1050 ^{o}C and divide by 105 mV, that is;

$$\frac{210mV \; x \; 1050 \; C}{105mV}$$

=2100 C

Section 17-3: Changing Phases

Introduction

In Unit 16, you learned that when energy (in the form of heat) is applied to objects, the speed of its molecules increases. This causes changes in phase. By the end of this section, you should be able to distinguish between the processes of boiling, evaporation, melting, solidification and condensation. These concepts are important to differentiate because they occur every day in our environment.

Time

There are 6 pages on the topic of changing phases.
You should spend approximately 1 hour on this topic.

Melting

Melting is the change of state from solid to liquid. During this process, heat energy is gained by the melting substance.

Activity 10

Activity

This activity will help you determine the melting point of water.

Take ice and crush it into small pieces. Put the crushed ice into a small container.

a) Put the thermometer in the crushed ice. What happens to the liquid in the bulb of the thermometer when the thermometer is put in the melting ice?

_____
_____
_____

b) Leave the thermometer in the ice until all the ice has melted. Does the temperature change as ice melts?

_____

c) Note the temperature 10 minutes after all of the ice has melted.

_____

d) Which process is this?

_____

I hope you were able to do the experiment. Now compare your findings to those given at the end of the section. It is important to understand that temperature stays the same when ice is melting. The temperature changes after all the ice has melted.

Different solids melt at different temperatures. You should have seen that the melting point of ice is 0^0C

Freezing

Freezing is the change of state from liquid to solid. It is also called **solidification.**

Freezing takes place at the same temperature as melting. This means that water freezes or solidifies at 0 C.

Does water gain or lose heat/kinetic energy when it solidifies?

_____

Compare your answer with the following:

When water freezes it loses heat energy, so the particles have less kinetic energy.

Activity

Boiling

We experience boiling every day, but we are going to learn some facts about boiling.

Activity 11

This activity will help you determine the boiling point of water.

In order to do this activity you need a laboratory thermometer, a long-handled spoon and a pot.

a) Pour 100 ml of water in the pot.

b) Put a thermometer in the water and record its temperature.

_____

c) Put the kettle on the stove or any source of heat and leave it until it boils.

d) Stir with a spoon so that the water does not have some parts hotter than others, which is called local heating.

e) Record the temperature reading when the water is boiling throughout the pot.

_____

f) While continuing to stir, observe the temperature as the water continues to boil. Does the temperature increase or remain the same?

_____

_____

I hope you were able to complete this experiment. Compare your results to those at the end of the section. It is important to understand that boiling takes place at the same temperature called the boiling point.

Boiling is the change of state from liquid to gas. During the boiling of water, steam is produced. Steam is water in the form of a gas. Boiling occurs at a definite temperature, called the **boiling point.**

During this process, heat energy is gained by the boiling water. This heat energy causes the particles to gain kinetic energy and vibrate until they escape as gas particles.

Condensation

This is another phase we experience every day. Do the following activity in order to learn about condensation.

Activity

Activity 12

Put a cold lid over the steam of boiling water, and wait for 3 minutes. What do you see on the bottom of the lid?

_____

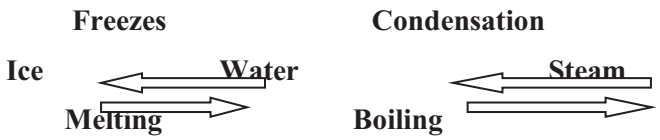
_____

Compare what you found to the results presented at the end of the section.

Condensation is the process in which a gas changes back to a liquid. During this process the gas gives off heat energy.

Summary of the Four Phases

The four processes are summarised diagrammatically below.



Boiling and Evaporation

Evaporation is the change of state from liquid to gas.

This activity will help you visualize the process of evaporation.

Activity 13

Activity

1. After it rains, you normally find small pools of water on the road but they soon disappear when the sun shines. What do you think has happened to the water?

   _____
   _____
   _____

2. After washing, you normally hang up your clothes in the open and over time they dry. What has happened to the water in the clothes?

   _____
   _____
   _____

Compare your answers to those at the end of the section. Continue when you understand the process of evaporation.

1) Most of the water is absorbed by the air and a little is absorbed by certain road surfaces.

2) All of the water is absorbed by the air.

We say that the water which is absorbed by the air has evaporated.

Activity 14

Activity

1. Write the:

a) Similarities between boiling and evaporation:

   _____
   _____
   _____
   _____
   _____

b) Differences between boiling and evaporation:

   _____
   _____
   _____

_____

_____

2. During which conditions do your clothes dry fast?

   a) _____

   b) _____

   c) _____

Compare your answers to those given at the end of the section. Pay particular attention to the conditions that affect the rate of evaporation. These ideas will be discussed further.

Factors Affecting the Rate of Evaporation

The answers to question 2 above are the factors which affect the rate of evaporation. Those are:

- Temperature: the higher the temperature, the higher the rate of evaporation.
- Area of the exposed surface: when hanging the clothes out to dry, we normally open them up so that the clothing is exposing a larger surface area to the air. The greater the exposed area, the faster is the rate of evaporation.
- Humidity of the surrounding air: humidity is a measure of the amount of water vapour in the air. If the humidity is high, there is more water vapour in the air. The more humid the surrounding air, the slower is the rate of evaporation.
- Motion of the air: wet clothes dry faster on a windy day than on a still day. The motion of the air carries away the water vapour formed during evaporation and brings drier air in contact with the wet clothes surface. This speeds up the rate of evaporation.

Answers to the Activities on Changing Phases

Activity 10

a) When the thermometer is put in the crushed ice, the level of the liquid in the tube dropped. (This will happen if the room temperature is more than 0 degrees Celsius.)

b) Melting takes place at the same constant temperature. This constant temperature is called the melting point.

c) 10 minutes after all the ice has melted, the temperature of water increases to more than that of the melting ice.

d) The process is melting.

Activity 11

f. The temperature remains constant as the water boils.

Activity 12

I hope you found that water droplets form on the cold lid. Water vapour has changed back to liquid. This process is called condensation.

Activity 13

1. When the sun comes out, the temperature will rise and evaporate the water in the pools.

2. The water will evaporate.

Activity 14

1.

a) The similarity between boiling and evaporation is that in both cases, water changes from liquid to gas.

b) The differences between boiling and evaporation are;

- *Boiling occurs at the boiling point, but evaporation occurs at all temperatures.*
- *Evaporation takes place only from the exposed surface of the liquid, but boiling occurs throughout the body of the liquid.*

2. Clothes dry fast when:

a) The temperature is high.

b) The air is dry, that is when air has low humidity.

c) The large surface area of the clothes is exposed to the sun and wind.

Unit Summary

Summary

Study the summary carefully. This will help you get a clear picture of what you have learned in this unit.

In this unit you learned that:

- The order of magnitude of expansion of gases is more than that of liquids and solids. Liquids expand more than solids.
- Temperature is the measure of how cold or how hot a substance is.
- A thermometer is an instrument used to measure temperature.
- The physical properties used to measure temperature in a liquid-in-glass thermometer are expansion and contraction. The thermometry liquids expand when heated and contract when cooled. Alcohol and mercury expand uniformly when heated. That is they have linear expansivity.
- The physical property used to measure temperature in a thermocouple thermometer is voltage or electromotive force.
- Two types of liquid-in-glass thermometers are: laboratory thermometer and clinical thermometer.
- A laboratory thermometer has a longer scale than a clinical thermometer.
- A clinical thermometer is more sensitive than a laboratory thermometer. That is it responds faster to temperature changes.
- A clinical thermometer has a constriction while the laboratory thermometer does not have a constriction.
- Expansion is a physical property used to measure temperature in the liquid-in-glass thermometer.
- Lower fixed point is the temperature of melting ice at standard atmospheric pressure.
- Upper fixed point is the temperature of steam of boiling water at standard atmospheric pressure.
- Melting is the change of state from solid to liquid. During melting temperature does not change.
- Freezing is the change of state from liquid to solid. Freezing takes place at the same constant temperature called the freezing point.
- Boiling is the change of state from liquid to gas. Boiling occurs at a constant boiling point.
- Evaporation is the change of state from liquid to gas. Unlike boiling, evaporation takes place at all temperatures.
- The rate of evaporation increases as temperature increases, wind speed increases or humidity decreases.

You have completed the material for this unit on thermal properties. You should now spend some time reviewing the content in detail. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers wave properties.

Assignment 17

Assignment 17

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:30]

1) In the rectangles below, show the arrangement of the particles in a solid before and after it is heated. (2)

Before heating

After heating

2) When heated, solids liquids and gases expand. Which one expands more? (1)

_____

3) Name the physical properties used to measure temperature in

a) the liquid-in-glass thermometer

_____

b) the thermocouple thermometer

_____

(2)

4) Name two types of liquids used in glass thermometers

_____

_____

(2)

5) Define the lower fixed point and the upper fixed point. (2)

_____

_____

_____

_____

_____

6) Explain how you would find the lower fixed point of a thermocouple thermometer. (3)

_____

_____

_____

_____

_____

7) Write the disadvantages of using mercury and alcohol in the

liquid-in-glass thermometer in the table below(6)

Mercury	Alcohol

8) Explain the features of a clinical thermometer which make it more sensitive as compared to the laboratory thermometer. (3)

_____
_____
_____
_____
_____

9) Write the advantages of a thermocouple thermometer over the liquid-in-glass thermometer. (3)

_____
_____
_____
_____
_____

10) The meter of a thermocouple thermometer reads 100 mV when its cold junction is put in melting ice and its hot junction is put in boiling water. When the hot junction is removed from boiling water and put in the bucket containing water at room temperature, the meter reads 20 mV. Calculate the temperature of the water in the bucket. (3)

_____
_____
_____
_____
_____
_____

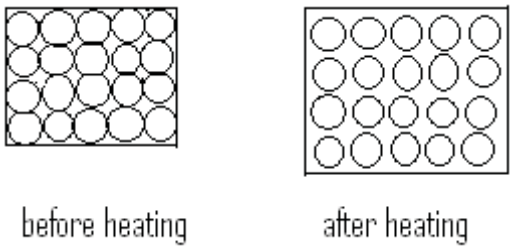
11) What is the difference between boiling, evaporation and condensation? (3)

_____
_____
_____
_____
_____

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 17

1.



(2)

2. ***Gases expand more than solids and liquids. (1)***
3. ***a) In the liquid-in-glass thermometer – the physical properties used to measure temperature are expansion and contraction.(1)***

   b) In the thermocouple thermometer – the physical property used to measure temperature is electromotive force. (1)

4. ***Clinical thermometer and laboratory thermometer.(2)***
5. ***The lower fixed point is the temperature of pure melting ice at standard atmospheric pressure. (1)***

   The upper fixed point is the temperature of the steam of boiling water at standard atmospheric pressure. (1)
6. ***Put the cold junction of the thermocouple in pure melting ice and the hot junction at room temperature, and then record the galvanometer reading. The voltage given by the galvanometer is the lower fixed point of the thermometer. (3)***

7.

Mercury	***Alcohol***
Is poisonous, so if the thermometer breaks accidentally, somebody using it will be at risk of inhaling its fumes.	***Clings onto glass. So it will give a slightly but not significantly inaccurate reading as some of the alcohol will be on the walls of the tube.***
Freezes at a low temperature of -39 C. So if the thermometer is used at places with very low temperatures mercury will freeze before the actual temperature is measured.	***Boils at a low temperature of 78 C. So if the thermometer is used to measure temperatures above 78 C, alcohol will boil before the actual temperature is measured.***

Is expensive.	*It cannot be seen clearly. So it will be difficult to see the meniscus when taking the temperature reading. Consequently, the alcohol must be dyed.*

(6)

8. *The clinical thermometer has:*

   A narrow capillary tube, so it responds to very small temperature changes. This means that a small expansion is recognised because mercury moves through a small surface area.

   A thin glass bulb, so heat is conducted fast through the glass bulb.

   A small bulb, so the volume of mercury is small hence the mercury will be heated fast. (3)

9. *Advantages of a thermocouple thermometer over the liquid-in-glass thermometer are;*

   - *It measures a wide range of temperatures that is from -200 C to 1700 C.*
   - *It measures rapidly changing temperatures because it is very sensitive.*
   - *Since the junctions of a thermocouple thermometer are pointed it is able to measure temperature at a point. (3)*

10. *100mV corresponds to 100 C degrees Celsius,*

    So 20 mV corresponds to: $\frac{20mVx100\ C}{100Mv}$

    = 20 C (3)

11. *Boiling is the change of state from liquid to gas and occurs at a constant boiling point.*

    Evaporation is the change of state from liquid, takes place at all temperatures and is fast when temperatures are high it is windy and dry.

    Condensation is the change of state from gas to liquid. (3)

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physics course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 17

Assessment 17

The assessment is divided into two sections. Answer all questions in both sections. In order to be sure that you have mastered the unit, you should at least score 80% in this section.

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

You should be able to complete this assessment in 30 minutes.

(Total Marks:22)

Section A (6 Marks)

Read the statements and then write TRUE or FALSE. If the statement is false explain why it is false.

1) Thermometric liquids are liquids that are used in thermometers (TRUE OR FALSE)

2) Clinical thermometers are used to measure temperature of melting ice. (TRUE OR FALSE)

3) The space above the alcohol column in thermometer contains air. (FALSE OR TRUE)

4) Boiling is the change of state from liquid to gas. (TRUE OR FALSE)

5) Clothes dry fastest when they are hanged out during a cloudy wet day. (TRUE OR FALSE)

6) Solids expand more than liquids and gases. (TRUE OR FALSE)

Section B (16 Marks)

Answer all questions in this section.

7) John complains that he has fever. His friend Sam uses the laboratory thermometer to find his body temperature. Explain what problems Sam is likely to encounter. Then suggest what Sam should do to solve those problems. (4)

8) When an alcohol thermometer was being calibrated, the length of the alcohol column was found to be 2.5 cm at 0^0C and 12.5 cm at 100^0C.

   a) Explain how the temperature of 0^0C is achieved? (2)

   b) Explain how the temperature of 100^0C is reached? (2)

   c) What is the increase in the length of the alcohol column for each 1^0C rise in temperature? (1)

   d) What is the temperature of the liquid if, when the thermometer is placed in it, the length of the alcohol column is 5.0 cm? (3)

9) Explain how expansion and voltage are used to measure temperature. (4)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

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Unit 18

General Wave Properties

Study Skills

Take note of all previous mistakes and make every effort to eliminate them from future practice. It has been shown experimentally that consciously reviewing mistakes, making note of exactly why they were incorrect, helps to reinforce the correct response. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

The term **wave** is very common to our ears. We often hear of water waves out at sea, as seen in Figure 1, radio and television waves and we have all probably at one point thrown a stone into the pond and seen circular waves called ripples form.

Figure 1: Sea wave accessed from Wikimedia Creative Commons, 2010.

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In this unit we are going to deal with the experimental study of waves, with special reference to water waves and sound waves.

Time

This unit consists of 30 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Outcomes

Study Skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Give* the correct SI units of the different physical quantities.
- *Solve* problems which involve physical forces, such as energy, light, magnetism and electricity.
- *Describe* matter and its related physical processes.

Upon completion of this unit you will be able to:

- *Describe* wave motion and related wave terms.
- *Calculate* the speed of the waves using the wave equation.
- *Distinguish* between longitudinal and transverse waves.
- *Describe* the nature and production of sound waves.
- *Describe* the use of water waves to show reflection and refraction.
- *Explain* diffraction.

Terminology

Transverse wave:	Wave which travels perpendicular to the vibration.
Longitudinal wave:	Wave which travels parallel to the vibration.
Frequency:	Number of waves produced per second.
Wavelength:	Distance between two successive points which are in the same phase.
Amplitude:	Height/depth of the wave.

Section 18-1: Properties of Wave Motion

Introduction

At the end of this section, you should be able to describe wave motion and related terms.

Time

There are 2 pages on the topic of properties of wave motion. You should spend approximately 40 minutes on this topic.

Wave Formation

Waves are disturbances. They are changes in the surface of the ocean, the air and electromagnetic fields. Normally these changes are travelling and the disturbance is moving away from whatever created it.

Waves form when objects (e.g. a rope, water) are disturbed at one point, and the particles at that point vibrate and send out a wave motion from the disturbed end to the other end.

When a small stone is thrown into a pond, circular ripples form outwards from the point at which the stone dropped in the water. So the source of any wave is a **vibration** or an **oscillation.**

Waves are then carried by vibrating particles of the medium in which they are travelling from the point of disturbance.

Waves carry energy from one point to another **without moving matter from one place to the other.** The amount of energy carried by the wave depends on the **amplitude** of the wave.

The following are terms used to describe wave motion as shown in Figure 2.

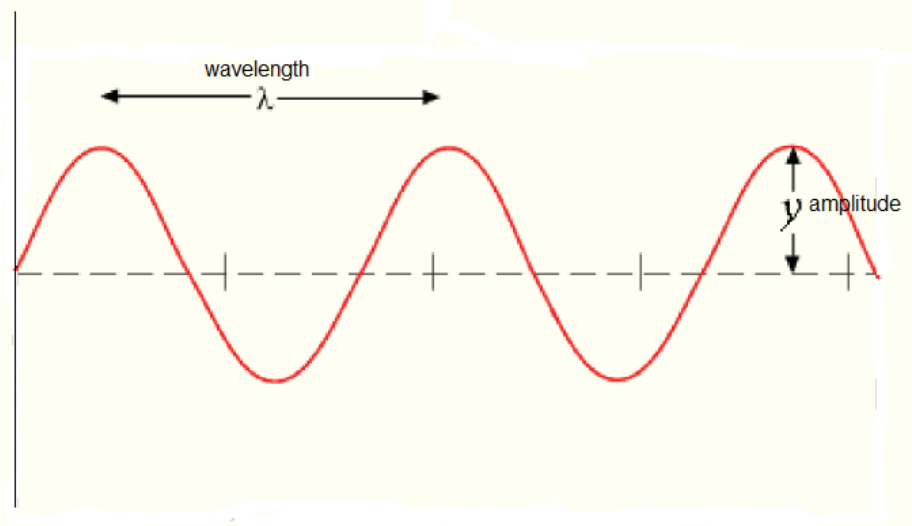

Figure 2: A wave diagram accessed from Wikimedia Creative Commons, 2010.

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It is important to know these definitions:

- **Amplitude**

  Is the maximum displacement of a wave particle from its resting position (height or depth of the wave).

- **Phase**

  Two points are in the same phase if they are moving in the same direction at the same speed and having the same displacement from the rest position. Any two crests or troughs are in the same phase.

- **Crest**

  The top of the wave formation.

- **Trough**

  The bottom of a wave formation.

- **Wavelength**

  Is the distance between two successive crests or troughs. Or just simply the distance between two points which are in the same phase. It is denoted with the Greek symbol (ג) called lambda. Its SI unit is the meter (m).

- **Frequency**

  Refers to the number of complete waves produced per second. The SI unit of frequency is the Hertz (Hz). The frequency of wave is 2Hz if 4 waves are produced in 2 seconds. Two are therefore produced in one second. It is denoted with the letter (*f*).

- **Period**

  Denoted with (T), is the time taken to produce one complete wave or one complete vibration $T = 1/f$ where f is the frequency. The SI unit of time is the second.

- **Wave front**

  An imaginary line which is used to join points which are in phase. A wave front may be drawn by joining all crests or troughs of a wave. The direction of travel of the wave is always at right angles to the wave front.

Reflection

If you have access to the internet, please go to:

http://phet.colorado.edu/sims/wave-on-a-string/wave-on-a-string_en.html

and try the simulation. What happens when you increase the amplitude of the wave? Does the frequency increase or decrease? Does the wavelength increase or decrease?

Note it!

The key points to remember in this section on properties of wave motion are:

- A wave is a spreading of a disturbance from one place to another.
- Waves are described in relation to wave terms such as wavelengths, frequency, amplitude, phase, period, wave front and wave speed.

The waves terms described above will be used in explaining transverse and longitudinal waves in the next section.

Section 18-2: Transverse and Longitudinal Waves

Introduction

At the end of this section, you should be able to distinguish between transverse and longitudinal waves and calculate the speed of waves using the wave equation.

Time

There are 9 pages on the topic of transverse and longitudinal waves. You should spend approximately 2 hours on this topic.

Transverse Waves

Waves are classified into two types: **transverse** and **longitudinal** waves based on particle motion and wave direction.

When a transverse wave travels through a substance, the particles of the substance are moved at right angles to the direction in which the wave is travelling.

When a transverse wave is formed from a rope for example, your hand moves up and down but the wave travels in the direction which is at right angles to the movement of the hand. This is shown in Figure 3. To view a video of creating a transverse wave, please go to: http://www.youtube.com/watch?v=UHcse1jJAto

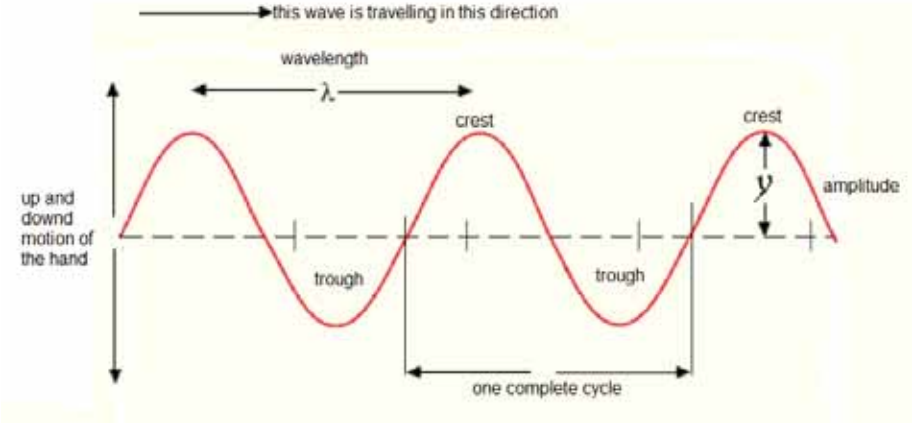

Figure 3: A transverse wave accessed from Wikimedia Creative Commons, 2010.

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Note that one complete wave is made from a complete upward and downward movement of the particles (a crest and a trough).

Activity

Activity 1

1. How many complete waves are present in the waveform in Figure 3?

   _____

2. A rubber ball is dropped vertically into a shallow puddle of water and bounces up and down in the puddle of water. What direction will the water waves produced take?

   _____
   _____

After attempting both questions compare your answers with the correct answers given at the end of this section.

Water waves are an example of a transverse wave. There is also a wide range of transverse waves called electromagnetic waves which will be discussed in depth in under the next unit: Unit 19: Light.

Longitudinal Waves

Longitudinal waves may also be a little difficult to imagine, because there aren't any examples that we can see in everyday life. If you have access to the internet, please go to: http://youtu.be/aguCWnbRETU to view a video of longitudinal waves. A mathematical description might be that in longitudinal waves, the waves (the disturbances) are along the same axis as the direction of motion of the wave. In comparison, transverse waves are at right angles to the direction of motion of the wave.

To visualize the difference between longitudinal and transverse waves, try imagining yourself as one of the particles that the wave is disturbing, such as a particle of water on the surface of the ocean. As the wave comes from behind you, a transverse waves lifts you up and then drops you down while a longitudinal wave pushes you forward and then pulls you back.

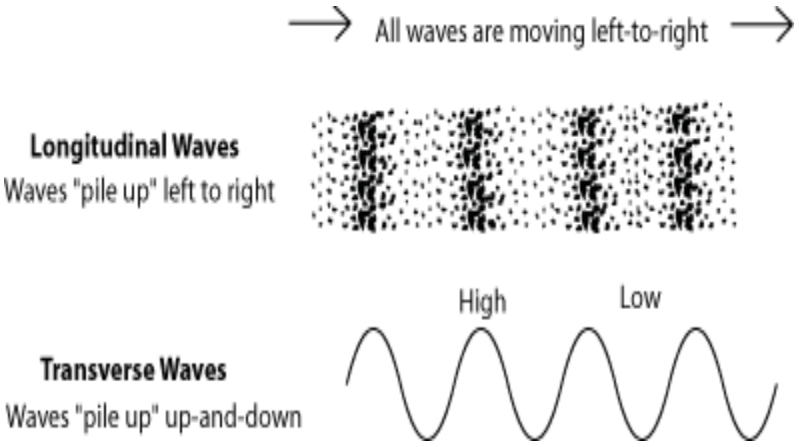

Figure 4: Longitudinal versus transverse wave accessed from Connections, 2010.

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A longitudinal wave travels in a direction parallel to the direction of the vibration.

Note that the high pressure points on a longitudinal wave are called **compressions** and low pressure points are called **rarefactions**. It is particularly hard to show amplitude in longitudinal waves, but longitudinal waves definitely have amplitude.

An example of a longitudinal wave is a sound wave. Sound can only travel through matter (solids, liquids and gases) but cannot travel in a vacuum.

Both transverse and longitudinal waves can be generated with the use of a slinky spring, as shown in figures 5(a) to 5(c), which is moved up and down at one point to produce a transverse wave and moved back and forth to produce a longitudinal wave.

Figure 5(a): A slinky spring photo taken by LDTC.

Figure 5b (i): A slinky spring illustrating longitudinal waves. *Photo taken by LDTC.*

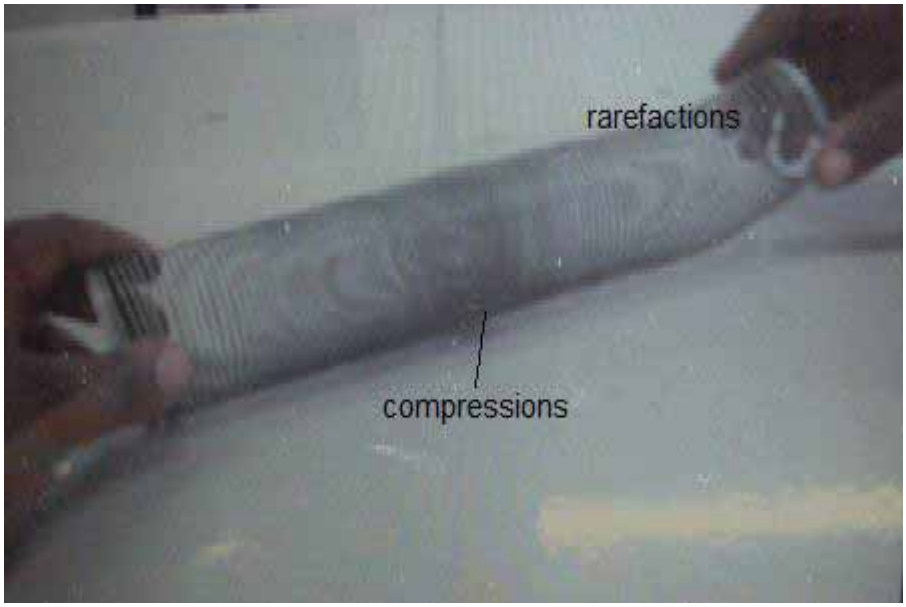

Figure 5b (ii): A slinky spring illustrating longitudinal waves. Photo taken by LDTC.

Figure 5(c): A spring illustrating transverse waves. Photo taken by LDTC.

Activity

Activity 2

Differentiating Between Transverse and Longitudinal Waves

At this point, can you describe the difference between transverse and longitudinal waves? With the help of Figure 6, fill in the table that follows.

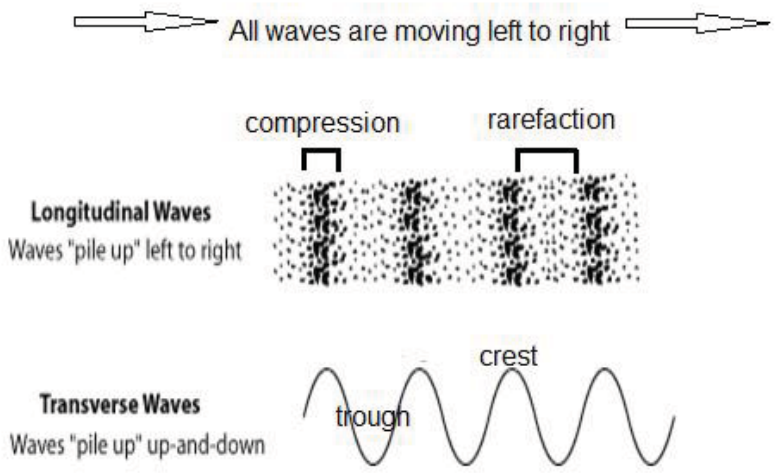

Figure 6: Differences between transverse and longitudinal waves accessed from Connections, 2010.

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TRANSVERSE WAVES	LONGITUDINAL WAVES
1.	Cannot travel in a vacuum.
ג - distance between two successive crests/troughs.	4.
5.	Vibrations parallel to direction of travel of the wave.

When you have filled in the blanks in the table above, compare your table to the table given at the end of the section.

The Wave Equation

Tie the end of a rope to a pole and pull the rope taut. Now, generate a transverse wave in the rope by slowly moving your hand up and down.

Move your hand faster and observe what happens to the frequency and the wavelength. Write your conclusion and then compare to the answer found below.

Conclusion:

_____

_____

Compare your conclusion to the following:

You should have observed that moving your hand faster causes a decrease in the wavelength but increases the frequency.

This shows that the speed with which the wave moves is related to its frequency (f) and wavelength (λ).

In equation form the **speed of the wave = frequency x wavelength**

In symbols $v = f \lambda$

Where:

v is the speed in m/s

f is the frequency in Hz and

λ is the wavelength in m

This wave equation applies to any wave.

Example 1

What is the speed of the wave whose wavelength is 2 m and frequency 4 Hz?

Solution

$V = f \lambda$

$= 4 \text{ Hz} \times 2 \text{ m}$

$= 8 \text{ m/s}$

Example 2

When a rope is disturbed at one end, 4 complete waves are produced in 2 seconds. The wavelength of the wave is 2 m. What is the speed of the wave?

Solution

The solution to this problem requires calculation of the frequency first!

If 4 complete waves are produced in 2 seconds, how many are produced in one second? That would be the frequency! And the answer is 2 Hz. 2 waves are produced per second.

So the speed = 2 Hz x 2 m

= 4 m/s

Example 3

Calculate the frequency of a wave whose wavelength is 50 cm and speed 20 m/s.

Solution

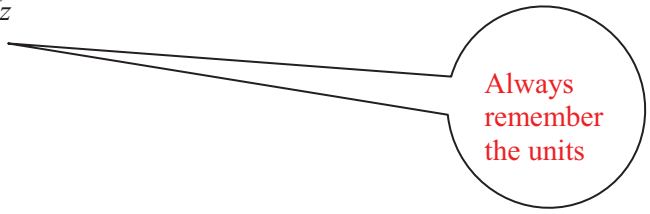
Tip

Rearrange the wave equation and make frequency the subject of the formula.

$F = v/\lambda$

$= 20/0.5$ *Note it the 50 cm wavelength is converted to m.*

$= 40$ *Hz*



Activity

Activity 3

Calculating the Speed of the Wave

(a) At what speed is the wave with a wavelength of 0.2 m and a 3 Hz frequency moving?

_____

_____

_____

(b) What is the frequency of a microwave moving with a speed of 3×10^8 m/s and has a wavelength of 3×10^{-2} m

_____

_____

_____

Compare your answers with those at the end of the section. Review the related content for any question that you missed.

Note it!

Key Points to Remember:

The key points to remember in this section on transverse and longitudinal waves are:

- The speed of a wave is calculated using the wave equation:

$v = f\lambda$ where:

v is the speed in m/s

f is the frequency in Hz and

λ is the wavelength in m

This wave equation applies to any wave.

- There are two types of waves, transverse and longitudinal waves. Transverse waves travel in a direction perpendicular to the direction of vibration while longitudinal waves travel in a direction parallel to the direction of vibration.

In the next section, we are going to find out how we can show reflection and refraction of water waves as transverse waves by using a ripple tank.

Answers to Activities on Transverse and Longitudinal Waves

Answers to Activity 1

1. ***Two complete waves.***
2. ***The water waves will move outwards. Remember that a transverse wave moves in the direction that is at right angles to the movement of the bouncing ball.***

Answers to Activity 2

TRANSVERSE WAVES	*LONGITUDINAL WAVES*
1.Travel through a vacuum.	*1. Cannot travel in a vacuum.*
2. λ – The distance between two successive crests/troughs.	*2. λ – The distance between two successive compressions/rarefactions.*
3. Vibrations are perpendicular to direction of travel of the wave.	*3. Vibrations are parallel to direction of travel of the wave.*

Answers to Activity 3

(a) $V = f\lambda$

$= 3\ Hz \times 0.2\ m$

$= 0.6\ m/s$

(b) $F = V/\lambda$

$= 3 \times 10^{8}/3 \times 10^{-2}$

$= 10^{10}$ *Hz*

Section 18-3: The Ripple Tank

Introduction

At the end of this section, you should be able to describe the use of water waves to show reflection and refraction.

Time

There are 9 pages on the topic of the ripple tank. You should spend approximately 40 minutes on this topic.

Water Waves

A comprehensive study of the behaviour of transverse waves in the form of water waves may be made from an instrument called the **ripple tank** as shown by Figure 7.

Ripple tanks are not very common instruments. You might find one at a nearby school laboratory.

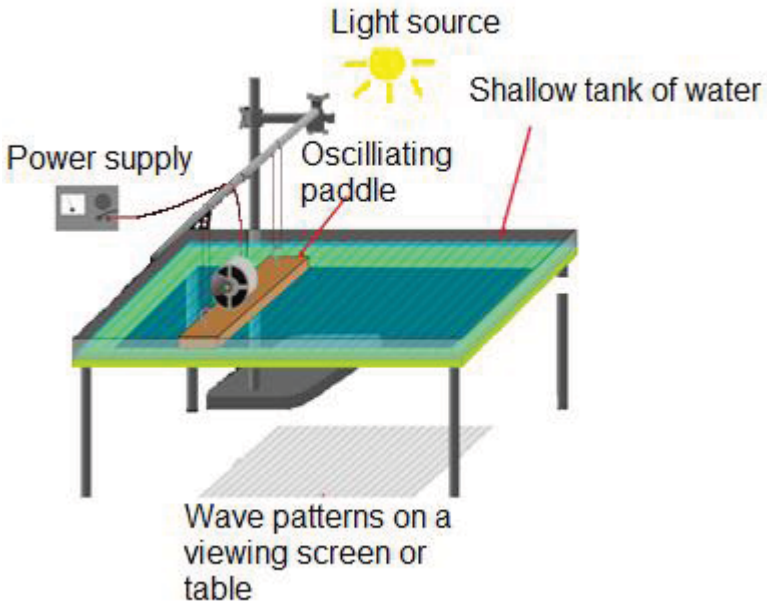


Figure 7: A ripple tank accessed from Wikimedia Creative Commons, 2010.

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Ripple tanks come in different shapes, sizes and with different accessories, but the major components are the same.

The major components of a ripple tank are:

- A shallow transparent tray which holds water
- A light source above the tray
- A white screen beneath the tray where the wave images are seen
- A spherical dipper for circular waves and a straight dipper for plane waves. When a dipper vibrates, waves are generated.

In a ripple tank, waves are generated using dippers as described above and their images are observed as alternate dark and bright lines (Figure 8) on the screen. These lines represent crests and troughs.

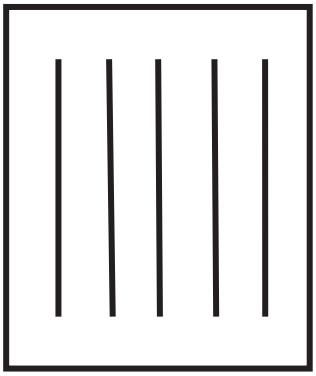


Figure 8: Images of waves on a ripple tank. Hand drawn by graphic designer at LDTC.

Reflection

Water waves are reflected (turned back) when an obstacle is placed in their path.

Let us now find out how the reflection of water waves be attained in a ripple tank.

Reflection can be demonstrated by placing a straight barrier standing upright in the water. It causes the incoming waves to be reflected.

Figure 9 shows reflection of water waves from a plane surface.

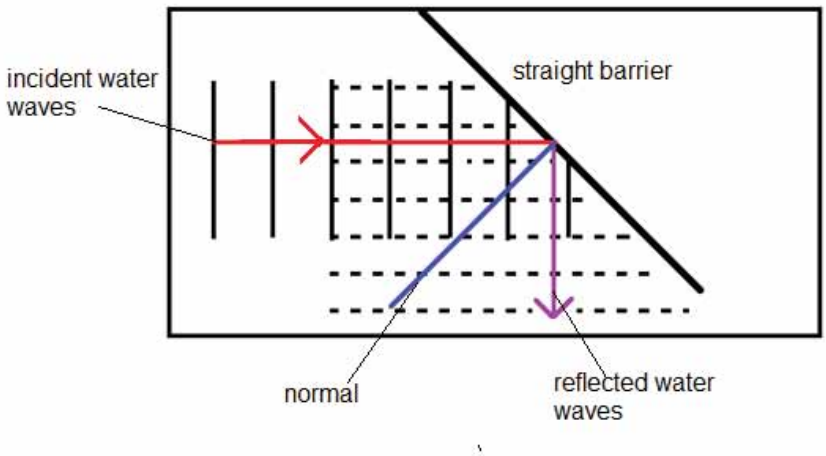


Figure 9: Reflection of water waves from a plane surface. Hand drawn by graphic designer at LDTC.

The solid lines running vertically are wave fronts representing the incoming waves and the dotted lines which run horizontally show the waves after reflection from the barrier.

Incoming waves are called **incident waves** and after reflection they are called **reflected waves**.

At this point it is important to know that reflection of water waves obeys the laws of reflection which state that:

- Angles of incidence and reflection are equal.
- The incident, the normal and the reflected waves all lie on the same plane.

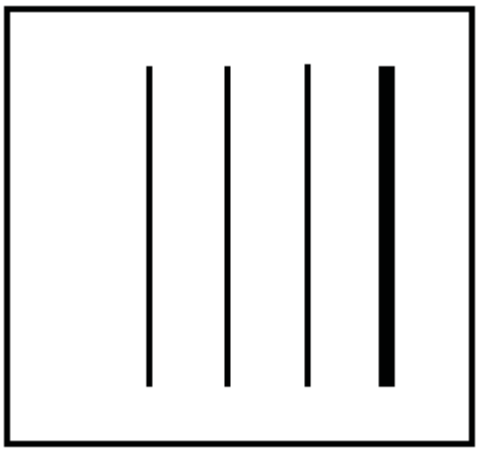
Reading

These laws are fully explained under the unit on light. Refer to this unit to read more on reflection and the laws of reflection.

Activity

Activity 4

Complete the figure below to show reflection of water waves from a straight barrier. Use dotted lines to represent the reflected waves. Use arrows to show the direction of the incident and reflected waves.



After completing the activity, compare your diagram to the diagram given at the end of the section.

Refraction

In a ripple tank, refraction of water waves can be demonstrated by placing a straight barrier e.g. glass block, plastic block etc at an angle to the incoming incident waves.

The block creates a different medium because the depth of the water over the block is shallower.

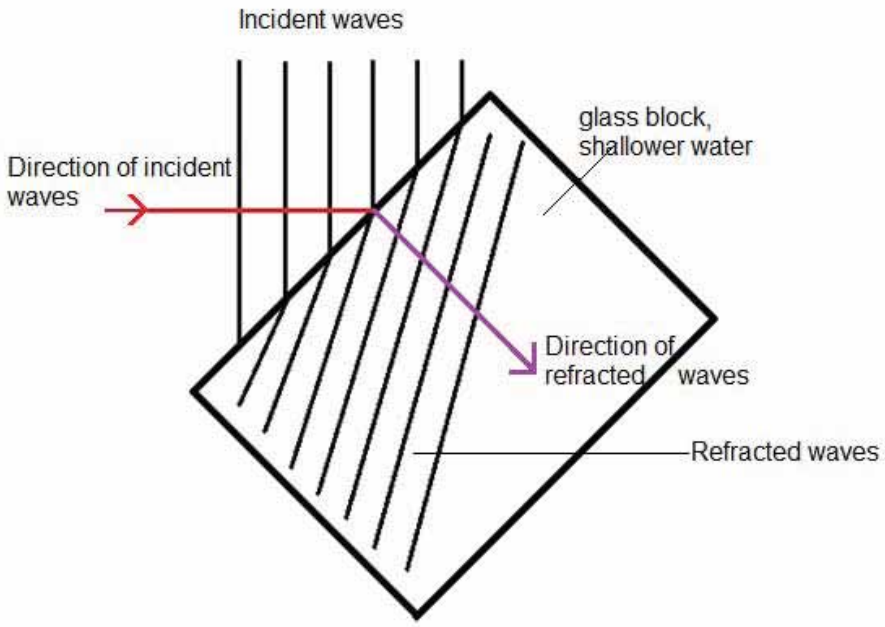


Figure 10: Refraction of water waves. Hand drawn by graphic designer at LDTC.

Reflection

Two things happen when the waves enter shallow water over the glass block, take a moment to think about what the two differences are.

- The direction of the waves changes
- The distance between two successive crests/troughs decreases. What name is given to this distance?

_____

Compare your answer to the answer given below.

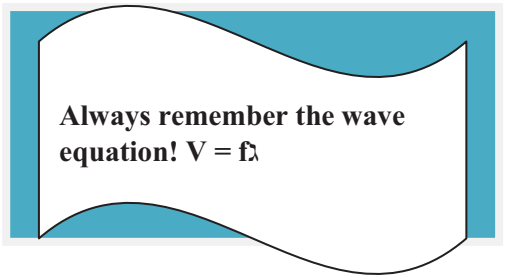
Wavelength

If the wavelength of the waves decreases as the waves enter shallower water, what does this imply about the speed of the wave?

_____

_____

Compare your answer to the one provided below.



A decrease in the wavelength causes a decrease in the speed of the waves.

The frequency remains the same because frequency of the waves depends on the frequency of the dipper.

Refraction therefore refers to the bending of waves when they enter a different medium. This bending occurs as a result of a change in the speed of the wave as it moves from one medium to another.

Activity 5

Activity

(a) What happens to the speed of the waves as they move from shallow water into deep water?

_____

(b) What changes would there be to water waves moving into water of the same depth as where they come?

_____

After attempting both questions, compare your answers to the ones given at the end of the section. Review the content for any mistake that you made.

Note it!

Key Points to Remember

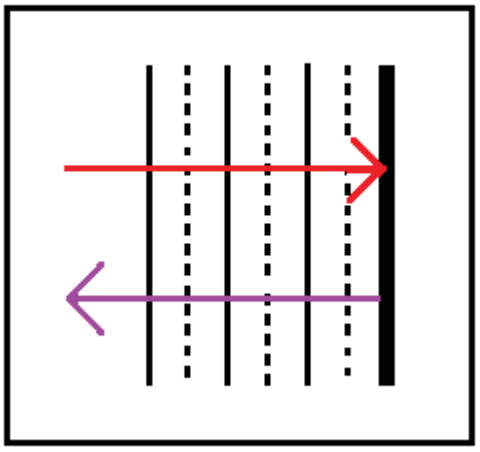
The key points to remember in this section on ripple tanks are:

- A ripple tank can be used in a laboratory to generate water waves.
- The ripple tank can be used to show reflection and refraction of waves.

Now that we have dealt with water as a transverse wave, we are going to deal with sound as a longitudinal wave in the next section.

Answers to Activities on the Ripple Tank

Activity 4



Note that the direction of the reflected waves is perpendicular to the barrier and the reflected rays overlap with the incident waves.

Activity 5

(a) ***The wavelength increases and so does the speed.***

(b) ***There is no change in the wavelength and hence no change in the speed as well.***

Section 18-4: The Nature, Production and Transmission of Sound Waves

Introduction

At the end of this section, you should be able to describe the nature and production of sound waves.

Time

There are 2 pages on the topic of the nature, production and transmission of sound waves. You should spend approximately 40 minutes on this topic.

Wave Formation

Earlier in this unit we discussed that sound is an example of a longitudinal wave.

How is sound really produced?

Sound is produced by vibrating sources and then travels out from the source in the form a longitudinal wave.

Reading

You can learn more about sound at:
http://science.howstuffworks.com/sound-info.htm

Figure 11: A guitar accessed from Wikimedia Creative Commons, 2010.

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Figure 12: A drum accessed from Flickr, 2010.

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Common sources of sound are musical instruments such as a guitar and a drum, as shown in Figures 11 and 12. What is common about these two instruments that enable them to produce sound?

_____

_____

Compare your answer to the correct one given below.

They both have a part which vibrates.

- A guitar has strings that vibrate when strummed.
- A drum has a stretched skin that vibrates when hit.

When a loud speaker cone, as shown in Figure 13, vibrates, the vibrations are passed to the neighbouring air particles. These in turn vibrate and pass on the vibrations further to our ears where the sound is detected.

Figure 13: Loud speaker accessed from Wikimedia Creative Commons, 2010.

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The air particles vibrate to and fro in the same direction in which the wave is travelling. This creates alternating high and low pressure areas as illustrated in Figure 14.

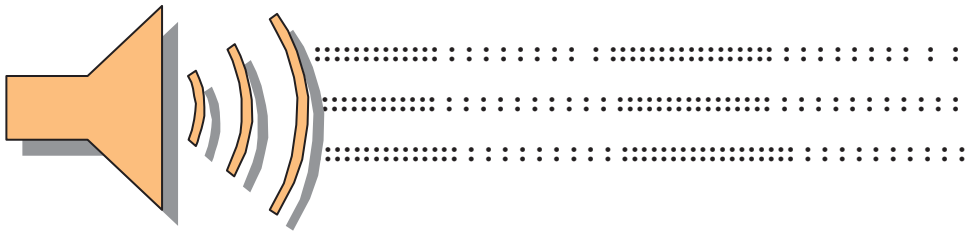

Figure 14: Loud speaker cone vibrating. Hand drawn by graphic designer at LDTC.

Reflection

Think back!

- What are the high pressure areas (air particles close) called?
- What are the low pressure areas (air particles apart) called?

If you cannot remember, review the above content.

From Figure 14, sound requires particles of a medium to vibrate in order to pass on the vibrations.

What does this imply for a place where there are no particles like a vacuum?

_____

Compare your answer to the correct answer given below.

It implies that sound will not be transmitted in a vacuum.

Sound does not travel through a vacuum, but can travel through **gases, liquids and solids.**

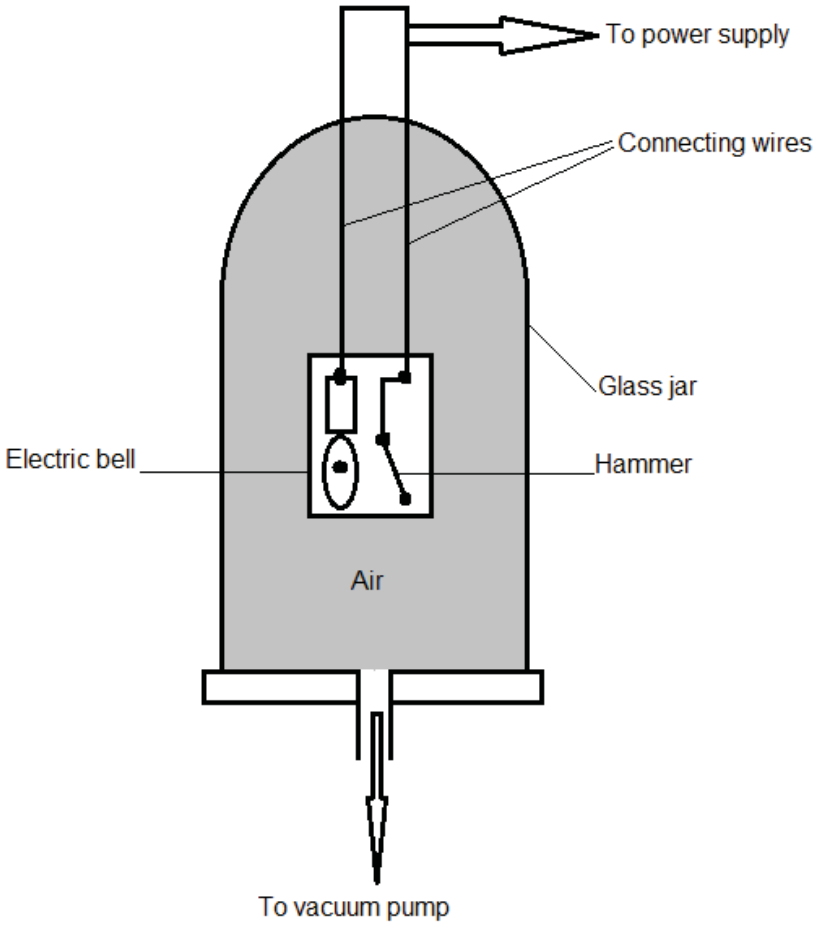

Figure 15: The bell jar experiment. Hand drawn by graphic designer at LDTC.

In the set-up, shown in Figure15, a pump removes the air and creates a vacuum.

Describe what you think happens to the sound of the bell as the vacuum is created.

_____
_____
_____

Compare your description to the answer provided below.

When the bell under the jar is connected to the battery it starts to ring and the sound it produces can be heard. The volume of the sound gradually decreases as the air is removed. After the air has been totally removed from the glass jar by the vacuum pump, the sound of the ringing bell can no longer be heard. The bell can only be seen vibrating, which suggests it is ringing.

To see a video of this experiment, please go to:
http://youtu.be/ce7AMJdq0Gw

Activity

Activity 6

(a) How is sound produced?

_____
_____
_____

(b) How is it transmitted?

_____
_____
_____

(c) Could sound travel from one spaceship directly to another? Explain your answer.

_____
_____
_____
_____

Compare your answers with those at the end of this section. Be sure that you understand each answer before continuing.

Although it is said that sound travels through different media like gases, solids and liquids, the speed of sound through these media varies considerably.

The table below gives some approximate values of the speed of sound through some media.

Medium	Approximate values (ms^{-1})
Air	300+
Water	1400 – 1500
Steel	6000
Iron	5000
Concrete	5000

Note it!

TAKE NOTE! Sound travels faster in liquids than gases, and fastest of all through solids.

Speed of Sound

The speed of sound in air is affected by physical conditions such as **temperature** and **humidity.** When the temperature and humidity of the air increases, the speed of sound in air also increases.

Key Points to Remember

The key point to remember in this section on the nature, production and transmission of sound waves is:

- Sound is produced by vibrations and it requires a material medium to be transmitted.

Just like water in the ripple tank, after production and transmission, sound also undergoes reflection and refraction. Let us find out how in the next section.

Answers to Activities on the Nature, Production and Transmission of Sound Waves

Answers to Activity 6

(a) Sound is produced by vibrating sources placed in a medium.

(b) Sound waves need a material medium to be transmitted.

(c) Sound cannot travel from one spaceship to another because of the presence of a vacuum between the different spaceships.

Section 18-5: Reflection and Refraction of Sound

Introduction

At the end of this section, you should be able to describe the reflection and refraction of sound.

Time

There are 6 pages on the topic of reflection and refraction of sound. You should spend approximately 1 hour on this topic.

Like transverse waves, longitudinal (sound) waves also undergo reflection as well as refraction.

An echo is a sound heard after a reflection of sound. Hard surfaces such tall brick walls reflect sound waves.

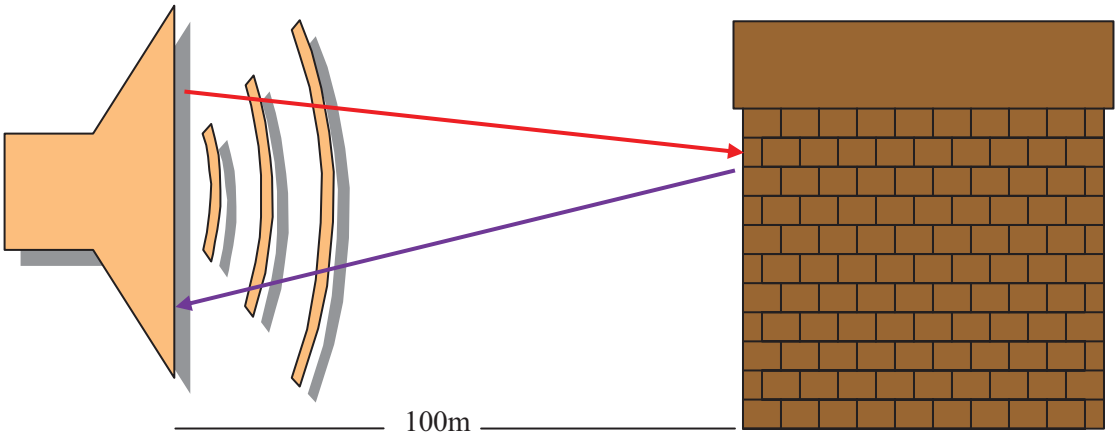

Figure 16: Reflection of sound. Hand drawn by graphic designer at LDTC.

Incident sound travels to the wall and reflected sound travels from the wall and is heard as an echo.

When the distance from the source of sound to the reflecting surface is known, as is the case in Figure 16 above, the speed of sound may be estimated.

What needs to be done is to note down the time interval (***t***) between sending out an original sound from the source and hearing the echo. During this time, sound will have travelled to and from the wall.

This means that sound has travelled twice the distance (***2d***), therefore the speed of sound may be computed from the equation

$$\text{Speed of sound} = \frac{\text{distance travelled by sound}}{\text{Time taken}}$$

$$= \frac{2d}{t}$$

Example

(a) If a girl stands 150 m from a tall cliff, shouts and hears her echo a second later. What is the speed of sound?

Solution

S = 2d/t

= 2 x 150 m / 1s

= 300 m/s

Echo sounding is used to estimate the depth of the sea bed or a shoal of fish. For example, a sound impulse is sent to the sea bed and sound generators fitted to the boat record the time for which it takes for the echo to return from the sea bed where it was reflected. Figure 17 shows how echo sounding takes place.

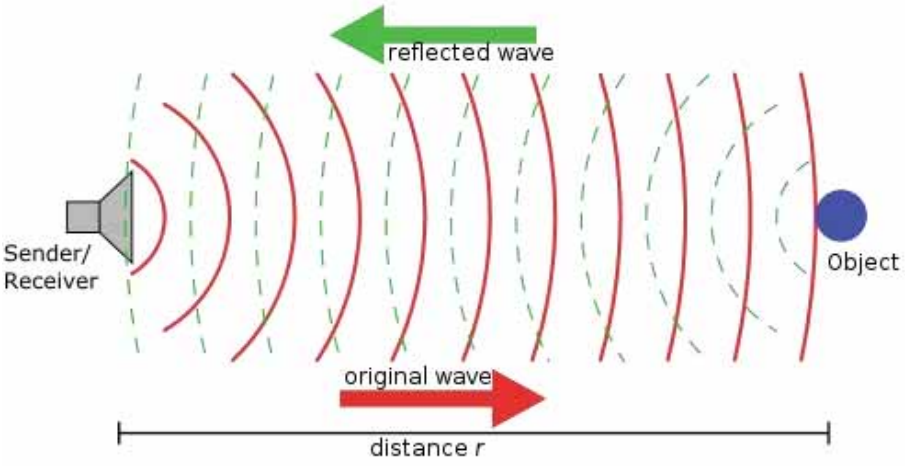

Figure 17: Echo sounding accessed from Wikimedia Creative Commons, 2010.

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Active sonar creates a pulse of sound, and then listens for reflections (echo) of the pulse. This pulse of sound is generally created

electronically using a sonar projector consisting of a signal generator, power amplifier and electro-acoustic transducer/array.

To measure the distance to an object, the time from transmission of a pulse to reception is measured and converted into a range by knowing the speed of sound.

Source: http://en.wikipedia.org/wiki/Sonar

From the equation $S = 2d/t$, when s and t are known, d can be calculated;

Rearranging the equation

$$d = \frac{S \times t}{2}$$

Example

How deep is the water under a ship if echo-sounding equipment fitted to the ship receives an echo 3 seconds after it was sent out if the speed of sound in water is 1400 m/s?

Solution

$$d = \frac{S \times t}{2}$$

$$= \frac{1400\ m/s \times 3\ s}{2}$$

$$= 2100\ m$$

Activity

Activity 7

1. If a young man stands 250 m from a tall building, shouts and hears his echo 2 seconds later. What is the speed of sound?

   _____
   _____
   _____
   _____
   _____

2. A girl stands some distance away from a cliff. She then gives a shout and hears her echo 4 s later. How far away is she from the cliff? Assume the speed of sound is 330 m/s.

   _____
   _____
   _____

_____
_____

3. How deep is water under the ship if echo-sounding equipment fitted to the ship receives an echo 6 seconds after it was sent out if the speed of sound in water is 1500 m/s?

_____
_____
_____
_____
_____

After completing the questions, compare them to the answers given at the end of the section.

Refraction of Sound

Like water waves, sound waves are also refracted (bent) when they enter a different medium. When sound travels from hot air to cold air or from cold air to hot air it will bend.

This is because the speed of sound is greater in hot air than it is in cold air, because when the air is hot, the molecules are moving fast and the vibrations of the sound wave are therefore transmitted faster.

Refraction of sound is particularly noticeable on a hot day or cold night

Imagine yourself on a river bank of a wide river during a warm day and you are doing some washing. You see some other people on the other side of the river but cannot hear them.

Now imagine yourself later at night coming to pick up your dry clothes and the people at the other side of the river are doing the same. This time you do not only see them, but you can also hear their conversations. In situations like this, the ability to hear sound carried over water only at night is due to the refraction of sound waves.

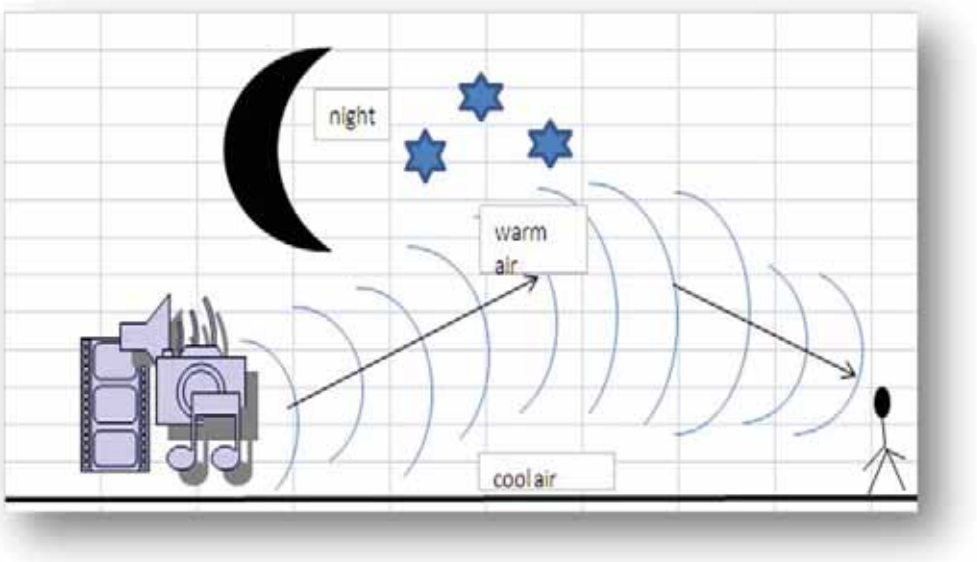


Figure 18: Refraction of sound. Hand drawn by graphic designer at LDTC.

The cool water keeps the air near the water cool, but the early sun has begun to heat the air higher up, creating a "thermal inversion". The fact that the speed of sound is faster in warmer air bends some sound back downward toward you - sound that would not reach your ear under normal circumstances.

As mentioned earlier, the speed of sound in air can be affected by factors such as temperature and humidity. In fact the speed of sound is slower in cooler air. Therefore on a cold night the air near the ground is cold and so the sound wave bends downwards due to refraction, there is now a change in the speed of sound.

This is why you can sometimes hear sounds from a long way away if the night air is cold, the sound that would not reach your ear under normal circumstances. This is illustrated in Figure 18. On a hot day, the air near the ground is hot so the sound waves bend upward from the hot air into the cold air. This is the opposite of a cold night.

Note it!

Key Points to Remember:

The key points to remember in this section on the reflection and refraction of sound are:

- Sound waves can be reflected and refracted.
- An echo is a reflected sound wave.
- Refraction of sound can be shown during a cold night or a hot day because the speed of sound changes due to temperature difference and one would hear sound that would not be heard under normal circumstances.

In the next section we are going to see the behaviour of sound around objects.

Answers to Activities on Reflection and Refraction of Sound

Activity 7

1. $S = 2d/t$

   $= 2 \times 250\ m / 2s$

   $= 250\ m/s$

2. $S = 2d/t$

   Therefore $d = \frac{Sxt}{2}$

   $= \frac{\frac{330m}{s} x 4}{2}$

   $= 660\ m$

3. $S = 2d/t$

   Therefore $d = \frac{Sxt}{2}$

   $= \frac{\frac{330m}{s} x 4}{2}$

   $= 660\ m$

Section 18-6: Diffraction

Introduction

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

Time

There is 1 page on the topic of diffraction. You should spend approximately 30 minutes on this topic.

Diffraction is the bending of a wave around objects or the spreading after passing through a gap as shown by Figures 19(a) and 19(b).

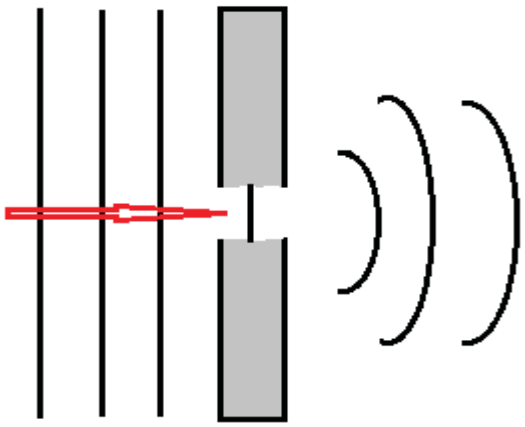


Figure 19(a): Diffraction of waves. Hand drawn by graphic designer at LDTC.

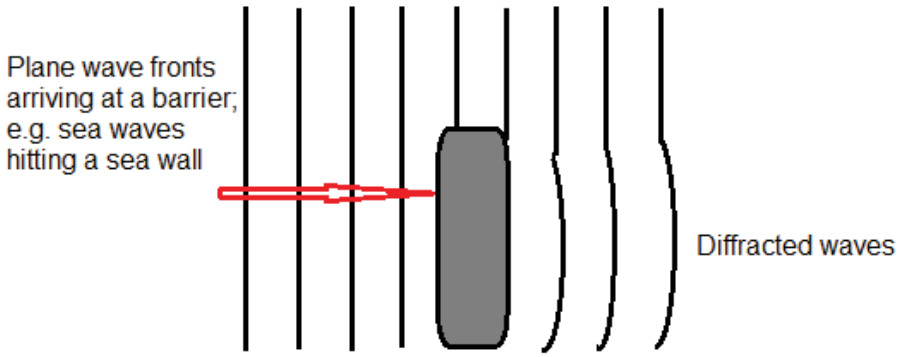


Figure 19 (b): Diffraction of waves. Hand drawn by graphic designer at LDTC.

Sound waves can diffract around objects, which is why one can still hear someone calling even when hiding behind a tree or is around the corner of a building.

Unit Summary

Summary

In this unit you learned that:

- A wave is a spreading of a disturbance from one place to another.
- Waves are described in relation to wave terms such as wavelengths, frequency, amplitude, phase, period, wave front and wave speed.
- The speed of a wave is calculated using the wave equation:

  $\mathbf{v = f \lambda}$ where:

  v is the speed in m/s

  f is the frequency in Hz and

  λ is the wavelength in m

  This wave equation applies to any wave.
- There are two types of waves, transverse and longitudinal waves. Transverse waves travel in a direction perpendicular to the direction of vibration while longitudinal waves travel in a direction parallel to the direction of vibration.
- A ripple tank can be used in a laboratory to generate water waves.
- The ripple tank can be used to show reflection and refraction of waves.
- Sound is produced by vibrations and it requires a material medium to be transmitted.
- Diffraction is the bending of a wave around objects or the spreading after passing through a gap.

You have completed the material for this unit on wave properties. You should now complete a thorough review of the content. Once you are sure that you can successfully write an exam on the concepts, try the assignment. Check your answers with the provided ones and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers light.

Assignment 18

Assignment 18

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:26]

Multiple choice questions (1 mark each)

1) What do waves transfer?

   A. Energy

   B. Force

   C. Molecules

   D. Matter

2) What is the speed of water waves produced in a ripple tank when a vibrator produces 10 waves per second and a wavelength of 2 cm?

   _____
   _____
   _____
   _____
   _____

   A. 0.2 m/s

   B. 0.02 m/s

   C. 2 m/s

   D. 20 m/s

3) Sound waves travel fastest in:

   A. Gases

   B. Solids

   C. Liquids

   D. Liquids and gases

4) Which statement is **not** true about transverse waves:

   A. can travel through a vacuum.

B. travel parallel to the vibrations.

C. comprise crests and troughs.

D. a water wave is an example.

5) Which one of the following is an example of a longitudinal wave?

A. A vibrating guitar

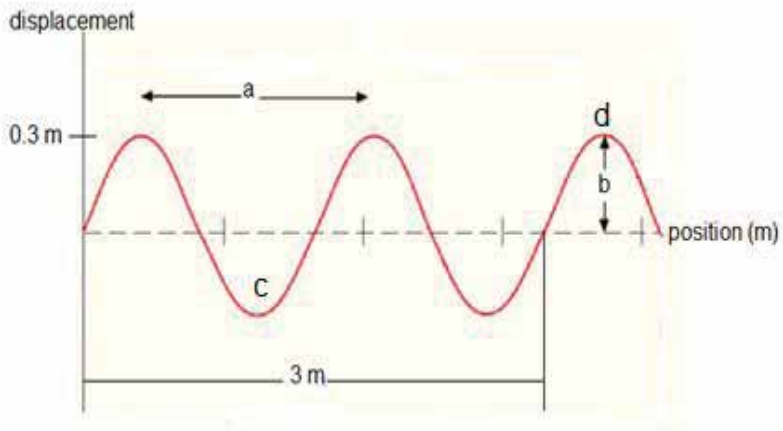
B. Light waves in water

C. Sound waves produced on a string

D. Waves in a ripple tank

Structured questions

1. The figure below show the displacement-position graph of a wave travelling along a length of a rope.



a) What is represented by "a" in the figure? (1)

_____

_____

b) What is represented by "b" in the figure? (1)

_____

_____

c) What is represented by "c" in the figure? (1)

_____

_____

d) What is represented by "d" in the figure? (1)

_____

e) Calculate the wavelength of the wave.(2)

_____
_____
_____
_____

2. a) Distinguish between transverse and longitudinal waves. (2)

_____
_____
_____
_____

b) Give an example of each. (2)

_____
_____
_____

3. An old man standing 0.5 km away from a storm hears a sound thunder 1.5 seconds after he sees a flash of lightning. Calculate the speed of sound in air.(3)

_____
_____
_____
_____
_____
_____

4. Describe, in the space below, with the aid of a labelled diagram how you can show that sound does not travel in a vacuum. (6)

5. Describe the diffraction of waves. (2)

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 18

1) *A*
2) *A*

$v = f\lambda$

$= 10\ s^{-1} \times 0.02\ m$

$= 0.2\ m/s$

3) *B*
4) *B*
5) *A*

Structured questions

1. *a) a is wavelength*

   b) b is amplitude

   c) c is a trough

   d) d is a crest

   e) Wavelength $\lambda = \frac{3\ m}{2}$

   $= 1.5\ m$

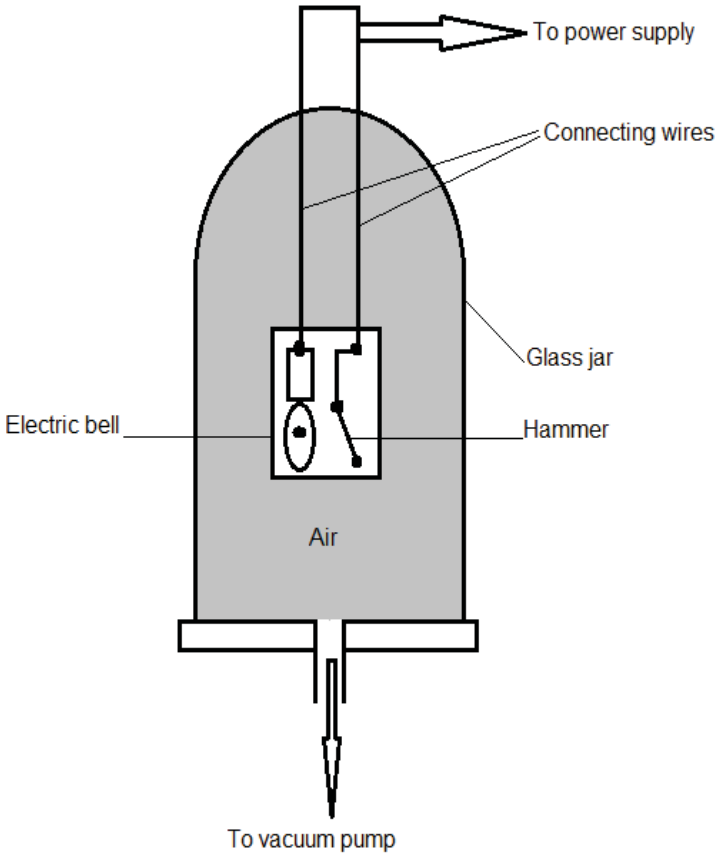
2. *a) Transverse waves are waves in which vibrations are perpendicular to direction of travel of the wave.*

   Longitudinal waves are waves in which vibrations are parallel to the travel of the wave.

   b) Examples of transverse waves can be water waves, waves on a rope and waves on a slinky spring.

   Examples of longitudinal waves are sound waves and waves on a slinky spring.

3. $S = 2d/t$
4. *When the bell under the jar is connected to the battery, as shown in the figure it starts to ring and the sound it produces can be heard, but after the air has been removed from the glass jar by a vacuum pump the sound of the ringing bell can no longer be heard. It can only be seen vibrating, which suggests it is ringing.*



5. ***Diffraction is the bending of a wave around objects or the spreading after passing through a gap.***

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physical science course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 18

Assessment 18

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:20)

1. Explain the following terms. (1 mark each)
   (i) Frequency
   (ii) Amplitude
   (iii) Wavelength
   (iv) Wave-front

2. Draw a labelled sketch to show a transverse waveform with wave length 5 cm and amplitude 3 cm. (4)

3. What is the frequency of the wave in (2) above if the wave moves at a speed of 0.5 m/s? (3)

4. Calculate the speed of a sound wave produced 1020 m away from a cliff if an echo is heard from the cliff after 6 s. (3)

5. Explain the differences between longitudinal and transverse wave motion. In your answer give an example of each. (4)

6. Give two instances in real life where diffraction of sound occurs. (2)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 19 Light

Light

Study Skills

Set study goals before you begin each period of study (number of pages, number of problems, etc.). ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

Look around your household. Do you have a mirror, a camera or even a lens? At shops, have you seen different types of cameras – digital and non-digital, mirrors – large and small, overhead projectors, photocopying machines and even spectacles? All these devices are used by our society to give us images of different objects. In this unit we are going to study how light enables us to be able to see these images.

Time

This unit consists of 40 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. You should focus on those skills while studying this unit.

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Describe* matter and its related physical processes.

Outcomes

Upon completion of this unit you will be able to:

- *Describe* an experiment that illustrates the laws of reflection.
- *Describe* the formation and characteristics of an optical image formed by a plane mirror.
- *Describe* refraction and experiments that show refraction of light.
- *Explain* how a thin converging lens affects a beam of light.
- *Draw* ray diagrams to show the formation of real and virtual images.
- *Describe* the properties of components of the electromagnetic spectrum.

Study Skills

Terminology

Light ray:	The direction of the path taken by light.
Light beam:	A stream of light energy.
Refractive index:	The value of the constant $n = \frac{\sin i}{\sin r}$ for a ray passing from one medium to another is the refractive index of the second medium with respect to the first medium.
Electromagnetic Spectrum:	The range of wavelengths for electromagnetic waves, from the very long to the very short.
Electromagnetic Waves:	Transverse waves with an electric and magnetic effect

Section 19-1: Reflection of Light

Introduction

By the end of this section, you should be able to describe an experiment that illustrates the laws of reflection and describe the formation and characteristics of an optical image formed by a plane mirror.

Time

There are 12 pages on the topic of reflection of light. You should spend approximately 5-6 hours on this topic.

What is Light?

Light is the part of the electromagnetic spectrum that can be detected by the human eye. The electromagnetic spectrum has other parts as we are going to find out later in the unit.

Rays and Beams of Light

What is a ray of light? Light travels in straight lines. **A ray is the direction of the path taken by light.** In diagrams, such as those in Figures 1(a), 1(b), and 1(c), light rays are represented by straight lines with arrows to show their direction of motion.

A beam is a stream of light energy. It is represented by a number of rays that may be parallel, converging or diverging as shown in figures 1(a), 1(b), and 1(c):

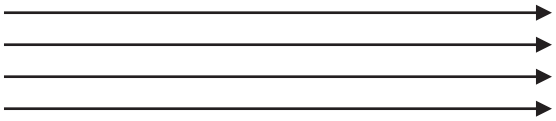

Figure 1(a): Parallel beam. Hand drawn by graphic designer at LDTC.

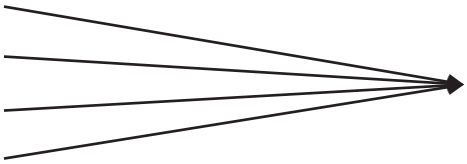

Figure 1(b): Convergent beam. Hand drawn by graphic designer at LDTC.

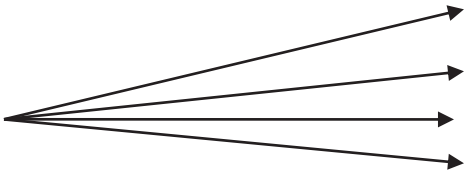

Figure 1(c): Divergent beam. Hand drawn by graphic designer at LDTC.

Sources of Light

The human eye can only see an object if light from it enters the eye. There are two types of objects:

- **Luminous sources** – objects that make their own light. Examples are the sun, lamps, fires and candles.
- **Non-luminous objects** – objects that reflect light from luminous sources. Examples are books, mirrors, tables, you and the moon.

Laws of Reflection

As mentioned above, light can be reflected from non-luminous objects. This reflection among other things allows us to see images in mirrors. Figure 2 below illustrates the reflection of light in a plane mirror.

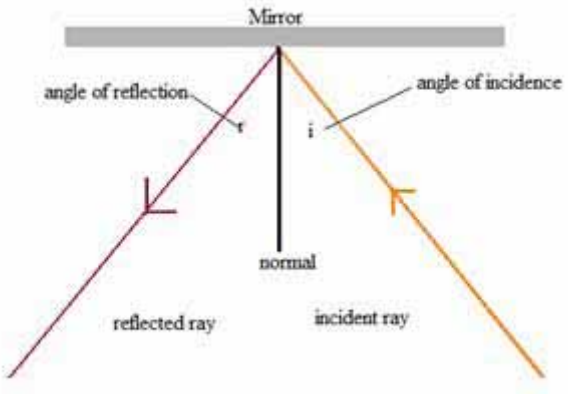

Figure 2: Laws of reflection. Hand drawn by graphic designer at LDTC.

NOTE:

Note it!

You should take note of the following from the above diagram:

- The incident ray is the ray of light approaching the mirror.
- The reflected ray is the ray of light leaving the mirror.
- The normal is a line that can be drawn perpendicular (at right angles) to the surface of the mirror at the point of incidence where the ray strikes the mirror. The normal line divides the angle between the incident ray and the reflected ray into two equal angles.
- The angle of incidence is the angle between the incident ray and the normal.
- The angle of reflection is the angle between the reflected ray and the normal.

First law of reflection:

The incident ray, the reflected ray and the normal drawn at the point of incidence all lie in the same plane (this means that they can all be drawn on a flat sheet of paper).

Second Law of Reflection

The angle of incidence is equal to the angle of reflection (i = r).

Note it!

NOTE:

A common mistake is to measure the angle of incidence or reflection from the surface of the mirror. You must remember to measure from the normal.

Activity 1

Activity

Answer the following questions to check for your understanding.

1. Refer to Figure 3(a) below.
   (a) Which one of the angles (A, B, C, or D) is the angle of incidence?

   _____

   (b) Which one of the angles is the angle of reflection?

   _____

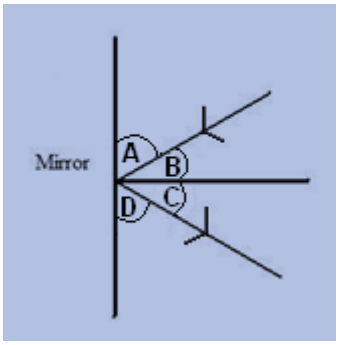

Figure 3(a): Reflection. Hand drawn by graphic designer at LDTC.

2. A ray of light strikes a mirror at an angle to the surface of 30°. Refer to Figure 3(b) below.

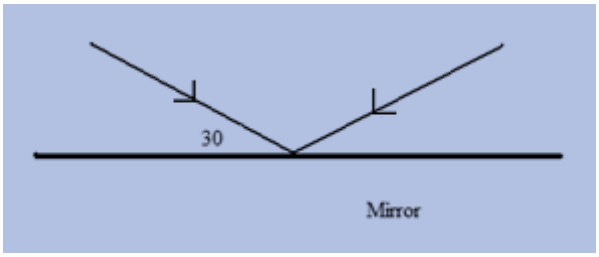

Figure 3(b): Reflection. Hand drawn by graphic designer at LDTC.

(a) Calculate the angle of incidence.

_____
_____
_____
_____

(b) What is the angle of reflection?

_____
_____
_____
_____

Compare your answers to those provided at the end of the section. Be sure that you understand how to do each calculation before continuing.

Activity

Activity 2

Experiment 1: An experiment that illustrates the laws of reflection.

Apparatus/materials:

- Plane mirror
- Pins
- Drawing board/card box/chart
- A white sheet of paper
- A protractor

Procedure: a) Place the white sheet of paper on a drawing board, as shown in Figure 4a. For those of you at home, use the sheet of a card box as a drawing board.

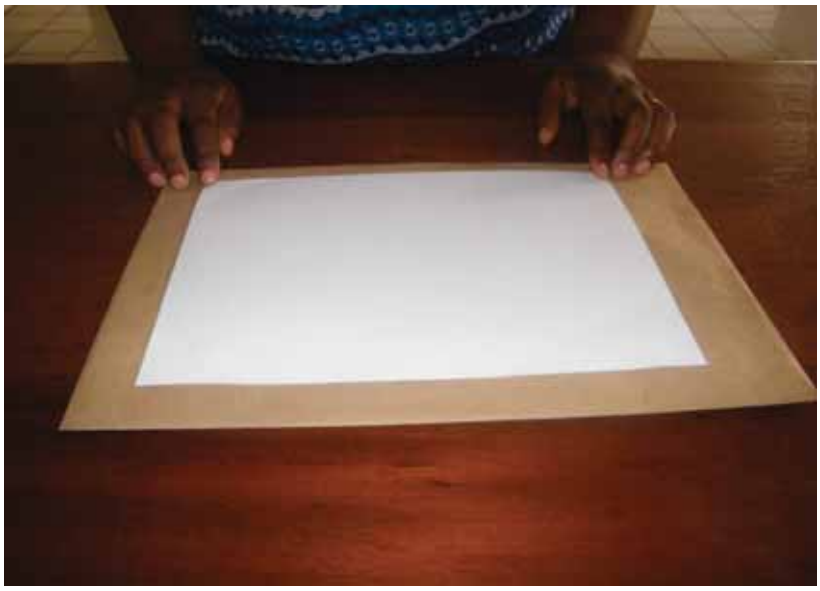

Figure 4(a): Sheet on drawing board. Photo taken by LDTC.

b) Draw a line in middle of the white paper as shown in Figure 4b.

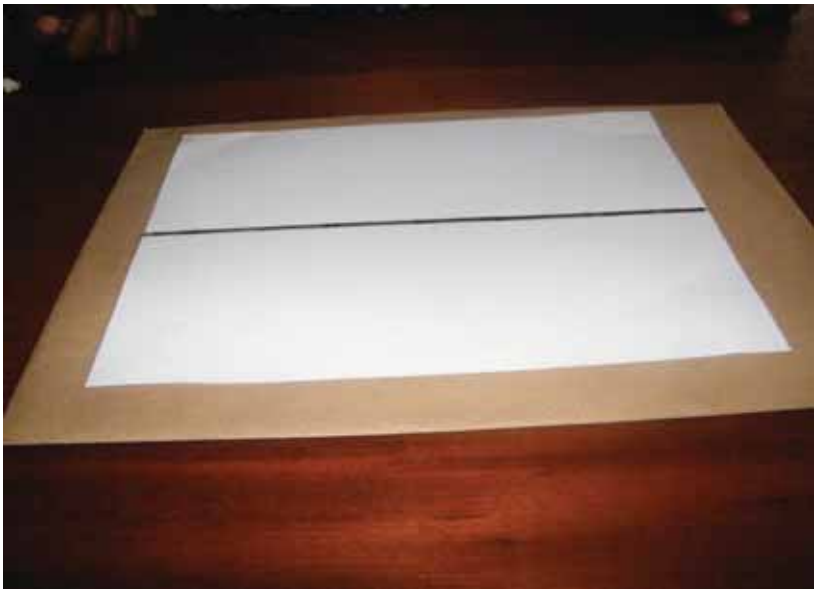

Figure 4(b): Horizontal line. Photo taken by LDTC.

c) Set up the mirror vertically on the drawn line, as shown in Figure 4(c).

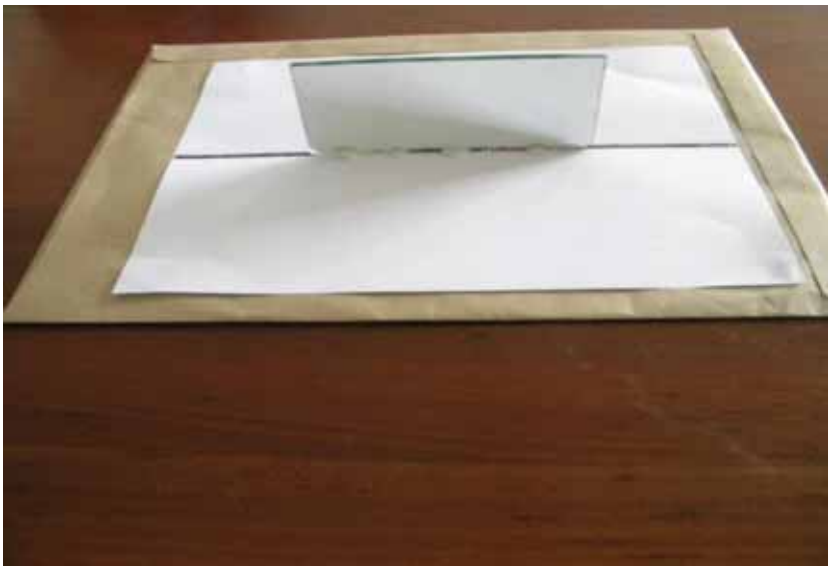

Figure 4(c): Mirror on along the horizontal line. Photo taken by LDTC.

d) Take a pin to serve as an object and stick it into the paper about 7 or 8 cm from the mirror, as shown in figures 4(d) and 4(e).

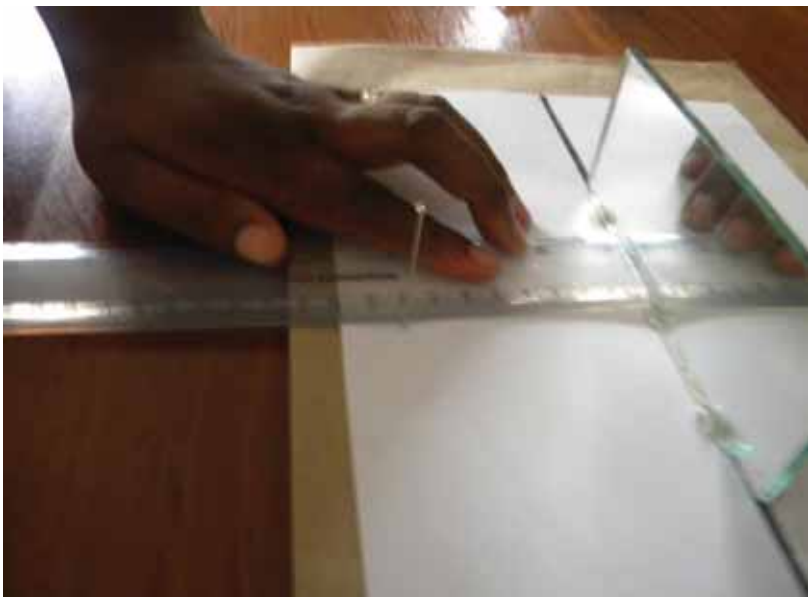

Figure 4(d): Placing the pin. Photo taken by LDTC.

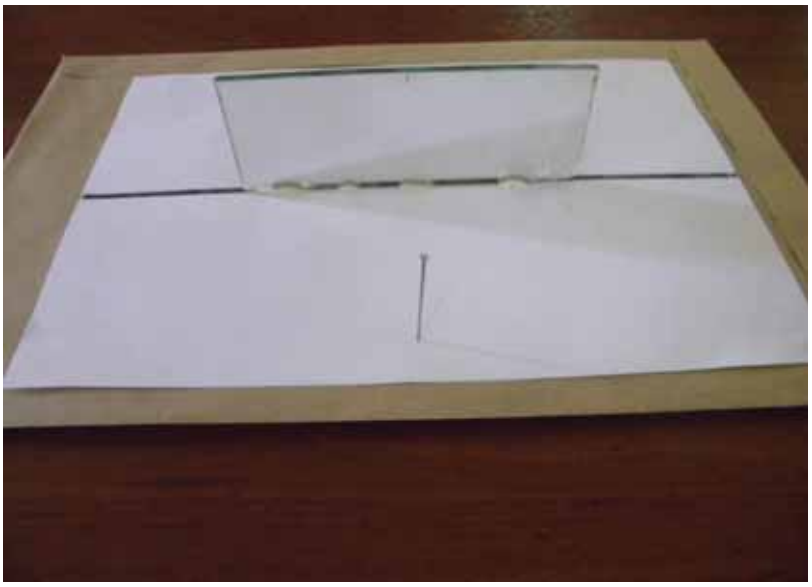

Figure 4(e): Placing the pin, front view. Photo taken by LDTC.

e) Choose two or more different locations to look into the mirror and see the image.

f) At each of these locations, take two pins and stick them into the paper so as they are in a straight line with the image seen in the mirror, as shown in figure 4(f). The pins represent the incidence ray when joined by a straight line.

Figure 4(f): Placement of other pins. Photo taken by LDTC.

g) Remove the mirror.

h) Join the locations of the pins by straight lines, as shown in figure 4(g).

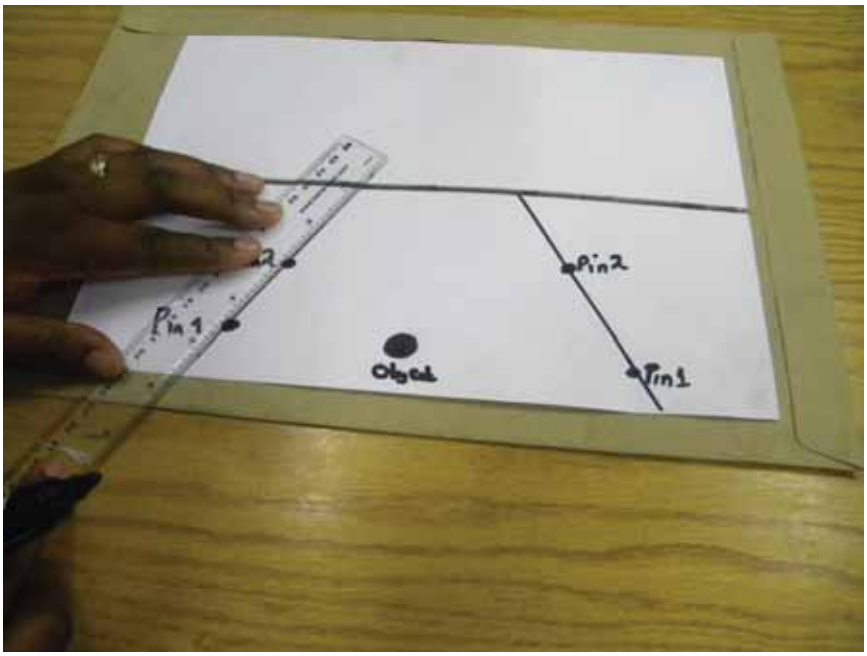

Figure 4(g): Joining the locations of the pins. Photo taken by LDTC.

i) Extend each line backwards behind the mirror, beyond the middle line you drew in 4(b) on the white paper, as shown in Figure 4(h).

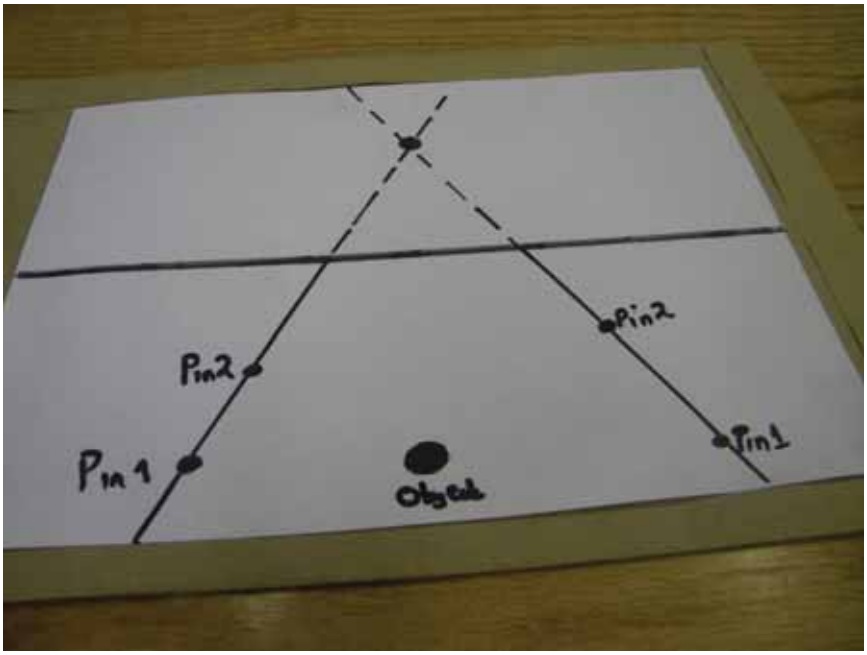

Figure 4(h): Extending the lines behind the mirror. Photo taken by LDTC.

What happens?

_____

_____

Compare your answer to the following:

The lines intersect at one point.

j) Construct a normal to each line, as shown in figure 4(i).

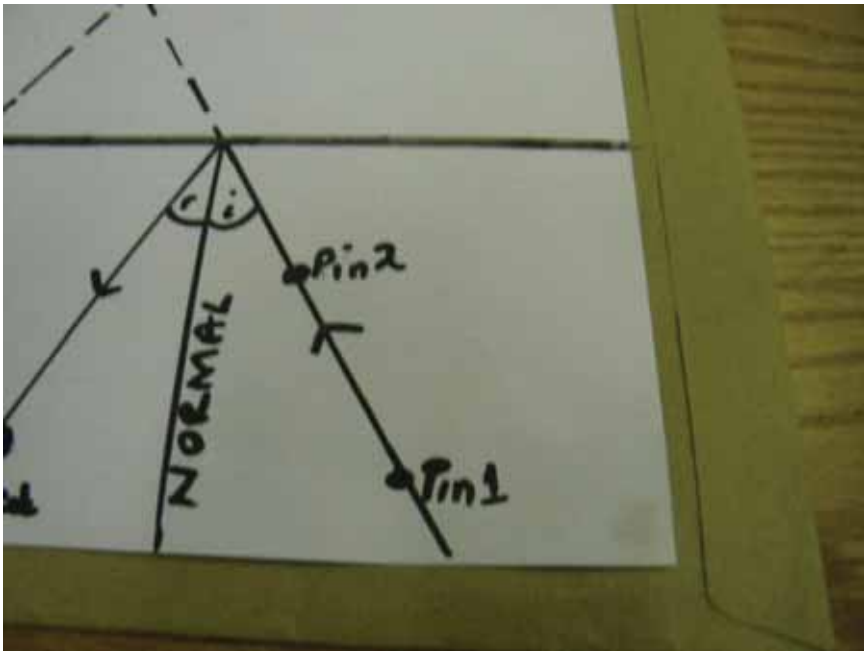

Figure 4(i): Constructing a normal to each line. Photo taken by LDTC.

For each case, measure the angles of incidence and the angles of reflection using a protractor. What do you find?

_____
_____
_____

Compare your answer to the following:

The angles of incidence should be equal to the angles of reflection for each case.

Observation:

When the line of sight from two lines drawn from different points is extended backwards, they will intersect at the same point, as shown by figure 4(j) below. This point is the image point of the object. Remember, the line approaching the mirror is the incident ray with its angle of incidence to the normal. The line leaving the mirror is the reflected ray with its angle of reflection to the normal.

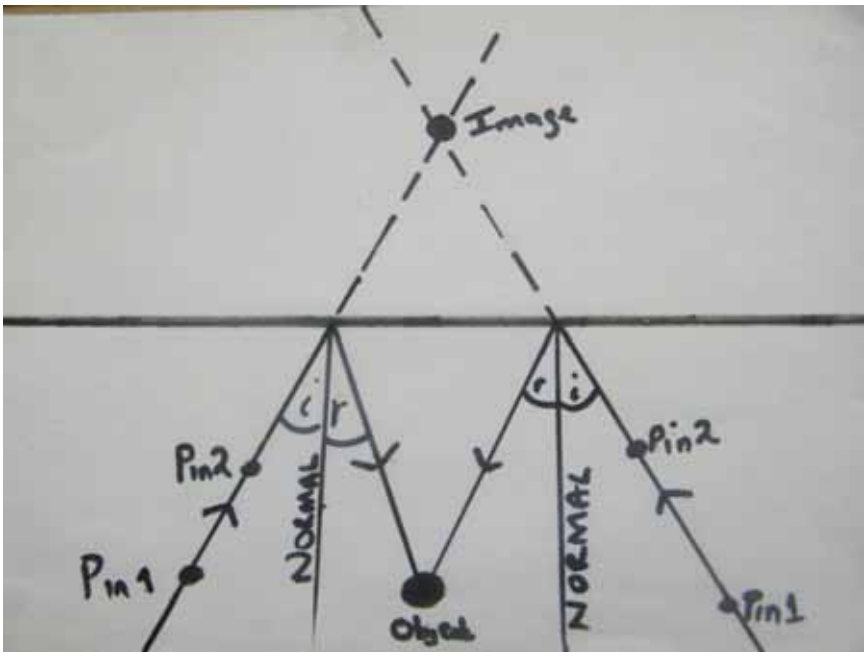

Figure 4(j): Reflection of light. Photo taken by LDTC.

Conclusion:

You should find that for all cases $i = r$ (the second law of reflection).

You may have noticed that you have carried out the experiment on a flat sheet of paper (the first law of reflection).

Formation of an Image by a Plane Mirror

So light is reflected as it enters a plane mirror. What kind of image is then formed by the mirror?

Figure 5 illustrates the formation of an image in a plane mirror.

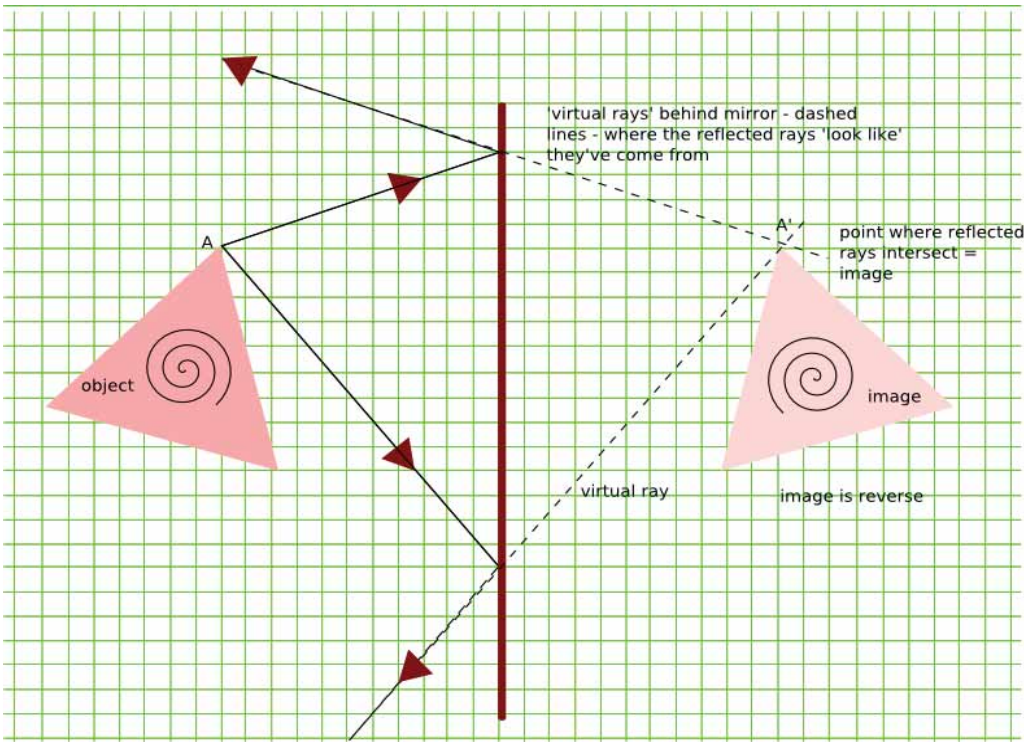

Figure 5: Formation of an image by a plane mirror accessed from Wikipedia Creative Commons, 2010.

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This is how the image will be formed in a plane mirror:

- Two rays coming from the object at point A which hit the mirror at an angle can be drawn. Since the angle of reflection = the angle of incidence, the two rays will be reflected as shown in Figure 5.
- The rays are then extended behind the mirror. Where the two appear to meet is where the corresponding part of the image is found. If you were to repeat the process for all of the corners of the triangle above, you would get the image shown.

Tip

TIP:

For those who can access internet, this site http://www.physicsclassroom.com/mmedia/optics/ifpm.cfm shows a very good animation of how an image is formed in a plane mirror.

Characteristics of an Image Formed in a Plane Mirror

1) The image is the same size as the object.
2) The image is laterally inverted. This means that, although the image is the right way up compared with the object, left is swapped with right: it is left-to-right inversion. In Figure 5, the spiral on it curls in the opposite direction.

3) The image is upright.
4) The image is virtual. This means that if you look behind the mirror, you won't find the image there.
5) The image is the same distance from the mirror as the object.

Activity

Activity 3

Answer the following questions to check your understanding.

1. State the laws of reflection.

_____
_____
_____
_____
_____

2. List 5 characteristics of the image formed by a plane mirror.

_____
_____
_____
_____
_____

3. While looking at your image in a large plane mirror, if you touch your right ear it appears as if your image has touched the left ear. Why?

_____
_____
_____

Compare your answers to the ones that you will find at the end of the section. It is important that you understand the principles before you move on.

Note it!

The key points to remember in this section on reflection of light are:

- The incident ray, the reflected ray and the normal drawn at the point of incidence all lie in the same plane.
- The angle of incidence is equal to the angle of reflection (i = r).

The next section will deal with how light is refracted.

Answers on Reflection of Light

Activity 1

1. (a) Angle of incidence i = B

(b) Angle of reflection r = C

2. *(a) i = 90° - 30°(remember the normal makes a right angle with the mirror)*
   = 60°
   (b) r = 60°(i = r)

Activity 3

1. ***The laws of reflection are:***
   a) The incident ray, the reflected ray and the normal drawn at the point of incidence all lie in the same plane.
   b) The angle of incidence is equal to the angle of reflection (i=r).

2. ***The image formed by a plane mirror is:***
   a) upright
   b) virtual
   c) of the same size as the object
   d) the image is at the same distance behind the mirror as the object is in front of it
   e) laterally inverted

3. ***It is due to lateral inversion that it appears like the image has touched the left ear.***

Section 19-2: Refraction of Light

Introduction

By the end of this section, you should be able to describe refraction and experiments that show refraction of light.

Time

There are 9 pages on the topic of refraction of light. You should spend approximately 4-5 hours on this topic.

Refraction

In the previous section, we saw how light is reflected when it is incident on a surface. Now let us see what happens when a ray of light travelling in one medium enters another medium of different optical density. Optical density is the degree to which a refractive medium slows transmitted rays of light.

Activity

Activity 4

Apparatus/materials:

- Glass
- water
- pencil/spoon

Procedure: Fill the glass 2/3 full of water.

Take a pencil/spoon and let it lean against the side of the glass. Look through the glass at the pencil. What do you notice?

_____
_____
_____
_____

Figure 6: Refraction in a glass of water accessed from Wikimedia Creative Commons, 2010.

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Now place the pencil/spoon in the glass and hold it straight up and down (***not*** at an angle). What do you notice?

_____
_____
_____
_____

Observations: The pencil appears straight when viewed through the side of the glass when it is held straight up.

The pencil appears bent when it is leaned against the side of the glass.

Can you think of why this might be occurring? How are these situations the same? How are they different?

Reflection

Conclusion: This is the effect of refraction or bending of light.

Refraction is the bending, or change in direction of light as it passes from one transparent material into another. The transparent material is called an **optical medium**. Light bends because it changes speed from one medium into another.

Let us consider an everyday scenario to understand why light changes speed. A car travelling on gravel road will change its speed as it enters a tarred road. In the same way, it will change its speed if it enters a rocky road.

In the same way, light will change its speed as it enters different media. A medium is said to be **optically dense** if it slows down the speed of light such that a ray of light will bend towards the normal. Light will bend away from the normal when it enters an optically less dense medium. Figure 7 shows the difference between refraction of light in water and in glass. Note that in glass, the angle of refraction is less than the angle of refraction in water.

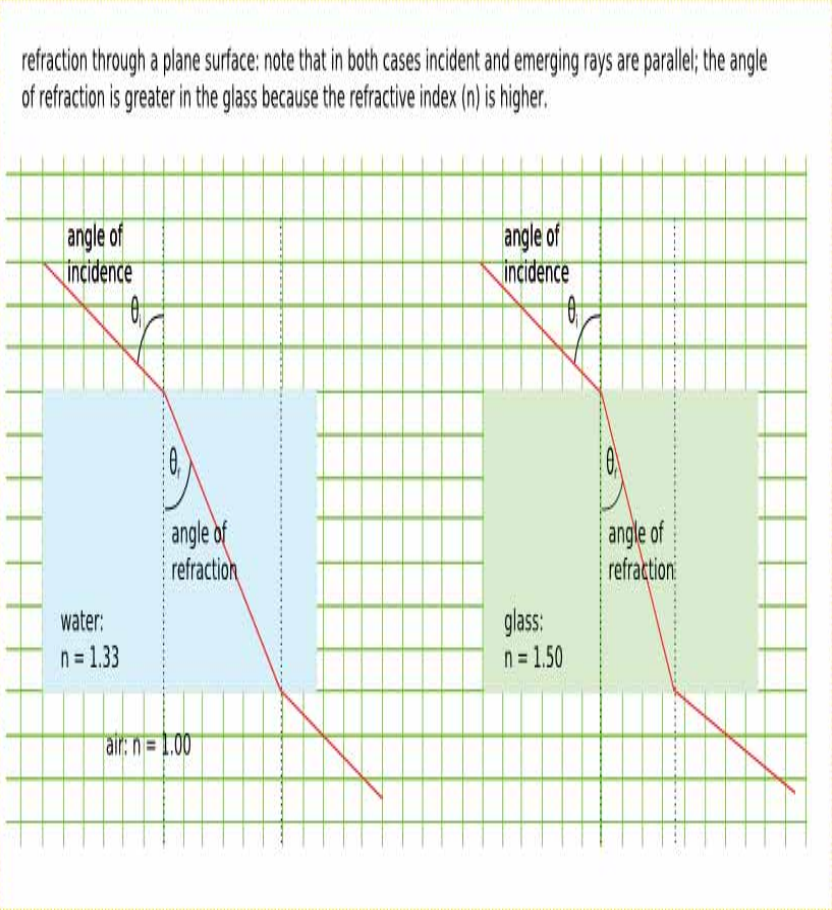

Figure 7: Refraction of light in water and in glass accessed from Wikipedia Creative Commons, 2011.

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If we have two different media, we have a ratio:

$$\frac{\sin\theta 1}{\sin\theta 2} = \frac{\sin i}{\sin r} = \text{(a constant) where}$$

$\theta 1$ = i = angle of incidence

$\theta 2$ = r = angle of refraction

If light is passing from a vacuum into a given medium the constant **n is the refractive index** for that medium with respect to a vacuum.

This is called **Snell's Law** where $n = \frac{\sin i}{\sin r}$

For light travelling from air into the medium, the ratio is very close to that passing from a vacuum. Hence for our purpose and most practical purposes, the value n is found with air in the place of a vacuum. As show in Figure 7, the refractive index of air is different from that of water and glass.

The table below gives the refractive indices of some substances.

Table 1: The refractive indices of different substances

Medium	Refractive index n
Air	1.00
Vacuum	1.00
Water	1.33
Ethanol	1.36
Glycerine	1.47
Crown glass	1.52
Quartz	1.54
Flint glass	1.61
Diamond	2.42

NOTE:

Please note that the refractive index of glass varies from 1.48 to 1.96 depending on the composition of the glass. Our example above is crown glass and flint glass.

Note it!

Example 1

1. Suppose a light ray is incident upon a piece of glass of refractive index 1.52 at an angle of 60°(Figure 8), what is the angle of refraction?

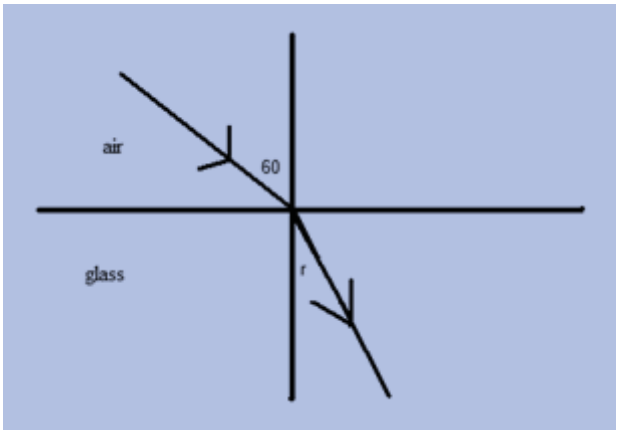


Figure 8(a): Refraction 1. Hand drawn by graphic designer at LDTC.

SOLUTION:

n = 1.52

$n = \frac{\sin i}{\sin r}$ *It then follows that:*

$$\sin r = \frac{\sin i}{n}$$

$$\sin r = \frac{\sin 60^\circ}{1.52}$$

$$\sin r = \frac{0.866}{1.52}$$

$$\sin r = 0.57$$

$$r = 34.8^\circ$$

Example 2

2. A ray of light passes from air into water of refractive index 1.33 as shown by Figure 8b below. Calculate the angle of incidence.

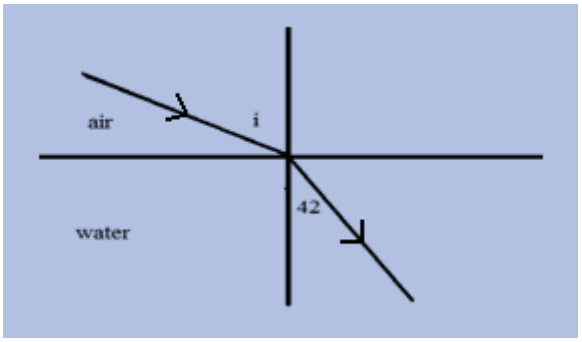


Figure 8(b): Refraction 2. Hand drawn by graphic designer at LDTC.

SOLUTION

$n = 1.33$

$n = \frac{\sin i}{\sin r}$ *It then follows that:*

$\sin i = n \sin r$

$= 1.33 \times \sin 42^\circ$

$= 1.33 \times 0.669$

$= 0.89$

Therefore $i = 62.8^\circ$

Example 3:

If light is incident upon a piece of glass at an angle of 45° and the angle of refraction is 27.7°, what is the refractive index of the glass?

SOLUTION:

$$n = \frac{\sin i}{\sin r}$$

$$= \frac{\sin 45^\circ}{\sin 27.7^\circ}$$

$$= 1.52$$

Activity

Activity 5

Attempt the following questions before moving on.

1. A ray of light in glass makes an angle of incidence of 50° with a glass-water boundary. What angle of refraction does the light make in the water? Refractive index of water n = 1.33

_____
_____
_____
_____
_____

2. A ray of light is incident on a rectangular glass block of refractive index 1.5. If the ray strikes the surface AB at an angle of incidence *i* of 45° as shown in Figure 9(a), calculate:

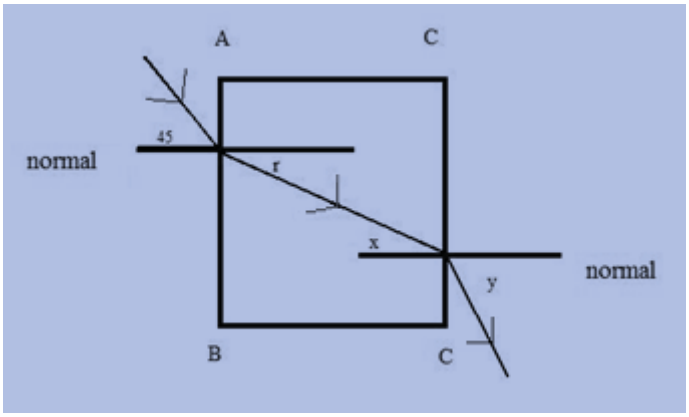


Figure 9(a): Refraction in glass block 1. Hand drawn by graphic designer at LDTC.

a) The angle of refraction *r* at the air to glass boundary AB.

_____
_____
_____

b) The angle of incidence *x* in the glass block.

_____
_____
_____

c) The angle of refraction *y* at the glass to air boundary CD.

_____
_____
_____
_____

3. For all questions that follow, refer to Figure 9(b) below. A ray of light is incident on a rectangular glass block of refractive index 1.5. If the ray strikes the surface EG such that is refracted at an angle of 30°:

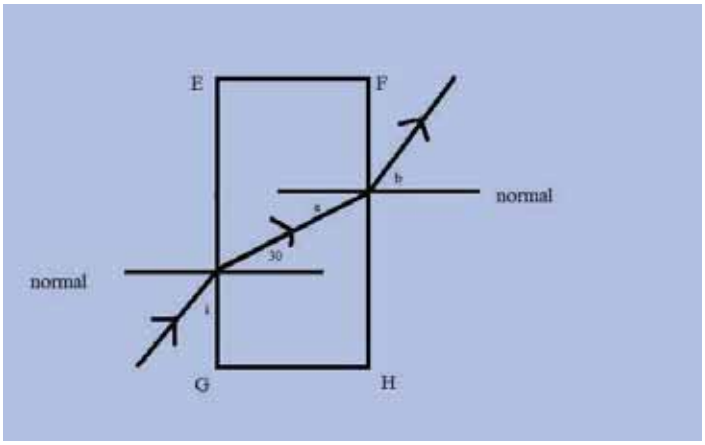


Figure 9(b): Refraction in glass block 2. Hand drawn by graphic designer at LDTC.

a) Calculate the angle of incidence

_____
_____
_____

b) What is the value of angle

_____
_____
_____

c) Calculate angle b.

_____
_____
_____

Compare your answers to the ones provided at the end of the section. If you can comfortably and reliably do these calculations, proceed on. If not, review the above examples and then try the activity again.

Reflection

If you have access to the internet, please go to:

http://phet.colorado.edu/en/simulation/bending-light

and run the simulation. What happens to the angle of incidence when you change the optical medium from air, to water to glass? Use the protractor to measure the angles of incidence.

Note it!

The key points to remember in this section on refraction of light are:

- Refraction is the bending, or change in direction of light as it passes from one transparent material into another.
- $n = \frac{\sin i}{\sin r}$ where i is the angle of incidence.
  r is the angle of refraction.
  n is the refractive index.

Answers to Activities on Refraction of Light

Activity 5

1. Given n = 1.33

$$n = \frac{\sin i}{\sin r}$$

$$\sin r = \frac{\sin i}{n}$$

$$\sin r = \frac{\sin 50^\circ}{1.33}$$

$$\sin r = \frac{0.766}{1.33}$$

$$\sin r = 0.576$$

$$r = 35.2^\circ$$

2. Given refractive index of glass n = 1.5

a) $n = \frac{\sin i}{\sin r}$

$$\sin r = \frac{\sin i}{n}$$

$$\sin r = \frac{\sin 45^\circ}{1.5}$$

$$\sin r = \frac{0.707}{1.5}$$

$$\sin r = 0.471$$

$$r = 28.1^\circ$$

b) $x = r$ *(alternate angles)*

$$x = 28.1^\circ$$

c) $y = i$ *(the incident ray is now out of the glass block into the air again, therefore the two angles are the same.)*

3 a). $n = \frac{\sin i}{\sin r}$

sini	**=**	***nsinr***
sini	**=**	***1.5 x sin30°***
sini	**=**	***1.5 x 0.5***
sin i	**=**	***0.75***
i	**=**	***48.6°***
b) a	**=**	***30°***
c) b	**=**	***48.6°***

Section 19-3: Thin Converging Lens

Introduction

By the end of this section, you should be able to explain how a thin converging lens affects a beam of light and draw ray diagrams to show the formation of real and virtual images.

Time

There are 12 pages on the topic of the thin converging lens. You should spend approximately 5-6 hours on this topic.

Refraction

Lenses are usually made of glass and plastic. Their usage varies and includes cameras, spectacles, projectors and telescopes. The human also uses lenses in the eye to form images. We have two main types of lenses, the convex lens and the concave lens.

The convex lens is also called a converging lens because it converges (brings together) light rays. It is thicker in the middle than at the edges. The concave lens is a diverging lens as it diverges (spreads out) light rays, it is thinner in the middle than at the edges. For this course we will only consider a thin converging lens. Figure 10 shows a simple convex lens.

Figure 10: A convex lens. Hand drawn by graphic designer at LDTC.

Figure 11 shows the action of a thin converging lens on a beam of light.

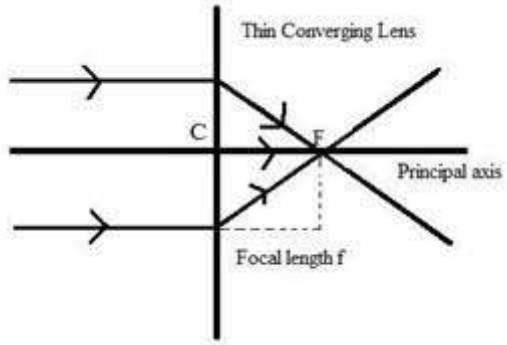


Figure 11: Features of a converging lens. Hand drawn by graphic designer at LDTC.

The vertical line represents a convex lens.

a) **The optical centre C** - the point midway between the lens surfaces on its principal axis.

b) **The principal axis** - a line that passes through the optical centre of the lens.

c) **The focal point (or principal focus) F** - a point where all rays converge to.

d) **The focal length f** - the distance between F and C.

Some rays will pass through the optical centre undeviated, whereas all other rays close to and parallel to the principal axis will converge to the focal point F. Light can pass through a lens from both the right and the left: a thin converging lens has two focal points. The focal length is the same on each side.

Ray Diagrams

When drawing ray diagrams we can choose two of the three most important rays to allow us to find the location of an image formed by a lens. The three rays are explained as follows:

1) An incident ray is parallel to the principal axis that passes through the focal point F on the other side of the lens.
2) An incident ray passes through the optical centre. It is undeviated.
3) An incident ray passes through the focal point F before the lens that becomes parallel to the principal axis.

Where the rays meet, an image will be formed. Figure 12 shows the three rays and the image formed. You should know that images formed by a thin converging lens vary in size and location as will be later summarized in Table 2.

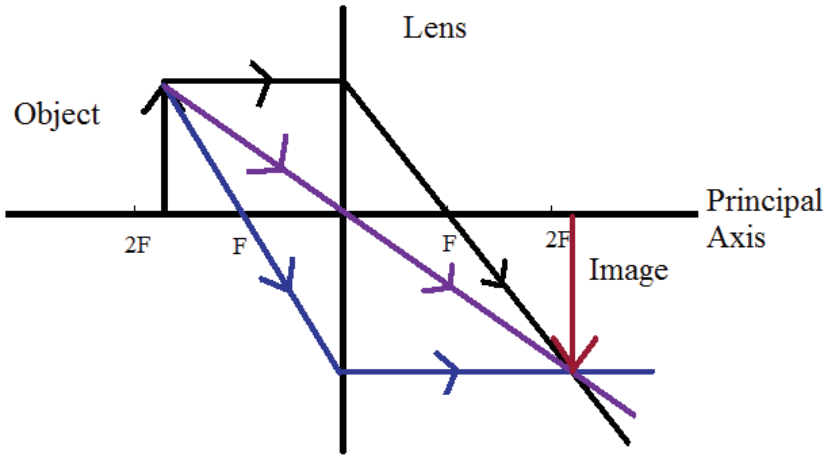


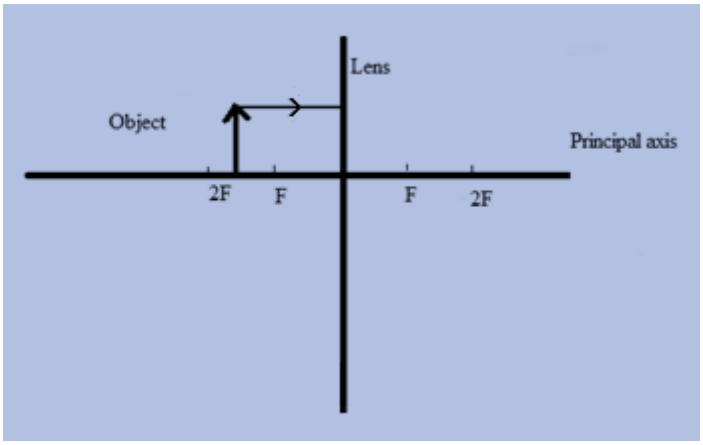
Figure 12: Image location through ray diagrams. Hand drawn by graphic designer at LDTC.

Activity 6

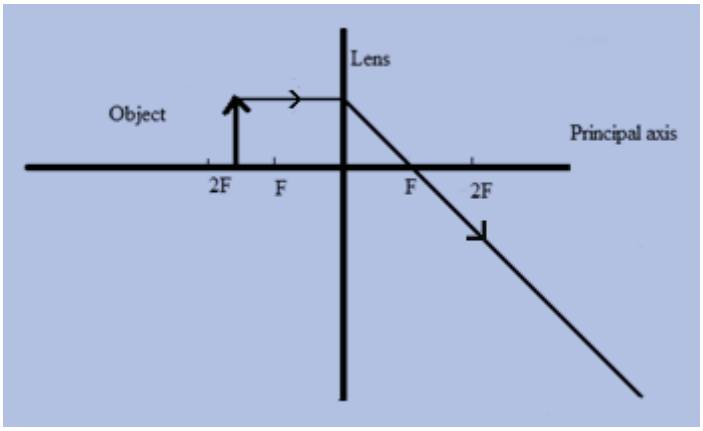
Activity

Let us now do our own step-by-step drawing of the rays. Please do your own drawing in the spaces provided under each illustrated drawing. Be sure to do your own drawing as you will need the skill in your final examinations.

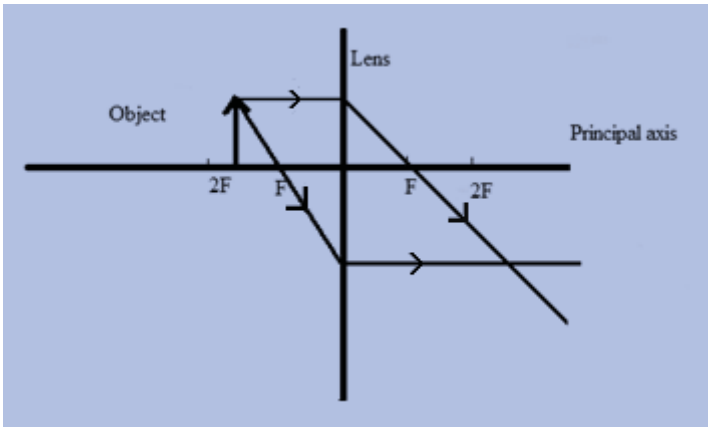
a) First, let's draw a ray parallel to the principal axis as shown below.



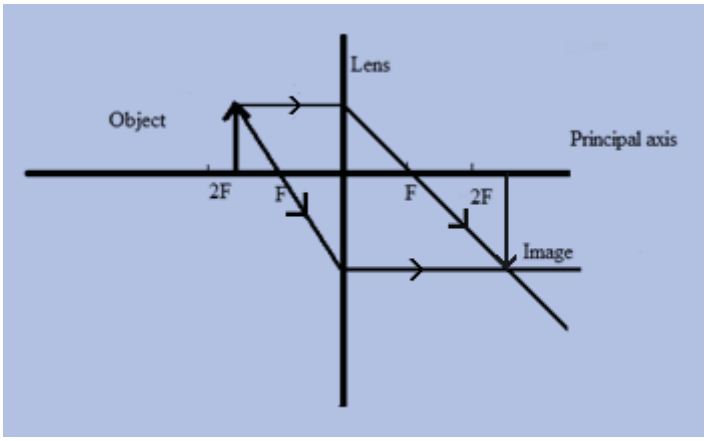
b) Secondly, let's draw the refracted ray so that it passes through the focal point F.



c) Thirdly, let's draw a ray passing through the focal point F before the lens that becomes parallel to the principal axis.



d) Lastly, where the rays meet is the location of the image.



Images Formed by a Thin Converging Lens

The following types of images will be formed following their different objects. Table 2 gives a summary of the different formations.

Table 2: Images formed by a thin converging lens

Object distance	Type of image	Image distance	Use
Infinity	Real, inverted and diminished/smaller	Image located at F	Lens of a telescope
Object beyond 2F	Real, inverted and diminished/smaller	Image located between F and 2F	Camera and eye
Object at 2F	Real, inverted and same size as object	Image located at 2F	Photocopier making equally sized copy
Object between 2F and F	Real, inverted and magnified/larger	Image located beyond 2F	Projector and photograph enlarger
Object at F	Virtual, upright and magnified/larger	Image is at infinity, same side as the object	To produce a parallel beam of light as in a spotlight
Object between F and the lens	Virtual, upright and magnified/larger	Image on the same side as the object	Magnifying glass

Figure 13 show the image location of an object placed between F and the lens and two rays used to locate it. The rays had to be extended

behind the object until they met to locate the image, shown by the dotted lines.

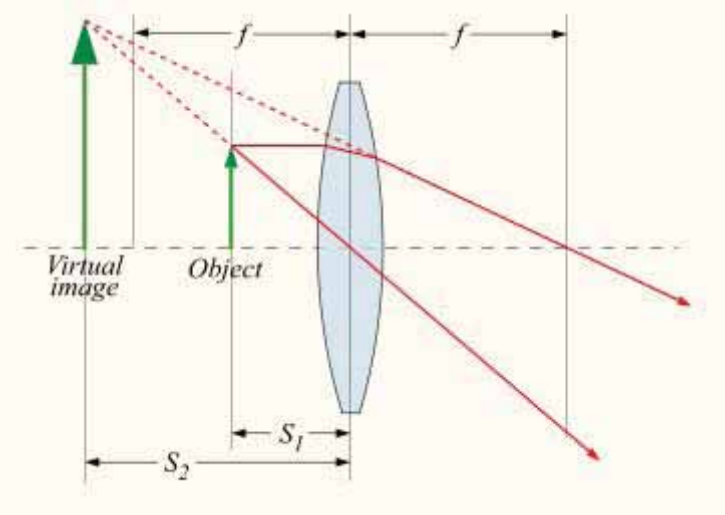


Figure 13: The image of an object between F and the lens accessed from Wikimedia Creative Commons, 2010.

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Notice that the image is virtual, upright, magnified and on the same side as the object. This brings us to the element of a converging lens acting as a magnifying glass, as shown in Figure 14.

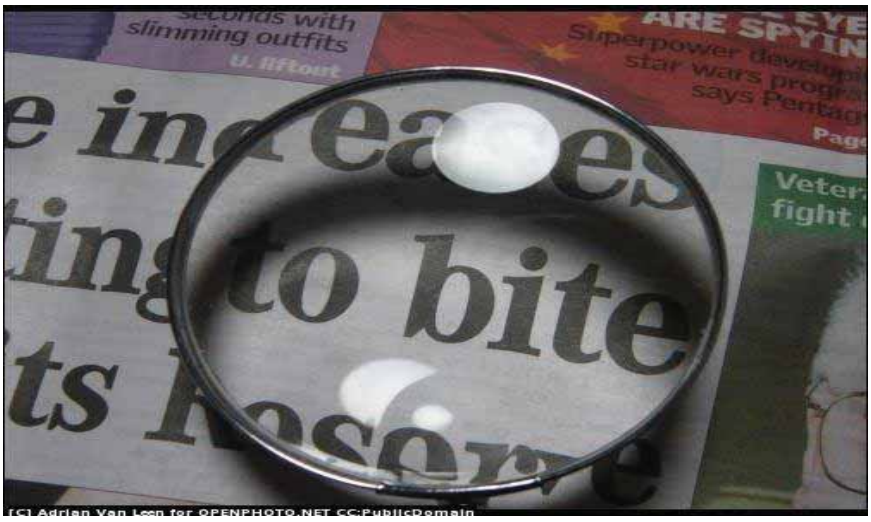

Figure 14: The action of a magnifying glass accessed from Creative Commons (OpenNet), 2010.

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Linear Magnification

If you look at Table 2, you will see that the size of the image produced by a lens differs with the position of the object. **Magnification** is the process whereby an object is enlarged only in

appearance, not in physical size. A number can be used to calculate this enlargement or **magnification**. When this number is less than one it refers to a reduction in size.

Linear magnification ***m*** is the ratio of the height of the image to the height of the object. It is also the ratio of the distance of the image from the lens to the distance of the object from the lens.

$$\boldsymbol{m} = \frac{height\ of\ image}{height\ of\ object}$$

$$\boldsymbol{m} = \frac{distance\ of\ image\ from\ lens}{distance\ of\ object\ from\ lens}$$

$$\boldsymbol{m} = \frac{v}{u}$$

It has also been proven that

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

where f = the focal length of the lens

Example 1:

An object 5 cm high is placed 15 cm from a thin converging lens. A real image is found to be 45 cm from the lens. Calculate the height of the real image.

SOLUTION:

$$m = \frac{height\ of\ image}{height\ of\ object} = \frac{v}{u}$$

Then, height of image $= \frac{v}{u}$ x height of object

$= \frac{45\ cm}{15\ cm}$ x 5 cm

$=$ 15 cm

Example 2:

1. An object with height of 3.5 cm is placed 25 cm from a converging lens of focal length 15 cm. (a) What is the position of the image? (b) What is the magnification of the lens? (c) What is the size of the image?

SOLUTION:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{15} = \frac{1}{25} + \frac{1}{v} \quad therefore \quad \frac{1}{v} = \frac{1}{15} - \frac{1}{25}$$

$$\frac{1}{v} = \frac{5}{75} - \frac{3}{75}$$

$$\frac{1}{v} = \frac{2}{75}$$

Therefore $$\frac{v}{1} = \frac{75}{2}$$

$$v = 37.5\ cm$$

$$\boldsymbol{m} = \frac{v}{u} \quad \textit{therefore} \quad \boldsymbol{m} = \frac{37.5cm}{75cm}$$

$$= 0.5$$

$$\boldsymbol{m} = \frac{height\ of\ image}{height\ of\ object} \quad \textit{therefore}$$

$$\textit{Height of image} = \boldsymbol{m}\ x\ \textit{height of object}$$

$$= 0.5\ x\ 3.5\ cm$$

$$= 1.75\ cm$$

$$= 175\ mm$$

Activity

Activity 7

Carry out this activity to help you understand the above concepts.

1. In the space provided below, draw a labelled ray diagram to show how a thin converging lens can be used to produce a virtual, magnified object.

2. a) An object with height of 1.6 cm is placed 50 cm from a converging lens of focal length 10 cm. What is the position of the image?

_____
_____
_____
_____
_____

b) What is the magnification of the lens?

_____
_____

c) What is the size of the image?

_____
_____

3. A thin converging lens has a focal point of 2 cm. An object is placed beyond 2F of the lens. Draw a labelled ray diagram to show the image formed.

Compare your drawings and calculations to those found at the end of the section. Spend the time needed to understand any differences you have.

The key points to remember in this section on the thin converging lens are:

Note it!

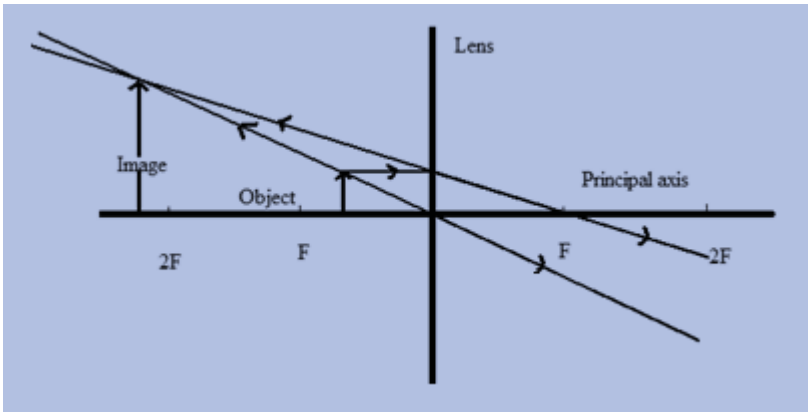
When drawing ray diagrams, we can choose two of the three most important rays to allow us to find the location of an image formed by a lens. The three rays are explained as follows:

- An incident ray is parallel to the principal axis that passes through the focal point F on the other side of the lens.
- An incident ray passes through the optical centre. It is undeviated.
- An incident ray passes through the focal point F before the lens that becomes parallel to the principal axis.

Answers to Activities on Thin Converging Lenses

Activity 7

1.



2. a) $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{10} = \frac{1}{50} + \frac{1}{v}$ ***therefore*** $\frac{1}{v} = \frac{1}{10} - \frac{1}{50}$

$\frac{1}{v} = \frac{5}{50} - \frac{1}{50}$

$\frac{1}{v} = \frac{4}{50}$

Therefore $\frac{v}{1} = \frac{50}{4}$

$v = 12.5\ cm$

b) $m = \frac{v}{u}$ ***therefore*** $m = \frac{12.5cm}{50cm}$

$= 0.25$

$$c)\ m = \frac{height\ of\ image}{height\ of\ object}\ therefore$$

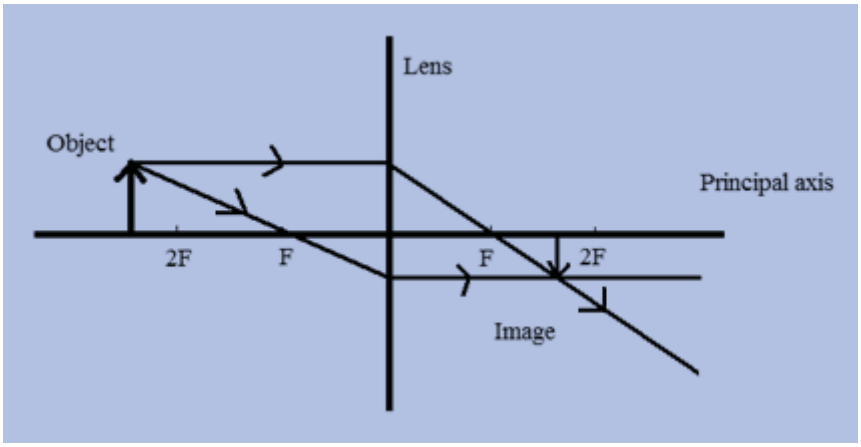
$$height\ of\ image = m\ x\ height\ of\ object$$

$$= 0.25\ x\ 1.6\ cm$$

$$= 0.4\ cm$$

$$= 4\ mm$$

3.



Section 19-4: Electromagnetic Spectrum

Introduction

By the end of this section, you should be able to describe the properties of components of the electromagnetic spectrum.

Time

There are 6 pages on the topic of the electromagnetic spectrum. You should spend approximately 3-4 hours on this topic.

Electromagnetic Waves

Do you listen to the radio or watch television? Do you ever wonder how you can hear and see someone who is so far away from you? Do you have a microwave oven at home? If you do, have you ever wondered how it cooks food, yet there is no fire? The radio, TV and

microwave oven are just a few of appliances that make use of electromagnetic waves.

What are these electromagnetic waves? Let us start this way: electricity can be static (refer to Unit 21), as can magnetism (refer to Unit 20). If the two move together, they make waves-electromagnetic waves. Electromagnetic waves are formed when an electric field couples with a magnetic field. These waves are also called electromagnetic radiation because they radiate from the electrically charged particles. They travel through empty space as well as through air and other substances.

Electromagnetic waves have amplitude, wavelength, velocity and frequency. The range of wavelengths for electromagnetic waves, from the very long to the very short, is called the **electromagnetic spectrum**. Figure 15 shows the electromagnetic spectrum, with waves of different wavelengths. The long waves are at one end and the short waves are at the other end.

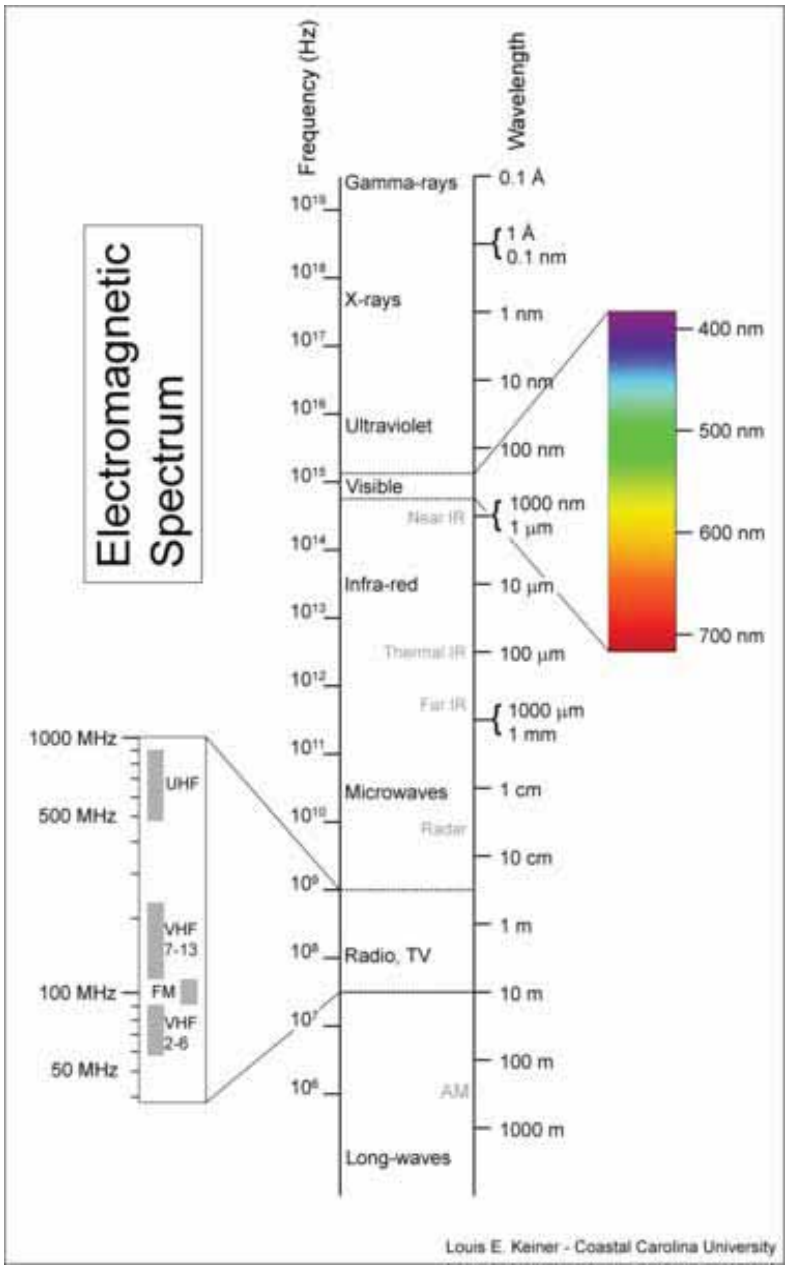


Figure 15: The electromagnetic spectrum accessed from Wikipedia Creative Commons, 2011.

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The main features of electromagnetic waves are:

1. They transfer energy from one place to another.
2. They are transverse waves.
3. They can travel through a vacuum.
4. They travel through a vacuum at the speed of light:
   300 000 000m/s (3 x 10^8 m/s).
5. They all show wave properties like reflection and refraction.

6. They obey the wave equation $v = f\lambda$ where v = velocity/speed

f = frequency

λ = wavelength

Recall that you learned about this equation in Unit 18.

The symbol λ that looks like an upside-down "y" is lambda, a Greek letter "l". It is the physics code for wavelength.

When we look at our Figure 15 showing the electromagnetic spectrum, we can see that most types of waves have a wide range of wavelengths. Light seems to have a narrow wavelength range. In physics we use the word **monochromatic** to refer to an electromagnetic wave/radiation of a single wavelength or of a very small range of wavelengths. Monochromatic light is light of a single wavelength. In practice though, it can refer to light of a narrow wavelength range.

The table below show common uses and known dangers of the electromagnetic waves.

Table 3: Electromagnetic waves and their common uses and dangers

Electromagnetic Wave	**Common Use**	**Dangers**
Radio Wave	Broadcasting Radio and TV Programmes	None
Microwave	Cooking and heating food	Living cells can absorb microwaves and may be damaged or killed by the heating effect of the waves.
Infrared	Heat provision through lamps and heaters. Ovens, grills and toasters to cook food. The transmission of information through the air to operate TV's, VCR's, DVD's etc by remote control.	Extreme infra-red radiation can damage or kill living cells such as skin cells.
Visible Light	Light provision through the sun, fluorescent lamps, etc.	None
Ultraviolet	Causes the human skin to tan.	Exposure to, especially for prolonged lengths of time,

	Start chemical reactions.	ultraviolet light from the sun can damage and kill living cells and cause skin cancer.
X rays	In hospitals as X ray photographs showing images of bones against a black background to find if bones are broken or damaged.	High intensity X rays can kill living cells. Low intensity X rays can damage living cells and cause skin cancer with repeated exposure.
Gamma	Used to sterilise hospital equipment such as surgical instruments. Used in radiotherapy to treat cancer.	High intensity gamma radiation can kill living cells. Low intensity gamma radiation can damage living cells and cause skin cancer with repeated exposure.

Activity

Activity 8

1. What are electromagnetic waves?

   _____
   _____
   _____
   _____

2. Fill in the table below that indicate electromagnetic waves and devices that give off the wave.

Electromagnetic Wave	**Device**
Radio wave	
	Microwave oven
Infrared	
	Globe

3. Can electromagnetic waves travel through a vacuum? Explain.

   _____
   _____
   _____

Compare your answers and table to the one provided at the end of the section. Note any differences and clarify any misunderstandings that you may have.

Note it!

The key points to remember in this subunit on electromagnetic waves are:

- Electromagnetic waves are transverse waves.
- They travel at the speed of light.

You have finished the content of this unit. Proceed to the unit summary following.

Answers to Activities on Electromagnetic Spectrum

Answers to Activity 8

1. ***Electromagnetic waves are transverse waves with an electric and a magnetic effect.***

2.

Electromagnetic Wave	***Device***
Radio wave	***Television, Radio***
Microwave	*Microwave oven*
Infrared	***Heater, Remote control, Toaster, Grill, Oven, Stove***
Light	*Globe*

3. ***Electromagnetic waves can travel through a vacuum. We feel the sun's heat and light through the electromagnetic waves that have travelled through empty space (a vacuum) to reach the Earth.***

Unit Summary

Summary

In this unit you learned:

- If a ray of light is reflected in a plane mirror, the angle of incidence *i,* equals the angle of reflection *r. (i = r).* This is the first law of reflection.
- The second law of reflection states that the incident ray, the reflected ray and the normal drawn at the point of incidence all lie in the same plane (this means that they can all be drawn on a flat sheet of paper).
- The image of an object produced by a plane mirror has the following features:
  - It is virtual.
  - It is upright.
  - It is the same size as the object.
  - It is the same distance away from the mirror as the object.
  - It is laterally inverted.
- Refraction is the bending of light as it moves from one medium into another medium. This happens because of the different speeds that light travel in the two media.
- Light will not be refracted if it enters a boundary at right angles.
- The value of the constant $n = \frac{\sin i}{\sin r}$ for a ray passing from one medium to another is the refractive index of the second medium with respect to the first medium.
- Convex lenses are called converging lens because they converge (bring together) rays of light to a point.
- The focal length of a converging lens is the distance between the focal point and the optical centre of the lens.
- If an object is placed between the focal point F and the optical centre C of a convex lens, the image produced will be virtual, upright and magnified. The lens will acting as a magnifying glass.
- If an object is placed beyond the focal point F of a convex lens, then the image produced will be real and inverted.
- The electromagnetic spectrum is made up of radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X rays and gamma rays listed in order of decreasing wavelength.
- All the electromagnetic waves travel at the speed of light in a vacuum.

You have completed the material for this unit on light. Your understanding will be improved if you now spend time reviewing the content. Once you are sure that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your final step for this unit is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers magnetism.

Assignment 19

Assignment 19

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes. Please show all of your work.

[Total Marks:23]

Multiple Choice Questions (1 mark each)

1. Which of the following statements is wrong about the size of an image formed in a plane mirror?

A. The height of the image depends on the object distance.
B. The image can be taller than the mirror.
C. The height of the image depends on the height of the object.
D. The width of the image is the same as the width of the object.

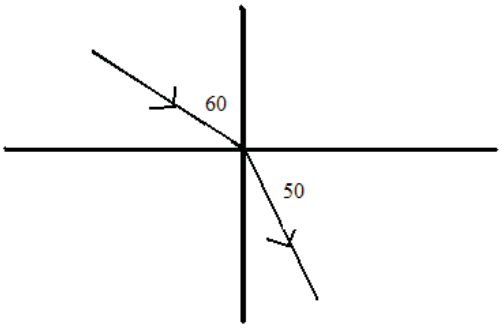
2. All electromagnetic waves have the same:

A. Speed in a vacuum
B. Speed in a given medium
C. Frequency in a vacuum
D. Frequency in a given medium

3. When light is travelling at an angle as it moves from water into air, it is refracted away from the normal as it enters the air. If you were to look into the water and see a fish, the fish will be:

A. Above the refracted image.
B. Below the refracted image.
C. Beside the refracted image.
D. In the same place as the refracted image.

4. The diagram shown below shows a ray of light incident on the surface of a liquid and its subsequent path.



The refractive index of the liquid is given by:

A. $\frac{\sin 30°}{\sin 50°}$

B. $\frac{\sin 60°}{\sin 50°}$

C. $\frac{\sin 40°}{\sin 60°}$

D. $\frac{\sin 60°}{\sin 40°}$

Structured Questions:

1. State the laws of reflection.
(2)

_____
_____
_____
_____

For any two given media in which a light ray is travelling, what is the normal?
(1)

_____
_____
_____

2. The electromagnetic spectrum has a variety of electromagnetic waves. Fill the names of the missing groups of electromagnetic waves.

Radio waves		Infra-red	Visible Light		X rays	

(3)

3. A converging lens of focal length 20 mm magnifies an object 15 mm high so that it is projected onto a screen where it is 30 mm high. The object is located at the distance of 30 mm away from the lens.

(a) What is the magnification?

_____
_____
_____
_____ (2)

(b) Where is the location of the image?

_____
_____
_____
_____ (2)

(c) What is the nature of the image?

_____
_____
_____
_____ (3)

(d) Draw a labelled ray diagram of the above in the space provided below. (7)

Reflection Question

4. Anne is in a boat trying to spear a fish she can see in the water. Should she aim above, below, or directly above the fish to spear it?

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 19

Multiple Choice Questions *(1 Mark each)*

1. A

2. D

3. A

4. B

Structured Questions

1. The laws of reflection:

First law of reflection:

The incident ray, the reflected ray and the normal drawn at the point of incidence all lie in the same plane (this means that they can all be drawn on a flat sheet of paper). (1)

Second Law of Reflection

The angle of incidence is equal to the angle of reflection (i = r). (1)

2. The normal is a line drawn at right angles to the boundary between the two media.(1)

3. (3)

Radio waves	Micro waves	Infra red	Visible Light	Ultra violet	X rays	Gamma rays

a) $m = \frac{height\ of\ image}{height\ of\ object}$

$= \frac{30\ mm}{15\ mm}$

$= 2(2)$

b) $m = \frac{height\ of\ image}{height\ of\ object} = \frac{v}{u}$

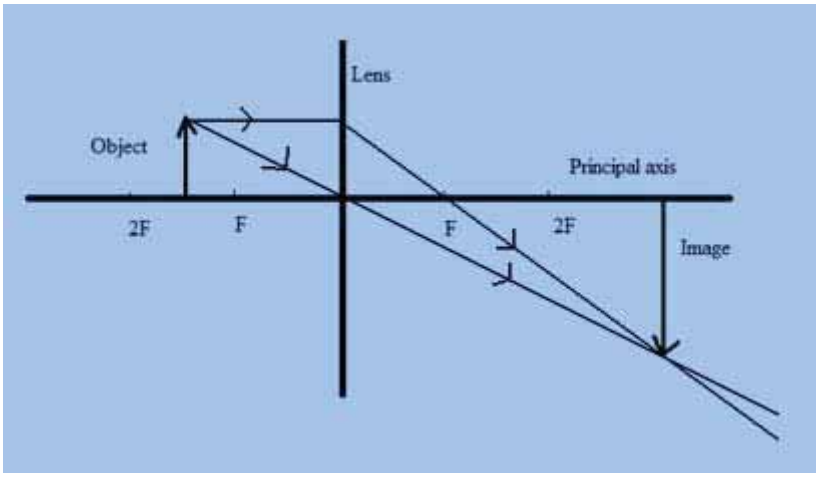
Therefore $v = mu$

$= 2 \times 30\ mm$

$= 60\ mm\ (2)$

c) The image is real, inverted and magnified. (3)

d) (7)



4. Due to refraction, a submerged object appears to be nearer to the surface than it actually is. For this reason, Anne should aim below the fish to make a direct hit.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physical science course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 19

Assessment 19

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:25)

Multiple Choice Questions (1 mark each)

1. When viewed at right angles, a fish under water is:

   A) Above the image.
   B) Below the image.
   C) Beside the image.
   D) In the same place as the image.

2. The bending of light as it passes from one medium into another is called ……..

   A) Deviation
   B) Dispersion
   C) Reflection
   D) Refraction

3. A convex lens

   A) Disperses light
   B) Diverges light
   C) Converges light
   D) Radiates light

4. Which of the following is not a property of electromagnetic waves?

   A) They are transverse waves.
   B) They are longitudinal waves.
   C) They can travel in a vacuum.
   D) They transfer energy from one place to another.

Structured Questions

5. With the aid of a labeled diagram, describe an experiment to illustrate the laws of reflection. (6)

6. Give three characteristics of an image formed by a plane mirror. (3)

7. An object is placed 5 cm away from a convex lens of focal length 10 cm.

A) Calculate the position of the image. (2)

B) Calculate the magnification of the image. (2)

8. Draw a labeled ray diagram for an object of height 20 mm placed 30 mm away from a thin converging lens of focal length 10 mm.
(7)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 20

Magnetism

Study Skills

It is very important that you perform the self-assessment activities. Try to do those activities without referring to the answers until you have completed as much as you can. This will help tell you what you need to study more. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In Unit 12, you learned about forces. Remember that a force is defined as a push or a pull. There is a force that is exerted by magnets on other magnets when they repel (push) or attract (pull) each other.

Have you ever asked yourself how a telephone works or how refrigerator doors seal tightly? They use magnetism. In this unit we are going to unfold how magnetism is important in our lives.

Time

This unit consists of 28 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. You should focus on those skills while studying this unit.

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Solve* problems which involve physical forces, such as energy, light, magnetism and electricity.

Study Skills

Unit Outcomes:

When reading the following learning outcomes, think about them as a guide to what you should focus on while studying this unit.

Upon completion of this unit you will be able to:

- *Describe* the differences between magnetic, non-magnetic and magnetised materials.
- *Explain* how substances can be magnetised and demagnetised.
- *Explain* how magnetic field lines are plotted.

- *Differentiate* between the magnetic properties of iron and steel.
- *Describe* applications of magnetic materials and magnetic effect of a current.

Terminology

Demagnetise:	Destroying the magnetism of a magnet.
Hard-magnetic material:	The magnetic material which is difficult to magnetise but keeps its magnetism for a long time.
Induced magnetism:	The magnetism an object has only when it is attracted to a permanent magnet.
Magnetise:	To make a material magnetic.
Magnetic field:	The area around the magnet where the attraction or repulsion force is felt.
Non-magnetic materials:	Materials which are not attracted by a magnet.
Soft-magnetic material:	The magnetic material which is magnetised easily but loses its magnetism fast.

Section 20-1: Laws of Magnetism

Introduction

In section 20-1, we are going to investigate the laws of magnetism. The following three activities will review the basic concepts regarding magnets and magnetic materials.

By the end of section 20-1, you should be able to

- *State* the laws of magnetism.
- *Differentiate* between magnetic and non-magnetic materials.

Time

Section 20-1 has 4 pages. You should spend approximately 1 hour on this topic.

Activity

Activity 1

In junior science, you learned about magnets. Answer the next two questions to see if you recall the basic ideas.

i) What does a magnet do when brought near an iron nail?

_____

_____

ii) What do we call the two ends of a magnet?

_____

_____

Compare your answers with those at the end of section 20-1.

When a magnet is brought near an iron nail it pulls the nail towards it. We say that the magnet **attracts** the nail.

The two ends of a magnet are called **poles.** They are called the **North Pole** and the **South Pole**.

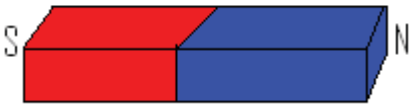


Figure 1: Bar Magnet (Hand drawn), 2011.

Activity 2

Activity

In this activity we are going to investigate how different materials behave when they are brought next to a magnet.

Collect the materials listed in the table below. Bring each of them close to a magnet and observe what happens in each case.

Complete the table below by stating what happens when each material is brought next to a magnet.

Nail	
Stone	
Money clips	
Safety pin	
Stick	
Plastic	
Rubber	

Compare your answers to those given at the end of section 20-1.

Magnetic Materials

These are materials which are attracted by a magnet. Some of them are iron, cobalt, nickel and many alloys based on these metals. Two such alloys are **steel,** which is an alloy of iron and carbon, and **alnico** which is an alloy of aluminium, nickel and cobalt. You learned about alloys in Unit 4 of chemistry.

Safety pins and money clips are made of steel and they are attracted by a magnet.

Non-Magnetic Materials

These are materials which are not attracted by the magnet. From the table you should have found that objects like: plastic, wood and rubber are not attracted by a magnet and so they are non-magnetic materials.

You should note that not all metals are magnetic materials.

Some people believe that all metals are magnetic materials because all materials which are magnetic are metals.

Other non-magnetic materials are copper, pure aluminium and water.

Activity

Activity 3

In this activity we are going to learn the laws of magnetism. If you do not have access to bar magnets, but have access to the internet, please go to: http://phet.colorado.edu/en/simulation/electric-hockey. Use the + and – 'pucks' as S and N poles respectively.

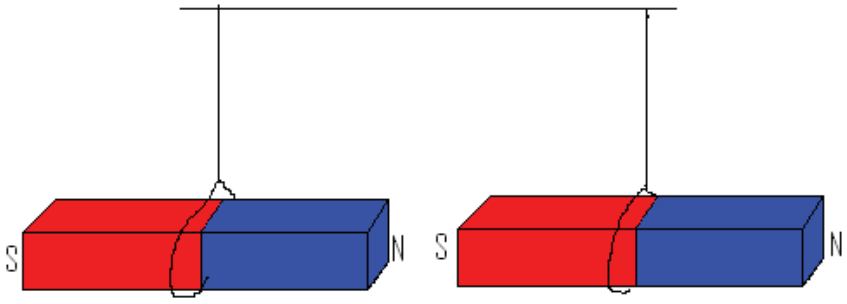
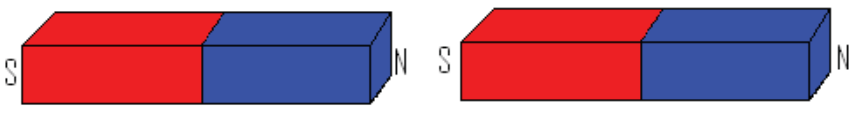


Figure 2: Suspended bar magnets (Hand drawn), 2011.

Take two bar magnets and predict what happens when you:

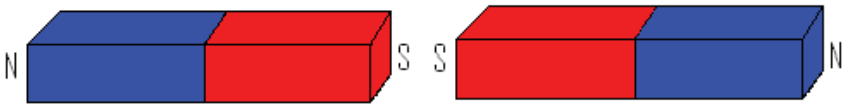
i) Bring the North pole of one magnet next to the South pole of the other magnet. After you have made your prediction, try it!



_____

_____

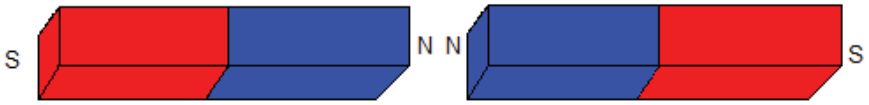
ii) Bring the South pole of one magnet next to the South pole of the other magnet. After you have made your prediction, try it!



_____

_____

iii) Bring the North pole of one magnet next to the North pole of the other magnet. After you have made your prediction, try it!



_____

_____

Compare your answers with those at the end of section 20-1. If you were not able to do the activity, use the answers provided to help you imagine what would have happened.

In summary, what happens when?

Like poles are brought next to each other:

_____

_____

Unlike poles are brought next to each other:

_____

_____

The summary gives us the **laws of magnetism**.

The law states that;

1**. Like poles repel**

2. **Unlike poles attract**

Keep these laws in mind as you proceed to the next section on induced magnetism.

Answers to Activities on Laws of Magnetism

Activity 1

i) The magnet pulls the nail onto itself.

ii) The ends of a magnet are called poles.

Activity 2

Nail	***Is attracted by the magnet.***
Stone	***Nothing happens.***
Money clips	***Are attracted by the magnet.***
Safety pin	***Are attracted by the magnet.***
Stick plastic	***Nothing happens.***
Plastic	***Nothing happens.***
Rubber	***Nothing happens.***

Activity 3

i) ***The poles pull each towards other (we say that the poles attract one another).***

ii) ***Two south poles push each other away when they are brought next to each other (we say that they repel each other).***

iii) ***Two North poles repel each other.***

iv) ***Like poles repel.***

v) ***Unlike poles attract.***

Section 20-2: Induced Magnetism

Introduction

By the end of section 20-2, you should be able to:

- *Explain* induced magnetism.
- *Describe* the methods of magnetisation and demagnetisation.

Time

Section 20-2 has 9 pages. You should spend approximately 2 hours on this topic.

Pay particular attention to this section as it is a foundation for the unit covering electromagnetic effects.

Activity

Activity 4

Move a magnet next to a pile of unmagnetic steel nails or money clips and observe what happens. If you do not have a magnet, Figure 3 shows what happens.

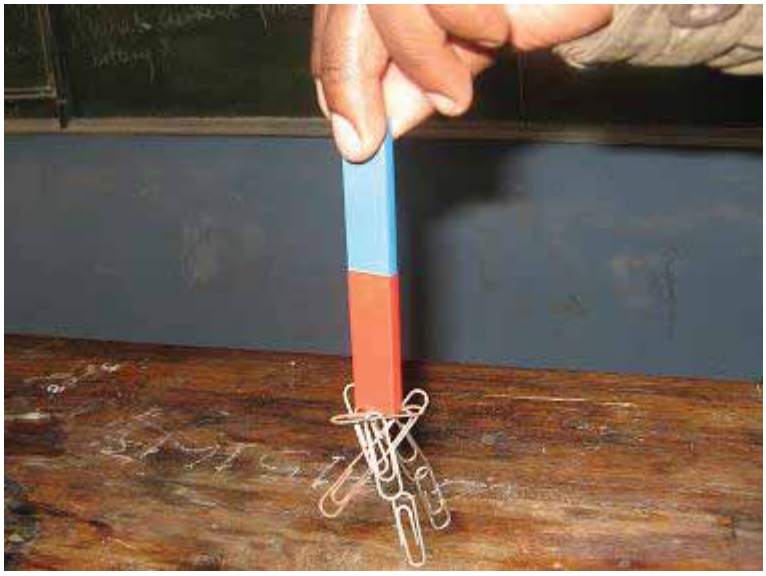


Figure 3: *A bar magnet attracting money clips.*

The money clips that are in contact with the magnet have become magnets; we say that they have **induced magnetism.** They attract other magnetic materials while in contact with the magnet, which in this case are other money clips in this case.

Methods of Magnetisation

As we have seen, unmagnetic materials can be magnetised. Magnets are made of magnetic materials.

1. The stroking method

Activity

Activity 5

You will need a steel rod or nail and a permanent bar magnet. If you do not have the magnet, then study figures 4(a) to (e) to see how to magnetise a magnetic material.

Do the following;

i) Single-stroke method

Put the rod on the table. Stroke the rod in the same direction ten times with the magnet as shown in Figures 4(a) through 4(e). Note that step d is simply moving the magnet high above the rod before stroking it again.

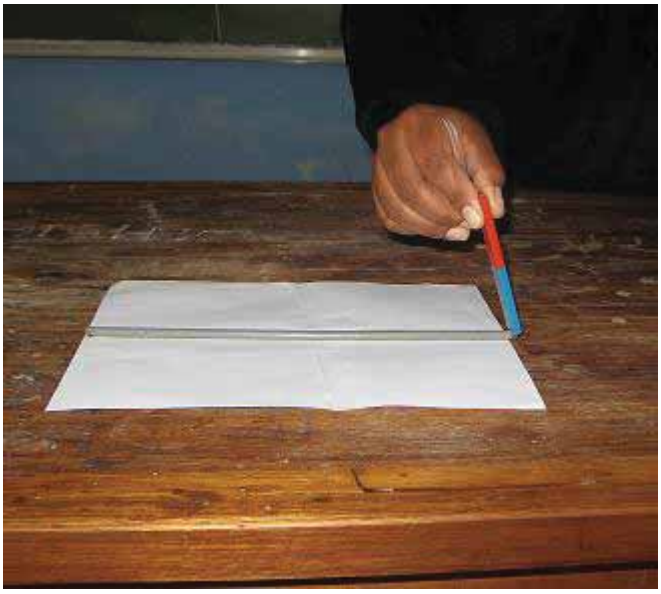


Figure 4(a)

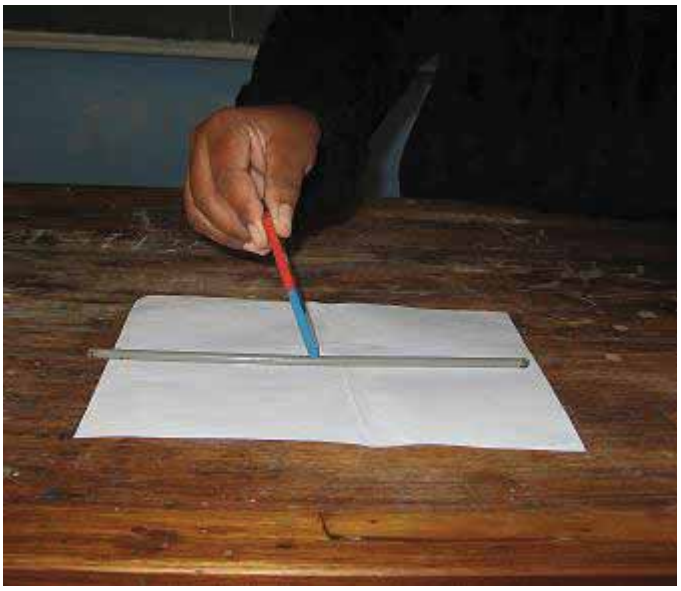


Figure 4(b)

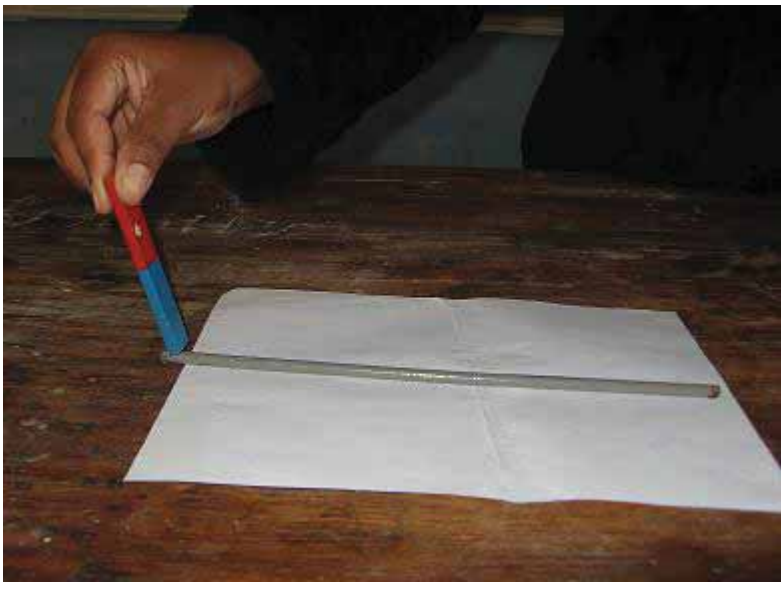


Figure 4(c)

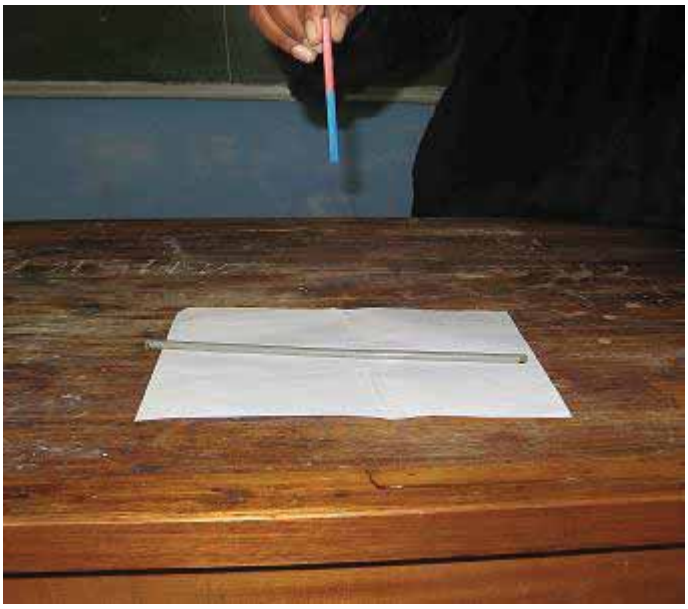


Figure 4(d)

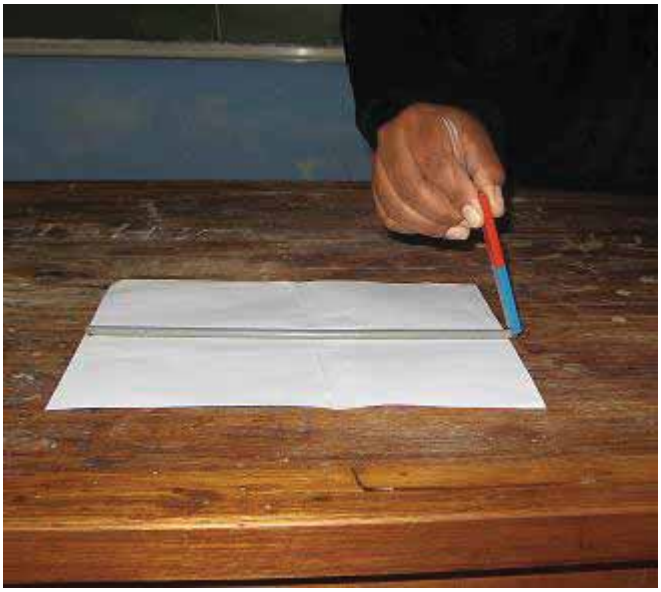


Figure 4(e)

ii) Double-stroke method

Stroke the rod with two magnets ten times as shown in Figures 5(a) to 5(c). This is called double stroking.

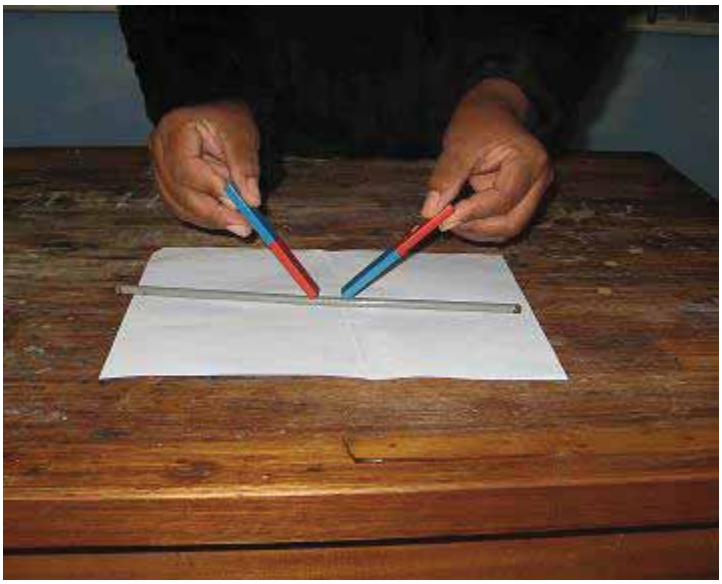


Figure 5(a): Magnets touching the rod near the centre.

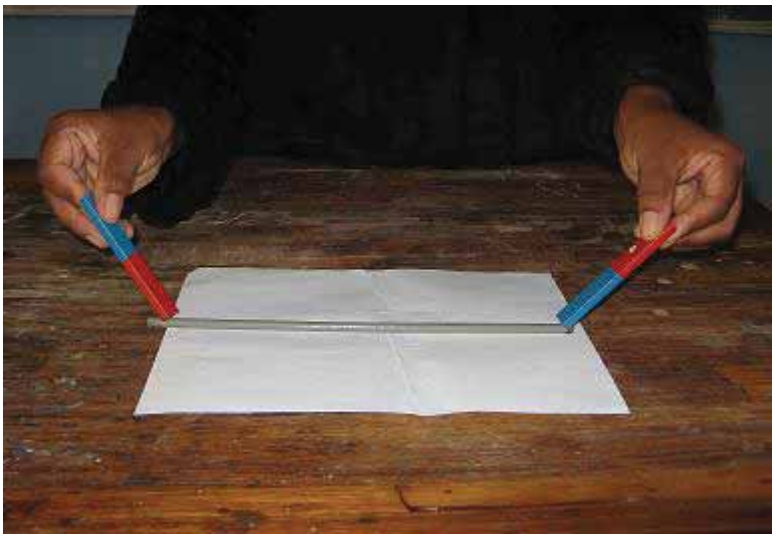


Figure 5(b): Magnets moved along the rod to the edge.

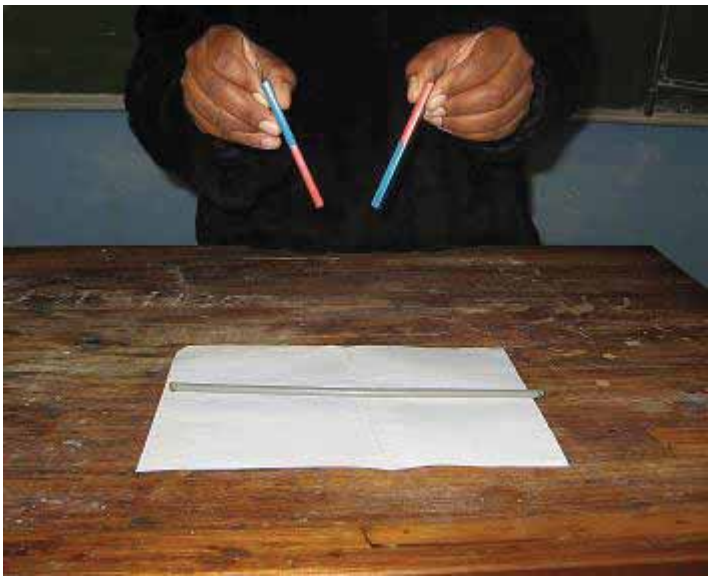


Figure 5(c): Magnets lifted above the rod will be brought down again.

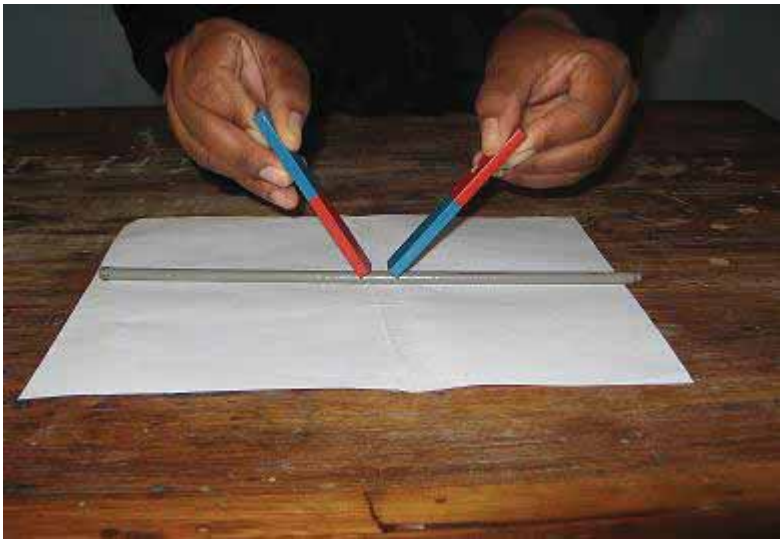


Figure 5(d): Magnets taken back to the rod.

Answer the following questions:

a) How can you test whether the rods in figure 4(d) and figure 5(e) are magnetised or not?

_____

_____

b) Label on the diagrams the poles of the rods in figures 4(d) and 5(e). Explain why you labelled the poles as you did.

_____

_____

_____

_____

Compare your answers with those at the end of section 20-2. Be sure that you understand each answer before continuing.

2. Magnetisation using an electric current

This is the best method for making powerful magnets.

Activity 6

Activity

Do the following:

i) Make a long coil of 10 turns with a copper wire like in Figure 6 below. You can coil the wire around a rod or stick, them remove it so that you have the coil only. This is called a **solenoid**.

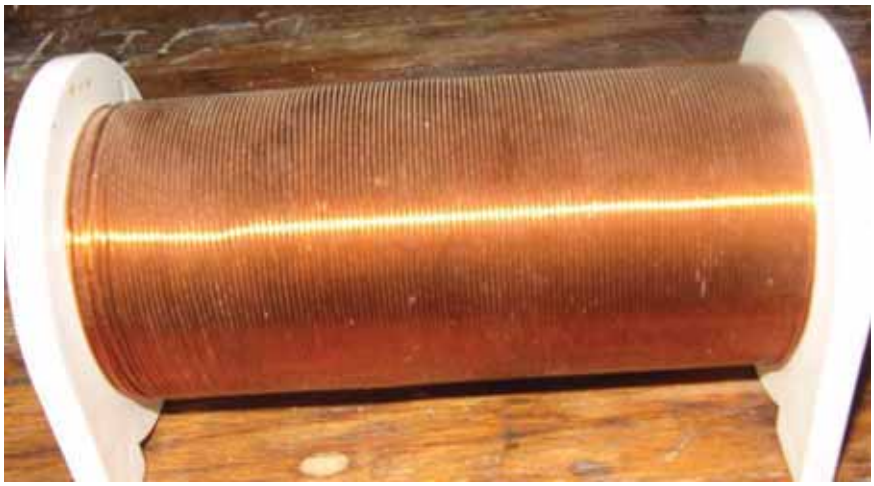


Figure 6 (a) A solenoid

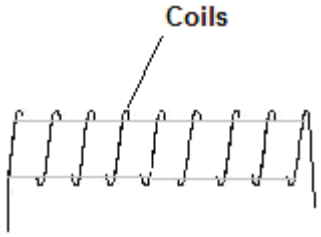


Figure 6 (b) how a solenoid you make yourself will look like.

ii) Connect the solenoid to a switch and a battery of 3 cells as in the diagram.

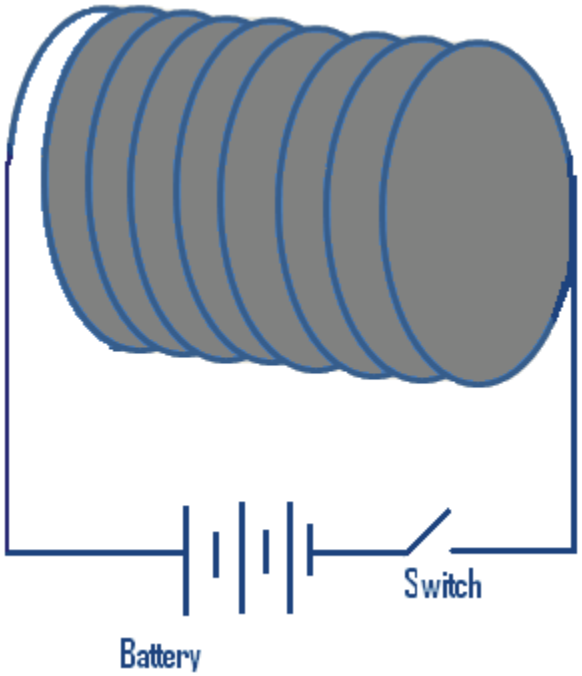


Figure 7: A solenoid connected to a battery and a switch.

Insert a steel bar through the centre of the solenoid, as shown in Figure 8, and close the switch for one minute.

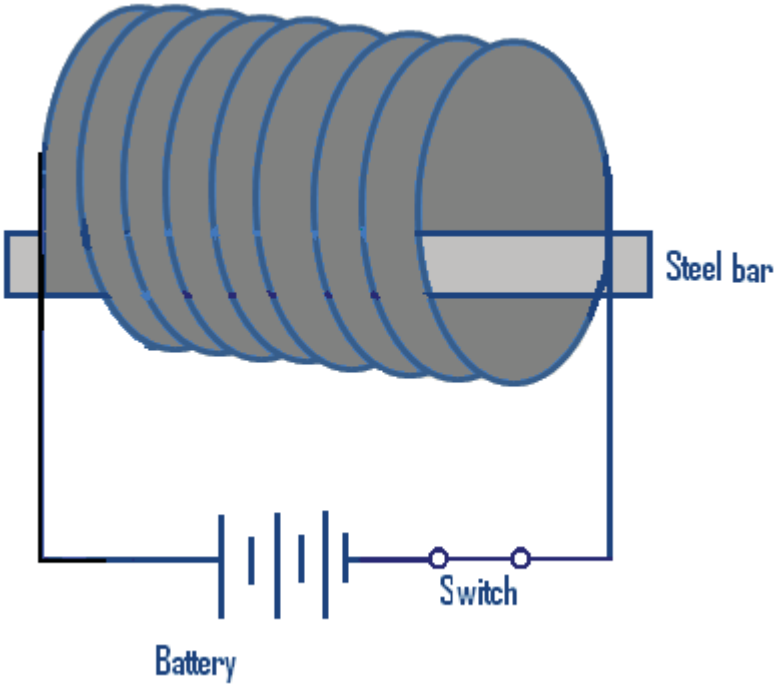


Figure 8: A connected solenoid.

Open the switch and take the rod near any magnetic material. What happens?

Compare your result with the following:

The rod should attract magnetic material.

When the direct current flows through the solenoid, a strong magnetic field is produced and the steel bar is magnetised.

Demagnetisation

The best way to destroy a magnet is by putting it in a solenoid connected to an alternating current. Magnets can also be destroyed by exposing them to excessive heat and by dropping them frequently.

Key Points to Remember

The key points to remember in this section on induced magnetism are:

- Induced magnetism is temporary.
- Induced magnetism stays only when the magnetic material is still attracted to a permanent magnet.

Note it!

Answers to Activities on Induced Magnetism

Activity 4

1. ***The nails do not attract because they are not magnets.***
2. ***When the nail which is attracted to the magnet is removed from the magnet, the other nail falls down. This is because while attracted to the magnet, the nail was also a magnet and it is able to attract other magnetic materials.***

Activity 5

a) I can test it by taking the rod next to any magnetic material, if it attracts it, then I know it is magnetised. Or if one pole of the permanent magnet repels it and the other pole attracts it, then I will conclude that it is magnetised, because like poles repel and opposites attract.

b) The poles of the rod in figure 4 will look like this:

The North Pole of the permanent magnet attracts the south pole of the domains. So the end of the rod where we start stroking has the pole opposite that of the pole of the permanent magnet.

Activity 6

The rod attracts the magnetic material.

Section 20-3: Theory of Magnetism

Introduction

The effects of magnetism have been known for centuries, yet scientists still do not know exactly what magnetism is! There is however a universally accepted theory of magnetism that we will look at in this section. It is sometimes difficult to understand how a material becomes magnetised.

By the end of section 20-3, you should be able to:

- *Explain* the theory of magnetism

It is believed that inside every magnetic material there are tiny magnets called domains, but the magnetism of each domain is very weak. When the magnetic material is not magnetised the domains are not arranged in order as shown in the Figure 9 below.

Figure 9: Domains in a non-magnetised magnetic material (Hand drawn), 2011.

Help

Still need help understanding the theory of magnetism? If you have access to the internet, please go to:

http://science.howstuffworks.com/magnetism-info3.htm

Activity 7

Activity

Let us suppose that the head of the arrow representing the domain is the North Pole and the tail is the South Pole.

Now draw arrows to show how the domains will allign when the rod is stroked with the North Pole of a permanent magnet as shown in the diagram

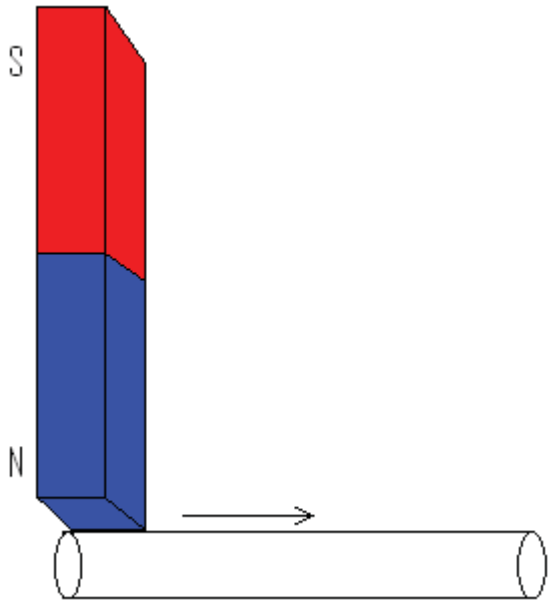


Figure 10: A rod stroked with the north pole of a permanent magnet (Hand drawn), 2011.

Compare your answers to those provided at the end of section 20-3. Check the image and read the explanation carefully to be sure you understand the concept.

Activity

Activity 8

Plotting the magnetic field around a bar magnet.

You will need a bar magnet, plotting compass pencil and a white plain paper. If you do not have access to these materials, but have access to the internet, please go to: http://phet.colorado.edu/en/simulation/magnet-and-compass for a simulation or follow along with the images.

Do the following:

1. Put the paper on a table and put the magnet on the paper.
2. Place the plotting compass next to one end of the magnet (either North or South). Which way does the compass needle point?

   Figure 11 shows all of the compass positions so that you see how a compass would be sequentially placed.

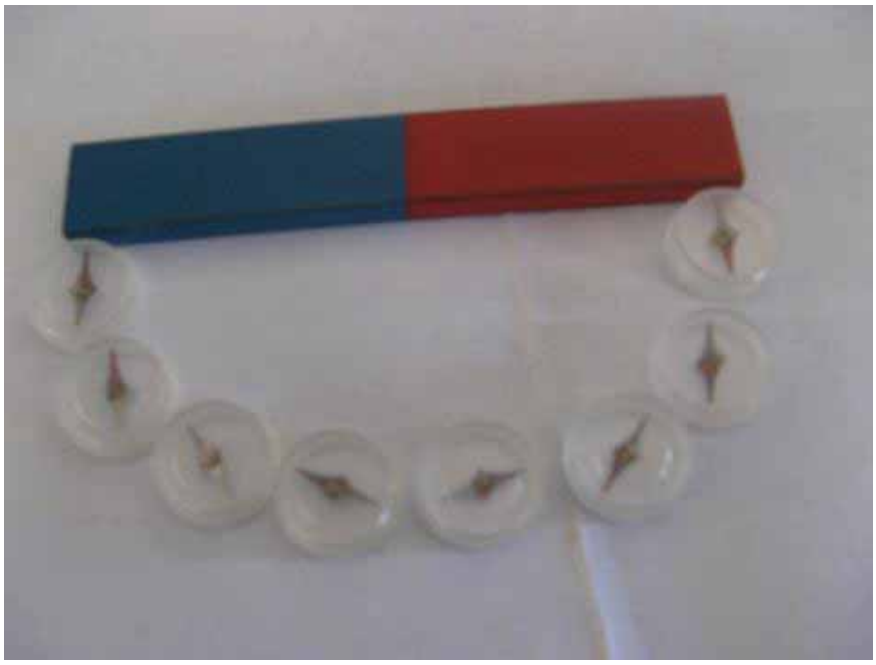


Figure 11: Plotting compasses used to plot the magnetic field around a bar magnet.

Reflection

When you look closely, you will see that each needle of the compass is coloured red on one end. The red coloured point is the South pole of the needle. Why do you think all the red coloured points are aligned towards the North pole of the bar magnet?

All of the red coloured points are aligned towards the North pole of the bar magnet because unlike poles attract.

3. When the arrow is aligned, such that the red end of the compass faces the North pole of the magnet, make dots at the beginning and end of the compass arrow.
4. Put the compass such that the dot at the end of the compass arrow is now at the beginning of the arrow.
5. Repeat step 4 until you get to the South pole.
6. When you reach South Pole join the dots and repeat steps 3 to 5 so that you can get many lines as in Figure 12 below. Your resulting pattern should look like Figure 12.

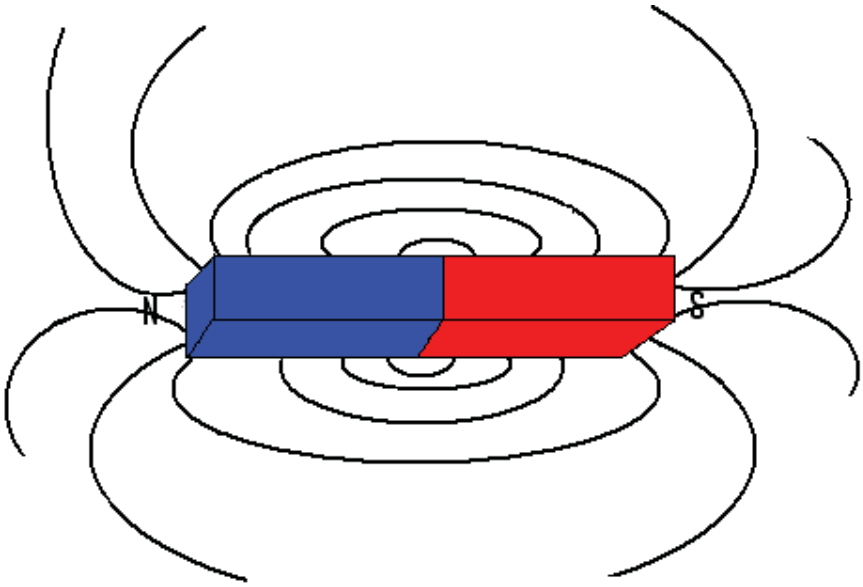


Figure 12: Magnetic field around a bar magnet (Hand drawn), 2011.

Facts about magnetic field lines

- The lines are closer to each other near the magnet because the forces of attraction and repulsion is strongest near the magnet. Away from the magnet, the field lines are further apart from each other because the forces of attraction and repulsion are weaker.
- The lines never cross each other.

Note it!

Key Points to Remember:

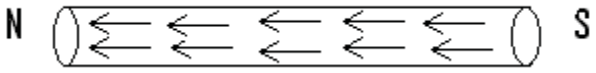
The key points to remember in this section on the theory of magnetism are:

- All magnetic materials have tiny magnets called domains.
- Magnetic field lines around a magnet are closer near the magnet because the force is stronger there and weaker further from the magnet.
- The field lines can never cross.

Answers to Activities on Theory of Magnetism

Activity 7

The domains will be arranged like below.



The poles of the rod in figure 11 will be like this. This is because the North Pole of the permanent magnet attracts the south pole of the domains.

Section 20-4: Magnetic Properties of Matter

Introduction

Different magnetic materials respond differently when magnetised. In this subunit we are going to learn how steel and iron respond when magnetised.

By the end of section 20-4, you should be able to

- *Differentiate* between hard and soft magnetic materials.

Time

Section 20-4 has 2 pages. You should spend approximately 30 minutes on this topic.

Both iron and steel are magnetic materials, but they behave differently in the presence of a magnet. In this subunit we are going to learn the magnetic properties of iron and steel.

Activity 9

Activity

i. Bring a bar magnet close to an iron nail and a steel rod so that it attracts it.

ii. Still attracted to the magnet, bring both the iron nail and steel rod close to money clips.

iii. Remove the iron nail and the steel rod carefully from the magnet. What happens to the money clips on:

a) The iron nail

_____
_____
_____

b) The steel rod

_____
_____
_____

Compare your results to those at the end of section 20-4.

Hard Magnetic Versus Soft Magnetic Material

Steel is a ***hard*** magnetic material because it is more difficult to magnetize and does not lose its magnetism fast. Iron is ***soft*** magnetic material. It is easy to magnetise it but it loses its magnetism fast. This is why the money clip immediately fell off the iron nail but not the steel rod.

Activity 10

Activity

What material do you think permanent magnets are made of? Explain why you think it is made of that material.

_____
_____
_____
_____

Compare your answers to those given at the end of section 20-4. Note that it is important to understand this concept. If you do not understand it, review this section.

Note it!

Key Points to Remember:

The key points to remember in this section on the magnetic properties of matter are:

- Iron is a soft magnetic material because it is easy to magnetise and loses its magnetism fast.
- Steel is a hard magnetic material because it is difficult to magnetise and keeps its magnetism for a long time.

Answers to Activities on Magnetic Properties of Matter

Activity 9

iii) a) The money clips on the iron nail fall immediately when the nail is removed from the magnet.

b) The money clips on the steel rod remain attracted even after the rod is removed from the magnet.

Activity 10

Permanent magnets are made of hard magnetic materials such as steel which are difficult to magnetise but which keep their magnetism well.

Section 20-5: Electromagnetism

Introduction

Electromagnets are used in many household tools; a door bell is an example. This section will help us understand the structure and function of an electromagnet.

By the end of section 20-5, you should be able to:

- *Differentiate* between a permanent magnet and an electromagnet.
- *Explain* how an electromagnet works.

Time

Section 20-5 has 3 pages. You should spend approximately 40 minutes on this topic.

Remember from junior science that ***current*** is the flow of charge.

An example of a source of current is a torch cell or battery. You will learn more about this in Unit 22.

Make a coil of copper wire around an iron or steel rod like in Figure 13 below. Then connect the wire to a battery. Current will flow in the wire when the switch is closed. If you do not have access to these materials, but have access to the internet, please go to: http://phet.colorado.edu/en/simulation/faraday and select: electromagnet.

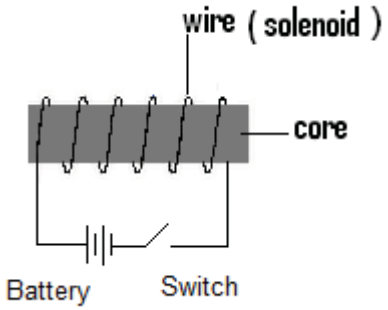


Figure 13: An electromagnet.

When a magnetic material like an iron nail is brought close to the core, it is attracted.

A wire wound around a core is called an ***electromagnet.***

An electromagnet has the magnetic effect only when current is flowing in the wire. When current stops to flow the magnetism is lost.

The electromagnet can be made stronger by increasing the number of coils like in figure 14 below.

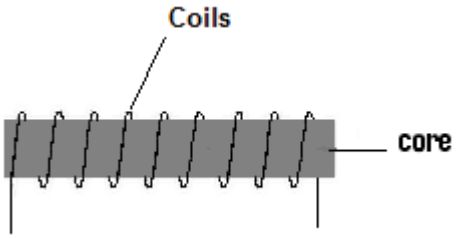


Figure 14: An electromagnet.

Reflection

The movement of a magnet through coils of wire can actually create current! If you have access to the internet, go to: http://phet.colorado.edu/en/simulation/faraday and select: pickup coil. What happens when you drag the bar magnet through the coils? How can you make the light bulb stay on consistently? Click on the Generator tab to see this in action.

Electric Bell

We are now going to learn the uses of an electromagnet.

If you can get access to an electric bell, as shown in Figure 15, look at how it is made. Compare it to the schematic diagram shown in Figure 16.

Figure 15: Electric bell accessed from Wikimedia Creative Commons, 2011.

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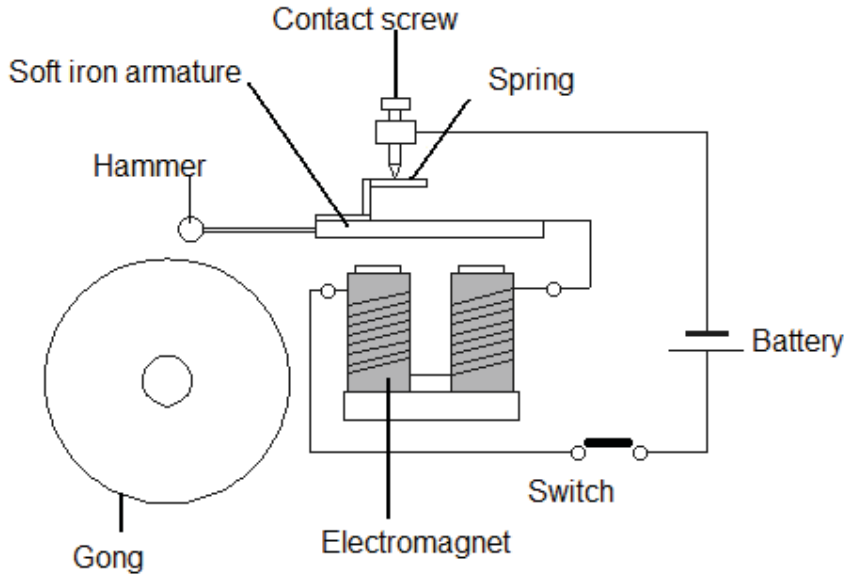

Figure 16: Electric bell circuit accessed from Wikimedia Creative Common, 2011.

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Reflection

If you have access to the internet, please go to: http://en.wikipedia.org/wiki/File:Electric_Bell_animation.gif to see an animation of how an electric bell works. Which principles of magnetism are being used here? What would happen if the electric current was turned off? What would happen if the number of coils was increased? Decreased?

If you do not have access to the internet, study the figures above.

Check the content below to determine whether you correctly determined how the bell works.

- When the switch is closed current flows in the coil and then we hear sound as we see the hammer hits the gong.
- The armature moves forward because it is attracted by the magnetised cores.
- When the armature is attracted by the electromagnet, the spring loses contact with the contact screw, so the circuit breaks and the armature moves backwards.
- **Note that**: When the armature moves backwards the spring contacts with the contact screw again and then current flows. When current flows through the wires the cores become magnetised and attract the armature again.
- Every time when the armature is attracted to the electromagnet, the hammer hits the gong and the bell rings.

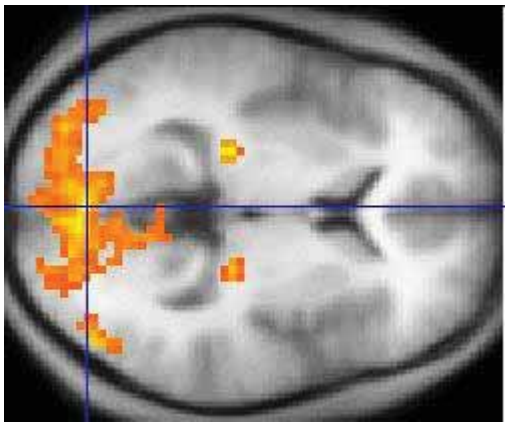

Image accessed from Wikimedia Creative Commons, 2011.

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Functional Magnetic Resonance Imaging (rMRI)

fMRI is a technique for measuring brain activity. It works by detecting changes in blood flow that occurs when a brain area is more active. An MRI scanner houses a very powerful electromagnet (50,000 times greater than the Earth's field). The magnet aligns the atomic nuclei of hydrogen in the direction of the magnetic field created. This produces a fMRI image like the one on the left. Scientists are continuing to discover new uses for electromagnets in the field of non-invasive medicine!

Activity 11

Activity

Name two other appliances which use the magnetic effect of current:

_____

_____

Compare your ideas with those at the end of section 20-5.

Key Points to Remember:

Note it!

The key points to remember in this subunit on electromagnetism are:

- Electromagnets work only when current is flowing through them.
- The strength of the magnetism depends on the number of coils around the core and the size of the current flowing in the coil.

You have now completed the last section of this unit on magnetism. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Answers to Activities on Electromagnetism

Activity 11

a) Two other appliances which use the magnetic effect of current are:

Loudspeakers, cranes and audio and video tapes

Unit Summary

Summary

This section gives you a list of thing you should have learned. Make sure that you go through it carefully and refer to the unit if you feel that you have forgotten something.

In this unit you learned:

- Magnetic materials are attracted by magnets.
- Non-magnetic materials are not attracted by a magnet.
- A magnet has a North Pole and South Pole.
- The laws of magnetism state that like poles repel and unlike poles attract.
- Magnetic field is the space around the magnet within which the attraction or repulsion force can be felt.
- The magnetic field lines are plotted around a magnet by using the plotting compass.
- If a magnet is dropped many times or exposed to excessive heat, it will be demagnetized. The best method to demagnetize a magnet is exposing it to excessive heat.
- A magnetic material can be magnetized by the stroking method and the electrical method.
- Steel is a hard magnetic material. It is difficult to magnetize but keeps its magnetism for a longer time than soft magnetic material.
- Iron is a soft magnetic material. It is easy to magnetize but loses its magnetism fast.
- When current flows in the wire wound around a magnetic material, an electromagnet is produced.
- An electromagnet has a magnetic effect only when current is flowing in the solenoid. When current stops flowing, the magnetism is lost.
- Electromagnets are used in cranes which are used to pick scrap metals, audio and video tapes and electric bells.

You have completed the material for this unit on magnetism. You should now spend some time reviewing the content. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers electrostatics.

Assignment 20

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:20]

1. State the laws of magnetism. (2)

_____
_____
_____

2. Name the two methods of magnetisation.(2)

_____
_____

3. Answer the following

   i) Describe how electromagnets are made. (2)

   _____
   _____
   _____
   _____

   ii) Explain how soft magnetic material is different from hard magnetic material. (2)

   _____
   _____
   _____
   _____
   _____
   _____
   _____
   _____

4. Ann holds a bar magnet next to a pile of money clips. She finds that the money clip which is attracted to the magnet attracts other money clips.

   i) Explain why this happens. (1)

   _____
   _____
   _____
   _____
   _____
   _____

   ii) Explain what induced magnetism is. (2)

   _____
   _____

5. What is the effect of dropping a permanent magnet repeatedly? (1)

_____
_____
_____
_____
_____

6. Explain how a plotting compass is used to plot the magnetic field around a permanent bar magnet. (3)

_____
_____
_____
_____
_____

7. Two metal rods A and B which are the same size but made of different materials are put in the solenoid and current is passed through the solenoid.

i) Explain what happens to the rods when current flows in the solenoid. (2)

_____
_____
_____
_____

ii) When the rods are taken out of the solenoid and brought closer to an iron nail, rod A attracts the nail and rod B does not attract the nail. Explain why this happens. (3)

_____
_____
_____
_____
_____

Reflection Question

8. Inside an electric guitar, there is a coil of wire around a small permanent magnet. The magnetic field of the magnet induces magnetic poles in the nearby guitar string. When the string is plucked, the waves in the sting produce the same waves in the magnetic field of the coil. This also causes the same waves in the voltage in the coil. This is amplified and sent to a speaker to make music! Why will this technology not work with nylon guitar strings?

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 20

1. *The laws of magnetism state that: like poles repel and unlike poles attract.*
2. *Magnetic materials can be magnetised by stroking magnetic materials with a permanent magnet or by passing direct current in the wire wound around the material.*
3.

i) An electromagnet is a magnet which has the magnetism only when current is flowing in the wire wound around the core.

iii) Soft magnetic materials are magnetic materials which are easy to magnetise and easy to loose their magnetism.

Hard magnetic material are difficult to magnetise and do not loose their magnetism fast.

4.

i) The money clip which is attracted the magnet has become a magnet, so it also attracts other money clips.

ii) Induced magnetism is the magnetism an object has only when it is attracted to a magnet, but looses its magnetism when it is removed from the magnet.

5. *When a temporary magnet is dropped repeatedly, it loses its magnetism.*
6. *1. Put the paper on a table and put the magnet on the paper.*

2. Put the plotting compass on one end of the magnet.

3. When the arrow is aligned, such that the red end of the compass faces the North pole of the magnet, make dots at the beginning and end of the compass arrow.

4. Put the compass such that the dot at the end of the compass arrow is now at the beginning of the arrow.

5. Repeat step 4 until you get to the South pole.

6. When you reach South Pole join the dots and repeat steps 3 to 5.

7.

i) The rods become magnetised when current flows in the solenoid.

ii) Rod A has not lost its magnetism that is why it attracts the other rod. Rod B has lost its magnetism. Rod A is made of a hard magnetic material while rod B is made of a soft magnetic material.

8. The nylon strings will not work because they are not magnetic- they do not have a north and south-pole.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physics course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 20

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

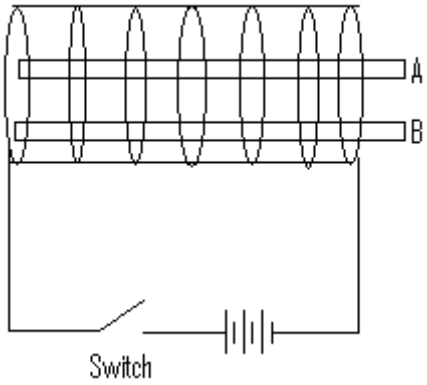
Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:15)

1. Describe the differences between:
   - i) Magnetic materials and non-magnetic materials.(2)
   - ii) Soft magnetic materials and hard magnetic materials. (2)

2. What is the direction of the field lines around a bar magnet? (1)
3. Explain how you would use plotting compasses to plot the magnetic field lines around a current carrying conductor. (3)
4. Explain with the aid of labelled diagrams
   - a) How you would use the stroking method to magnetise an iron rod. (2)
   - b) How you would use electricity to demagnetise a permanent magnet. (2)
5. Two rods are put inside the solenoid as shown in the diagram.



These are the two observations made:

1. When the switch is closed the rods roll away from each other.

2. When the switch is opened the rods roll towards each other.

Explain why this happen. (3)

Physics

Grade 12

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Unit 21

Electrostatics

Study Skills

Keep a pad of paper handy to jot down extraneous thoughts that cross your mind while studying, get them out of your mind and on to paper.
Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.

Introduction

You may sometimes feel a shock go through your hand as you touch a door knob. Sparks may jump as you put on some night clothes.

During a thunderstorm, you may a flash of lightning in the sky. All of these events are connected to electrostatics.

Image accessed from Wikimedia Creative Commons, 2011.

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In this unit we are going to find out why these three incidences happen.

Time

This unit consists of 39 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. They are a guide to what you should focus on while studying this unit.

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Give* the correct SI units of the different physical quantities.
- *Solve* problems which involve physical forces, such as energy, light, magnetism and electricity.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.
- *Analyse* experimental data.

Study Skills

Upon completion of this unit you will be able to:

- *Describe* experiments to show the production and detection of electrostatic charges.
- *Apply* electrostatics to real life situations.

Terminology

Coulomb:	The SI unit of charge.
Pith Ball:	A very small, lightweight object that picks up electric charge quite well.
Van de Graaf Generator:	An electrostatic generator.
Grounded:	A conducting object, such as a wire, that is connected to such a position of zero potential.

Section 21-1: Laws of Electrostatics

Introduction

By the end of this section, you should be able to describe experiments to show the production and detection of electrostatic charges.

Time

There are 7 pages on the topic of laws of electrostatics. You should spend approximately 40 minutes on this topic.

Friction and Charge

Try this out! Take a small sheet of paper and cut it into very small pieces. Take a hair comb and bring it next to the small pieces of paper. What happens?

_____

_____

Next, take the hair comb and rub it on your jersey. Bring the rubbed comb next to the small pieces of paper. What happens?

_____

_____

Compare your answers to the following:

You should find that before rubbing, the comb does not attract the small pieces of paper and after rubbing, the comb attracts the small pieces of paper. The implication is that friction due to rubbing has changed the nature of the surface of the comb. Friction has caused the comb to be electrically charged.

The following are simple experiments that can be carried out in a laboratory or in your home. Before carrying out the experiments, take note of the following:

A **pith ball** is a very small, lightweight object that picks up electric charge quite well. A pith ball is often made from Styrofoam for experimentation purposes. At home, instead of a pith ball, you can use a balloon or a small piece (e.g., 2 cm by 2 cm) of Styrofoam cut from a cup. You will also need:

- 2 glass rods. At home you can use two plastic straws.
- 1 rubber rod. At home you can use a rubber/eraser instead.
- Thread that is thin.
- A piece of silk material.

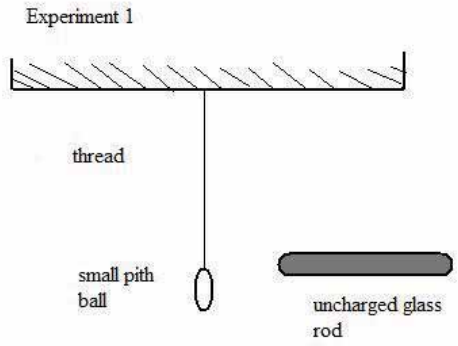

Figure 1: Experiment 1. Hand drawn by graphic designer at LDTC.

Experiment 1:

Tie a small pith ball to a piece of thin thread and allow it to hang freely in air as shown by Figure 1 above. Bring a glass rod near the pith ball.

What happens?

_____

_____

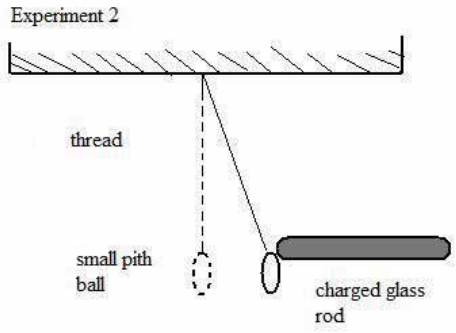

Figure 2: Experiment 2 Results. Hand drawn by graphic designer at LDTC.

Experiment 3:

Another similar glass rod is rubbed with silk to charge it. Then one of the charged glass rods is left to hang freely in air and the other one brought close to it. What would you expect to see happening?

_____

_____

Compare your answer to the following:

The two glass rods will repel each other as shown by Figure 3. This is because the two glass rods have similar or like charges.

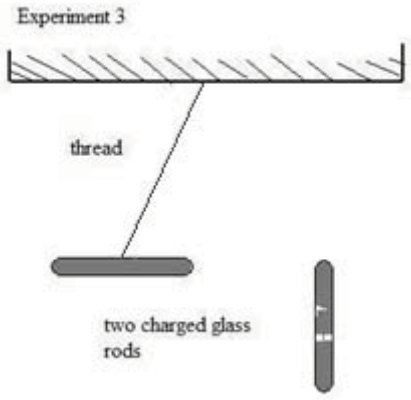

Figure 3: Experiment 3 Results. Hand drawn by graphic designer at LDTC.

Experiment 4:

A rubber rod is charged by rubbing it with fur and brought close to the charged hanging glass rod. What do you expect will happen?

_____

_____

Compare your answer to the following:

The two charged rods will attract each other as shown by Figure 4. This is because the glass rod and the rubber rod have different or unlike charges.

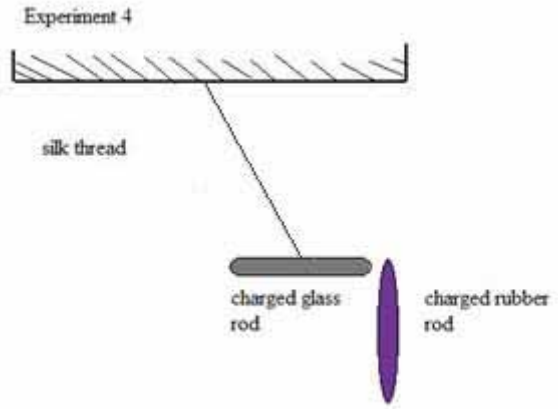

Figure 4 – Experiment 4 Results. Hand drawn by graphic designer at LDTC.

Electrostatic Charges

Experiments 1 to 4 can help us summarise electrostatic charges as follows:

- There are only two types of charge, positive and negative charges.
- Like charges always repel each other.
- Unlike charges always attract each other.
- These electric charges, both the negative charge and the positive charge, are measured in coulombs (C). This is the SI unit of charge.

An Explanation of Charging by Friction

Matter is made up of small particles called atoms (Refer to Unit 2). Each atom has negatively charged electrons moving around a nucleus that has positively charged particles called protons and neutral particles called neutrons.

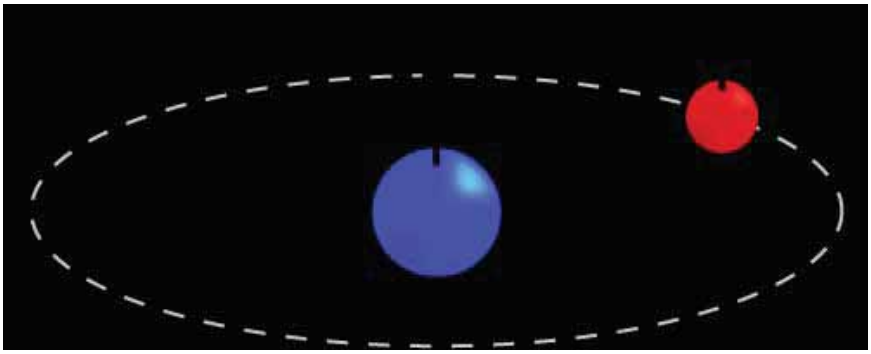

Figure 5: A hydrogen atom accessed from Wikipedia Creative Commons, 2010.

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Figure 5 shows a hydrogen atom in its neutral state with one electron moving around a nucleus with one proton. For atoms to be electrically balanced they need to have the same number of electrons as protons such as the hydrogen atom shown.

An electrified atom has its electrical balance disturbed when some electrons are removed or added to the atom. When charging by friction such as rubbing a comb through hair or a glass rod with silk, electrons from one surface are transferred to another. Table 1 below summarises the kind of charged produced in some objects:

Table 1: Charging by friction

Materials	Positive charge	Negative charge
Glass rod rubbed with silk	Glass	Silk
Rubber rod rubbed with fur	Fur	Rubber
Plastic comb rubbed through hair	Hair	Plastic comb
Plastic ruler rubbed with woollen duster	Ruler	Duster

Activity

Activity 1

Answer the following questions to check your understanding.

1. How many kinds of charge exist? List them.

_____
_____
_____
_____

2. What is the SI unit of charge?

_____
_____

3. If a pith ball is NOT attracted by a glass rod that is brought near to it, what conclusion can be drawn about charges on the pith ball and the glass rod?

   A Only the glass rod is charged.

   B Only the pith ball is charged.

   C One is positively charge and the other is negatively charged.

   D Both the pith ball and the glass rod are uncharged.

4. With the aid of a labelled diagram, describe an experiment that shows how electrostatic charges can be detected using a pith ball and a rubber rod.

_____
_____
_____

Compare your answers to the correct answers provided at the end of this section. Continue on if you understand each answer. If not, review the content before continuing.

Reflection

If you have access to the internet, please go to:
http://phet.colorado.edu/en/simulation/balloons
and try the simulation.

What happens when you rub the balloon on the jersey? What happens when you then bring the jersey close to the wall? Close to the jersey?

Note it!

The key points to remember in this section are:

- There are two types of charges: positive and negative charge.
- Like charges attract and unlike charges repel.

Answers to Activities on Laws of Electrostatics

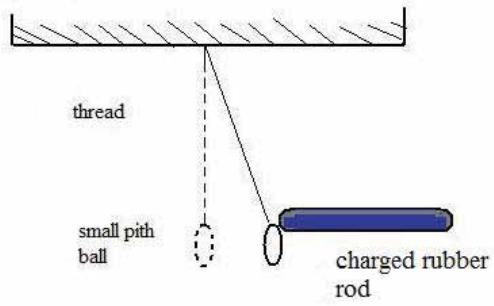
Activity 1

1. ***Two kinds of charge exist.***

a) Positive charge

b) Negative charge

2. ***The SI unit of charge is the coulomb.***
3. ***D. Since there is no attraction, neither would be charged. If one was charged, there would have been attraction.***
4. ***A small pith ball is tied with a thread and let to hang freely in air. Then a rubber rod is rubbed with fur and brought close to the hanging pith ball. The pith ball will be attracted to the rubber rod to show electrostatic charge has been developed due to rubbing the rubber rod as shown by the figure below.***



Section 21-2: Applications of Electrostatics

Introduction

By the end of this section, you should be able to apply electrostatics to real situations.

Time

There are 5 pages on the topic of applications of electrostatics. You should spend approximately 40 minutes on this topic.

Practical Applications of Electrostatics

1. High voltage generators

   A Van de Graaff generator as show by Figure 6 is an electrostatic generator that is used to:

   - Accelerate electrons to sterilize food and process materials.
   - Accelerate protons for nuclear physics experiments.

Figure 6: Van de Graaff Generator accessed from Wikimedia Creative Commons, 2010.

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2. Spray painting

   Wet spray painting is a painting method where a device sprays a coating such as paint, ink or varnish through air onto a surface. In electrostatic spray painting, the particles are made to be electrically charged, thereby repelling each other and spreading themselves evenly as they exit the spray nozzle. The object being painted is charged oppositely, or grounded to be neutral. To **ground** an object is to attach it to an object, such as a wire, that is connected to such a position of zero potential.

   The paint is then attracted to the object giving a more even coat than wet spray painting, and also increasing the percentage of paint that actually sticks to the object. Paint also covers hard-to-reach areas. Car body panels and bike frames often use electrostatic spray painting. This method of spray painting is effective, efficient and economical.

   Source: http://en.wikipedia.org/wiki/Spray_painting

Hazards of Electrostatics

1. Lightning

We commonly see flashes of lightning such as portrayed by Figures 7 (a) and (b) before and during thunderstorms. They occur due to a large quantity of electric charge being built up in thunderclouds.

Figure 7(a): Lightning accessed from Wikimedia Creative Commons, 2010.

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Figure 7(b): Lightning accessed from Wikimedia Creative Commons, 2010.

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The thunderclouds are charged by the action between water molecules and the air molecules. When the charge on

thunderclouds is large, it can ionise the air which then provides a conducting path for the huge quantity of charge to be discharged to the nearest or sharpest object on earth. To prevent lightning from damaging tall buildings, lightning conductors as shown by Figure 8 are used. The purpose of a lightning conductor is to provide a steady discharge path for the huge number of electrons in the air to flow from the top of the building to the Earth.

Activity

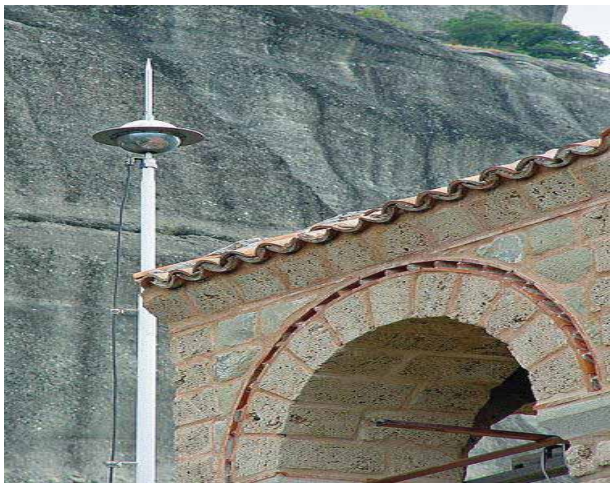

Figure 8: Lightning conductor at a church accessed from Wikimedia Creative Commons, 2010.

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Activity 2

1. State two applications of electrostatics.

   _____
   _____

2. Give two uses of the Van de Graaff Generator.

   _____
   _____
   _____

3. How does a lightning conductor on a tall building work?

   _____
   _____
   _____

Compare your answers to the answers placed at the end of this section. Continue to the unit on if you understand each answer. If not, review the content before continuing.

The key points to remember in this section are:

- Electrostatics can be applied in spray painting and in high voltage generators.
- Lightning can be a very dangerous form of electrostatics.

Note it!

Answers to Activities on Applications of Electrostatics

Activity 2

1. ***Two applications of electrostatics:***
   a) ***Spray painting***
   b) ***High voltage generators***
2. ***Two uses of a Van de Graaff Generator:***
   - ***To accelerate electrons to sterilize food and process materials.***
   - ***To accelerate protons for nuclear physics experiments.***
3. ***A lightning conductor provides a steady discharge path for the huge number of electrons in the air to flow from the top of a tall building to the earth.***

Unit Summary

Summary

In this unit you learned that:

- Friction can produce two types of charge on different materials.
- Only two types of charges exist, the positive and the negative charges.
- Like charges repel each other while unlike charges attract each other.
- The SI unit of charge is the Coulomb (C).
- Some applications of electrostatics are spray painting and the use of high voltage generators such as the Van de Graaff Generator.
- One of the hazards of electrostatics is lightning.
- A lightning conductor can be used to prevent lightning from hitting tall buildings.

You have completed the material for this unit on electrostatics. You should now spend some time reviewing the content. Once you are confident that you can successfully write an examination on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It addresses current electricity.

Assignment 21

Assignment 21

Answer all the questions that follow.

You should be able to complete this assignment in 20 minutes

[Total Marks:15]

Multiple Choice Questions (1 mark each)

1. If a pith ball can be repelled by a rubber rod, what conclusion can be drawn about charges on the pith ball and the rubber rod?

   A Only the rubber rod is charged.

   B Only the pith ball is charged.

   C Neither has a charge.

   D Both the pith ball and the rubber rod are charged with like charges.

2. The SI unit for electric charge is the

   A ampere

   B coulomb

   C volt

   D watt

Structured Questions

1. With the aid of a labelled diagram in the space provided below, describe an experiment that can be carried out to show that like charges attract. (7)

   _____
   _____
   _____
   _____
   _____

2. a) Explain how lightning is formed. (4)

   _____
   _____
   _____
   _____
   _____

b) Why is lightning a hazard of electrostatics? (2)

_____
_____
_____
_____
_____
_____

Reflection Question

3. If you walk across a rug and rub off electrons from your feet, are you positively or negatively charged?

Compare your answers to those provided below. Pay particular attention to any errors that you made and spend the time needed to understand how to fix those errors.

Answers to Assignment 21

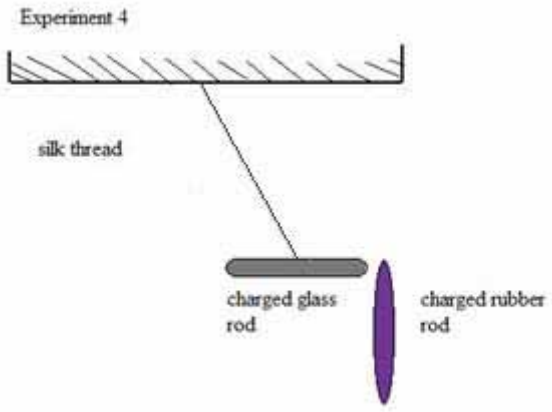
Multiple Choice Questions

1. ***D***
2. ***B***

Structured Questions

1. ***A rubber rod can be charged by rubbing it with fur and a glass rod be charged by rubbing with silk. Then the glass rod will be left hanging freely in air as shown by the figure below. The rubber rod will then be brought close to the charged hanging glass rod.***

   The two charged rods will attract each other as they have unlike charges.



(7)

2. a) The following happens for lightning to occur: (4)

- *Water and air molecules in thunderclouds charge each other by friction.*
- *A large quantity of electric charge is then built up in the thunderclouds.*
- *When the electric charge is large, it ionizes the air.*
- *The ionized air then provides a conducting path for the huge quantity of charge to be discharged to the nearest or sharpest object on earth as lightning.*

2. b) Lightning is a hazard of electrostatics as it is very destructive to objects that are in its path.(2)

3. You are positively charged because you now have fewer electrons (the rug is now negatively charged).

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physical science course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 21

Assessment 21

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:7)

Show all of your work for full marks.

1. With the aid of a labelled diagram, describe an experiment that can be carried out to show that unlike charges attract. (5)
2. Give two examples where electrostatic spray painting can be used. (2)

Unit 22

Current Electricity

Study Skills

Do you have trouble concentrating? Break-up the content of study by mixing up subjects and building in variety and interest and removing boredom. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

We use electricity for many things in our lives. We can use it to light our homes, to listen to the radio, to warm ourselves, to cook and many other things. In this unit we are going to discuss electrical quantities such as current, electromotive force, potential difference and resistance.

This unit extends some of the content learned in the electrostatics unit about positive and negative charges and what happens when you separate them. However, the next unit that addresses practical electrical circuitry takes some of the concepts learned in this unit yet further. So, it is important to learn the content in this unit well as you will then be better able to follow the material taught in the following unit.

Time

This unit consists of 61 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. You should focus on those skills while studying this unit.

Outcomes

Study Skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Give* the correct SI units of the different physical quantities.
- *Solve* problems which involve physical forces, such as energy, light, magnetism and electricity.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.
- *Analyse* experimental data.

Unit Outcomes:

Upon completion of this unit you will be able to:

- *Describe* how quantities, such as electromotive force, voltage and resistance, relate to current electricity.
- *Calculate* different quantities related to current electricity using a variety of formulae.
- *Describe* the use of an ammeter and voltmeter.
- *Calculate* the net effect of a number of resistors connected in series and in parallel.
- *Describe* Ohm's law and its limitations.

Terminology

Electric circuit:	A closed conducting path of current.
Electric current:	The rate of flow of charge.
Electromotive force:	The work done by a source to drive a unit charge around a complete circuit.

Section 22-1: Current

Introduction

At the end of this section, you should be able to calculate different quantities related to current electricity using a variety of formulae. You should also be able to describe the use of an ammeter.

Time

There are 8 pages on the topic of current. You should spend approximately 1 hour on this topic.

Current

In the previous unit that covered electrostatics, you learned about electric charges at rest. If the charges move in a conductor, we say that an electric current is flowing. The rate of flow of electric charge is called an electric current and it is measured in amperes (A), its SI unit. This means the amount of an electric current flowing determines the amount of charge passing a given point in one second.

This can be shown in the form of an equation:

$I = \frac{Q}{t}$ where I is the electric current in amperes (A)

Q is the electric charge in coulombs (C)

t is the time in seconds (s)

Examples:

1. A lamp is switched on to give light for 5 hours and the current in it is 0.3 A. What is the total electric charge passing through the lamp?

Solution:

Given $t = 5\ h = (5 \times 60 \times 60)\ s$

$I = 0.3\ A$

Then $I = \frac{Q}{t}$

Therefore $Q = It$

$= 0.3\ A\ (5 \times 60 \times 60)\ s$

$= 5400\ C$

2. A bus driver switches on a starter motor of the bus for 5 s before moving the bus. The charge that flows in that 5 s is 40 C. How large is the electric current flowing in the wires of the starter motor?

Solution:

Given $t = 5\ s$

$Q = 40\ C$

$$\text{Then} \quad I = \frac{Q}{t}$$

$$= \frac{40\ C}{5\ s}$$

$$= 8\ A$$

Activity 1

Work out the following questions:

Activity

1. A cross-section of a 2 mm wire is isolated and 20 C of charge is determined to pass through it in 40 s. What is the current flowing in the wire?

2. If the current through a stove is 6 A, what is the charge that passes in

   a) 10 s

   b) 4 minutes

After you have attempted both questions, compare your answers to the correct answers given at the end of the section on current. If you have any misunderstandings, refer also to the example given earlier.

Measurement of Current

In order to measure an electric current, an electric circuit is required. An electric circuit is a closed conducting path of current. The charge carriers are electrons, but for historical reasons, the direction of the current in electrical circuits has been taken as the direction of positive charge flow which is in the opposite direction. This is known as the flow of conventional current.

Current is measured by an ammeter in a circuit as shown by figure 1. The ammeter must be connected **in series (*sequence/succession*)** in the circuit. In a series circuit there is only one conduction path. Note that while other components in the circuit can be in parallel, the ammeter must be connected in series.

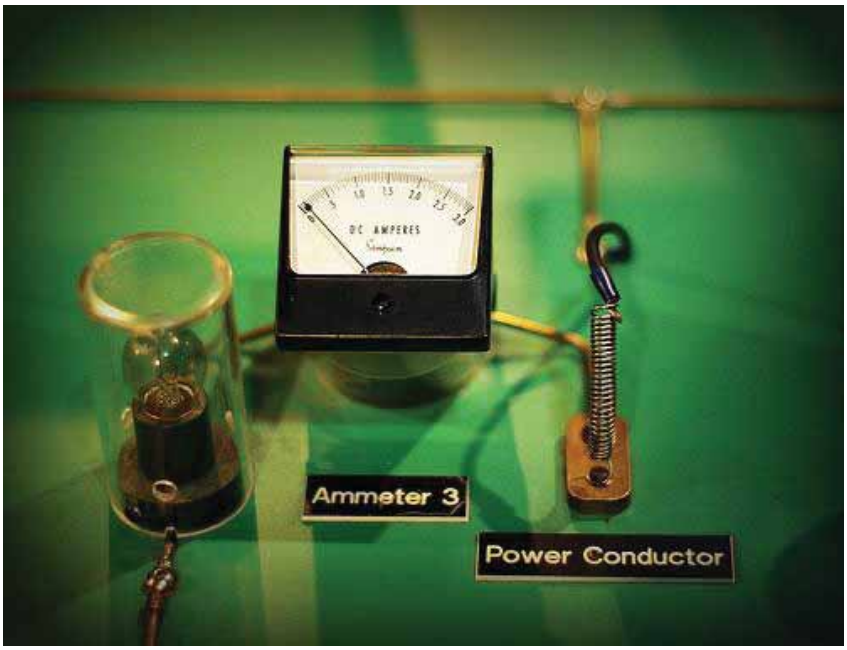


Figure 1: An ammeter accessed from Flickr, 2010.

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Electric Symbols

In order to draw simple and clear diagrams, electric symbols are used. Figure 2 shows a diagram of a simple circuit as a pictorial diagram and schematic of the same circuit using electric symbols. It also shows an ammeter connected in series as mentioned earlier.

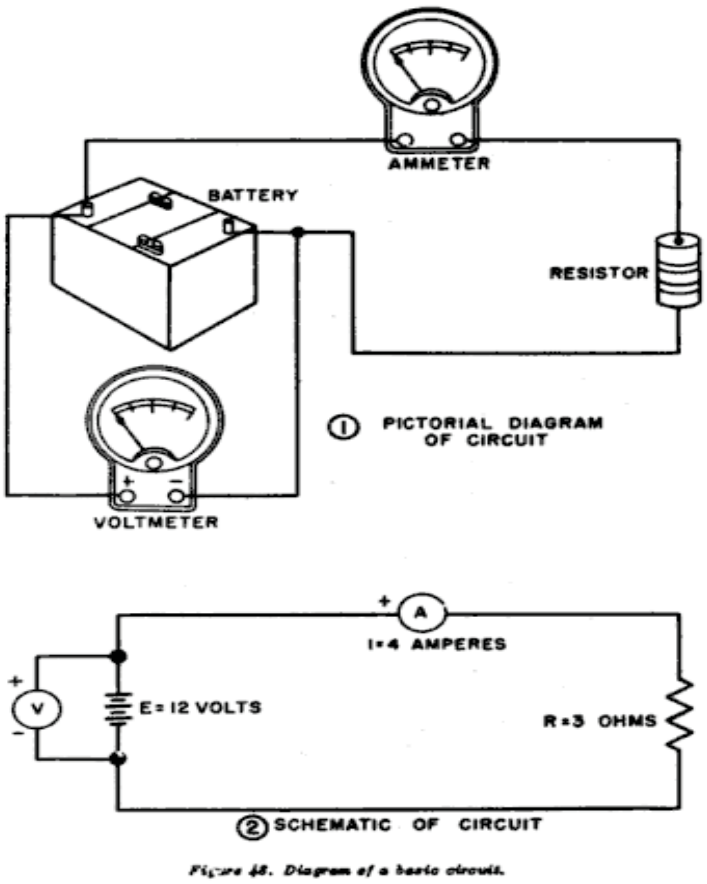

Figure 2: The diagram of a basic circuit accessed from Wikimedia Creative Commons, 2010.

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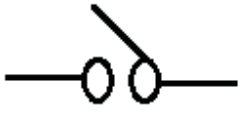
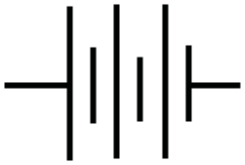
The following shows electrical devices and their symbols as used in circuit diagrams.

Switch

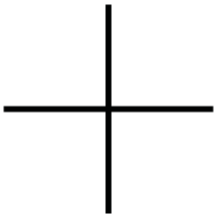


Cell

Battery

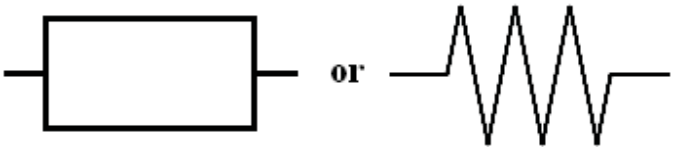


Wires joined

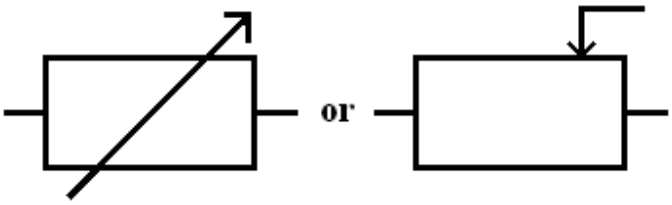


Lamp/bulb/globe

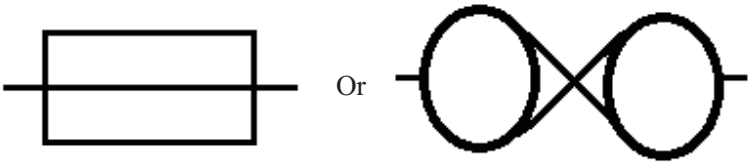
Fixed resistor



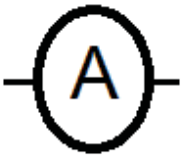
Variable resistor/rheostat



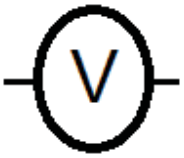
Fuse



Ammeter



Voltmeter



Galvanometer

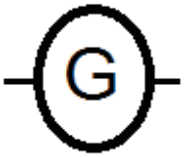


Figure 3 below shows the measurement of current using an ammeter connected in series by use of electric symbols. In the subsequent sub units, circuits will be shown with symbols.

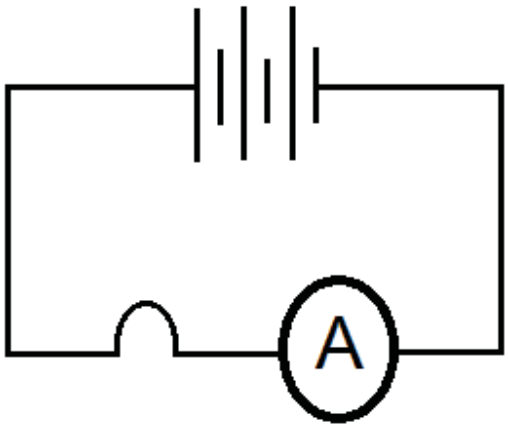


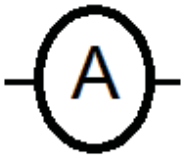
Figure 3: Measuring an electric current using an ammeter. Hand drawn by graphic designer at LDTC.

Activity

Activity 2

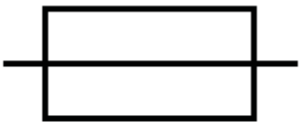
Answer the following questions by filling in the spaces provided.

1. What do the following symbols represent?



a) _____

b) _____



c)

_____

2. What is the name of the instrument used to measure current?

_____

After completing the activity, compare your answers to those provided at the end of this section. Be sure you can identify the other symbols as well before continuing.

Note it!

The key points to remember in this subunit on current are:

- An electric current is the rate of flow of charge.
  - $I = \frac{Q}{t}$
- The instrument used to measure current in the ammeter.
- An ammeter must always be connected in series in an electric circuit to measure current.

If you are confident you know this material, continue to the next section that covers electromotive force.

Answers to Activities on Current

Activity 1

1. $I = \frac{Q}{t}$

$= \frac{40\ C}{20\ s}$

$= 2\ A$

2. a) Given $I = 6\ A$ *and* $t = 10\ s$

Q = It

= 6 A x 10 s

= 60 C

b) Given ***I = 6 A***

t = 4 minutes

= (4 x 60) s

= 240 s

Q = It

= 6 A x 240 s

= 1440 C

Activity 2

1. ***a) Ammeter***
   b) Bulb/Globe/Lamp
   c) Fuse

2. ***An ammeter is used to measure current.***

Section 22-2: Electromotive Force

Introduction

At the end of this section, you should be able to describe how electromotive force relates to current electricity and calculate electromotive force using formulae.

Time

There are 4 pages on the topic of electromotive force. You should spend approximately 40 minutes on this topic.

Electromotive Force

As mentioned earlier, electric current is produced when there is a flow of charge. But then what causes this charge to flow? A source of energy is needed to push the electric charge (electrons) around a circuit. Sources of electrical energy for use in circuits include cells, batteries, and generators.

In a cell or battery, chemical changes release the energy needed to push the electric charge around the circuit. For instance energy changes for a light bulb connected to the cell or battery will be:

chemical energy → electrical energy → light energy

Electromotive force (e.m.f.) is a measure of how much work would be done by moving the electric charge. This can be shown by the following equation

$$\varepsilon = \frac{W}{Q}$$

where ε is the e.m.f.

W is the work done to move the charge

Q is the electric charge

From this equation, it follows that the unit of e.m.f. is the Joule/Coulomb (J/C) which is the same as the volt (V). They represent the SI unit of the e.m.f.

The work done to move the electric charge is the same as the energy converted from the non-electrical form to the electrical form when the charge passes through the source. Therefore, in the light bulb mentioned earlier, the chemical energy from the cell/battery is the non-electrical energy.

EXAMPLE:

1. The e.m.f. of a cell is 1.5 V. What is the work done in driving 0.4 C of charge around a circuit?
2. The e.m.f. of a battery is 6 V. What will be the amount of energy dissipated by the battery if a charge of 0.2 C is driven around the circuit?

SOLUTION:

1. $\varepsilon = 1.5\ V = 1.5\ J/C$

$Q = 0.4\ C$

$\varepsilon = \frac{W}{Q}$

Therefore:

$W = \varepsilon Q$

$= \quad 1.5\ J/C \ x\ 0.4\ C$

$= \quad 0.6\ J$

2. $\varepsilon = 6\ V = 6\ J/C$

$Q = 0.2\ C$

$W = 6\ J/C \times 0.2\ C$

$= \quad 1.2\ J$

Activity

Activity 3

Solve the following problems:

1. A battery with an e.m.f. of 3 V drives a an electric charge of 0.8 C. What is the work done to drive the charge?

_____
_____
_____
_____

2. A car battery is used to give light energy through car lamps of 50J. If the charge travelling in the wires of the car is 16 C, calculate the e.m.f. of the car battery.

_____
_____
_____
_____

3. Calculate the charge being pushed by a cell with an e.m.f. of 1.5 V if the work done to push the charge is 6 J.

_____
_____
_____
_____

Compare your solutions with those below at the end of this section. Be sure that you understand the solution to each question before proceeding.

Note it!

The key points to remember in this section on electromotive force are:

- The electromotive force is the work done by a source of electrical energy to drive a unit charge around a complete circuit.

$$\varepsilon = \frac{W}{Q}$$

- The work done by the source is the same as the energy converted from a non-electrical form to the electrical form when the charge passes through the source.
- The SI unit of the e.m.f. is the volt (V) which is the same as joule/coulomb (J/C).

If you know this content well, continue to the next section which covers potential difference.

Answers to Activities on Electromotive Force:

Activity 3

1. $\varepsilon = 3\ V = 3J/C$

$Q = 0.8\ C$

$\varepsilon = \frac{W}{Q}$

Therefore:

$W = \varepsilon Q$

$= 3\ J/C \times 0.8\ C$

$= 2.4\ J$

2. $W = 50\ J$

$Q = 16\ C$

$\varepsilon = \frac{W}{Q}$

$= \frac{50\ J}{16\ C}$

$= 3.125\ J/C$

$= 3.125\ V$

3. $\varepsilon = 1.5\ V = 1.5\ J/C$

$W = 6\ J$

$\varepsilon = \frac{W}{Q}$

Therefore:

$Q = \frac{W}{\varepsilon}$

$$Q = \frac{6\ J}{1.5\ V}$$
$$= 4\ C$$

Section 22-3: Potential Difference

Introduction

At the end of this section, you should be able to describe how potential difference relates to current electricity, calculate potential difference using formulae and describe the use of a voltmeter.

Time

There are 4 pages on the topic of potential difference. You should spend approximately 40 minutes on this topic.

Potential Difference

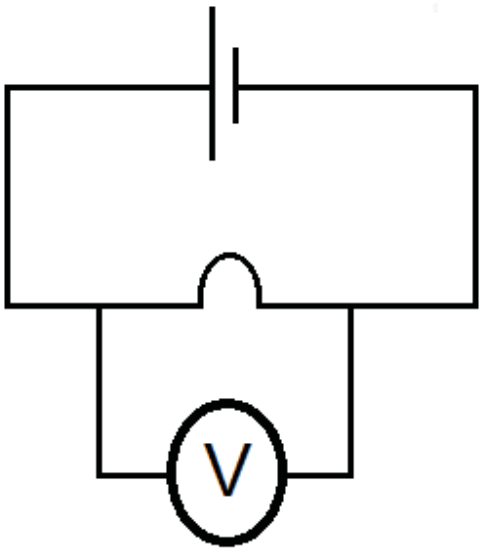


Figure 4: Potential difference in a bulb. Hand drawn by graphic designer at LDTC.

Based on Figure 4, If the cell was to be removed from the circuit, would the bulb light? Why or why not?

_____

_____

_____

_____

Compare your answer to this one provided.

The bulb would not light. The e.m.f. of the cell provides the energy needed by the bulb to light up.

In the figure, a voltmeter (*refer to circuit diagrams*) is connected across the bulb. This voltmeter measures the potential difference (p.d.) across the bulb. What is this potential difference?

The potential difference across a component in a circuit is the work done to drive a unit charge through the component.

Potential difference $= \frac{Work\ done}{Charge}$

$V = \frac{W}{Q}$

Where V is the potential difference

W is the work done

Q is the charge

The SI unit of the p.d. is the volt (V). Another name for the p.d is ***voltage.***

The p.d. across two points in a circuit is measured by a voltmeter as shown by Figure 4. Figure 5 shows a typical voltmeter that can be used in a laboratory to measure p.d. or voltage. In order to measure the p.d., a voltmeter must always be connected **in parallel (*across*)** to the component in which it is being measured as in Figures 2 and 4.

For correct readings, the positive terminal of a cell/battery must connect to the positive terminal of a voltmeter and the negative terminal of the cell/battery must connect to the negative terminal of the voltmeter.

Figure 5: A voltmeter accessed from Wikimedia Creative Commons, 2010.

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Examples:

1. When a charge of 4 C flows through a potential difference of 16V, how much energy is involved?
2. Calculate the p.d. across an electrical heater that gives out heat energy of 9 MJ when a charge of 3.75 x 10^4 C passes through the heater.

SOLUTION:

1. V = $\frac{W}{Q}$

Therefore:

$W = VQ$

$= 16\ V \times 4\ C$

$= 64\ J$

2. V = $\frac{W}{Q}$

$= \frac{9 \times 10^6\ J}{3.75 \times 10^4\ C}$

$= 240$ V

Activity 4

Answer the following questions in the spaces provided.

Activity

1. What is the difference between electromotive force (e.m.f.) and potential difference (p.d.)?

2. Calculate the amount of energy involved when a charge of 3 C flows through a p.d. of 10 V.

3. An electric kettle uses 18 MJ of electrical to boil water when a charge of 7.5 x 10^4 C passes through it. Calculate the p.d. across the kettle.

Compare your answers to the correct ones given below. Spend the time needed to understand each answer.

Answers to Activities on Potential Difference

Activity 4

1. ***The e.m.f. is a measure of how much work would be done by a cell/battery to move an electric charge. The p.d. on the other hand is the work done to drive the electric charge through a component in a circuit.***

2. $V = \frac{W}{Q}$

   Therefore:

   $W = VQ$

   $= 10\ V \times 3\ C$

   $= 30\ J$

3. $V = \frac{W}{Q}$

$= \frac{18 \times 10^6\ J}{7.5 \times 10^4\ C}$

$= 240\ V$

The key point to remember in this section on potential difference is:

Note it!

- The p.d. across a component in a circuit is the work done to drive the electric charge through the component. The work done is equal to the energy converted from electrical energy to other forms of energy of the component.

  $V = \frac{W}{Q}$

If you can comfortably follow this material, continue to the next section that covers resistance.

Section 23-4: Resistance

Introduction

At the end of this section, you should be able to describe how resistance relates to current electricity, calculate resistance using formulae and describe Ohm's law and its limitations.

Time

There are 12 pages on the topic of resistance. You should spend approximately 2-4 hours on this topic.

Resistance

Reflection

Resistance is a property of a material in which the material restricts the movement of current in the material. Resistance therefore determines the amount of current that can pass through a material. It acts in a similar way to friction as explained in Unit 12 on force.

If you have access to the internet, please go to:
http://phet.colorado.edu/en/simulation/battery-resistor-circuit

Describe the movement of the electrons through the resistor. How does it compare to the movement of electrons through the rest of the circuit?

To find the resistance of any material the following formula is used:

$R = \frac{V}{I}$

Where R is the resistance of a material

V is the voltage/p.d.

I is the current.

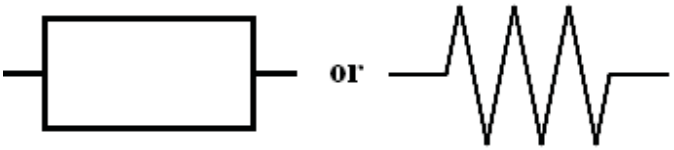
The SI unit of resistance is the ohm (Ω). $1\ \Omega = \frac{1\ A}{1\ V}$

Reflection

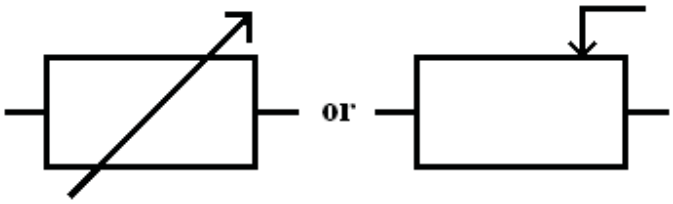
Go back to: http://phet.colorado.edu/en/simulation/battery-resistor-circuit
What happens to I (amps) /flow of electrons when you increase the resistance? What happens to I(A)/ flow of electrons when you increase the voltage (V)?

Materials that are used specifically to provide a known value of resistance in a circuit are called resistors. The purpose of a resistor is to control the amount of current flowing in a circuit. There are two types of resistors, the fixed resistor and the variable resistor often called a rheostat. The following are symbols of resistors used in circuit diagram. Figure 6(a) is a photograph of fixed resistors and 6(b) is a photograph of a variable resistor.

Fixed resistor



Variable resistor/rheostat



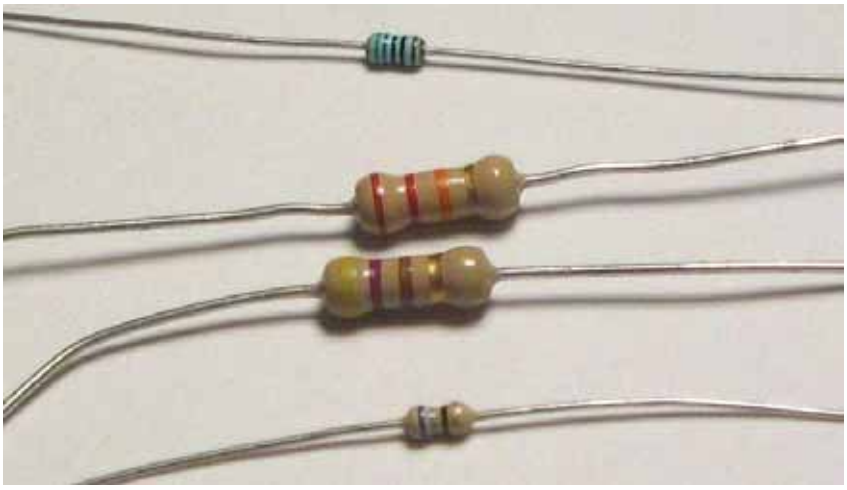


Figure 6(a): Fixed resistors accessed from Wikipedia Creative Commons, 2010.

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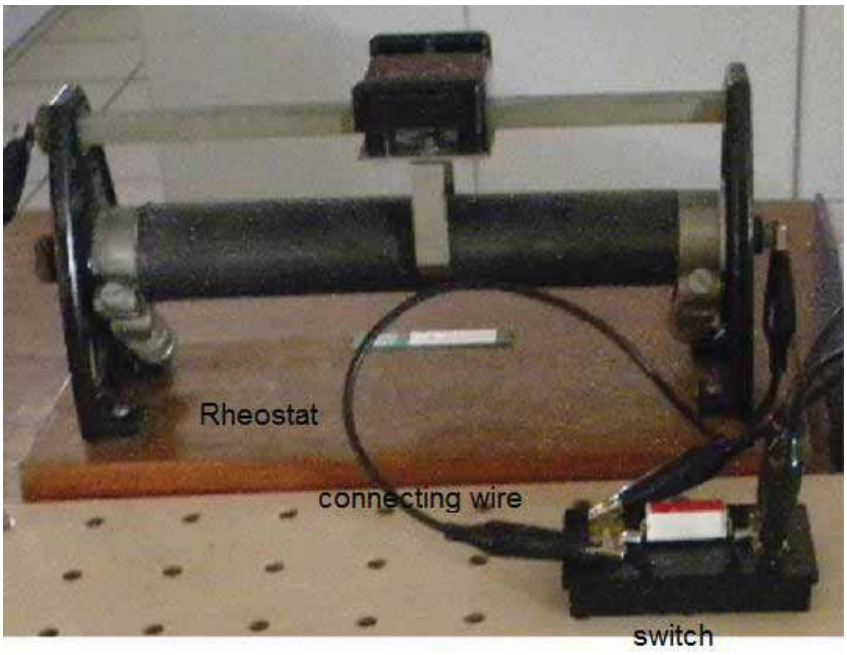

Figure 6(b): A rheostat connected to a switch accessed from Wikipedia Creative Commons, 2010.

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Examples:

1. A lamp draws a current of 0.3 A when it is connected to a 240 V source. Calculate the resistance of the lamp.
2. What is the current flowing through a 3 Ω resistor when a p.d. of 1.5 V is applied to it.

SOLUTIONS:

1. $I = 0.3\ A$

$V = 240\ V$

$R = \frac{V}{I}$

$= \frac{240\ V}{0.3\ A}$

$= 800\ \Omega$

2. $R = 3\ \Omega$

$V = 1.5\ V$

$R = \frac{V}{I}$

Therefore:

$I = \frac{V}{R}$

$= \frac{1.5\ V}{3\ \Omega}$

$= 0.5\ A$

Activity

Activity 5

An experiment to determine the resistance of a resistor using a voltmeter and an ammeter

If there is a nearby school, ask your tutor if you can do the experiment there. Otherwise you will have to cope with just reading how it is done.

Apparatus:

- voltmeter
- ammeter
- variable resistor
- fixed resistor of unknown value

Procedure: 1. Set up the apparatus as shown by the figures 7(a) and 7(b) below.

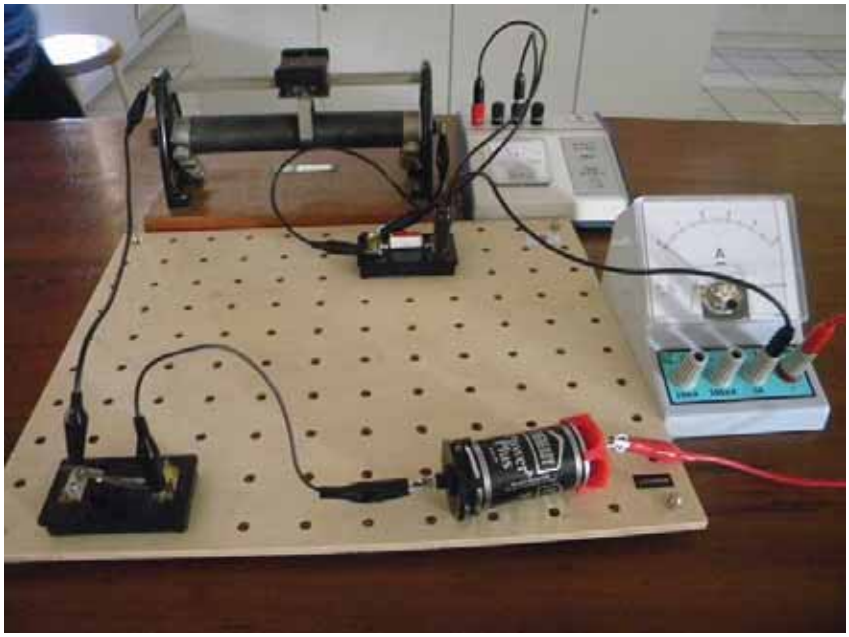

Figure 7(a): Activity 5 Setup. Photo taken by LDTC.

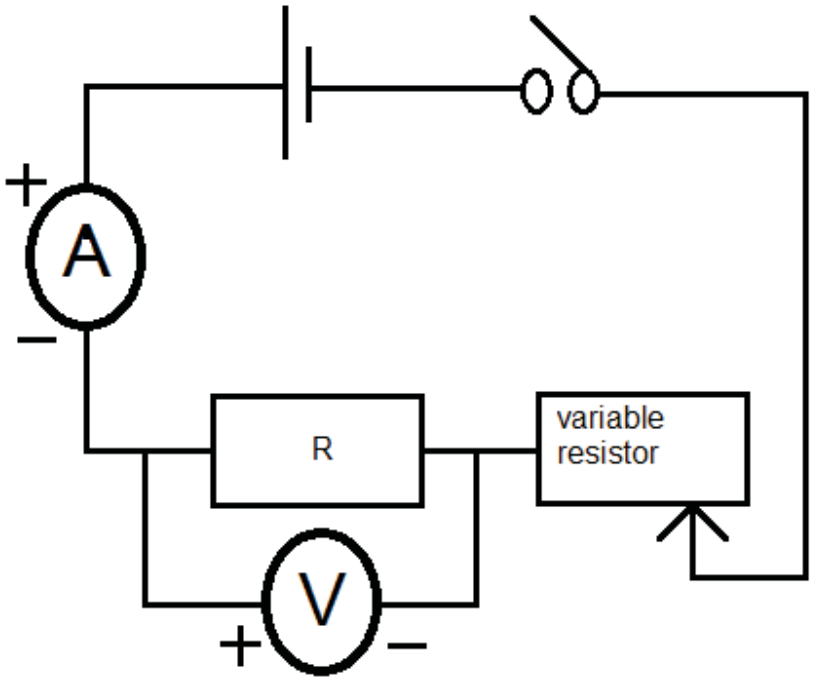

Figure 7(b): Schematic Diagram of Activity 5. Hand drawn by graphic designer at LDTC.

2. Close the switch and adjust the variable resistor to allow for the smallest possible current shown by the ammeter to flow in the circuit.

3. Note the voltmeter and ammeter readings.

4. Adjust the variable resistor again to allow a different current to flow in the circuit. Again note the voltage and current readings. Tabulate your results as shown in the table below.

Voltage V (V)	Current I (A)

5. Repeat step 4 until you have completed the chart.

Results: If you were not able to perform the above steps, the table below that has typical results for voltage and current.

Voltage V (V)	Current I (A)
20.0	1.5
25.0	2.1
35.0	3.0
45.0	4.1
60.0	5.6
74.0	7.0

6. Plot a graph of V against I in the space provided below to determine the gradient of the graph. The gradient, $\frac{V}{I}$ of the line represents the average value of R.

Compare your graph with the graph below:

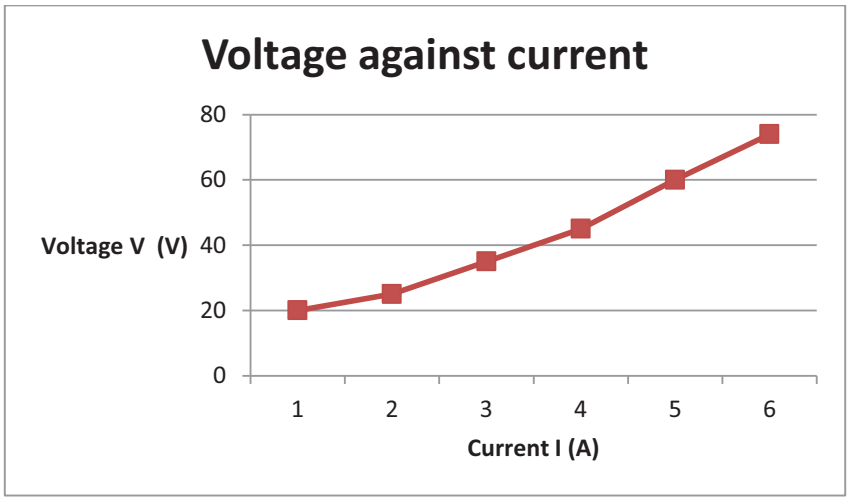

Figure 7(c): Graph of V against I. Hand drawn by graphic designer at LDTC.

Calculation of the gradient of the graph:

$\frac{V}{I}$	**Gradient**
$\frac{20}{1.5}$	13.33
$\frac{25}{2.1}$	11.9
$\frac{35}{3}$	11.67
$\frac{45}{4.1}$	10.97
$\frac{60}{5.6}$	10.71
$\frac{74}{7}$	10.57

In experiments like the one above, there is usually some experimental error. For example, the gradients are different and not accurate. Therefore the average of all six gradients has to be calculated as:

$$\frac{13.33 + 11.9 + 11.67 + 10.97 + 10.71 + 10.57}{6}$$

$$= \frac{69.15}{6}$$

$$= 11.53\ \Omega$$

Conclusion: The gradient of a voltage V against current I equals the resistance of the unknown resistor.

The resistance of a given piece of wire depends on the length of the wire and its cross-sectional area.

Think of water flowing through a hose. The amount of water flowing through the hose is comparable to the current in the wire. Just as more water can pass through a fat fire hose than a skinny garden hose, a fat

wire can carry more current than a skinny wire. **The larger the cross-sectional area of a wire, the lower the resistance. The smaller the cross-sectional area of a wire, the higher the resistance.** Now consider the length. It is harder for water to flow through a very long hose simply because it has to travel farther. Similarly, it is harder for current to travel through a longer wire. **A longer wire will have a greater resistance.**

Reading

Read more: http://science.jrank.org/pages/2335/Electrical-Resistance.html#ixzz0Vbhj0RTL

From the above two conclusions can be made:

R is inversely proportional to the cross sectional area A and R is proportional to l.

$R \quad \alpha \quad \frac{1}{A}$

$R \quad \alpha \quad l$

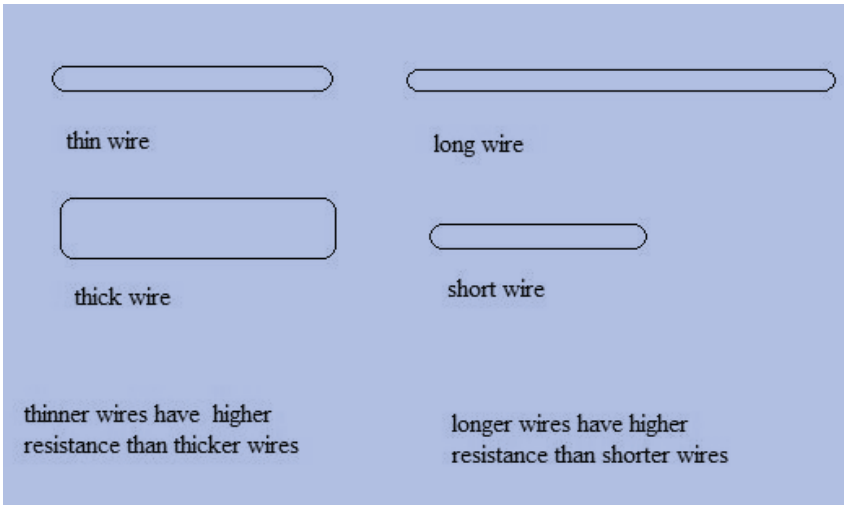

Figure 8: Resistance in wires. Hand drawn by graphic designer at LDTC.

Ohm's Law

The current (I) passing through a metallic conductor is directly proportional to the potential difference V, between its ends provided temperature and other physical conditions are constant (e.g. length of the conductor).

$I \quad \alpha \quad V$

This is the same as:

$\frac{V}{I} \quad = \quad$ constant

The constant is called resistance hence the equation:

$$R = \frac{V}{I}$$

A conductor that obeys Ohm's Law is called an **ohmic conductor**. Not all materials obey Ohm's law. Those that do not are called **non-ohmic conductors**. As shown by Activity 4, V and I can be measured experimentally and a graph can be plotted to show results.

The following graphs show typical results for ohmic and non-ohmic conductors. The voltage is usually put on the y-axis and the current on the x-axis. This is done to let resistance be found from the gradient.

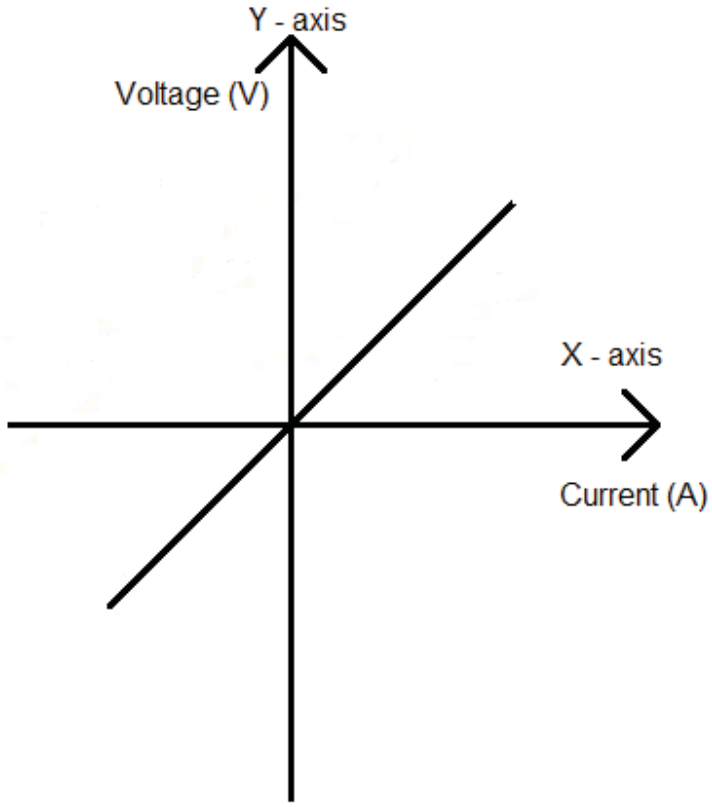

Figure 9: V/I characteristics for ohmic conductors. Hand drawn by graphic designer at LDTC.

The straight line illustrates a **constant ratio** between voltage and current, for both positive and negative values. Ohm's Law is therefore obeyed.

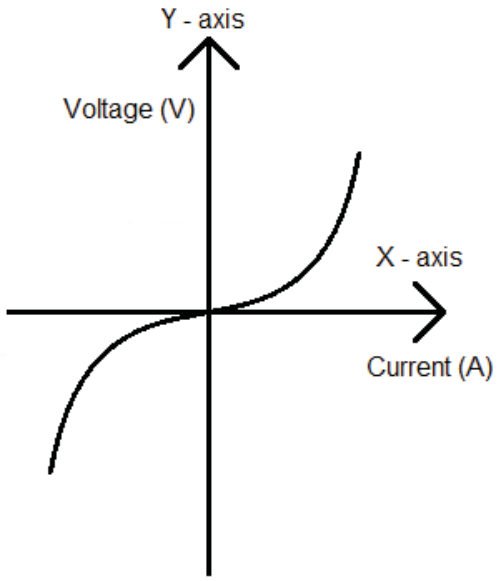

Figure 10: V/I characteristics of a filament bulb. Hand drawn by graphic designer at LDTC.

In Figure 10, the resistance **increases** as the filament gets **hotter**. This is shown when the **gradient gets steeper**.

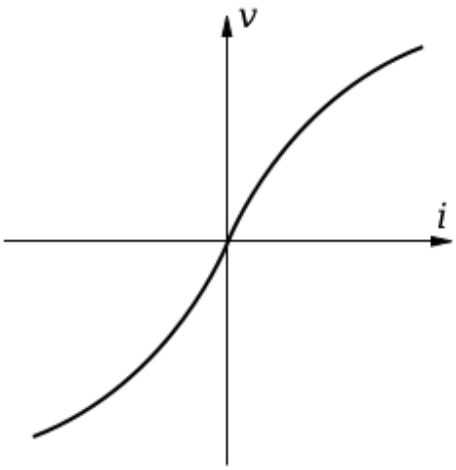

Figure 11: V/I characteristics of a thermistor accessed from Creative Commons, 2010.

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Figure 11 shows the resistance of a thermistor, a heat sensitive resistor.

A **thermistor** is a type of resistor whose resistance varies with temperature. Thermistors are used as:

- temperature sensors
- self-resetting overcurrent protectors
- self-regulating heating elements

Help

Need more help visualising Ohm's Law? Go to: http://phet.colorado.edu/sims/ohms-law/ohms-law_en.html to see the effects if increasing/decreasing V, I or R!

Activity

Activity 6

Answer the following questions by referring to the subunit on Ohm's Law.

1. What is Ohm's Law?

   _____
   _____
   _____
   _____

2. Refer to Figure 10. Why does the shape of the graph in Figure 10 suggest that a light bulb does not obey Ohm's Law?

   _____
   _____
   _____
   _____

3. Does a thermistor obey Ohm's Law? Give an explanation to your answer.

   _____
   _____
   _____
   _____

Compare your answers to the correct ones given at the end of this section. Be sure you understand the explanations before continuing.

The key points to remember in this section on resistance are:

Note it!

- **Ohm's Law** states that the current in a metallic conductor is directly proportional to the potential difference between its ends provided that the temperature and other physical conditions remain constant.

  $$R = \frac{V}{I}$$

- Materials that obey Ohm's law are called ohmic conductors and those that do not are called non-ohmic conductors.

If you know the content on resistance well, continue to the next section that covers electric circuits.

Answers to Activities on Resistance

Answers to Activity 6

1. ***Current and voltage current are directly proportional: $I \propto V$ if temperature is the same.***
2. ***It is not a straight line.***
3. ***A thermistor does not obey Ohm's Law because:***
   a) ***Its graph of V/I is not a straight line.***
   b) ***The thermistor gets hot resulting in decrease in resistance.***

Section 23-5: Electric Circuits

Introduction

At the end of this section, you should be able to calculate the net effect of a number of resistors connected in series and in parallel.

Time

There are 20 pages on the topic of electric circuits. You should spend approximately 6-7 hours on this topic.

Electric Circuits

As we have earlier explained, an electric circuit is a complete or closed path of current. There are two types of circuits, series circuits and parallel circuits.

Series Circuits

In a **series circuit**, there is only one path in which charge can flow, therefore, current is the same through every component in the circuit. In Figure 12, all ammeter readings, A1, A2, A3 and A4 are the same when the switch is closed.

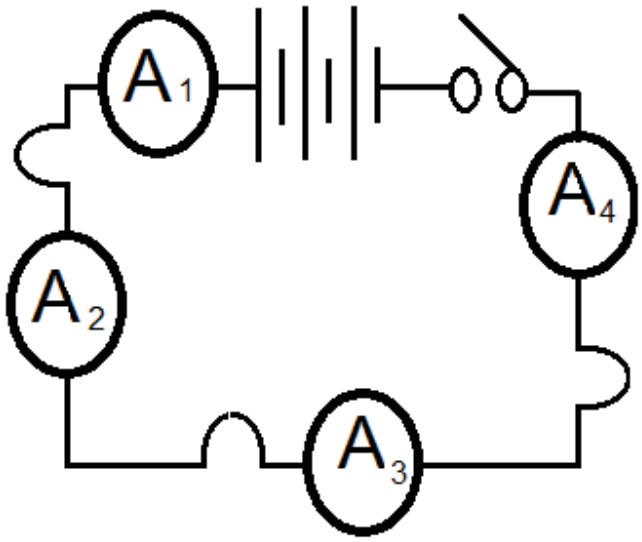


Figure 12: Current in a Series Circuit. Hand drawn by graphic designer at LDTC.

Resistors in Series

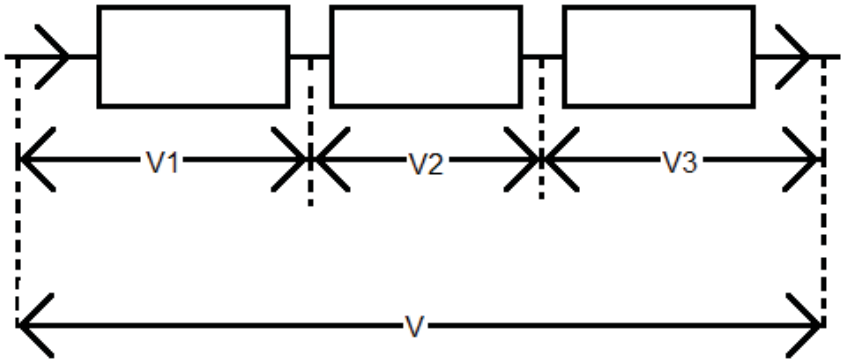


Figure 13: Current flowing in resistors in series. Hand drawn by graphic designer at LDTC.

In Figure 13, three resistors R1, R2 and R3 are connected in series and the current flowing in the them (I) is the same. The sum of individual p.d's/voltages V1, V2 and V3 across R1, R2 and R3 is equal to the voltage V across all three resistors. According to Ohm's law, the potential differences V1, V2, and V3 across R1, R2 and R3 can be found by using the equations

$V1 = IR1,$

$V2 = IR2,$

$V3 = IR3$

Let V be the p.d. across the combination of all three resistors and R be the combined resistance of the three resistors.

Since $V = V1 + V2 + V3$

$= IR1 + IR2 + IR3$

$= I(R1 + R2 + R3)$

Therefore $\frac{V}{I} = R1 + R2 + R3$

By definition $\frac{V}{I} = R$

Therefore $R = R1 + R2 + R3$

In general, if we have *n* resistors in a series circuit, where $n \geq 2$, the combined resistance is given by:

$$R = R1 + R2 + \ldots + Rn$$

Examples:

1. Four resistors R1 = 3 Ω, R2 = 12 Ω, R3 = 5Ω and R4 = 4 Ω are connected in series to a 12 V battery.
   a) Calculate the current that flows in this circuit.
   b) What is the p.d. across each resistor?

2. Find the combined resistance of the resistors in series as shown by figure 14 given that R1 = 1 Ω, R2 is unknown and R3 = 2 Ω. The current I recorded in the ammeter is 2A and the voltmeter reading across R2 is 6V.

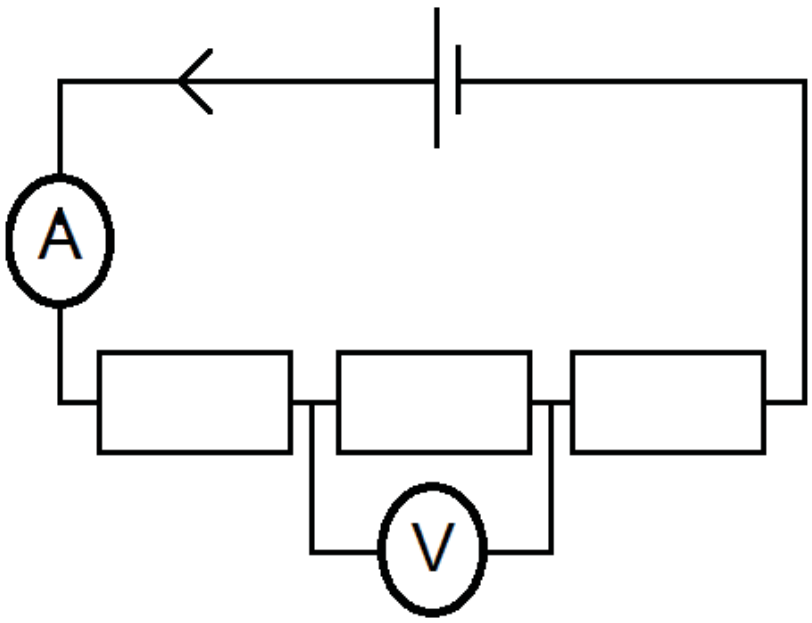


Figure 14: Three resistors in series. Hand drawn by graphic designer at LDTC.

SOLUTIONS:

1. *To answer this question, having a circuit diagram is best in order to get a picture as shown by Figure 15:*

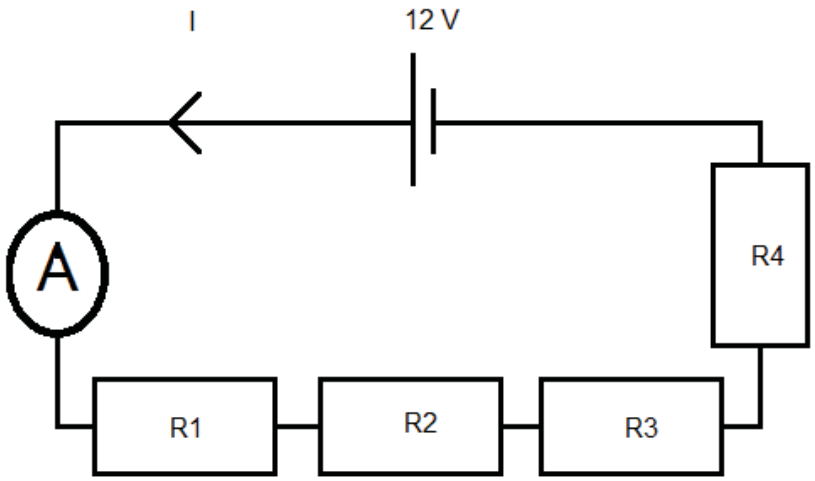


Figure 15: Four resistors in series. Hand drawn by graphic designer at LDTC.

a) The total resistance in the circuit is:

$R = 3\ \Omega + 12\ \Omega + 5\ \Omega + 4\ \Omega$

$= 24\ \Omega$

$I = \frac{V}{R}$

$= \frac{12V}{24\Omega}$

$= 0.5\ A$

b) In a series circuit, current is the same for all four resistor.Then:

For R1, $V1 = IR1$

$= 0.5A \times 3\ \Omega$

$= 1.5V$

For R2, $V2 = IR2$

$= 0.5A \times 12\ \Omega$

$= 6V$

For R3, $V3 = IR3$

$= 0.5A \times 5\ \Omega$

$= 2.5V$

For R4, $V4 = IR4$
$= 0.5A \times 4\ \Omega$
$= 2V$

Note that the sum of the four separate p.d.'s is 12V.

2. *Use the diagram provided in the question.*
By definition the unknown resistance:

$R2 = \frac{V}{I}$

$= \frac{6V}{2A}$

$= 3\ \Omega$

For resistors in series, the combined resistance R is given by:

$R = R1 + R2 + R3$
$= 1\ \Omega + 3\ \Omega + 2\ \Omega$
$= 6\ \Omega$

Activity 7

Calculate the following in the provided spaces:

Activity

1. Four resistors R1 = 6 Ω, R2 = 24 Ω, R3 = 10Ω and R4 = 8 Ω are connected in series to a 24 V battery.

a) Calculate the current that flows in this circuit.

b) What is the p.d. across each resistor?

2. Find the combined resistance of the resistors in series as shown by figure 15 given that R1 = 2 Ω, R2 = 4 Ω and R3 is unknown. The current I recorded in the ammeter is 3A and the voltmeter reading across R3 is 12V.

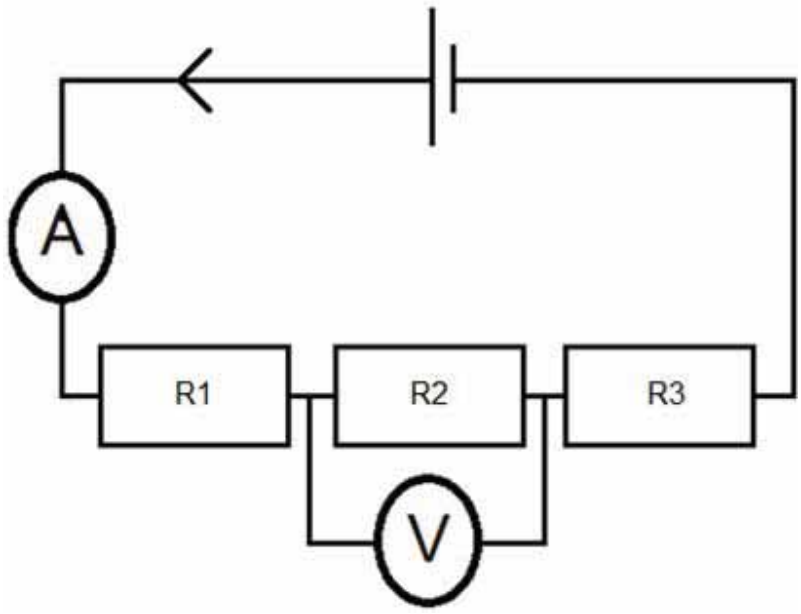


Figure 16: Three resistors in a series circuit. Hand drawn by graphic designer at LDTC.

After completing the two questions, compare your answers to the correct answers provided at the end of the section. If you answered each question correctly continue on to parallel circuits. If you made one or more mistakes review the content and try this activity again.

Parallel Circuits

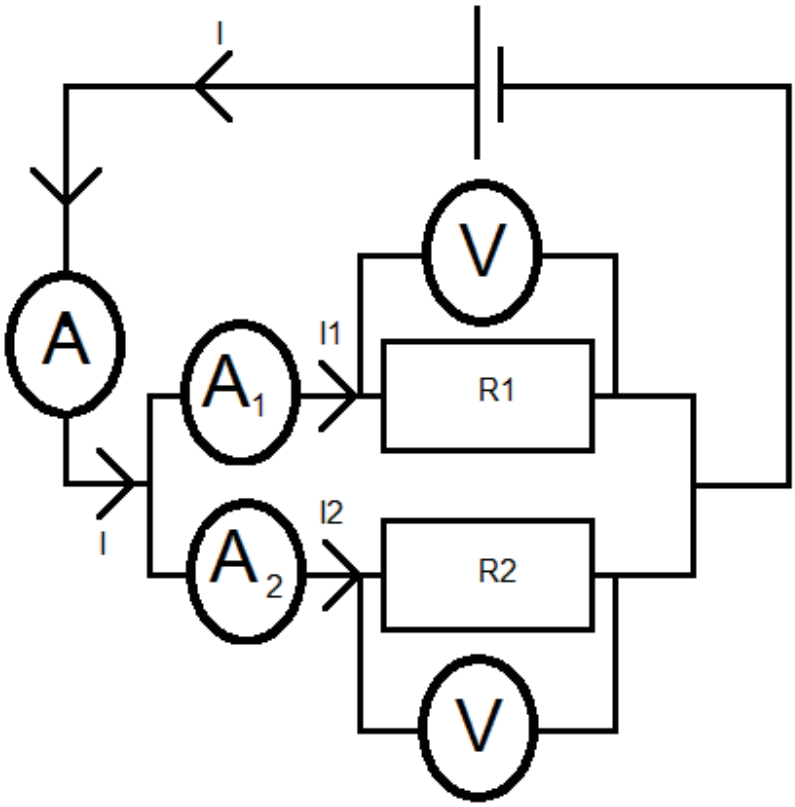


Figure 17: A parallel circuit. Hand drawn by graphic designer at LDTC.

Figure 17 shows a circuit in which two resistors R1 and R2 are connected in parallel. In parallel circuits, there is more than one path that current can follow.

Potential Difference and Current in a Parallel Circuit

The two voltmeters in Figure 17 connected across R1 and R2 will register the same reading. This means that the p.d. across the two resistors in parallel is the same. On the other hand, the two ammeters A1 and A2 will register two different readings from ammeter A. This means that current I splits into currents I1 and I2 in the parallel connection.

Note that the current does not necessarily split evenly. The amount of current in each path is determined by the amount of resistance in each path.

$$V = V1 = V2$$

$$I = I1 + I2$$

Resistors in Parallel

Current from the cell is shared by the two resistors whereas the p.d. is common to both resistors. Therefore:

$$I = \frac{V}{R} = \frac{V}{R1} + \frac{V}{R2}$$

Where R is the combined resistance of the two resistors. Therefore for a parallel circuit the combined resistance is found by:

$$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2}$$

In general if we have *n* resistors in a parallel circuit, where $n \geq 2$, the combined resistance is given by:

$$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} \cdots \frac{1}{Rn}$$

Example:

1. Find the combined resistance of the resistors shown by Figure 18 below.

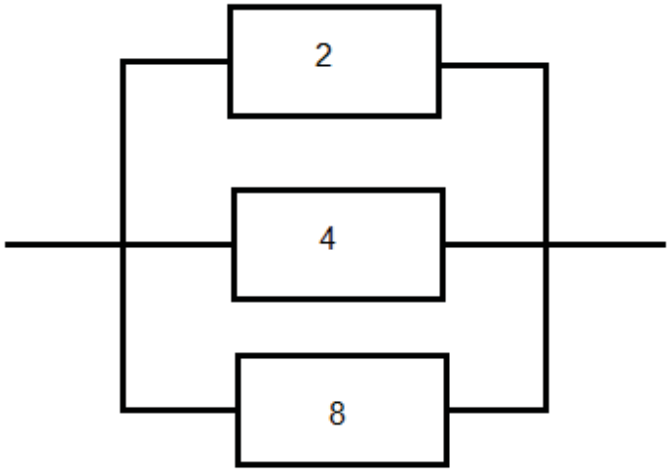


Figure 18: Three resistors in parallel. Hand drawn by graphic designer at LDTC.

SOLUTION:

$$1.\quad \frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$$

$$= \frac{1}{2} + \frac{1}{4} + \frac{1}{8}$$

$$= \frac{4}{8} + \frac{2}{8} + \frac{1}{8}$$

$$= \frac{7}{8}$$

$$\textit{Therefore } R = \frac{8}{7}\,\Omega$$

$$= 1\frac{1}{7}\,\Omega$$

$$= 1.14\,\Omega$$

Activity 8

Activity

Do the following two problems on resistors in parallel in the spaces provided.

1. Find the effective resistance of the resistors connected in parallel as shown by Figure 19.

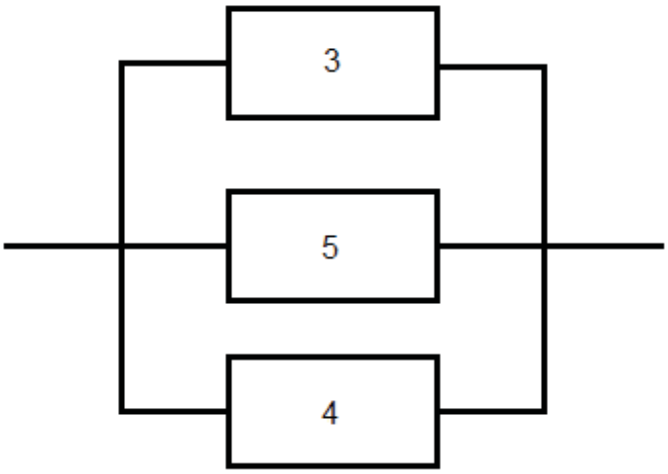


Figure 19: Resistors in parallel. Hand drawn by graphic designer at LDTC.

2. For Figure 20 below, calculate:

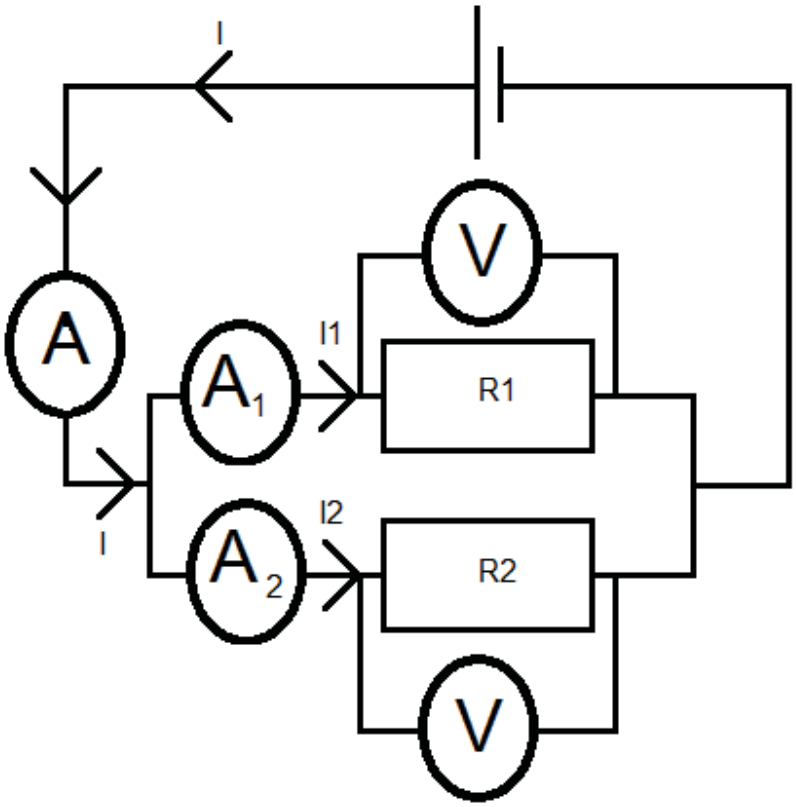


Figure 20: Parallel resistors in a circuit. Hand drawn by graphic designer at LDTC.

a) The effective resistance, if R1 = 3 Ω and R2 = 6 Ω.

b) If the voltage in the cell is 12 V, what will be the ammeter A reading?

Compare your answers to the correct answers at the end of the section. If needed, review this content on resistors in parallel before continuing.

Resistors in Series and in Parallel

Electric circuits can be very complex. This topic covers circuits that contain resistors in series and in parallel.

Example:

1. Figure 21 shows a 4 Ω and a 12 Ω resistor being connected in parallel and a 5 Ω resistor is connected in series with them. Calculate:

a) The combined resistance of 4 Ω and 12 Ω resistors.
b) The total resistance of all three resistors.

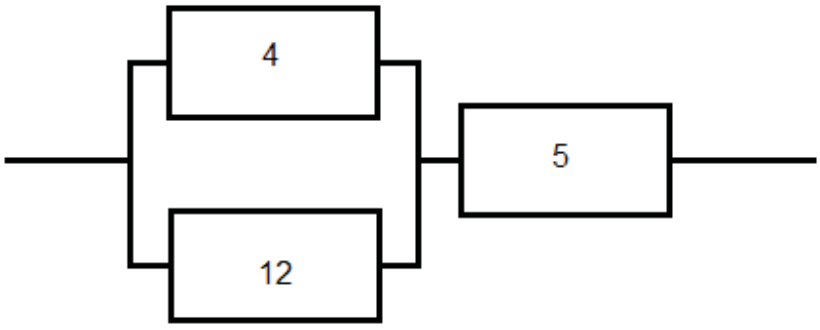


Figure 21: Resistors in a circuit. Hand drawn by graphic designer at LDTC.

SOLUTION:

1. *Since the 4 Ω and the 12 Ω resistors are in parallel, then*

a)

$$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2}$$

$$= \frac{1}{4} + \frac{1}{12}$$

$$= \frac{3}{12} + \frac{1}{12}$$

$$= \frac{4}{12}$$

$$R = \frac{12}{4}$$

$$= 3\ \Omega$$

b) The two parallel resistors are now in series with the 5 Ω resistor; their total resistance is then given by:

$$R_{total} = R + 5\ \Omega$$

$$= 3\ \Omega + 5\ \Omega$$

$$= 8\ \Omega$$

Activity

Activity 9

Work out the following question in the spaces provided:

1. Using Figure 22 below:

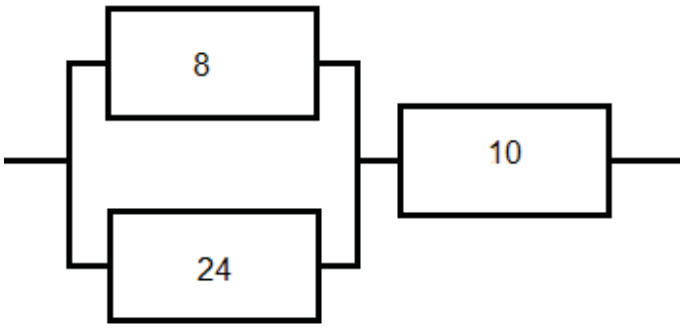


Figure 22: Resistors in a circuit. Hand drawn by graphic designer at LDTC.

a) Calculate the combined resistance of the 8 Ω the 24 Ω.

_____
_____
_____
_____

b) The total resistance of the three resistors.

_____
_____
_____
_____

2. In an electric circuit, resistors R1 = 4.0 Ω and R2 = 16.0 Ω are connected in parallel, while resistor R3 = 4.8 Ω is connected in series with them, as shown in Figure 23.

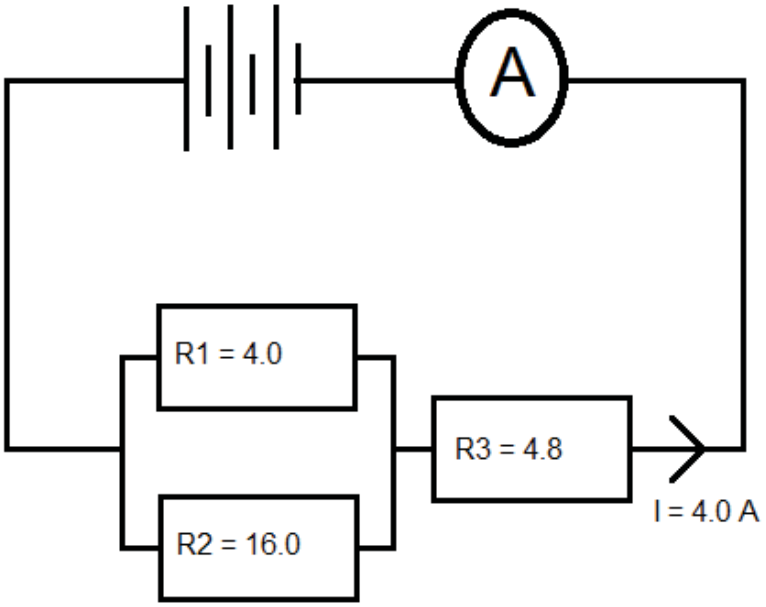


Figure 23: Resistors in series and parallel. Hand drawn by graphic designer at LDTC.

If a current of 4.0A flows through R3, calculate:

a) The combined resistance of R1, R2 and R3.

b) The p.d. across the combined resistance.

c) The current flowing through R1.

Compare your answers to the correct answers provided at the end of this section. If you can do the calculations involving resistors in both series and parallel, continue on.

The key points to remember in this subunit on electric circuits are:

Note it!

- The current at every point in a series circuit is the same.
- The sum of p.d.'s in a series circuit equals the p.d. across the whole circuit.
- For *n* resistors in a series circuit where $n \geq 2$, the combined resistance R is given by

  $R = R1 + R2 + ...+ Rn$

- The current from the source in a parallel circuit is the sum of currents in the individual branches.
- The p.d. across one or more resistors in parallel is the same.
- For *n* resistors in a series circuit where $n \geq 2$, the combined resistance R is given by:

$$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} \dots \frac{1}{Rn}$$

If you know the content on electric circuits well, continue to the unit summary.

Answers to Activities On Electric Circuits

Activity 7

1. *To answer this question, having a circuit diagram is best in order to get a picture as shown by Figure 24:*

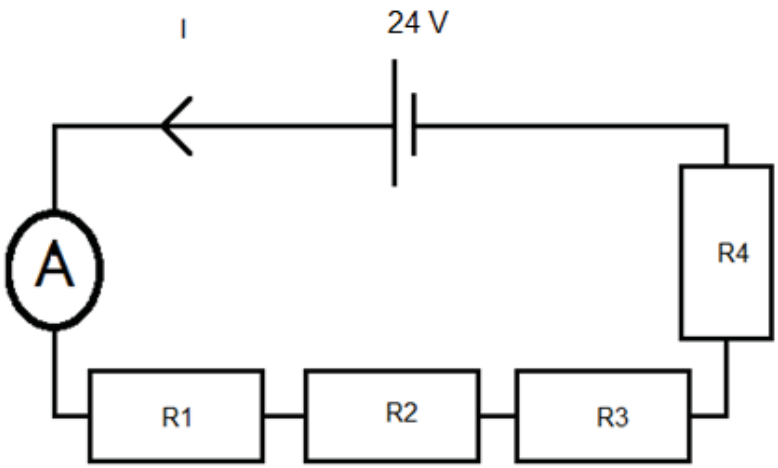


Figure 24: Hand drawn by graphic designer at LDTC.

a) The total current in the circuit is:

$$R = 6\,\Omega + 24\,\Omega + 10\,\Omega + 8\,\Omega$$
$$= 48\,\Omega$$

$$I = \frac{V}{R}$$
$$= \frac{24V}{48\Omega}$$
$$= 0.5\,A$$

b) In a series circuit, current is the same for all four resistors. Then:

For R1, $V1 = IR1$
$= 0.5A \times 6\,\Omega$
$= 3V$

For R2, $V2 = IR2$
$= 0.5A \times 24\,\Omega$

$= 12V$

For R3, $V3 = IR3$
$= 0.5A \times 10\ \Omega$
$= 5V$

For R4, $V4 = IR4$
$= 0.5A \times 8\ \Omega$
$= 4V$

Note that the sum of the four separate p.d.'s is 24V.

2. Use figure 15, given V at R3 = 24 V and I = 3 A
By definition the unknown resistance

$R3 = \frac{V}{I}$

$= \frac{12V}{3A}$

$= 4\ \Omega$

For resistors in series, the combined resistance R is given by

$R = R1 + R2 + R3$
$= 2\ \Omega + 4\ \Omega + 4\ \Omega$
$= 10\ \Omega$

Activity 8

1. $\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}$

$= \frac{1}{3} + \frac{1}{5} + \frac{1}{4}$

$= \frac{20}{60} + \frac{12}{60} + \frac{15}{60}$

$= \frac{47}{60}$

$R = \frac{60}{47}$

$= 1.28\ \Omega$

2. **a)** $\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2}$

$= \frac{1}{3} + \frac{1}{6}$

$= \frac{2}{6} + \frac{1}{6}$

$= \frac{3}{6}$

$= \frac{1}{2}$

$R = \frac{2}{1}$

$R = 2\ \Omega$

b) $I = \frac{V}{R}$

$= \frac{12}{2}$

$= 6\ A$

Activity 9

1. Since the 4 Ω and the 12 Ω resistors are in parallel, then a)

$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2}$

$= \frac{1}{8} + \frac{1}{24}$

$= \frac{3}{24} + \frac{1}{24}$

$$= \frac{4}{24}$$

$$R = \frac{24}{4}$$

$$= 6\ \Omega$$

b) The two parallel resistors are now in series with the 5 Ω resistor; their total resistance is then given by:

$$R_{total} = R + 5\ \Omega$$

$$= 6\ \Omega + 10\ \Omega$$

$$= 16\ \Omega$$

2. *a) Let us first find the combined resistance R4 of the resistors in parallel.*

Given that $R1 = 4.0\ \Omega$

$R2 = 16.0\ \Omega$

Then:

$$\frac{1}{R4} = \frac{1}{R1} + \frac{1}{R2}$$

$$= \frac{1}{4.0} + \frac{1}{16.0}$$

$$= \frac{5}{16}$$

Therefore:

$$R4 = \frac{16}{5}$$

$$R4 = 3.2\ \Omega$$

The combined resistance of R1 and R2, is 3.2 Ω. R1 and R2 are therefore now considered as one resistor R4 of 3.2 Ω. The arrangement of resistors in series can now be regarded as shown in Figure 25:

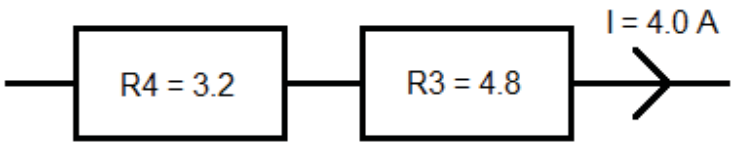


Figure 25: Combined Resistance. Hand drawn by graphic designer at LDTC.

Now let the combined resistance of all resistors be R. Given then that R4 = 3.2 Ω and R3 = 4.8 Ω:

$$R = R4 + R3$$
$$= 3.2\ \Omega + 4.8\ \Omega$$
$$= 8\ \Omega$$

The combined resistance of all three resistors is hence 8.0 Ω.

b) Now let the potential difference across the combined resistance be V.

Given then that $R = 8\ \Omega$
$I = 4\ A$
Use the equation $V = IR$
$= 4\ A \times 8\ \Omega$
$= 32\ V$

The potential difference across the combined resistance is therefore 32V.

c) The combined resistance of the parallel network R4 = 3.2 Ω. The potential difference across the parallel resistors is given by:

$$V = IR$$
$$= 4\ A \times 3.2\ \Omega$$
$$= 12.8\ V$$

So the p.d. across the parallel resistors is 12.8 V. For the 4 Ω resistor, R1 = 4 Ω, V = 12.8 V

$$I = \frac{V}{R}$$
$$= \frac{12.8\ V}{4\Omega}$$
$$= 3.2\ A$$

The current flowing through R1 is therefore 3.2 A.

Unit Summary

Summary

In this unit you learned that:

- An electric current is the rate of flow of charge.

  $I = \frac{Q}{t}$

- The instrument used to measure current in the ammeter.
- An ammeter must always be connected in series in an electric circuit to measure current.
- The electromotive force is the work done by a source of electrical energy to drive a unit charge around a complete circuit.

  $\varepsilon = \frac{W}{Q}$

- The work done by the source is the same as the energy converted from a non-electrical form to the electrical form when the charge passes through the source.
- The SI unit of the e.m.f. is the volt (V) which is the same as joule/coulomb (J/C).
- The p.d. across a component in a circuit is the work done to drive the electric charge through the component. The work done is equal to the energy converted from electrical energy to other forms of energy of the component.

  $V = \frac{W}{Q}$

- **Ohm's Law** states that the current in a metallic conductor is directly proportional to the potential difference between its ends provided that the temperature and other physical conditions remain constant.

  $R = \frac{V}{I}$

- Materials that obey Ohm's law are called ohmic conductors and those that do not are non-ohmic conductors.
- The current at every point in a series circuit is the same.
- The sum of p.d.'s in a series circuit equals the p.d. across the whole circuit.
- For n resistors in a series circuit where $n \geq 2$, the combined resistance R is given by

  $R = R1 + R2 + ... + Rn$

- The current from the source in a parallel circuit is the sum of currents in the individual branches.
- The p.d. across one or more resistors in parallel is the same.

- For *n* resistors in a series circuit where $n \geq 2$, the combined resistance R is given by

$$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} \cdots \frac{1}{Rn}$$

You have completed the material for this unit on current electricity. You should now spend some time reviewing the content. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers practical electrical circuitry.

Assignment 22

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:20]

Show all of your work for full marks.

Multiple Choice Questions (one mark each)

1. The current in a lamp is 0.2 A. If the lamp is switched on for 2 hours long, what is the electrical charge passing through the lamp?

   A 0.4 C

   B 240 C

   C 600 C

   D 1 440 C

2. The potential difference required to pass a current of 0.2 A in a wire of resistance 20 Ω is

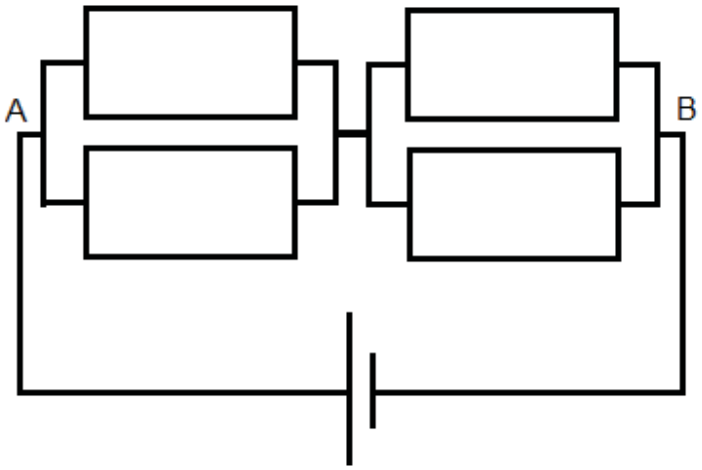
   A 0.1 V

   B 4 V

   C 40 V

   D 100 V

3. The figure below show four resistors each of 1 Ω connected in a circuit. What is the resistance across AB?



A 0.5 Ohms

B 1 Ohms

C 2 Ohms

D 4 Ohms

Structured Questions

1. Give the relationship between current I and charge Q. State the SI units of each quantity.

_____
_____
_____
_____
_____ (2)

2. A car battery is used to give light energy through car lamps of 100 J. If the charge travelling in the wires of the car is 25 C, calculate the e.m.f. of the car battery.

_____
_____
_____
_____
_____ (2)

3. a) What instrument is used to measure potential difference?

_____
_____
_____ (1)

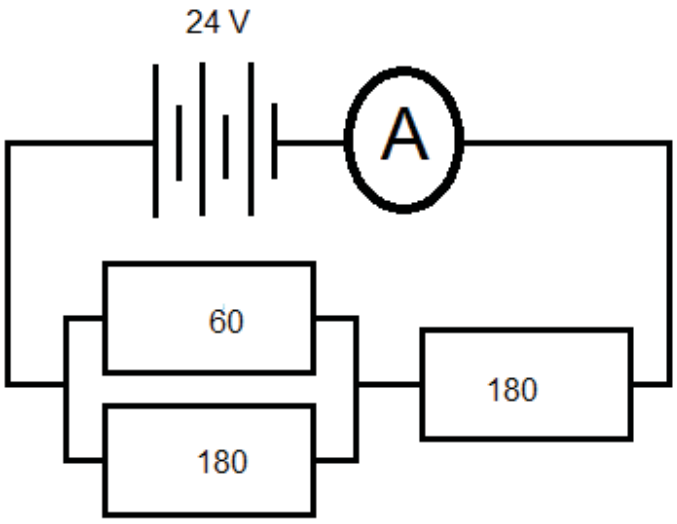
b) How should it be connected in a circuit?

_____
_____
_____ (1)

4. If a potential difference of 1.5V causes 3A of current to flow in a wire, how much current will flow when 6V is applied?

_____
_____
_____
_____
_____ (3)

5. In the circuit below:



a) Calculate the effective resistance of the resistors connected in parallel.

_____
_____
_____
_____
_____
_____
_____ (3)

b) Calculate the current flowing in the ammeter.

_____
_____
_____
_____
_____
_____
_____ (3)

c) Determine the current flowing through the 60 Ω resistor.

_____
_____(2)

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 22

Multiple Choice Questions

1. D

$Q = It$

$= 0.2\ A \times 2\ hours$

$= 0.2\ A \times (2 \times 60 \times 60)\ seconds$

$= 1\ 440\ C$

2. B

$V = IR$

$= 0.2\ A \times 20\ \Omega$

$= 4\ V$

3. D

$R_t = \left(\frac{1}{1} + \frac{1}{1}\right) + \left(\frac{1}{1} + \frac{1}{1}\right)$

$= 2 + 2$

$= 4\ \Omega$

Structured Questions

1. $I = \frac{Q}{t}$

The SI unit of: Current I is the ampere (A)

Charge Q is the coulomb (C)

Time t is the second (s)

2. $W = 100\ J$

$Q = 25\ C$

$\varepsilon = \frac{W}{Q}$

$= \frac{100\ J}{25\ C}$

$= 4\ J/C$

$= 4\ V$

3. a) A voltmeter is used to measure p.d.

b) It should be connected in parallel.

4. Voltage and current are proportional --- the voltage is multiplied by a factor of 4 so the current is also multiplied by 4. Hence 12A of current will flow.

1.5V x 4 = 6V hence 3A x 4 = 12 A

5. a) Let us first find the combined resistance R4 of the resistors in parallel.

Given that $R1 = 60\ \Omega$

$R2 = 180\ \Omega$

Then:

$\frac{1}{R4} = \frac{1}{R1} + \frac{1}{R2}$

$= \frac{1}{60} + \frac{1}{180}$

$= \frac{4}{180}$

Therefore:

$R4 = \frac{180}{4}$

$= 45\ \Omega$

The combined resistance R4 of R1 and R2 is 45 Ω. They are therefore now considered as one resistor R4 of 45 Ω.

b) *Now let the combined resistance of all resistors be R. Given then that R4 = 45 Ω and R3 = 180 Ω:*

$$R = R4 + R3$$
$$= 45\ \Omega + 180\ \Omega$$
$$= 225\ \Omega$$

The combined resistance of all three resistors is hence 225 Ω.

Now let the potential difference across the combined resistance be V.

Given then that $R = 225\ \Omega$

$V = 24\ V$

Use the equation $I = \frac{V}{R}$

$$= \frac{24}{225}$$
$$= 0.12\ A$$

The current flowing in the ammeter is 0.12 A.

c) *The current in the 60 Ω is given by:*

$$I1 = \frac{V}{R1}$$
$$= \frac{24}{60}$$
$$= 0.4\ A$$

So the current flowing in the 60 Ω resistor is 0.4 A.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physics course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 22

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

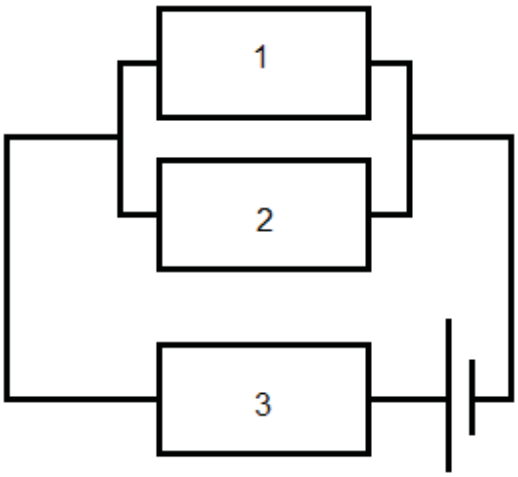
(Total Marks:27)

Show all of your work for full marks.

Multiple Choice Questions (1 mark each)

1. When there is an electric current passing through a wire, the particles moving are:
   A. atoms
   B. electrons
   C. ions
   D. protons
2. The unit of current is the:
   A. ampere
   B. coulomb
   C. volt
   D. watt
3. The resistance of an electric bulb drawing a current of 1.2 A at 6V is:
   A. 0.5 Ω
   B. 5 Ω
   C. 0.2 Ω
   D. 2 Ω
4. Ohm's law relates potential difference to:
   A. current
   B. energy
   C. power
   D. time

5. In the figure below:



A. Resistor 1, 2 and 3 are in series.

B. Resistors 2 and 3 are in parallel and they are in series with resistor 1.

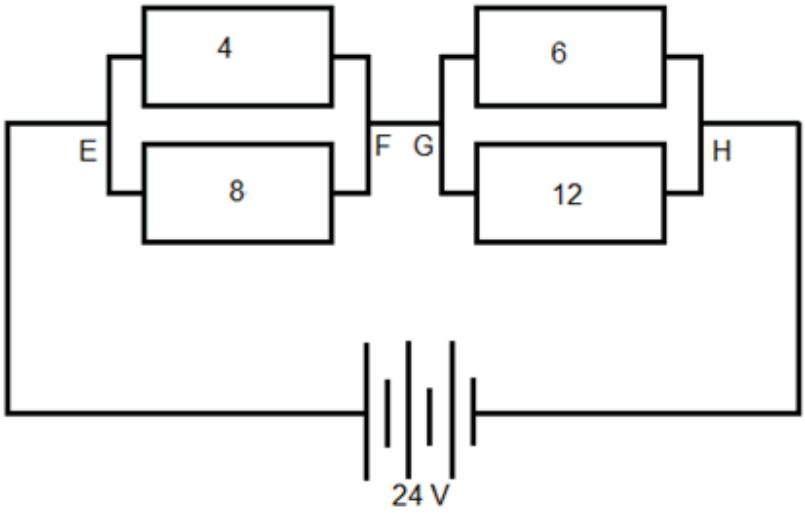
C. Resistor 1, 2 and 3 are in parallel.

D. Resistor 1 and 2 are in parallel and resistor 3 is in series.

Structured Questions

1. Describe with the help of a labelled circuit diagram, how you can confirm the resistance of a 10 Ω using a voltmeter, ammeter and any other apparatus that you may need. What are some possible sources of error in your results? (7)

2. For the circuit given below:



Calculate:

a) The effective resistance across EF in parallel. (3)

b) The effective resistance across GH in parallel. (3)

c) The combined resistance of the whole circuit. (2)

d) The current in the 12 Ω resistor. (3)

3. Draw graphs of current I against p.d. V for the following materials:

   a) A filament lamp (2)

   b) A pure metal (2)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 23

Practical Electric Circuitry

Study Skills

*Decide on an **order of importance.** Some things are more important than others. In a particular study unit, decide what these are and organize the important material into an outline or framework. "Over-learn" this particular framework. **Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

Electricity is one of the main sources of energy used abundantly worldwide. It is a necessity in all households. It is one of the things people look for when finding a place to stay. So in this unit we are going to discuss the uses of electricity, how to calculate the cost of electrical appliances and the safety measures we need to take when using electricity.

Time

This unit consists of 20 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Spend a moment reading the following learning outcomes. They are a guide to what you should focus on while studying this unit.

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Solve* problems which involve physical forces, such as energy, light, magnetism and electricity.

Study Skills

Unit Outcomes

Upon completion of this unit you will be able to:

- *Calculate* electrical consumption.
- *Describe* the safety precautions while using electricity.

Terminology

Earth wire:	A safety wire which conducts current to the Earth should a fault result in the main supply.
Electric power:	The rate at which electrical energy is released.
Fuse:	A safety device which breaks the circuit if large current accidentally flows in the circuit.
Live wire:	A wire through which current is flowing. It is at the potential difference equal to that of the main supply.
Neutral wire:	A wire which is at zero potential difference.
Resistor:	Resistors restrict the flow of electric current.
Switches:	Are safety devices which are used to turn electrical devices on and off.

Section 23-1: Uses of Electricity

Take a minute and think about things that use electricity.

In this subunit we are going to discuss the uses of electricity. I hope you will enjoy this as electricity is one of the main sources of power.

Time

There is 1 page on the topic of uses of electricity. You should spend approximately 30 minutes on this topic.

Activity 1

Activity

1. List some uses of electricity:

   _____
   _____
   _____

2. How is heat produced in an electric kettle?

   _____
   _____
   _____

Compare your answers to those provided below.

Answers to Activity 1

1. ***Electricity is used for heating and lighting.***
2. ***In an electric kettle, the heating element is placed inside a metal tube and is electrically insulated from the tube. When current flows through the element, heat is produced in the resistor and the metal tube becomes hot. The water around the element is heated first by conduction, and then heat is spread through the water by convection.***

Electric irons, kettles, heaters and cookers all have heating elements. Heating elements are all made of electric conductors which have high resistance. This is a topic within the next section.

Section 23-2: Calculating the Cost of Power Consumption

Introduction

By the end of this section, you should be able to calculate the cost of power consumption.

Time

There are 21 pages on the topic of calculating the cost of power consumption. You should spend approximately 5-6 hours on this topic.

Resistance

In the unit on electricity, you learned that current is the flow of charge. It is easy for current to flow through some materials and it is difficult to flow through other materials.

Materials that resist the flow of current are called **resistors**.

Imagine that you are running in a track and eventually you reach the point where the track is muddy. Think about how that would affect your ability to run.

It becomes very difficult to run in the mud and your speed decreases. You try to overcome the resistance, and in the mean time you could become very hot.

The same thing goes with current as it flows through a resistor.

Electrical Energy

Remember from the unit on electricity that:

One ***joule*** of energy (E) is released if one ***coulomb*** of electric charge (Q) flows through a potential difference (V) of one ***volt.***

These quantities are connected by the formula

E =VQ

Remember also that Q = It

Where 'I' is current and 't' is the time in seconds.

So energy can be represented as

E = VIt

Example 1

In Figure 1, a battery with a potential difference of 1.5 V and a current of 0.5A flows for 5 seconds. How much chemical energy is changed into electrical energy?

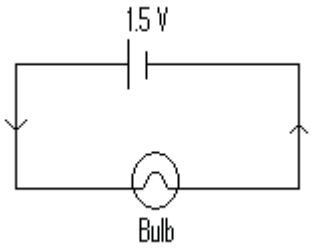

Figure 1: An electric circuit. Hand drawn by graphic designer at LDTC.

SOLUTION

Remember that:

E = VIt

and given that:

V = 1.5V, I = 0.5A and t = 5 seconds

then E = 1.5 V x 0.5A x 5 sec

= 3.75 Joules

Electric power is the rate at which electrical energy is released.

$$\text{Power} = \frac{\textit{Electrical energy released}}{\textit{Time taken}}$$

The units of power (P) are Watts (W) = J/s

1 watt (W) =1 joule per second ($^{J}/_{s}$). Other convenient units of power include:

1milliwatt (mW) = W

1kilowatt (kW) =1000 W

1 megawatt (mW) = 1000 000 W

$P = \frac{E}{t}$

$= \frac{VIt}{t}$

When we cancel the't's we get

P =VI This is equation 1 from Ohms law.

$R = \frac{V}{I}$

V = IR This is equation 2.

So if we substitute equation 2 into equation 1 we get:

P = RI x I

From Ohms law again $I = \frac{V}{R}$ this is equation 3.

If we substitute equation 3 into equation 1 we get:

$P = \frac{RV \times V}{R \times R}$

By cancelling R:

$P = \frac{V \times V}{R} = V^2/R$

So the three equations for electrical power are:

- P = VI
- $P = R\, I^2$
- $P = V^2/R$

In general, all electrical appliances should indicate the correct working voltage and power consumption needed to use it. For example a light bulb may be marked 60 W 240 V, and an electric kettle may be marked 240 V, 2400W.

Example 1

An electric kettle is labelled 240 V, 2400 W. Find:

a) The resistance of the heating element.

b) The amount of current that will flow through the element.

c) The amount of heat that will be produced in 5 minutes.

Solution 1

a) We are given that V = 240 V and P = 2400 W, so we use the formula for power which has both voltage and resistance.

Since P = 2400 W

We will use the third equation of power:

P = V^2/R

In order to have R on its own side we multiply both sides of the equation by R to get PR = V^2 . Then divide both sides by P to get

R = V^2/R

The resistance R = $\frac{240V \; x \; 240 \; V}{2400w}$

= 24 Ohms

b) We now use P = VI when we divide both sides by N, we get:

$$I = \frac{P}{V} = \frac{2400W}{240V}$$

= 10 A

c) Given that P = 2400W and t = 5 x 60s = 300 s and since energy released E = VIt

= power x time

= 2400V x 300 s

= 720000 J

= 720 kJ

When electrical energy is changed into heat in an electric kettle, there is power output. Every electrical appliance has its own power rating, which is the amount of power it uses.

Measuring Electricity Consumption

Electrical energy is sold in kilowatt hours (kWh). One kilowatt hour is the energy used by a 1kW electrical appliance in an hour.

Remember that Power = $\frac{Energy\ transfered}{Time\ taken}$

So Energy = power x time

Since 1 hour = 60 x 60 =3600 seconds

Then 1Kwh = 1000W x 60 x 60

= 3 600 000 J

This means that 1Kw electrical appliance uses an electrical energy of 3 600 000 J in one hour.

Example 2

If 1 kWh of energy costs 82 lisente in Lesotho, how much would you have to pay the Lesotho Electricity Company if you used a 40 W lamp and a 120 W television for 5 hours a day for the month of April?

Solution

Total power used by the lamp and television = 40 W + 120 W

= 160 W

The total time in hours = 5 hours x 30 days

= 150 hours

Energy used = power x time

= 160 W x 150 h

= 24 000Wh

= 24 kWh

The cost of 24 kWh = 24 x M0.82

= M19.68

Activity

Activity 2

In this activity we are going to learn how to perform calculations of the cost of electricity.

1. A torch light bulb is labelled 2.5 V, 0.3A. How many joules of electrical energy are changed to heat and light energy if the bulb is switched on for 2 minutes?

   _____

   _____

2. If 1kWh of energy costs 15 lisente, how much would it cost to operate a 750 W electric iron for 4 hours?

Compare your answers to those that are given at the end of the section. Continue on if you can reliably do these calculations. If not, review the above content.

Note it!

Do you see that you can calculate the cost of electricity you use at home?

Let us remind ourselves about what we have learned so far:

- **Electric power** is rate at which electricity is used.
- The units of power are Watts (W).
- 1 kWh is the energy used by a 1 kW electrical appliance in 1 hour.

Overheating

Electricity may be very helpful but can also be very dangerous when not used with care. One of the electric hazards is overheating.

Why could there be overheating when many electric appliances are plugged into the same plug?

Compare your answer with the following:

Each appliance draws its own power from the main supply and all the power is drawn through the same cable. This power may be so large that the cable becomes overloaded and overheated. This is the topic of the next subunit. It covers the safe use of electricity.

Note it!

Key Points to Remember:

The steps for calculating the cost of power consumption are:

- Find the total power used by all the appliances used.
- Find the total time in hours, spend using the appliances.
- Use the formula: energy = power x time
- Find the cost of power consumption by multiplying energy used by a 1 kW electrical appliance in 1 hour by the cost of 1kWh.

Answers to Activities on Calculating the Cost of Power Consumption

Activity 2

1. $E = VIt$

   $= 2.5V \times 0.3\ A \times 2 \times 60\ sec$

   $= 90\ J$

2. $Energy\ used = P \times t$

   $= 750\ W \times 2\ h$

   $= 150\ Wh$

   $= 0.150\ kWh$

$Cost\ of\ 0.150\ kWh = 0.150 \times 55\ lisente$

$= 8.25\ lisente$

It will cost 8 lisente to operate an electric iron of 750 W if it is operated for 4 hours.

Section 23-3: Safe Use of Electricity

Introduction

Electricity is a source of energy which is very helpful, but it can also be very dangerous. So it is important to use it safely. By the end of this subunit, you should be able to describe the safety precautions while using electricity.

Time

There are 8 pages on the topic of safe uses of electricity. You should spend approximately 3-4 hours on this topic.

Fuse

A fuse is a safety device which is made up of a tin-coated copper wire and alloys. In many countries, a fuse is fitted into a three- pin plug. In practice, fuses are made with the following ratings; 1A, 2A, 5A, 10A and 13A. Normally we choose a fuse which can take current slightly larger than the maximum current that can pass through the electrical appliance before it overheats.

Activity 3

Activity

1. Calculate the current used by a 1600 W hair dryer connected to a 240 V supply. Suggest a suitable rating for a fuse to be used to prevent the hair dryer from overheating.

   _____
   _____
   _____
   _____
   _____

2. A vacuum cleaner with a power rating of 700W is connected to a 240V supply. Calculate the current the vacuum cleaner uses and suggest the fuse rating that can be connected to the vacuum cleaner.

   _____
   _____
   _____
   _____
   _____

Compare your answer to the one given at the end of the section. Be sure that you can comfortably do these calculations before continuing.

The Earth Wire

There are three wires in a power circuit: the **live wire**, the **neutral wire** and the **earth wire**, which is also called a ground wire.

The earth wire serves as a safety device. It is joined to the metal case or chassis of an electrical appliance, as shown in Figure 2, which is called the *earth case.*

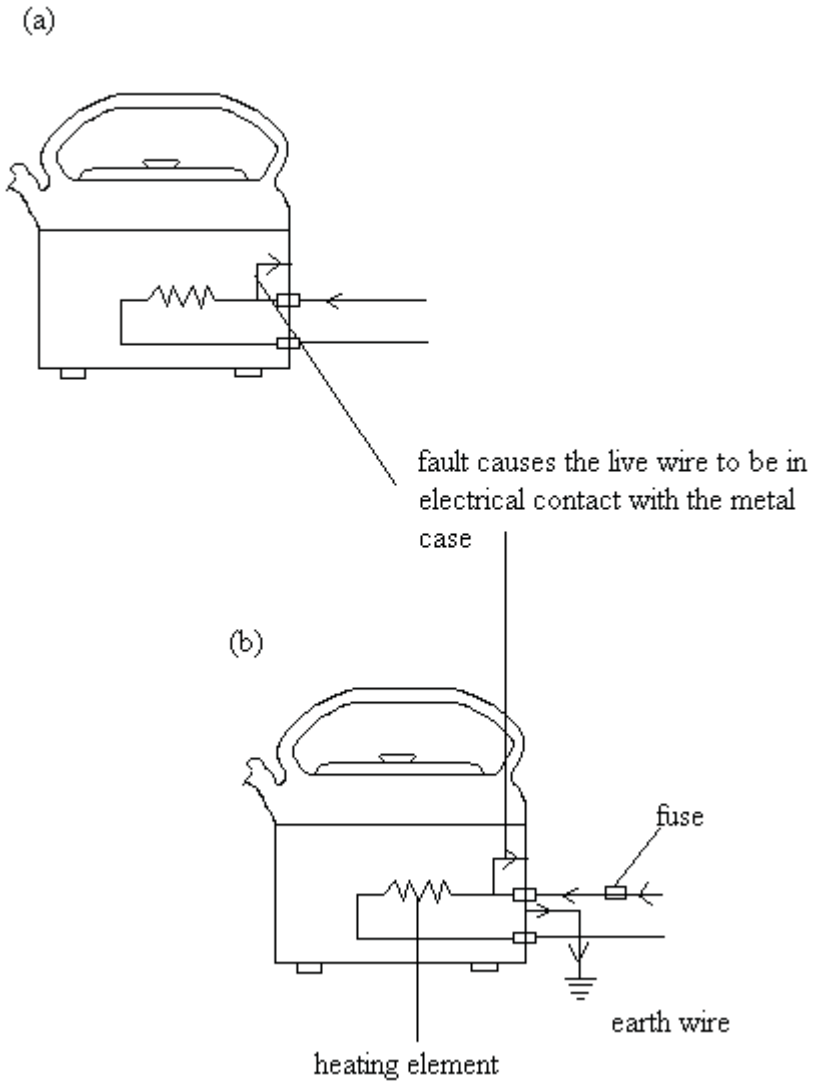

Figure 2: Shows the function of an earth wire. Hand drawn by graphic designer at LDTC.

a) Electric kettle which is not earthed.

b) Electric kettle which is earthed.

In (a);

If the faulty heating element happens to touch the metal case of the kettle, the kettle will become 'live' with the voltage that equals the main supply voltage. There will not be a flow of current because the kettle is insulated from the earth. But if a person accidentally touches the kettle in (a), current will flow through the person's body into the earth and cause an electric shock.

In (b), since the kettle is connected to the earth, when the live wire touches the case there will be a short circuit. A large flow of current will melt the fuse and break the live wire connection. A person touching the kettle will not have an electric shock. So an earth wire is a safety device.

Activity 4

Activity

Thabo boils water with an electric kettle whose heating element is faulty. The element accidentally touches the metal case of the kettle which is not earthed. What do you think will happen to Thabo when he touches the kettle?

_____

_____

_____

_____

Compare your answer to the one given at the end of the section.

Apart from the ***earth wire***, other wires in the electric circuit are the ***live wire*** and the ***neutral wire***. If the mains voltage is 240 V, then the ***live wire*** has the potential difference of 240 V. The ***neutral wire*** on the other hand is at a zero potential.

The importance of a neutral wire in a circuit is to conduct power back into the source and to complete the circuit.

Double insulation

Not all electric appliances are earthed, for example hair driers. Such appliances use 2-pin plugs, using only the live and the neutral wires. So in order to avoid electric shock, such appliances are double insulated.

Switches

Some switches are safety devices which are used to turn an electrical appliance on or off.

Activity 5

Activity

In which wire do you think switches must be inserted, why?

_____

_____

_____

Compare your answer to the one given at the end of the section. Be sure that you understand the explanation before continuing.

Wiring a 3-Pin Plug

Activity

Activity 6

1. Take an electric kettle or any electric appliance you can find. Be sure that it is not plugged in. Using a screw driver, open the plug to expose the wires.
2. How many strands of wires do you see? _____
3. What colour are the wires?

   _____

   _____

   _____

I hope you were able to find a 3-pin plug.

In Activity 7, you are going to wire the 3-pin plug of the appliance you used in Activity 6.

Activity

Activity 7

In this activity you are going to learn how to wire a 3-pin plug.

Take a 3-pin plug and wire it following the steps below.

Figure 3(a): 3-pin plug. Photo taken by LDTC.

Steps to follow when wiring a 3-pin:

1. Remove the cover to access the inside of the 3-pin plug.

Figure 4(a). Photo taken by LDTC.

Figure 4(b): 3 wires inside the 3-pin plug. Photo taken by LDTC.

2. Remove the insulating plastic from the ends of the three wires, as shown in Figure 4(c).

Figure 4(c): *Photo taken by LDTC.*

3. Twist the wires and push the ends into the holes of each terminal, as shown in Figure 4(d).

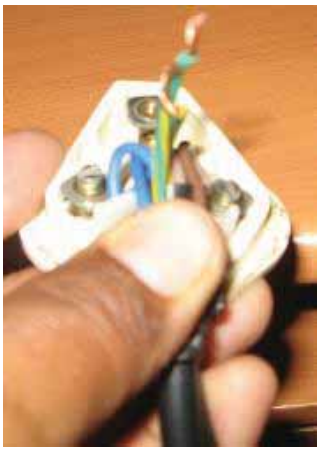

Figure 4(d): Photo taken by LDTC.

4. Tighten the screws.

Figure 4(e): Photo taken by LDTC.

5. Check that there are no loose strands anywhere in the plug as in Figure 3 above. Then replace the cover.

Figure 4(f): Photo taken by LDTC.

I hope you managed to do the activity. If you do not have the plugs do not worry, study all the steps to learn how to wire a 3-pin plug.

Key Points to Remember:

Note it!

The key points to remember in this subunit on the safe use of electricity are:

- Do not overload plugs because they may overheat and produce fire.
- Electrical appliances must be earthed so that should a fault occur in the appliance, current should be conducted to the earth through the earth wire.
- Switches must be placed in live wires so that when opened there should be no flow of current.

You have now completed the last section of this unit on practical electrical electricity. Do a quick review of the entire content of this unit and then continue on to the unit summary.

Answers to Activities on Safe Uses of Electricity

Activity 3

1. ***Power = VI***

$$I = \frac{1600W}{240V}$$

$$= 6.667A$$

Hence a 10A fuse should be used.

2. ***Power = VI***

$$I = \frac{700W}{240V}$$

$$= 2.91A$$

Hence a 5A fuse can be used.

Activity 4

Thabo will get an electric shock. This means that electric current will flow inside Thabo's hands into his body then down through his feet.

Activity 5

Switches must be placed in live wires because that is where current flows. When the switch is off, current will not flow.

Activity 6

1.

2. There are three wires and they are colour coded in order to differentiate one from the other.

3 The wires are:

Brown – it is a Live wire, which carries current.

Blue- it is a Neutral wire.

Yellow and green (or just green) – it is an Earth wire which carries current to the earth should a fault result in the appliance

Unit Summary

Summary

This section provides you with the summary of everything you learned in this subunit.

In this unit you learned:

- **Electric power** is rate at which electricity is released.
- The units of power are Watts (W).
- 1 kWh is the energy used by a 1 kW electrical appliance in 1 hour.
- A three pin plug has three colour coded wires.
- The live wire is live because at is at a potential difference equal to the main supply potential.
- The neutral wire is at a zero potential.
- The earth wire protects against fire by carrying excessive current to the earth should there be a fault in the main supply.
- A fuse is a safety device which trips when overheating occurs.
- Some switches are safety devices which are used to turn electrical appliances on and off.

You have completed the material for this unit on practical electrical circuitry. You should now spend some time reviewing the content. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers electromagnetic effects.

Assignment 23

Assignment

It is important to answer all the questions. This will help you find out if you understood everything you were supposed to learn.

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:18]

1. What is electrical power? (1)

2. Name the wires used in the mains plug. (3)

3. Name the wire which is used as the safety device. (1)

4. On which wire is the fuse placed in the plug? (1)

5. An electric kettle is marked 1200 W and 240 V. Calculate the maximum current that can flow in the kettle? (2)

6. a) A vacuum cleaner is marked 700 W and 240 V. Calculate the maximum current that can flow in the cleaner. (2)

b) If the vacuum cleaner is operated in the country where 1kWh of energy costs 82 cents, how much would it cost if it used for 30 minutes? (4)

_____
_____
_____
_____
_____
_____

7. If 1 kWh of energy costs 50 cents, how much would you have to pay the Electricity Company if you used a 60 W lamp and a 120 W television for 2 hours a day for the month of April? (4)

_____
_____
_____
_____
_____
_____
_____

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 23

1. ***Electrical power is the rate at which electricity is released.***
2. ***The wires used in the plug are; the live wire, the neutral wire and the earth wire.***
3. ***The earth wire is used as the safety wire.***
4. ***A fuse is placed in the live wire so that when large current flows in the wire the fuse can blow off before that current reaches the device.***
5. ***Power = VI***

$$I = \frac{P}{V}$$

$$= \frac{1200W}{240V}$$

$$= 5A$$

6. *a) Power = VI =*

$$I = \frac{P}{V}$$

$$= \frac{700W}{240V}$$

= 2.9 A

b) Total power = 700 W

Total time of use = 30 minutes = 0.5 hours

Energy used = power x time

= 700 W x 0.5 h

= 350 Wh

= 0.35 kWh

Total cost = 82 cents x 0.35 kWh

= 28.7 cents

= 29 cents

7. *Total power = 180 W*

Total time = 5 hrs

Energy used = power x time

= 180 W x 5 hrs

= 900 Wh

= 0.9 kWh

Total cost = 50 cents x 0.9 kWh

= 45 cents

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physics course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 23

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:16)

Show all the necessary work.

Section A- 4 marks

Circle the letter of the correct answer

1) A fuse is fitted in the:
   - A. Live wire.
   - B. Neutral wire.
   - C. Earth wire.
2) This trips when too much current flows in the circuit:
   - A. Resistor.
   - B. Fuse.
   - C. Switch.
3) Current flows in the:
   - A. Neutral wire
   - B. Live wire
   - C. Earth wire
4) An electric shock and fire can be caused by:
   - A. insulated wires
   - B. double insulation
   - C. damaged insulation

Section B- 12 marks

5) Explain how

   a) To wire a 3-pin plug. (3)

   b) A fuse works. (2)

6) The heating element of an electric kettle breaks in the centre. Each of the broken ends touches the earthed metal cover of the kettle. Describe and explain what happens. (3)

7) If you watched a 140 W television for 3 hours and used a 20 W table lamp for 4 hours every day for 30 days, how much would you have to pay at the end of the 30 days, assuming that electrical energy costs 15 cents per kWh? (4)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

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Unit 24

Electromagnetic Effects

Study Skills

Try a little role-playing. Take the point of view of the teacher, for a change. Rephrase and explain the material, in your own words, to a classmate. If you can't explain something, you don't really know it. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In this unit we are going to look at the effect of **moving a conductor through a magnetic field** which produces an electric current. The reverse of this is also possible in that passing an **electric current through a conductor which is placed in a magnetic field** produces movement of the wire. Thus there is a relationship between the concepts of electricity and magnetism.

Time

This unit consists of 20 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Spend a few moments reading the following learning outcomes. They are a guide to what you should focus on while studying this unit.

Outcomes

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Solve* problems which involve physical forces, such as energy, light, magnetism and electricity.
- *Apply* correctly various formulae which relate the different physics concepts and theories to the world around us.

Study Skills

Outcomes

Unit Outcomes

Upon completion of this unit you will be able to:

- *Describe* an experiment which shows that a changing magnetic field can induce an e.m.f. in a circuit.
- *Describe* a rotating-coil generator and the use of slip rings.
- *Sketch* a graph of voltage output against time for a simple a.c. generator.
- *Describe* the structure and principle of operation of a simple iron-cored transformer as used for voltage transformations.
- *Solve* problems using the (Vp/Vs) = (Np/Ns) and VpIp = VsIs equations.

Terminology

A.C.:	Alternating current.
e.m.f:	Electromotive force.
Electromagnetic induction:	A process by which e.m.f is induced into a conducting wire when it is moved across a magnetic field.

Section 24-1: Electromagnetic Induction

Introduction

By the end of this section, you should be able to describe electromagnetic induction.

Time

There are 7 pages on the topic of electromagnetic induction. You should spend approximately 2-3 hours on this topic.

Principle of Electromagnetic Induction

When a conducting wire which forms part of a circuit is **moved** across a magnetic field, as shown in figure 1, a small electromotive force (e.m.f) is produced in the wire and causes a small current to flow. This effect is called **electromagnetic induction** because e.m.f. has been induced into the wire.

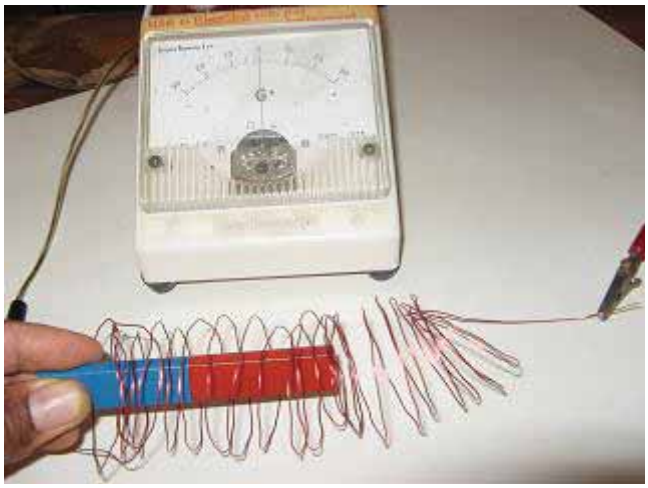


Figure 1(a): Electromagnetic induction. Photo taken by LDTC.

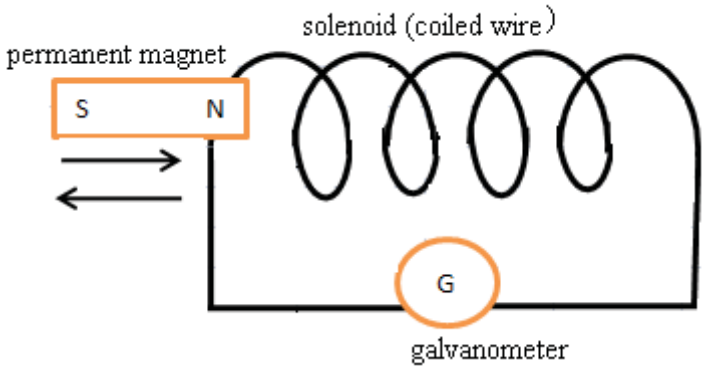


Figure 1(b): Electromagnetic induction. Hand drawn by graphic designer at LDTC.

When the permanent magnet is pushed into the coil, the galvanometer needle deflects to one side. When the magnet is withdrawn, the needle deflects to the opposite side. Refer to Figures 2(a) and 2(b) to visualize this.

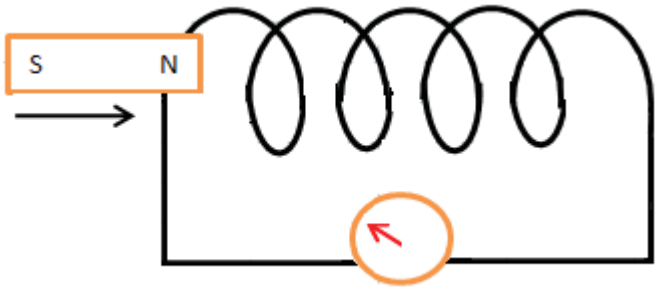


Figure 2(a): Direction of the needle when pushing in the magnet. Hand drawn by graphic designer at LDTC.

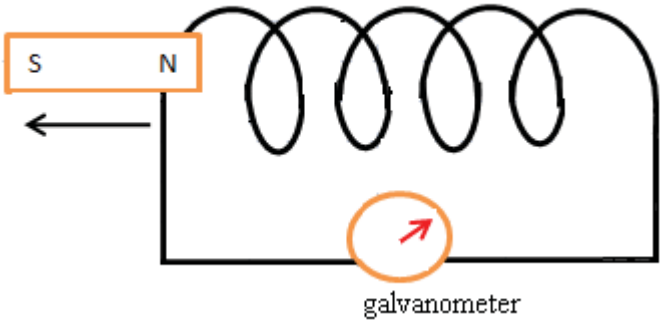


Figure 2(b): d\Direction of the needle when withdrawing the magnet. Hand drawn by graphic designer at LDTC.

Note it!

Note:

The deflection of the needle indicates that there is a flow of current.

Remember from the unit on *current electricity* that current flows when there is an electromotive force (e.m.f).

When the magnet is held still inside the coil, the galvanometer does not deflect. This shows that current flows only when the magnet is moving inside the coil.

Let us now increase the number of coils and see how the needle deflects. Compare Figure 2(b) to Figure 3.

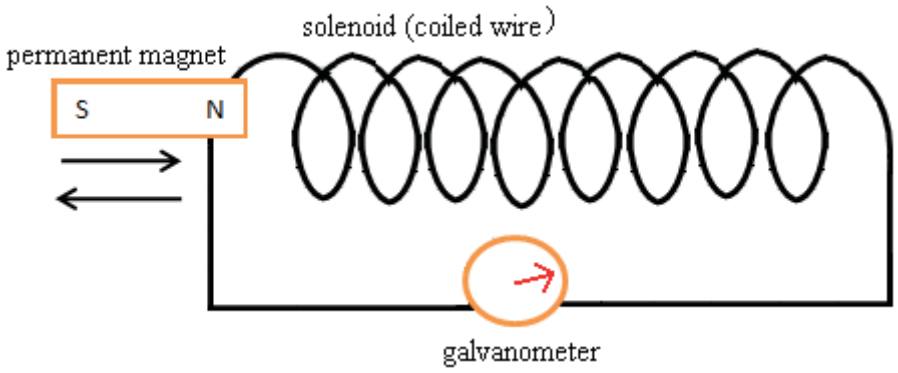


Figure 3: The effect of increasing the number of coils on the induced e.m.f. Hand drawn by graphic designer at LDTC.

Note it!

Note

Remember from the *Practical Electrical Circuitry* unit that there is a magnetic field around any permanent magnet. So when the magnet is pushed in and out of the coil the field lines are cut by the coil.

The amount of e.m.f. and induced current can be increased by:

- Moving the magnet faster.
- Using a stronger magnet.
- Increasing the length of the wire by increasing the number of coils.

These results are summed up by Faraday's law of electromagnetic induction which states:

The e.m.f. induced in the conductor is directly proportional to the rate at which the conductor cuts through the magnetic field lines.

Direction of Induced Current

Let us now investigate the direction in which the induced current flows.

The direction of the induced current depends on the pole of the magnet that is being pushed in or pulled out of the coil and is marked by the deflection of the galvanometer needle as shown in Figures 2(a) and 2(b).

When the magnet is pulled out of the coil, compare how the galvanometer deflection in Figure 3 differs from that in Figure 2(b).

When the poles of a magnet are reversed by pushing the south pole of a bar magnet into the coil the direction in which the current flows in the wire also reverses. Compare how the galvanometer deflection in Figure 4 differs from that in Figure 2(b).

Will the needle deflect to the same or opposite direction when the South Pole is pulled out of the coil?

Check your answer by comparing Figures 4 and 5.

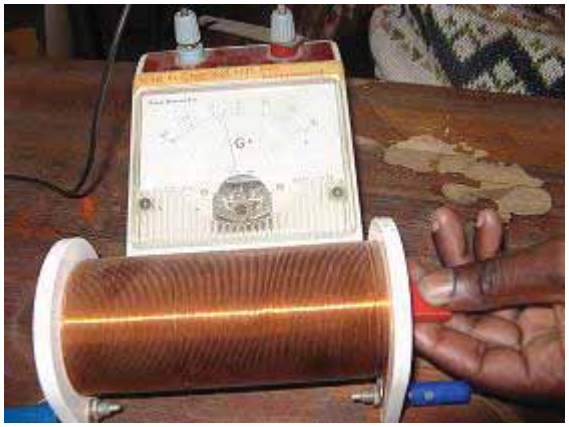


Figure 4(a): Pushing in the North Pole. Photo taken by LDTC.

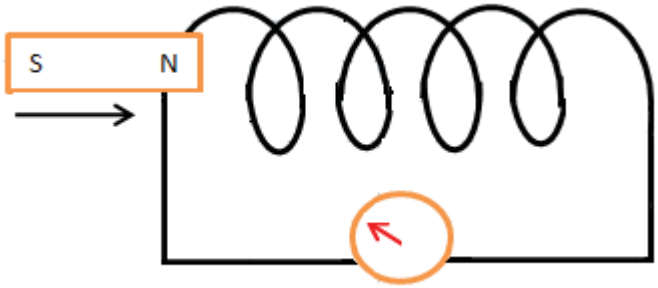


Figure 4(b): Pushing in the North Pole. Hand drawn by graphic designer at LDTC.

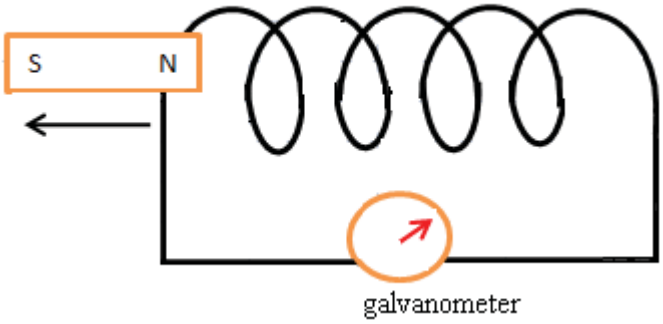


Figure 5: Pulling out the North Pole. Hand drawn by graphic designer at LDTC.

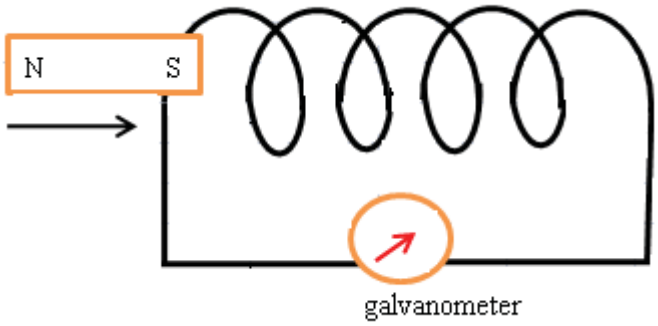


Figure 6: Pushing in the South Pole. Hand drawn by graphic designer at LDTC.

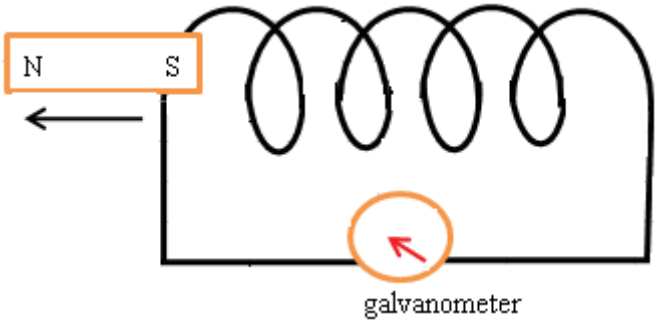


Figure 7: Pulling out the South Pole. Hand drawn by graphic designer at LDTC.

Activity

Activity 1

Are the following statements **True** or **False**?

1. When the magnet is pushed into the coil, current flows in one direction. When it is pulled out it flows in the opposite direction.

   _____

2. Pushing the North Pole in has the same effect as pulling the South Pole out of the coil.

   _____

3. Pushing the South Pole in has the same effect as pulling the North Pole out of the coil.

   _____

Compare your answers to those given at the end of the section.

Henry Lenz summarised these observations into one law which he called **Lenz's Law** and it states that:

The direction of induced current is such that it opposes the change producing it.

This means that an opposite movement causes an opposite deflection.

Like Lenz's law, the direction of the induced current can also be deduced by using **Fleming's Right-Hand Rule**. This rule works best with a straight wire rather than a coiled wire.

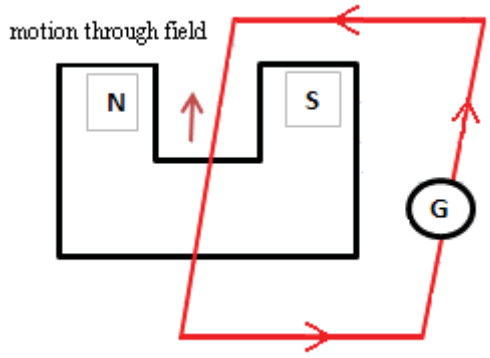


Figure 8(a): Moving the wire upwards. Hand drawn by graphic designer at LDTC.

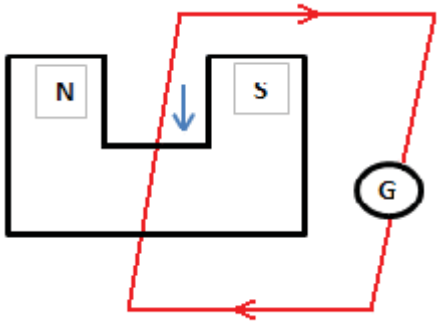


Figure 8(b): Moving the wire downwards. Hand drawn by graphic designer at LDTC.

From the above diagrams, note that reversing the direction of movement of the wire reverses the direction in which the current flows.

To determine the direction of current in each case:

Using your right hand, hold out the thumb and the first two fingers at right angles as shown in the diagram below.

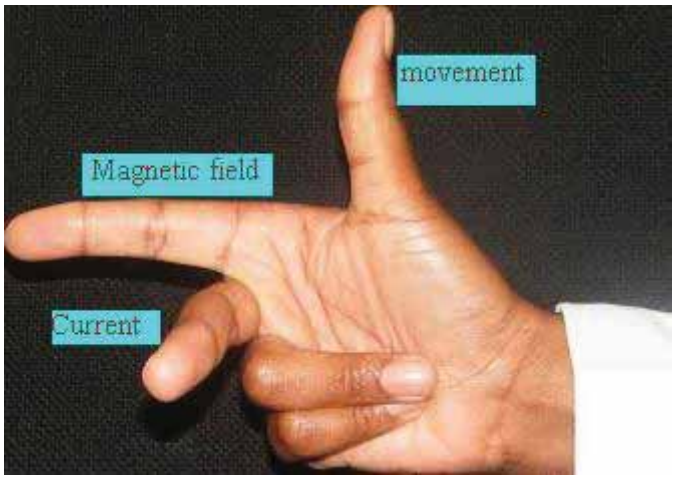


Figure 9: Direction of induced current. Photo taken by LDTC.

In Figure 9, the fingers are horizontal at right angles, while the thumb is vertical and at right angle to both fingers. All three fingers are at right angle.

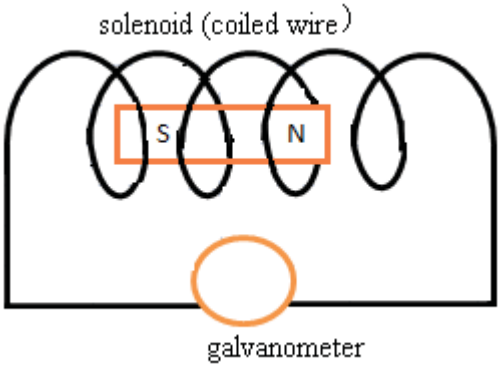
The se**C**ond finger gives the direction of the induced *current*, the **F**irst finger points in the direction of the *field* and the thu**M**b points in the direction of the *motion* of the wire.

To help you remember, notice the capitalised letters, **C** for current, **F** for field and **M** for motion!

Activity

Activity 2

1. The magnet is pushed into the coil and is held still inside the coil, draw an arrow to indicate the direction in which the galvanometer needle would point.



2. List three ways in which induced current may be increased:

(i) _____

(ii) _____

(iii) _____

Compare your answers to those given at the end of the section.

Key Points to Remember:

Note it!

The key points to remember in this section on electromagnetic induction are:

- When a magnet is pushed in the coil electromotive force (e.m.f.) is induced.
- When the magnet is pushed in, the galvanometer needle deflects on one side and when it is withdrawn it deflects to the opposite side.
- The direction of the induced current can also be deduced by using Fleming's right-hand rule.
- The size of the induced e.m.f. depends on the number of coils, the strength of the magnet and the speed in which the magnet is pushed in and out of the magnet.

Reflection

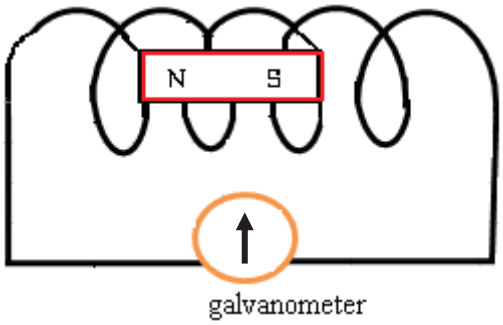
If you have access to the internet, please go to:
http://phet.colorado.edu/en/simulation/faraday
1. Select the "Pickup Coil" tab. What happens when you move the magnet in an out of the coils? What happens when you increase the speed of the magnet going in and out of the coils?
2. What happens when you increase the number of coils in the electromagnet?
3. What happens when you increase the strength of the bar magnet?
4. Select the voltmeter. What happens to the direction of the deflection of the needle when you move the bar into the coil? Out of the coil?

The next section is about a.c. generators. You will need to apply the principle of electromagnetic induction to understand it.

Answers to Activities on Electromagnetic Induction

Activity 1

1. ***The galvanometer needle would not deflect when the magnet is held still inside the coil as no cutting of the field lines occurs***



2. The induced current may be increased by:

(i) Using a stronger magnet

(ii) Moving the magnet in and out of the coil faster

(iii) Increasing the number of turns of the coil

Section 24-1: A.C. Generator

Introduction

By the end of this section, you should be able to explain the function and structure of an AC generator.

Time

There are 8 pages on the topic of generators. You should spend approximately 2-3 hours on this topic.

Structure of a Simple Alternating Current Generator

The concept of electromagnetic induction as studied above forms the basis of construction of alternating current generators. These generators vary in size, make and design depending on their purpose. They may be small ones (bicycle dynamos) or giant ones in the power stations that provide us with electricity in our homes.

Figure 10 shows a simplified structure of an AC generator and some of its major components.

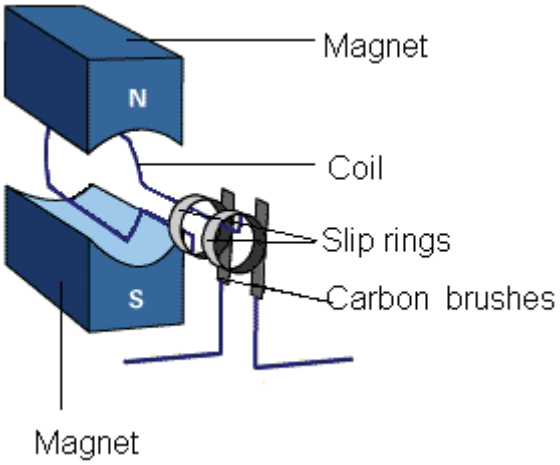


Figure 10: Simple AC generator accessed from School for Champions, 2010.

The ends of the coil are connected to two **slip rings** which are pressed against the **carbon (**contact**) brushes** and transfer induced current in the coil to the external circuit.

How an Alternating Current Generator Operates

When the **axle** on which the rectangular coil is mounted is rotated, the coil is forced to rotate along with it as shown in 11(a). One side of the coil moves upwards (side AB) while the other side moves downwards (CD). As the coil moves, it cuts across the magnetic field lines of the magnet and hence an e.m.f. is induced in the coil which causes current to flow in the circuit.

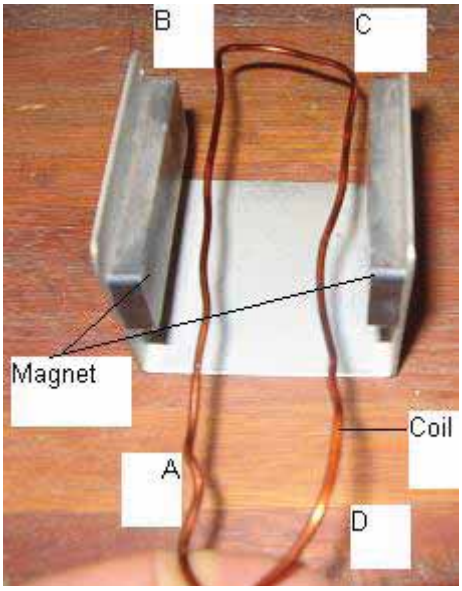


Figure 11(a): Simple AC generator. Photo taken by LDTC.

At the start of rotation:

- The coil lies in a vertical position with side AB at the top. The e.m.f. induced in the coil is zero since sides AB and CD are moving along the field lines and no cutting of the field lines occurs. The coil is parallel with the magnetic field. See Figures 11(b) and 11(c).

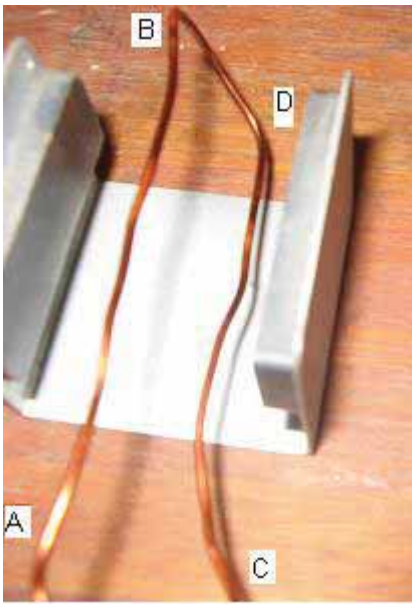


Figure 11(b): Simple AC generator. Photo taken by LDTC.

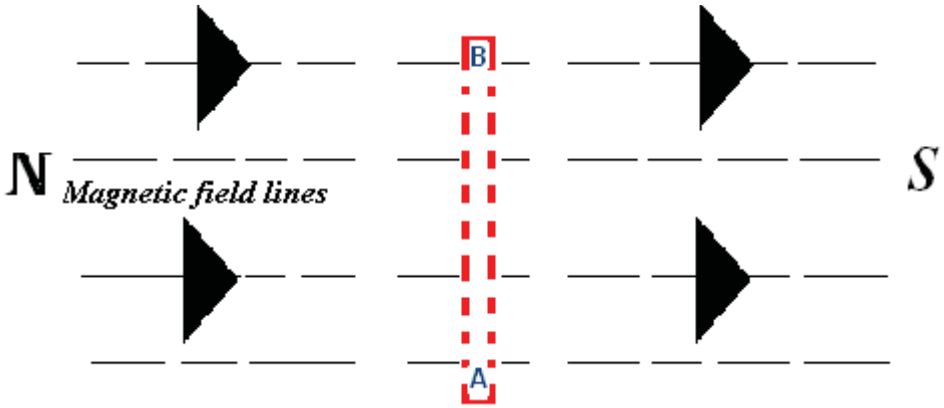


Figure 11(c): Side CD and AB parallel to field no cutting of the field occurs (AB uppermost). Hand drawn by graphic designer at LDTC.

- The induced e.m.f. is at maximum during the next half turn when the coil is horizontal and perpendicular to the magnetic lines. Sides AB and DC are cutting the field lines at the greatest rate in Figures 12(a) and 12(b).

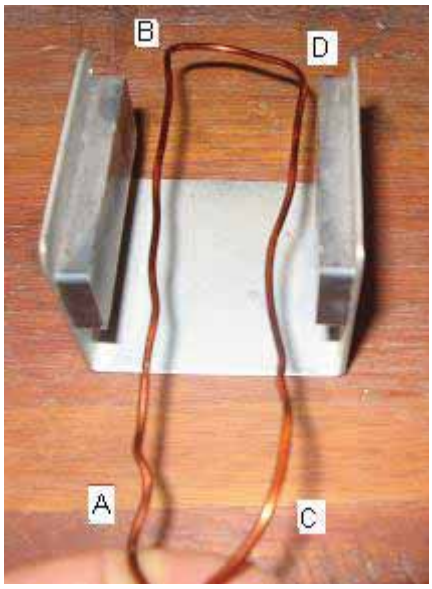


Figure 12(a): Simple AC generator. Photo taken by LDTC.

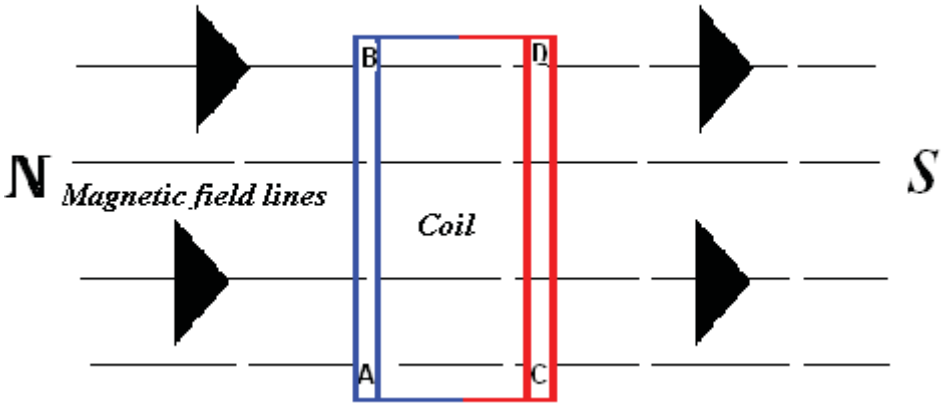


Figure 12(b): Side AB cuts magnetic field lines at greatest rate, e.m.f. maximum. Hand drawn by graphic designer at LDTC.

- After a 180° rotation, side **CD** is now upper most, **AB** and **CD** once again are moving along the field lines (parallel to the magnetic field lines) and no cutting of the field lines is occurring. The induced e.m.f. is therefore **zero.** This is shown in figures 13(a) and 13(b).

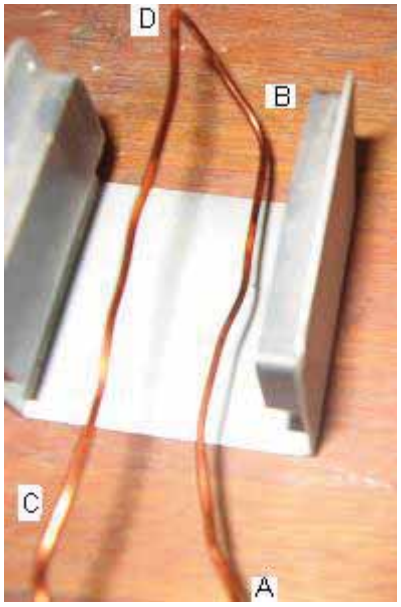


Figure 13(a): A coil cutting through the field lines. Photo taken by LDTC.

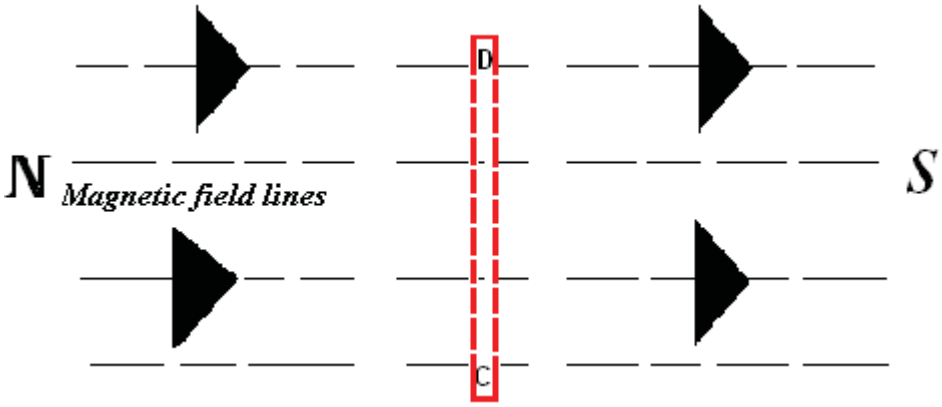


Figure 13(b): Side CD and AB parallel to field no cutting of the field occurs, AB now uppermost. Hand drawn by graphic designer at LDTC.

- During the next half rotation, current reverses because side CD is now moving downwards while AB is now moving upwards, as seen in figure 13(c).

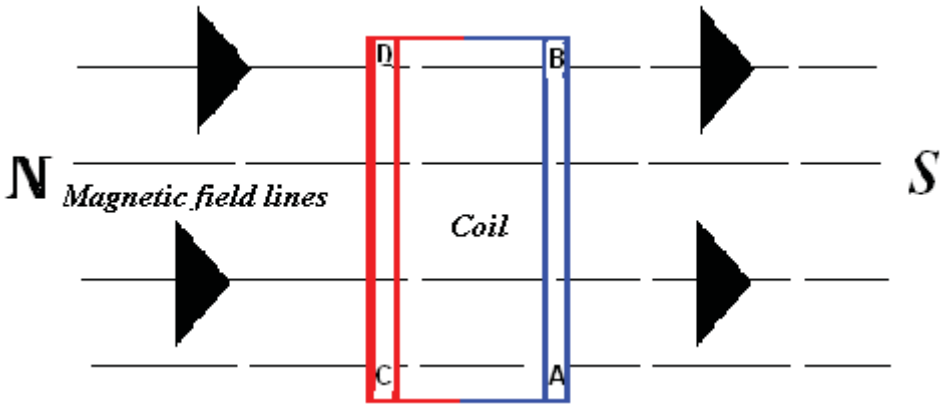


Figure 13(c): Sides AB and CD are cutting the field lines at 90 ^{0}. Hand drawn by graphic designer at LDTC.

The e.m.f. is maximum once again but in the opposite direction hence current now flows in the reverse direction.

> ***Remember the direction of the induced current depends on the direction of movement of the wire! Use Fleming's right hand rule to verify this.***

Output Voltage Graph of an AC Generator

The position of the coil and hence the output e.m.f. can thus be presented on a graph, as shown in Figure 14.

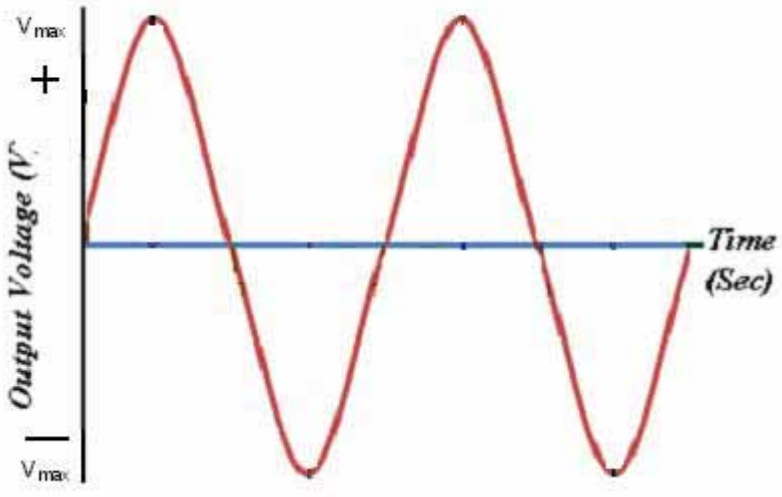


Figure 14: A graph of voltage output against time for a simple AC generator. Hand drawn by graphic designer at LDTC.

From the above graph notice that the voltage (e.m.f) induced in the coil alternately changes direction, so does the current which flows in the wire.

Activity 2

Activity

1. What type of current is produced by an AC generator?

_____

Explain your answer:

_____
_____
_____
_____

2. List 4 things that can increase the induced e.m.f and hence the current:

_____
_____
_____
_____

Now compare your answer to the one given at the end of the section. Be sure that you understand the concept before continuing.

Frequency

The number of complete cycles made in a second mark the frequency of an AC generator. The main supply AC has a frequency of 50 Hz.

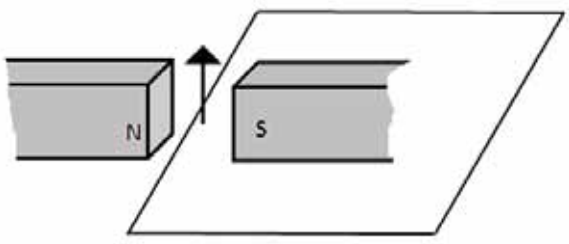
What exactly does this mean?

It means the current which is flowing through the mains in our homes flows backwards and forward 50 times every second. This is so fast that the intervals between reversals become unnoticeable.

Activity 3

Activity

Now let us reflect back on what we have learnt so far about an AC generator by going through the following activity:



(a) Name the process by which current in the wire is induced when the wire is moved in the direction shown.

_____

(b) Name the rule that would be applicable to determine the direction of this current.

_____

(c) Mark on the diagram the direction in which the current would flow when the wire is moved in the direction shown.

(d) What would be the effect of moving the wire in the opposite direction?

_____

(e) What would be the effect of moving it faster?

_____

(f) Sketch a graph of the output voltage against time for an AC generator.

Compare your answers to those given at the end of the section.

Key Points to Remember:

Note it!

The key points to remember in this subunit on AC generator are:

- When the coil cuts through the magnetic field lines e.m.f. is induced in the coil.
- The size of the induced e.m.f depends on the length of the wire cutting through te field lines and the speed at which the field lines are cut.
- The direction of the induced current can be found by Fleming's right hand rule.
- Electricity generators use the principle of electromagnetic induction to produce electricity.

Note it!

If you have access to the internet, please go to:
http://phet.colorado.edu/en/simulation/faraday
1. Select the "Electromagnet" tab.
2. Select the AC current source.

Answer to Activities on A.C. Generators

Activity 2

1. Alternating current or AC.

It is because the current induced alternately changes direction of flow (moves forward and backwards in the coil. One complete cycle on the graph (Figure 14) marks one forward and backward flow of current.

2. The induced e.m.f. and hence the current can be increased by:

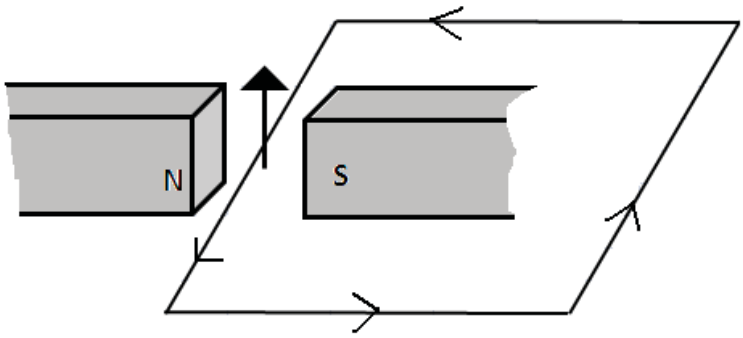
- ***Using a coil with more turns.***
- ***Winding the coil on an iron armature.***
- ***Rotating the coil at a higher speed (which increases the frequency of the AC generated).***
- ***Using a stronger magnet.***

Activity 3

(a) Current in the wire is induced by electromagnetic induction.

(b) Fleming's right hand rule.

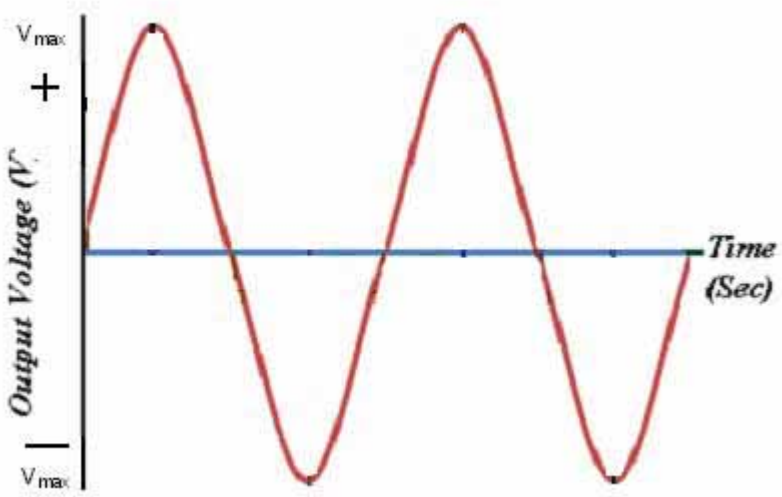
(c)



(d) If the wire was moved in a different direction (downwards), the direction of current would reverse.

(e) Moving the wire faster would result in an increase the induced current.

(f) Graph of the output voltage against time for an AC generator.



Section 24-2: Transformer

Introduction

By the end of this section, you should be able to explain the structure and function of a transformer and perform calculations related to transformers.

Time

There are 8 pages on the topic of transformers. You should spend approximately 2-3 hours on this topic.

Mutual Induction

The effect of inducing an e.m.f. in the coil can be attained without necessarily moving the magnet or coil as in electromagnetic induction.

The same effect can be achieved by simply switching current on and off (changing it) in one coil; a voltage is induced in the neighbouring coil. The effect is called **mutual induction**, as shown in Figure 15.

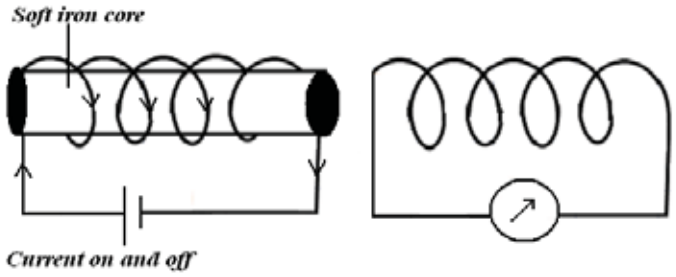


Figure 15: Mutual induction. Hand drawn by graphic designer at LDTC.

Remember from the Magnetism unit that when the current is switched on, the iron core is magnetised and its magnetic field lines grow outwards from the primary coil and cut the neighbouring coil when they sweep past it. This induces e.m.f. in this coil and causes the galvanometer to register a brief flow of current, a similar effect as pushing the magnet into the coil.

When the current is switched off, the iron core loses its magnetism and the field weakens. This results in the field cutting through the coil as it weakens. An e.m.f. is again induced in the neighbouring coil but this time current flows in the opposite direction, an effect similar to pulling the magnet out of the coil.

The above diagram can be modified and the amount of e.m.f. induced increased if both coils are wound on a looped iron core as shown in Figure 16. The core ensures magnetic field linkage between the two coils

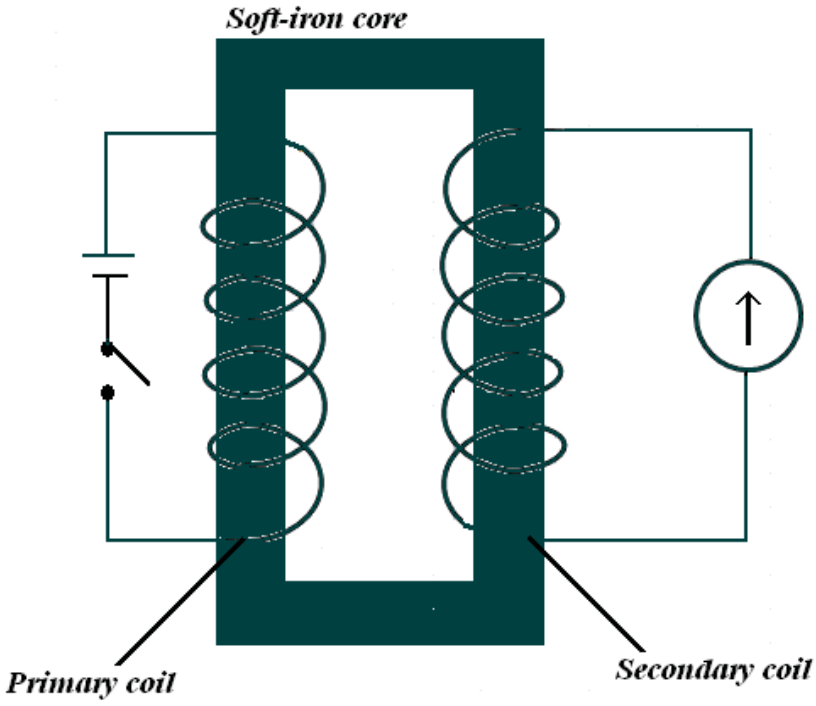


Figure 16: e.m.f. induced in the secondary coil is increased by winding both coils on a soft iron core. Hand drawn by graphic designer at LDTC.

For e.m.f. to be induced in the secondary coil from Figure 16, the current would have to be switched on and off in the primary coil. To avoid switching on and off, mutual induction systems are modified by connecting the primary coil to an AC supply, as shown in Figure 17.

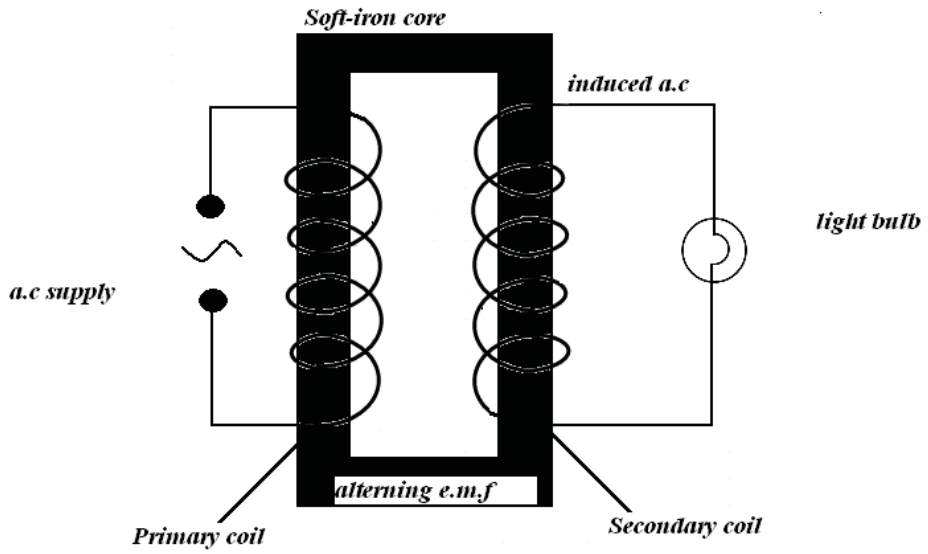


Figure 17: Transformer. Hand drawn by graphic designer at LDTC.

Transformers

The primary and secondary coils together with the iron core together form a **transformer.**

A transformer is a device that continually transfers electrical energy from the primary coil to the secondary coil when the primary coil is connected to an **AC supply.**

The mains voltage used in most countries is 240 V but different appliances need different working voltages. For example, a door bell may work on a 6V supply. In order for it to work, a transformer is fitted so that it changes the mains voltage to the one needed by the bell to function.

We have done a lot up to this point. Let's review by carrying out the following activity.

Activity

Activity 3

(a) Name a device that transfers electrical energy from the primary coil to the secondary coil when the primary coil is connected to an AC supply.

_____

(b) Briefly explain how this device works.

_____

_____

_____

Compare your answers to those given at the end of the section. Note that it is important to understand this concept. If you do not understand it, review the above content and try the activity again.

Step - Up and Step – Down Transformers

E.m.f. induced in the secondary coil depends on **the number of turns** of the primary and secondary coils.

That is, a transformer changes an alternating voltage from one value to another of greater or smaller value.

A step-up transformer is therefore one where the e.m.f. in the secondary coil is greater than the e.m.f. in the primary coil. If an electric appliance needs a working voltage greater than the mains voltage, then a step-up transformer is fitted in the appliance so that it increases the voltage to the appropriate value.

Conversely **a step-down transformer** is one where the e.m.f. in the secondary coil is less than the e.m.f. in the primary coil. This is needed when the working voltage is smaller that the supply voltage. For example, electricity needed in households is far less than the voltage at which electrical energy is transmitted from power stations. So a step-down transformer is fitted before electricity is supplied for household consumption.

An equation that links the alternating voltages across the two coils and the number of turns on each is:

$$\frac{\text{Secondary voltage}}{\text{primary voltage}} = \frac{\text{number of secondary turns}}{\text{number of primary turns}}$$

In symbols, $\frac{V_2}{V_1} = \frac{N_2}{N_1}$

From the above equation it can be seen that the number of secondary turns N_2 should be greater than the number of primary turns N_1 for a step-up transformer.

Example 1

If the voltage V_1 supplied to the primary coil is 24V with N_1 number of turns in the primary coil as 200 turns and the number of turns of the coil in the secondary coil N_2 is 2000, how much voltage V_2 will be induced in the secondary coil?

Solution

If we rearrange the above formula and substitute in the values then:

$\mathbf{V_2 = (N_2/N_1)\ x\ V_1}$

$$= \frac{2000}{200} \times 24$$

= 240 V (notice that V_2 is greater than V_1)

For a step down transformer, N_2 turns in the secondary coil is smaller than N_1 number of coils in the primary.

Example 2

If the voltage V_1 supplied to the primary coil is 24V with N_1 number of turns in the primary coil as 2000 turns and the number of turns of the coil in the secondary coil N_2 is 200, how much voltage V_2 will be induced in the secondary coil?

Solution

If we rearrange the above formula and substitute in the values then

$\mathbf{V_2 = (N_2/N_1)\ x\ V_1}$

$$= \frac{2000}{200} \times 24$$

= 2.4V (notice that V_2 is now less than V_1 for a step- down transformer)

Power Transfers in s Transformer

For an ideal transformer (that is one which is 100% efficient), power supplied to the primary coil is fully transferred to the secondary coil.

We already know from unit on electricity that electrical power is calculated as:

P = VI,

So for an ideal transformer;

Power in primary coil = power in secondary coil

$$P_1 = P_2$$

$$V_1I_1 = V_2I_2$$

That is:

$P_1 = P_2$

$V_1I_1 = V_2I_2$

where I_1 and I_2 are currents in the primary and secondary coils respectively.

Rearranging the equation yields:

$$\frac{V_1}{V_2} = \frac{I_1}{I_2}$$

This means for an ideal transformer when the induced voltage is doubled, the induced current is halved and vice versa. A transformer which reduces voltage will increase current by the same proportion.

There is no power loss or gain in an ideal transformer. In practice though, power losses are incurred for a variety of reasons such as friction in a wire although these losses are kept to a minimal in well designed transformers, such as those used in transmission of electrical energy from power stations.

Example

A 12V lamp which draws a current of 0.8A is connected to the secondary coil of a transformer. Calculate current flowing in the primary coil if the voltage of the AC source is 240V, assuming there are no power losses in the transformer.

Solution

$V_1 \times I_1 = V_2 \times I_2$

$240V \times I_1 = 12V \times 0.8A$

$$I_1 = \frac{9.6}{240V}$$

$= 0.04A$

Activity 4

Now let us do calculations on the transformer!

Activity

1. A transformer has an input voltage of 24V, 100 turns in the primary coil and the output voltage of 120V. Find the number of turns in the secondary coil.

2. A transformer has a primary coil of 6000 turns which is connected to a 240V AC supply and a secondary coil with 150 turns. A 3Ω resistor is connected to the secondary coil.

Calculate:

(a) The secondary coil voltage.

(b) The current through the resistor.

(c) The current in the primary coil.

(d) The power taken from the supply.

Check your performance against the solutions given at the end of this section. Continue if you are satisfied with your ability to answer the questions. If not, review the above content and try the activity again.

Key Points to Remember:

Note it!

The key points to remember in this section on transformers are:

- Two types of transformers are step-down and step-up.
- There are two coils wound on either side of the laminated soft iron core.
- When AC current flows in the primary coil, alternating emf is induced on the secondary coil.

This is the end of the content for this unit on electromagnetic effects. You should now go through the unit to capture the main points and compare them to the unit summary given in the following section.

Solutions to Activities on Transformers

Activity 3

(a) ***A device that transfers electrical energy from the primary coil to the secondary coil when the primary coil is connected to an AC supply is a transformer.***

(b) ***An alternating current in the primary coil sets up an alternating magnetic field in the core which induces an e.m.f. and hence current in the secondary coil.***

Activity 4

1. $V_2 / V_1 = N_2 / N_1$

Number of turns in the secondary coil:

$N_2 =$

$$\frac{120\ V \times 100}{24\ V} = 500\ turns$$

2. ***A transformer has a primary coil of 6000 turns which is connected to a 240V AC supply and a secondary coil with 150 turns. A 3Ω resistor is connected to the secondary coil.***

Calculate:

(a) The secondary coil voltage

$$V_2 = \frac{N_2 x\ V_1}{N_1}$$

$$= \frac{150 \times 240}{}$$

$$= \frac{6000}{1000}$$

$$= 6V$$

(b) Current through the resistor (From Ohm's law under electricity unit)

$$I = \frac{V}{R}$$

$$= \frac{6V}{3\Omega}$$

$$= 2A$$

(c) The current in the primary coil:

$$I_1 = \frac{I_2 \times V_2}{V_1}$$

$$= \frac{2A \times 6V}{240V}$$

$$= 0.05A$$

(d) The power taken from the supply

$$P = VI$$

$$= 240\ V \times 0.05A$$

$$= 12W$$

Unit Summary

Summary

Go through the summary carefully and refer back to the unit if you feel something is not clear.

In this unit you learned:

- Electromagnetic induction is the principle through which electromotive force is induced in the wire that moves within the magnetic field.
- Induced e.m.f. increases when: the coil is moved fast in the field, when the length of the wire moving in the field is long, when strong magnets which produce powerful fields are used.
- The direction of the induced current is found by Fleming's right-hand rule.
- An AC generator produces AC current.
- An AC generator uses the principle of electromagnetic induction.
- A transformer is a devise that changes or transforms voltage and current from one value to the other.
- Two types of transformers are: step-up and step-down transformer.
- In a step-up transformer the input voltage is smaller than the out put voltage.
- In a step-down transformer the input voltage is larger than the out-put voltage.
- In a step-up transformer current is stepped down by the same ratio as voltage is stepped up.
- In step-down transformer, current is stepped up by the same ratio as voltage is stepped down.
- For a 100% efficient transformer, the power supplied to the primary coil is fully transferred to the secondary coil.

You have completed the material for this unit on electromagnetic effects. You should now spend some time reviewing the content in detail. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit.

Assignment 24

Assignment

Now that you have gone through the activities in this unit, it is important to check whether you have learned and understood everything. You should get no less than 80% in this assignment.

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:14]

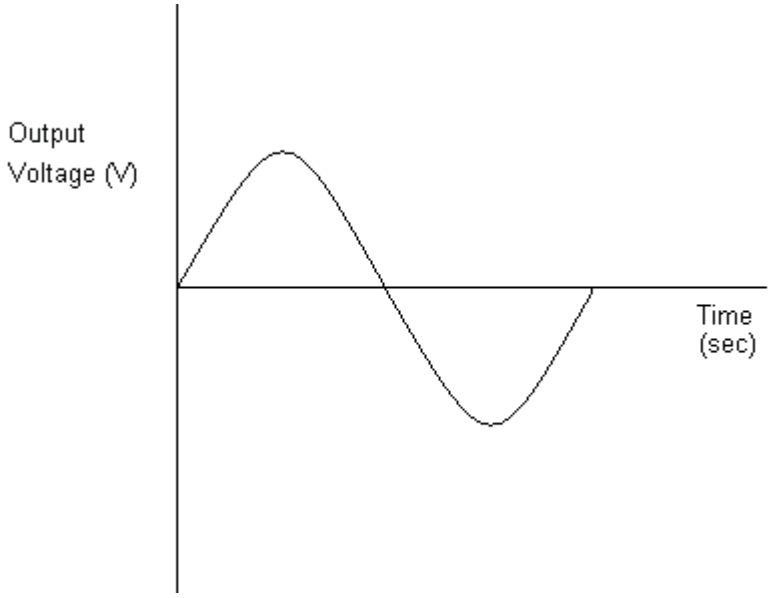
1) Define electromagnetic induction. (2)

_____
_____
_____

2) List the factors that affect the size of the induced e.m.f. (3)

_____
_____
_____
_____

3. The graph of the induced e.m.f. against time for a simple generator is shown below.



On the same axes, draw the graph showing the output voltage when the same coil rotates two times faster. (2)

4. Write the differences in structure and operation of the step-down and step-up transformer. (4)

_____
_____
_____
_____
_____
_____

5. A transformer has the input voltage of 240V and 100 turns in the primary coil. Calculate the output voltage if it has 1000 turns in the secondary coil. (3)

Reflection Question

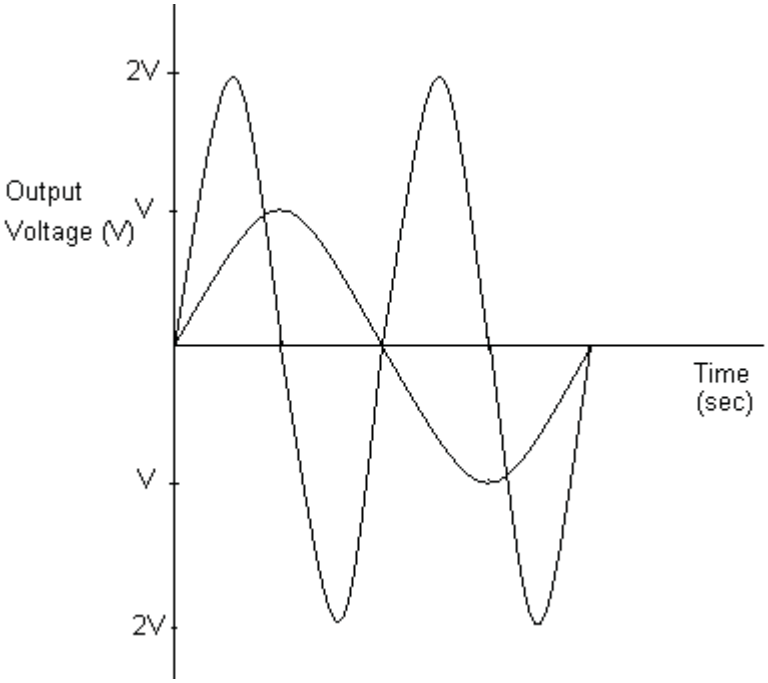
6. If your metal car moves over a wide closed loop of wire that has been put into the surface of the roadway, will this change the magnetic field of the Earth inside the loop? Do you think this will change the current? What might be an application of this knowledge at a traffic intersection? If you have access to the internet, please go: http://auto.howstuffworks.com/car-driving-safety/safety-regulatory-devices/question234.htm for more information.

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to Assignment 24

1. ***Electromagnetic induction is the principle by which electromotive force is induced in the wire that moves within the magnetic field.***
2. ***The factors affecting the size of the induced e.m.f. are:***
   - ***a) If the magnet is move at a high speed the size of the induced e.m.f. increases.***
   - ***b) If strong magnets are used the size of the induced e.m.f. increases.***
   - ***c) If the length of the wire cutting through the field lines is increased by making many coils, the size of the induced e.m.f. increases.***

3.



4.

b) Step-down transformer:

There are many coils in the primary coil compared to the secondary coil.

In-put voltage is larger than the out-put voltage.

Step-up transformer:

The numbers of coils in the primary coil are less than the number of coils in the secondary coil.

The input voltage is smaller than the output voltage.

5. We are given that:

$V_1 = 240\ v$

$N_1 = 100$

$V_2 = ?$

$N_2 = 1000$

We use the formula:

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

Then when we make V_2 the subject of the formula and get:

$$V_2 = \frac{N_2 V_1}{N_1}$$

Substituting the given values in the formula we get:

$$\frac{240V \times 180}{1080}$$

$$= 24V$$

6. When the car moves over the coils, this increases the current in the wire because the core of the electromagnet is now a large steel car. This change in current can be detected by traffic lights and so it can detect when a car is parked at an intersection.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physics course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 24

Assessment

The assessment prepares you for the final examination you will write at the end of the science course. Make sure that you take it seriously and put all the effort so that you can be sure that you have mastered the unit. A score of at least 80 % would indicate your mastery of the content.

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:27)

1. Multiple Choice Questions (5)

1) Which of the following will NOT affect the magnitude of induced e.m.f. in the coil?

A. The resistance of the coil cutting the magnetic field.

B. The speed with which the coil cuts across the field lines.

C. The number of turns of the coil.

D. The strength of the magnetic field.

2) Why is a soft-iron core used in the core of a transformer?

A. It will not melt easily when the induced current is too large.

B. It conducts the induced current very well.

C. It ensures better magnetic field linkage between the two coils.

D. It has a low resistance.

3) What is the main function of a step – down transformer?

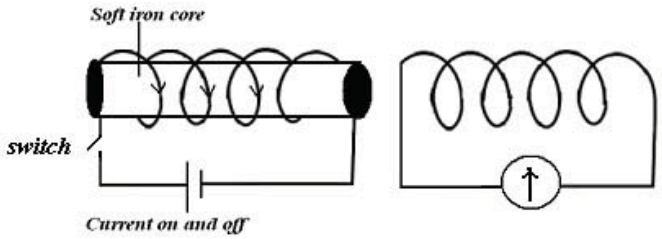
A. To decrease the current.

B. To decrease the voltage.

C. To change AC to DC.

D. To change DC to AC.

4) When the switch is closed in the figure below, the pointer of the meter moves to the right. What happens to the pointer if the switch is kept closed?



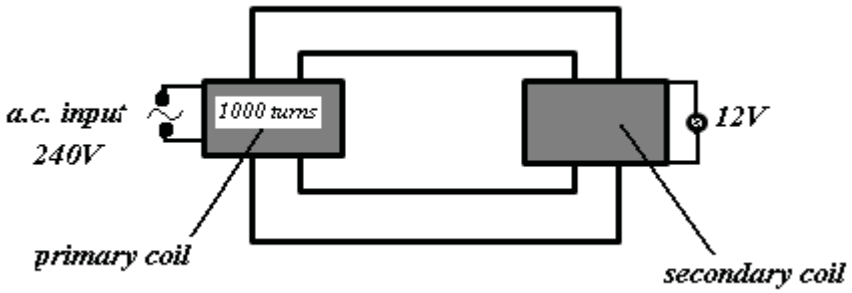
A. It returns to zero.

B. Stays on the right.

C. Moves to the left and stays there.

D. Moves to and fro.

5) How many turns are on the secondary coil?



A. 50

B. 500

C. 20

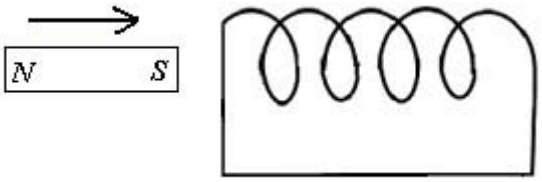
D. 2000

2. **Structured Questions**

(a) (i) Define electromagnetic induction. (3)

(ii) State the factors which affect the amount of the induced e.m.f. (3)

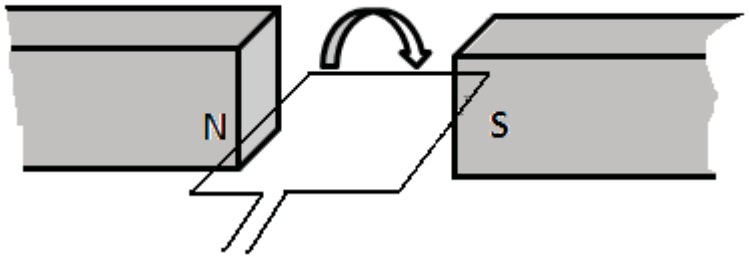
(b) (i)



A bar magnet is being pushed into the coil; mark the direction of the induced current on the diagram above. (1)

(ii) State Lenz's law for the direction of the induced current. (2)

(c)



Considering the coil to be rotating in a clockwise direction as indicated in the above diagram.

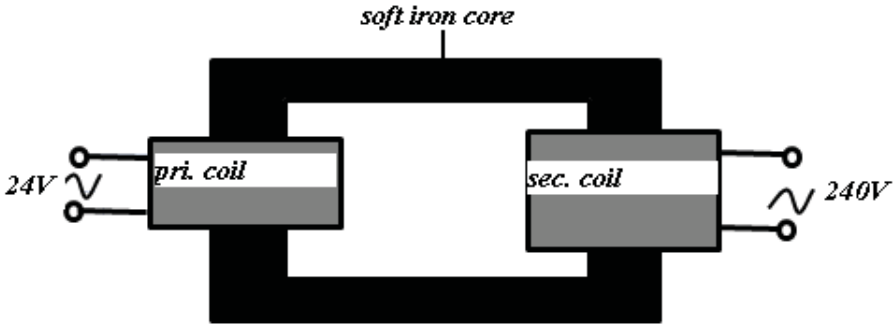
(i) Use Fleming's right hand rule to indicate (by arrows on the loop), the direction of induced current. (1)

(ii) State at what positions of the coil the e.m.f. will be maximum and minimum. (2)

(iii) Sketch a graph to show the waveform generated. (3)

(iv) How would the induced e.m.f alter if the coil were to be rotated faster? (1)

(d) The figure below shows a simple demonstration of a transformer:



(i) Is this transformer a step-up or step-down transformer? (1)

(ii) If the primary coil has 50 turns how many turns should be on the secondary coil? (3)

(iii) If the primary current is 25A, what is the greatest possible secondary current? (2)

Physics

Grade 12

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Contents

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Unit 25

Cathode Rays and Cathode Ray Oscilloscope

Study Skills

Schedule your study time so that the time at which something is learned or relearned is close to the time at which it will be used. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

In this unit we are going to learn about one of the most fascinating studies in physics: **electronics**. The discovery of electronics has led to great advances in technology. TV sets, computers, cathode ray oscilloscopes etc. are some of the electronic products that were developed using electronic technology. Not only have they made our lives interesting, but comfortable too!

It is important that this study begins with a good understanding of the production of the electron beam which is the basis of the products listed above. The emission of an electron beam and how it is controlled and focused is therefore going to be the centre of attention for this unit.

Time

This unit consists of 25 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Spend a few moments reading the following learning outcomes. They are a guide to what you should focus on while studying this unit.

Outcomes

Study Skills

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Solve* problems which involve physical forces, such as energy, light, magnetism and electricity.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.

Unit Outcomes

Upon completion of this unit you will be able to:

- *Describe* the production and detection of cathode rays.
- *Describe* their deflection in electric and magnetic fields.
- *Describe* the structure and action of cathode ray-oscilloscopes.
- *Describe* how to operate a cathode-ray oscilloscope to display waveforms.

Terminology

Cathode rays:	Beams of electrons moving at high speed
Thermionic emission:	Outflow of electrons into a vacuum from a heated conductor.

Section 25-1: Thermionic Emission

Introduction

At the end of this section, you should be able to describe the production and detection of cathode rays and be able to describe their deflection in electric and magnetic field.

Time

There are 6 pages on the topic of thermionic emission. You should spend approximately 1-2 hours on this topic.

Thermionic emission is a process by which charge carriers like electrons or ions move over a surface of some sort of energy barrier by the induction of heat. In this process, electrons can outflow into a vacuum.

The outflow can occur in a conductor, for example, a tungsten filament if it is sufficiently heated to a high temperature. The electrons from the hot metal then have enough energy to break from the metal surface and escape into the vacuum surrounding the filament.

The filament is heated by passing a small current through it. See the Figure 1.

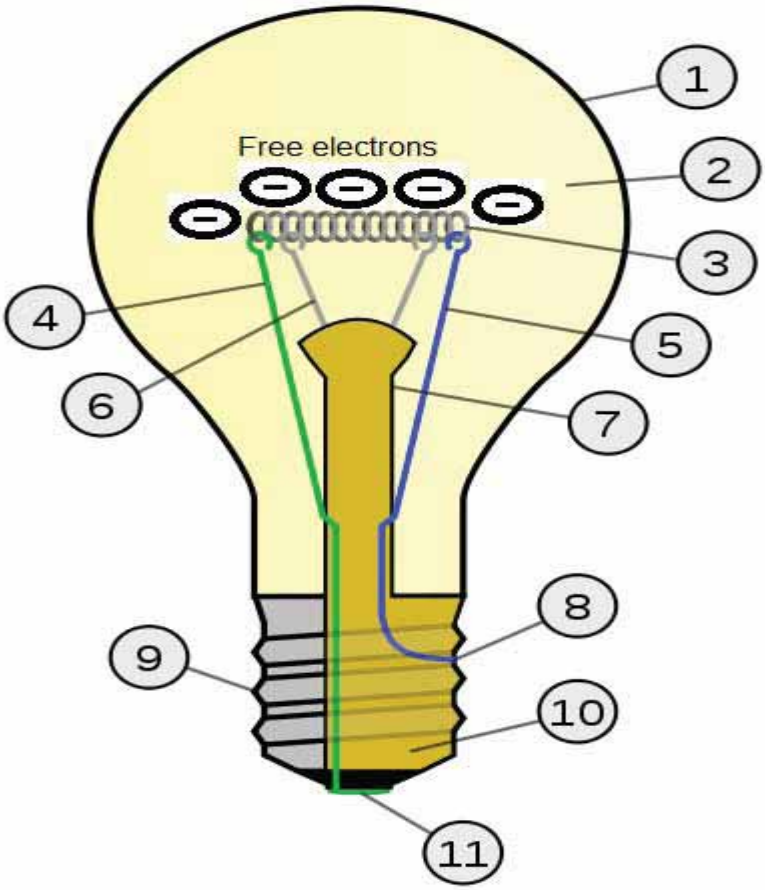

Figure 1(a): Thermionic emission in a tungsten filament accessed from Wikimedia Creative Commons, 2010.

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Whereby 1 - Glass bulb

2 - Inert gas

3 - Tungsten filament (heated and giving off electrons)

4 - Contact wire (goes to foot)

5 - Contact wire (goes to base)

6 - Support wires

7 - Glass mount/support

8 - Base contact wire

9 - Screw threats

10 - Insulation

11 - Electrical foot contact

The behaviour of electrons emitted from the hot filament can be studied in more detail as illustrated by the following figure.

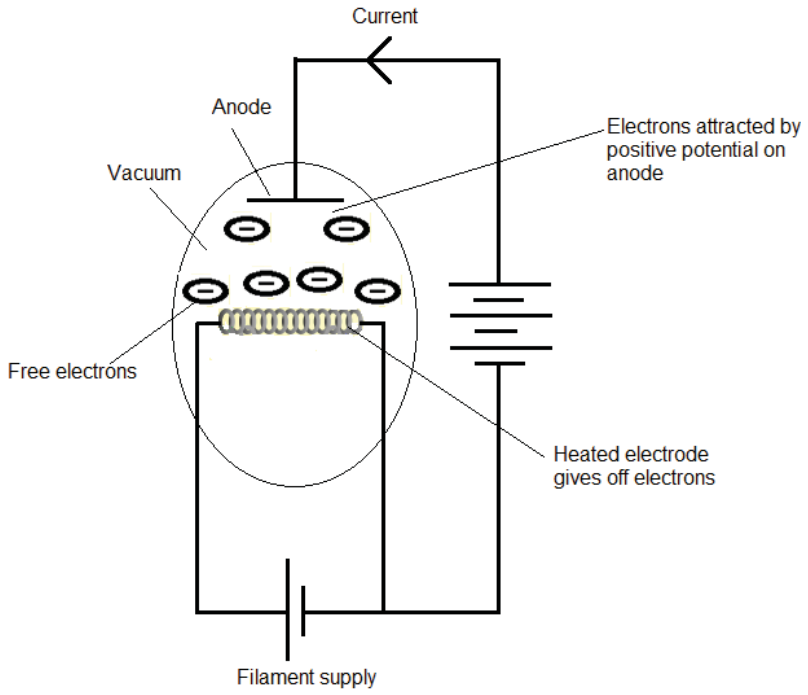

Figure 1(b): Thermionic emission in a tungsten filament. Hand drawn by graphic designer at LDTC.

Recognise the following features of the circuit in Figure 1(b):

The circular part represents a glass tube inside which there is:

- A metal plate called an **anode** because it is connected to the positive terminal of a powerful power supply.
- A small coil of wire or **filament** called a **cathode** because it is connected to the negative terminal. The filament is heated by current from a small (6V) power supply.
- The anode and cathode are collectively called **electrodes**.

- Air is removed from the glass tube so that the electrons from the cathode are free to move without colliding with air molecules.

Notice that there is a flow of current in the circuit above despite the fact that there is a gap between the two electrodes.

How can this be explained?

The hot filament emits electrons which being negatively charged, become attracted towards the positive anode and accelerate towards it, and hence current flows around the circuit.

The electrons have enough energy to break free from the metal filament. The higher the temperature of the filament, the greater the number of electrons emitted.

Beams of electrons moving at high speed are called **cathode rays**.

The glass tube and the electrodes together form a **thermionic diode**.

At this stage let us check if we are still together by carrying out the following activity.

Activity

Activity 1

(i) In your own words, describe thermionic emission.

_____
_____
_____

(ii) What are the main components of a thermionic diode?

_____
_____
_____

(iii) Why should all the air be removed from the inside of the glass tube?

_____
_____
_____

Compare your answers with those at the end of the section. If you got the questions correct, continue. If you struggled then refer back and try the activity again!

Properties of Cathode Rays

Properties of cathode rays may be demonstrated by a special tube called a Maltese cross tube shown below.

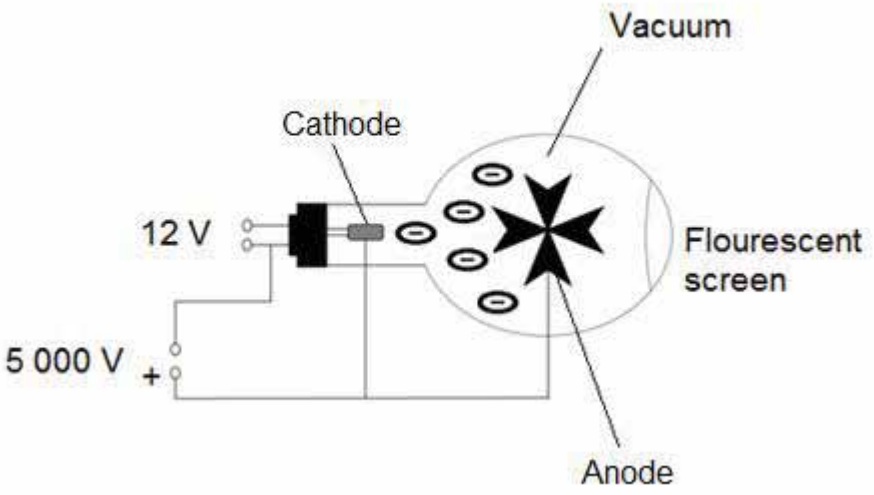

Figure 2: A Maltese cross tube. Hand drawn by graphic designer at LDTC.

Note that the "cross" is connected to the positive end of the 5000 V power supply and therefore it is the anode. When electrons are emitted from the cathode, they are accelerated towards the cross which is connected to a high positive potential of about 5kv. Some of the electrons are stopped by the cross, while those that miss it strike the screen and cause it to fluoresce with green/blue light. Consequently, a shadow of the cross is seen on the screen.

Cathode rays:

- **Travel in straight lines**

If a magnetic field is applied at right angles to the tube, by bringing the north pole of a magnet to the neck of the tube, the rays and the fluorescent shadow can be seen to move upwards towards the N pole and this shows that the rays:

- **Are deflected by magnetic fields**

If a potential difference is created across two parallel metal plates placed **horizontally** same distance apart in the tube, we would observe that the rays **bend vertically** towards the positive plate. These plates are referred to as the **"y"** plates because they deflect the electron beam vertically. Study the diagram below.

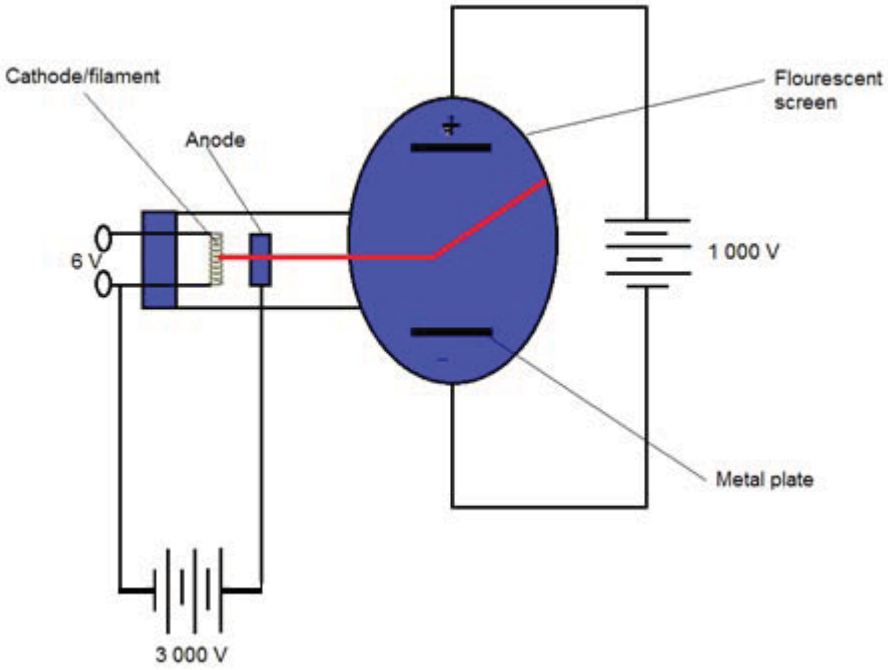

Figure 3: Cathode rays in an electric field. Hand drawn by graphic designer at LDTC.

Alternatively, if a potential difference is created across two parallel metal plates placed **vertically,** we would observe that the rays **bend horizontally** towards the positive plate. These plates are referred to as the **"x"** plates because they deflect the electron beam horizontally.

Electrons are repelled by the negative charges on the negative plate and attracted by the positive charges on the positive plate.

It can therefore be concluded that:

Cathode rays:

- **Are also deflected by an electric field**

Activity

Activity 4

State three properties of cathode rays:

(i) _____

(ii) _____

(iii) _____

Compare your answers with those at the end of the section.

Note it!

Key Points to Remember:

The key points to remember in this section on cathode rays and cathode ray oscilliscopes are:

- Beams of electrons moving at high speed are called **cathode rays**. They are emitted by a hot filament-the cathode through a process called **thermionic emission.**
- Cathode rays can be detected by use of a Maltese Cross Tube.
- Cathode rays travel in straight lines and can be deflected magnetically or electrically.
- Electrical deflection of cathode rays is applied in a cathode ray oscilloscope which is used for many purposes in our school laboratories, for measuring short time intervals, frequencies, voltages and displaying waveforms.

Answers to Activities on Thermionic Emission

Activity 1

(i) Thermionic emission is the process through which electrons are emitted by a hot filament which is heated by passing a small current through it.

(ii) Evacuated glass tube, two electrodes; the anode and cathode.

(iii) To prevent the rays emitted by the hot filament from colliding with the air particles.

Activity 2

Cathode rays:

(i) travel in straight lines

(ii) are deflected by an a magnetic field

(iii) are deflected by an electric field

Section 25-2: The Cathode-Ray Oscilloscope

The cathode- ray oscilloscope abbreviated (CRO) is a very special instrument which is used for a variety of purpose as shall be studied during the course of this unit. As its name suggests it makes use of cathode rays which we just learnt about.

If there is a nearby school visit the school laboratory to see one and to familiarise yourself with its use. Figures 4(a) and 4(b) show a typical CRO.

Figure 4(a): Cathode ray oscilloscope accessed from Wikimedia Creative Commons, 2010.

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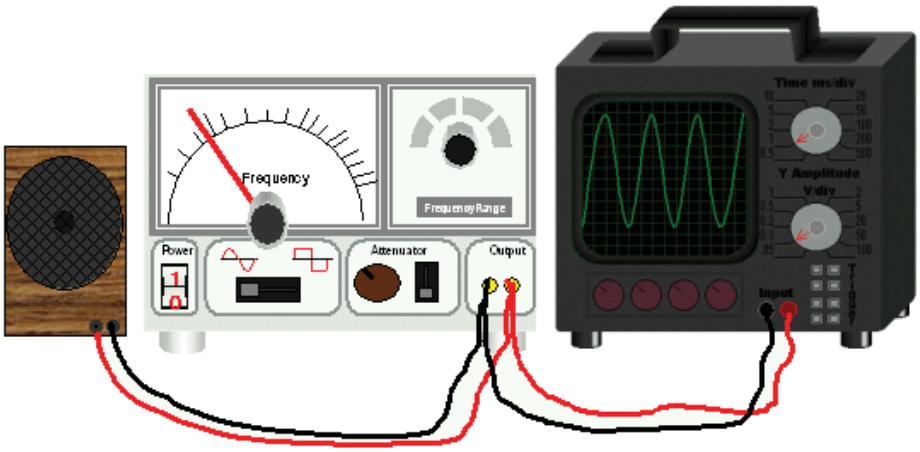

Figure 4(b): Cathode ray oscilloscope accessed from Wikimedia Creative Commons, 2010.

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The CRO consists of a cathode **ray tube** which has three main components:

(i) A fluorescent screen

(ii) An electron gun

(iii) A deflection system

Figure 5 shows these parts:

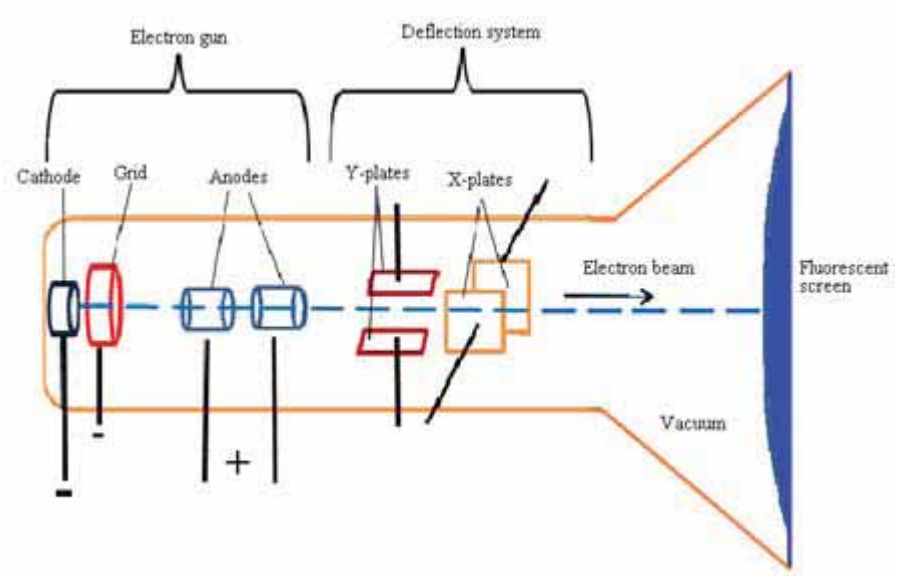

Figure 5: A cathode ray tube accessed from Wikimedia Creative Commons, 2010.

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(i) A Fluorescent Screen

The inside of the CRO screen is coated with zinc sulphide which fluoresces into a bright spot when the electron beam strikes it. A bright spot is then observed on the front of the screen, as shown in Figure 6(a).

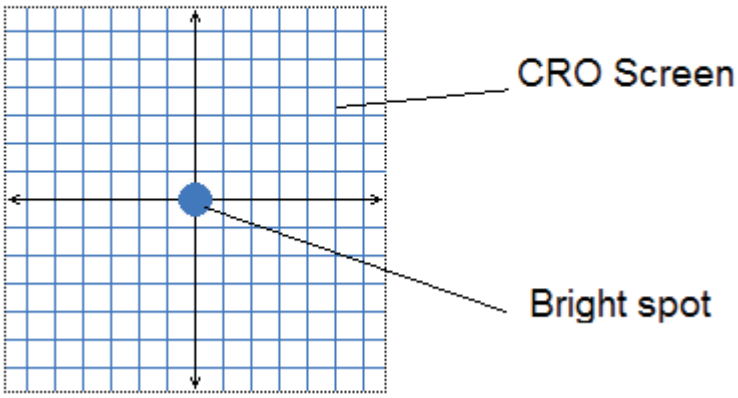


Figure 6(a): A CRO screen. Hand drawn by graphic designer at LDTC.

(ii) An electron gun – Is responsible for producing a narrow beam of electrons.

It consists of the **filament,** an electrode called **the grid** and **two other anodes.** The function of the filament has already been discussed.

The grid as shown in Figure 6(a) is at a negative potential. It repels the electrons emitted by the filament and therefore controls the amount of electrons passing through its hole. The brightness of the spot on the screen is controlled by the grid. Operating the **intensity or brilliance control**, as shown in Figure 6(b), on the CRO varies the potential of the grid.

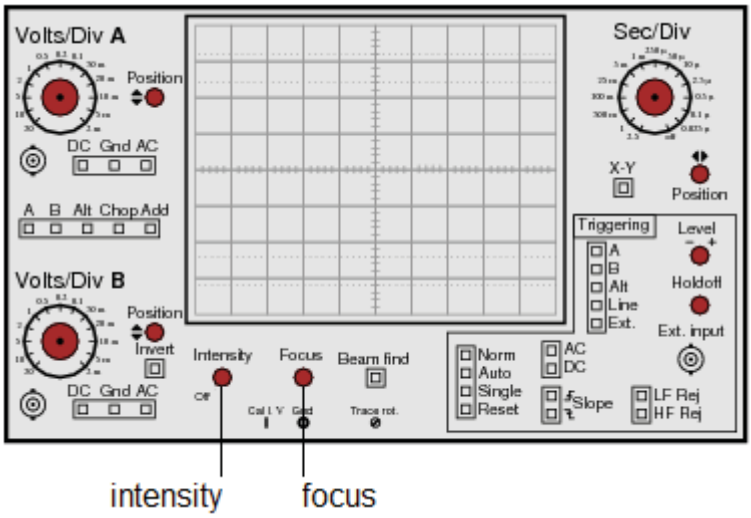


Figure 6(b): Oscilloscope showing intensity and focus controls accessed from Creative Commons, 2010.

The anodes are at a positive potential. Their function is to **accelerate the electrons along the tube to the screen, and to focus them into a narrow beam.** Turning the **focus control**, as shown in Figure 6(b), on the CRO varies the focusing ability of the anodes.

Activity 3

Activity

In an electron gun, what is the function of:

(i) The filament

_____

_____

(ii) The grid

_____

_____

(iii) The anode

_____

_____

Compare your answers with those at the end of this section. Be sure that you understand each answer before continuing. If you have any misunderstandings, review this content and work through the activity again.

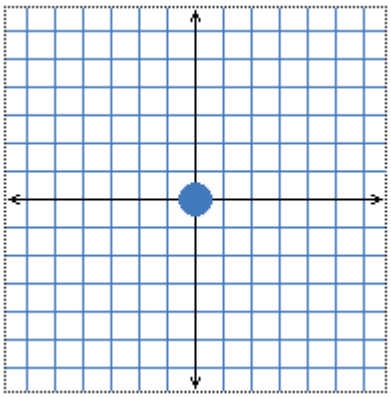
(iii) A Deflection System

Consists of two pairs of plates as described above which deflect the electron beam on the screen when a potential difference is created across them. They are called the "X" plates and the "Y" plates.

The following figures show the deflection of the spot as would be seen on the CRO screen as the potential difference is varied across the deflection plates.

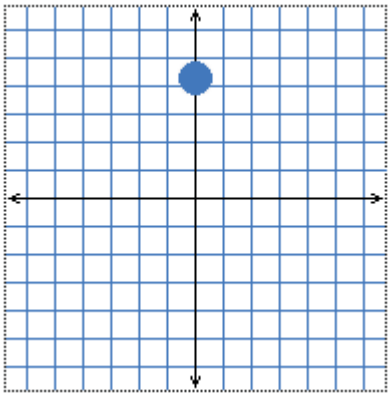
Vertical Deflection

To create an electric field between the Y-plates, a potential difference is applied to the **Y- input** terminals on the front of the CRO and can be amplified by a **Y-amp gain control**. It gives a reading in **V/cm or V/div** (which means that the spot is deflected 1 cm or one division vertically for every volt). Different scenarios and their deflection are shown by Figures 6(a) to 6(d) and accompanied by explanations in the boxes beside the figures. Remember, this is what you would see on the CRO screen in the different scenarios.



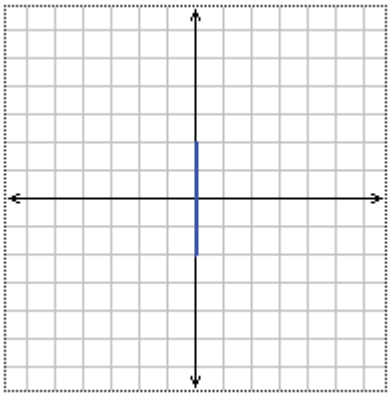
There is no deflection when the potential across the Y plates is zero. **Notice the spot is in a central position**.

Figure 6(a): Zero potential difference across Y plates. Hand drawn by graphic designer at LDTC.



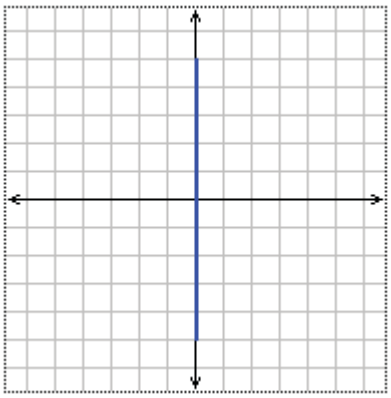
There is deflection upwards when there is DC voltage across the Y plates. In this case, the upper plate is positive.

Figure 6(b): DC voltage across Y plates. Hand drawn by graphic designer at LDTC.



There is a rapid upward and downward deflection when there is a 50 Hz a.c. voltage across the Y- plates. The spot oscillates up and down so fast that it produces a vertical line. Compare this to the above result when there is a d.c. voltage.

Figure 6(c): 50Hz AC voltage across Y plates. Hand drawn by graphic designer at LDTC.



Note how the Y-amp gain control has been turned to increase the vertical deflection.

Figure 6(d): Y – amp gain control turned on. Hand drawn by graphic designer at LDTC.

Activity 4

Activity

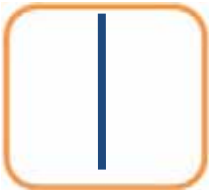
1) On the figure below, label the Y and X plates.

2) Indicate with a (-), a negative plate in the following figure.

3) Is the voltage applied across the plates in the figures below AC or DC _____

Is it amplified in (a) or (b)? _____

(a)



(b)

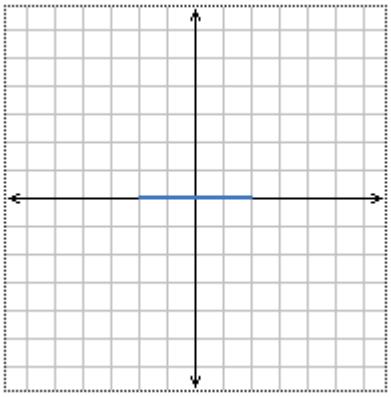
Check your performance against the given solutions at the end of this section. Continue if you are satisfied with your ability to answer the questions. If not, review the above content and try the activity again.

Horizontal Deflection

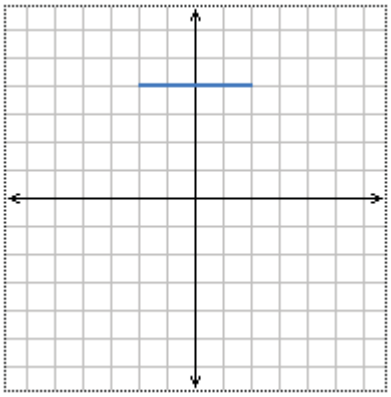
The spot will be made to deflect horizontally from the **time base** circuit in the CRO. The time base circuit automatically sets a voltage to the X-plates which makes the spot move from left to right on the front of the CRO.

When the spot completes one movement across the screen it, it flies back to its starting position and the process is repeated.

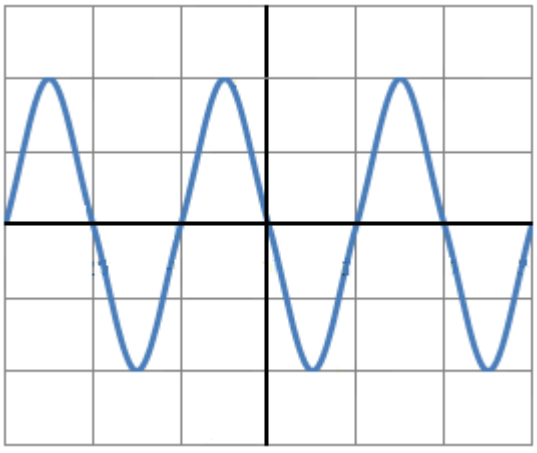
Turning the time base control, the speed with which the spot moves across the screen is increased, such that a straight horizontal line is observed on the screen. The time base is set in **ms/div (which means it takes one millisecond for the spot to move across every one horizontal division on the CRO).**



This has the time base on and the Y input at zero. **Notice the central line.**



This has the time base on and the Y input with a DC voltage across the Y plates. In this case, the upper plate is positive.



This has the time base on and the Y input with an AC voltage across the Y plates.

At this point you have studied some of the most important controls that would be found on the front of the CRO and their uses. These are:

- brilliance control
- focus control
- Y-amp gain control
- time base

Take note! These are not the only controls on the CRO, but are the basic ones that you need to learn to at least get started on the CRO.

Activity

Activity 5

Draw a diagram to show the pattern that would form on the CRO screen when the lower Y plate is positive, it is connected to a DC voltage supply and the time base is on.

Compare your answer with the solution at the end of the unit. Be sure you understand why the answer is correct.

Uses of the CRO

The CRO comes in a variety of sizes, complexities and uses. In the school laboratory it is commonly used for the following purposes:

(i) To display waveforms and hence study the waves produced by sound by connecting a microphone to the CRO input terminals.

(ii) Measuring voltage.

(iii) Measuring frequency.

(iv) Measuring time intervals.

Measuring Voltage

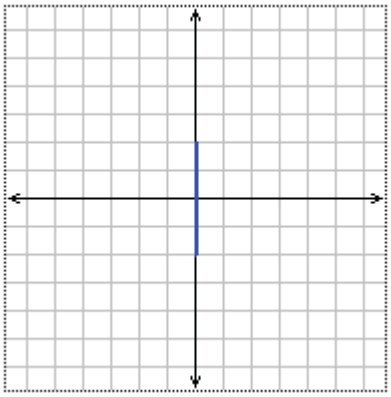
The vertical deflection depends on the voltage applied to the Y-input terminals. A CRO may therefore be used as both an ac/dc voltmeter when

the potential difference to be measured is connected to the Y-input terminals.

Example

What voltage is shown by the CRO if it displays a 2 cm vertical deflection (assuming that every division is equal to 1 cm) when the Y-amp gain is set to 2V/cm?

(See the figure below)



Solution

When the Y-amp is set to 2V/div means that every 2V is represented by one division vertically. So for 2 divisions:

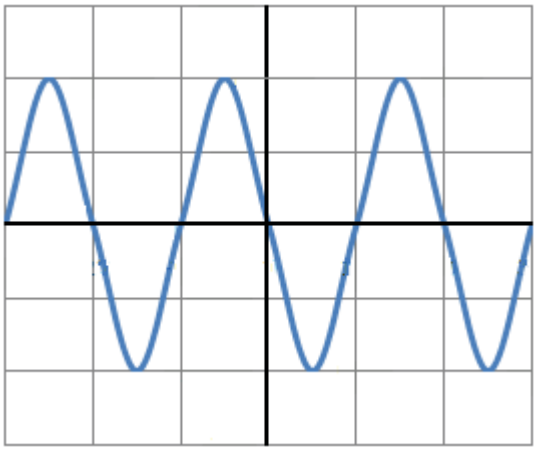
Voltage = 2divisions x 2v/div

= 4V

Measuring Time Intervals and Frequency

If the time base is set to 10 ms/div, this means that the spot takes 10 milliseconds to move across every one horizontal division.

When the waveform displayed on the CRO shows a complete wave covering two divisions as illustrated below, this means that the period of the wave is
20 ms.



Remember the formula T = 1/f? Where T is the period and f is the frequency.

If T = 20 ms, we need to change it into seconds first

20 ms = 0.02 sec

f = 1/T

f = 1/0.02 sec

= 50 Hz

Activity

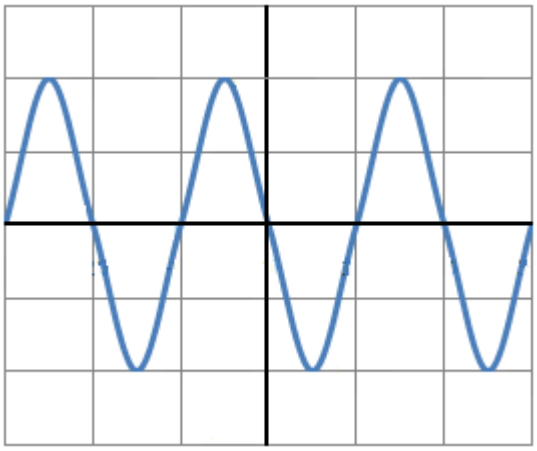
Activity 6

The figure below shows the display of an AC voltage applied to the Y-plates. The Y-amp gain is set to 3V/div and the time base is set to 2 ms/div.

Calculate the:

(i) voltage and

(ii) the frequency as shown by the displayed waveform.



Note it!

Key Points to Remember:

The key points to remember in this section on the cathode ray oscillioscope are:

- The CRO consists of a **cathode ray tube** which has three main components:
  - i. An electron gun
  - ii. A deflection system and
  - iii. A fluorescent screen
- In order to operate a CRO, the following controls are the basic controls to use:

i. Brilliance control

ii. Focus control

iii. Y-amp gain control

iv. Time base

Answers to Activities on the Cathode Ray Oscilloscope

Activity 3

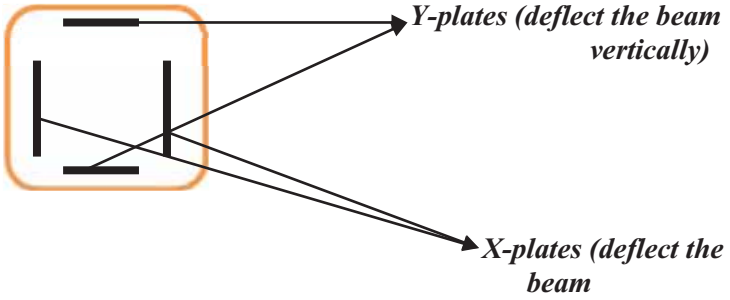
(i) The filament emits electrons when it is heated.

(ii) The grid controls the number of electrons which pass through its hole.

(iii) The anode accelerates the electrons forward and narrows the electrons into a fine beam.

Activity 5

(i)



(ii) The upper-plate is negative since the spot is attracted to the bottom plate which is positive.

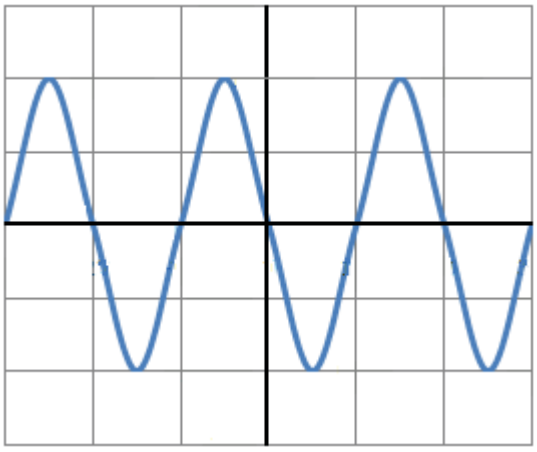
(iii) The line on the screen suggests that the voltage across the Y plates is from an AC supply. The line is longer in (b) because the voltage is amplified.

(b) *(b)*

Activity 5

The line appears towards the bottom because the positive Y- plate is towards the bottom and is stretched horizontally because the time base is on.

Activity 6



(i) When the Y-amp is set to 3V/div, it means that every division represents 3V. Which means:

Voltage = 2 divisions x 3V/div

= 6V

(ii) From the diagram, a complete wave covers two divisions horizontally. This implies that the period of the wave is 4 ms since the time base is set to 2 ms/div.

From the formula T = 1/f where T is the period.

0.004 s = 1/f (remember to convert the ms to the second!)

f = 1/T

= 1/0.004

= 250 Hz

Unit Summary

Summary

In this unit you learned that:

- Beams of electrons moving at high speed are called **cathode rays**. They are emitted by a hot filament, **the cathode**, through a process called **thermionic emission.**
- Cathode rays can be detected by use of a Maltese Cross Tube.
- Cathode rays travel in straight lines and can be deflected magnetically or electrically.
- Electrical deflection of cathode rays is applied in a cathode ray oscilloscope which is used for many purposes in our school laboratories, for measuring short time intervals, frequencies, voltages and displaying waveforms.
- The CRO consists of a cathode **ray tube** which has three main components:
  - iv. An electron gun
  - v. A deflection system and
  - vi. A fluorescent screen
- In order to operate a CRO the following controls are the basic controls to use:
  - v. Brilliance control
  - vi. Focus control
  - vii. Y-amp gain control
  - viii. Time base

You have completed the material for this unit on cathode rays. You should now spend some time reviewing the content in detail. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify any misunderstandings that you have. Your last step is to complete the assessment. Once you have completed the assessment, proceed to the next unit. It covers atomic physics.

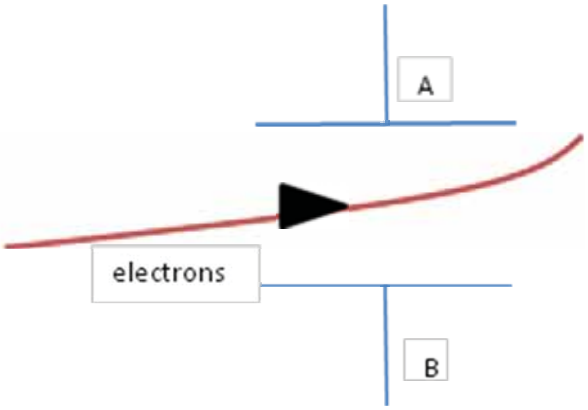
Assignment 25

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:26]



Refer to the above diagram in order to answer the following questions.

(a) What name is given to the process by which the electrons above are produced?

_____

(2)

(b) Name the plates A and B above.

_____

(2)

(c) A certain field exists between the two plates, what is the name of the field?

_____

(2)

(d) Explain why the electrons deflect towards the upper plate.

_____

_____

(4)

(e) The same effect of deflecting the beam can be achieved the electrons pass through another field, name it.

_____

(2)

(f) If these electrons were moving towards the screen of a CRO in a cathode ray tube, name the part that:

(i) accelerates them towards the screen.

_____

(2)

(ii) controls the numbers of electrons reaching the screen.

_____

(2)

(g) Name two functions of a CRO as it would be used in the school laboratory:

(i) _____

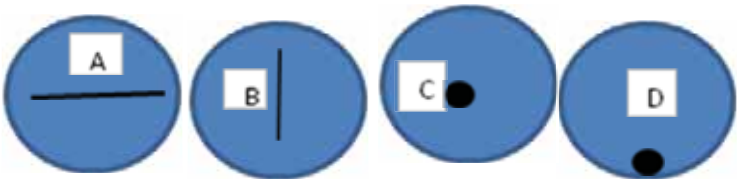
(2)

(ii) _____

(2)

Multiple Choice Questions

(a) Which of the following patterns would be seen on a screen of a CRO when the time base is switched off and a 50 Hz AC supply is connected to the Y plates? (2)



(b) Which of the following controls on the front of the CRO is responsible for altering the potential difference across the X – plates? (2)

A. Brilliance control

B. Focus control

C. Y-amp gain control

D. Time base

(c) A wave-form pattern on the CRO is formed when: (2)

A. An AC potential difference is supplied across the Y –plates and the time base is on.

B. A DC potential difference is supplied across the Y-plates and the time base is off.

C. An AC potential difference is supplied across the Y – plates and the time base is off.

D. Zero potential difference across the deflection plates.

Compare your answers to those provided below. Pay particular attention to any mistakes that you made and clarify those misunderstandings.

Answers to the Assignment 25

(a) Thermionic emission

(b) Y-plates

(c) Electric field

(d) It is at a positive potential

(e) Magnetic field

(f) (i) Anode

(ii) Grid

(g) (i) Measuring voltage

(iii) Measuring time intervals

Answers to Multiple Choice Questions

(a) B

(b) D

(c) A

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physics course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 25

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:24)

Show all of your work for full marks.

1. Describe how cathode and anode rays formed in a filament. (4)
2. With the aid of a labelled diagram explain how the Maltese Cross Tube can be used to show that:
   (a) Cathode rays travel in straight lines. (5)
   (b) Cathode rays are deflected by magnetic fields. (5)
3. State the three main components of a cathode ray tube and their functions. (6)
4. When using a CRO, what is the function of:
   (a) The focus control (2)
   (b) The brilliance or intensity control (2)

Physics

Grade 12

COL Open Schools Initiative
Lesotho

Contents

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Unit 26

Atomic Physics

Study Skills

Make sure to take rest periods when you study. Make the most of rest periods-do something quite different. ***Refer back to the Learning Approaches section of the Course Overview for more ways to approach your self-directed learning.***

Introduction

The world is nowadays discussing nuclear radiation. We often see movies that portray the usefulness of nuclear radiation, but also how dangerous it can be. In 1986, a nuclear power plant in Chernobyl, Ukraine went out of control. The result of this was an explosion and the release of large amounts of radiation into the atmosphere. Since then, over 1000 cases thyroid cancer have been reported in people who were children in Chernobyl at the time of the accident as well as many cases of mutations in animals. Scientists still do not know all of the long-term effects that this accident will have on the area or the world. In this unit we will learn about nuclear radiation, how it comes about from radioactive substances, its uses, hazards and precautions when handling radioactive substances.

To better understand this unit on atomic physics, it may help if you review unit one.

Time

This unit consists of 34 pages and will take you approximately 20 hours or 3 weeks to complete. Remember that this is just an estimate. Some topics will take you less time, and some topics may take you more time. It is important to create a schedule and stick to it!

Take a moment to read the following learning outcomes. You should focus on those skills while studying this unit.

Course Outcomes:

When you have completed this unit, you should be comfortable with being able to:

- *Describe* matter and its related physical processes.
- *Describe and perform* experiments which are used to illustrate and clarify concepts in physics.

Outcomes

Study skills

Unit Outcomes:

Upon completion of this unit you will be able to:

- *Describe* the structure of an atom.
- *Define* the term isotope.
- *Describe* the characteristics and detection of radioactive emission.
- *Explain* the three processes of radioactive decay.
- *Calculate* the half-life of a radioactive source.
- *Describe* the safety precautions while handling radioactive substances.

Terminology

Proton/atomic number:	The number of protons in the nucleus of an atom.
Nucleon/mass number:	The total number of protons and neutrons in the nucleus of an atom.
Nuclide:	The nucleus of an atom with a certain number of protons and neutrons.
Isotope:	Atoms of the same element with the same number of protons but different number of neutrons.
Radioactive decay:	A process in which an unstable nucleus spontaneously loses energy by emitting ionising particles and radiation.
Half-life:	The amount of time taken for half of the radioactive nuclei to decay.

Section 26-1: The Structure of an Atom

Introduction

By the end of this section, you should be able to describe the structure of an atom and define the term isotope.

Time

There is one page on the topic of the structure of an atom. You should spend approximately 30 minutes on this topic.

An Atom

Refer to Unit 1 for a thorough explanation of the structure of the atom. You should recall that the nucleus of an atom has protons and neutrons. We sometimes call them nucleons. The **number of protons** is called the **atomic number/proton number (Z),** whereas the number of **protons plus neutrons** is called the **mass number/nucleon number (A).** This can be shown by nuclide notation:

$${}^{A}_{Z}X$$ Where Z = the proton number

A = the nucleon number

X = an atomic nuclide

The proton number/atomic number is the same because that is what identifies an element. An element will always have the same number of protons (proton/atomic number). This number identifies an element. However the number of neutrons is not always the same.

Atoms of the same element with the same number of protons but different number of neutrons are called **isotopes**. An isotope can be formed from a radioactive atom that is unstable.

The unstable nucleus will decay and emit radioactivity. This will be explained further in the coming sections. Radioactive nuclei are also called radioactive isotopes.

Section 26-2: Detection of Radioactivity

Introduction

By the end of this section, you should be able to describe the characteristics and detection of radioactive emission.

Time

There 11 pages on the topic of detection of radiation. You should spend approximately 5-6 hours on this topic.

The Discovery of Radioactivity

Radioactivity was first discovered in 1896 by a French scientist named Henri Becquerel. He noticed that photographic plates wrapped in black paper and then placed on uranium ore became exposed. The conclusion he made was that the uranium compounds were emitting radiation and this he called radioactivity.

Subsequent research by other scientists showed that there are three types of radiation:

Alpha (α), beta (β) and gamma (γ).

Radiation Detectors

Apart from the photographic method of detecting radioactivity discovered by Becquerel, there are other methods which will subsequently be explained.

1. **The gold leaf electroscope**

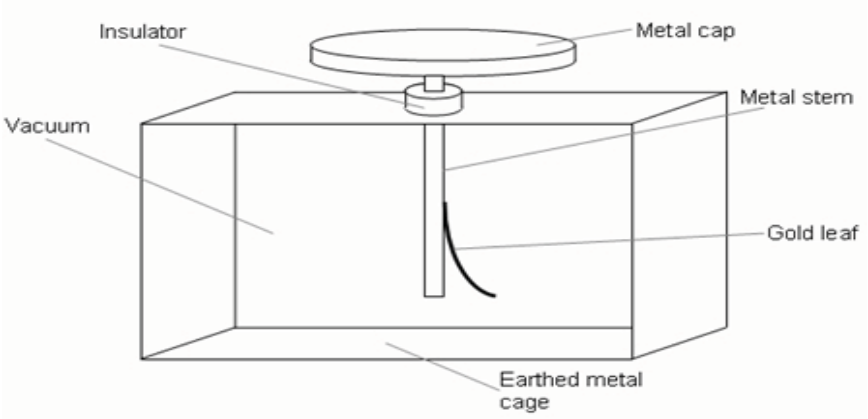

Figure 2(a): A gold leaf electroscope accessed from Creative Commons, 2010.

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The electroscope has a very thin piece of gold foil called the gold leaf fixed at the top to a piece of metal, usually copper. The metal/copper has a large round top, called the cap. It is then put into a glass case to stop air from blowing the gold leaf around. The piece of metal/copper goes through an insulator at the top of the glass case to prevent any charge on the gold leaf from escaping.

Charge can be transferred to the electroscope by wiping a charged object across the cap. The charge then flows over the conducting copper/metal and gold, and the gold leaf rises as it is repelled because it has the same charge as the copper.

The charged electroscope can then be used to detect α -particles. A radium source, which emits α –particles, can be brought to the cap of the charged electroscope. This ionises the air molecules above the cap. Unlike charges on the cap will be attracted thereby neutralising the charged electroscope causing the gold leaf to fall. The more intense the radiation, the faster the leaf falls.

2. The Geiger – Muller Tube (GM Tube)

A **GM Tube** is the sensing element of a Geiger counter instrument that can detect a single particle of radiation usually β- particles and γ-rays but certain models can also detect α- particles.

Figure 2(b): A deflection needle type Geiger counter accessed from Creative Commons, 2010.

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Figure 2(c): A combined Geiger counter and metal detector accessed from Creative Commons, 2010.

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Figure 2(c) above shows a Geiger counter and metal detector combined for detecting both metal and radioactive materials for security purposes. This is normally used at airports.

3. The diffusion cloud chamber

The **diffusion cloud chamber** is also used for detecting particles of ionising radiation. In its most basic form, a cloud chamber is a sealed environment containing a super cooled, super-saturated water or alcohol vapour.

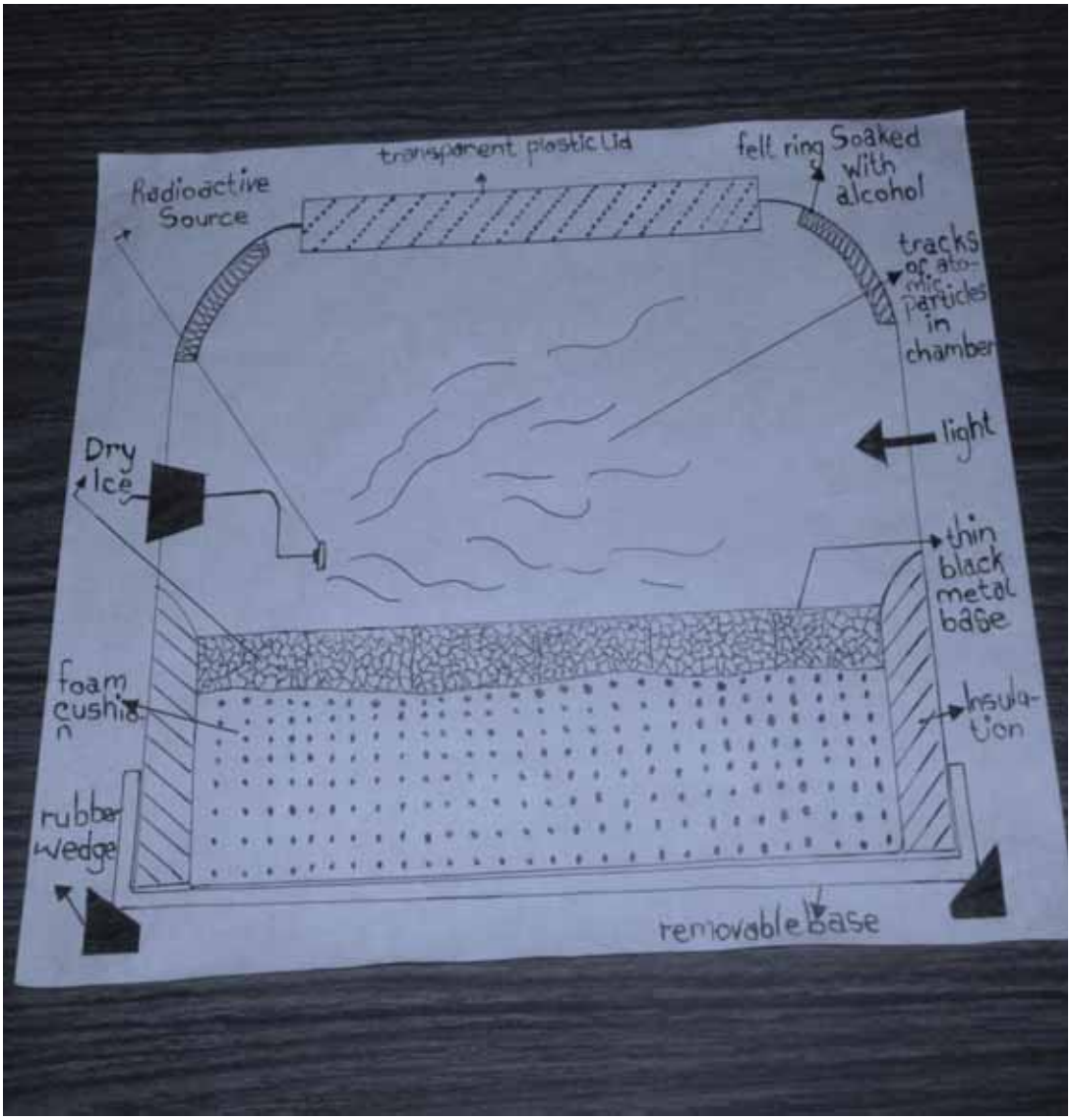

Figure 2(d): The diffusion cloud chamber. Hand drawn by graphic designer at LDTC.

When an α- particle, a β- particle or a γ – ray interacts with the mixture, it ionises it. The resulting ions act as condensation nuclei, around which a mist will form.

The high energies of α and β particles and γ – rays mean that a trail is left, due to many ions being produced along the path of the charged particle. These tracks have distinctive shapes.

Figure 2(e): Cloud chamber with visible tracks from ionising radiation (short, thick: α-particles; long, thin: β-particles) accessed from Creative Commons, 2010.

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Activity 1

Activity

Let us now answer the following questions. Write your answers in the spaces provided.

a) Which type of radiation can be detected with a gold leaf electroscope?

_____
_____

b) Give a description of how the detection is done.

_____
_____
_____
_____

c) Why is this method not suitable for other forms of radiation?

_____
_____

Compare your answers with those at the end of the section. Review the related content for any question that you missed.

Characteristics of the Three Kinds of Emission

1) Nature of Radiation

Alpha radiation

It has been identified as a stream of helium nuclei. The α-particle is therefore a positively charged helium nucleus with two protons and two neutrons. It is a very stable particle.

Beta radiation

Beta radiation is a stream of high energy electrons. The β-particle is therefore a negatively charged electron. It is formed by a nucleus decay process.

Gamma radiation

It has been identified as high frequency electromagnetic radiation. They are electromagnetic waves of very short wavelength.

2) Ionising Power

α-particles have the highest ionising power compared to β-particles and γ – rays as they produce the highest number of ions in their tracks. In comparison with γ – rays, β-particles are more ionising.

3) Penetrating Power

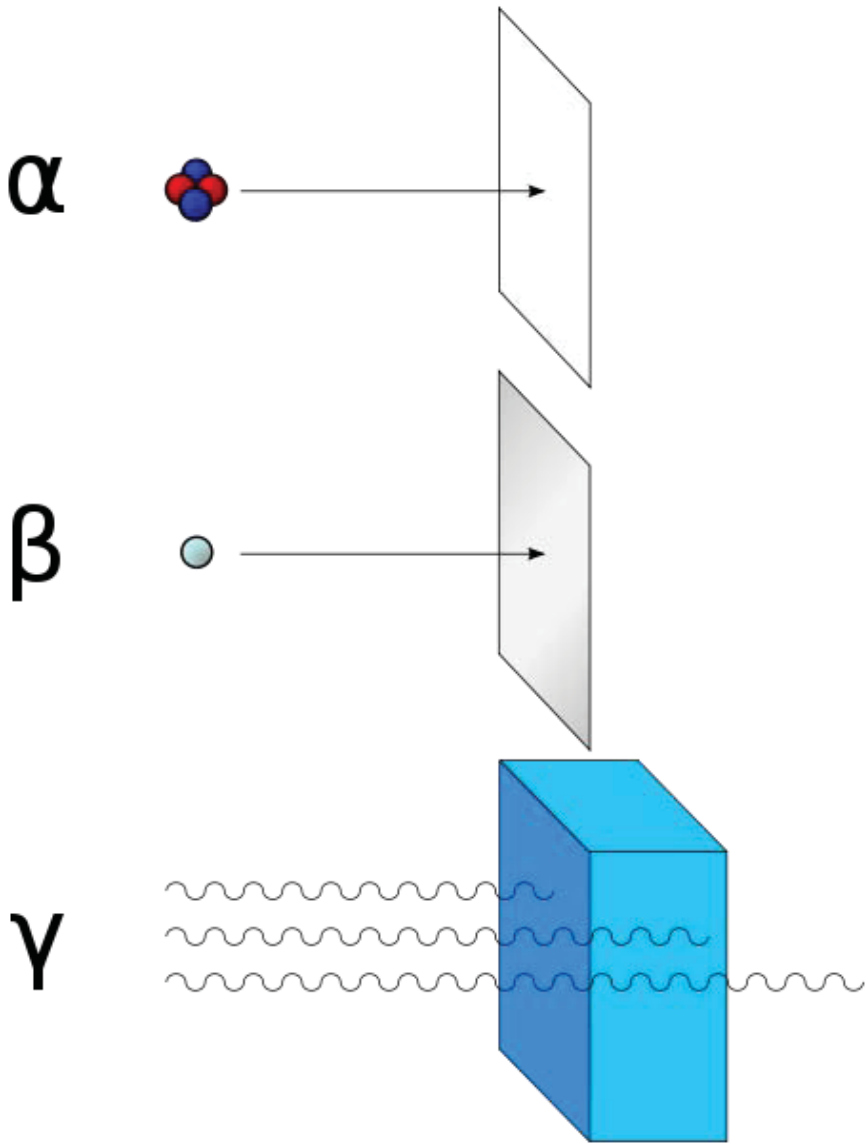

Figure 3(a): Relative penetrating powers of the three kinds of radiation accessed from Creative Commons, 2010.

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Figure 3(a) shows the relative penetrating powers of the three kinds of radiation. The α-particle can be easily stopped by a sheet of paper. The β-particles have a range of several metres in air but can be stopped by a
5 mm thick aluminium sheet. γ – rays are the most penetrating; they have a range of a few hundred metres in air and can be stopped by a 2 cm thick lead shield or a few metres of concrete.

4) Deflection by Electric and Magnetic Fields

If a radioactive source is placed at one end of an electric field and a GM Tube at the other end, it has been found that α-particles are deflected to the negative plate, the β-particles are deflected to the positive plate and γ – rays are undeflected as indicated by Figure 4(a).

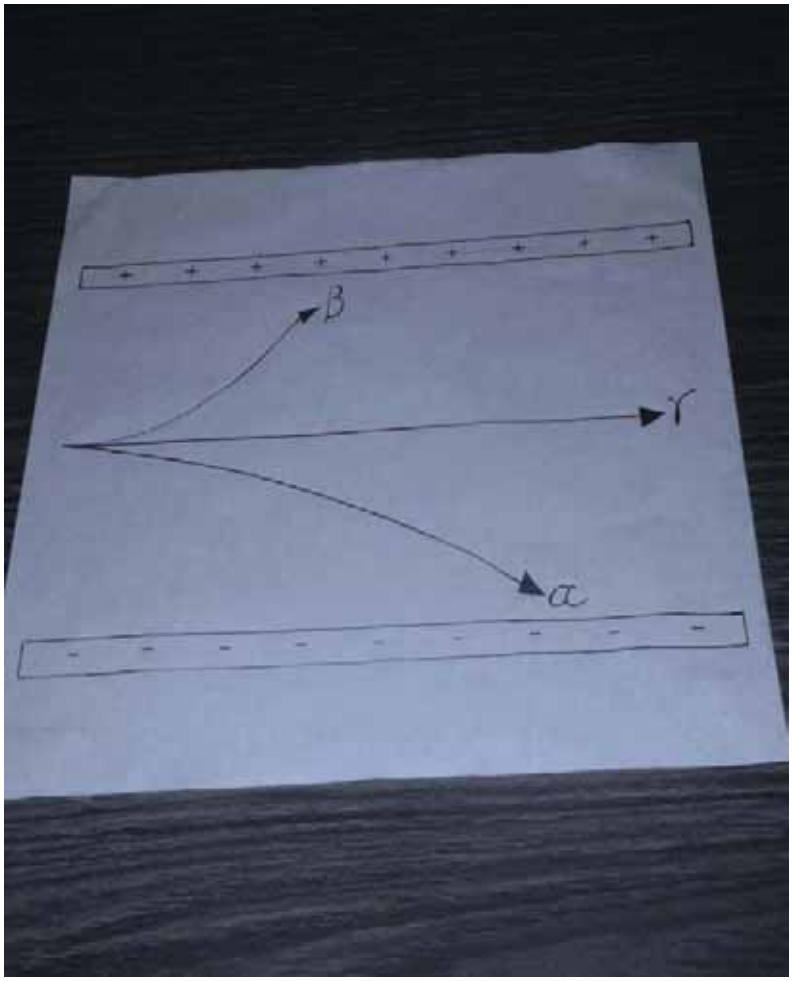


Figure 4(a): α-particles, β-particles and γ -rays in an electric field. Hand drawn by graphic designer at LDTC.

The conclusion made is that α-particles are positively charged, β-particles are negatively charged and γ-rays are neutral.

In a similar manner, a beam containing all three kinds of radiation sent through a strong magnetic field produces the deflection as shown by Figure 4(b).

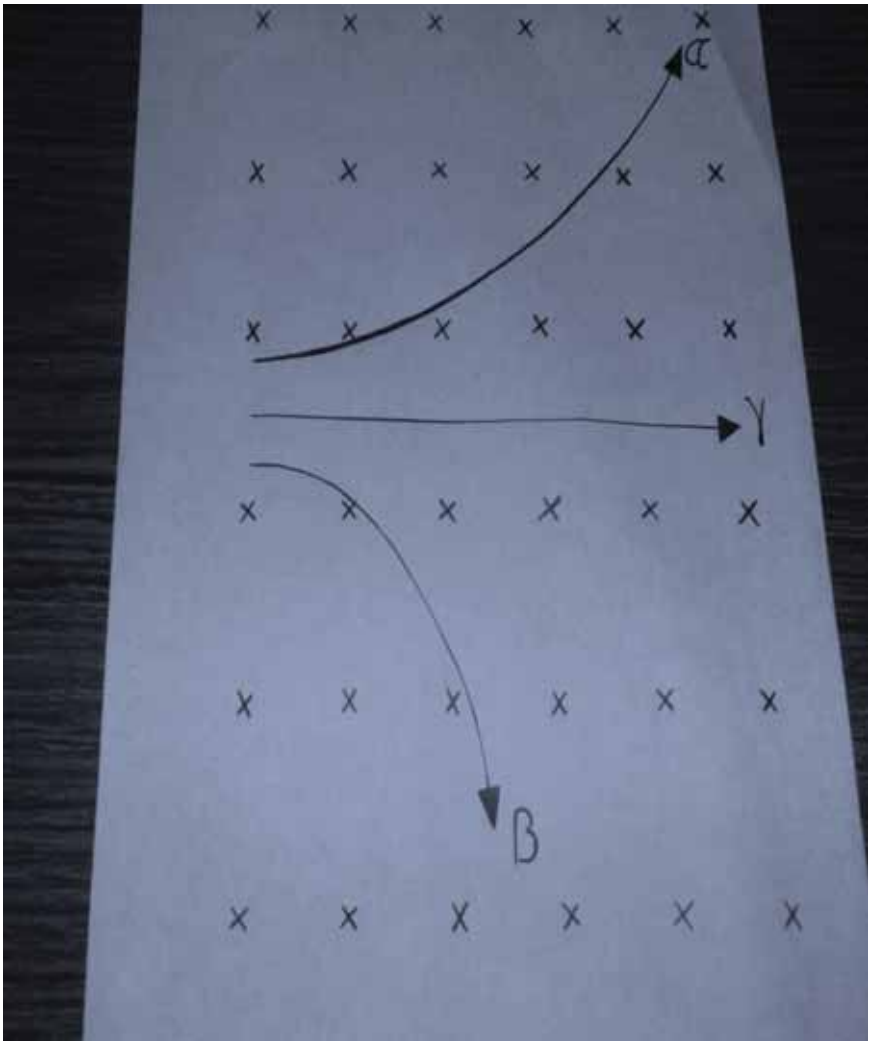


Figure 4(b): Deflection of α-particles, β-particles and γ – rays in a magnetic field. Hand drawn by graphic designer at LDTC.

Activity

Activity 2

Fill in the blank spaces in the table below that summarise the characteristics of the three kinds of radiation.

Type of radiation	Nature of radiation	Deflection in electric/ magnetic field	Ionisation strength	Stopped by
Alpha α		Deflected like positively charged particles	Strong	

Beta β	High energy electron			Aluminium (5 mm)
Gamma γ	High energy electromagnetic wave		Very weak	

Compare your table to the table at the end of the section. Based on your results, review the above content if needed. If you are confident that you understand the concepts, continue to the next section on radioactive decay.

Answers to Activities on Detection of Radiation

Activity 1

a) Alpha particles can be detected by the gold leaf electroscope.

b) Charge can be transferred to the electroscope by wiping a charged object across the cap. The charge then flows over the conducting copper/metal and gold, and the gold leaf rises as it is repelled because it has the same charge as the copper.

c) This method is not suitable for other forms of radiation because beta and gamma radiation cause weak ionisation in air.

Activity 2

Type of radiation	**Nature of radiation**	**Deflection in electric/ magnetic field**	**Ionisation strength**	**Stopped by**
Alpha α	*Helium nuclei*	Deflected like positively charged particles	Strong	*Thin paper*
Beta β	High energy electron	*Deflected like negatively charged particles*	*Weak*	Aluminium (5 mm)

Gamma γ	High energy electromagnetic wave	*No deflection*	Very weak	*Thick lead or thick concrete*

Section 26-3: Radioactive Decay

Introduction

By the end of this section, you should be able to explain the three processes of radioactive decay.

Time

There 2 pages on the topic of radioactive decay. You should spend approximately 1-2 hours on this topic.

An Atom

As mentioned earlier, the nucleus of a radioactive atom is unstable. It can become more stable if a change happens to it. The change is called decay. When a nucleus decays, it gives produces radioactivity.

Radioactive decay is a process in which an unstable nucleus spontaneously loses energy by emitting ionising particles and radiation – α, β or γ radiation. This decay or loss of energy, results in an atom called the parent nuclide being transformed to an atom of a different type called the daughter nuclide.

Decay is a random process. It is spontaneous and cannot be controlled. The chemical composition of an atom or physical conditions such as temperature and pressure do not affect radioactive decay. It cannot be stopped or slowed down and it is unknown which atom will decay next.

Nuclear Processes Involved in Radioactive Decay

1) Alpha decay

An atom that decays by α-emission decreases its nucleon number by 4 and its proton number by 2 as shown by the following equation:

${}^{A}_{Z}X$	→	${}^{A-4}_{Z-2}Y$	+	${}^{4}_{2}He$
Parent		daughter		α-particle
Nuclide		nuclide		(helium nucleus)

A: represents the mass number
Z: represents the atomic number

Example

Radium (Ra) becomes Radon (Rn) by emitting an α -particle.

$$^{224}_{88}Ra \rightarrow {}^{220}_{86}Rn + {}^{4}_{2}He$$

This nuclear equation is balanced because the mass number on the left of the arrow equals the sum of mass number to the right i.e. 224 = 220 +4. The atomic numbers are also equal i.e. 88 = 86 + 2.

2) Beta decay

An atom that decays by β-emission increases its proton number by 1 but its nucleon number remains the same as shown by the following equation:

$$^{A}_{Z}x \rightarrow {}_{Z+1}{}^{A}Y + {}^{0}_{-1}e$$

Parent Nuclide	daughter nuclide	β-particle (electron)

Example

Carbon-14 becomes Nitrogen-14 by emitting a β-particle.

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

This nuclear equation is also balanced as the mass number on the left of the arrow equals the sum of mass number to the right i.e. 14 = 14 + 0. The atomic numbers are also equal i.e. 6 = 7 – 1.

Remember that the reason that the mass number does not change is because a B-particle has been emitted, which has a negligible mass.

3) Gamma emission

After an unstable atom has gone through the radioactive decay process through α or β decay, it will sometimes be left with excess energy. This excess energy will be given out in the form of gamma radiation. The emission of gamma rays has no effect on either the nucleon or the proton number of the atom.

Examples:

$$^{224}_{88}Ra \rightarrow {}^{220}_{86}Rn + {}^{4}_{2}He + \text{energy}$$

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \text{energy}$$

Activity

Activity 4

Fill in the blank spaces by balancing the equations provided. Use the periodic table to determine the elements.

1. $^{212}_{83}Bi \rightarrow {}^{208}_{81}Tl + \ldots\ldots\ldots\ldots$

2. $^{212}_{83}Bi \rightarrow \ldots\ldots\ldots\ldots + {}^{0}_{-1}e$

Compare your answers to those that follow. Proceed to the next subunit on half-life once you understand how each equation was balanced.

Answers to Activities on Radioactive Decay

Answers to Activity 3

1. $^{212}_{83}Bi \rightarrow {}^{208}_{81}Tl + {}^{4}_{2}He$

The mass number is 212 – 208 = 4 and the atomic number is 83 – 81 = 2. Therefore the unknown particle formed is an α-particle $^{4}_{2}He$.

2. $^{212}_{83}Bi \rightarrow {}^{212}_{84}Po + {}^{0}_{-1}e$

The mass number remains 212 since 212 + 0 = 212 and the element formed is $^{212}_{84}Po$ since the atomic number becomes 83 = 84 – 1.

Section 26-4: Half-Life

Introduction

By the end of this section, you should be able to calculate the half-life of a radioactive source.

Time

There 7 pages on the topic of half-life. You should spend approximately 1-2 hours on this topic.

Half-Life

Half-life is the amount of time taken for half of the radioactive nuclei to decay. If we take an example of Carbon-14 which has a half-life of about 5500 years, a quantity of Carbon-14 will decay to half its original amount in 5500 years. It does not matter how big or small

the original quantity is. After another 5500 years, a quarter of the original quantity will remain. Placing a GM Tube and a Geiger counter near a radioactive source can show a number of disintegrations over a specified time. The number of disintegrations over a specified time is called the count rate.

If we had a beaker filled with sodium chloride that contained some radioactive sodium, Na-24 or $^{24}_{11}Na$, the decay pattern could be studied using a GM Tube and a counter to find the number of counts per second at various time intervals.

The decay graph of Na-24 as shown by figure 5a indicates that after 15 hours, the counts per second have decreased to half their value at the beginning of the experiment. This has happened because half of the Na-24 has decayed. After another 15 hours, the count rate will have been halved to become a quarter of the original value.

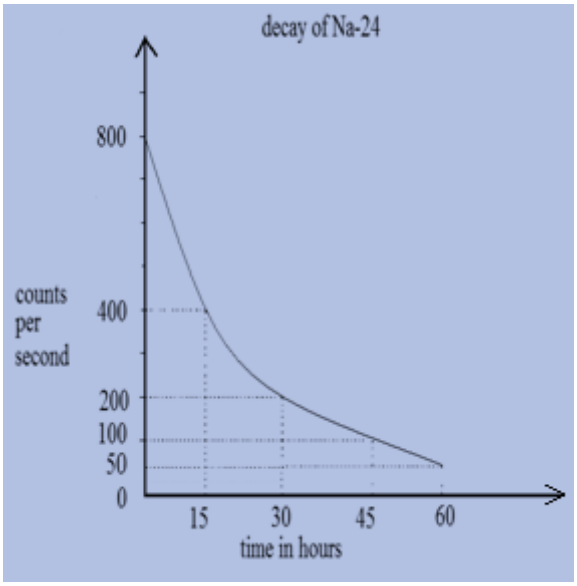


Figure 5(a): The decay graph of Na-24. Hand drawn by graphic designer at LDTC.

Examples:

1. A scientific laboratory has in its storage, 8 mg of strontium - 90 (Sr-90) with a half-life of 28 years. How much Sr-90 is left after 56 years?

Solution:

1. Half-life = 28 years

56 years = $\frac{56}{28}$ half lives = 2 half lives

Amount left after 56 years = $\frac{1}{2} x \frac{1}{2} x$ 8 mg = 2 mg

The amount of Sr-90 left after 56 years is 2 mg.

2. The starting count rate of a radioactive substance is 512 counts per second and its half-life is 10 hours. What is the count rate after 20 hours?

Solution:

Half-life = *10 hours*

Starting count rate = *512*

20 hours = $\frac{20}{10}$ *half lives* = *2 half lives*

Count rate after 20 hours = $\frac{1}{2} x \frac{1}{2} x$ *512*

= *128 counts per second*

Therefore the count rate after 20 hours is 128 counts per second.

3. A radioactive substance has an initial count rate of 480 counts per second. The count rate became 60 counts per second after 60 minutes. What is the half-life of the radioactive substance?

Solution:

480 → *240* → *120* → *60*

This shows that the decay process has gone through 3 half-lives.

So 3 half-lives = *60 minutes.*

1 half-life = $\frac{60}{3}$ = *20 minutes*

Therefore the half-life of the substance is 20 minutes.

4. The graph in figure 5b shows the count rate of a radioactive sample plotted against time. What is the half-life of the sample in minutes?

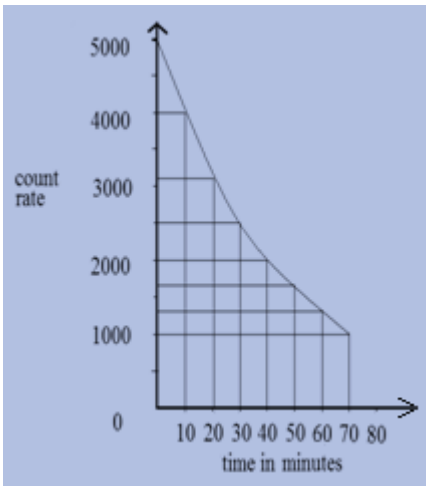


Figure 5(b): Half-life graph. Hand drawn by graphic designer at LDTC.

Solution:

The half-life = 30 minutes

Note that this is the time when the count rate has gone down by half, from 5000 to 2500.

Activity

Activity 5

Answer the following questions on half-life:

1. In 15 days, the activity of radioactive bismuth in a school laboratory decreases to one-eighth of its original activity. What is its half-life?

   _____
   _____
   _____
   _____
   _____
   _____

2. The starting count rate of a radioactive substance is 768 counts per second and its half-life is 15 hours. What is the count rate after 30 hours?

   _____
   _____
   _____
   _____
   _____
   _____

3. A radioactive substance has an initial count rate of 720 counts per second. The count rate became 180 counts per second after 60 minutes. What is the half-life of the radioactive substance?

   _____
   _____
   _____
   _____
   _____
   _____
   _____

4. The table below shows a sample set of results of the count rate obtained at different times for a certain radioactive substance.

Count rate in counts per minute	Time in minutes
400	0
200	2
100	4

50	6
25	8

i) Plot a graph of the count rate against time showing a decay curve of the radioactive substance.

ii) What is the half-life of the substance?

i)

ii)

_____

_____

Compare your answers with those below. Continue to the next section on uses, hazards, and safety precautions when you are confident that you can answer each type of question.

Answers to Activities on Half-Life

Activity 4

1. *Given that: the final activity after 15 days is* $\frac{A_o}{8}$

   Where A_0 *= original activity.*

   Let the half-life of bismuth be $t_{½}$*. Then*

Time in days	*Activity*
0	A_0
$t_{½}$	$\frac{A_o}{2}$
$2t_{½}$	$\frac{A_o}{4}$
$3t_{½}$	$\frac{A_o}{8}$

   The activity of bismuth decreases to one-eighth of its original activity in a time $3t_{½}$ *as shown by the analysis in the table above.*

   Therefore $3t_{½}$ = *15 days*

   $t_{½}$ = *5 days*

   The half-life of bismuth is 5 days.

2. *Half-life = 15 hours*

   Starting count rate = 768

   30 hours = $\frac{30}{15}$ *half lives = 2 half lives*

   Count rate after 20 hours = $\frac{1}{2} x \frac{1}{2} x$ *768*

   = 192 counts per second

   Therefore the count rate after 30 hours is 192 counts per second.

3. *720 → 360 → 180*

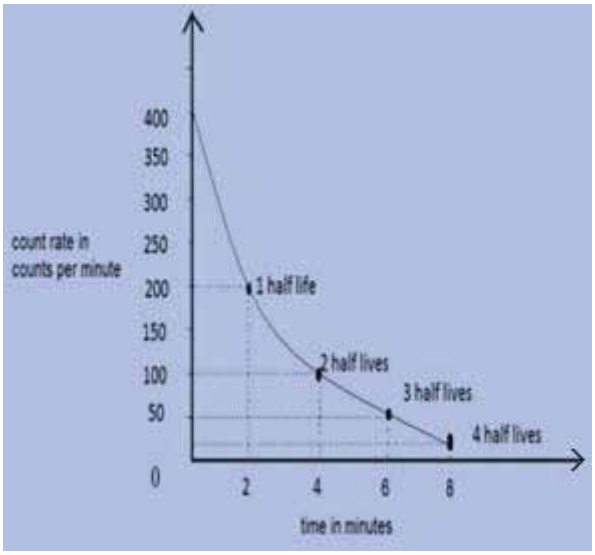
   This shows that the decay process has gone through 2 half-lives.

So 2 half-lives = 60 minutes.

1 half-life $= \frac{60}{2} =$ *30 minutes*

Therefore the half-life of the substance is 30 minutes.

4. i)



ii) The half-life of the substance is 2 minutes.

Section 26-5: Uses, Hazards and Safety Precautions

Introduction

By the end of this section, you should be able to describe the safety precautions while handling radioactive substances.

There 4 pages on the topic of uses, hazards and safety precautions. You should spend approximately 40 minutes on this topic.

Time

Uses of Radioactive Materials

Radioactive materials are used in a number of different ways in medicine, industry and agriculture. Some of these uses are discussed in the following paragraphs.

1. Radioactive tracers

These are used:

- In agriculture to detect how readily a plant takes in phosphates and where the phosphate will accumulate in the plant.
- In medicine to detect suspected brain tumours and blood clots before they become dangerous.
- By engineers to measure how fast engines wear out, to trace obstructions in oil, gas or water, to detect leakages of pipes laid underground and to look for small flaws and cracks in aircraft engine parts.

2. Radiotherapy

Radiation from radioactive cobalt-60 is used to treat certain types of cancer through killing the cells in the malignant tumour of a cancer patient.

3. Sterilisation

- γ-rays are used to sterilise bandages, dressings, syringes and other equipment that must be bacteria/virus-free.
- Bacteria in pre-packaged or frozen food are killed by γ-rays to sterilise the food and prevent food poisoning.

4. Thickness control

In manufacturing, relevant radioactive sources are used to check the thickness of rolled sheets of metal, paper or plastic.

5. Archaeology

Radioactive Carbon-14 has a half-life of nearly 5500 years. It is present in the atmosphere in small amounts. Living plants therefore absorb it through carbon dioxide and become slightly radioactive. The rate of radioactivity in these living plants is almost constant as in all living matter.

When plants die (such as cutting down a tree) they no longer absorb the Carbon-14 and therefore its amount starts to decrease as well as the radioactivity. Scientists are then able to calculate the age of archaeological samples such as ornaments, furniture, tools and paintings by measuring the activity of Carbon-14 in them.

Hazards

- Overexposure to radioactive radiation may cause radiation burns. The burns can lead to sores and blisters that can take a long time to heal.
- Extreme overexposure can lead to radiation sickness such as leukaemia, cancer and cell mutations and even death.

Safety Precautions

It is very important to take precautions to prevent overexposure to radiation, some of which are outlined below:

- Radioactive sources that are used in school laboratories are not very strong. They should be stored in a sealed container and when being used:

  1. They should be handled with tongs or forceps, never with bare hands.
  2. They should be kept at an arm's length, pointing away from the body.
  3. They should always be kept as far away as possible from the eyes.

- Radioactive sources used in industry can be very strong. They should be stored in lead containers with sides that are a few centimetres thick and labelled "Radioactive Source" or with a sign as shown by Figure 5. When being used:

  1. Fully protective clothing such as suits lined in lead and lead lined gloves should be worn.
  2. Tweezers must be used to pick them up.

Figure 5: Radiation symbol accessed from Creative Commons, 2010.

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- The radiation symbol as shown by Figure 5 must be displayed at all radiation laboratories as a warning to other people.
- Great care must be taken for the disposal of radioactive waste.

Activity

Activity 6

Answer the following questions in the provided spaces, and then compare with the correct answers provided immediately after.

1. State any two uses of radioactive materials:

_____
_____
_____
_____
_____

2. If a worker in a nuclear plant were to pick up a radioactive source using his/her hands, what is likely to happen?

_____
_____
_____

3. Give any two precautions that have to be taken when handling radioactive sources:

_____
_____
_____

Answers to Activities on Uses, Hazards and Safety Precautions

Activity 6

1. ***Any two of the following: radioactive tracers, radiotherapy, sterilisation, thickness control and archaeology.***
2. ***The worker would probably have radiation burns.***
3. ***Choose any two of the following:***

   a) They should be handled with tongs or forceps or tweezers, never with bare hands.
   b) They should be kept at an arm's length, pointing away from the body.
   c) They should always be kept as far away as possible from the eyes.

   d) Fully protective clothing such as suits lined in lead and lead lined gloves should be worn.

Unit Summary

Summary

Key points to remember:

- An atom of an element X can be represented by a nuclide notation $\boldsymbol{{}^{A}_{Z}X}$.
- Isotopes of an element are atoms with the same number of protons but different number of neutrons.
- Radioactive substances emit radiation that can be detected by:
    - Photographic film
    - A charged gold leaf electroscope
    - A GM Tube
    - A diffusion cloud chamber
- A nucleus that emits radiation is said to decay. This is radioactive decay and it is a random process.
- α-decay causes the nucleon number to decrease by 4 and the proton number to decrease by 2.
- β decay causes no change in the nucleon number but the proton number increases by 1. The neutron has changed into a proton and an electron. This electron is released as a β particle.
- γ emission has no effect on both the nucleon and the proton number.
- The time taken for half the atoms in any sample of a radioactive element to decay is called the half-life of that element.
- Alpha decay
    - $^{A}_{Z}x \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$
    - Beta decay
    - $^{A}_{Z}x \rightarrow {}_{Z+1}{}^{A}Y + {}^{0}_{-1}e$
    - Gamma radiation
    - It has no effect on either the nucleon or proton number.
- Uses of radioactive materials include being used as tracers, for radiotherapy, sterilisation, and thickness control and in archaeology.
- Being exposed to large amount of radiation is harmful to health.
- Safety precaution must be taken when dealing with radioactive substances.

You have completed the material for this unit on atomic physics. You should now spend some time reviewing the content. Once you are confident that you can successfully write an exam on the concepts, try the assignment. Check your answers with those provided and clarify

any misunderstandings that you have. After reviewing the concepts again, your last step is to complete the assessment. Once you have completed the assessment, you have completed content of this course!!!

You should now plan for studying for final examination. Review each unit early enough so that you can have your questions answered well in advance of the examination.

Assignment 26

Assignment

Answer all the questions that follow.

You should be able to complete this assignment in 30 minutes

[Total Marks:26]

Structured Questions:

1. One nuclide of radium is represented by $^{226}_{88}Ra$. Give the number for each of the following quantities: (1 mark each)

a) Atomic number _____

b) Mass number _____

c) Number of protons _____

d) Number of neutrons _____

e) Number of nucleons _____

2. $^{207}_{81}Tl$ is an isotope of thallium.

a) What quantity is the same for the nuclei of all isotopes of thallium?

_____ (1)

a) Give the number of:

i) Protons _____ (1)

ii) Neutrons _____ (1)

3. State any two methods of detecting radioactivity.

_____

_____ (2)

4. Draw a diagram to show the effects produced on the three types of radiation in a magnetic field. (3)

5. Find the element produced by filling in the blank spaces in the equations. Make use of the period table provided in unit 1.

a) $^{220}_{86}Rn \rightarrow$ ..... + $^{4}_{2}He$

b) $^{238}_{92}U \rightarrow$ ..... + $^{4}_{2}He$ (2)

6a.Radioactive sources are said to have a half-life. Explain the meaning of half-life.

_____

_____

_____ (2)

6b. The starting count rate of a radioactive substance is 1024 counts per second and its half-life is 20 hours. What is the count rate after 40 hours?

_____

_____

_____ (2)

7. Describe any two uses of radioactive sources in industry, medicine or research.

_____

_____

_____

_____

_____ (4)

8. Give two common hazards of radiation.

_____

_____

_____ (2)

Reflection Question

9. If you have access to the internet, please go to: http://www.iaea.org/newscenter/features/chernobyl-15/cherno-faq.shtml

to learn more about the accident at the nuclear power plant in Chernobyl, Ukraine. What are some of the consequences of that accident? How could accidents be prevented in the future?

After attempting all questions on the assignment, compare with the correct answers that have been provided immediately after. For any that you got wrong, go back to the section for clarification.

Answers to Assignment 26

1. $^{226}_{88}Ra$

a) Atomic number = 88 (1)

b) Mass number = 226 (1)

c) Number of protons = 88 (1)

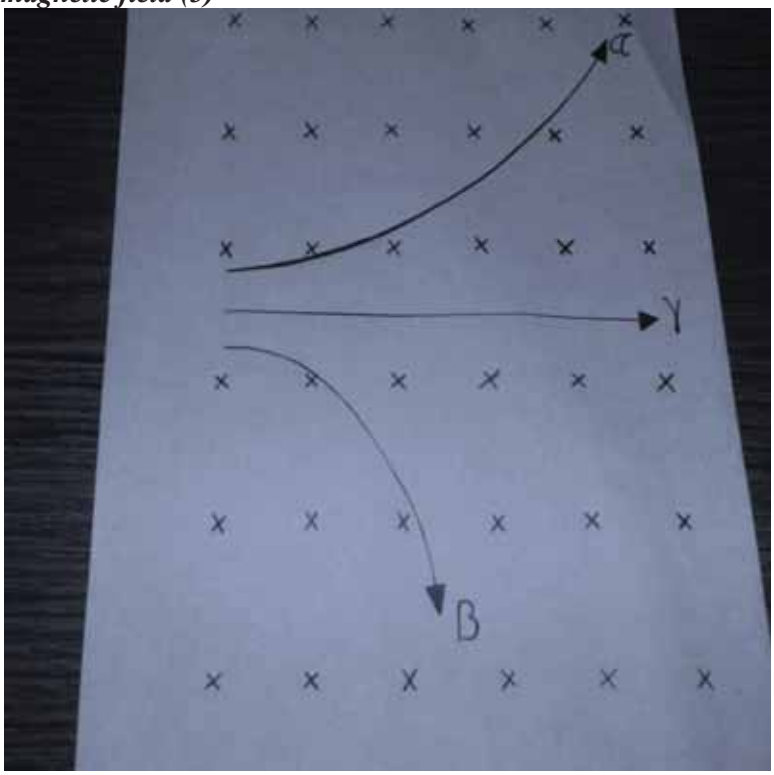
d) Number of neutrons = 138 (1)

e) Number of nucleons = 226 (1)

2. The atomic number/proton number 81 is the same for all **isotopes** *of thallium.(3)*

3. Choose from the gold leaf electroscope, the Geiger – Muller Tube, the diffusion cloud chamber.(2)

4. The deflection of α-particles, β-particles and γ – rays in a magnetic field (3)



5) a) $^{220}_{86}Rn \rightarrow {}^{216}_{84}Rn + {}^{4}_{2}He$

b) $^{238}_{92}U \rightarrow {}^{238}_{92}U + {}^{4}_{2}He$ **(2)**

6. a) Half-life is the time taken for half of radioactive nuclei to decay.(2)

6. b) Half-life = 20 hours

Starting count rate = 1024

40 hours = $\frac{40}{20}$ *half lives* = *2 half lives*

Count rate after 20 hours = $\frac{1}{2} x \frac{1}{2} x$ *1024*

= *256 counts per second*

Therefore the count rate after 20 hours is 256 counts per second (3)

7. Choose two of the following: (4)

a) Radioactive tracers

These are used:

- *In agriculture to detect how readily a plant takes in phosphates and where the phosphate will accumulate in the plant.*
- *In medicine to detect suspected brain tumours and blood clots before they become dangerous.*
- *By engineers to measure how fast engines wear out, to trace obstructions in oil, gas or water, to detect leakages of pipes laid underground and to look for small flaws and cracks in aircraft engine parts.*

b) Radiotherapy

Radiation from radioactive cobalt-60 is used to treat certain types of cancer through killing the cells in the malignant tumour of a cancer patient.

c) Sterilisation

- *γ-rays are used to sterilise bandages, dressings, syringes and other equipment that must be bacteria/virus-free.*
- *Bacteria in pre-packaged or frozen food are killed by γ-rays to sterilise the food and prevent food poisoning.*

d) Thickness control

In manufacturing, relevant radioactive sources are used to check the thickness of rolled sheets of metal, paper or plastic.

e) Archaeology

Radioactive Carbon-14 has a half-life of nearly 5 500 years. It is present in the atmosphere in small amounts. Living plants therefore absorb it through carbon dioxide and become slightly radioactive. The rate of radioactivity in these living plants is almost constant as in all living matter.

When they die, such as cutting down a tree, they no longer absorb the Carbon-14 and therefore its amount starts to decrease as well as

the radioactivity. Scientists are then able to calculate the ages of archaeological samples such as ornaments, furniture, tools and paintings by measuring the activity of Carbon-14 in them.

8. Hazards: (2)

- *Overexposure to radioactive radiation may cause radiation burns. The burns can lead to sores and blisters that can take a long time to heal.*
- *Extreme overexposure can lead to radiation sickness such as leukaemia, cancer and cell mutations and even death.*

9. 30 people died as a direct result of the accident. About 1800 people who were children at the time of the accident developed thyroid cancer. There were also psychological effects (suicide, alcoholism, apathy). Many animals with mutations were discovered. Identifying weaknesses in and improving the designs of the reactors as well as upgrading the power plants and training staff will help to prevent future accidents.

Based on your results and the recommendation that you should aim for at least 80% to ensure your overall success in this course and any subsequent physical science course you take, determine how much you should study the overall unit before you attempt the assessment.

Assessment 26

Assessment

This is a tutor-marked assessment. When you have completed the assessment, please send it to the tutoring centre for marking.

Answer all the questions that follow:

You should be able to complete this assessment in 30 minutes.

(Total Marks:20)

Structured Questions:

1. One nuclide of uranium is represented by $^{238}_{92}U$. Give the number of the following:

a) Atomic number _____

b) Mass number _____

c) Number of protons _____

d) Number of neutrons _____

e) Number of nucleons _____ (5)

2. Fill in the following table: [10]

Element	Nuclide notation	Nucleon number	No. of protons	No. of neutrons	No. of electrons
Helium	$^{4}_{2}He$		2		2
Lithium		7	3		3
	$^{9}_{4}Be$		4	5	4
Oxygen	$^{16}_{8}O$	16		8	8
	$^{35}_{17}Cl$	35	17	18	
Uranium	$^{238}_{92}U$	238	92		92

3. Give a brief explanation of how the diffusion cloud chamber can be used to detect radiation. (2)

_____

_____

_____

_____

_____

4. Fill in the table below to show the characteristics of the three types of radiation: (3)

Type of radiation	**Nature of radiation**	**Deflection in electric/ magnetic field**	**Ionisation strength**	**Stopped by**
Alpha α	Helium nuclei	Deflected like positively charged particles		Thin paper
Beta β		Deflected like negatively charged particles	weak	Aluminium (5 mm)
Gamma γ	High energy electromagnetic wave		Very weak	Thick lead or thick concrete

5. An experiment was carried out to determine the half-life of radon – 220 with the following results:

Time in seconds	**Count rate /s^{-1}**
0	30
10	26
20	23
30	21
40	18
50	16
60	14
70	12

a) Plot a graph of count rate (vertically) against the time (horizontally) and determine the half-life of Radon-220. Show clearly on your graph how you have obtained your answer. (6)

b) Radon-220 will decay by emitting a β-particle into the element polonium. Write an equation to represent this change. (2)

6. When experiments are carried out in a school laboratory with radioactive source, students are given the following instructions:

a) The radioactive source should never be held by bare hands.

b) There should be no eating or drinking in the laboratory.

Why is it very important for these instructions to be followed? (2)