Natural Science

Grade 9

Learner's Book

Natural Science Grade 9 Learner's Book

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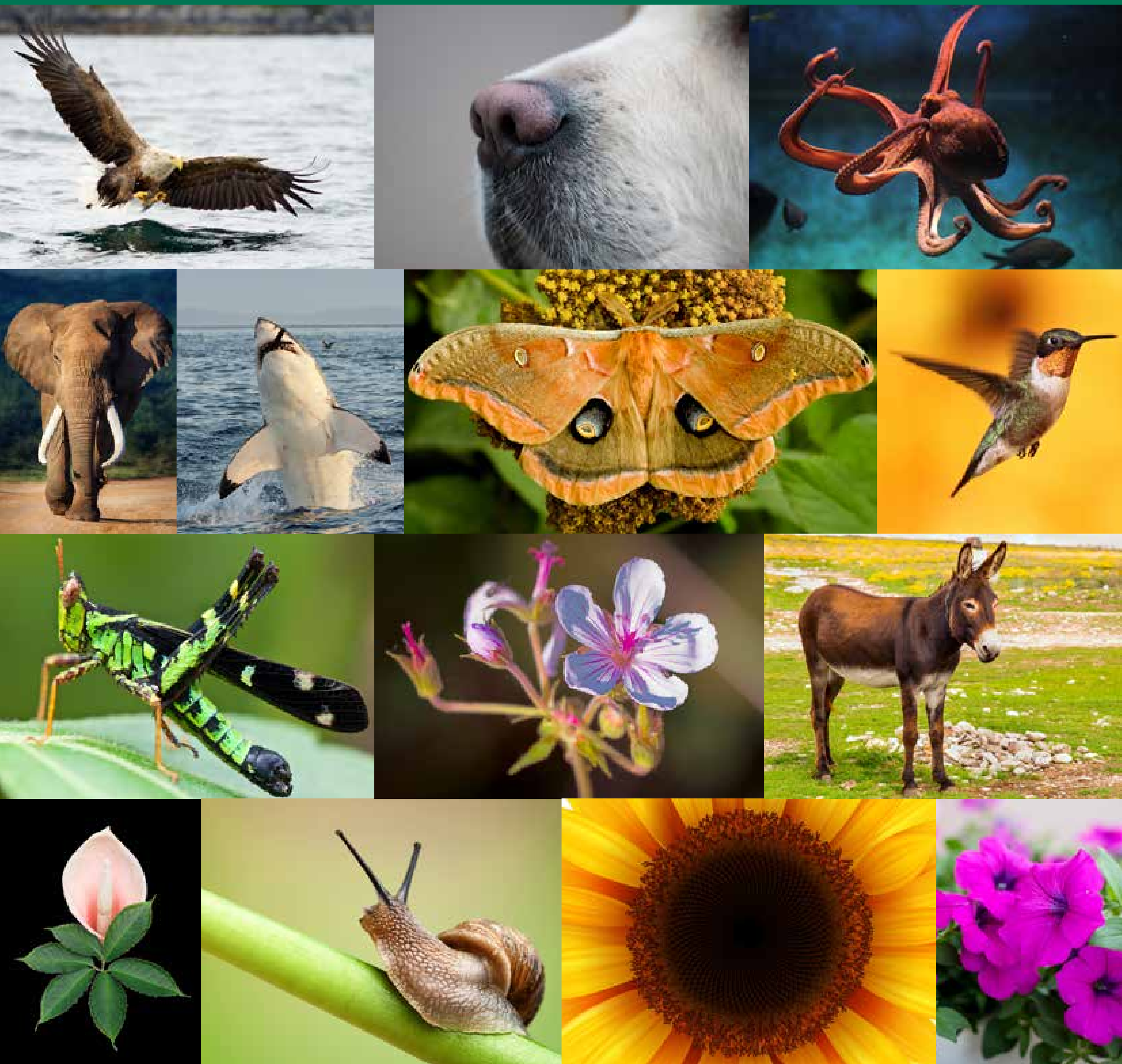
STRAND

Life and Living



1 Cells as the basic units of life

Key questions

- What are cells?
- Why are cells so small?
- What does it mean to be microscopic?
- Are there different types of cells?
- What is inside a cell and why is it there?
- Are plant and animal cells the same?

In this unit we will learn about the basic units of life which enable all of functions within living organisms – cells.

Did you know?

All the Keywords listed in the boxes in the margin are defined in the Glossary at the end of this strand.

Take note

The Visit boxes in the margins contain links to interesting websites and videos. Simply type the link exactly as it is into the address bar in your browser.

Keywords

- cell
- cytoplasm
- eukaryote
- membrane
- microscope
- microscopic
- nucleus
- organism
- prokaryote

1.1 Cell structure

What are cells?

All living organisms, including plants, animals, bacteria and fungi, are made up of cells. Cells are the smallest parts of all living organisms.

There are two main types of organisms based on the structures of their cells. The most important difference in structure is the presence of a nucleus. Cells that contain a nucleus are classified as eukaryotic cells, while those without a nucleus are prokaryotic cells. In this unit we will specifically look at eukaryotic cells that make up organisms such as plants and animals. Examples of organisms with prokaryotic cells are bacteria.

We can say that cells are the basic *structural* and *functional* units of all living organisms. You cannot see most individual cells with the naked eye, because they are too small – you need to use a microscope to be able to see cells. We say cells are microscopic because they can be seen only under a microscope.

Figure 1.1: Robert Hooke (1635–1703)

Robert Hooke was the first cytologist to identify cells under his microscope in 1665. He decided to call the microscopic shapes that he saw in a slice of cork '*cells*' because the shapes reminded him of the cells (rooms) that the monks in the nearby monastery lived in.

ACTIVITY Brainstorm the Seven Functions of Life

Do you remember the test you learnt about in previous grades to decide whether an organism is living or non-living? Perhaps you had a mnemonic to remember the seven processes, such as 'MRS GREN'.

1. Work in your group and see how many of the seven functions of life you can remember. Write them down in your exercise books.
2. Do you think that an individual cell is living? Explain your answer.

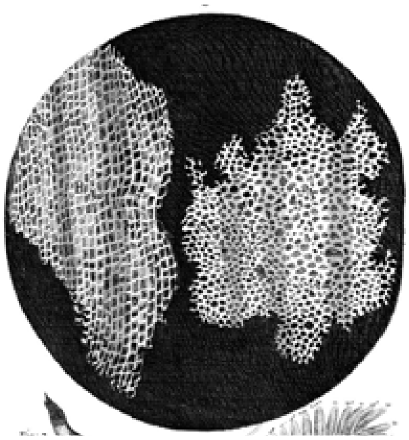


Figure 1.2: Robert Hooke was the first to use the term 'cell' when he studied thin slices of cork with a microscope.

Figure 1.3: Robert Hooke's microscope that he used to view cells for the first time.

Take note

In this section you'll often read the prefix 'cyto'- as in cytoplasm, cytosol or cytoskeleton. Cyto- means 'cell' so if you read 'cytoskeleton' it actually says: 'cell-skeleton'.

Different types of cells

Your body is made up of many different kinds of cells. Cells are **specialised** to perform a specific function. Depending on the function of the cell, it can be specialised by having a different shape or size or may have some components which other cells do not have.

Did you know?

We call the study of cells cytology, 'cyto'- meaning 'cell' and -'logy' meaning 'study', while -'logist' refers to the person who does the studying. The cytoplasm (cytosol and organelles) and the nucleus together are referred to as protoplasm.

Even though there are many different types of cells, there are components of the cell structure which are common to all cells. There are also some structures which most, but not all, cells have. Let us take a look at this in the next section.

Similar components of cells

All cells have some common structures. These are:

- a cell membrane
- cytoplasm; and
- in most eukaryotic cells, a nucleus.

Keywords

- carbon dioxide
- cell membrane
- cellular respiration
- DNA
- hereditary
- inherited
- medium
- mitochondria
- nuclear membrane
- nucleolus
- organelle
- oxygen
- protein
- selectively permeable
- specialised
- species
- vacuoles
- variation

Let's now have a look at the structure of these components of the cell, and some of the other organelles common to cells. An **organelle** is a specialised structure within the cell that performs a function for the cell. Examples of organelles in cells are **vacuoles** and **mitochondria**. Look at the diagram which identifies the different components in a simple animal cell.

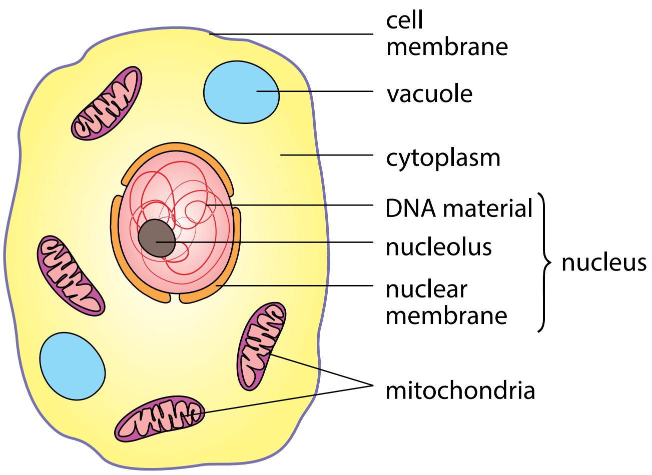


Figure 1.4: A drawing of a typical animal cell

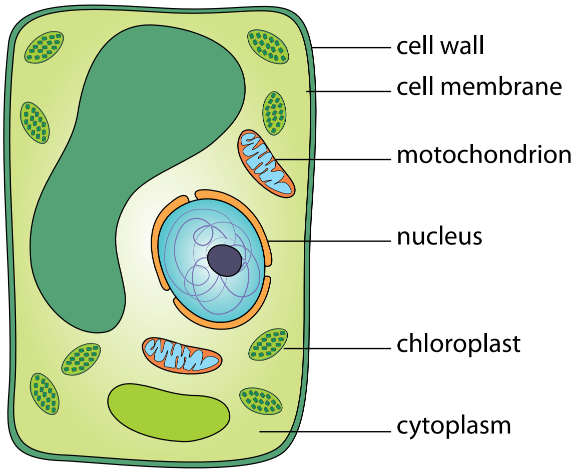


Figure 1.5: A drawing of a typical plant cell

> **Take note**
>
> If something is 'permeable', then it means that substances, such as gases and liquids, can pass through it freely.

Cell membranes

All cells have a cell membrane around them. The cell membrane is a thin layer that encloses the cell's contents and separates the cell from its environment.

Many different substances have to pass in and out of a cell in order for it to function. The cell membrane controls which substances are allowed to enter and leave the cell. The cell membrane is **selectively permeable**. The organelles are also surrounded by membranes.

Cytoplasm

The cytoplasm is made up of a jelly like medium (called cytosol) in which all living parts of the cell are suspended within the cell membrane, but excluding the nucleus. The cytoplasm is made up of the cytosol and the cell organelles. The cytosol is a watery, jelly-like medium made of 70% – 90% water, and is usually colourless. The cytosol suspends organelles and nutrients in the cell, and provides a medium for all the activities in the cell.

The cytosol is a mixture of different soluble substances dissolved in water. These substances within the cytosol include salts, various elements, such as sodium and potassium, and more complex molecules, such as **proteins**.

> **Did you know?**
>
> Identical twins come from the same fertilised egg which splits in two. They have the same DNA. However, they are not exactly the same due to environmental factors that can influence how they develop. Non-identical twins develop from two different eggs and two different sperm.

The cell organelles making up the cytoplasm include mitochondria, chloroplasts and vacuoles. Vacuoles are organelles enclosed by a membrane and contain mostly water with other molecules in solution. The size and number of vacuoles within a cell varies greatly and depends on the type and function of the cell.

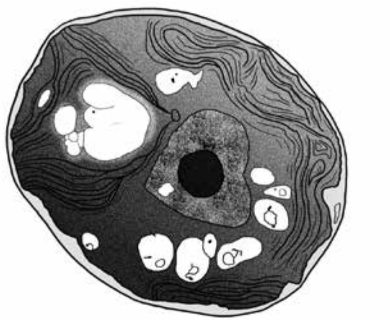


Figure 1.6: This is a micrograph of a plant cell. Can you see the clear, white organelles, which are the vacuoles? The cytoplasm appears very granular in this image.

Nucleus

Plant and animal cells have a **nucleus** inside (but not suspended in) the cytoplasm. It controls all the processes and chemical reactions that take place inside the cell. The nucleus also contains the cell's genetic material which is organised into long **DNA** molecules.

The nucleus is structured as follows:

- A double membrane called the **nuclear membrane** encloses the DNA. This nuclear membrane contains pores (holes) for substances to pass through.
- There is a **nucleolus** inside the nucleus. This is often seen as a darker area within the nucleus.
- The DNA contains information about **inherited** characteristics (**hereditary**), such as whether the person will have blue, brown or green eyes.

Have a look at the micrograph of a nucleus and the diagram of the nucleus.

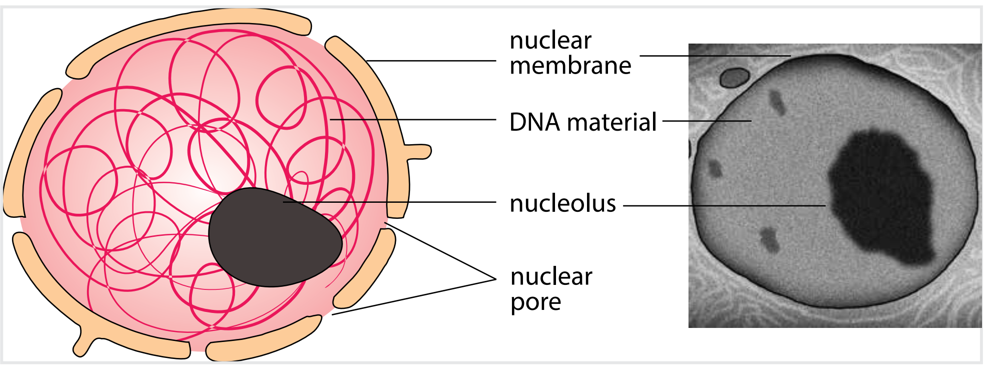


Figure 1.7: Left) A Diagram of a nucleus. Right) A micrograph of a cell nucleus.

DNA is a very important part of all cells and therefore of all life. DNA contains information that encodes all our inherited traits or characteristics. This refers to characteristics which are passed down in families, such as your skin and eye colour, whether you have allergies and also the likelihood of contracting different types of illnesses.

Take note

The difference between eukaryotic and prokaryotic cells is that eukaryotic cells have a nucleus which contains the genetic material surrounded by a membrane. Prokaryotic DNA floats in the cytoplasm without a membrane.

Every organism has unique DNA. The difference in DNA that occurs between individuals is called **variation**. Even the slightest difference in DNA may cause significant variations within **species** and between species. Within species DNA differences or variations can lead to albino animals or the transference of similar illnesses, like sickle cell anaemia.

Figure 1.8: An albino (white) lion lacks pigment due to an alteration in the lion's DNA.

Take note

Singular or plural? Mitochondr*ion* is the singular and mitochondr*ia* is the plural form of the word.

Did you know?

Mitochondria have their own 'mitochondrial DNA' that is completely different from the DNA in the nucleus. What do you think we can we deduce from this fact?

Mitochondria

Mitochondria are organelles enclosed by a double membrane. Cells that are very active would typically have more mitochondria than cells that are less active. The function of the mitochondria is to provide energy for the cells. Which type of cell, do you think, will have more mitochondria: a muscle cell or a bone cell?

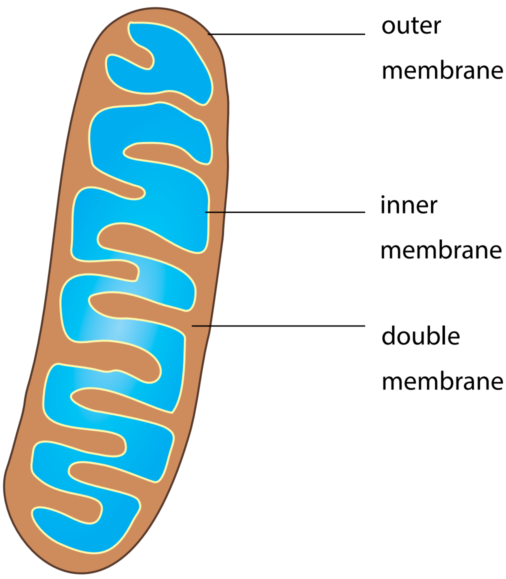


Figure 1.9: Diagram of a mitochondrion

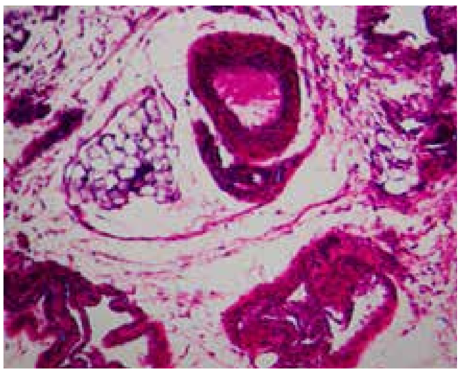


Figure 1.10: A micrograph of muscle tissue in a mouse. Can you see all the darker grey circles? These are mitochondria.

ACTIVITY Summarise what you have learnt

Now that you've studied the internal structure of a cell, let us summarise what we have learnt so far. Copy and complete this table in your exercise book filling in the main function of each of the cell structures.

Cell Structure	Function(s)
Cell membrane	
Cytoplasm	
Nucleus	
Mitochondrion	

1.2 Differentiate between plant and animal cells

Now that we know what the main similarities are between all plant and animal cells, let's see how they are different.

Keywords

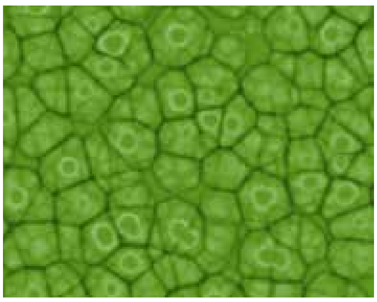
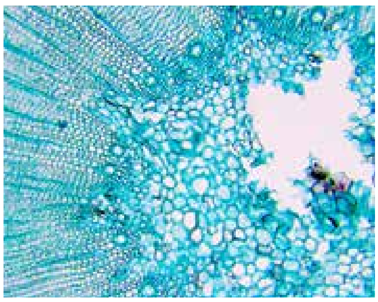
- cell wall
- cellulose
- chloroplast
- flaccid
- turgid

Plant cells differ from animal cells

Why do plant and animal cells have differences? Plant and animal cells differ because they have to perform different functions.

ACTIVITY Identify differences between plant and animal cells

1. Study the pictures in the table below. On the left is a picture of plant cells and on the right is a picture of some animal cells, which have been stained blue.
2. Write the differences that you observe between the pictures of the cells in your exercise books.

Plant cells	Animal cells
	

Cell wall

Animal cells often have an irregular shape, whereas plant cells have a much more regular, rigid shape.

Plant cells have an additional layer surrounding the cell on the outside of the cell membrane. This is called the cell wall. The cell wall provides a protective framework for support and stability for the plant cell.

Did you know?

Other organisms also have cell walls, like bacteria or fungi, but in these organisms the cell walls are not the same as plant cell walls. Only plant cells are made of cellulose.

The cell wall is formed from various compounds, the main one being cellulose. Cellulose helps maintain the shape of the plant cell. This allows the plant to remain rigid and upright even if it grows to great heights.

> **Did you know?**
>
> The sea slug, *Elysia chlorotica*, has evolved to take up the chloroplasts from the algae that it eats and incorporate them into its own cells where the chloroplasts function as if in a plant!

Chloroplasts

You might remember learning about photosynthesis in previous grades. Can you still remember why photosynthesis is so important to all life on earth?

Did you notice the green organelles present in plant cells which were not there in the animal cells in the previous activity? These are chloroplasts. Chloroplasts are the only cell organelles that can produce food from the sun's energy. Only plants with chloroplasts are able to photosynthesise because they contain the very important green pigment, chlorophyll. Chlorophyll can absorb radiant energy from the sun and convert this to chemical energy that plants and animals can use.

Vacuoles

Does a plant have a skeleton? Turn to a friend and discuss what could possibly be used in a plant cell as a skeleton. Think for example of a blade of grass, or a long-stemmed rose.

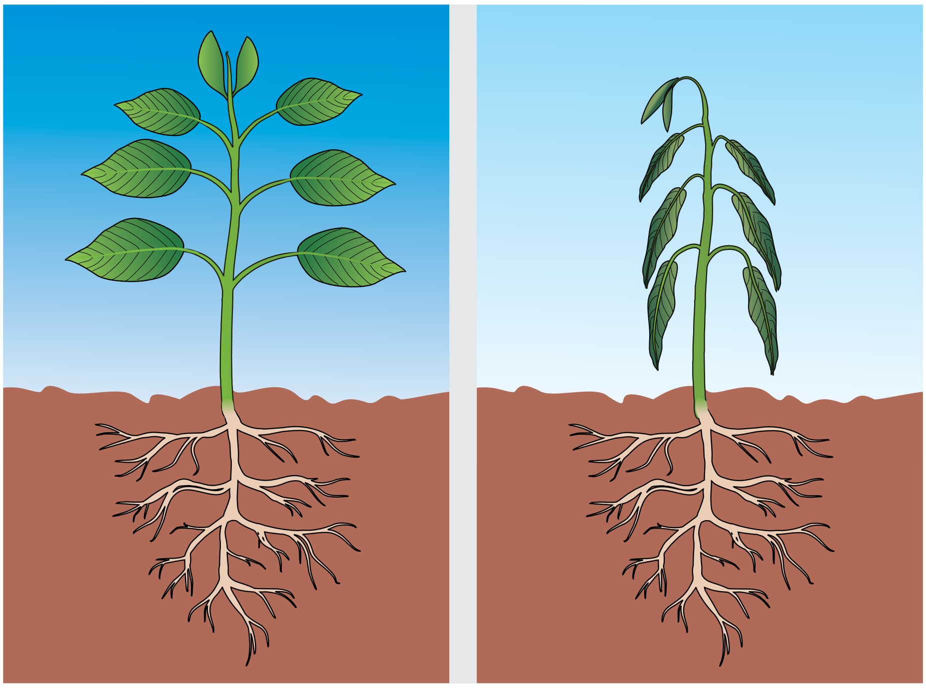


Figure 1.11: Left: A plant with turgid vacuoles is rigid and stands upright. Right: A plant with flaccid vacuoles droops (called wilting).

Vacuoles in plant cells are usually quite large organelles that can occupy as much as 90% of the cell's volume. The liquid in the vacuole, called cell sap, helps to support the plant. The full vacuoles push out against the cell wall and make the cells, and therefore the plant, rigid. We say the cells are turgid in this condition. The opposite to turgid is flaccid.

You can easily see when a plant's vacuoles are full and when they are not. When the vacuoles are full the plant's stem and leaves will be held upright and firm. However, if the leaves and stem are drooping, the vacuoles might have lost a lot of water because the soil is too dry and the cell was forced to use up this water to survive.

Vacuoles are present only in some animal cells and they are typically very small and have a short life-span.

ACTIVITY Comparing plant and animal cells

Study the two diagrams of plant and animal cells below.

1. Draw a table of differences between the two cell types in your exercise books. Give the table a suitable heading.
2. Also provide labels for the different cell structures and organelles.

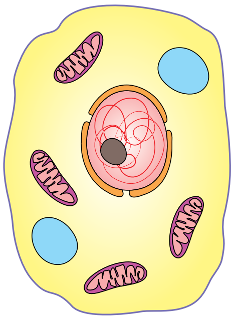


Figure 1.12: A typical animal cell.

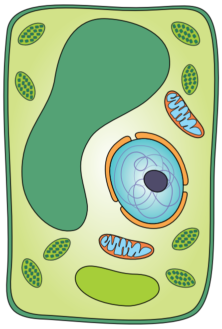


Figure 1.13: A typical plant cell.

ACTIVITY 3D model of a cell

In a 3D cell model, we will be making built models out of materials where we will use other objects to represent the actual parts of the cell.

Instructions

1. You must create a 3D model of a cell.
2. You may use whatever materials or 'media' you choose to create your cell.
3. Your model must clearly show the following:
   a) cell membrane
   b) nucleus with nuclear membrane
   c) cytoplasm
   d) mitochondria
   e) vacuoles
   f) chloroplasts
   f) any other organelles that you might have learnt about.

Requirements for your cell model

- Your model and the examples of the organelles need to show some resemblance to the real organelle that we have learnt about so far.
- Your model needs to be clearly marked with a heading and your name.
- Each organelle needs to be clearly labelled and with each label you need to add a description of the function of that particular organelle.
- You also need to make an accompanying drawing (at least the size of an A4 page) including the labels of the structure of a basic plant and animal cell.
- Your teacher will assess your model according to a rubric.

Keywords

- cover slip
- multicellular
- organisms
- slide
- specimen
- unicellular
- wet mount

1.3 Cells in tissues, organs and systems

Now that you have learnt all about different cells, are you ready to see them for yourself?

Observing cells under a microscope

Have you ever used a microscope before? Microscopes are instruments that are used to look at and study objects that are too small to be seen with the naked eye. Since the days of Hooke's observations, the development of microscopes has come a long way. Today we have incredibly powerful microscopes called electron microscopes which use electrons instead of light to observe very fine detail – even as small as a single column of atoms!

Figure 1.14: A modern electron microscope

Figure 1.15: A basic light microscope

Before we start working with microscopes, let's have a look at the different parts of a basic light microscope and the safety precautions we need to follow when using these pieces of equipment.

A microscope allows you to see detail in specimens that you cannot see with the naked eye. The image you see needs to be:

- well lit with enough light provided to see the specimen
- well focused
- contrasted with its surroundings to clearly see details.

The next image explains the different parts of a light microscope and what they are used for.

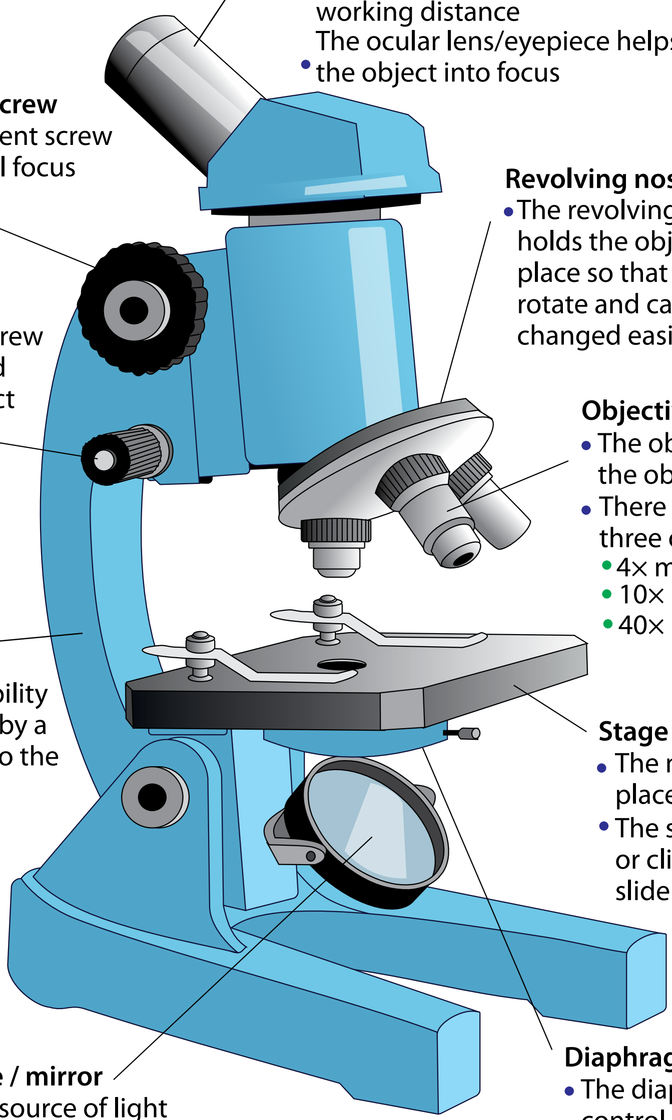


Figure 1.16: Part of the microscope

When you use a microscope, make sure to follow these safety precautions:

1. There is a special way to carry the microscope: one hand supports the base and the other holds the frame of the microscope.
2. Put it down on a stable, horizontal, clear counter.
3. Before using the microscope, clean the lenses with proper lens paper. Do not touch the lenses with your fingers! Make sure the stage and slides are clean.
4. When handling the slides, do not use broken or cracked slides and handle cover slips by the edges.
5. When focusing with the objectives:
   - focus smoothly and slowly
   - be careful with the objectives and do not scratch them.

Did you know?

We can use water, brine (salt water), glycerine or immersion oil for wet mounts.

6. When you are done:
   - always turn the lowest magnification objective into place before storing the microscope
   - make sure that the stage and slides are clean before putting everything away
   - always store the microscope in a box or covered with a dust jacket to avoid dust from settling on the lenses.

To view cells under a microscope, we need to make and prepare something called a **specimen** on a **slide**.

A specimen is a small part or slice, or an example of an organism that we want to examine. When we view a specimen under a microscope it needs to let light pass through the specimen so we can see it. Therefore, we need to prepare the specimen and cut extremely thin slices of less than 0.5 mm. Specimens are then placed on a glass slide.

We can prepare samples or specimens on a slide using these different techniques:

- **wet mount** – good for observing living organisms and is especially used for aquatic samples
- **dry mount** – good for observing hair, feathers, pollen grains or dust
- **smears** are often made of blood or slime that is smeared over the slide and allowed to dry before observing them.
- **stains** are added to wet or dry mounts by dropping colouring chemicals onto the specimens, like iodine solution, methylene blue or crystal violet. We use staining to improve the colour contrasts on the slide.

ACTIVITY Evaluating microscopic images

Instructions

1. Carefully study this image of onion cells that have been stained blue. Evaluate this image in terms of the focus, light and contrast visible in the photo.
2. These same onion cells were viewed under a microscope which had not been adjusted properly and the following photos were taken. Identify what is wrong with the photograph compared to the one above. Complete the table in your exercise books.

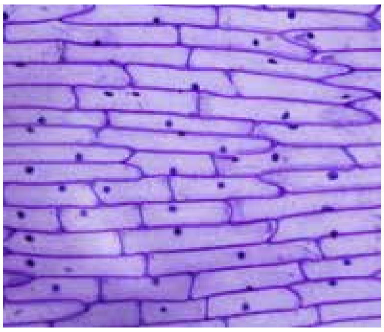
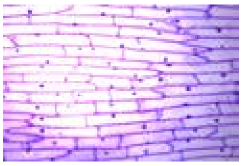
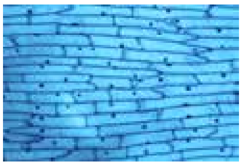


Figure 1.17: Onion cells that have been stained blue.

Image	What is wrong with the image?	How could the image have been adjusted and corrected, using what part of the microscope?
		
		
		

ACTIVITY Making a wet mount with onion and cheek cells

There is a very specific way to prepare slides for viewing under a microscope.

You will use this technique very often in Natural Sciences to study specimens.

Materials

- onion
- scalpel or knife
- dissecting needle
- forceps
- microscope slides
- coverslips
- dropper
- tissue paper or filter paper
- distilled water
- iodine solution
- light microscope

Take note

You will need to work quite quickly as the onion cells will dry out!

Instructions

Step 1: Prepare your microscope and slides as discussed in the safety methods above.

Step 2: Cut the onion into blocks of about 1 cm square with a sharp knife or scalpel.

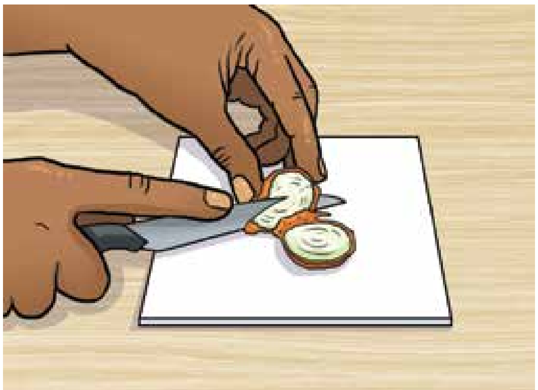


Figure 1.18: Cutting the onion to expose the layers.

Figure 1.19: Carefully pulling the lining off the onion layer.

Take note

If you have accidentally trapped an air bubble, gently press on the middle of the coverslip to get rid of any trapped air using the dissecting needle or drop some extra fluid right next to the edge of the coverslip.

Step 3: Use forceps to pull or peel a small piece of the very thin membrane-like epidermis lining off one of the inner layers of the onion.

Step 4: Place a drop of iodine solution onto the slide.

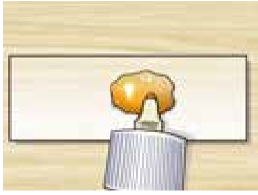


Figure 1.20: Adding iodine solution to the slide.

Step 5: Place the membrane directly in the drop on the slide.

Step 6: Gently lower a coverslip at an angle onto the onion cells. Hold the coverslip up with a dissection needle and gently lower the slip. This prevents air bubbles from getting trapped under the cover slip.

Figure 1.21: Lowering the coverslip onto the specimen.

Step 7: Wipe off excess fluid around the edge of the coverslip with tissue paper or filter paper.

Step 8: Make sure the lowest power objective lens (this is the shortest lens) is in line with the eyepiece. Switch on the lamp or use the mirror to reflect the light onto your stage. Place the prepared slide onto the stage and secure it with the stage clips.

Figure 1.22: The slide secured on the microscope stage.

Step 9: While on the low power, look from the side and lower the objective lens to just above the coverslip. Then look through the eyepiece and use the fine focus to focus your image.

Step 10: Magnify your cells by swapping the objective lens to a higher powered lens. Only use the fine focus adjustment to focus clearly.

Step 11: Make careful drawings of your observations in your exercise books and remember to label what you see. Add a heading including the specimen, the stain used and the magnification.

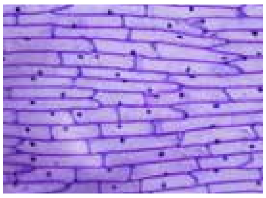


Figure 1.23: Onion cells.

Now that you have prepared slides of onion cell specimens, use a toothpick to scrape the inside of your cheek *gently* to collect cheek cells using the side of the toothpick or ice cream stick. Follow the same instructions as above to prepare the cheek cell specimen and to view it under the microscope. Draw and label the cheek cells that you viewed under the microscope in your exercise books.

Did you see something like this?

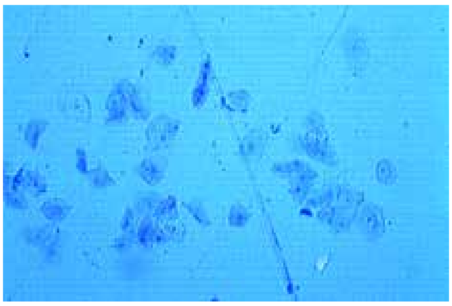


Figure 1.24: Some cheek cells stained with methylene blue.

Question

1. What are some of the differences and similarities you noted between the animal and cheek cells?

ACTIVITY Research the discovery of light and electron microscopes

The invention and improvement of microscopes has led to incredible cellular discoveries (among others) in the last 400 years. Without microscopes, many of the microscopic organisms we know of today would never have been identified!

Instructions

1. You can work individually or in groups for this task.
2. Research the history and discovery of the light and electron microscopes and how they are used today.
3. Design a brochure for the local Science museum where you tell visitors about the history of the development of microscopes.
4. Remember that a brochure must be informative, but not contain too much text.
5. Include some photographs or drawings.

Cells differ in shape and size

We looked at the basic differences between plant and animal cells. However, not all plant cells and not all animal cells are the same. Cells within an organism need to have different shapes and sizes because they fulfil different functions.

Keywords
- differentiation
- stem cell

Look at the photo of the rose. Do you think the cells in the roots, stem, leaves, and petals of the rose all look the same?

The cells in the different parts of the rose all have to perform very specific functions and therefore have different sizes and shapes.

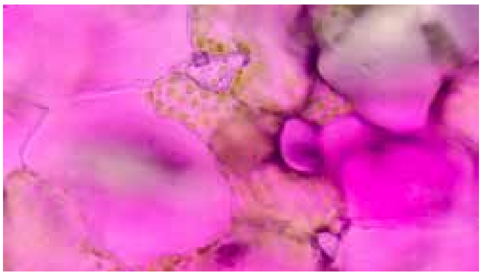


Figure 1.25: The rose's petals are pink due to pigments in the vacuoles of the petal cells which are round.

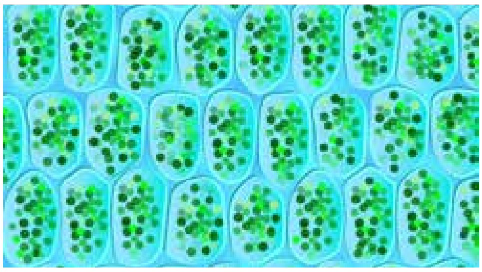


Figure 1.26: Cells in the leaves are full of chloroplasts for photosynthesis. They are long and rectangular in shape.

Your body contains a great number of **specialised** cells, meaning they have different functions. They have differences in their structures allowing them to have different functions. We say they have **differentiated**.

Did you know?

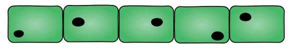
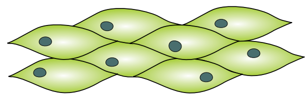
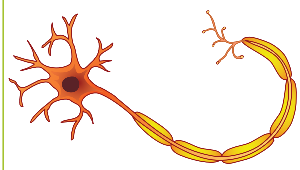
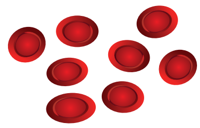
Stem cells are also harvested from the umbilical cord at birth and used for research. There are many ethical concerns regarding stem cell research.

Take note

Microscopic and macroscopic describe whether an organism can be seen with the naked eye, while unicellular and multicellular refer to the number of cells an organism has.

Do you remember we spoke about nerve cells and red blood cells briefly in the beginning of the unit? Some of them are summarised in the following table.

What do you think?

Specialised cell	Structure	Function
Epithelial cells: they are mostly flat		They cover the surface of the body for protection.
Muscle cells: some are long and spindle shaped		Muscle cells can contract and relax allowing for movement within your body.
Nerve cells: they are very long and have branched ends		Nerve cells are specialised to carry messages that coordinate the functions of the body.
Red blood cells: round and biconcave shape		Red blood cells carry oxygen and carbon dioxide throughout the body.

Stem cells

Stem cells are unspecialised cells which can divide and develop into many different types of specialised cells. Stem cells are quite amazing as they can divide and multiply while at the same time keeping their ability to develop into any other type of cell. Embryonic stem cells are the little ball of 50–150 cells that forms 4–5 days after conception. Embryonic stem cells are very special as they can become absolutely any cell in the body, for example, blood cells, nerve cells, muscle cells or brain cells.

For this reason, scientists are using stem cells to conduct research. There are many benefits in doing this, but there are also many controversial and ethical issues surrounding stem cell research.

Are you curious about stem cell research? Find out more and discover the possibilities!

Microscopic and macroscopic organisms

We have just looked at specialised cells within organisms. The organisms that we have discussed, plants and animals, consist of many, many cells. Your body has millions of cells! Did you know that there are some organisms which consist of only a single cell? We have many different specialised cells to perform the different functions within our body whereas in a single-celled organism, all the functions it performs are done in this one cell. We can make a distinction between organisms that are made of one cell (unicellular) and those that are made of many cells (multicellular).

Microscopic organisms

We call one-cell organisms, that can only be seen with the help of a microscope, microscopic organisms. There are many single-celled microscopic organisms.

Have a look at the images.

Figure 1.27: A group of *Escherichia coli* bacteria which are found in the intestines of many animals.

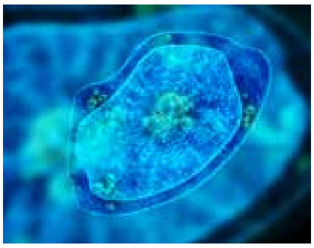


Figure 1.28: An amoeba, which is a single cell organism that lives in water.

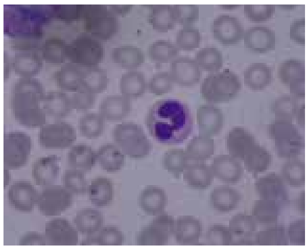


Figure 1.29: Red blood cells showing some which have been infected with malaria (purple dots).

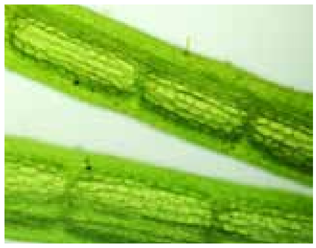


Figure 1.30: A single-celled algae called a desmid.

Macroscopic organisms

In contrast to microscopic single-celled organisms, macroscopic organisms are visible to the naked eye and consist of many cells. Macroscopic organisms can have a few cells working together or trillions of cells that form larger organisms.

Organisation of cells in macroscopic organisms

In microscopic single-celled organisms, the individual cell has to perform all the life processes for that microscopic organism.

So what about the cells in macroscopic organisms that consist of many cells?

We have already learnt about specialised cells in macroscopic organisms, so we know that not all cells perform all the processes – they are specialised to perform a specific function.

Specialised cells that perform a specific function group together to form a tissue. For example, muscle cells will group together to form muscle tissue, epithelial cells will group together to form the skin, and nerve cells will group together to form the brain and nerves.

Groups of tissues that work together form organs. Think of the stomach, for example – it is made of many different specialised cells that form muscle tissue to make it contract and epithelial tissue (made from specialised epithelial cells) which lines the inside of the stomach and produces mucus.

When organs work together we say they form systems or organ systems. There are many different systems in your body where specific organs work closely together to make your body function. Have a look at the following diagram. It shows how cells are organised into tissues in the stomach which form part of the digestive system in a human (the organism).

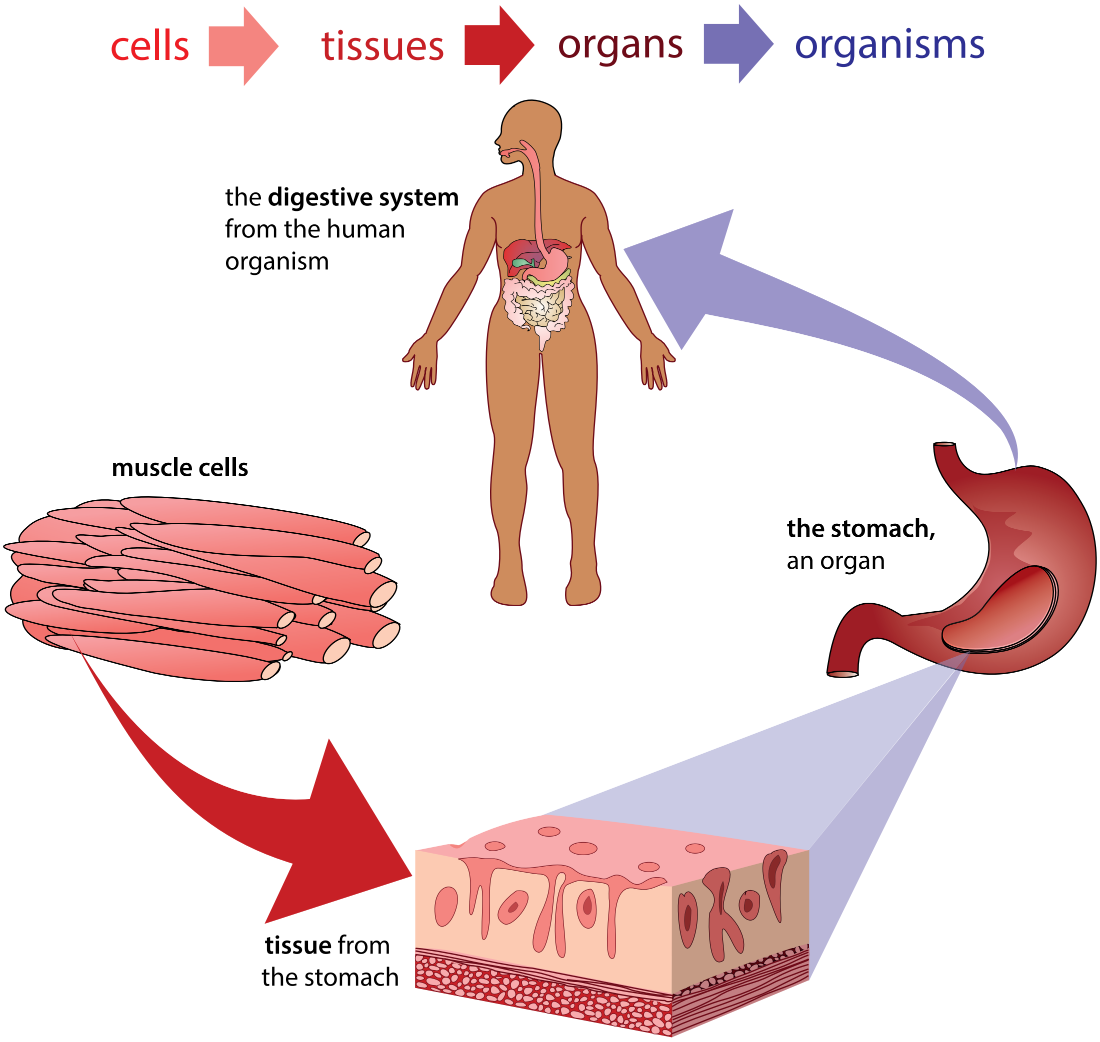


Figure 1.31: How cells are organised into tissues in the stomach to form part of the digestive system.

All the systems work together to form an organism. We will be looking at some of these systems later on in the term.

Summary

In the summary, we first have the 'Key concepts' for this unit. This is a written summary and the information from this unit is summarised using words. We can also create a concept map of this unit, which is a map of how all the concepts (ideas and topics) in this unit fit together and are linked to each other. A concept map gives us a more visual way of summarising information.

Different people like to learn and study in different ways; some people like to make written summaries, while others like to draw their own concept maps when studying and learning. These are useful skills to have, especially for later in high school and after school!

Have a look at the concept map which shows what we have learned about the cell in this unit and how these concepts link together. Can you see how the arrows show the direction in which you must 'read' the concept map?

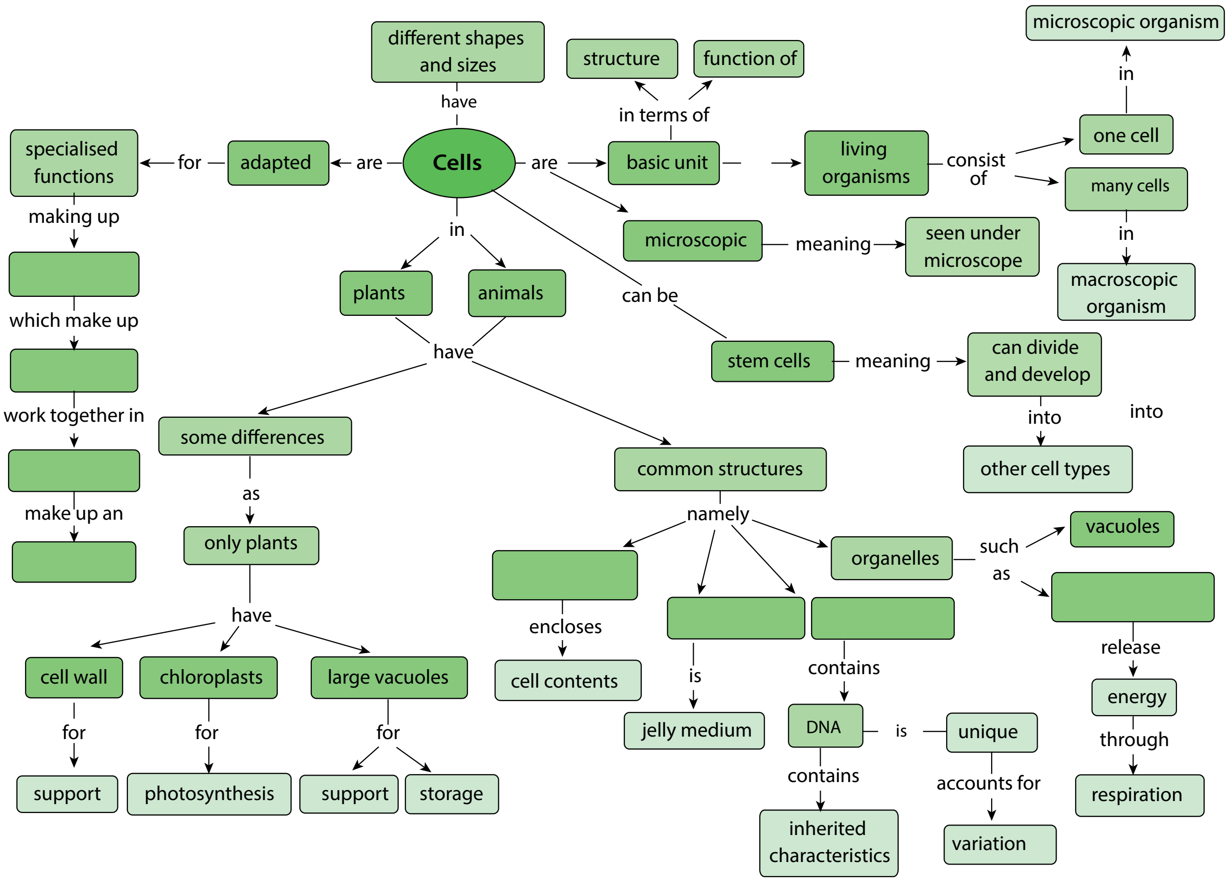
There are some empty spaces in the concept map that you need to fill in. For example, some of the common structures in cells have been left out. You need to look at the concepts linking from these bubbles to work out which structure goes where. For example, what structure in a cell encloses the cell contents? Write the answer in the correct space using the concept map provided by your teacher. On the left-hand side of the concept map there are also empty spaces – can you see that this describes the hierarchy of how cells are organised into tissues, which are organised further into organs, and so on? Fill in each level of organisation into the spaces.

Key concepts

- Cells are the basic structural and functional units of all living organisms.
- Most cells are microscopic and can be seen only under a microscope.
- Plant and animal cells have cell membranes, cytoplasm, a nucleus and organelles such as mitochondria and sometimes vacuoles.
- The cell membrane encloses the contents of the cell and separates it from its environment.
- Cell membranes are selectively permeable, which means they only allow certain substances to pass into and out of the cell.
- The cytoplasm includes the organelles and the cytosol. The cytosol is the jelly-like medium in which many chemical reactions take place in the cell. Everything inside the cell membrane, except the nucleus, is considered the cytoplasm.
- The nucleus in eukaryotic cells is enclosed by a nuclear membrane and contains the DNA.
- DNA contains inherited characteristics of an organism and controls the cell's activities. It is unique to each organism, resulting in variation within a species.
- Cell respiration takes place in the mitochondria.
- Plant cells have a cell wall around the cell membrane that is rigid and provides support and protection of the cell's content.
- Plants have chloroplasts with the pigment chlorophyll to photosynthesise and produce glucose (food).
- Plant cells also have large vacuoles to store water and glucose, and to provide support for the plant
- Vacuoles in animal cells are temporary (or absent) and much smaller.

- Cells come in many different shapes and sizes.
- Stem cells are cells that have the ability to divide and develop into many different cell types.
- Microscopic organisms can only be seen under a microscope. All single-celled organisms, such as bacteria, are microscopic. However, some multicellular organisms such as dust mites are also too small to see with the naked eye.
- Macroscopic organisms consist of many cells and can be seen with the naked eye.
- Specialised cells perform special functions. Specialised cells that work together to perform a specific function form tissue.
- A group of different tissues makes up an organ.
- Organs working together in groups form systems or organ systems.
- Organ systems make up an organism, such as a human.

Concept map



Revision

1. Why would you say cells are considered to be the smallest unit of life? [2]
2. Explain what **selectively permeable** means when referring to the cell membrane. [1]
3. Eukaryotic and prokaryotic cells differ. What is the main difference between these two types of cells? [2]
4. What is the main function of the nucleus and what is the function of the DNA? [2]
5. When a Grade 9 learner labelled one of the cell organelles 'Powerhouse', their teacher marked it wrong. What should the learner rather have written? [1]
6. A plant and an animal cell are similar in some ways yet very different in others. Compare the two types of cells in a paragraph. [10]
7. Make two drawings to show the differences between plant and animal cells using the examples of plant and animal cells you studied under the microscope. Follow the drawing guidelines for making scientific drawings. [10]
8. There are different types of specialised cells and tissues in plants and animals that perform different functions. Match each function to the corresponding tissue. [3]

Smooth muscle tissue	receives and sends messages and helps the body respond to stimuli.
Nerve cell	carry oxygen around the body in mammals
Red blood cells	contracts and enables movement

9. Use words from this box to complete the sentences below. Write the sentences out in full in your exercise books. [4]

Organs
Tissues
organ systems
specialised cells

Macroscopic organisms consist of many different____________ that are made of individual ____________ that work together in a very particular way. These are formed from ____________ that are in turned created when groups _______________ of function together in a specific way.

Total [35 marks]

2 Systems in the human body

Key questions

- How does the body do the things it does, such as breathe, move and think?
- What happens when one of the systems in our bodies does not work properly and has a 'system error'?
- How can you best look after your body?

The human body has been studied by artists and scientists, mechanical engineers and medical practitioners throughout history. The mechanical beauty and operation of each and every part in the human body has fascinated human beings throughout history. Be curious, and get ready to be fascinated!

New word

- integrate

Body systems

The human body consists of several integrated systems for the body to function well.

In the following pages we willl study seven of the main systems in our bodies. At the end of each organ system you will need to make a summary of that organ system to show:

- the main purpose or function of the system in the body;
- the main processes that take place in the system;
- the main components (organs) that make up the system; and
- the main health issues that relate to that particular system.

Therefore pay close attention and make notes as you study each organ system to help you with your summary.

ACTIVITY Research and writing about health issues

Instructions

1. You are going to learn about many of the health issues related to each of the different systems. Choose one of these health issues to research.
2. You will need to:
   a) Consult at least 3 different resources to find out more about that particular health issue.
   b) Suggest ways that this health issue may be prevented (if this is possible).
   c) Suggest treatment for the health issue in question.
3. Present your findings on an A3 poster as part of an oral presentation (of 3–4 minutes) to the class.

2.1 The digestive system

Our cells need **protein**, **carbohydrates**, **fats**, **vitamins** and **minerals** to function. Yet we eat large pieces of food that are too big to pass through the selectively permeable cell membranes. So how does the food we eat eventually get to our cells in a small enough form to be absorbed?

Purpose of the digestive system

Our digestive system is responsible for breaking down the food that we eat into small particles that can be **absorbed** into the bloodstream. They are then **transported** to the cells throughout our body.

The digestive system is made up of the different parts of the **alimentary canal**.

This canal is a long, twisting, pipe-like structure (about 9 metres in total) that starts at the mouth and ends at the anus. Along the way the food is broken down from chunks into molecules small enough to pass through cell membranes and supply energy to cells.

Main processes in the digestive system

There are four main processes that occur in the digestive system at different parts along the alimentary canal. They are:

- **Ingestion**: This occurs when you take food into your body through your mouth by eating or drinking it.
- **Digestion**: This is the process of breaking down large food pieces into particles that are small enough to be absorbed and pass through cell membranes.
- **Absorption:** This occurs when the digested particles move into the cells of the digestive tract (they are absorbed) and move to the bloodstream from where they are carried to all the cells in the body.
- **Egestion**: Any undigested or unwanted particles that travel through the digestive tract are later passed out as faeces. This process is known as egestion.

Components of the digestive system

Have a look at the diagram on the right which gives an overview of the different parts making up the digestive system.

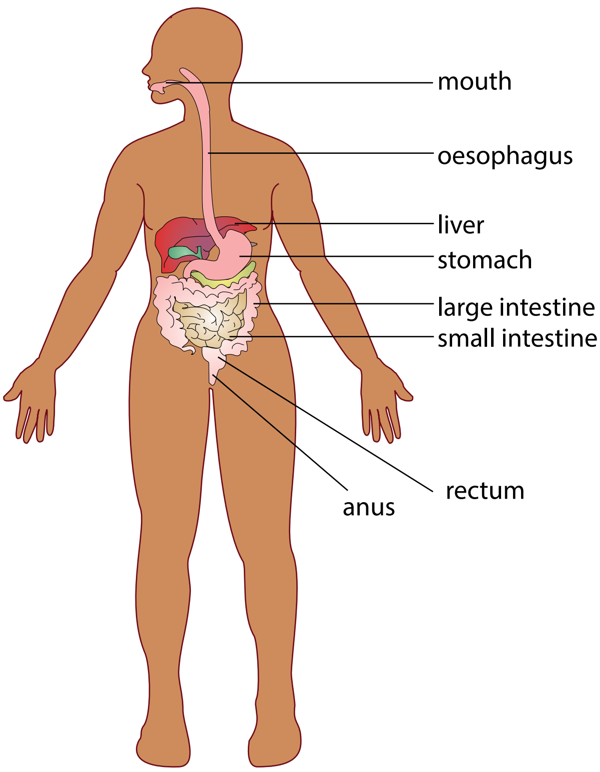


Figure 2.1: Components of the digestive system.

Keywords

- absorption
- alimentary canal
- carbohydrates
- digestion
- dissolve
- fats
- glucose
- minerals
- nutrients
- protein
- transport
- vitamins

Did you know?

Our digestive system is sometimes also referred to as the 'gastrointestinal tract', the 'digestive tract' or the 'alimentary canal'.

Keywords

- anus
- chemical digestion
- egestion
- faeces
- fibre
- ingestion
- jaundice
- metabolic
- saliva
- small intestine
- stomach
- ulcer

The mouth and oesophagus

Digestion starts in the mouth as food is chewed and mixed with saliva. It then travels down the oesophagus when you swallow.

Stomach

The chewed food enters the stomach and is further digested. The stomach has substances called enzymes to help digest the food. The stomach also contracts to break the food down further into a liquid.

Small intestine

Most of the digestion takes place in the small intestine. Absorption of the food particles also takes place in the small intestine.

Large intestine (or colon)

By the time the food reaches the large intestine, most of the nutrients have been absorbed. What is left is water, salts, and indigestible fibre. The water that is left is absorbed in the large intestine.

Did you know?

Bacteria that live in the large intestine produce Vitamin K and some Vitamin B.

Rectum and Anus

The remaining substances (called faeces) are passed into the rectum and then out through the anus. This is called egestion.

ACTIVITY Flow diagram of the digestive system

Flow diagrams are diagrams that show how the different sets of a process fit together in a sequence. They show the direction (flow) by using arrows. These are important tools to help you think about processes in Science.

Take note

There is a difference between egestion and excretion. Egestion occurs when undigested particles are passed out as faeces. Excretion occurs when the body gets rid of metabolic waste formed from chemical reactions taking place in the body.

Instructions

1. Draw a flow diagram to represent the passage of food from the time it is taken into the body to the time it is egested from the body.
2. The blocks must show the main components involved in digestion, listed in order, with arrows in between. Under each component include the main processes that occur at each of these stages.

Health issues involving the digestive system

Common diseases of the digestive system

Ulcers

Sometimes open sores or ulcers develop on the lining of the mouth, oesophagus, stomach or upper portions of the small intestine. Ulcers can be very painful. They are generally caused by bacterial infections and some medications.

Anorexia nervosa

This is one of many eating disorders. People who suffer from this eating disorder have an abnormal fear of gaining weight and therefore starve themselves on purpose. This can lead to many health issues such as bone thinning, kidney damage, heart problems and even death.

Diarrhoea

Someone who passes very frequent, loose, watery stools has diarrhoea. Many diseases cause undigested food to pass through the large intestines too quickly for water to be absorbed and cause diarrhoea.

Do not forget to wash your hands with lots of soap and water!

Liver cirrhosis

This disease slowly replaces healthy liver tissue with scar tissue and eventually prevents the liver from functioning properly. Alcohol abuse and fatty liver caused by obesity and diabetes are the most common causes of liver cirrhosis.

Take note

It is good to know the dangers and health consequences of an unhealthy lifestyle.

2.2 The circulatory system

Did you know that the blood moving throughout your body forms a system? To 'circulate' means to move around, and so we have the circulatory system within the human body which transports blood.

Purpose of the circulatory system

The circulatory system is responsible for transporting blood with oxygen (O_2) from the lungs to cells and then transporting blood with carbon dioxide (CO_2) back to the lungs. It also has to distribute nutrients from the digestive system to the cells in the body and remove waste products to be excreted.

Keywords

- arteries
- blood
- blood vessels
- capillary
- closed blood system
- deoxygenate
- excrete
- gaseous exchange
- heart
- lungs
- network
- oxygenate
- temperature
- veins

Components of the circulatory system

The circulatory system is composed of the heart and a system of blood vessels, including arteries, veins and capillaries.

Heart

The heart is a very strong muscle and pumps blood throughout the body. There are four chambers in the heart that receive and send blood to all parts of the body. The two top chambers are called *atria* (singular = atrium) and the two bottom chambers are called *ventricles*.

Blood vessels

There are various blood vessels which carry the blood throughout the body.

These are:

- arteries
- capillaries
- veins

Did you know?

The first heart transplant in the world was done by Dr Chris Barnard in South Africa in 1967!

Did you know?

On average your heart beats about 100 000 times a day and 30 million times a year. If you live to age 70, your heart would beat an average of 2,5 billion times!

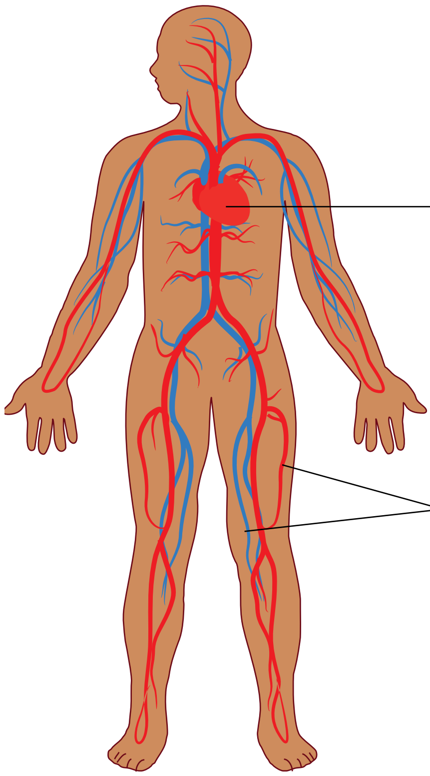


Figure 2.2: The circulatory system is composed of the heart and blood vessels.

Blood

The blood is transported throughout your body and carries various substances.

Substances such as carbon dioxide, nutrients and waste products can be dissolved in the blood liquid (plasma), or else in the red blood cells (like oxygen).

Main processes in the circulatory system

Our circulatory system is actually made up of two systems that function together:

- a short system that circulates blood between the lungs and the heart; and
- a much longer system that circulates blood from the heart throughout the body and back again.

This process occurs as follows:

- Blood is circulated from the heart to the lungs. At the lungs, carbon dioxide (CO_2) leaves the blood and oxygen (O_2) enters the blood. This process is known as **gaseous exchange**. Since the blood now contains more oxygen than carbon dioxide, we say it is **oxygenated**. This oxygenated blood returns to the heart again.
- Once in the heart the oxygenated blood is circulated to deliver the oxygen to all the cells in the body before returning to the heart. At the same times as it delivers oxygen, the blood also collects carbon dioxide from the cells. This blood has more CO_2 than O_2, so it is **deoxygenated** blood. The carbon dioxide is excreted when it returns to the lungs.

This process occurs over and over again throughout your life, thousands of times a day!.

ACTIVITY Chart the circulatory system

Instructions

1. Study the diagram below that explains the circulatory process.

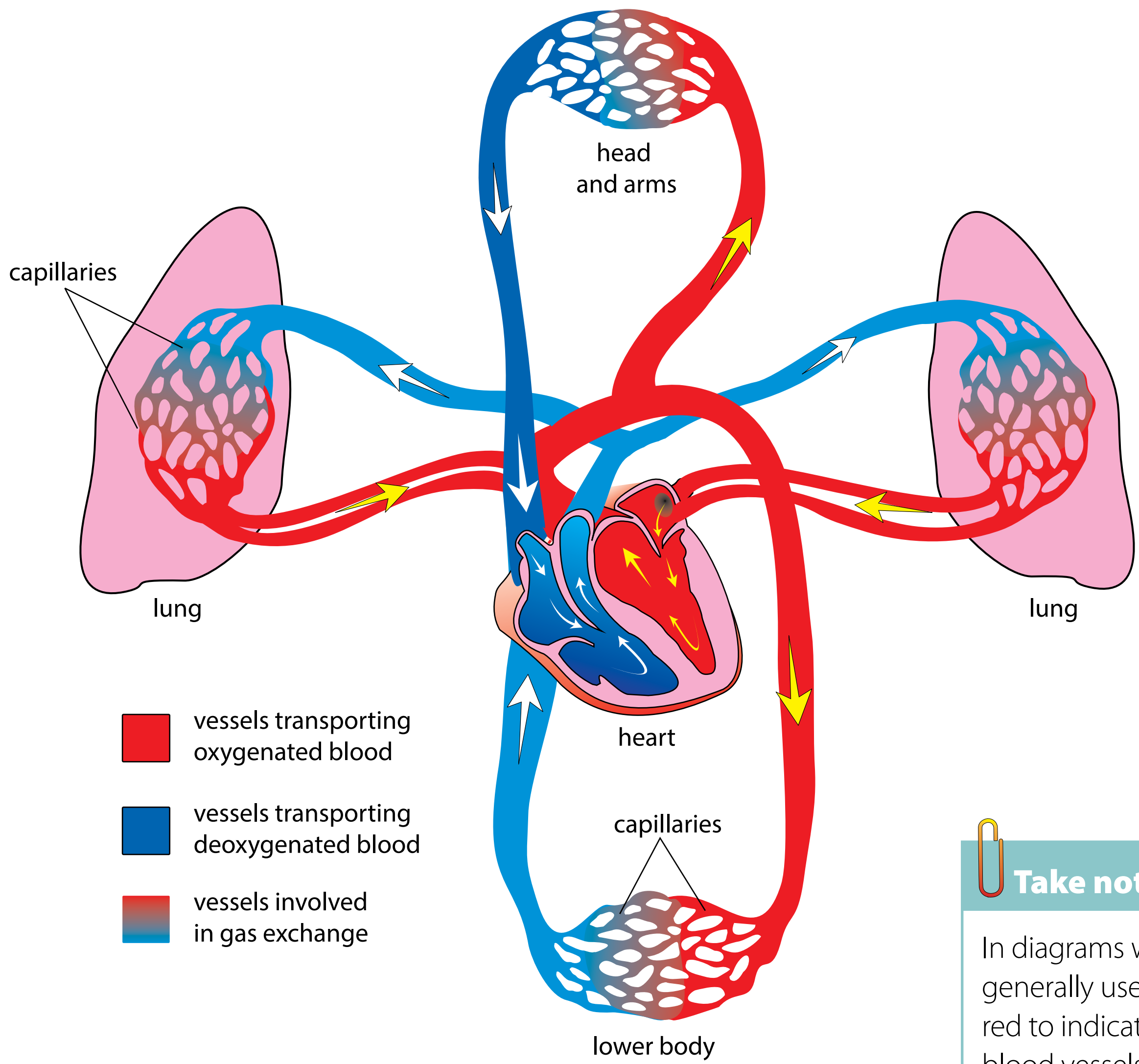


Figure 2.3: The circulatory process

Use the diagram above to draw a circular diagram in your exercise books to show how blood travels through the circulatory system (composed of two systems).

2. Your circular diagram will form a complete circle.
3. Add arrows to show the direction in which the process occurs.

Take note

In diagrams we generally use red to indicate blood vessels that contain oxygenated blood and blue to show blood vessels with deoxygenated blood.

Take note

You can find out lots more online by visiting the links provided in the Visit boxes. Be curious, and discover the possibilities!

Health issues involving the circulatory system

Common diseases of the circulatory system include:

High blood pressure

This occurs when the force with which the blood pushes against the walls of the blood vessels is too high and can cause damage to the capillaries and several organs.

Keywords

- blood pressure
- deprived
- rupture

Heart attacks

Heart attacks occur when a narrowing or blood clot develops in one of the blood vessels that supplies the heart muscle with blood. If the narrowing or blood clot is big enough it can stop the blood flow to the heart muscle and can stop the heart from pumping, which is called a heart attack. The person can die.

Strokes

Strokes occur when cells in your brain are deprived of oxygen. This often occurs as a result of a blockage in the blood vessels leading to the brain, or when one of these vessels rupture (break or burst open).

2.3 The respiratory system

Keywords

- alveoli
- breathing
- bronchi
- cilia
- diaphragm
- exhale
- inhale
- lungs
- mucus
- pharynx
- trachea

Closely linked to the circulatory system is the respiratory system. The circulatory system maintains the circulation of blood in the body, while the respiratory system deals with the exchange of gases in your body.

Purpose of the respiratory system

The respiratory system is responsible for supplying the body's cells with oxygen and for removing carbon dioxide.

Components of the respiratory system

Various organs play a vital role in the respiratory system.

Mouth and nose

Oxygen-rich air enters the body through the mouth and nose where it is warmed.

Trachea (also called the windpipe)

The trachea is a tube that enters the chest and allows air to flow from the mouth into the bronchi and from there into the lungs. It is kept open by cartilage rings.

When dust particles and germs in the air enter the trachea during inhalation, the mucus lining the trachea traps these particles and the **cilia** work together to remove them from the body. When you sneeze or cough you expel the mucus and foreign particles from your body.

Did you know?

Using a patient's own stem cells, surgeons were able to develop and transplant the first human trachea in 2008.

Bronchi

The trachea splits into two air tubes, called bronchi, that connect to each of the lungs. These tubes divide even further into smaller and smaller tubes that connect with the tiny air bags (alveoli) of the lungs.

Lungs

The main organs of the respiratory system are the lungs. The tiny alveoli or air bags in the lung are surrounded by small capillaries where gaseous exchange takes place.

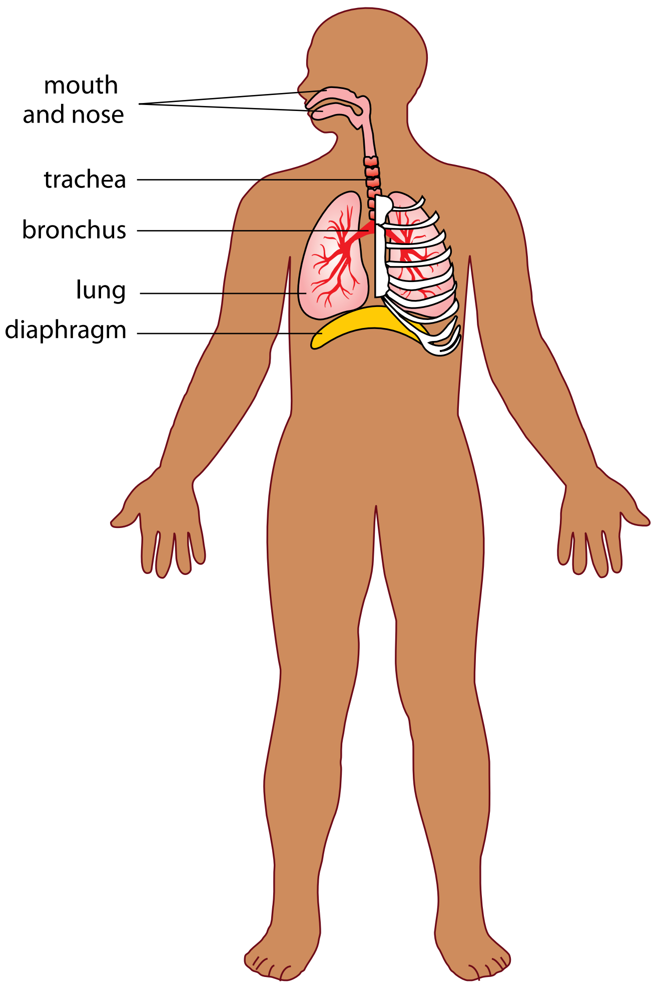


Figure 2.4: A diagram of the structures that make up the respiratory system

Diaphragm

This dome-shaped muscle below the lungs enables you to breathe. When it contracts, it moves downwards and your lungs fill with air. When it relaxes again it moves upwards and forces the air out of your lungs. This is the main muscle used for breathing.

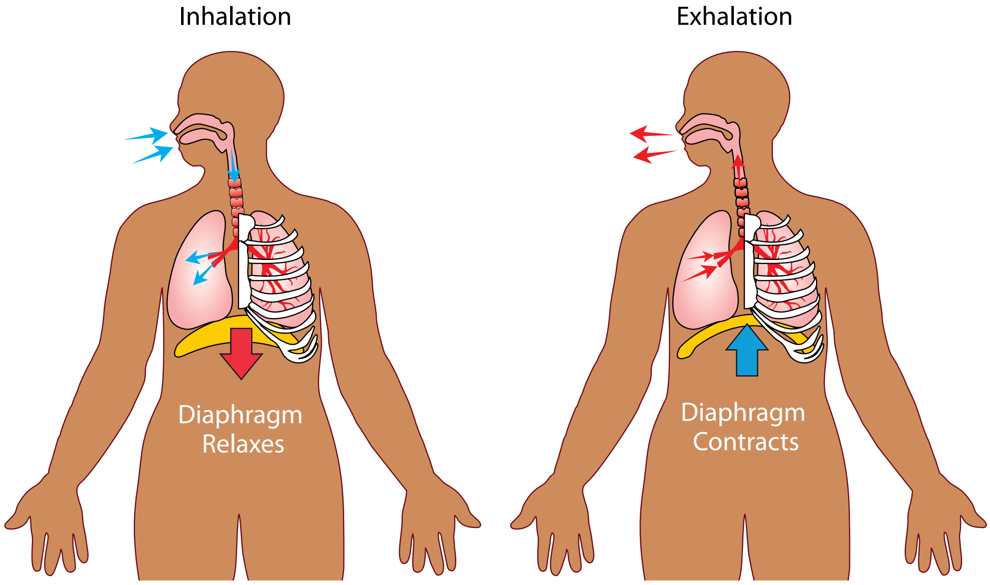


Figure 2.5: This diagram helps us to understand how breathing occurs showing how the diaphragm contracts and relaxes.

New word

- diffusion

Take note

People often confuse respiration with breathing. Breathing is taking air into the body through the lungs. Respiration or cellular respiration takes place inside the cells to release energy when oxygen is combined with glucose and other nutrients.

Main processes in the respiratory system

Three distinct processes occur in the respiratory system:

- **Breathing** occurs when we take oxygen into the body (lungs) and push carbon dioxide out of the body (lungs). Breathing therefore occurs in two folds:
  - Inhalation – drawing air in
  - Exhalation – pushing air out.
- **Gaseous exchange** takes place at two locations by a process called **diffusion**:
  - in the alveoli, oxygen diffuses into the blood from the lungs and carbon dioxide diffuses from the blood back into the lungs
  - in the body tissues oxygen diffuses from the blood into the cells and carbon dioxide from the cells diffuses into the blood
- **Cellular respiration** occurs within the mitochondria of cells to release the chemical energy in food.

Health issues involving the respiratory system

Some common health issues of the respiratory system are:

- **Asthma:** caused by allergies that inflame and narrow the airways
- **Lung cancer:** uncontrolled growth of cells within the lungs which may be caused by smoking and toxic air pollution
- **Bronchitis:** swelling of the lining of the bronchi due to infection which causes coughing and makes it difficult to get air into the lungs
- **Pneumonia:** an infection in the lungs where the alveoli fill with fluid
- **TB (Tuberculosis):** an infectious disease caused by the bacteria, *Mycobacterium*

2.4 The musculoskeletal system

All the movements that your body performs rely on a system of muscles, tendons, ligaments, bones and joints that work together. These are the components of your musculoskeletal system.

Keywords

- brittle
- cartilage
- collagen
- contract
- fracture
- frame structure
- joint
- ligament
- mineral salts
- muscle
- tendons

Purpose of the musculoskeletal system

Muscle tissue is responsible for producing movement in the body. However, muscles need to be attached to a frame structure to produce movement.

The bones of the skeleton provide a frame for muscles to attach to, so that movement is possible. The skeleton also protects the body, especially the soft, fragile organs such as the heart, lungs and brain.

Components of the musculoskeletal system

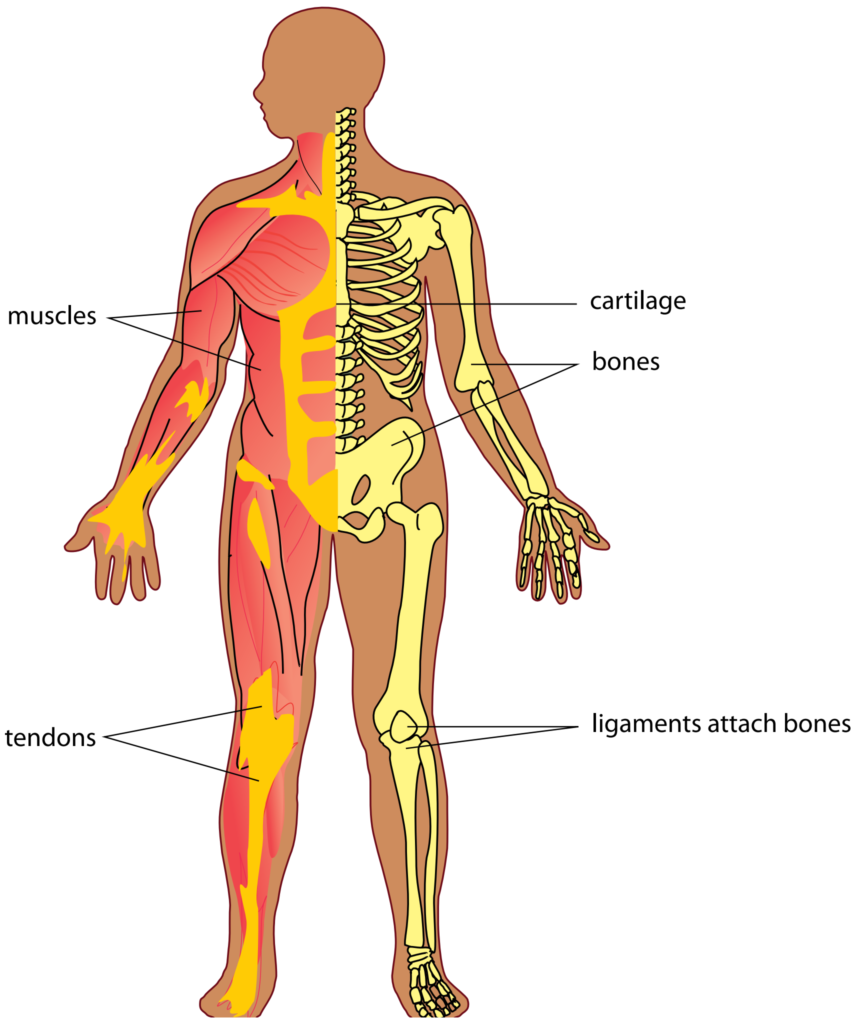


Figure 2.6: The components of the musculoskeletal system help bring about movement.

Did you know?

You use 200 muscles when taking only one step!

The components of the musculoskeletal system include the following:

Muscles

Muscles allow us to move because they are able to contract (become shorter) and relax (become longer).

Bones

Bones provide support and help to form the shape of the body. The place where bones meet is called a joint - think of your knee or elbow joint, or your finger and toe joints.

Cartilage

Cartilage is stiff yet flexible and is found between bones in joints and between the ribs and breastbone (as indicated in the diagram). It also forms the ears, nose and bronchial tubes, and forms discs between the bones of the spinal column.

Tendons

Your muscles attach to the bone with strong cords called tendons. You can feel some of the tendons in your body, for example behind your ankle (called the Achilles tendon).

Ligaments

Ligaments occur between bones at joints and hold bones together within the joint. Ligaments are extremely strong.

Keywords

- bowing
- locomotion
- self-propulsion

Main processes in the musculoskeletal system

We can move our entire bodies from one place to another through **self-propulsion**. This is called **locomotion**. Locomotion is different to movement. Movement is the change in shape, direction, position or size of a part of the body. Animals show movement and locomotion. What about plants? Do you think plants show movement and locomotion?

Locomotion and movement are made possible through the contraction and relaxation of muscles. Muscles are stimulated by nerves to contract.

Did you know?

The muscle that moves the fastest in your body is the muscle that controls your eyelids! There is a reason why we use the phrase 'in the blink of an eye' to mean very fast!

Health issues involving the musculoskeletal system

Common disorders of the musculoskeletal system include:

Rickets

This disorder is caused by a lack of vitamin D, calcium or phosphate which results in soft, weak bones. A typical symptom in children who have rickets is a **bowing** (bending outwards) of the bones of the legs.

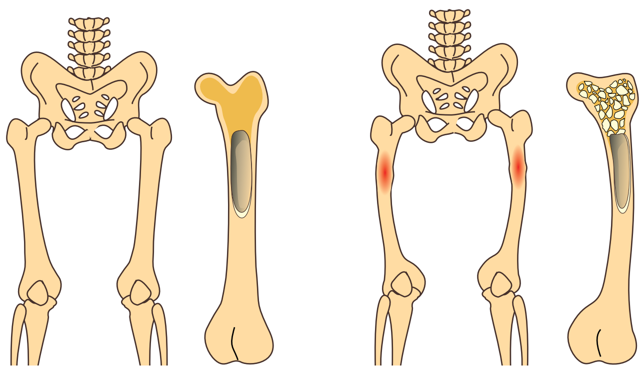


Figure 27: Can you see how the shape of the bones changes when a person has rickets?

Arthritis

This is a condition where the joints in the body become inflamed, painful and swollen. The cartilage between the joints breaks down, causing the bones to rub against each other, which is very painful.

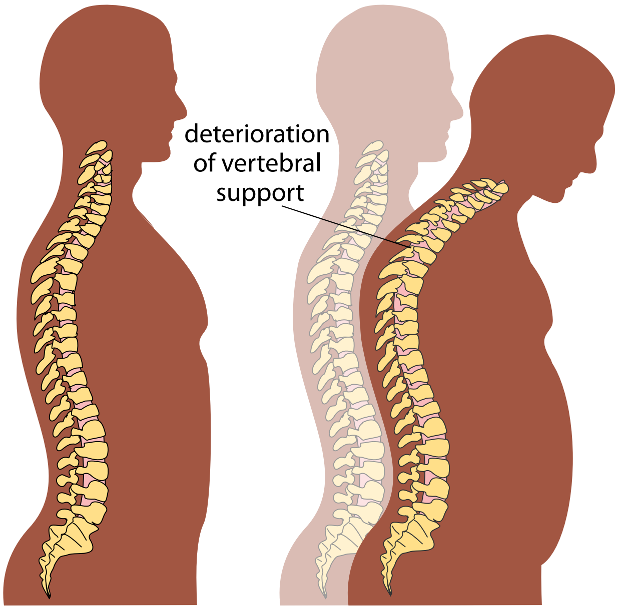


Figure 2.8: As this woman grew older, she developed osteoporosis, causing her vertebral column to crumble and collapse. So she now stoops over.

Osteoporosis

This occurs when the bone tissue becomes brittle, thin and spongy. These fragile bones can break easily, and they start to crumble and collapse. Although osteoporosis is common in older people (especially older women), teenagers and young adults may also develop it.

Did you know?

Babies are born with 305 bones while adults only have 206 bones. As babies grow into adults, many smaller bones fuse together to form bigger bones

2.5 The excretory system

We will now be looking at the excretory system. This is often confused with egestion, which we previously learned about.

Keywords

- bladder
- excretion
- kidney
- metabolic waste products
- metabolise
- toxic
- urea
- ureter
- urethra
- urinate

ACTIVITY Differentiating between excretion and egestion

Do you remember learning about the difference between excretion and egestion? Explain what you understand the difference between these terms are.

1. Egestion is …
2. Excretion is …

Purpose of the excretory system

Our cells use oxygen and nutrients to function and in the process also produce various metabolic waste products including:

- urea: a substance that is formed when protein is broken down in the liver
- carbon dioxide: a by-product of cellular respiration.

The organs of the excretory system are responsible for removing these harmful metabolic waste products from the blood so that they do not build up to high concentrations. But in the process, they have to retain the nutrients and water for the body to function. One of the main functions of the excretory system is to prevent too much or too little water in the body.

Did you know?

The first kidney transplant occurred in 1954.

> **Did you know?**
>
> On average, your kidneys produce 1,5 litres of urine each day.

Components of the urinary system as an example of the excretory system

We already know that the lungs excrete carbon dioxide (CO_2) when you exhale.

Another organ that excretes waste is the skin. When you sweat, your skin excretes excess water, salts and a small percentage of urea. In this section, however, we will focus on the excretory system to remove metabolic waste from our blood in the form of urine.

Organs of a urinary system

To do this, the body uses the urinary system, which consists of four main parts.

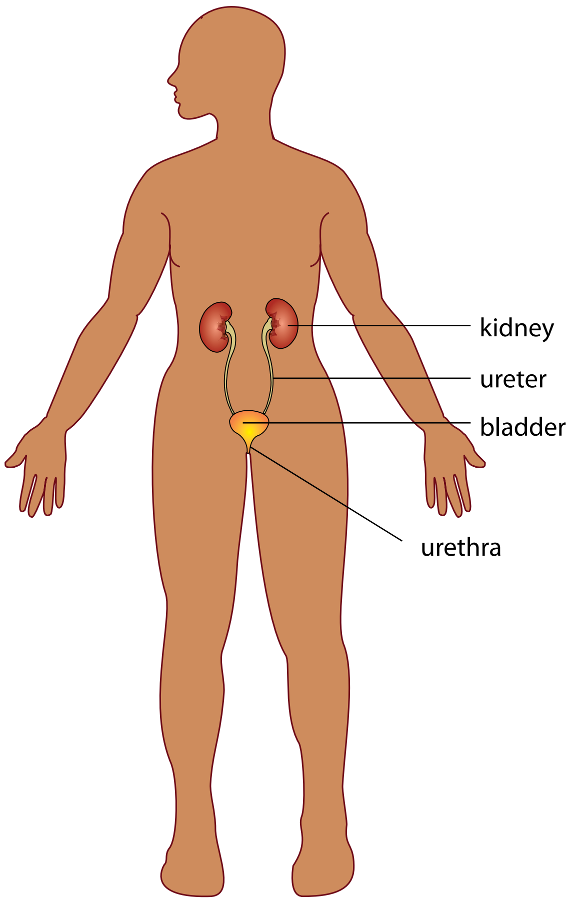


Figure 2.9: The excretory system is responsible for removing metabolic waste products from the blood.

> **Did you know?**
>
> Your kidneys filter about 125 ml of blood every minute! Since you have about 7 to 8 litres of blood in your body, all your blood gets filtered 20 to 25 times per day through your kidneys!

Kidneys

The kidneys filter all the blood in your body to remove urea from the blood. You have two kidneys, each about the size of your fist and bean-shaped. Your kidneys produce urine which is a combination of excess water and waste products.

Ureters

There are two ureters (thin tubes) which connect each kidney with the bladder and carry the urine from the kidney to the bladder.

Bladder

The bladder is a balloon-like organ that stores the urine before excreting it during urination.

Urethra

The urethra is a tube that connects the bladder to the outside of the human body through which the urine is excreted.

Main processes in the excretory system

There are four main processes discussed below.

Filtration

All the blood in the body passes through the kidneys as part of the circulatory system. The kidneys filter the blood to remove unwanted minerals and urea, and also excess water. Some water is removed so that the metabolic waste products can be excreted in solution in the liquid urine.

Absorption

Once the blood is filtered by the kidneys, the substances that the body needs are re-absorbed back into the blood so that they are not lost in the urine.

Keywords

- antibiotic
- infection
- filtration
- absorption
- excretion

Diffusion

The substances are transported into and out of the specialised cells of the kidney through the process of diffusion.

Excretion

The kidneys funnel the liquid urine through the ureters to the bladder where it is stored. When the bladder has filled up, it uses muscles to force the urine out of the body through the urethra. This is called excretion.

Health issues involving the excretory system

Common diseases of the excretory system include:

Kidney failure

When this happens the kidney loses its ability to properly filter and remove metabolic waste which allows this waste to build up in the body. This is very harmful and may be fatal. In such cases the patient needs to undergo very regular kidney dialysis. Dialysis involves using a machine which filters the blood for the patient to remove waste products.

Figure 2.10: A patient is receiving dialysis to filter his blood because the kidneys are not working as they should.

Kidney stones

Kidney stones form when fluid intake is too low, resulting in the concentration of solutes (salts and minerals) in the kidney becoming too high. This can result in a small crystal (stone) forming. The kidney stone may stay in the kidney or move down the ureter to be excreted in the urine. A larger stone may, however, cause severe pain along the urinary

Figure 2.11: A kidney stone, which is about 4,5 mm in diameter

tract and may even get stuck, blocking the flow of urine and causing severe pain or bleeding.

Bladder infection

This is one of the most common infections in women but is quite rare in men. Bacteria can enter the bladder and cause an infection. This causes swelling and pain when urinating.

2.6 The nervous system

Purpose of the nervous system

Our nervous system is a complex network that transmits nerve impulses between different parts of the body. The nerves in our body receive stimuli from inside the body or from the environment (from the ears, eyes, skin or tongue, for instance). These are turned into impulses, which travel to the brain and spinal cord.

Components of the nervous system

Keywords

- auditory
- brain
- conduct
- degenerative
- impulse
- nerve
- neuron
- optic
- stimulus
- transmit
- vision

The nervous system consists of two parts, the central nervous system and the peripheral nervous system.

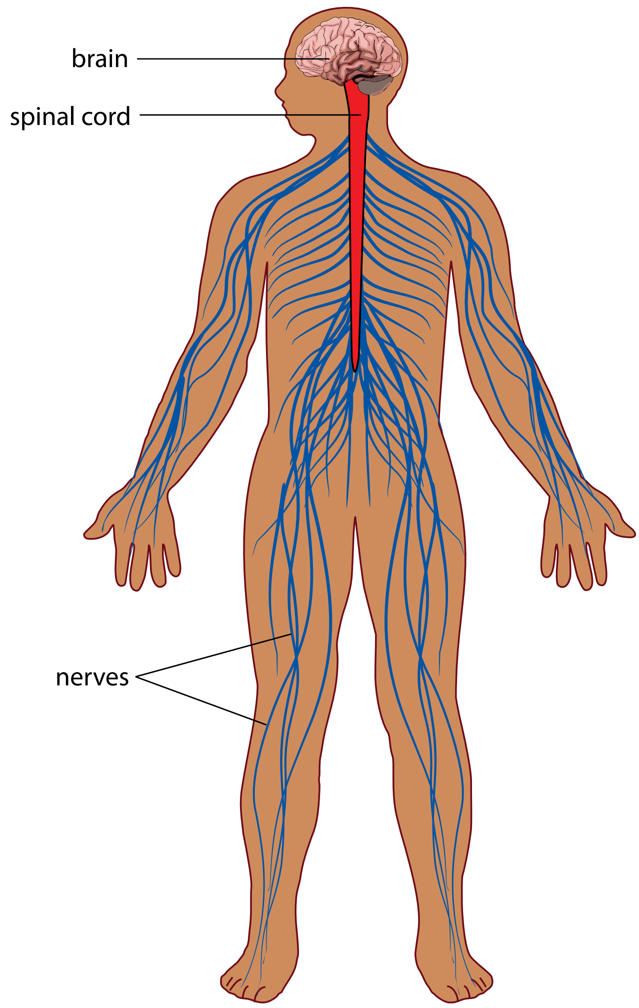


Figure 2.12: Components of the nervous system

Nerves

Nerves are the long fibres which transmit messages from the brain and spinal cord to the rest of the body and back. Each nerve is actually an enclosed bundle of nerve cells, called neurons. The nerves work together to carry messages throughout the body. They make up the nerve tissue in the nervous system.

Take note

'Stimuli' is the plural form of the word 'stimulus'.

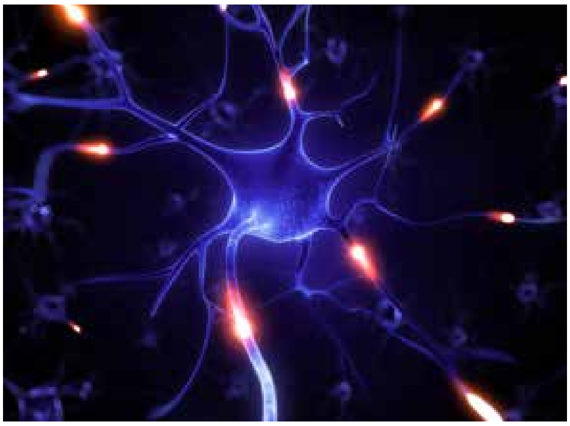


Figure 2.13: This fluorescent image shows nerve cells from a rat brain, which were grown in the laboratory.

Brain

Your brain is located inside your skull. The brain is part of your central nervous system and sends messages to the rest of your body. There are different areas in the brain that have different functions. All these different areas also communicate with each other.

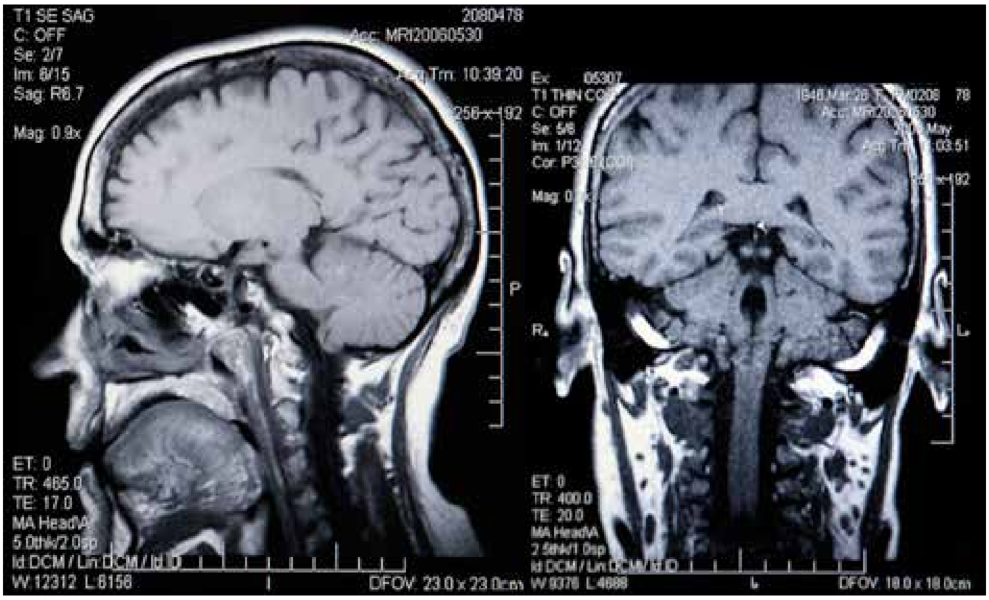


Figure 2.14: A MRI (magnetic resonance imaging) scan of a person's head showing the position of the brain within the skull.

Spinal cord

The spinal cord runs from the brain through your spine, protected by your vertebral column. The spinal cord is a bundle of nervous tissue and other support cells. The brain and the spinal chord are the main organs of the central nervous system.

Take note

'Peripheral' means on the outside. So the peripheral nervous system is outside the central nervous system.

Did you know?

The amount of electricity used by the brain to send and receive messages can power the light in your refrigerator!

Sensory organs

The second part of the nervous system within our bodies is the peripheral nervous system.

The peripheral nervous system connects the central nervous system to the muscles and organs. Various sensory organs are responsible for collecting information and sending it via sensory nerves to the central nervous system.

Our sensory organs are our:

- ears
- nose
- eyes
- skin
- tongue.

Main processes in the nervous system

The nervous system is responsible for the following processes. These are discussed next.

Sending and receiving impulses: Nerve cells in the brain send and receive multiple messages from multiple sources at any given moment. These are transmitted as electrical impulses. The central nervous system interprets these signals and this is how we sense the world around us.

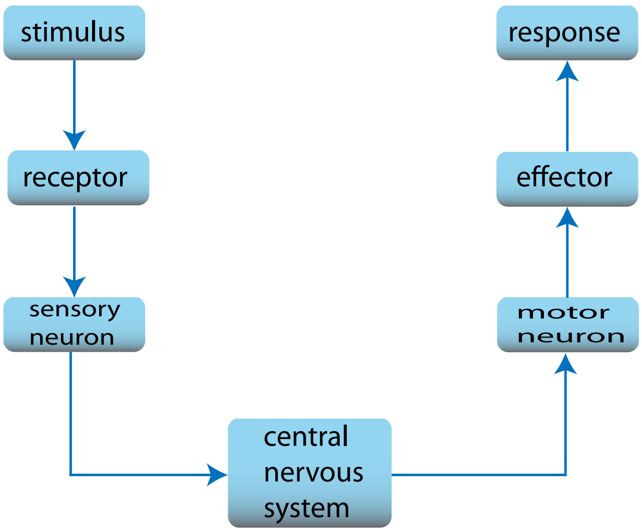


Figure 2.15: Sending and receiving impulses.

Hearing

In the ear, sound waves are transformed into electrical signals that travel along the auditory nerve to the brain. This allows us to understand what we are hearing.

Seeing

Seeing and understanding what you see are complex processes.

Light enters your eye and stimulates specialised cells within your eye. These cells transmit signals to the brain along the optic nerve, where they are interpreted as sight.

Feeling

The skin allows us to feel and experience the world around us through touch. Millions of nerve endings in the skin, called receptors, cover the skin, muscles, bones and joints, as well as internal organs and the circulatory system. These receptors respond to pressure, pain, temperature and movement.

Tasting

Taste buds in your tongue and parts of your mouth can distinguish between the different flavours: sweet, sour, bitter, salty. These receptors work very closely with the receptors in the nose. Together the taste and odour of food is sent to the brain where it is processed and interpreted.

Smelling

Nerve cells in the lining of your nose respond to molecules in the air. They send messages to the brain which interprets the smell accordingly and recognises any one of about 10 000 different smells!

Regulating temperature

An important part of the nervous system is to maintain a balance within the human body. This includes regulating our body temperature. Our bodies need to be kept at about 37 °C to work effectively. If the body is too hot the brain may try to cool the body through increased sweating. If you are very cold, your body will start to shiver to generate heat energy. These responses to changes in body temperature are controlled by your nervous system.

Did you know?

Nerve impulses travel to and from the brain at 274 km per hour.

Did you know?

Your brain makes up less than 2% of your total body weight, yet it uses 20% of your body's energy!

Health issues involving the nervous system

Trauma and injuries to brain and spinal cord

Any damage to the brain or spinal cord can have devastating effects on the human body. For example, people who break their necks in an accident, often damage their spinal cord. This prevents the brain from sending and receiving messages to the body and the person can become paralysed.

Stroke

If blood flow to the brain is stopped, brain cells begin to die, even after just a few minutes without blood or oxygen. This can lead to a stroke, where a part of the brain function is lost.

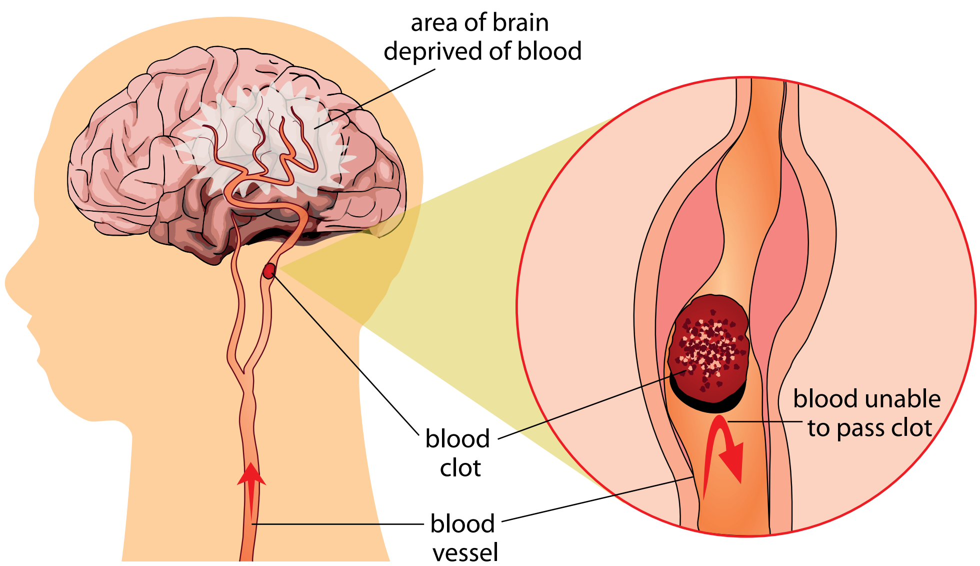


Figure 2.16: When the brain is deprived of blood and oxygen due to a blood clot, the person may suffer from a stroke.

Degenerative disorders

There are several problems associated with the nervous system that cause a gradual loss of function over time (degenerative). These conditions include Alzheimer's Disease, Parkinson's Disease and Multiple Sclerosis.

Mental health problems

Examples include depression, anxiety disorder and personality disorders.

Sensory organ problems

We have discussed the various sensory organs that are associated with the nervous system. These organs can also have problems, such as:

- deafness
- blindness
- short sightedness.

Effects of drug and alcohol on the brain: Different types of drugs target different areas in the brain and it is mostly the brain's reaction(s) that make people want to take drugs and/or alcohol.

Alcohol and drug abuse can cause irreversible brain damage, a loss of memory, decreased learning capability, an increased risk of strokes and heart attacks, and a variety of emotional and mental health problems.

Keywords

- ejaculation
- fertilisation
- ovary
- ovulation
- ovum
- penis
- puberty
- reproduction
- scrotum
- sperm
- testes
- uterus
- vagina
- womb

2.7 The reproductive system

Purpose of the reproductive system

In humans, as in other eukaryotic organisms, the main purpose of the reproductive system is to produce sex cells to ensure the continuation of the species.

Components of the reproductive system

We will be looking at the reproductive organs in more detail in the next unit.

For now, let's get an overview of the main components in the reproductive system.

The male and female reproductive organs differ:

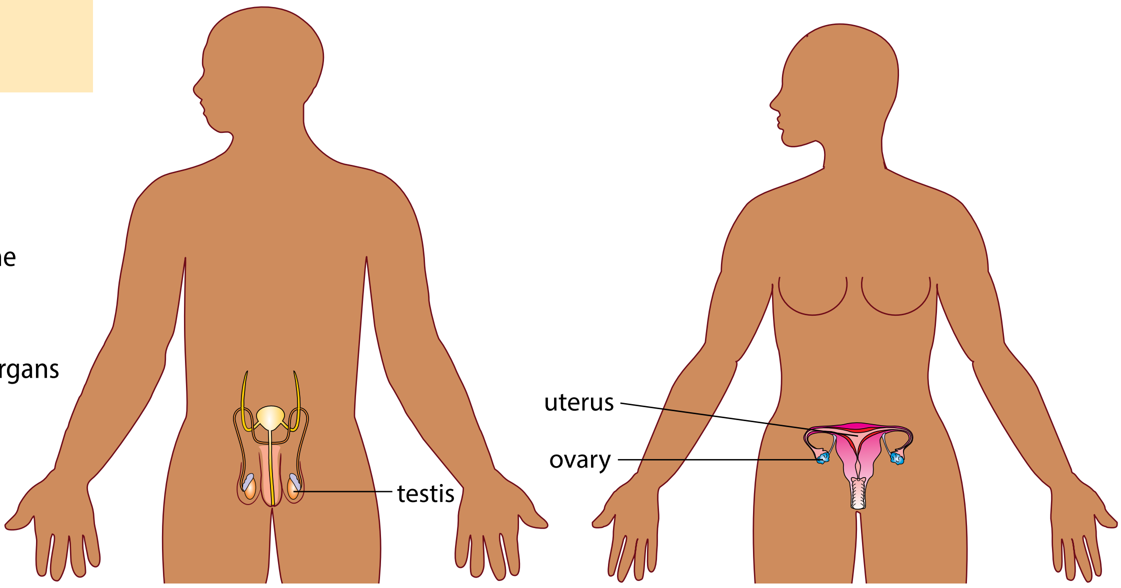


Figure 2.17: The male (left) and female (right) reproductive organs

Ovaries

The ovaries are located inside the female's body in the lower abdomen and produce mature egg cells (ova).

Uterus

The uterus (also known as the womb) has a thick lining and muscular wall. This is where a fertilised egg will implant and develop during pregnancy.

Testes

The sex organs in males are located in the scrotum, a pouch of skin that hangs between the legs. During puberty the testes start to produce sperm cells.

> **Did you know?**
>
> The largest cell in the human body is the ovum (egg cell) and the smallest cell is the sperm cell

Main processes in the reproductive system

During sexual reproduction, the egg and sperm have to combine to form a new individual. Let's do an activity to find out about the main processes in the reproductive system.

ACTIVITY Defining the main processes involved in reproduction

Instructions

- Below is a list of the main processes involved in the reproductive system.
- Look up each term, either in your dictionary or on the internet, and write a brief description in your exercise books.
- The first three have been done for you.

> **Did you know?**
>
> Some of the strongest muscles in the female body are found in the uterus! Can you think of reasons why this is?

Growth

Growth is the increase in size and mass of an organism as it develops over time.

Cell division

Cell division is the process when a parent cell divides into two daughter cells. In the reproductive system, cell division occurs within the ovaries and testes to produce gametes (sperm and egg cells).

Maturation

Maturation is the process of becoming mature. In humans, this refers to puberty where sexual organs mature so that they are able to reproduce.

1. Copulation
2. Ejaculation
3. Ovulation
4. Menstruation
5. Fertilisation
6. Implantation

Health issues involving the reproductive system

Infertility

About 10% of heterosexual couples have problems falling pregnant and may even be completely unable to reproduce sexually. This is known as infertility, and it affects both men and women.

Foetal Alcohol Syndrome

When a pregnant mother drinks alcohol during her pregnancy, the alcohol may cause serious birth defects in the unborn baby. This will affect the child throughout their entire life and in most cases cannot be reversed.

Sexually Transmitted Diseases (STDs)

Many life-threatening diseases such as HIV/AIDS, syphilis and gonorrhoea can be transferred during sexual intercourse.

Summary

Key concepts

- There are many complex systems functioning in our bodies.
- Each system has very specific organs and tissues that are key components in making the system function optimally.
- Different processes take place that are dependent on the key components in each system.
- There are various health issues that affect the systems of the body and that can often be prevented with a healthy lifestyle and wise (informed) life choices.

Concept map

Revision

1. What does digestion mean? [4]
2. List the four main processes involved in the digestive system. [4]
3. Describe the different components of the digestive system and their function. [15]
4. Diarrhoea is can be very dangerous in babies.
   a) Why do you think this is so? [1]
   b) How can diarrhoea be prevented? [3]
5. Distinguish between inhalation and exhalation. [2]
6. Is carbon dioxide in your body excreted or egested? Explain why you say so. [3]
7. Draw a simple diagram to show how blood is circulated around the body in a closed system. [10]
8. What is the difference between breathing and respiration? [5]
9. Give two parts of your musculoskeletal system you use when you have to climb stairs. [3]
10. What are the functions of the bones in the skeleton? [2]
11. Drugs and alcohol have various negative effects on the body. List at least three. [3]
12. Explain why it is so dangerous for a pregnant woman to drink alcohol during pregnancy. [2]

Total [71 marks]

3 Human reproduction

Key questions

- What is puberty, and what does it mean when we 'reach puberty'?
- Why do we all go through puberty at different times and rates?
- What changes take place inside our bodies during puberty?
- What do our reproductive organs look like when they are mature?
- How does reproduction occur?
- What is menstruation and why does it occur once a month?
- How does a baby grow inside a woman's uterus?
- Are there ways to prevent pregnancy and the transmission of STDs?

At this stage in your life, your body is probably going through all sorts of changes as it grows, develops and matures. In this unit we will learn more about these changes and why they occur.

3.1 Purpose and puberty

Keywords

- birth control
- conception
- fertilisation
- implantation
- population growth rate
- puberty
- sexual intercourse
- sperm

The purpose of reproduction

You have previously learnt that reproduction is one of the seven life processes, and like all organisms, humans need to reproduce to ensure the survival of the species.

ACTIVITY Reflecting on population growth

Have a look at the website link provided in the visit box about our 'Breathing Earth'. This will give you an idea about how our population is growing.

In 2011 the world's population grew to 7 billion people, one billion more than in 1999. Medical advances and increases in agricultural production (food) allow more and more people to live longer lives. In ancient times, countries such as India, Rome and Greece saw a large population as a source of power. The Romans even made laws about how many babies a couple could have and punished those who did not follow the rules. Yet Confucius (551–478 BC) thought that too many people was a problem, as there wouldn't be enough food to feed everyone, leading to war and famine and various other problems. Today in China this philosophy still applies and couples are allowed only one baby and are heavily taxed if they have more than one.

South Africa's population grew by 15,5%, or almost 7-million people in the space of 10 years to reach a total of 51,7-million in 2011. This is according to the country's latest national census, which took place in 2011. The previous census took place in 2001.

Questions

1. List any possible reasons why you think South Africa would want to have a large population.
2. What are some advantages and disadvantages to the country in which the number of children per couple is limited so that the population growth is limited?
3. Predict what possible long-term problems may arise if the population in South Africa continues to grow at the fast rate at which it is currently growing.
4. Have a look at the following diagram which shows the percentage growth of a country's population in a year. The different colours give an indication of the growth rate, as shown in the key. For example, countries which are colour coded yellow have an annual growth rate of 3%. This means their population increases by 3% each year. Answer the questions which follow.

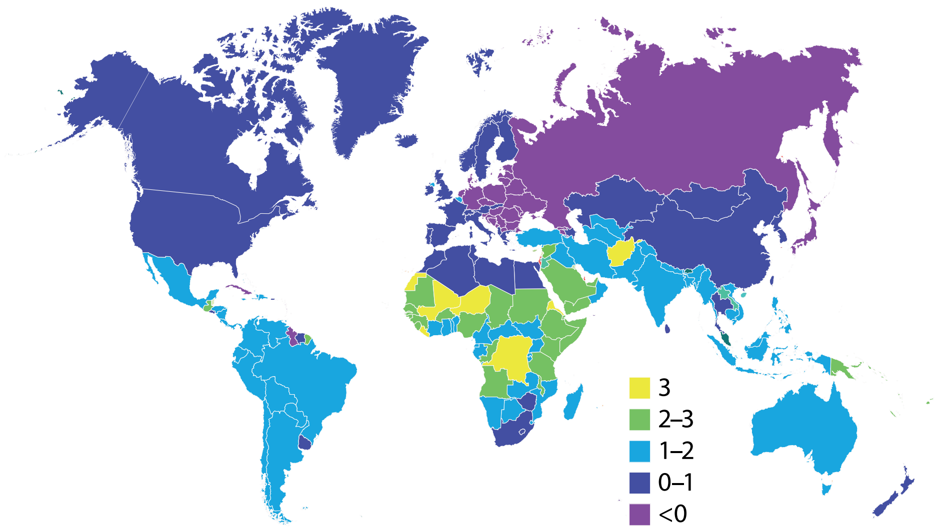


Figure 3.1: Percentage growth rate of each country.

5. Which continent would you say has the largest percentage growth rate each year? Justify your answer.
6. Many countries in Europe are coloured light purple in the diagram. What does this mean?
7. Various population control methods are put in place around the world: contraceptives to stop women from falling pregnant, abortion clinics, large tax incentives to convince people not to want more children, and others.
8. What is your opinion about population control methods, and do you think they should be allowed in modern society?

Keywords

- hormone
- menstrual cycle
- oestrogen
- penis
- testes
- testosterone
- uterus

What is the purpose of puberty?

The human body is geared towards reproduction to ensure the survival of the species. Men have to produce sperm and ensure that they come into contact with a female egg cell. Women have to produce (and store) egg cells that can be fertilised by a male sperm cell.

Children's bodies and sexual organs are not mature and cannot yet perform the reproductive function. Puberty is the time when a child's body develops and changes. The sexual organs mature to enable the body to produce sex cells. These sex cells are called gametes.

How does puberty just 'start'?

- Puberty is the stage in the life cycle of humans when we become capable of sexual reproduction. Girls and boys do not, generally, go through puberty at exactly the same time. So how does puberty 'start'?
- Many of the complex actions that take place in our bodies are controlled by chemical messengers called hormones. Hormones are produced by different glands in our bodies. The pituitary gland is an important gland which controls most of the body's hormones and hormonal activities. It is about the size of a pea and located at the base of the braiån.
- Puberty is brought on when the pituitary gland releases specific hormones into the bloodstream. These hormones then travel to the immature sex organs and signal the hormones in these to be released.
- In girls, the ovaries are stimulated by hormones released by the pituitary gland to release the hormone oestrogen. In males, the testes are stimulated to release the hormone testosterone. These hormones initiate all the bodily changes that you experience during puberty.

What changes during puberty?

The main purpose of puberty is for the sexual organs to mature. However, the hormones which are released from the reproductive organs also start a number of other changes in the human body. We call these secondary sexual characteristics.

Puberty brings about the following secondary changes in females:

- **Breasts** start to develop that may be used for breastfeeding a baby after childbirth.
- **Pubic hair** starts to grow at the onset of puberty. Underarm hair also starts to grow.
- **Menstruation** occurs in girls in a monthly cycle once they reach puberty.
- **Body shape** also changes due to the rising levels of oestrogen in the body.
- **Body odour and acne** develop as more oil is secreted and the smell of sweat in the body changes.

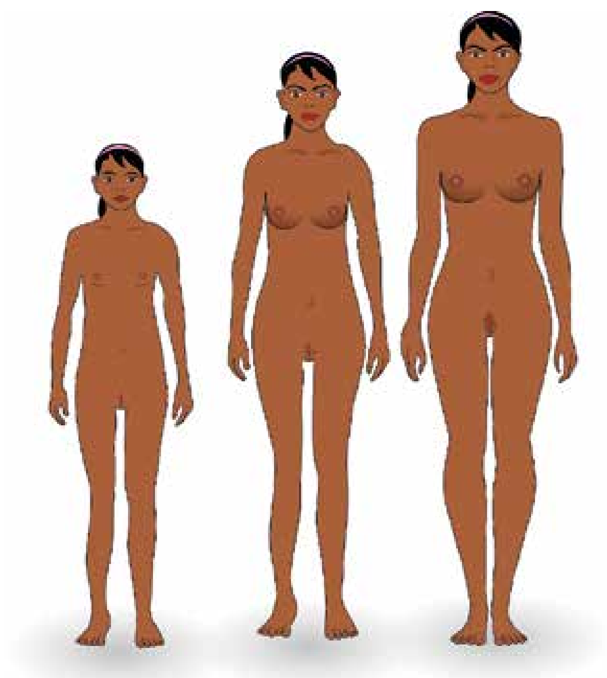


Figure 3.2: Puberty changes in females

At the start of puberty boys are, on average, 2 cm shorter than girls, yet adult men are approximately 13 cm taller than adult women. Puberty brings about the following secondary changes in males' bodies:

> **Take note**
>
> 'Testes' is plural and 'testis' is singular.

- Testicle and penis size increases.
- Hair starts to grow on the pubic areas, the limbs, chest and the face.
- Voice becomes deeper as the larynx (voice box in your throat) grows.
- Body shape changes occur as the skeletal muscle and bones increase in size and shape.
- Body odour and acne start to develop, as with females.

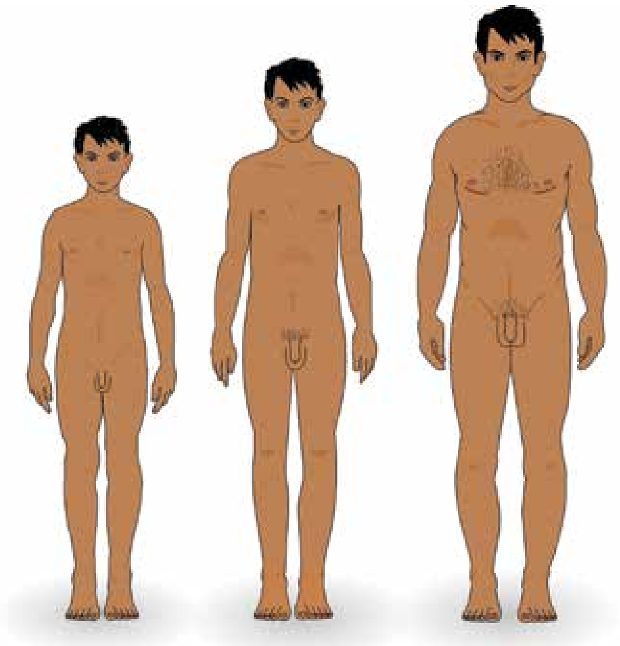


Figure 3.3: Puberty changes in males

Let's take a look at the reproductive organs.

> **Keywords**
>
> - erection
> - foreskin
> - scrotum
> - semen
> - sperm duct (*vas deferens*)
> - vagina

3.2 Reproductive organs

Let's take a closer look at the male and female reproductive organs to see how they are structured and what functions they perform.

ACTIVITY Identify the role of the male and female bodies in reproduction

In your exercise books, explain what you think the role of the male and female bodies are in reproduction.

1. The male body has to …
2. The female body has to …

> **Did you know?**
>
> Semen contains sperm cells, dissolved nutrients and enzymes that nourish and protect the sperm inside the woman's body. Every millilitre of semen can contain up to 100 million sperm cells!

Male reproductive organs

The male reproductive organs include:

Testes and scrotum

Males are born with their two testes hanging outside their bodies. The testes in young boys do not produce sperm. During puberty the two testes release testosterone which then triggers the production of sperm. The two testes are each contained in a pouch of skin

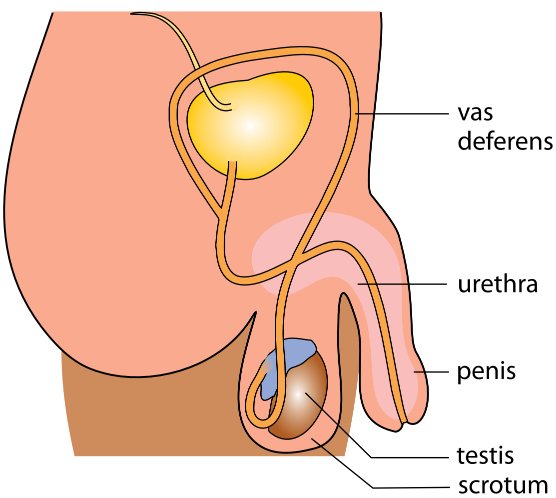


Figure 3.4: The male reproductive organs

called the scrotum. The scrotum ensures that the testes are kept at a constant temperature of 35°C which is the temperature at which sperm is produced.

Sperm duct (*vas deferens*)

Different tubes (ducts) carry the semen from the testes to the penis. The sperm duct carries the sperm from the testes to the urethra in the penis.

The penis

The penis is the external sex organ. The head is often covered by a loose fold of skin called the foreskin. The penis needs to be erect (stiff and hard) to be able to go into the vagina to deliver the sperm to the cervix during ejaculation.

Urethra

The semen moves through the urethra to the outside during ejaculation. The urine passes through the urethra during urination, but the semen and urine do not move through the urethra at the same time.

Take note

Some cultures have the foreskin removed, called circumcision. This is done when the boy is a baby or at puberty.

ACTIVITY Identify structure and function

1. Study the diagram of the male reproductive system. Label each part using its correct scientific name.
2. In the table, identify the function(s) of the male reproductive organs mentioned.
3. Copy the table below in your exercise books. In the last column, suggest how you think the structure of the organ is adapted to perform the function most effectively.

Reproductive organ	Function	Adaptation
Penis		
Testes and scrotum		

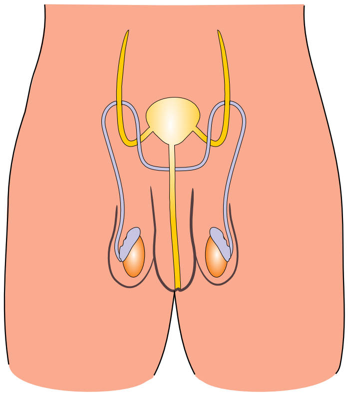


Figure 3.5

Keywords

- cervix
- Fallopian tube (oviduct)
- ovary
- ovulation
- womb

Female reproductive organs

The female reproductive organs include:

Vagina

The vagina is a tube that connects the uterus with the outside of the body. During intercourse the vagina acts as a canal for the penis to fit into to deliver sperm. Once a month, during menstruation, the menstrual blood leaves the

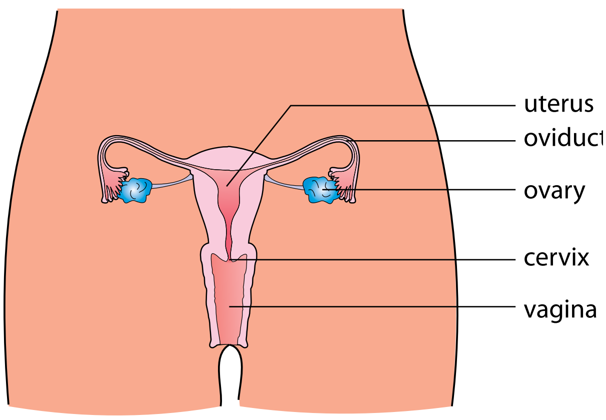


Figure 3.6: The female reproductive organs

Did you know?

Women are born with thousands of immature egg cells in each ovary, but very few ever reach maturity.

body through the vagina. The vagina is also the birth canal during childbirth, when it stretches to allow the baby to pass through.

Uterus

The uterus is hollow, with extremely strong muscular walls that can carry and protect a baby. Two oviducts (Fallopian tubes) at the top of the uterus connect it to the ovaries. The bottom neck of the uterus is called the cervix, which is tightly closed to protect the inside of the uterus.

Take note

The plural of ovum is ova.

Ovaries

There are two ovaries on either side of the uterus. They produce oestrogen and contain the ova. Each month the ovaries take turns to produce a mature ovum. This is called ovulation.

Oviducts (Fallopian tubes)

The uterus and ovaries are connected through a pair of muscular tubes called the oviducts or Fallopian tubes. The mature ovum travels into these tubes to the uterus. Fertilisation occurs in the oviduct.

ACTIVITY Comparing the reproductive organs

1. Explain how the structures of the vagina, cervix and uterus are specially adapted to fulfil their functions.
2. Provide at least 2 reasons why the uterus needs to have strong muscular walls.
3. Compare the position and functions of the ovaries with those of the testes. Create a table to show these differences.

Keywords

- contraception
- contraction
- embryo
- gestation (pregnancy)
- labour
- menopause
- surrogacy
- umbilical cord
- zygote
- foetus

3.3 Stages of reproduction

We have already mentioned most of the processes that take place during reproduction. These processes occur in stages. Let's first have a look at the female reproductive cycle.

The reproductive cycle

The female reproductive cycle repeats every 28–30 days to release an egg cell to be fertilised if sperm are present. This cycle will repeat for many years from puberty to **menopause** (when the reproductive cycle comes to an end). The processes that occur will differ depending on whether the ovum is fertilised or not. After ovulation, if fertilisation does not occur, the reproductive organs 'reset' through menstruation to start the process again.

Ovulation

Once a month, one of the ovaries releases one mature ovum into the oviduct. This process is called ovulation. At the same time the uterus wall thickens and develops extra blood vessels. This is in preparation for the *possible* implantation of a fertilised egg.

Menstruation

When there is no fertilised egg cell (**zygote**) to implant in the uterus, the thick layer of blood and tissue is no longer needed. It is passed out through the vagina during menstruation. The entire process is called the menstrual cycle and it normally repeats every 28–30 days.

Fertilisation

During sexual intercourse the erect male penis enters the female vagina. This is called **copulation**.

The male penis deposits sperm into the female vagina through **ejaculation**.

There can be millions of sperm cells in one ejaculation, but only one will be able to penetrate the outer membrane of the ovum.

After ejaculation into the vagina, the sperm swim into the cervix and through the uterus to the oviducts. Once inside the oviducts, the sperm swim to meet the mature egg that was released from the ovaries and is now travelling towards the uterus.

One sperm cell burrows into the surface of the ovum. Only the sperm's head enters, the tail stays outside. As soon as one has penetrated the outer layer, the surface of the ovum changes and no more sperm will be allowed to enter.

This process is called **fertilisation** and it takes place in the outer part of the oviduct, and not in the uterus or vagina.

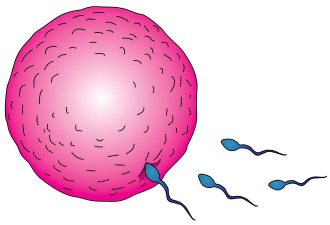


Figure 3.7: Once the sperm on the right has entered the outer layer of the ovum, no more sperm will be able to penetrate.

> **Take note**
>
> There are times in the menstruation cycle near to ovulation when there is a high chance of becoming pregnant. All girls need to be aware of where they are in their own menstrual cycle as each cycle differs slightly.

ACTIVITY Comparing fertilisation and menstruation

Instructions

1. Use the following diagram to compare what happens when an egg is fertilised compared to when it is not fertilised. You can use coloured pens if you have them.
2. Use labels and arrows to illustrate on the left-hand side what happens to the ovum if it is fertilised by a sperm cell.
3. Use arrows and labels to illustrate on the right-hand side what happens if the ovum is not fertilised and the woman subsequently menstruates.

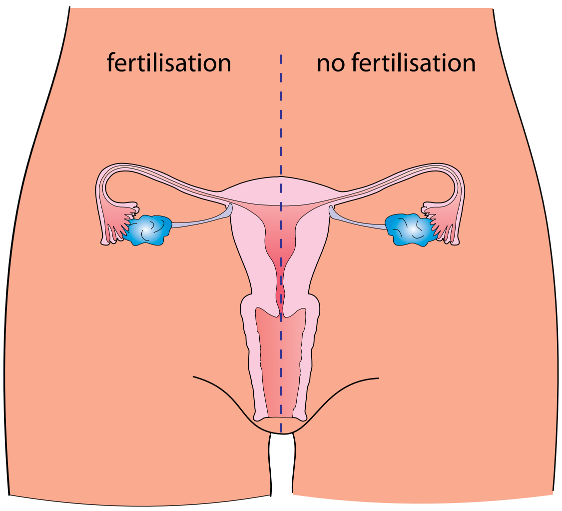


Figure 3.8

ACTIVITY Flow diagram of the pathway of sperm

Instructions

1. Use a flow chart to track the progress of a sperm cell from the testes in the male body to the ovum in the female body.
2. Draw your flow diagram in your exercise books. Remember to draw arrows.
3. Use the following terms in your flow chart, in the correct order.
   a) Cervix
   b) Uterus
   c) Urethra
   d) Penis
   e) Testes
   f) Sperm duct
   g) Oviduct/Fallopian tube
   h) Vagina

Pregnancy and birth

In humans, pregnancy is about 40 weeks (9 months). We call this the gestation period.

Pregnancy begins the moment the female egg cell is fertilised by the male sperm cell. This is then called a zygote. The zygote will then start to divide and grow as it moves down the oviduct. It will then implant in the uterus lining, where it will continue to grow. The fertilised egg is now called an embryo and undergoes cell division over and over again. This forms a cluster of cells with the different cells differentiating to become the specialised cells, tissues and organs that make up the human body.

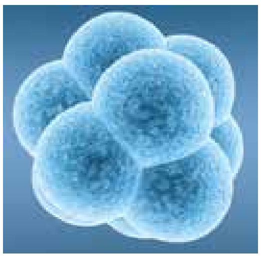


Figure 3.9: An 8-cell human embryo on day 3 after fertilisation.

Where the embryo implants into the spongy, blood-vessel rich lining of the uterus, some of the cluster of cells that formed after fertilisation form the placenta. The placenta is partly formed by the mother and partly by the embryo. The embryo develops an umbilical cord to attach itself to the placenta. The embryo can receive food and oxygen and remove its wastes through the umbilical cord and placenta.

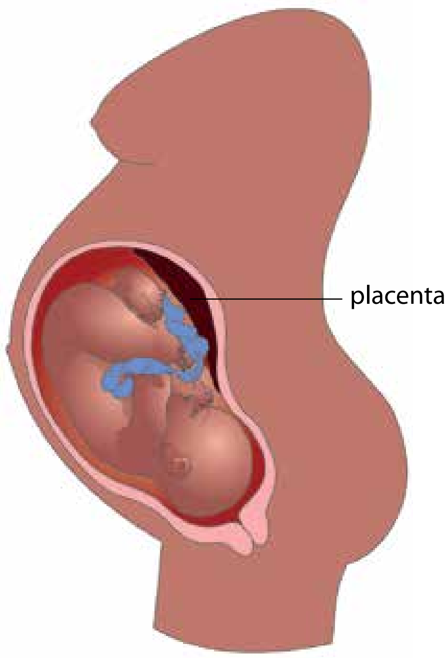


Figure 3.11: The foetus is attached to the placenta by the umbilical cord.

Birth

Towards the end of the pregnancy, the uterus starts to contract. This pushes the head of the foetus into the vagina (birth canal). After the head has appeared the rest of the body comes out quite quickly. The last to come out is the placenta.

Figure 3.10: A newborn baby

ACTIVITY Debate surrogacy

Many couples, for various reasons, are unable to fall pregnant. A surrogate mother can be impregnated with the couple's fertilised embryos and can therefore carry the couple's baby to full term. South African law allows only certain individuals to do this; it is not available to just anybody.

Instructions

1. Work in groups of 6.
2. Debate the issue of surrogacy in your group. Base your debate on the ethical concerns below or any others you may think of.
3. Appoint a spokesperson for the group.
4. Each of the groups' spokesperson must then share their group's points of view with the class.
5. Debate these issues in the class.

There are many ethical issues concerning surrogacy:

- In many cases, the surrogate mother is paid to grow the baby inside her body. Often women who are poor agree to be surrogate mothers and it is suggested that people who pay them to carry their babies are exploiting them. Should women be paid to be pregnant and deliver babies?
- In certain religions, surrogacy (including the donation of sperm and ova) is seen as 'highly immoral' because it involves the intrusion of a third person on a couple's relationship. Should religious institutions be allowed to prevent surrogacy in this way?

Write down some notes on any other points your group discusses.

Influences on the unborn baby

During pregnancy, what the mother eats, drinks and takes into her body has been shown to directly affect the unborn child. Other substances such as cigarettes, alcohol and drugs have a negative influence on an unborn baby.

The placenta transports nutrients and oxygen to the foetus, and removes metabolic waste products and carbon dioxide. However, it cannot differentiate between nutrients and harmful products, such as nicotine, alcohol or drugs. If the mother uses these substances during pregnancy, they will most likely pass through the placenta to the foetus causing great harm to the unborn child.

Pregnant mothers who drink alcohol during pregnancy may cause irreversible birth defects in their unborn babies. This is called Foetal Alcohol Syndrome (FAS).

Did you know?

Hearing is one of the first senses to develop in a foetus. So it is thought that unborn babies can hear and are affected by sounds while in the womb.

Prevention of pregnancy and contraceptives

Anyone who is sexually active and who wants to prevent an unwanted or unplanned pregnancy can take certain precautions.

There is a range of different contraceptives that can be used to prevent pregnancy. There are four different types of contraceptives:

1. **barrier** – physically prevent sperm from reaching uterus
2. **hormonal** – prevent ovulation and fertilisation in the female using hormones
3. **intra-uterine devices** – prevent the embryo from implanting
4. **sterilisation** – by surgery in men and women . It is permanent and not reversible.

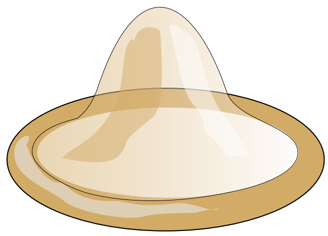
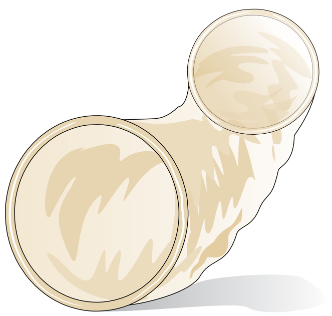
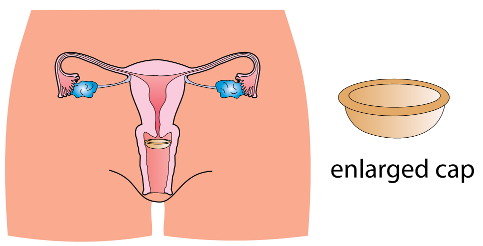
ACTIVITY Describing different contraceptives

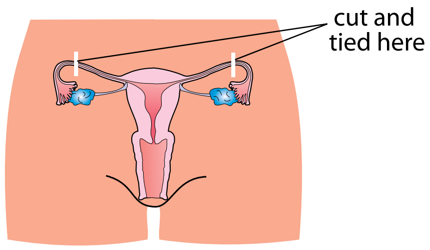
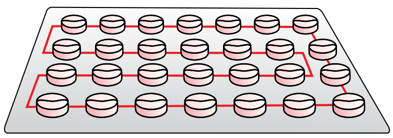
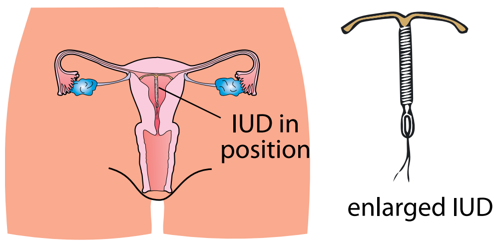
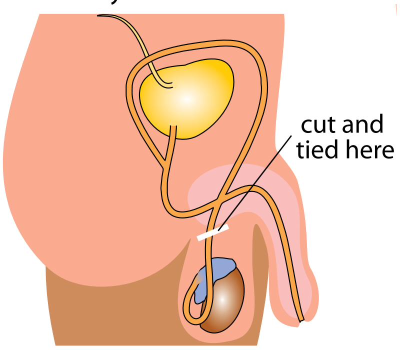
Instructions

1. In the following table, several different types of contraceptives have been listed, along with a picture and description.
2. You need to read the information, look at the images and classify the types of contraceptive as one of the following:
   a) barrier
   b) hormonal
   c) intra-uterine device
   d) sterilisation.

Take note

'Contra-' means against, so 'contraception' means against conception.

Contraceptive	Description	Classification
Male condoms 	These thin sheaths of rubber are placed over the erect penis before inserting it into the vagina. When the male ejaculates the sperm and seminal fluid is caught in the condom and cannot enter the cervix.	
Female condoms 	A female condom is a barrier method that a woman can use to help prevent pregnancy or sexually transmitted infections, including HIV. A thin polyurethane sheath, with two rings. It lines the vagina and the area outside and prevents sperm from entering the woman's vagina during sex.	
Diaphragm 	The diaphragm is a small rubber cap that is placed at the entrance to the uterus before sexual intercourse to create a seal and prevent sperm from entering the uterus	

Contraceptive	Description	Classification
Tubal ligation in women 	A surgical procedure in women in which the oviducts are cut and tied, which prevents mature eggs from reaching the uterus for fertilisation.	
Oral contraceptive pill 	Often referred to as 'the Pill', it is taken every day by mouth. It contains a combination of female hormones which prevents ovulation each month.	
Female intra-uterine device (IUD) 	A small 'T'-shaped device is inserted into the uterus to prevent fertilisation. It is long-acting, reversible contraception as the device may be removed again. It is not suitable for women who have not yet had a baby, and must be inserted by a doctor.	
Vasectomy 	A surgical procedure in males in which the *vas deferens* is cut and tied. Sperm are therefore prevented from becoming part of the ejaculate.	

Sexual intercourse with many different partners is very risky behaviour as there are many diseases that are transmitted through the fluids involved in the sexual act. We call these **Sexually Transmitted Diseases** (STDs). There are many different STDs, for example; HIV/AIDS, Herpes virus, Syphilis, Gonorrhoea and genital warts.

Being faithful to one partner limits your chances of contracting STDs. If you know that your partner has an STD he or she can either get medical treatment for this and/or you can take the necessary precautions to prevent contracting the disease. One of the most popular precautions to prevent the transmission of STDs is for the male partner to wear a condom. However, condoms can break and this can expose you to an STD, so you still have to be careful.

ACTIVITY Forum discussion

Hold a forum discussion regarding the choices women have when they do not want to be pregnant or raise a child. Before the discussion, do research and interviews with your parents, caregivers, or health professionals, or ask your Life Orientation teacher.

How to hold a forum discussion

In a forum discussion, experts are asked to sit on a panel and give their opinion about a particular topic. There are specific roles in a forum discussion:

- **Moderator**: This person keeps the discussion focused and on track.
- **Participants**: The experts. This will be you, the learners, after you have conducted your research.

1. Work in groups of 6.
2. Choose a moderator.
3. Discuss the different choices that women have regarding unwanted pregnancies using the information you obtained from the interviews you conducted.

Rules for a forum discussion

1. The speakers need to take turns to give their opinions.
2. Treat everyone with dignity and respect. Speak politely.
3. Use the correct scientific terminology.

Record your findings

Record the findings from the forum discussion in your exercise books explaining what choices women have when faced with an unwanted pregnancy.

Summary

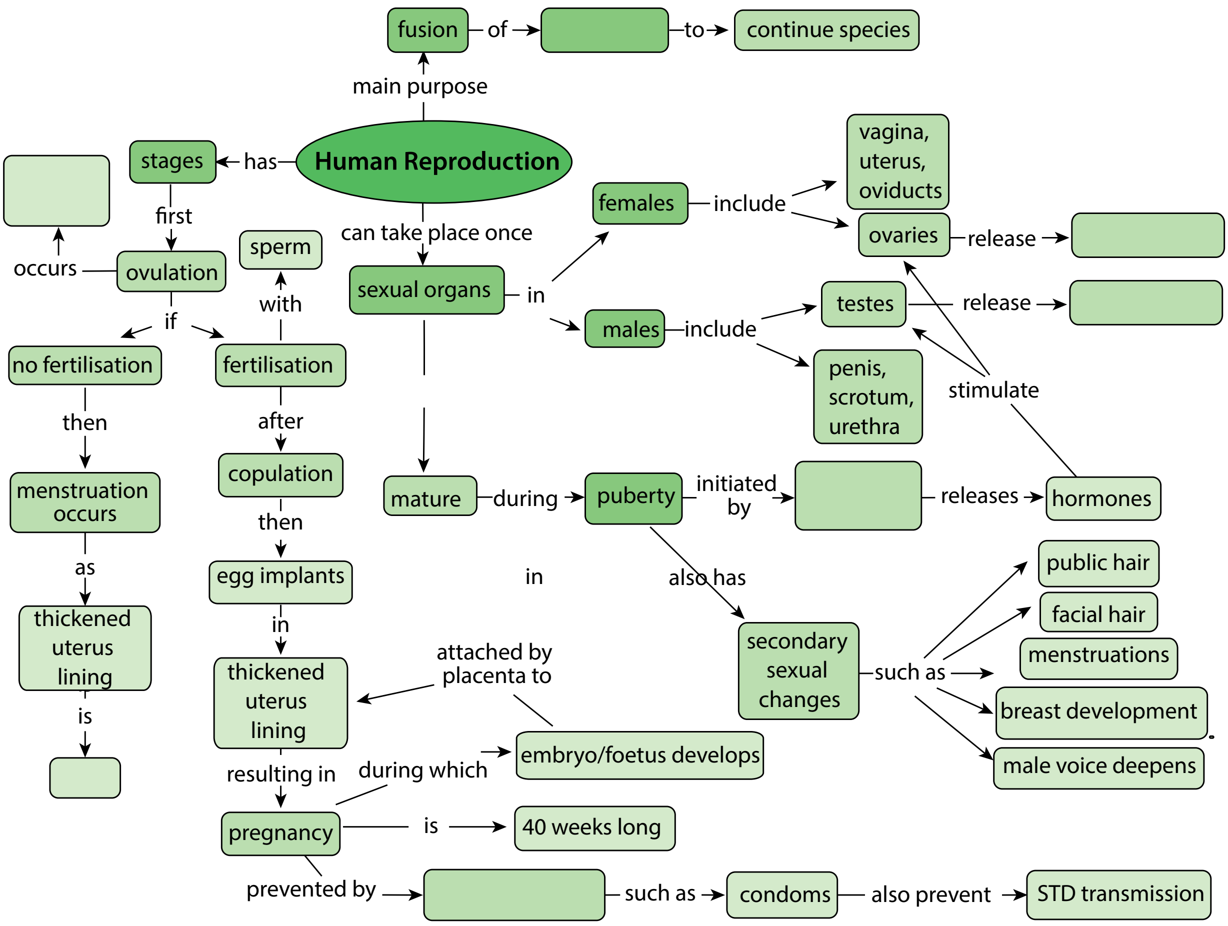
Key concepts

- The main aim of human reproduction is to produce babies to continue the species.
- In human reproduction, two gametes (the sperm and egg cell) fuse during conception to form a zygote that will eventually become a new baby.
- Puberty is the stage in the human life cycle when the sexual organs mature and prepare for reproduction.
- The pituitary gland below the brain releases hormones that stimulate the testes and ovaries to release hormones that will start the production of sperm in the male and the maturation of ova (egg cells) in the female.
  - In males, the hormone testosterone stimulates the testes to produce sperm.
  - In females, the hormone oestrogen stimulates the ovaries to produce mature ova.
- Testosterone and oestrogen cause different secondary changes in the body.
  - Females begin to menstruate, grow breasts and grow pubic and underarm hair, and may experience acne.
  - Males grow hair on the pubic area, on the face, chest and underarms, develop a deep voice and may develop acne.
- The male reproductive organs are: penis, sperm duct (*vas deferens*), testes, scrotum and urethra. Sperm is produced in the testes.
- The female reproductive organs are: vagina, cervix, uterus, oviducts (Fallopian tubes) and the ovaries. Ova are produced in the ovaries.
- Stages in the reproductive cycle include:
  - ovulation
  - copulation
  - fertilisation
  - embryo implants in uterus
  - results in pregnancy
  - gestation lasts 40 weeks
  - childbirth.
- Pregnancy can be prevented by using contraceptives. Condoms prevent the sperm from reaching the ovum and also prevent the spread of STDs.
- Pregnant women have various options if they do not want to keep their babies. Very early in the pregnancy they can undergo an abortion. They may also give the baby up for adoption.

Concept map

This concept map shows all that we have learned about reproduction in humans. Write the words to complete the blank spaces your exercise books. You may find this quite tricky, but you need to learn to 'read' a concept map by constructing sentences. For example, 'Human reproduction can take place once sexual organs are mature. They mature during puberty which is initiated by __________. The ____________ releases hormones which stimulate the ovaries and testes.'

What is this gland which initiates puberty and releases hormones, and which hormones do the ovaries and testes release?



Revision

1. Explain the changes that occur to the male and female body during puberty. [10]
2. Describe the hormonal control of the start of puberty. Name the organs involved and the hormones. [5]
3. At what stage of the reproductive cycle can one say that a woman is pregnant? [1]
4. There is an urban legend or myth that says that a girl cannot fall pregnant the first time she has sexual intercourse. Think carefully about everything you have learnt about conception and fertilisation, and discuss whether this myth is true or false. [2]
5. Explain why you think it is important for someone who considers becoming sexually active to know how reproduction occurs in humans. [1]
6. Imagine someone who has many sexual partners asks you for advice on which contraceptive to use. What advice would you give them? [3]
7. Some people have religious reasons for not using contraceptives. Decide whether you agree with them or not and why. Write a short letter to the editor of local newspaper expressing your concerns about contraceptives from this specific point of view. [6]
8. Do you think schools should teach learners about different contraceptives? Why do you say so? [3]
9. During pregnancy the pregnant mother needs to take care of herself in order to provide a healthy and safe environment for the unborn child. Your local clinic has asked you to produce a brochure that they can display in their waiting room for first-time mothers. Write a detailed list of instructions for a pregnant woman explaining what she needs to do to keep herself and her unborn baby healthy. You can chose how you want to do this - perhaps a list of 'Do's' and 'Dont's', or else provide some headings under which you can list some instructions such as 'Diet', 'Lifestyle', and so on. [6]

Total [37 marks]

4 Circulatory and respiratory systems

Key questions

- Why do we have to breathe?
- Are our lungs like big balloons in our chest, or what do they look like?
- How does the oxygen in the air that we breathe in pass from our lungs into our blood?
- How does blood move around our bodies and get to each cell to deliver oxygen?
- We know that carbon dioxide is produced as a waste product in cellular respiration, so how is it removed from our bodies?
- How are the circulatory and respiratory systems linked?

If we do not get oxygen for a few minutes, humans get permanent brain damage and may die. Cell respiration needs a constant oxygen supply to provide us with enough energy, so we constantly need to breath and keep blood circulation going to deliver this oxygen and remove the carbon dioxide. The respiratory and circulatory systems need to work together. Let's briefly revise the main components involved.

ACTIVITY Main components in the circulatory and respiratory systems

Instructions

1. Study the diagrams below.
2. In your exercise books, write down the different components that form part of the respiratory and circulatory system.

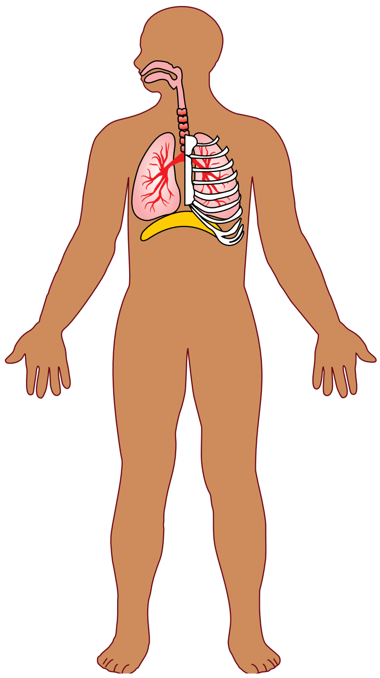


Figure 4.1: The respiratory system.

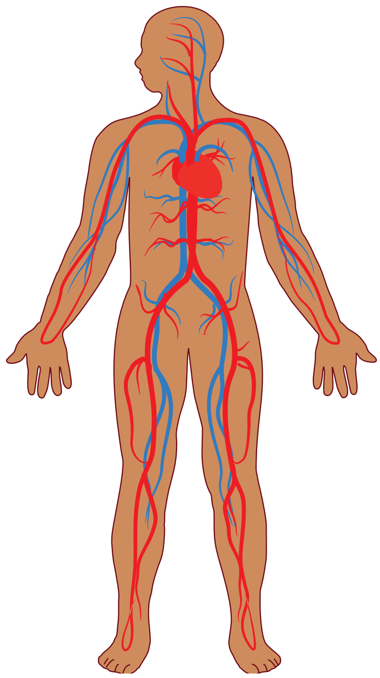


Figure 4.2: The circulatory system.

We will now look at these two systems under the following processes:

- breathing
- gaseous exchange
- circulation and respiration.

4.1 Breathing

We already learnt in Unit 2 that breathing consists of:

1. inhalation
2. exhalation.

When we inhale we take in air with a high concentration of oxygen and when we exhale we breathe out air that has more carbon dioxide in it. These processes take place in a continuous cycle.

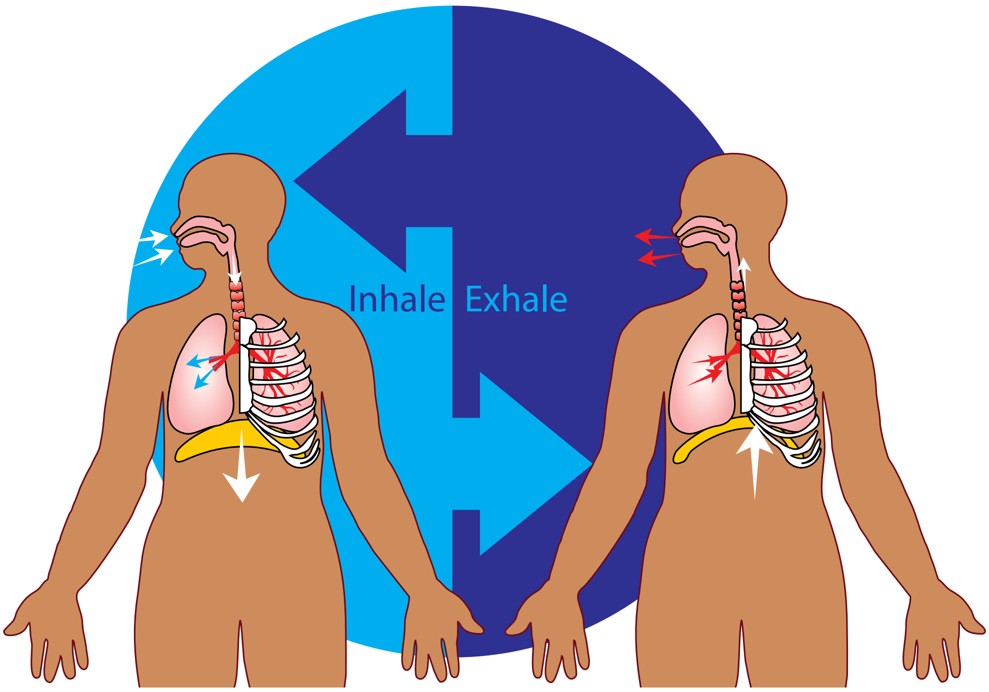


Figure 4.3: Breathing.

During **inhalation** the following takes place:

- The rib cage moves upwards and outwards.
- The diaphragm contracts and flattens causing it to move downwards.
- This causes the chest volume to increase and the pressure decreases.
- As a result the lungs are also forced to become bigger.
- This allows the air to be drawn into the extra space inside the lungs.

During **exhalation** the following takes place:

- The rib cage moves downwards and inwards.
- The diaphragm also relaxes, causing it to become more dome-shaped.
- This causes the chest volume to decrease and the pressure increases.
- As a result the lungs are squeezed smaller.
- This forces the air out of the lungs.

Keywords

- blood
- blood vessels
- bronchi
- bronchioles
- diaphragm
- diffuse
- exhale
- heart
- heart chamber
- inhale
- lungs
- pharynx
- pulse
- respiration
- trachea

Take note

The two tubes that branch from the trachea are called bronchi (plural) or a bronchus (singular).

ACTIVITY Summarise breathing using a flow chart

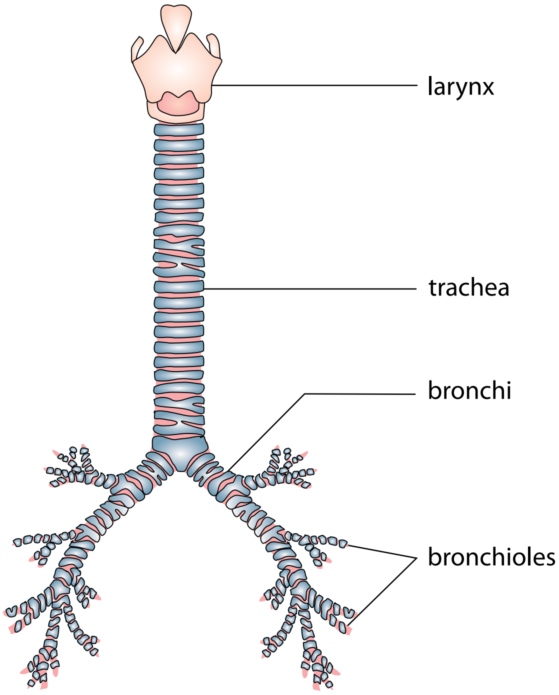


Figure 4.4: This image shows how the larynx joins the trachea, which branches into the bronchi within the lungs.

A flow chart allows us to write short summaries of processes that take place.

When you study for a test or exam you can picture the flow chart in your head, which often helps to trigger memories of what you learnt.

Use a flow chart to show how breathing (inhalation and exhalation) takes place.

You may choose your own design for the flow chart but it needs to show that inhalation and exhalation occur in a cycle.

During inhalation, air travels to the two bronchi – tubes that lead to each lung.

The bronchi are themselves branched (divided) into thousands of tiny bronchioles. During exhalation, the reverse takes place as air leaves the lungs and body.

What happens to the air within the lungs?

Keywords

- alveoli
- capillaries
- cartilage
- diffusion
- haemoglobin
- red blood cells

4.2 Gaseous exchange in the lungs

Gaseous exchange takes place in the lungs and in the cells of the body. The structure of the lung is adapted to fulfil the function of gaseous exchange.

Structure of the lung

Although the lungs inflate during inhalation and deflate during exhalation, they are not hollow. The lungs in a healthy individual are soft, pink and *spongy*.

Take note

The colours of the different bronchioles in the diagram indicate air travelling to different parts of the lungs.

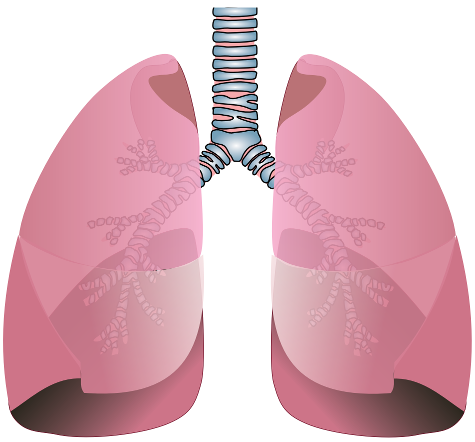


Figure 4.5: External structure of the lungs

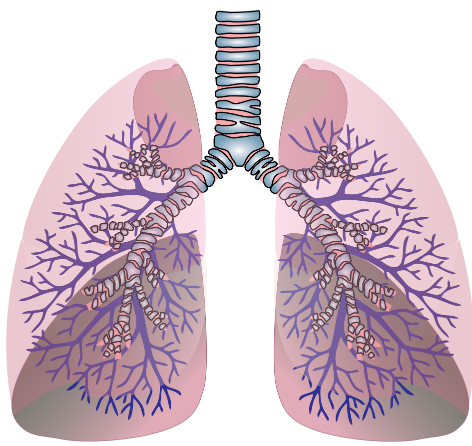


Figure 4.6: Internal structure of the lungs

The alveoli look like small grape-like structures made up of many individual air sacs. A big network of capillaries surrounds each alveolus. Have a look at the following image showing this.

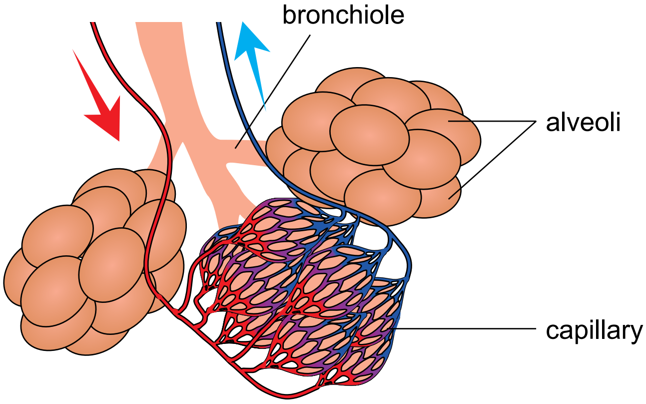


Figure 4.7: Alveoli and surrounding capillaries

An alveolus is one air sac but a group together (plural) is called alveoli.

ACTIVITY Lung dissection

If you are not able to do this in class, you can watch some of the videos showing a lung dissection.

Materials

- lung
- tray
- scalpel
- dissecting scissors
- rubber tubing (for example the Bunsen burner tubing) or hose pipe
- ruler
- beaker of water
- water and soap for washing hands
- disinfectant

Health and safety tips

1. The lungs may carry some bacteria. It is not necessary to wear gloves, as we do not wear gloves when preparing meat in a kitchen, but you must wash your hands thoroughly.
2. Clean all equipment and your work surface with disinfectant after the dissection.
3. Be careful when handling sharp equipment, such as the scalpel.
4. Decide how you are going to dispose of the lungs.

Instructions

Part 1: Preparation

1. Place the lung on the tray on your workbench.
2. Make sure all your dissecting instruments have been disinfected and are sharp. Lay them out next to your tray.
3. Make sure you have access to a first aid kit if necessary.

Part 2: External structure

1. Take note of the external structure of the lung. Look at the general shape, colour and texture.
2. If you have access to a scale, measure the mass of the lung.
3. Use your ruler to measure the length of the lung.
4. Identify the following parts of the lung.
   a) The **trachea** (windpipe) which is the main tube bringing air into and out of the lungs
   b) The **hard rings** in the trachea. What do you think these rings are for?
5. The **bronchi**. There are two bronchi that branch off from the trachea – one to each lung.
6. See if you can identify the first **bronchioles** branching off from the bronchi.
7. Are there any **blood vessels** visible that are attached to your lung? If so, feel these vessels and describe what you feel.
8. Use the rubber tubing or straw or hosepipe and insert this into the tube leading into the lung. Hold the trachea tightly closed around the pipe. Blow on the end of this tube to see if you can inflate the lung. Do not breathe the air back into your own lungs!

Part 3: Internal structure

1. Using the scalpel and dissecting scissors, cut down into the lung.
2. Observe the inner tissue of the lung and think how you would describe it.

Discuss this with your group.

3. Cut out a piece of the lung tissue and feel for tiny bronchioles (they feel like hard little lumps in the soft lung tissue). Place this piece of lung tissue into a beaker of water. Observe the piece of lung tissue. Does it float or sink?

Questions

1. Write a description of the look, feel and colour of the lung you observed. If you were able to measure the mass, write it down, and include the length of the lung in centimeters.
2. What structures made the trachea stay open, but still able to bend?
3. When you cut the lung open, was it like a hollow balloon or bag, or was it spongy inside? What else did you observe when you cut the lung open and observed the inside?
4. When you placed a piece of the lung tissue into water, why do you think it floated?
5. When you blew air into the lung, what did it look and feel like? Did you have to squeeze the lung to force the air out again?
6. In a human, what is responsible for pushing the air out of the lungs?

The process by which gaseous exchange occurs is called **diffusion**.

How does diffusion work?

The movement of particles from an area where there is a high concentration to where there is an area of low concentration is called **diffusion**.

In the lung, each alveolus is surrounded by a network of capillaries. The two gases which diffuse between the alveoli and the blood in the capillaries are oxygen and carbon dioxide.

- Oxygen diffuses into the cells of the alveolus and then into the blood in capillaries.
- Carbon dioxide diffuses out of the blood and into the cells of the alveoli, then into the air.

ACTIVITY Drawing gaseous exchange in the alveoli

Instructions

1. Draw a diagram to show alveoli surrounded by a capillary.
2. On this diagram, name the gases and indicate the direction in which the gases diffuse.
3. Indicate whether the blood is oxygenated or deoxygenated in the capillaries that travel towards and away from the alveolus.
4. Give your diagram a heading.

4.3 Circulation and respiration

Blood is continually circulated to support cell respiration. Let's have a look at how this takes place.

Blood circulation from the lungs to the heart

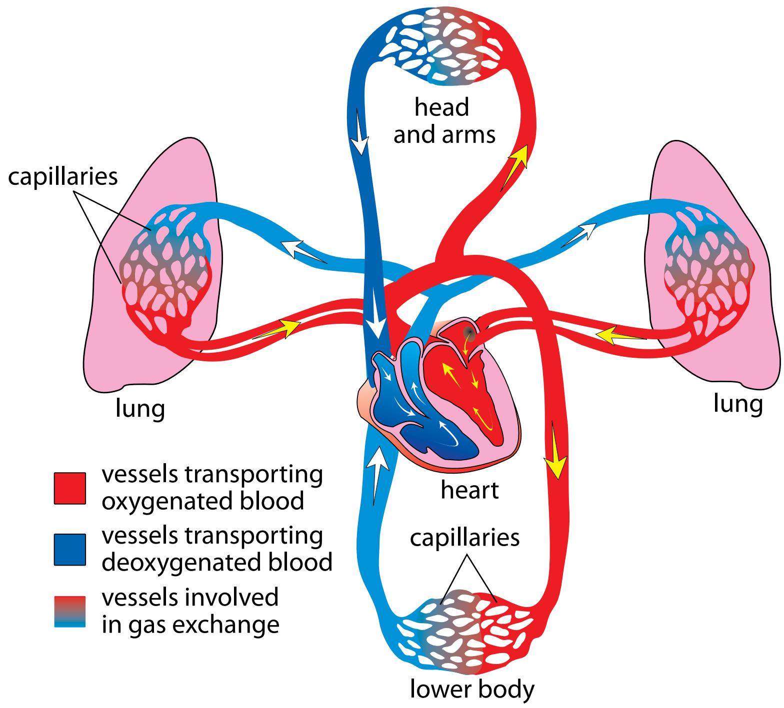


Figure 4.8: Blood circulation from the heart to the lungs

Keywords

- arteries
- atrium
- blood pressure
- veins
- ventricles

The heart pumps the blood around your body by rhythmic, repeated contractions. This is felt as your **heartbeat**.

The oxygenated blood flows from the lungs to the left side of the heart.

The left side then contracts to pump the blood out of the heart and into the aorta. The aorta is the main artery leaving the heart.

Have a look at the diagram on the previous page, which shows how the blood flows from the lungs to the heart and then to the rest of the body.

Let's take a closer look at the structure of this vital organ in the circulatory system.

ACTIVITY Heart dissection

Materials

- heart (sheep or pig)
- tray
- scalpel
- dissecting scissors
- rubber tubing (for example the Bunsen burner tubing) or straw
- ruler
- beaker of water
- water and soap for washing hands
- disinfectant

Figure 4.9: The heart of a sheep.

Health and safety tips

As with the lung dissection, the same health and safety tips apply to the heart dissection.

Instructions

Part 1: Preparation

1. Place the heart on the tray on your workbench.
2. Make sure all your dissecting instruments have been disinfected and are sharp. Lay them out next to your tray.
3. Make sure you have access to a first aid kit if necessary.

Part 2: External structure

1. Take note of the external structure of the heart. Look at the general shape, colour and texture.
2. If you have access to a scale, measure the mass of the heart.
3. Use your ruler to measure the length of the heart.
4. Identify the following parts of the heart:
   a) There are blood vessels entering and leaving the heart (**arteries and veins**). Arteries have much thicker, more rubbery walls than veins which have thin walls. See if you can identify the difference.

b) Place your fingers inside the blood vessels to feel their texture and strength. Look inside the main arteries and veins as well and describe to your group what you see. Push one finger down the aorta and see if you can feel any structures. The photo on the right shows the aorta opening.

5. Examine the **surface** of the heart for blood vessels. Why do you think the surface of the heart also has blood vessels attached to it?
6. Locate the **atria** and **ventricles**.
7. Locate which is the right- and which is the left-hand side of the heart.

Part 3: Internal structure

1. We are now going to cut into the heart to view the internal structure. Use the following diagrams to help you orientate the heart before cutting.
2. Make a cut down the aorta and then through the left ventricle to the tip of the heart. A tip is to cut through the aorta first using scissors, and then to cut through the left ventricle using the scalpel.
3. Once you have made the cut, pull the ventricle walls apart so that you can view the inside. Can you see the structures at the base of the aorta that you felt in Part 1 (step b)? What do you think these structures do?
4. Look at the following diagram, and make the second cut upwards into the left atrium.
5. Using your ruler, measure the thickness of the left atrium wall and the left ventricle wall. Write these measurements down.
6. You can now cut open the right side of the heart in the same way. Measure the thickness of the right ventricle wall. The

Figure 4.10: Can you see the large opening of the aorta?

Figure 4.11: Take note of the surface of the heart and the blood vessels attached to it.

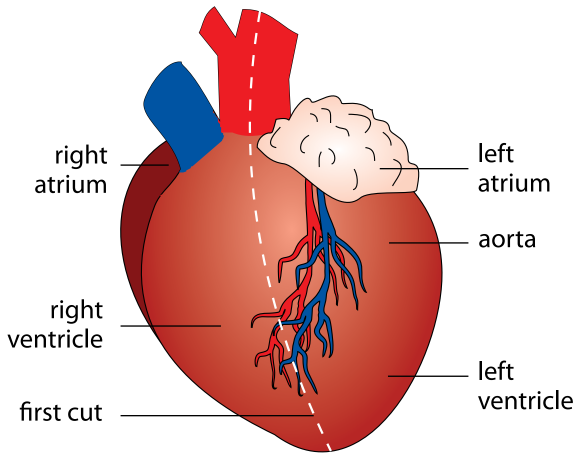


Figure 4.12: Structure of the heart.

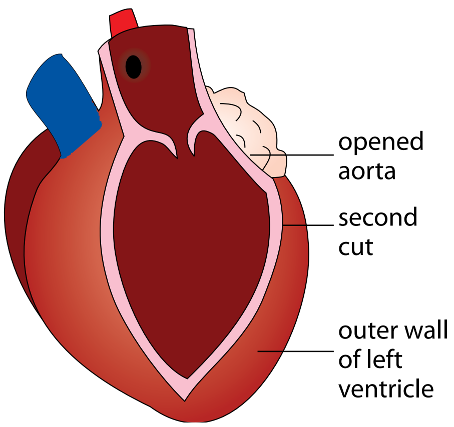


Figure 4.13: The heart showing the cuts.

Did you know?

The average human heart, beating at 72 beats per minute, will beat approximately 2,5 billion times during an average 66 year lifespan.

Take note

Remember that arteries carry blood AWAY FROM the heart and veins carry blood TOWARDS the heart.

following diagram provides a detailed overview of the internal structure of the heart. We have not discussed all of these structures and you are not required to know all of these. However, for this dissection, use this diagram to see how many of these parts you can identify in your dissected heart. If you are able to locate them in the actual heart, draw a ring around the label in the following diagram.

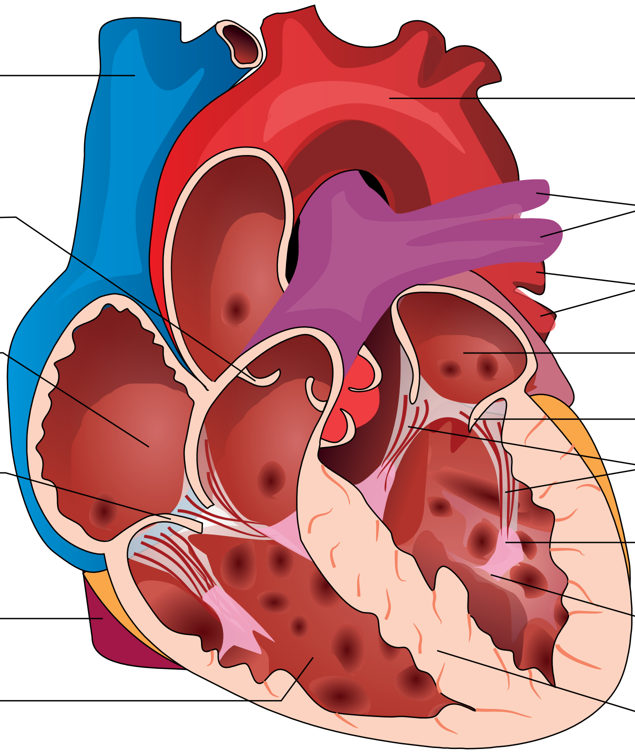


Figure 4.14: Diagram of the internal structure of the heart.

Questions:

1. Write a description of the look, feel and colour of the heart you have observed. If you were able to measure the mass, write this down, and include the length of the heart in centimetres.
2. Write down the thickness that you measured for the left ventricle and atrium walls. Why do you think there is a difference in the thickness of these walls? Hint: Think back to where the atria have to pump the blood and to where the ventricles have to pump blood.
3. Write down the thickness that you measured for the right ventricle wall. Mention possible reasons for the difference in thickness between the left and right ventricle walls. Once again, think about the area to which each ventricle is pumping blood.

Once the blood is pumped out of the heart, it enters the circulatory system in the body.

Blood circulation from the heart to the rest of the body

Once blood leaves the heart in the aorta, this main artery branches into smaller arteries which form a network throughout the body.

ACTIVITY Feel your blood rushing through your body!

Instructions

1. Put your index (pointer) and middle fingers against your neck in the hollow between your trachea (windpipe) and the large neck muscles. Use your finger tips as these are more sensitive. You should feel the throbbing of your blood.
2. Can you find your pulse in your wrist?
   Place your middle and index fingers just below the creases in the skin of your wrist - on the side of your thumb.
   Press lightly until you feel the pulse which means the blood is pushing under your skin.
3. You can also try and find your pulse behind your knee, on the inside of your elbow or near the ankle joint.
4. Each throb of your pulse is when your heart pumps the blood from the left side of your heart into the arteries of your body, causing the pressure in the arteries to rise.

Figure 4.15: Measuring heart rate in the wrist.

Questions

1. Count how many times your heart beats in one minute. Alternatively, count your heart beats for 30 seconds while a friend or your teacher times you, and write the number in your exercise books.
2. Now, calculate your heart rate in beats per minute and write your answer in your exercise books.

Take note

A rate always measures something over time. In this activity we are calculating heart rate as beats per minute, as this is the standard measurement used for heart rate. Can you think of some other units of measurement which indicate a rate?

Arteries subdivide to form capillaries. Capillaries are in close contact with the body cells. Capillaries are much smaller than arteries. They form a fine network throughout the body's cells to make sure that all cells get a supply of blood and oxygen. The capillaries leaving the cells with deoxygenated blood then combine to form veins. Veins from the body carry deoxygenated blood back to the heart.

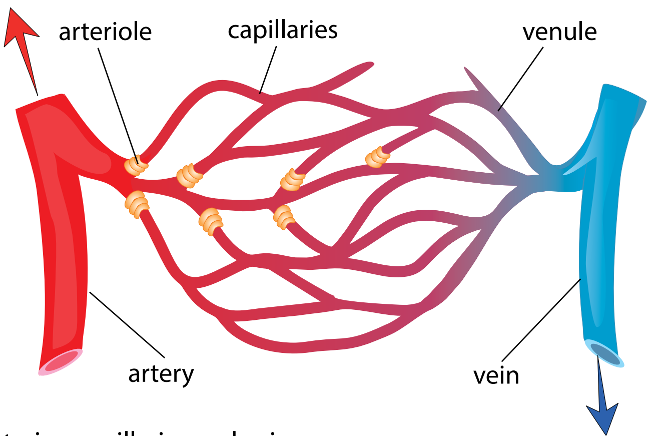


Figure 4.16: Arteries, capillaries and veins

Take note

An exception to the rule of arteries carrying oxygenated blood are the pulmonary arteries, which carry deoxygenated blood away from the heart to the lungs to become oxygenated.

Arteries

- Arteries transport blood **away** from the heart.
- Arteries transport oxygenated blood (except for the pulmonary arteries).
- Arteries need to have strong muscular walls because they carry blood away from the heart under high pressure.

Veins

- Veins transport blood **towards** the heart.
- Veins transport deoxygenated blood (except for the pulmonary veins).
- The blood is flowing back to the heart and therefore the blood pressure in the veins is much lower.

Did you know?

If you put TEN capillaries next to each other, together they would be as thick as only ONE human hair!

Capillaries

- Capillaries form webs or networks around each cell to ensure that all cells receive nutrients and oxygen.
- Capillaries are much smaller than veins and arteries.

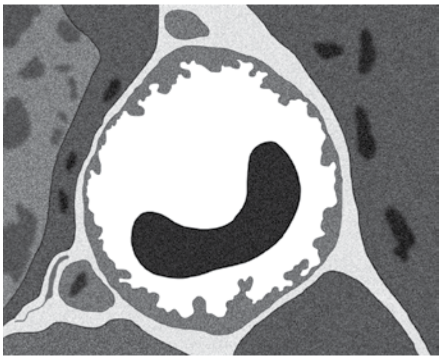
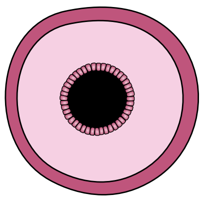
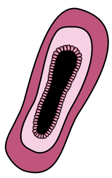
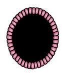


Figure 4.17: This transmission electron micrograph shows a cross-section through a capillary. The semi-circular black structure within the capillary is a red blood cell. This shows how small capillaries are. They are only just wider than a red blood cell.

ACTIVITY Tabulating differences between the blood vessels

Instructions

1. Compare arteries, veins and capillaries.
2. Use the following table in which to do this comparison.

Blood vessel type	Artery	Vein	Capillary
Image			
Function			
Type of blood			
Exceptions			

Respiration within the cells

Within the cells, the mitochondria use oxygen to respire. This is called cellular respiration.

- The mitochondria combine oxygen with food particles, such as glucose.
- Energy from the food particles is released and can be used by the cell to perform various processes.
- During cellular respiration, carbon dioxide is released as a by-product.

The carbon dioxide diffuses from the cells back into the blood in the capillaries.

This blood therefore becomes deoxygenated as oxygen has been removed and carbon dioxide is added.

Blood circulation from the body back to the heart and lungs

The deoxygenated blood in the body then returns to the right side of the heart through the veins in the circulatory system.

The right side of the heart pumps the deoxygenated blood to the lungs through the pulmonary arteries.

ACTIVITY A circulation simulation!

We are going to create a simulation of our circulation!

Instructions

1. Imagine that you are a red blood cell and you will be carrying oxygen around the body.
2. Your teacher will help your class to lay out the huge body in your exercise books using A4 sheets with labels and hula hoops as in the diagram.
3. There are two colours of paper blocks at each organ or body part and in the lungs. One colour (preferably red) will represent oxygen and the other colour (preferably blue) will represent carbon dioxide.
4. Start off by standing in the lungs and pick up oxygen. You now represent oxygenated blood.
5. Walk to the left side of the heart.
6. The heart now pumps you out to the body in the circulatory system. Leave the left heart hula hoop and walk to the organ or body part you are going to supply with oxygen.
7. When you reach the body part, drop off your oxygen block into the container and now pick up a coloured block representing carbon dioxide. You now represent deoxygenated blood.
8. Walk to the right side of the heart.
9. From here, the heart pumps you to the lungs. Walk to the lungs.

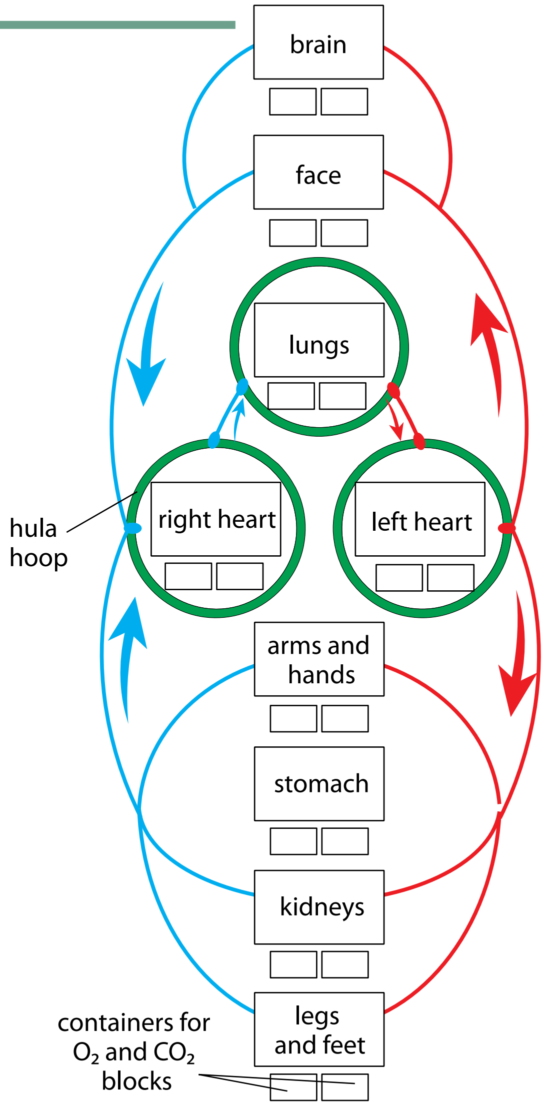


Figure 4.18: A circulation simulation

10. At the lungs, gaseous exchange takes place. Drop off the carbon dioxide you were carrying and pick up oxygen again.
11. You can now repeat the cycle and walk to a different body part.

Heart rate

Your resting heart rate is often used as an indicator of how fit you are or whether there are possible health concerns that you should pay attention to.

ACTIVITY Homework activity to measure your resting heart rate

Instructions

1. Take your resting heart rate first thing when you wake up in the morning. Record how many times per minute your heart beats.
2. Repeat this over 3 days to get an average – this is more reliable than a once-off reading.
3. Copy the table into your exercise books, then record your resting heart rates.

	Heart rate (beats per minute)
Day 1	
Day 2	
Day 3	
Average	

We have now had a look at our heart rate when we are resting. But what happens when we do some kind of physical activity? Will your heart rate increase or decrease? Do you think you could use your heart rate as a measure of how fit you are? Let's investigate!

Investigation Measuring and comparing heart rates before and after exercise

Instructions

Measure the heart rate of at least 10 learners in your class after they have done 2 minutes of skipping or running on the spot. Discuss in your group how you are going to do this and write down your method. Record your measurements and use a graph to display your findings. Make deductions about your class' fitness levels based on their heart rates after completing the graphs and discuss the benefits of exercise for the circulatory and respiratory system (also known as the cardiovascular system).

Aim

What is the aim of your investigation?

Hypothesis

What is your hypothesis for your investigation?

Variables

In any scientific investigation, it is crucial to identify the variables at the start.

- When you do an investigation you are going to change or vary one factor to answer your question. This is called the **independent variable**.
- The factor that you are measuring or observing is the **dependent variable**.
- Normally, you will have a third variable, the **control variable**. These are the factors that you want to keep the same (unvaried) during your test so they cannot affect your results.

What are the variables involved in this investigation?

Materials

Write a list of the materials you will need for this investigation.

Possible materials to be listed are:

- stopwatch
- skipping rope (if learners are to skip, otherwise they may just run on the spot)
- recording sheet and pen.

Method

Write down the method in your exercise books. The steps must be numbered.

Results

1. Design a table that will record the heart rate of the 10 learners when at rest and after 2 minutes of physical activity (skipping or jogging on the spot).
2. Remember to give your table a heading.

Analysis

In order to analyse your results, it is helpful to plot a graph, as this helps you to see the relationship between the dependent and independent variables and to make comparisons. Below is a description of different types of graphs and when they are used.

- **Line graph:** A line graph is used if the data you have is numerical and changes continuously, often over time. A line graph is useful for visualising a trend in the data over time.
- **Bar graph:** A bar graph is used to compare different categories or groups, normally when the categories are words. There are spaces between the bars in a bar graph.
  A *double* bar graph can compare two sets of data. In a double bar graph, two of the bars touch and are shown in different colours, and are separated by a space from the next two bars.

- **Histogram**: A histogram is used when the data for the independent variable is numerical and can be grouped into categories which are continuous. The bars in a histogram touch each other.
- **Pie graphs:** Pie graphs (or sector diagrams) are used to show the relative proportions or percentages of the categories when they make up a whole.

1. Which type of graph will you use to represent the data in this investigation? Give a reason for your answer.
2. How will you differentiate on your graph between the two sets of measurements for each learner (in other words, heart rate before and after exercise)?

Tips for drawing your graph

- Start by giving your graph a title, something that shows which dependent and independent variables you were studying.
- Use the appropriate axes for each variable: x-axis = independent variable (along the bottom of the graph) and y-axis = dependent variable (along the side).
- Label your x-axis and y-axis.
- Use an appropriate scale and use the graph paper that you have been given to draw the graph wisely.

Draw a graph of your results

1. Which learner in your group had the smallest increase in heart rate from before to after physical activity?
2. Which learner in your group had the largest increase in heart rate from before to after physical activity?
3. Rank the learners in your group from the smallest increase to the largest increase.
4. What deductions can you make about the fitness level of the learners in your group based on their heart rates before and after the physical activity? When you make deductions, ask yourself these questions:
   a) What do you see is happening?
   b) What do you notice that is different?
   c) What does this imply?

Discussion and evaluation

An important part of an investigation is to discuss your results and observations and evaluate them. At this point you get to talk about your results and explain them.

You also point out any shortcomings of the investigation. What could you have done to improve the investigation? You can also point out any unexpected results in your investigation and try to explain these using your science background. You should do some background research into the benefits of exercise for the cardiovascular system and write some points in your discussion.

Conclusion

Write a conclusion for your investigation. In a conclusion, you need to refer back to your hypothesis to see whether your results support or reject the hypothesis.

References

If you researched any additional information to support your discussion, you need to reference these sources in the following way:

- **Books:** Surname of author, Name of book, Year published, Name of publisher, Page numbers you used.
- **Internet:** Give the full URL for the website.
- **Person:** Personal communication with 'Name, Surname, Occupation.'

Take note

Simply listing Google or Wikipedia as your source is not recognised as a reference for your discussion.

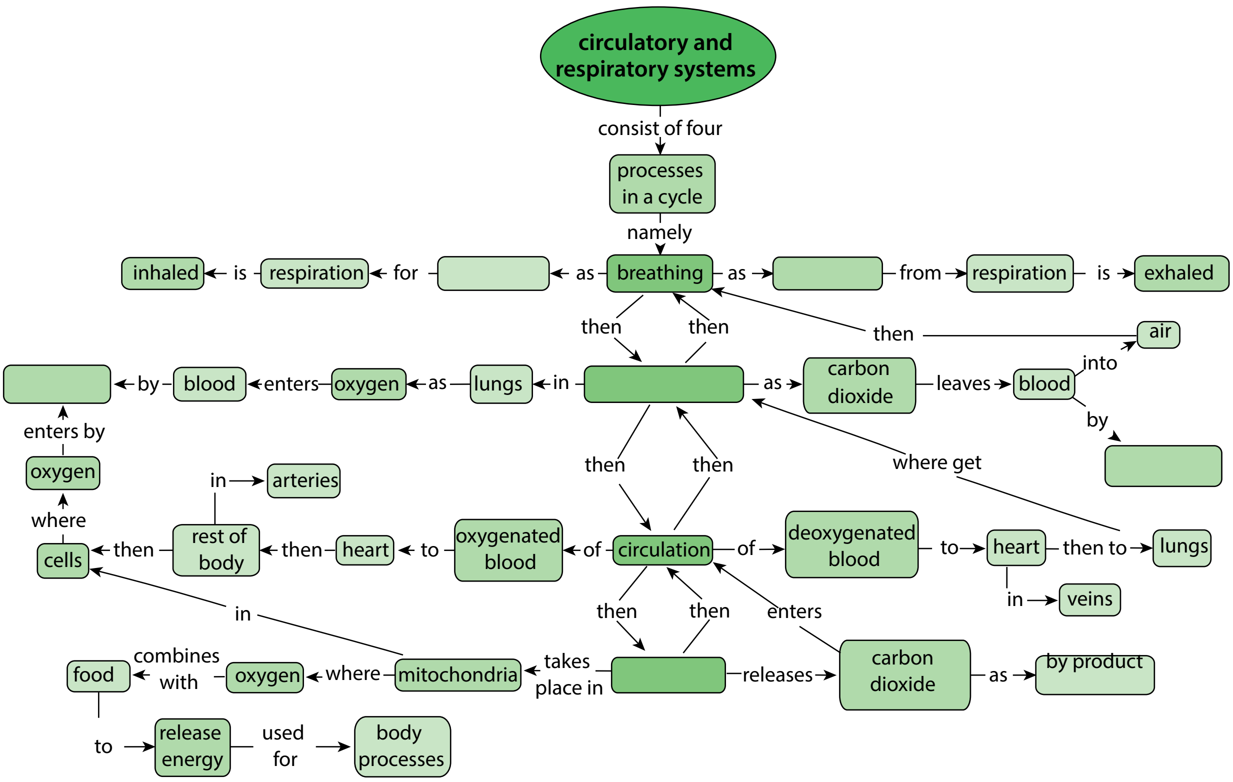
Summary

Key concepts

- During breathing oxygen is inhaled and carbon dioxide is exhaled.
- In the lungs, gaseous exchange occurs by diffusion.
- Oxygenated blood is transported in pulmonary veins from the lungs to the left side of the heart.
- The oxygenated blood is pumped through the aorta and arteries to the different parts of the body.
- Arteries divide into capillary networks between the cells, where oxygen and food diffuse from blood to cells.
- The cells carry out cell respiration, forming carbon dioxide, which diffuses back to the capillaries.
- Capillaries flow into veins that carry the deoxygenated blood to the right side of the heart.
- When the deoxygenated blood reaches the heart, it is transported to the lungs by the pulmonary artery, where gaseous exchange takes place once more.
- The carbon dioxide from cellular respiration diffuses out of the blood into the lungs and is exhaled.

Concept map

From what we have learnt in this unit, we can say that the circulatory and respiratory systems consist of 4 processes which occur in a cycle. Two of these processes are named in the concept map. Write the other two in your exercise books. During breathing, what is the gas which is inhaled for respiration, and which is the gas which is exhaled during respiration? Fill these in too. What is the name for the process by which these gases move across the cell membranes?



Revision

1. Draw a flow diagram to show how the different components of the respiratory and circulatory systems function in a cycle. [6]

2. Complete these sentences. Write just the word in your exercise books. [13]
   a) Oxygen diffuses into the blood from the air in the _______________
   b) The blood vessels that carry blood away from the heart are called _______________
   c) Tiny blood vessels called _______________come into close contact with _______________
   d) Carbon dioxide _______________ out of the cells into the _______________
   e) _______________ carry the _______________ blood to the heart from where it is sent to the _______________to be oxygenated.
   f) The chemical reaction that takes place in the _______________ of the cell when oxygen and glucose combine to release _______________ is called _______________

3. Copy and complete the table in your exercise books to describe what happens in the chest during breathing. [6]

	Inhaling	Exhaling
Chest volume		
Pressure on lungs		
Air movement		

4. Copy the table in your exercise books and match the word on the left to its correct meaning on the right. Write only the letter next to the word to indicate the correct meaning. Use each letter only once. [13]

Breathing	a	arteries, veins and capillaries
Diaphragm	b	the type of tissue that keeps the trachea open
Alveoli	c	small grape-like bunches at the ends of the bronchiole
Trachea	d	the movement of particles through a permeable membrane from a high to a low concentration
Heart	e	the tube that carries air to and from the mouth to the bronchi
Veins	f	blood vessels that transport blood away from the heart
Respiration	h	blood vessels that carry blood towards the heart
Cartilage	i	tubes leading from the trachea into the lungs
Bronchi	j	the process takes place in mitochondria to release energy for the cell to use
Capillaries	k	the organ responsible for pumping blood throughout the body
Types of blood vessels	l	inhaling and exhaling
Diffusion	m	these blood vessels surround alveoli to allow for gaseous exchange
Arteries	n	a large dome-shaped muscle across the bottom of the ribcage

5. The following image is an artist's drawing of one of the structures you learnt about in this unit. What does it represent? Give three reasons for your answer. [3]

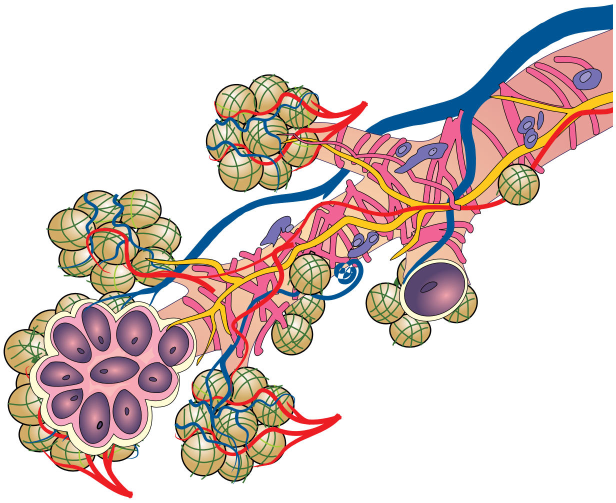


Figure 4.19

6. Describe how capillaries are suited to their function of allowing gaseous exchange within the lungs and at the cellular level in the body. [3]

Total [44 marks]

5 Digestive system

Key questions

- Why do we need to follow a healthy diet? What does a healthy diet consist of?
- What makes one type of food healthy and another type of food unhealthy?
- Is it possible to prevent things like diarrhoea or constipation? What about ulcers?
- Why do we need to digest food?
- How is food digested in our bodies?
- Where does the digested food go?

In this unit we are going to look more closely at the food we eat to see why certain foods are considered healthy and others unhealthy. We will then investigate how the food from our plates gets to our cells and why our digestive system is so well adapted for its job.

5.1 A healthy diet

Our human bodies are very active. Our bodies need a huge variety of different nutrients and substances in order to perform all these processes. We obtain these nutrients from the food we eat. The human body needs a balanced, healthy diet to keep functioning property.

ACTIVITY Comparing healthy and unhealthy foods

Instructions

1. Work with a partner.
2. We often know if a food is healthy or unhealthy. Make a list of at least 10 healthy and 10 unhealthy foods in your exercise books.

When you are done share your food list with the class and record the class's ideas of healthy and unhealthy foods on a large sheet of paper or on the board.

Display this in the class.

Study the list of healthy and unhealthy food.

1. What common characteristics can you identify in the food that the class listed as healthy?
2. What common characteristics can you identify in the food that the class listed as unhealthy?

Let's take a closer look at what makes up a healthy diet.

Keywords

- balanced diet
- carbohydrates
- dehydration
- diet
- enzymes
- fats
- fibre
- glucose
- iodine solution
- minerals
- nutrients
- protein
- starch
- sugars
- vitamins

The seven components of a healthy diet

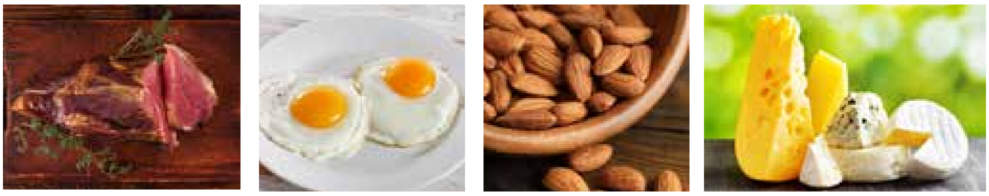
The foods that we eat can be divided into different groups:

- proteins
- carbohydrates
- fats and oils
- vitamins
- minerals
- fibre (non-digestible carbohydrates)
- water.

A healthy diet consists of foods from all of these groups.

Proteins

Proteins are our bodies' building blocks. They build and repair body cells and tissues. Foods rich in protein are: fish, meat, poultry, eggs, cheese and other food from animal sources. There are also many sources of protein from plants, for example, products made from soya beans, peas and beans, nuts and seeds.



Meat Eggs Almond nuts Cheese

Figure 5.1: Example of proteins

Carbohydrates

Carbohydrates are the main supply of energy for our bodies. They break down in our digestive system to form glucose (which is a sugar). Examples of foods that contain carbohydrates are: wholegrain bread, potatoes, pasta, rice, fruit, vegetables, maize and legumes.

Whole wheat bread Potatoes Rice Mealies (corn)

Figure 5.2: Example of carbohydrates

Unfortunately, many people eat too many carbohydrates, especially processed carbohydrates like sweets and biscuits, chips, pastries, soft drinks, and sweetened fruit juices.

Take note

Often, fruit juice is not the healthiest choice of drink as some fruit juices contain the same amount of sugar or more than the average soft drink. The best choice is water!

Fats and oils

Fats and oils are important for many body processes:

- Fat protects and insulates your organs
- They help maintain healthy hair and nails.
- Some vitamins can be absorbed and transported only when attached to fat molecules.
- Fats and oils also provide the body with energy.

However, some fats are better than others, and having too much of any type is not a good idea.

Figure 5.3: Olive oil and canola oil are both healthy oils.

Figure 5.4: Sardines are high in healthy fats.

Vitamins

Figure 5.5: Our sources of vitamins are fruit and vegetables.

Vitamins help with the different chemical reactions in our bodies:

- **Vitamin A** helps strengthen our immune system and is good for eyesight in the dark.
- **B vitamins** help us process energy from food.
- **Vitamin C** helps to keep your skin and gums healthy and improves the immune system.
- **Vitamin D** helps to build strong bones and teeth.

Our main sources of vitamins are from fruit and vegetables, as shown in the diagram alongside.

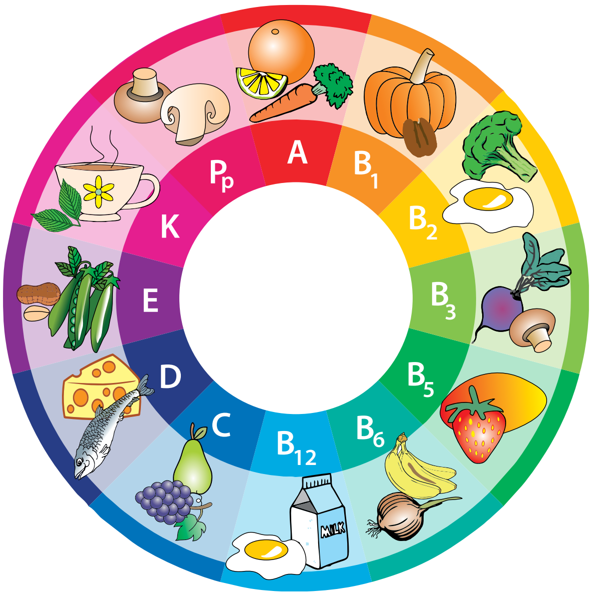


Figure 5.6: Food sources of different vitamins.

Minerals

Our bodies cannot produce minerals and we therefore need to include these in our diets. Some of the minerals we should include in our diets are:

- **calcium**, which is essential for strong bones and teeth
- **iron**, which is needed for healthy blood
- **magnesium**, which is used for building strong bones, teeth and muscles
- **sodium**, which is also needed for muscle and nerve function, and more importantly, it helps regulate the amount of water in the blood.

Take note

Many people take large amounts of supplements to ensure they get enough vitamins and minerals. However, it is rather wasteful, as the body excretes any excess vitamins and minerals and stores only a few vitamins such as Vitamins A, D, E and K.

There are a variety of sources of minerals. For example, high levels of calcium are found in dairy products, meat is a high source of iron, and magnesium is found in lots of foods such as bananas, nuts, green leafy vegetables and milk.

The most common source of sodium is in sodium chloride, which is table salt.

Fibre

Fibre found in the skins of fruit and vegetables, and in wholegrain cereals, cannot be digested. It therefore travels through the alimentary canal. We need fibre in our diet as it helps us to have regular bowel movements and avoid constipation.

Beans are a good source of fibre.

High-fibre breakfast cereal.

Figure 5.7: Examples of sources of fibre.

Figure 5.8: You need to drink water daily.

Water

Our bodies are made up of more than 50 percent water. Water is necessary to help our blood carry nutrients and waste around the body and to help the chemical reactions that occur in our cells. Water forms most of sweat, saliva and tears.

ACTIVITY Comparing meals

Instructions

1. Below are photographs of different meals for breakfast, lunch and dinner.
2. One of the meals is healthier than the other.
3. Choose the healthier option and explain why. Write the answers in your exercise books.
   a) Breakfast:

Option 1: Fruit loops	Option 2: Fruit salad
	

b) Lunch:

Option 1: Hamburger	Option 2: Omelette with salad
	

c) Supper:

Option 1: Chicken pieces	Option 2: Beef, peas and rice
	

Different cultures and religions follow different diets. Some cultures will eat only certain types of food and will avoid other combinations. Some religions may restrict their followers to only certain foods, while others have no real dietary laws. Within South Africa, we have a very diverse population with people from many cultures, backgrounds and religions. This makes our country a truly unique, diverse and interesting place in which to live!

Testing food

There are various chemical tests which are used to easily identify the type of food molecules present in different foods.

One such test is the **starch test**. We can also test for the presences of fats and oils using the **emulsion test**.

Keywords

- emulsion

Investigation: Which foods contain starch or fats and oils?

In this investigation you will have to design the investigation and then write up your findings in an experimental report.

Materials

- various food items to test for starch: for example, pieces of bread, apple, tomato, boiled egg, cheese, cucumber, potato, yoghurt, ham (some substances must contain starch and some not)
- various food items to test for fats and oil: for example, the above food items can be used, and in addition, you could also provide peanut butter and butter
- petri dish per group or learner for the starch test
- bottle of iodine solution and dropper

Take note

Precaution
If you are allergic to iodine, rather observe this experiment and do not participate.

Take note

You may recall doing the starch test on plants in lower grades to see which leaves store starch from the glucose produced in photosynthesis.

Take note

If you are allergic to iodine, rather observe this experiment and do not participate.

- several test tubes for the fat emulsion test
- water
- glass rod (or any other suitable hard, round item) for crushing food substances for the fat emulsion test
- bottle of ethanol
- forceps

Instructions

1. Conduct an investigation to test whether the food substances you have been provided with contain starch or fats and oils or both.
2. A summary of each test is given below. You will need to design your investigation and conduct it.
3. Before starting, think about how you will record your results and write out your proposed method.

Starch iodine test

Iodine solution is an orange-brown colour. When iodine is added to a substance which has starch in it, the iodine reacts with the starch to produce a blue-black colour. The blue-black colour indicates the presence of starch.

Fat emulsion test

To conduct the test, crush a piece of the food (or liquid) in a small amount of ethanol. Pour some of the mixture onto paper. Once the ethanol has evaporated, oil stains on the paper will indicate the presence of fats or oils in the food.

Aim

What is the aim of your investigation?

Hypothesis

What is your hypothesis for this investigation?

Materials and apparatus

List the materials and apparatus you used in this investigation.

Method

Write down the method which you followed in this investigation.

Results and observations

Record your results and observations from this investigation in your exercise books.

Discussion

Discuss and evaluate your results and findings and the importance of food tests.

Conclusion

What do you conclude from this investigation?

Health problems relating to diet

In Unit 2 this term, we looked at some of the health issues relating to the digestive system, such as ulcers, diarrhoea and eating disorders. There are also health issues which arise directly from your diet. The following activity will introduce you to some of these health concerns.

ACTIVITY How does your diet affect your health in the short and long term?

Instructions

Use any available resource and research about the listed malnutrition

1. Below is a table with descriptions of several health issues relating to a poor diet.
2. You need to read the descriptions and use your knowledge of the food groups to classify what the diet of the person is deficient in, or what they have a surplus of in their diet.
3. For some conditions, there may be a variety of causes, but this activity is focusing on the causes related to diet.

Name of health issue	Description	What does this person have a deficiency or surplus of in their diet?
Osteoporosis	Osteoporosis is a disease, most common in older women, where the bones become fragile and are more likely to break. Usually the bones lose density and become porous.	
Anaemia	Anaemia is a condition of the blood where there are not enough healthy red blood cells. A patient feels tired and weak as the tissues and organs in the body are not able to get enough oxygen so respiration slows down.	
Marasmus	This is a severe form of malnutrition due to starvation. The person becomes extremely thin (emaciated).	
Constipation	A person has constipation when they have a bowel movement less than 3 times per week. The person may have hard stools and difficulty and pain when passing stools.	
Kwashiokoh	Kwashiorkor, also known as "edematous malnutrition" because of its association with edema (fluid retention), is a nutritional disorder most often seen in regions experiencing famine.	

5.2 Digestion and the alimentary canal

Keywords

- digestion
- dissolve
- enzymes
- faeces
- gastric
- peristalsis

What is digestion?

Digestion involves a variety of complex processes that turn the food that you eat into tiny molecules that can then be absorbed and transported to the cells of the body.

There are two types of digestion:

1. **Mechanical digestion** occurs when food is physically broken down – these include chewing, churning and mashing. Mechanical digestion takes place in your mouth and in your stomach.
2. **Chemical digestion** takes place when different digestive **enzymes** break down the bits of food into smaller molecules. Enzymes are special proteins that speed up certain chemical reactions in the body. Chemical digestion starts in the mouth, where enzymes in your saliva start to break down starch. Chemical digestion also takes place in the stomach and small intestine.

The alimentary canal

We already studied the alimentary canal in Unit 2, so we'll start by reviewing what we learnt there.

ACTIVITY The different organs in the digestive system

Instructions

1. Label the following diagram.

Labels to include

- large intestine
- anus
- oesophagus
- rectum
- stomach
- mouth
- small intestine
- liver
- gall bladder
- pancreas

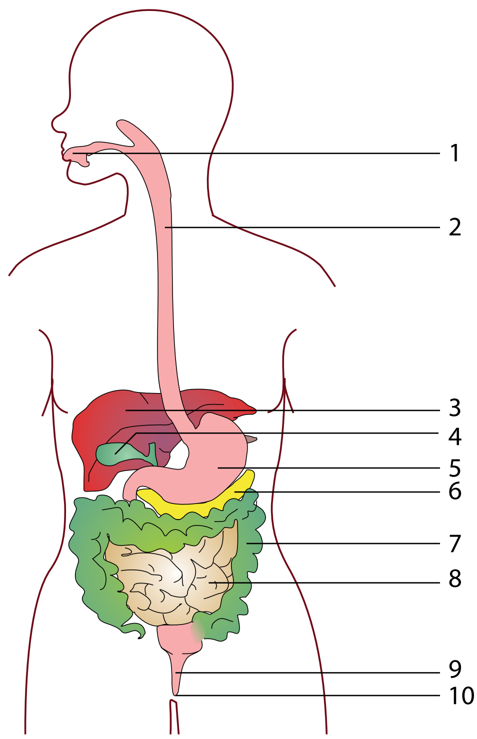


Figure 5.8

2. Let us make a model of the alimentary canal that can demonstrate mechanical and chemical digestion in the different parts. We will also learn about how the different parts are structurally adapted to suit their function.

ACTIVITY A digestion simulation

Materials

Each group will need the following:

- large dish to work over, or black bags and newspaper
- crackers, white bread or viennas
- mixing bowl
- scissors, pestle and potato masher
- water bottle that can squirt water through a small hole
- the inner tube of a kitchen paper towel roll or toilet paper roll
- a clear plastic Ziploc bag
- 30 – 40 ml of lemon juice, vinegar or a fizzy drink
- full-length stocking with the toe section cut open – it helps if one leg is put inside the other to form a double layer
- bicarbonate of soda dissolved in water in syringes (10ml)
- large bowl

Instructions

1. Work in groups and construct a model to demonstrate the different processes that food goes through in the different parts of the alimentary canal.
2. Make careful observations and describe in detail what happens at each stage.
3. Work over a large bowl or tray or sheets of newspaper and a black bag to contain the mess, which may be produced during this activity.

Stage 1 – The mouth

The function of the mouth is to ingest food and to start to digest the food. The mouth is specifically adapted for its function as follows:

- The lips keep the food in the mouth while chewing.
- Food is bitten off with the front teeth.
- Food is cut, torn and mashed into smaller parts by the different teeth in the mouth – this is mechanical digestion.
- The tongue moves the food around the mouth while it is being chewed. It also prepares the food for swallowing.
- Salivary glands secrete saliva. Saliva coats the food in the mouth making it easier to swallow. Saliva also contains enzymes which start to digest chemically.

1. Using the mixing bowl to represent the mouth and the scissors, pestle and potato masher to represent and simulate the digestion of your food type that occurs in the mouth.
2. Squirt some water onto the mixture as you are 'digesting' the food.
3. Describe what is happening to the food at this point.
4. Compare the model to the actual process in your mouth and what each part and action you are performing in the simulation represents.

Did you know?

Dr William Beaumont (1785 – 1853) discovered how food is digested in the stomach. He dropped food, attached to silk threads, into the stomach of a patient who had a gunshot wound in the stomach that would not close, and examined what happened.

Stage 2 – The oesophagus

- The pharynx (the throat) moves food from the mouth to the oesophagus. The oesophagus transports food from the pharynx to the stomach.
- A flap in the pharynx covers the trachea (windpipe) to prevent food from accidentally going into the trachea and causing the person to choke.
- The oesophagus is a muscular tube that moves the food by contracting in sections and relaxing in other sections. This is called peristalsis.
- A special circular muscle shuts the entrance of the stomach. It prevents the contents of the stomach from pushing back into the oesophagus, which may lead to vomiting.

1. Roll the ball of food you created in the mouth down the cardboard tube and into the clear Ziploc bag.
2. Describe what is happening to the food at this point.
3. Compare the model to the actual process in your oesophagus. Can you think of a better way of simulating the action of moving the food from the mouth to the stomach?

Did you know?

Our bodies produce about 1.7 litres of saliva *each day*.

Stage 3 – The stomach

The stomach is specifically adapted for its function as follows:

- The stomach has strong muscles which help churn the food to break it up further. This also mixes the pieces of food with the digestive gastric juices.
- Since the stomach has to store food and liquid, it has many folds and ridges in the wall that help to expand the stomach further.
- The lining of the stomach is replaced to prevent the stomach from digesting itself.
- The stomach secretes gastric juices when food is present. This helps the functioning of the enzymes in the chemical digestion of proteins.
- Cells in the stomach lining are adapted to absorb water.
- The lower end of the stomach has muscles which can control the emptying of the stomach contents.

1. The Ziploc bag represents the stomach. After the food has entered the stomach, pour one of the digestive juices (lemon juice, vinegar or Coca Cola) into the bag over the ball of food.
2. In your body, a special circular muscle closes and seals the stomach and digestive juices from the oesophagus. Seal the Ziploc as if you were sealing the actual upper end of the stomach.
3. Squeeze the bag to show the churning of food in the stomach.
4. Describe what is happening to the food at this point.
5. Compare the model to the actual process in your stomach.

Stage 4 – The small intestine

In the small intestine, the digestion of proteins, carbohydrates and fats is completed and the end-products of these digestion processes are absorbed. The small intestine is specifically adapted for its function as follows:

- Since most of the digestion and absorption process takes place in the small intestine, it is exceptionally long and folded to create an even bigger absorption area.
- The inner layer of the small intestine is lined with small finger-like structures called villi, which aid absorption and increase the area for absorption.
- The small intestine has a large network of capillaries surrounding it to transport the absorbed food away.
- The muscles of the small intestine control the direction in which the food flows by peristalsis.
- The stocking that you have been provided with represents the small intestine. Cut a small corner off the bottom of the Ziploc bag and insert this end into the stocking.

1. Work over a large dish or black plastic bags for this part. While one learner is holding the stocking, the other learner should squeeze the food mixture into the stocking.
2. Use the syringes with the dissolved bicarbonate of soda and squirt the bicarbonate of soda into the food as it enters the stocking.
3. Simulate the action that takes place in the small intestine to move the food mixture through.
4. Describe what is happening to the food at this point.
5. Compare the model to the actual process in your small intestine.

Stage 5 – The large intestine

The large intestine absorbs water and mineral salts, to make some vitamins, and to decay the undigested food materials and form faeces. The large intestine is specifically adapted for its function as follows:

- Undigested waste remains in the large intestine for up to 24 hours in order to maximise the absorption of water from this region.
- The muscles in the large intestine are able to turn the waste material into faeces preparing it for egestion.
- When it is time to egest waste, the muscles in the large intestine create strong peristaltic movements to force the faeces out of the body via the rectum and anus.
- Circular muscles in the anus control the emptying of the waste materials.

1. Was this a worthwhile activity for you? Explain what you learnt from this activity and whether you think it was a worthwhile activity or not, giving reasons for your opinion.

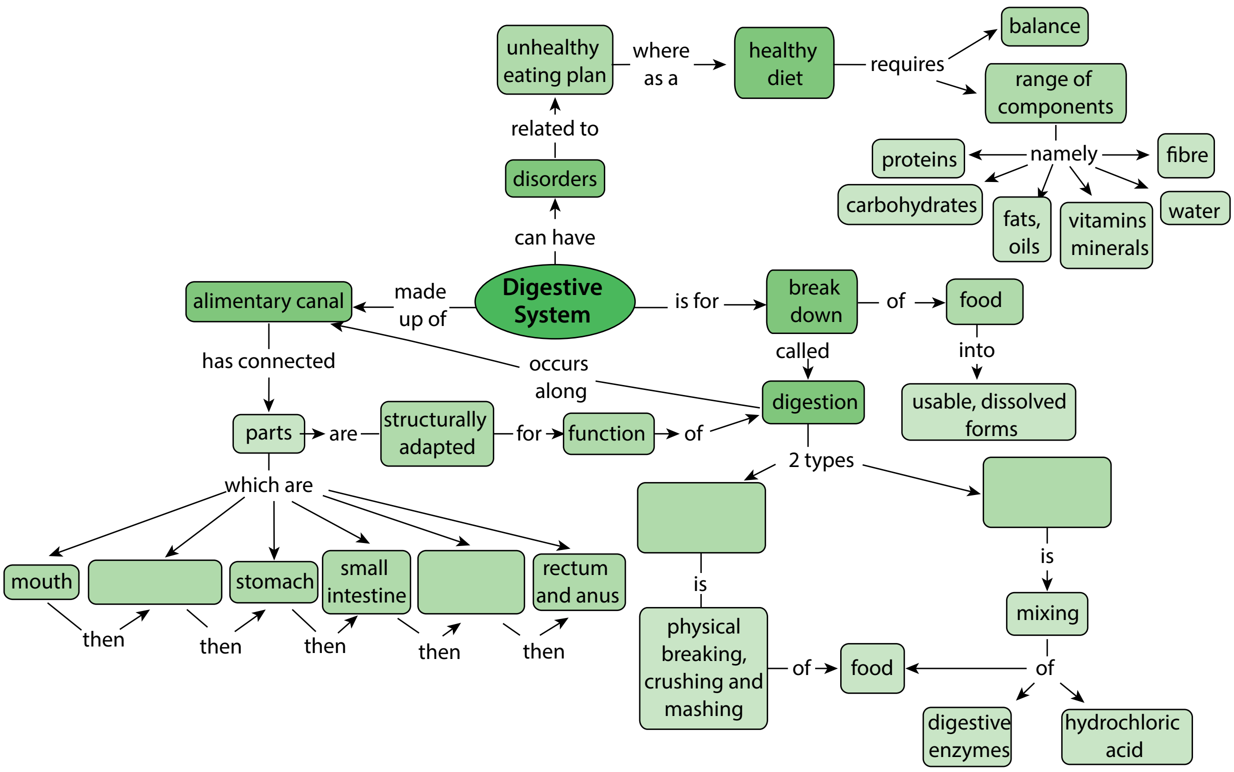
Summary

Key concepts

- There are seven buildings blocks in a healthy diet: proteins, carbohydrates, fats and oils, vitamins, minerals, fibre and water.
- A healthy diet includes the correct proportions of the seven building blocks.
- Problems in our digestive system can be related to an inappropriate diet that does not give our bodies the correct nutrients.
- Our alimentary canal is composed of the mouth, oesophagus, stomach, small intestine, large intestine, rectum and anus.
- Digestion is the breaking down of food into usable, dissolvable forms that can be absorbed.
- There are two types of digestion: mechanical (or physical) and chemical digestion.
- Each structure in the alimentary canal is specifically adapted to suit its purpose.

Concept map

The alimentary canal is made of several parts linked together – two of these parts are missing from the concept map. We also looked at two types of digestion in this unit. What are these? When filling them in on the concept map provided by your teacher, you need to decide which space to put them in by looking at the concepts, which come afterwards to describe each type.



Revision

1. Describe what you understand the term 'healthy diet' to mean. [2]

2. Copy the following table in your exercise books. For each of the following food items, classify what nutrients you can get from them (i.e. protein, carbohydrates, vitamins, etc). Some food items provide more than one class of nutrient. [10]

Food item	Nutrients	Food item	Nutrients
 Fried chips		 Strawberries	
 Chicken pieces		 Bran biscuits	
 Butternut		 Yoghurt	
 Assorted nuts		 Split peas and lentils	
 Green beans		 Margarine	

3. Which of the foods in Question 2 contain starch? How can you test if they contain starch? [9]

4. Why is it important to limit your intake of take-aways? [3]

5. Give at least 2 reasons why we should eat raw fruit and vegetables. [2]

6. Some food may take up to 24 to 36 hours to digest and be fully absorbed. Why do you think this process takes so long and why is this a good thing? [2]

Total [28 marks]

Glossary

absorption food molecules pass into the bloodstream

alimentary canal the tube that runs from your mouth to your anus where food is digested, nutrients are absorbed and solid waste is egested

alveoli clusters of tiny air sacs in the lung that together provide a very large surface area

antibiotic a medicine that kills bacteria

anus the opening at the lower alimentary canal through which waste is eliminated from the body

arteries blood vessels that carry blood away from the heart

atrium the upper left and right chambers of the heart

auditory of or relating to the sense of hearing

balanced diet a way of eating that includes adequate amounts of the necessary nutrients required for healthy growth and activity in their correct proportions

birth control the limitation or control of the number of children that a couple or a woman want to conceive by the planned use of contraceptive techniques

bladder the membranous, balloon-like sac in our bodies in which urine is collected for excretion

blood the red liquid in the blood vessels of the body that transports nutrients and oxygen to cells and removes waste and carbon dioxide from the cells

blood pressure the pressure of the blood in the circulatory system against the walls of the blood vessels

blood vessels tube-like structures that carry blood to and from tissues and organs

bowing bending

brain the organ in the skull made of soft nervous tissue that coordinates activities, senses and intelligence

breathing taking air into the body through the mouth, trachea, bronchi and lungs and releasing carbon dioxide-rich air from the lungs, trachea and mouth

brittle hard but easily broken or shattered

bronchi the two large air tubes going into each lung from the trachea

bronchioles smaller, branched air passages in the lungs

capillary /capillaries the smallest branching blood vessels that form a network between cells and join arteries to veins; diffusion between blood and cells occurs here

carbohydrates nutrients from plants, such as sugar and starch, that serve as a major source of energy in animals' diets

carbon dioxide a colourless, odourless gas that is released from the chemical breakdown of food during cellular respiration

cartilage firm, whitish, flexible connective tissue found in joints, outer ear, larynx, nose, and in rings around the trachea

cell the structural and functional unit of all living organisms; the smallest living part of plants and animals

cell membrane the selectively permeable membrane that surrounds the cytoplasm of a cell

cellular respiration process whereby organic substances (from food) combine with oxygen in order to release energy; carbon dioxide and water are by-products

cell wall tough, usually flexible layer that surrounds a plant's cell membrane; supports and protects the plant cell

cellulose a special type of carbohydrate made up of many glucose molecules that are packed very tightly together so that it doesn't dissolve in water; provides support in plants

cervix the neck of the uterus

chemical digestion breaking food into molecules that can dissolve in the blood and be transported to the cells using chemical agents (enzymes)

chloroplast a cell organelle found in plants that contains chlorophyll and can therefore photosynthesise

cilia small hair-like extensions in specialised cells in the lining of the nose and all breathing tubes that trap and remove dust and germs from the body

closed blood system blood never leaves the blood vessels

collagen a strong, flexible protein in connective tissue that cannot stretch

conception moment of fertilisation when the male sperm and the female ovum fuse together and a new individual is formed

conduct to carry impulses from one neuron the next

contraception any method that prevents pregnancy

contract to get smaller or shorter

contraction the shortening (tensing) of a muscle; term used to refer to the forceful tensing of the uterus muscles during childbirth

cover slip a small glass square which is placed over the specimen on a slide to view under a microscope

cytoplasm the gel-like material found within a plant or animal cell that is enclosed by the cell membrane but excluding the cell nucleus

degenerative a worsening in function over time

dehydration when the body loses too much water

deoxygenate to remove oxygen

deprived not given enough of something

diaphragm the dome-shaped muscle that separates the thorax from the abdomen; it plays a major role in breathing

diet what a person (or an animal) regularly eats or drinks

differentiation process by which a less specialised cell type becomes more structurally specialised to perform certain functions

diffuse move from an area of high concentration to an area of low concentration through a permeable membrane

diffusion the movement of a substance from an area of high concentration to a region of low concentration

digest break into pieces that are small enough to dissolve in the bloodstream and be absorbed into the cytoplasm

digestion breaking up food into small soluble parts that can be absorbed

dissolve when a solid breaks down into smaller and smaller particles until it mixes completely with a liquid (goes into solution)

DNA DeoxyriboNucleic Acid; molecule that stores information on how to make proteins and what characteristics the organism inherited from its parents

egestion passing out solid, undigested waste

ejaculation/ejaculate the release of sperm from the penis

embryo a very young, developing baby

emulsion a mixture of two liquids that normally do not mix together, such as oil and water

enzymes special proteins that help reactions to take place in the body of the organism

erection the enlarged state or condition of tissues around the penis

eukaryote an organism that has genetic material inside a nucleus

excrete to remove metabolic waste products and carbon dioxide from the body

excretion removing harmful wastes that were made in the body and need to be removed from the body

exhale letting air rich in carbon dioxide out of the body through the mouth or nose, breathing out

faeces the waste from your body formed from undigested food in the intestines and passed out through the anus

fallopian tube (oviduct) a tube extending from the ovary to the uterus to transport a mature ovum

fats nutrients that are very high in energy, don't mix with water, and are found in oils and greasy foods

fertilisation when a sperm fuses with an egg

fibre the cell walls of plant material that we eat that cannot be digested by humans
flaccid soft and hanging loosely
foreskin a layer of skin that covers and protects the head of the penis
fracture crack or break
frame structure a structure made by connecting beams and columns

gamete cells another name for 'sex cells' that fuse during fertilisation
gaseous exchange the process in the lungs when oxygen enters the bloodstream and carbon dioxide is removed; at cellular level, occurs when oxygen is removed from the bloodstream and enters the cells and carbon dioxide is removed from cells and enters the bloodstream
gastric of or relating to the stomach
gestation (pregnancy) the period (9 months in human beings) of development in the uterus from conception to birth
glucose a simple sugar molecule that is produced during photosynthesis and is the main source of energy for living organisms

haemoglobin a red iron-rich protein responsible for transporting oxygen in the blood
heart the organ responsible for pumping blood throughout the body
heart chamber any of the four spaces of the mammalian heart
hereditary characteristics that are transmitted from the parent to the offspring
hormone the body's chemical messengers that travel in the bloodstream to tissues and organs to affect many different reactions in the body

implantation the attachment of the fertilised egg into the wall of the uterus of the mother
impulse an electrical signal travelling along a nerve cell
infection when bacteria or viruses invade and multiply in the body's tissues and cells causing disease and illness
ingestion taking food into the mouth and body
inhale taking air rich in oxygen into the body through the mouth or nose; breathe in
inherited genetic characteristics received from the parent
integrate to make into a whole by bringing all the parts together; unify
iodine solution a brownish-orange liquid that is used as an antiseptic and dye; it changes colour in the presence of starch

jaundice yellowing of the eyes and skin, common in liver conditions
joint the place where two or more bones meet

kidney organ in the abdomen that filters the blood and produces urine

labour the process or effort of childbirth; the time during which this takes place
ligament a short band of tough, flexible, fibrous connective tissue that connects two bones or cartilage, or holds together a joint
locomotion movement or the ability to move from one place to another
lungs the organs used for breathing and gaseous exchange

medium a solution in which cells or organelles are suspended and in which reactions take place
membrane a thin flexible sheet or skin that acts as a boundary around a cell or cell organelle
menopause the changes that occur in an older female (around age 50) body when she is no longer able to reproduce
menstrual cycle a recurring series of bodily changes in women that occurs roughly every 28 days in which the lining of the uterus thickens in preparation for the possible implantation of a fertilised egg; when that doesn't happen the lining of the uterus breaks down and is discharged as menstrual blood
metabolic relating to the chemical processes and changes that happen within the cells of plants and animals
metabolic waste products any unwanted substance produced by the various body processes
metabolise any build-up or break-down process in the body

microscope an optical instrument used for viewing very small objects not often visible to the naked eye
microscopic so small that it can be seen only under a microscope
mineral salts chemical elements in food needed for growth and development, like, sodium, potassium, calcium, iron, phosphorous, and so on
minerals the elements (such as iron, sulfur and calcium) that are essential to animals and plants
mitochondria a cell organelle that uses oxygen and food molecules to release energy for the cell
mucus a slimy substance secreted by the mucous membranes and glands (in the nose for instance) for lubrication and protection
multicellular organisms organisms that have many cells
muscle a type of tissue in the body that can contract to produce movement

nerve a whitish bundle of neuron fibres that transmits impulses between the nerve centres in the brain and spinal cord and various parts of the body
network a structure that interconnects many different parts
neuron a specialised nerve cell that transmits nerve impulses
nuclear membrane a double-layered membrane that separates the content of the nucleus from the cytoplasm
nucleolus small dense round structure in the nucleus of a cell
nucleus structure with a membrane around it that contains the cell's hereditary information and controls the cell's growth and reproduction
nutrients components of food that provide the body with energy or supply the building blocks for growth and repair

oestrogen the female sex hormone that causes the development of many of the female secondary sex characteristics
optic of or relating to the eye or vision
organelle(s) specialised structures inside the cytoplasm of the cell that perform functions for the cell
organisms an individual animal, plant or single-celled life form
ovary the organ that produces the female ova (egg cells), as well as the female hormones oestrogen and progesterone
ovulation the process whereby a mature ovum or egg cell gets released from the ovaries
ovum the female egg cell produced in the ovaries of a woman
oxygen a colourless, odourless reactive gas is used in cell respiration of all organisms
oxygenate to supply with oxygen

penis one of the male sex organs
peristalsis the wave-like contraction and relaxation of the walls of the alimentary canal that helps move food forward
pharynx throat
population growth rate growth of a population over time seen as the change in the number of individuals (of any species) in a population per unit of time
prokaryote a type of organism that does not have a separate nucleus but has its hereditary material in the cytoplasm
protein group of biological molecules that provide structure and enable chemical reactions
puberty the time between childhood and adulthood when the sex organs mature with accompanying changes in the body that prepare the person's body for reproduction
pulse the rhythmical throbbing of the arteries as blood is pumped through them by the heart

red blood cells specialised cells in the bloodstream that contain haemoglobin and can therefore carry oxygen
reproduction any process by which organisms produce offspring
respiration the chemical process in cells that releases energy from food molecules by using oxygen and forming carbon dioxide as a waste product
rupture break or burst open

saliva the watery substance in the mouth that covers chewed food and moistens the mouth

scrotum the external sac of skin that encloses the testes in males

selectively permeable **a** feature and a function of the cell membrane that allows it to regulate the substances that enter and leave the cell

self-propulsion having the ability to move itself

semen the fluid that is produced in the male reproductive organs, containing sperm and other chemicals suspended in a liquid medium

sexual intercourse how the male sperm is introduced into a woman's body when the penis is placed inside the vagina

slide a small glass plate on which we mount specimens to examine under a microscope

small intestine the part of the alimentary canal between the stomach and large intestine where most of the digestion and absorption of nutrients takes place

specialised able to perform a particular function

species the most basic biological classification of organisms; organisms that are capable of mating with one another to produce FERTILE offspring

specimen a sample or small part of a larger organism that we want to examine or analyse; it can also mean an object or organism that was selected and presented as part of a collection or series

sperm the male sex cell produced by the testes

sperm duct (*vas deferens*) the tube that connects the testes to the ejaculation duct

starch a large storage molecule in plants that is made from many glucose molecules joined together

stem cell a special undifferentiated cell that can become any of the other cell types

stimulus any change that is detected inside or outside the body, to which we need to react

stomach the wider part after the oesophagus where food is stored for a short while; proteins are digested here

sugars group of sweet-tasting simple carbohydrates that are made by plants during photosynthesis

surrogacy when a person or animal acts as a substitute for another third person; when a woman carries and delivers a child for another couple or person

synthesis the process by which organic molecules are made inside organisms

temperature how much heat is present in an object, substance or body; the degree of internal heat of someone's body

tendons inelastic cords of strong fibres made of collagen tissue that attaches a muscle to a bone

testes male glands that produce sperm cells and male hormones

testosterone the male sex hormone that causes physical changes during puberty and controls the production of sperm

toxic poisonous

trachea (windpipe) the tube that carries air from the mouth and nose to the bronchial tubes in the lungs

transmit send out a message

transport move from one part of the body to another

turgid swollen or bulging outwards

ulcer an open sore in the alimentary canal

umbilical cord the cord or tube-like structure that connects the foetus at the abdomen with the placenta of the mother; it transports nourishment and oxygen to the foetus and removes waste

unicellular consisting of a single cell

urea a metabolic waste product that is formed when protein is broken down in the liver

ureter the duct (tube) that joins the kidney and bladder and allows urine to pass from the kidney to the bladder

urethra the thin tube that allows urine to flow from the bladder to the outside

urinate to excrete or pass urine out of the body

uterus the hollow muscular organ in the pelvic area of female mammals in which the fertilised egg implants and develops (also known as the *womb*)

vacuoles a fluid-filled bag in the cytoplasm of most plant cells

vagina an elastic muscular tube or canal that connects the neck of the uterus (cervix) with the external opening

variation a change or slight difference

veins blood vessels that carry blood back to the heart

ventricles the lower left and right chambers of the heart

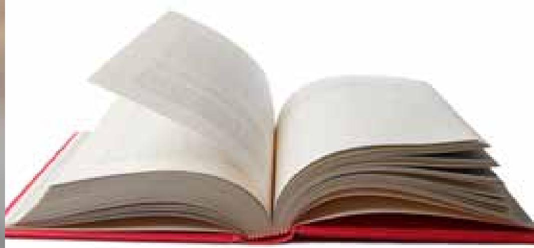
vision the ability to see

vitamins organic substances essential to normal growth and development in the body and found naturally in plant and animal products

wet mount a specimen mounted on a slide using a drop of liquid

womb another non-technical term for uterus

zygote the result of two gametes that fuse; a fertilised ovum


STRAND

Matter and Materials











6 Compounds

Key questions

- What is a compound?
- How is a compound different from an element?
- How is a mixture of elements different from a compound?
- What does the position of an element on the Periodic Table of elements tell us about its properties?
- Where do we find metals, non-metals and semi-metals on the Periodic Table?
- What are the vertical columns of the Periodic Table of elements called?
- What are the horizontal rows of the Periodic Table of elements called?
- What do elements belonging to the same 'group' of the Periodic Table of elements have in common?
- What additional information about an element can we find on the Periodic Table?
- What does the formula of a compound tell us about it?

Revision

- In a compound, atoms of two or more different kinds are chemically bonded in a fixed ratio.
- The atoms that make up a molecule are held together by special attractions called chemical bonds.
- Compounds can be formed and broken down in chemical reactions.
- A chemical reaction in which a compound is broken down into simpler compounds and even elements is called a decomposition reaction.
- Compounds cannot be separated by physical processes, but they can be separated into their elements (or simpler compounds) by chemical processes.

Keywords

- Periodic Table
- symbol (or element symbol)
- atomic number
- unique

6.1 The Periodic Table of elements

We first learnt about the Periodic Table in Grade 7. Here is a summary of what we already know:

1. All the elements that are known can be arranged on a table called the Periodic Table.
2. The discoveries of many scientists over many years contributed to the information in the Periodic Table, but the version of the table that we use today was originally proposed by Dmitri Mendeleev in the 1800s.
3. Each element has a fixed position on the Periodic Table. The elements are arranged in order of increasing atomic numbers, with the lightest element (hydrogen: H) in the top left-hand corner.
4. An element's position on the Periodic Table tells us whether it is a metal, a non-metal, or a semi-metal.
   a) metals are found on the left-hand side of the table;
   b) non-metals are found on the far right-hand side of the table; and
   c) semi-metals are found in the region between the metals and non-metals.
5. An element can be identified in 3 different ways:
   a) each element has a unique name;

b) each element has a unique chemical symbol; and
c) each element has a unique atomic number.

6. Metals are usually shiny, ductile, and malleable. Most are solids at room temperature and have high melting and boiling points.
7. Non-metals can be solids, liquids or gases at room temperature. They have a great variety of properties that usually depend on the state they are in.
8. The semi-metals are all solids at room temperature. They usually have a combination of metallic and non-metallic properties.

Take note

There is a large version of the Periodic Table printed on the inside cover of your workbooks for you to refer to easily.

We learnt about the origins of the Periodic Table in Grade 7. Let's also revise what we learnt then, so that we have a firm foundation for our new learning.

The Periodic Table is basically a chart that scientists use to list the known elements. The table consists of individual tiles for each of the elements. What information can we find on the Periodic Table? That is what the next section is all about.

What information can we find in the Periodic Table?

The information that most commonly appears on each tile of the Periodic Table is the following:

- The chemical symbol; and
- The atomic number
- The mass number

The diagram alongside shows an example of one of the tiles on the Periodic Table. Can you identify the element it represents? How many protons does an atom of this element have? What is the atomic mass number of the atom of this element?

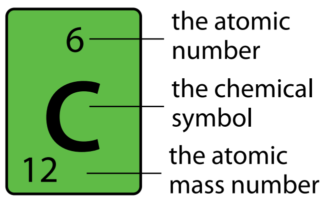
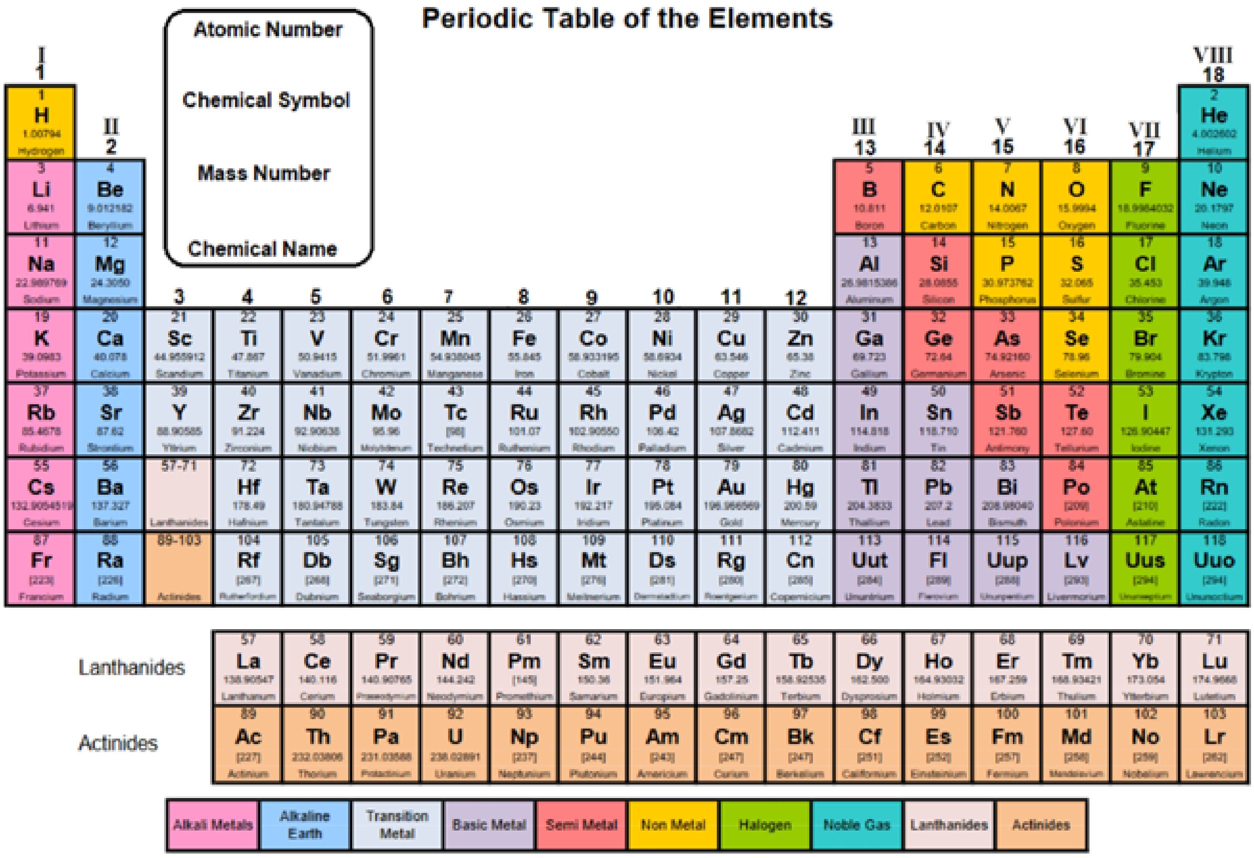


Figure 6.1: An example of one of the tiles on the Periodic Table



There are different versions of the Periodic Table, which can each contain different information about the elements. Can you identify what information is provided about the elements in the following table?

The following Periodic Table only shows the symbols for the elements.

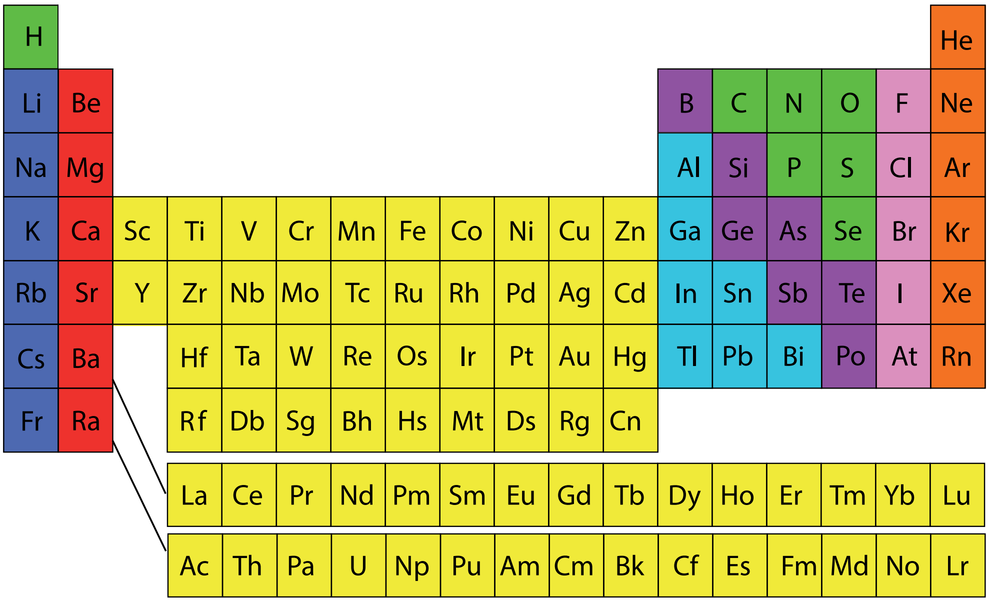


Figure 6.2: Periodic Table showing only the symbols for the elements.

Other versions of Periodic Table may contain additional information, such as:

- The element name; and/or
- The atomic mass, usually indicted at the bottom of each tile for an element.

The diagrams below show examples of how this information is sometimes presented.

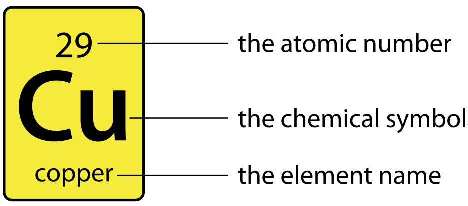


Figure 6.3: This tile shows information about the element copper.

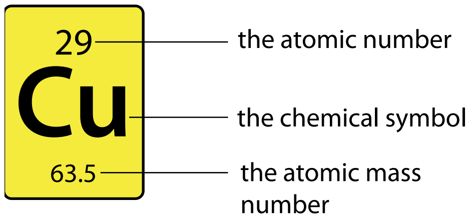


Figure 6.4: This tile also shows information about the element copper. Instead of the element name, the atomic mass of copper is given.

How are the elements arranged in the Periodic Table?

We have learnt that the elements on the Periodic Table are arranged in a very specific way.

The elements are arranged in order of increasing atomic numbers. The element with the smallest atomic number is hydrogen (H: atomic number = 1) is in the top left-hand corner of the table. The elements with the largest atomic numbers are found at the bottom of the table.

The elements are also arranged in regions and these regions are often presented in different colours. The following Periodic Table shows us where the metals, non-metals and semi-metals can be found.

Keywords

- metal
- non-metal
- semi-metal
- group
- period
- electrons
- neutrons
- protons

ACTIVITY [??]

Instructions

Look at the diagram below and answer the questions.

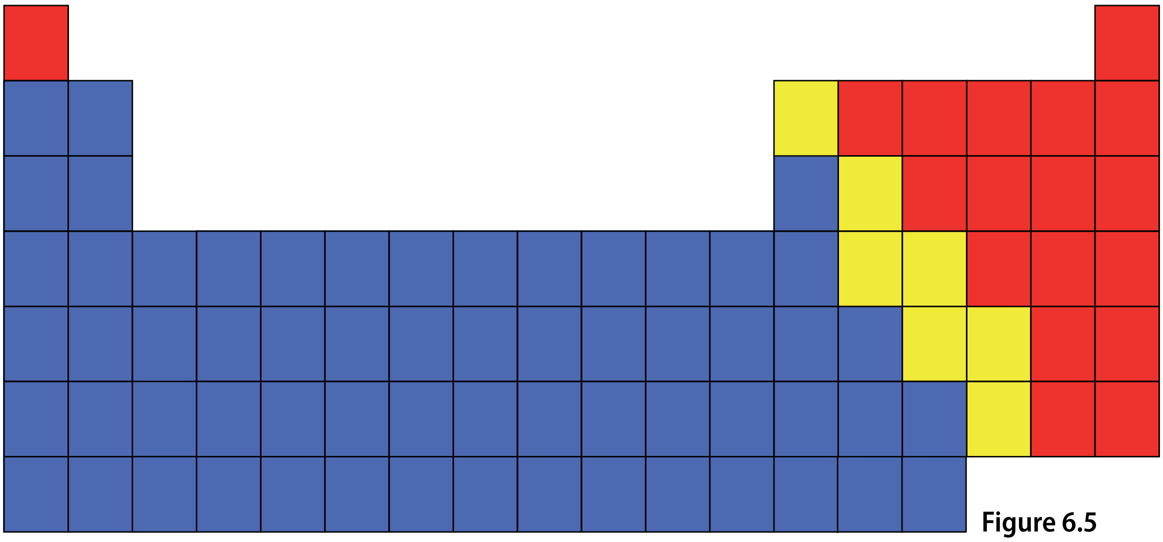


Figure 6.5

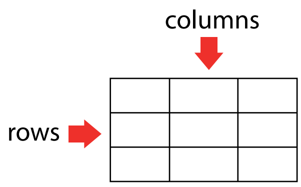
1. Where do we find metals in the Periodic Table?
2. Where do we find non-metals in the Periodic Table?
3. Where do we find semi-metals in the Periodic Table?

Take note

The semi-metals are also sometimes referred to as the metalloids.

All tables have rows and columns. Can you remember the difference between vertical and horizontal? Draw short lines to show the difference between 'vertical' and 'horizontal' in your exercise books.

Vertical runs 'up and down', and horizontal runs 'from side to side'. In a conventional table the columns run vertically, and the rows run horizontally.



There are special words to describe the columns and rows of the Periodic Table.

The following diagram shows what the column and rows are called.

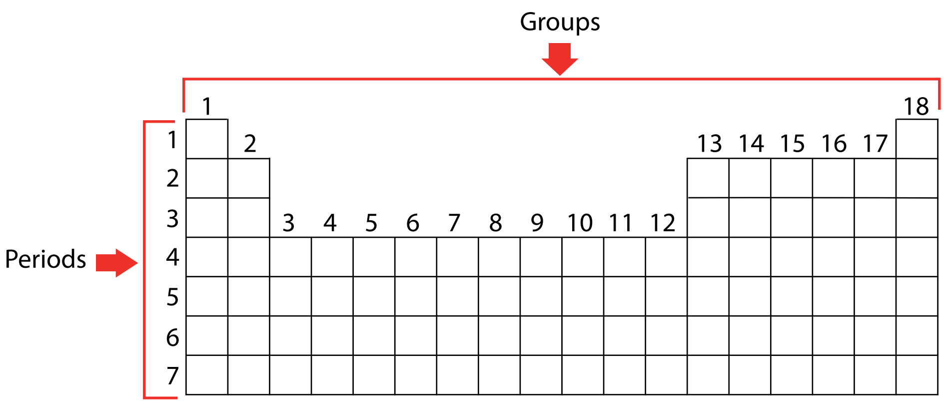


Figure 6.6: Diagram indicating Periods and Groups on the Periodic Table.

Groups: The vertical columns of the Periodic Table are called groups. The groups on the Periodic Table are numbered in such a way that Group 1 is on the left. The groups are numbered from 1 to 18. On older tables, the groups are numbered in a more complicated way. The colourful Periodic Table from Grade 7 (shown earlier) is an example of the numbering style that you may find in older textbooks and other science resources.

Periods: The horizontal rows of the Periodic Table are called periods. The first period is at the top of the table.

Names and chemical symbols

In Grade 7 we learnt that each element has a unique name. We also learnt that each element has a unique symbol. There is a list of simple rules to remember when using chemical symbols:

1. Every element has its own, unique symbol.
2. The first letter of the symbol is always a capital letter.
3. If the symbol has two letters, the second letter is always a small letter.
4. Some elements have symbols that come from their Latin names.

As scientists, we are expected to know the names and symbols of all the most important elements. You will not be expected to learn all of them off by heart just yet, but at the end of this unit you must know the names and chemical symbols of the first 20 elements on the table. To make them a little easier to remember, copy and complete the table below in your exercise books.

ACTIVITY Elements on the Periodic Table

Instructions

1. Use your Periodic Table to complete the following table.
2. Copy the table below in your exercise books. Write the chemical symbol and element name for each of the first 20 elements, identified by their atomic numbers.

Take note

You need to know the names and symbols of the first 20 elements on the Periodic Table, as well as iron, copper and zinc.

Atomic number	Chemical symbol	Element name
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Atomic number	Chemical symbol	Element name
13		
14		
15		
16		
17		
18		
19		
20		

3. There are three important industrial metals of which you need to know the names and formulae. Their atomic numbers have been written in the table below. Copy and complete the table below by filling in the chemical symbols and element names in your exercise books.

Atomic number	Chemical symbol	Element name
26		
29		
30		

Questions

1. What does the atomic number tell us about the atoms of an element?
2. How many protons are there in each oxygen atom?
3. How many neutrons are there?
4. In a neutral oxygen atom, how many electrons will there be?
5. What is the charge on protons and electrons?
6. How are the protons, neutrons and electrons (the sub-atomic particles) arranged in an atom?
7. Draw a model of an oxygen atom in your exercise books. Label your diagram.
8. What is the first element in the third period?
9. Which element is in Group 14 and in the second period? Write its symbol and its name.

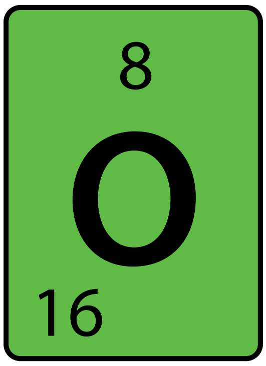


Figure 6.7

6.2 Elements and compounds

Can you remember learning about compounds in Grade 8 Matter and Materials?

We will start this unit by summarising and revising some of the main ideas about elements and compounds from Grades 7 and 8. This should help us to link the new ideas in this unit to what we already know.

Keywords

- compound
- crystal lattice
- diatomic molecule
- element

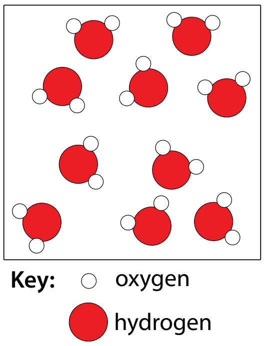


Figure 6.8: Water molecules.

The particles that make up compounds

The particles of a compound always consist of two or more atoms. In Physical Sciences Grade 10 you will learn that these atoms combine in different ways. In some cases they can form molecules. You may remember that 'molecule' is the word scientists use for a cluster of atoms that stick together in a specific way. Other compounds consist of atoms which are arranged in a regular pattern called a crystal lattice.

The molecules of a compound always consist of two or more different kinds of atoms, like the molecules of water in the diagram on the left.

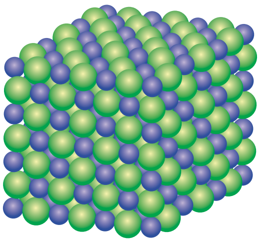


Figure 6.9: A sodium chloride crystal lattice consisting of sodium (purple) and chloride (green) atoms in a fixed ratio.

Compounds

Compounds that form crystal lattices consist of many atoms, but they always combine in a fixed ratio. For example, in sodium chloride (table salt), there is one chlorine atom for every sodium atom in the crystal. The smallest 'unit' that is repeated in the crystal consists of one Na and one Cl. The formula NaCl represents one 'formula unit' of NaCl.

From the diagram of the water molecules and the sodium chloride lattice on the left, we can see that a compound is not simply a mixture of elements. A mixture of the elements hydrogen and oxygen would look like the diagram on the right:

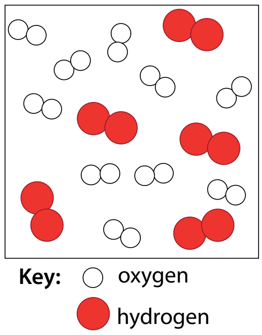


Figure 6.10: A mixture of hydrogen and oxygen molecules.

Why are the hydrogen and oxygen atoms paired in the diagram on the right? Before we answer that question, here is an important reminder: Elements are made up of just one kind of atom. Diatomic means 'consisting of two atoms'.

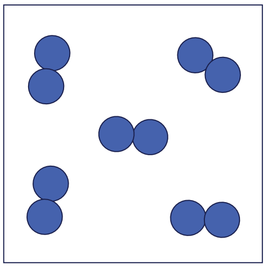


Figure 6.11: Some elements exist as diatomic molecules.

Some elements exist as diatomic molecules, like the ones in the diagram on the right below and the hydrogen and oxygen molecules in the 'mixture' diagram above. The most important examples of diatomic molecules are H_2, N_2, O_2, F_2, Cl_2, Br_2, and I_2.

Can you see that the water molecules in the diagram on the right are all identical?

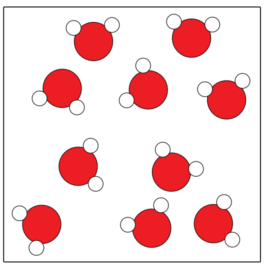


Figure 6.12: All water molecules consist of one O atom and two H atoms and this gives water its specific properties.

That brings us to the next point about compounds.

The atoms in molecules and lattices are combined in a fixed ratio.

In water, for example, one oxygen atom (O) has combined with two hydrogen atoms (H). All water molecules are exactly the same in this respect.

Any other combination of hydrogen and oxygen atoms would NOT be water. For example, hydrogen peroxide consists of the same elements as water (hydrogen and oxygen) but the ratio is different: two oxygen atoms have combined with two hydrogen atoms.

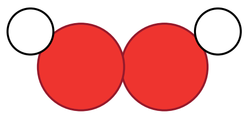


Figure 6.13: The hydrogen peroxide molecule consists of two O atoms and two H atoms. This gives hydrogen peroxide different properties from water.

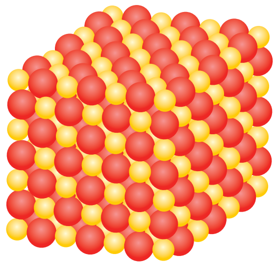


Figure 6.14: In the crystal lattice of black iron oxide, there is one iron (Fe) atom for every oxygen (O) atom.

The next important point about compounds is the following.

Each compound has a unique name and formula

Water can be represented by the formula H_2O.

The formula tells us that two hydrogen atoms (H) are combined with one oxygen atom (O) in a molecule of water.

What is the formula of hydrogen peroxide? Can you remember the name of the compound with the formula CO_2? Remember to take notes as you discuss things in class!

What formula represents one 'formula unit' of the type of iron oxide in the previous diagram?

Keywords

- chemical bond
- reactant
- product
- chemical formula

The atoms in a compound are held together by chemical bonds

What holds the clusters of atoms that we call molecules together? When atoms combine to form molecules, they do so because they experience an attractive force between them. The forces that hold atoms together are called **chemical bonds**.

Next, we need to be reminded where compounds come from.

Compounds form during chemical reactions

In all chemical reactions, the atoms in molecules rearrange themselves to form new molecules. This is how compounds form: the atoms in one set of compounds separate as bonds break between them, and they get rearranged into new groups as new bonds form. When this happens, we say a chemical reaction has occurred. Look at the following illustration.

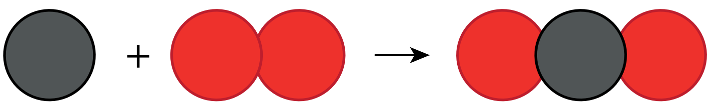


Figure 6.15

In the example above, the elements to the left of the arrow are called the **reactants**. They have rearranged to form a new compound. This is called the **product** and it is shown to the right of the arrow.

Can you describe what happened to the atoms and the bonds in this reaction?

Discuss which bond broke, which ones formed, and how the atoms were rearranged during the reaction.

The final aspect of compounds that we learnt about in Grade 8 is that each compound can be represented by a unique chemical formula.

A compound has a chemical formula

Compare the formula for water with the diagram of the water molecule you saw earlier. Can you make the connection?

The **chemical formula** of a compound is the same for all the molecules of that compound. When we read the formula, the subscripts tell us how many atoms of a particular element is in one molecule of that compound:

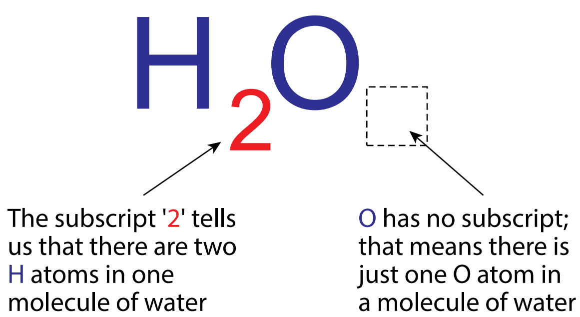


Figure 6.16

When we write H_2O, we actually mean H_2O_1. According to convention, we do not use 1 as subscript in formulae, so the first formula is the correct one.

What it means is that there are 2 hydrogen atoms to every 1 oxygen atom. This is also a ratio and can be written as 2:1. We will practise writing formulae in the next activity.

ACTIVITY Writing formulae and revision

Instructions

1. In the following table, the names of some pure substances are given in the left-hand column. The middle column tells us what one molecule of each compound is made of.
2. You must use this information to write the formula of each compound in the final column, on the right.
3. The first row has been filled in for you, so that you have an example.
4. Column 1 contains the name: water.
5. Column 2: one molecule of water contains two H atoms and one O atom.
6. Column 3: From the information in column two we can write the formula: H_2O.

Name of substance	What it is made of?	Chemical formula
Water	2 H atoms and 1 O atom	H_2O
Carbon dioxide	1 C atom and 2 O atoms	
Ammonia	1 N atom and 3 H atoms	
Methane	1 C atom and 4 H atoms	

Questions

1. What holds the atoms together in a compound?
2. The following diagram shows how carbon and oxygen react to form carbon dioxide.

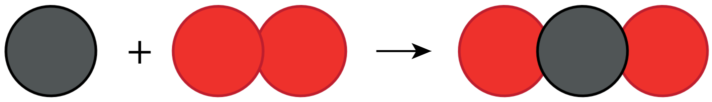


Figure 6.17

What are the reactants, and what is the product in this reaction? Copy the diagram into your exercise books and write these names onto it.

3. Why is oxygen represented as two circles together?
4. Magnesium oxide has the formula MgO. What does this ratio tell us about the atoms in the compound?

Now that we have refreshed our memories, we are going to return to the table that scientists use to organise their knowledge about the elements. Can you remember what it is called?

6.3 Names of compounds

Perhaps there are two or more people in your class with the same name? Then you will know how confusing it can be when two people have the same name! We have learnt that each element has a unique name. This is important, so that we do not end up confusing elements with each other.

Keywords

- systematic name
- suffix
- prefix

Each compound has a unique name

It is just as important for each compound to have a unique name.

When we write the chemical formulae for compounds, they are always a combination of the symbols of the elements in the compound. For example, when we see the formula NaCl, we know that this compound consists of Na and Cl.

When we name compounds, the names of the elements in the compound are combined and sometimes changed slightly, to make a name for the compound.

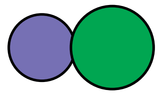
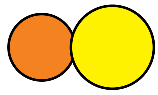
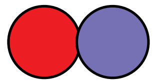
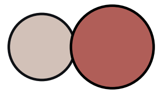
In the name sodium chloride, for instance, it is quite obvious that the compound being described must consist of sodium and chlorine. But, why is it chloride and not chlorine? Well, as you will see shortly, when we join up the names of the elements, the one that is named last is changed.

Take note

A 'suffix' is something placed at the end of a word. A 'prefix' is something placed at the beginning of a word.

Type 1: Compounds that contain a metal and a non-metal

For compounds of this type, the rule is simple. The metal comes first and the non-metal second. The name of the non-metal changes slightly: the suffix -ide replaces the ending of the name.

Formula	Consists of	Name	
NaCl	Sodium and chlorine	Sodium chloride	
FeS	Iron and sulfur	Iron sulfide	
MgO	Magnesium and oxygen	Magnesium oxide	
LiF	Lithium and fluorine	Lithium fluoride	

ACTIVITY Naming compounds of metals and non-metals

Instructions

1. Copy the table below in your exercise books and refer to the Periodic Table.
2. You need to identify the elements which make up the compound and give the name of the compound.

Formula	Which elements does it consist of?	Name
Li_2O		
KCl		
CuO		
NaBr		

Type 2: Compounds that contain only non-metals

This type of compound is slightly more complicated to name. There are three rules that you have to follow. They are as follows:

Take note

The prefix mono- is usually left out from the beginning of the first word of the name. For instance, CO is carbon monoxide, not *mono*carbon monoxide.

Rule 1:

The name of the element further to the left on the Periodic Table comes first, followed by the name of the element further to the right on the table. The name of the second element changes slightly: the suffix -ide replaces the ending of the name.

For example:

- oxygen becomes oxide
- fluorine becomes fluoride
- chlorine become chloride
- nitrogen becomes nitride.

Rule 2:

When two or more compounds have different numbers of the same elements (like CO and CO_2 in our example above), we must add prefixes to avoid confusion.

The first four prefixes are listed in the table below:

Number of atoms	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-

Here are some examples of how this rule should be applied:

Compounds of carbon and oxygen:
- CO – carbon monoxide (notice that it is not mono-oxide, but monoxide)
- CO_2 – carbon dioxide

Compounds of nitrogen and oxygen:
- NO_2 – nitrogen dioxide
- N_2O_4 – dinitrogen tetroxide (did you notice how tetra-oxide becomes tetroxide?)

Compounds of sulfur and oxygen:
- SO_2 – sulfur dioxide
- SO_3 – sulfur trioxide

We are going to practice what we have learnt so far in the next two short activities. First, we will write names from formulae.

ACTIVITY Writing names from the formulae of compounds

Materials

play dough, beans or beads

Instructions

1. How would you name the following compounds? Copy the table on the next page in your exercise books and write the name next to each formula.
2. Build one molecule of each compound with play dough, beans or beads. If you are not sure how to arrange the atoms, here is an important tip: the atom that comes first in the name (it will usually also be the first atom in the formula) must be placed at the centre of the molecule. All the other atoms must be placed around it. They will be bonded to the atom at the centre, but not to each other.

3. Draw a picture of your molecule in the final column of the table.

Formula of the compound	Name of the compound	Picture of one molecule of the compound
CO_2		
H_2O		
PF_3		
SF_4		
CCl_4		

Next, we will write formulae from the names of some compounds.

ACTIVITY Writing formulae from the names of compounds

Materials

play dough

Instructions

1. What formulae would you give the following compounds? Copy the table below in your exercise books and write the formula next to each name.
2. Build a model of each compound with play dough.
3. Draw a picture of one molecule of each compound in the final column of the table.

Formula of the compound	Name of the compound	Picture of one molecule of the compound
	hydrogen fluoride	
	dihydrogen sulfide	
	sulfur trioxide	
	carbon monoxide	

Take note

Now we have learnt an important new skill, namely to write and interpret the names and formulae of compounds.

There is one additional rule – an easy one to remember!

Rule 3:

Many compounds are not usually referred to by their systematic names. Instead, they have common names that are more widely known. For example, we use the name water for H_2O, ammonia for NH_3, and methane for CH_4.

In this unit we reviewed all the information about compounds and about the Periodic Table that we have learnt in previous years. We added some new information to both of these topics.

Summary

Key concepts

Elements

- All the atoms in an element are of the same kind. This means that an element cannot be changed into other elements by any physical or chemical process.
- Elements can be built up of individual atoms, or as bonded pairs of atoms called diatomic molecules.
- When atoms of different elements combine chemically, they form compounds.

Compounds

- In a compound, atoms of two or more different kinds are chemically bonded in a fixed ratio.
- The atoms that make up a molecule are held together by special attractions called chemical bonds.
- Compounds can be formed and broken down in chemical reactions.
- A chemical reaction in which a compound is broken down into simpler compounds and even elements is called a decomposition reaction.
- Compounds cannot be separated by physical processes, but they can be separated into their elements (or simpler compounds) by chemical processes.

The Periodic Table

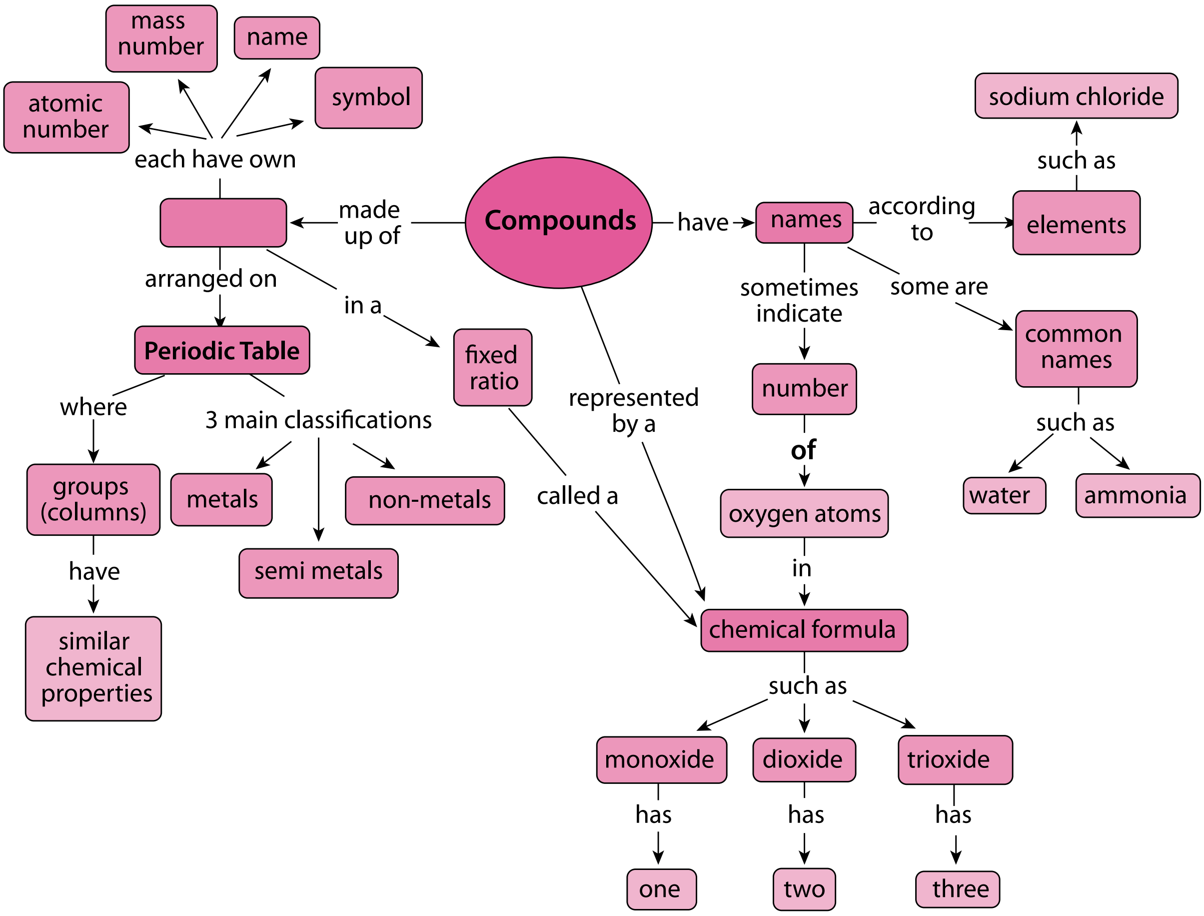
- Each element has a fixed position on the Periodic Table. The elements are arranged in order of increasing atomic number, with the lightest element (hydrogen: H) in the top left-hand corner.
- An element's position on the Periodic Table tells us whether it is a metal, a non-metal or a semi-metal:
  - metals are found on the left-hand side of the table;
  - non-metals are found on the far right-hand side of the table; and
  - semi-metals are found in the region between the metals and non-metals.
- An element can be identified in three different ways:
  - each element has a unique name;
  - each element has a unique chemical symbol; and
  - each element has a unique atomic number.
- The vertical columns of the Periodic Table are called groups. The Periodic Table has 18 groups.
- The horizontal rows of the Periodic Table are called periods. There are seven periods.
- Elements belonging to the same 'group' of the Periodic Table exhibit the same chemical behaviour, and will often have similar properties.
- Many different versions of the Periodic Table exist. Typically, the element symbol, the atomic number, and the atomic mass of each element are given on the table.

Names and formulae

- Each compound has a unique name and formula.
- The formula of a compound tells us which elements are in the compound and how many atoms of each element have combined to form one molecule of that compound.
- There are rules for naming compounds that take into account how many atoms of each type are in one molecule of the compound.

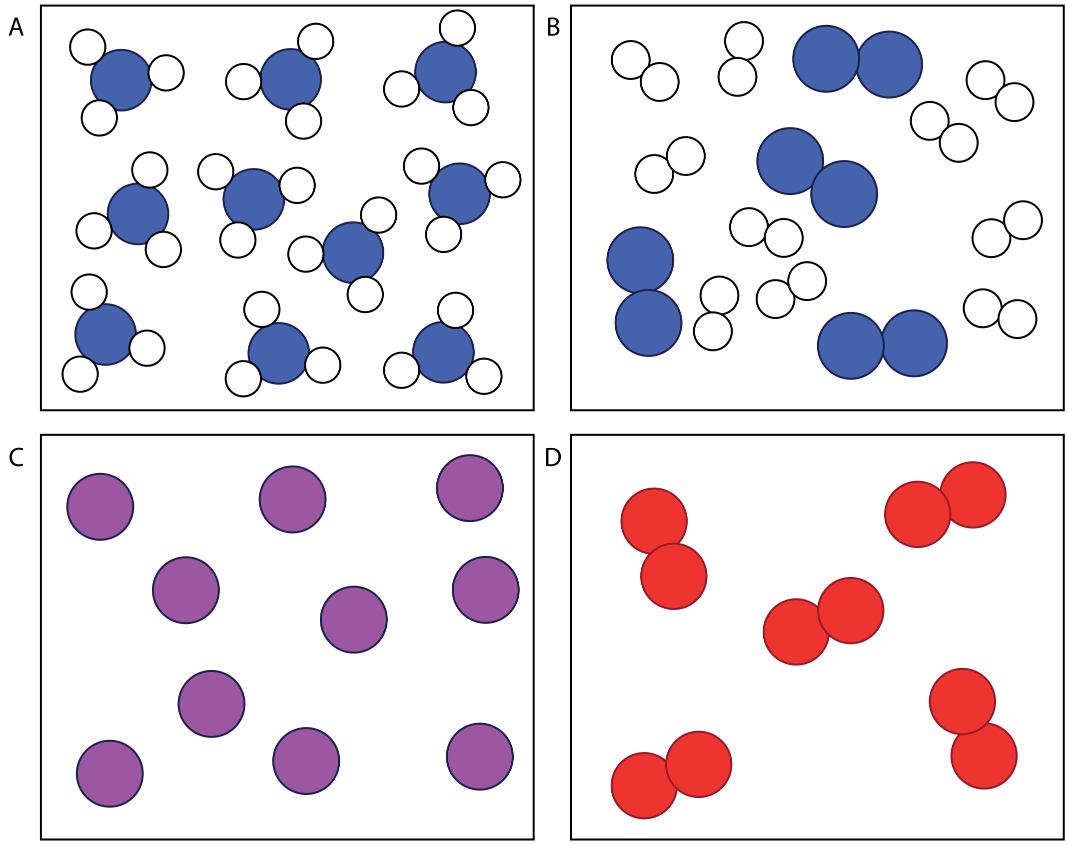
Concept map

Study the concept map below summarising what we have learnt in this unit about compounds.



Revision

1. Each of the four blocks below (labelled A to D) contain some matter. You must answer the following questions using the diagrams in the blocks. Each question may have more than one answer! [12]



   a) Which block represents the particles of an element?
   b) Which block represents the particles in a compound?
   c) Which block represents the particles in a mixture?
   d) Which block represents diatomic particles?
   e) If the blue atoms are N and the white atoms are H, write the formula for the molecules in block A.
   f) If the blue atoms are N and the white atoms are H, write the formula for the molecules in block B.
   g) Which blocks contain molecules?
   h) Which block contains single atoms?

2. How would you name the following compounds?
   a) Copy the table below in your exercise books and write the name next to each formula.
   b) Build a model of each compound with play dough.

c) Draw a picture of one molecule of each compound in the final column of the table. [12]

Formula of the compound	Name of the compound	Picture of one molecule of the compound
NH_3		
CO_2		
$CuCl_2$		
SO_2		

3. What are the formulae of the following compounds? [4]

Formula of the compound	Name of the compound
	sodium chloride
	dinitrogen monoxide
	sulfur trioxide
	carbon monoxide

4. Here is a balanced chemical equation. Answer the four questions below that relate to this equation: [8]

$CO + H_2 \rightarrow CO_2 + H_2$

a) Write the formulae of the reactants of this reaction.

b) Write the names of the reactants of this reaction.

c) Write the formulae of the products of this reaction.

d) Write the names of the products of this reaction.

5. The table below contains the chemical formulae of a few compounds. You have to write the number of atoms of each element(s) combined in one molecule of each compound. The first row has been filled in for you as an example. [8]

Chemical formula	What it is made of?
H_2O	2 hydrogen atoms and 1 oxygen atom
SF_4	
NO_2	
Fe_2O_3	
Na_2O	

Total [44 marks]

7 Chemical reactions

Key questions

- What is a chemical reaction?
- How can we represent what happens in a chemical reaction?
- What do the different symbols in a chemical reaction equation mean?
- What do the numbers in a chemical reaction mean?
- What does it mean to balance a chemical equation?
- How can we tell if a reaction is balanced?
- How do we translate between word equations, picture equations and chemical equations?

Keywords

- bond
- reactant
- product
- chemical reaction
- macroscopic
- submicroscopic
- symbolic

In Grade 8 Matter and Materials we learnt about chemical reactions for the first time. Can you remember the main ideas about chemical reactions? Here they are again:

During chemical reactions, materials are changed into new materials with new chemical and physical properties.

The materials we start with are called **reactants**, and the new materials that form are called **products**.

During a chemical reaction, atoms are rearranged. This requires that bonds are broken in the reactants and new bonds are formed in the products.

In this unit we are going to build on these ideas. We will focus on two things:

1. how to write chemical reaction equations; and
2. how to balance chemical reaction equations.

This will prepare us for the units that follow this one, in which we will be looking at different types of chemical reactions.

Before we get to chemical reactions, however, it is important that we remind ourselves of the different ways that we have been thinking about chemical compounds up to now. The next section will show how they all fit together

7.1 How do we represent chemical reactions?

Keywords

- chemical equation
- coefficient
- subscript

How would you define a chemical reaction? Write down some of your ideas.

The following words may help you formulate your sentences.

reactants, products, bonds, rearranged, atoms, molecules, new compounds

A chemical reaction is a rearrangement of atoms in which one or more compounds are changed into new compounds.

All chemical reactions can be represented by equations and models. To some people, chemical equations may seem very hard to understand. Since atoms and molecules cannot be seen, they have to be imagined, and that can be quite difficult! Luckily, we have had some preparation because we have been drawing molecules since Grade 7.

Any time that atoms separate from each other and recombine into different combinations of atoms, we say a chemical reaction has occurred. No atoms are lost or gained, they are simply rearranged.

Word equations

When we represent a chemical reaction in terms of words, we write a **word equation**. For example, when hydrogen gas reacts with oxygen gas to form water, we can write a word equation for the reaction as follows:

hydrogen + oxygen → water

To the left of the arrow, we have the 'before' situation. This side represents the substances we have before the reaction takes place. They are called the **reactants**. What are the reactants of this reaction?

The arrow shows that the chemical reaction has taken place.

To the right of the arrow we have the 'after' situation. This side represents the substances that we have after the reaction has taken place. They are called the products. What is the product of this reaction?

Picture equations

The same reaction of hydrogen reacting with oxygen can also be represented in pictures called submicroscopic diagrams. The diagram below shows that the atoms in two hydrogen molecules (H_2) and one oxygen molecule (O) on the left rearrange to form the two water molecules (H_2O) on the right of the arrow.

Hydrogen atoms are white circles and oxygen atoms are red circles.

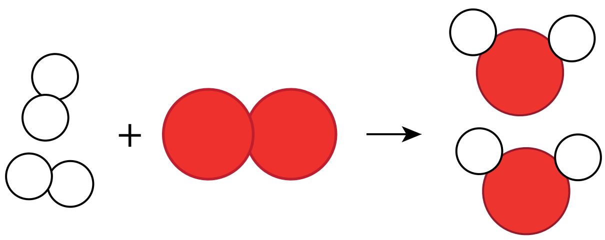


Figure 7.1

Questions

- 1. What is the product of the above reaction?
- 2. What are the reactants of the above reaction?
- 3. Write their formulae.

Chemical equations

When we represent a chemical reaction in terms of chemical formulae (symbols), it is called a **chemical equation**. The chemical equation for the above reaction would be as follows:

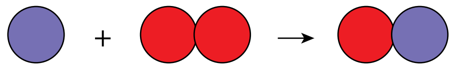
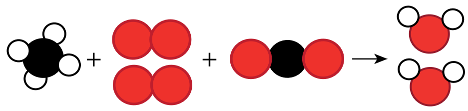
$$2H_2 + O_2 \rightarrow 2H_2O$$

On which side of the arrow are the reactants?

ACTIVITY Identifying the different types of equations

Instructions

Complete the following table by identifying the different types of equations which have been shown, namely word, picture or chemical equations.

Equation	Type of equation
	
carbon dioxide + water → glucose + oxygen	
$Fe + O_2 \rightarrow Fe_2O_3$	
	
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$	

Coefficients and subscripts in chemical equations

When you look at the reaction equation above you will notice two kinds of numbers:

- Numbers *in front* of chemical formulae in the equation. They are called **coefficients**.
- Smaller numbers used inside and below the chemical formulae. These are called **subscripts**.
- Coefficients and subscripts mean different things, as you will see in the next section.
- Why is there a '2' in front of the formula for water (H_2O) in the chemical equation for water? This is because two molecules of H_2O can be made from two molecules of H_2 and one molecule of O_2 in our reaction.

Keywords
- balanced
- chemical formula
- rust
- tarnish

The numbers in front of the formulae in the chemical equation are called coefficients. They represent the numbers of individual molecules that are in the chemical reaction.

You will notice that O_2 does not have a coefficient in the reaction above. When there is no coefficient, it means that just one molecule of that substance takes part in the reaction.

In the previous unit, we learnt how to interpret chemical formulae. When we read the formula, the subscripts tell us how many atoms of a particular element are in one molecule of that compound.

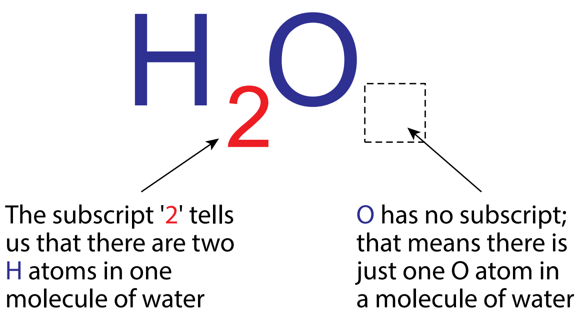


Figure 7.2

Visit

Simulation on balancing chemical equations. bit.ly/17ImOVN

7.2 Balanced equations

Now we are going to learn what it means when a reaction is **balanced**. Here is our picture again.

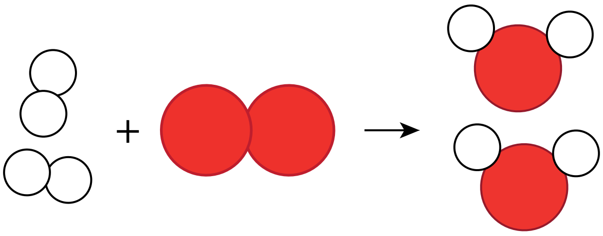


Figure 7.3

1. Count how many H atoms are on the left side of the reaction. How many on the right?
2. Count how many O atoms are on the left side of the reaction. How many on the right?
3. Did you notice that the numbers and types of atoms are the same on the left and on the right of the reaction?
4. The reactants have four H atoms and two O atoms.
5. The products have four H atoms and two O atoms.
6. When this is true of a reaction equation, we say the equation is balanced.

ACTIVITY When is a reaction balanced?

Instructions

1. Study the equation below. The black atoms are carbon (C), and the red atoms are oxygen (O). They will not always necessarily be this colour – this is just a representation.
2. Answer the questions that follow.

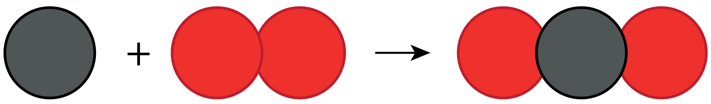


Figure 7.4

Questions

1. Write a symbolic representation (a chemical equation) for the above reaction.
2. Write the formulae for the reactants of this reaction.
3. Write the formula for the product of the reaction.
4. Count how many C atoms are on the left side of the reaction. How many on the right?
5. Count how many O atoms are on the left side of the reaction. How many on the right?
6. Is the reaction balanced? Why do you say so?

ACTIVITY Magnesium burning in oxygen

When magnesium metal burns in oxygen, we can write the following word equation for the reaction that occurs between these two elements:

magnesium + oxygen → magnesium oxide

Questions

Refer to the picture equation below and answer the questions that follow.

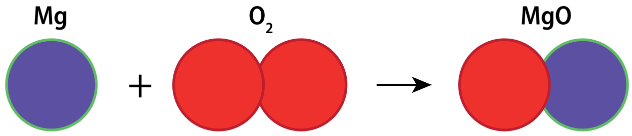


Figure 7.5

Number of atoms	Reactants	Products
Mg	1	1
O	2	1

1. From what you have in the table, is the equation balanced? Explain your answer.
2. Write a balanced the symbolic chemical equation.

ACTIVITY Iron reacts with oxygen

When iron rusts, it is because the iron metal reacts with oxygen in the air to form iron oxide.

Figure 7.7: An old car with rust on the bonnet.

The word equation is the following:

iron + oxygen → iron oxide

The chemical equation is the following:

$$Fe + O_2 \rightarrow Fe_2O_3$$

Is the equation balanced? Draw a submicroscopic picture to help you decide.

Figure 7.8: A close-up photo of a rusted barrel.

Did you know?

Magnesium flakes are often used in some fireworks, such as sparklers, because when they burn they create bright, shimmering sparks.

Figure 7.6: Magnesium flakes burning in oxygen in a sparkler.

You could also use a table like the one below:

Number of atoms	Reactants	Products
Fe		
O		

What is your verdict: Is the equation balanced? Explain your answer.

How could we balance the reaction? Three possibilities (Plans A, B and C) are given below. You must evaluate each plan, and say if it is allowed or not.

Plan A

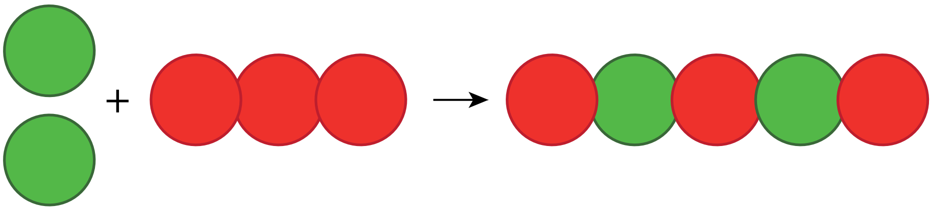


Figure 7.9

Changes made	Is this change allowed? Yes/no?	Reason
Add one Fe atom on the reactant side.		
Change O_2 to O_3 on the reactant side of the equation.		

1. Convert the picture equation above to a chemical equation.
2. Did any coefficients change? Remember that this is allowed.
3. Did any formulae change, or were any new formulae added? Remember that this is NOT allowed.
4. What do you think: Can this plan work? Explain your answer.

Plan B

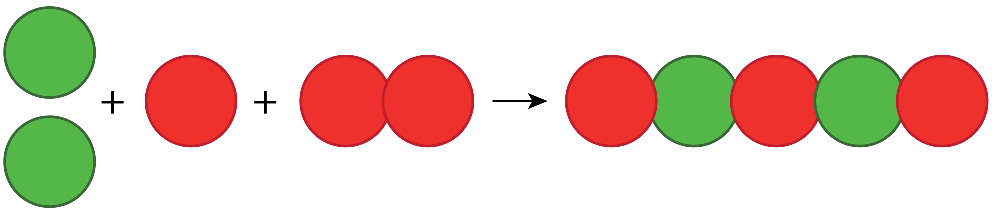


Figure 7.10

Changes made	Is this change allowed? Yes/no?	Reason
Add one Fe atom on the reactant side.		
Add one O atom on the reactant side.		

1. Convert the picture equation to a chemical equation.
2. Did any coefficients change? Remember that this is allowed.

3. Did any formulae change, or were any new formulae added? Remember that this is NOT allowed.
4. What do you think: Can this plan work? Explain why or why not.

Plan C

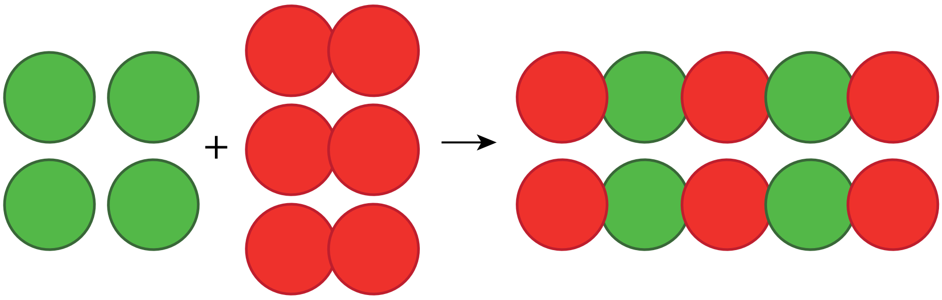


Figure 7.11

Changes made	Is this change allowed? Yes/no?	Reason
Add three Fe atoms on the reactant side.		
Add two O_2 molecules on the reactant side.		
Add one Fe_2O_3 on the product side.		

1. Convert the picture equation to a chemical equation.
2. Did any coefficients change? Remember that this is allowed.
3. Did any formulae change, or were any new formulae added? Remember that this is NOT allowed.
4. What do you think: Can this plan work? Explain why or why not.
5. Which of the three plans (A, B or C) helped us to balance the equation using only moves that are allowed?
6. Are there any other plans that you can think of to balance this equation?

In the next activity we will balance an equation that is much simpler, but we are not going to include all the explanations of the previous activity.

ACTIVITY Copper reacts with oxygen

Have you ever noticed how copper items tarnish over time?

This dark layer of tarnish is the result of a slow reaction between copper and oxygen to form copper oxide.

Figure 7.12: One of these copper coins is tarnished as it has become coated in a black substance.

Questions

1. Write the word equation for this reaction in your exercise books. The words are all in the sentence above; they just need to be placed in the correct positions.

	+		→	

2. Convert the word equation into a chemical equation. You do not have to balance it yet.
3. Convert the chemical equation to a picture equation. It does not have to be balanced.

	+		→	

4. Now, redraw the picture equation so that it is balanced. Remember that no 'new' compounds may be added; we are allowed to draw only more of the molecules that are already there.
5. Convert the balanced picture equation to a balanced chemical equation.

	+		→	

In the units that follow, there will be more opportunities to write and balance chemical equations.

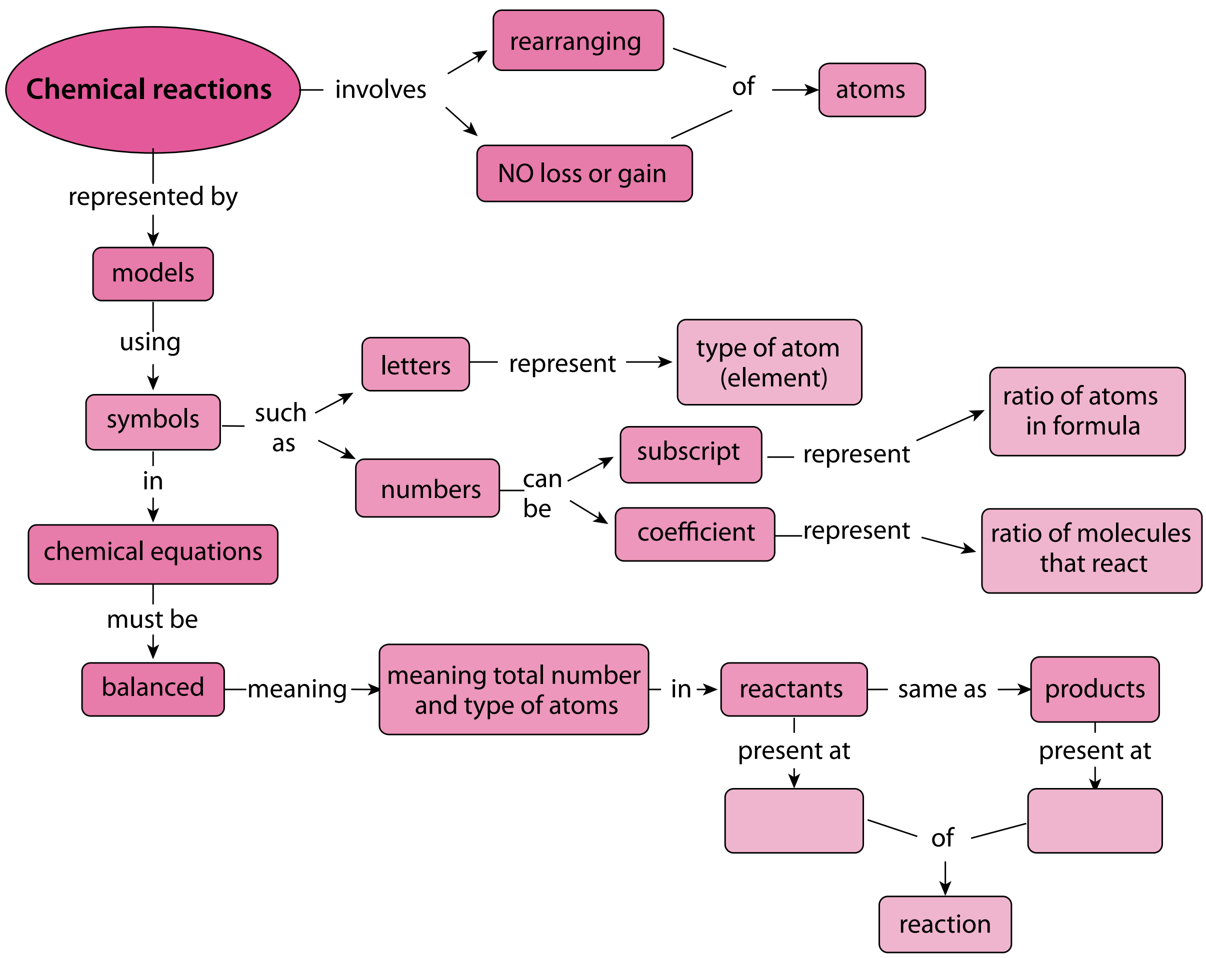
Summary

Key concepts

- There are a number of different ways to represent chemical equations:
  - With models and pictures (in submicroscopic representations);
  - with symbols and formulae (in chemical equations); and
  - with words (in word equations).
- Numbers are used in two different ways in chemical equations:
  - Coefficients in front of chemical formulae indicate the numbers of atoms or molecules of a specific type that take part in the reaction; and
  - Subscripts inside chemical formulae indicate the number of atoms of a specific type in that particular compound.
- Chemical reactions happen when atoms in compounds rearrange; no atoms are lost or gained during a chemical reaction.
- In a balanced equation equal numbers of the same kinds of atoms are on opposite sides of the reaction equation.

Concept map

The following concept map is incomplete. You need to describe when you get reactants and when you get products in a chemical reaction.



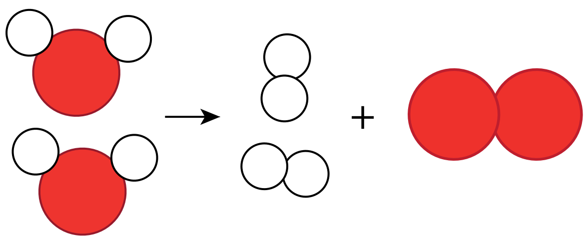
Revision

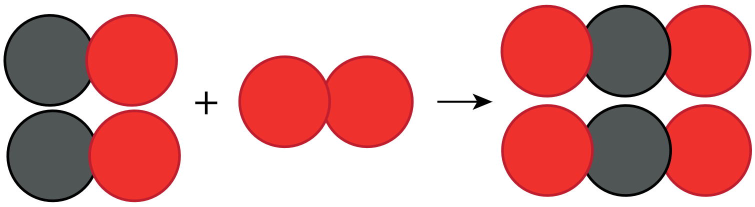
1. Why can we not change the subscripts in the formulae of reactants and products when we want to balance an equation? [2]
2. Write the balanced chemical equation between carbon and oxygen to form carbon dioxide. [1]
3. Write the balanced chemical equation between hydrogen and oxygen to form water. [1]
4. Here is a balanced chemical equation:
   $C + H_2O \rightarrow CO + H_2$
   Answer the four questions below that relate to this equation: [8]
   a) Write the formulae of the reactants of this reaction.
   b) Write the names of the reactants of this reaction.
   c) Write the formulae of the products of this reaction.
   d) Write the names of the products of this reaction.
5. The balanced equation below represents the reaction between nitrogen monoxide (NO) and bromine (Br_2):
   $2\ NO + Br_2 \rightarrow 2\ NOBr$
   Complete the table by counting how much of each atom is on each side of the reaction equation. [6]

Number of atoms	In the reactants	In the product
Nitrogen (N)		
Oxygen (O)		
Bromine (Br)		

6. Turn the following chemical equations into word equations: [2 × 3 = 6]
   a) $2\ CO + O_2 \rightarrow 2\ CO_2$
   b) $2\ Mg + O_2 \rightarrow 2\ MgO$
7. Turn the following word equations into chemical equations: [2 × 3 = 6]
   a) sulfur + oxygen → sulfur dioxide
   b) carbon monoxide + water → carbon dioxide + hydrogen
8. Turn the following picture equations into chemical equations. [2 × 3 = 6]
   - The red circles represent oxygen (O) atoms.
   - The white circles represent hydrogen (H) atoms.
   - The grey circles represent carbon (C) atoms.
   - The yellow circles represent sulfur (S) atoms

   a)



b) 

9. Write the following chemical equations as word equations: [4 × 1 = 4]

a) $4\ Fe + 3\ O_2 \rightarrow 2\ Fe_2O_3$

b) What is the color of the product formed in a)?

c) $2\ Mg + O_2 \rightarrow 2\ MgO$

d) What is the color of the product formed in c)?

10. Turn the following chemical equations into picture equations: [2 × 4 = 8]

a) $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

b) $CS_2 + 3\ O_2 \rightarrow CO_2 + 2\ SO_2$

Total [48 marks]

8 Reactions of metals with oxygen

Key questions

- What happens when a metal reacts with oxygen?
- What is the product called?
- How can we represent the general reaction between a metal and oxygen?
- What is a combustion reaction?
- What is rust and how does it form?
- How can iron be made more rust-resistant?

Take note

The metals will react similarly with the other elements in the same group as oxygen (group 16).

In the previous unit, we learnt how to write and balance equations. The three examples we learnt about were:

- magnesium + oxygen → magnesium oxide
- iron + oxygen → iron oxide
- copper + oxygen → copper oxide

Which groups do magnesium, iron and copper come from?

In these reactions, the elements that react with oxygen are all **metals**. If you are not convinced of this, find them on the Periodic Table. Can you see that they are all found in the region occupied by the metals?

Metal Oxides

Where are metals located in the Periodic Table?

The names of the products of the three reactions above have something in common. Write down the names. Can you see what they have in common?

The products are all **metal oxides**. What exactly are metal oxides? As we will see later when we draw diagrams and write formulae to represent these reactions, they are compounds in which a metal is combined with oxygen, in a fixed ratio.

Keywords

- combustion

8.1 The reaction of iron with oxygen

We will be looking at how iron reacts with oxygen. In some cases, you may use steel wool for these experiments. Do you know what steel wool is? It is wire wool made of very fine steel threads. Steel is an alloy made mostly of iron. So, when we look at how steel wool burns in oxygen, we are actually looking at how iron reacts with oxygen.

Take note

A metal alloy is a solid mixture of two or more different metal elements. Examples are steel and brass.

Figure 8.1: Steel wool spinning creates interesting photos as the iron burns in oxygen and creates orange sparks.

When a substance burns in air, the reaction is called a **combustion** reaction. When a substance combusts in air, it is really reacting with oxygen.

ACTIVITY The reaction of iron with oxygen

Materials

- Bunsen burner or spirit burner
- matches
- safety goggles
- steel wool
- tongs

Instructions

1. Your teacher will demonstrate the combustion of iron in oxygen (which is present in air).
2. You should make careful observations during the demonstration and write these down in your exercise books. To guide you, some questions have been provided.

Questions

1. We used steel wool in this demonstration, but what is steel wool mostly made of?
2. Look at the metal before it is burned. Describe what it looks like.
3. Can you see the oxygen that the metal will react with? Can you describe it?
4. What do you observe during the reaction? Describe anything you see, hear, or smell.
5. What does the product of the reaction look like? Describe it in as much detail as possible.

If you think the reaction when iron burns in oxygen is spectacular, the next demonstration will amaze you!

Keywords

- camera flash
- ignite

8.2 The reaction of magnesium with oxygen

ACTIVITY The reaction of magnesium with oxygen

Materials

- Bunsen burner or spirit burner
- matches
- safety goggles
- magnesium ribbon
- tongs
- watch glass or beaker

Figure 8.2: Magnesium burns with a bright white flame.

Instructions

1. Your teacher will demonstrate the combustion of magnesium in oxygen.
2. You should make careful observations during the demonstration and write these down in your exercise books.

Questions

1. Describe the physical form (shape) of the metal in this experiment.
2. What do we call reactions where a substance burns in air?
3. How would you describe the physical appearance or colour of the metal before it is burned?
4. Can you see the oxygen that the metal will react with? Can you describe it?
5. What do you observe during the reaction? Describe anything you see, hear, or smell.
6. What does the product of the reaction look like? Describe it in as much detail as possible.

Magnesium is in group 2 in the Periodic Table. Do you remember that we said that elements in the same group will behave similarly? This means that they will react in a similar way. We have studied how magnesium reacts with oxygen, but calcium, for example, will behave in a similar way. You can watch the video in the visit link to confirm this.

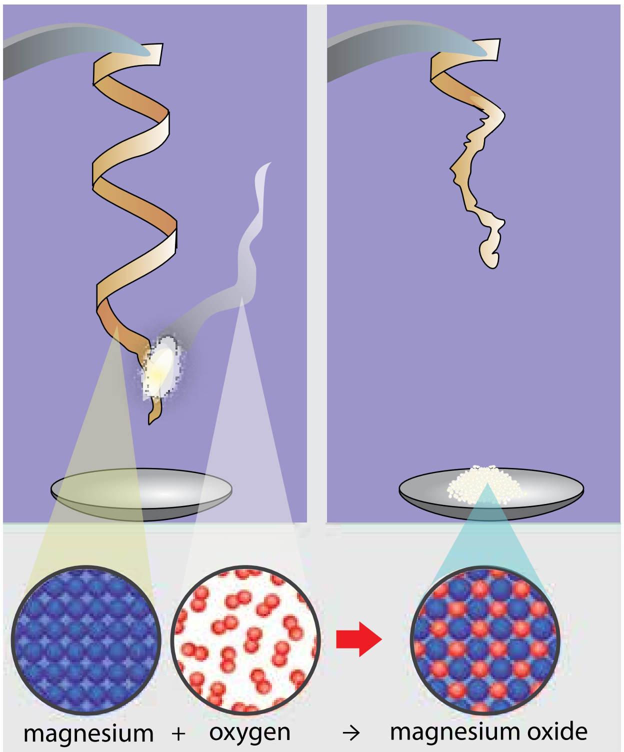


Figure 8.3: The diagram shows the combustion of magnesium to form magnesium oxide.

Did you know?

To take a photo in the dark, we need a camera flash. The earliest flashes worked with flash powder that contained magnesium grains. They had to be lit by hand and burned very brightly, for a very short period.

8.3 The general reaction of metals with oxygen

Let us start by writing word equations for the two reactions that we have just performed. Word equations are often easier to write than picture equations or chemical equations and so they are a good starting point when we want to write reactions.

Instruction

Write the word equation for the reaction between iron and oxygen and for the reaction between magnesium and oxygen.

The general equations

We can write a general word equation for reactions in which a metal reacts with oxygen:

metal + oxygen → metal oxide

When we use words to describe a reaction, we are still operating on the macroscopic level. Next, we are going to translate our word equation to a picture equation.

The chemical equation

We can show the reaction between magnesium and oxygen using a symbolic chemical equation.

$$2\,Mg + O_2 \rightarrow 2\,MgO$$

Since the chemical equation consists of symbols, we can think of this as a symbolic representation.

Keywords

- word equation
- picture equation
- chemical equation
- reactants
- product
- metal oxide

> **Did you know?**
>
> Group 1 metals are referred to as the Alkali Metals and Group 2 metals are referred to as the Alkaline Earth Metals.

Keywords

- rust
- corrosion
- corrosive
- rust-resistant
- steel

As we have said, the metals in the same group will react in the same way as each other with oxygen. So calcium reacts with oxygen in the same way as magnesium reacts with oxygen. The chemical equations also show similarities.

The chemical equation for the reaction between calcium and oxygen is:

$$2\ Ca + O_2 \rightarrow 2\ CaO$$

Questions

1. What is the product called in this reaction?
2. What group are calcium and magnesium from?

8.4 The formation of rust

Do you know what rust is? The pictures below will provide some clues.

Figure 8.4: Different objects which rust.

ACTIVITY The reaction between iron and oxygen in air

Materials

- test tube
- clamp
- retort stand
- dish
- iron filings
- water

Instructions

1. Rinse a test tube with water to wet the inside.
2. Carefully sprinkle a spatula of iron filings around the sides of the test tube.
3. Invert the test tube in a dish of water. Use a clamp attached to a retort stand to hold the test tube in place.
4. Over the three days the water must remain above the lip of the test tube.

On the right is a simple diagram showing the experimental setup with the clamp holding the test tube upright.

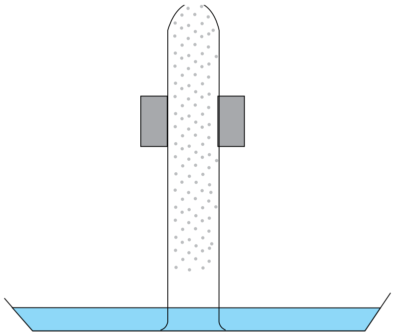


Figure 8.5: Experimental setup.

Questions

1. What do the iron filings look like at the start of the experiment?
2. What are the reactants in this experiment?
3. Is there something present that is aiding or speeding up the reaction?
4. What does the product look like at the end of the reaction?

Rust is a word to describe the flaky, crusty, reddish-brown product that forms on iron when it reacts with oxygen in the air. When your teacher burned the iron earlier, it reacted quickly with oxygen to form iron oxide. Here is a picture of iron oxide to remind you what it looked like.

Figure 8.6: A sample of iron oxide.

Rust is a form of iron oxide

When iron is exposed to oxygen in the air, a similar reaction occurs, but at much slower rate. The iron is gradually 'eaten away' as it reacts slowly with the oxygen. Under wet or moist conditions iron will rust more quickly.

Rust is actually a mixture of different oxides of iron, but the Fe_2O_3 of our earlier example is an important part of that. The rusting of iron is actually a good example of the process of **corrosion**. The equation for rusting is:

$$4Fe + 3O_2 \quad 2Fe_2O_3$$

Rusting tends to happen much faster near the ocean. Not only are there water droplets, but these droplets have salt in them and this makes them even more corrosive. Rusting also happens more quickly in the presence of acids. Inside laboratories, or factories where acids are used or stored, the air is also very corrosive. When the air in a specific area contains moisture mixed with acid or salt, we refer to the area as having a **corrosive climate**.

Figure 8.7: An abandoned car quickly rusts and corrodes near the sea.

Figure 8.8: A garden sculpture that was intended to rust to give it more texture.

If you live in a corrosive climate, for example near the ocean, it is often better to make the window frames and doors of your house from wood instead of iron and steel, because wood does not rust. Many people also use aluminium as this metal does not rust.

Keywords

- collide
- barrier
- exposed
- porous
- penetrate
- chromed metal
- galvanised metal
- galvanise
- oxidise

8.5 Ways to prevent rust

Rust forms on the surface of an iron or steel object when that surface comes into contact with oxygen. The oxygen molecules collide with the iron atoms on the surface of the object, and they react to form iron oxide. If we wanted to prevent that from happening, what would we have to do? There are 3 ways: painting, electroplating and galvanising.

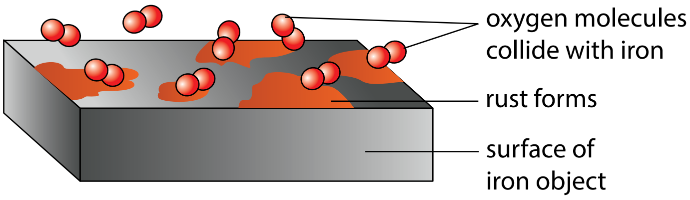


Figure 8.9: How rust forms

1. Paint provides a barrier to rust

If we wanted to prevent the iron atoms and oxygen molecules from making contact, we would need to place a barrier between them. That is what we are doing when we paint an iron surface to protect it from rust.

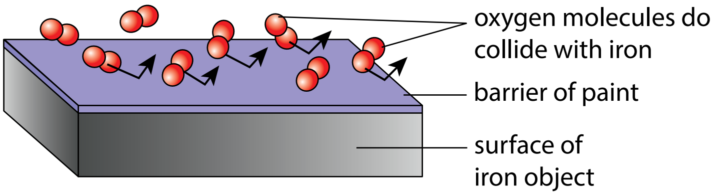


Figure 8.10: Painting to prevent rust

Paint is not the ultimate barrier, though. If the paint surface is scratched, or it starts to peel off, the metal will be exposed and rust can still form.

2. Electroplating

Electroplating is using electricity to coat with the metal with a metal that doesn't rust.

3. Galvanising

Galvanising is a process of applying a protective zinc coating to steel or iron to prevent rusting. The most common method is submerging the steel or iron parts in a bath of molten zinc.

The following diagram shows a segment of galvanised steel, with a scratch in the protective coating. What do you think will happen to the steel that is exposed to the air by the scratch in the coating?

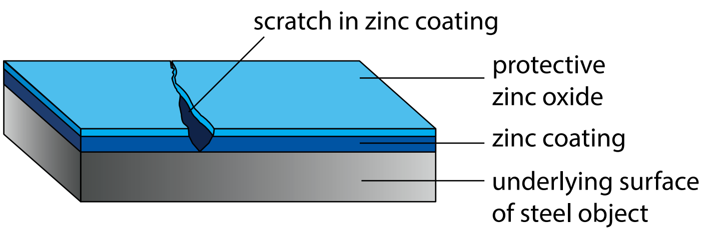


Figure 8.10: A segment of galvanised steel, showing damage to the zinc coating.

Did you know?

Zinc is in a different group from iron on the Periodic Table. This tells us that it does not react the same way as iron does with oxygen.

Iron that is galvanised is used for many different purposes. You will most probably have seen it being used as galvanised roof panels or other galvanised building materials, such as screws, nails, pipes, or floors.

Figure 8.11: Galvanised panels used for walls or roofs.

Figure 8.12: A galvanised watering can.

In this unit we learnt how metal oxides form. We saw two demonstrations of reactions in which metals oxides formed as products. Finally, we learnt about a metal oxide (iron oxide or rust) from our everyday experience as well as ways to prevent objects from rusting, especially those used in buildings and industry.

Figure 8.13: Galvanised nuts and bolts.

Figure 8.14 Galvanised flooring.

Did you know?

Cut apple slices turn brown as the iron compounds in the apple flesh are reacting with the oxygen in the air! The reaction is aided by an enzyme in the apple, so dripping lemon juice onto the slices will destroy the enzyme and prevent them from turning brown.

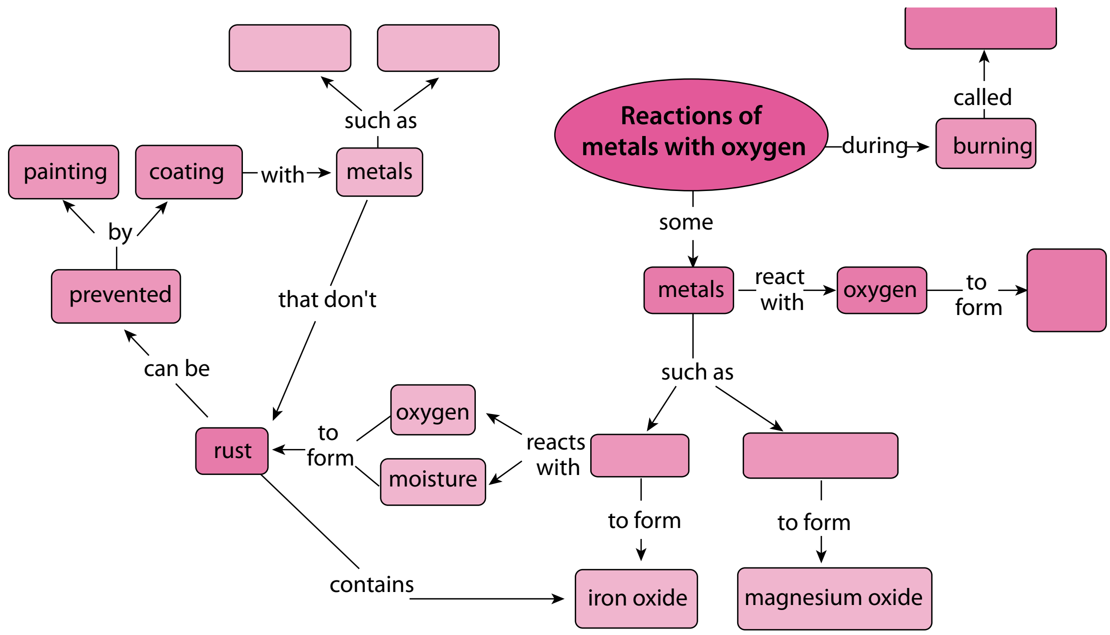
Summary

Key concepts

- When a metal reacts with oxygen, a metal oxide forms.
- The general equation for this reaction is: metal + oxygen → metal oxide.
- Some metals will react with oxygen when they burn. These reactions are called combustion reactions. Two examples of combustion reactions are:
  - Iron reacts with oxygen to form iron oxide:
    $4\ Fe + 3\ O_2 \rightarrow 2\ Fe_2O_3$
  - Magnesium reacts with oxygen to form magnesium oxide:
    $2\ Mg + O_2 \rightarrow 2\ MgO$
- Rust is a form of iron oxide, which forms slowly when iron is exposed to oxygen.
- Iron can be transformed to steel (an alloy), which is more resistant to rust.
- Rust can be prevented by coating iron surfaces with paint, or with rust-resistant metals such as chromium or zinc.

Concept map

What is the proper name for 'burning'? Fill this into the concept map. Fill in the examples of the metals that you studied in this unit. You will have to look at the products formed to know where to put which one. Lastly, give two examples of metals that you learnt about in this unit which do not rust.



Revision

1. Read the sentences and fill in the missing words. Write the completed sentences in your exercise books. [9]
   a) A chemical reaction where a compound and oxygen react during burning to form a new product is called a reaction.
   b) Magnesium + ____________ → magnesium oxide
   c) ____________ + oxygen → iron oxide
   d) copper + oxygen → ____________
   e) Another word for iron oxide is ____________
   f) Metal that is covered by a thin layers of zinc and zinc oxide is called ____________ metal.
   g) The gradual destruction of materials (usually metals) by chemical reaction with the environment is called ____________
   h) When the air in a specific area contains moisture mixed with acid or salt, we refer to the area as having a ____________ climate.
   i) The product of the reaction between a metal and oxygen is called a ____________

2. List three materials that can be used to protect iron or steel from corrosion. [3]

3. Copy and complete the table in your exercise books by providing the missing equations for the reaction between iron and oxygen. [4]

Word equation	
Chemical equation	
Balanced equation	

4. Copy and complete the table in your exercise books by providing the missing equations for the reaction between magnesium and oxygen. [4]

Word equation	magnesium + oxygen → magnesium oxide
Chemical equation	
Balanced equation	

5. Copy and complete the table in your exercise books by providing the missing equations for the reaction between copper and oxygen. [4]

Word equation	
Chemical equation	$Cu + O_2 \rightarrow CuO$
Balanced equation	

6. Copy and complete the table in your exercise books by providing the missing equations for the reaction between zinc and oxygen. [6]

Word equation	
Chemical equation	
Balanced equation	

Total [30 marks]

9 Reactions of non-metals with oxygen

Key questions

- What happens when a non-metal and oxygen react?
- How should we write equations for the reactions of carbon and sulfur with oxygen?
- Do all non-metals form dioxides with oxygen?

Oxygen is all around us in the air we breathe. It is a very **reactive** element. When an element is reactive, it means that it will readily react with many other substances. We saw evidence of the reactive nature of oxygen when we observed how it reacted with iron and magnesium to form metal oxides.

In this unit we look at a few reactions of non-metals with oxygen. Where do we find non-metals on the Periodic Table?

Keywords

- alternative
- fuel
- fossil fuel
- generate
- inert
- non-metal oxide
- non-renewable
- oxidise
- reactive
- renewable

Take note

Substances that are not reactive are called unreactive or inert.

9.1 The general reaction of non-metals with oxygen

When a non-metal burns in oxygen, a **non-metal oxide** forms as product. Here is the word equation for the general reaction:

non-metal + oxygen → non-metal oxide

Can you see that it looks similar to the word equation for the reaction between a metal and oxygen? The only difference is that the word 'metal' has been replaced with 'non-metal' on both sides of the equation. Non-metal oxides have different chemical properties from metal oxides. We will learn more about this later on in the term.

Let's look at a few specific examples of reactions in which non-metals react with oxygen. The first one is one that you are already familiar with, namely the reaction of carbon and oxygen.

9.2 The reaction of carbon with oxygen

Have you ever seen coal burning in air?

Coal is a form of carbon that is used as **fuel** for many different purposes. It is one of the primary **fossil fuels** that humans use to **generate** electricity for powering our industries, our activities and our living spaces. We will look at this in more detail next term in *Energy and Change*.

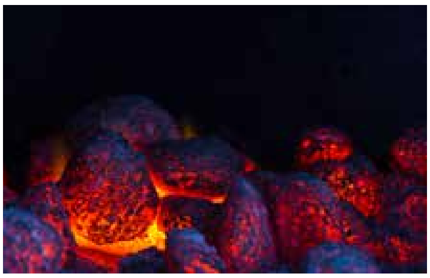


Figure 9.1: Coals burning in a fire.

Figure 9.2: A coal-powered power station.

ACTIVITY Coal burning in air

The energy in coal comes from the energy stored in plants and other organisms that lived hundreds of millions of years ago. Over the millennia, layers of dead plants and other biological waste were covered by layers of water and soil. The heat and pressure from the top layers caused the plant remains to turn into energy-rich coal.

Did you know?

37% of the electricity generated worldwide is produced from coal.

The energy released by burning coal is used to generate electrical energy in coal-powered power stations.

Coal is a form of carbon and when it burns in oxygen we can represent the reaction with the following word equation:

carbon + oxygen → carbon dioxide

Questions

1. Write a chemical equation for this reaction.
2. Balance the chemical equation you wrote.
3. In which group is carbon found in the Period Table of elements?

The other elements in the same group as carbon will react in the same way as carbon with oxygen.

9.3 The reaction of sulfur with oxygen

Keywords

- toxic
- preservative

What is the name of the product of the reaction between sulfur and oxygen? Use the name of the product and the general equation given at the start of the unit to complete the following word equation:

sulfur + oxygen →

Figure 9.3: Sulfur is a yellow substance, which burns with a blue flame in oxygen.

Figure 9.4: Sulfur mining is very dangerous to the miners who inhale the toxic sulfur dioxide gas.

Sulfur burns in oxygen to form sulfur dioxide. Your teacher will not demonstrate this reaction, because the sulfur dioxide that forms is a poisonous gas that you and your classmates should not be exposed to. Sulfur dioxide is sometimes used as a **preservative** for dried fruits, such as dried peaches and apricots and the guava rolls that many of us love to eat. The fact that it is toxic means that very small quantities of it can be added to food and drinks to preserve it. In very small quantities SO_2 does not permanently harm a large organism such as a human being, but bacteria cannot survive when it is present. Sulfur dioxide is also an important preservative in many South African wines.

Figure 9.5: Dried fruit, such as apricots, are preserved with. sulfur dioxide.

Figure 9.6: Many South African wines are preserved with sulfur dioxide.

ACTIVITY The reaction between sulfur and oxygen

In the following activity we are going to review word equations, picture equations and chemical equations, using the reaction between sulfur and oxygen as our context.

You wrote the word equation for the reaction between sulfur and oxygen above. Did you write the following?

sulfur + oxygen → sulfur dioxide

Questions

1. In what group do we find sulfur in the Periodic tTble of elements?
2. What are the reactants of this reaction? Write their names and formulae.
3. What is the product of the reaction? Write its name and formula.
4. Now, use the formulae of the reactants and products to write a chemical equation.
5. When is a reaction balanced?
6. Is your reaction above balanced? Why do you say so?
7. Draw a picture equation for the reaction, using the example of carbon above as guide.
8. Use play dough or clay to build models of the reactants and products of the reaction. This is what your starting reactants could look like:

Figure 9.7

Challenge question: How many bonds were broken and how many bonds were formed during this reaction?

Did you know?

The archaic (very old) name for sulfur is 'brimstone'.

Keywords
- dioxide
- systematic name

Take note

You may not cover this section in class as it is an extension.

9.4 Other non-metal oxides

We have looked at two examples of non-metals reacting with oxygen to form non-metal oxides. Both of our examples had a **dioxide** as product (carbon dioxide and sulfur dioxide). Do all non-metals form non-metal dioxides when they react with oxygen? What do you think?

Not all non-metal oxides are dioxides, as the following examples show.

The reaction between phosphorus and oxygen

Phosphorus is a very reactive non-metal. Can you remember what reactive means?

When phosphorus reacts with oxygen the chemical equation for the reaction is the following:

$$4\,P + 5\,O_2 \rightarrow 2\,P_2O_5$$

How many phosphorus atoms are in P_2O_5? How many oxygen atoms are in P_2O_5?

What is the **systematic name** of the product of this reaction? (If you are unsure how to name it, sneak a peek at Unit 6!)

Can you write a word equation for this reaction?

Our final example is a compound with which you should be very familiar!

The reaction between hydrogen and oxygen

Hydrogen and oxygen also react spectacularly. The reaction between a large quantity of hydrogen and oxygen in the air produces a beautiful orange fireball and a very loud boom! (You can watch the video in the visit box to see this in slow motion.)

Here is a diagram to show what is really happening to the compounds in this reaction. The purpose of the candle shown in the picture is to set the hydrogen gas alight, in other words, to provide enough energy for the reaction to start.

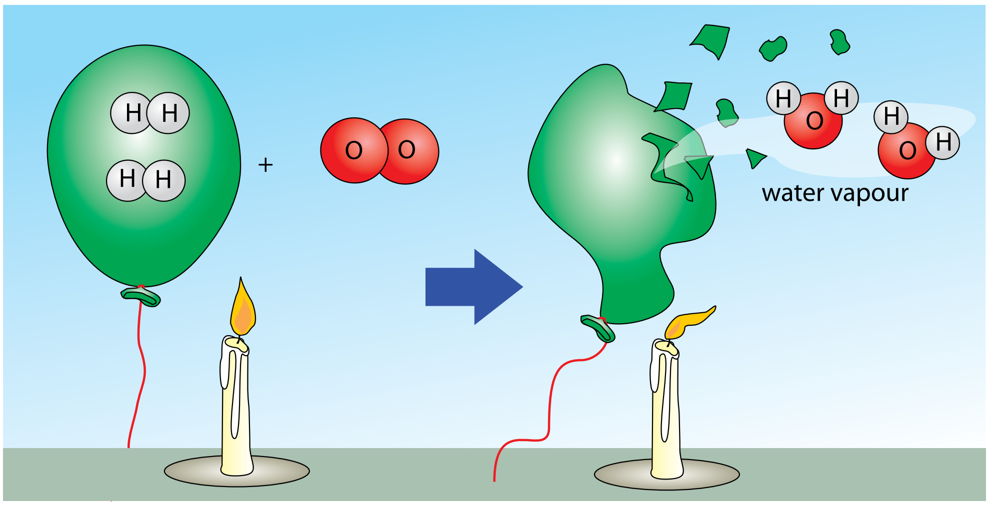


Figure 9.8

Can you complete the following chemical equation? The reaction is between hydrogen and oxygen. Write the product where it belongs.

$2\ H_2 + O_2 \rightarrow$

What is the common name of the product of this reaction? What is the systematic name of the product of this reaction? (If you are unsure how to name it, sneak a peek at Unit 6!)

Figure 9.9: In 1937, a German airship exploded and fell to the ground in a huge fireball as the hydrogen gas which kept it floating ignited and reacted with the oxygen in the air.

Did you know?

When a substance reacts with oxygen, we say it oxidises. It is called an oxidation reaction. Early chemists used the term oxidation for all reactions in which oxygen was a reactant. The definition of an oxidation reaction is broader and includes other reactions which you will learn about in Grade 10 if you continue with Physical Sciences.

Summary

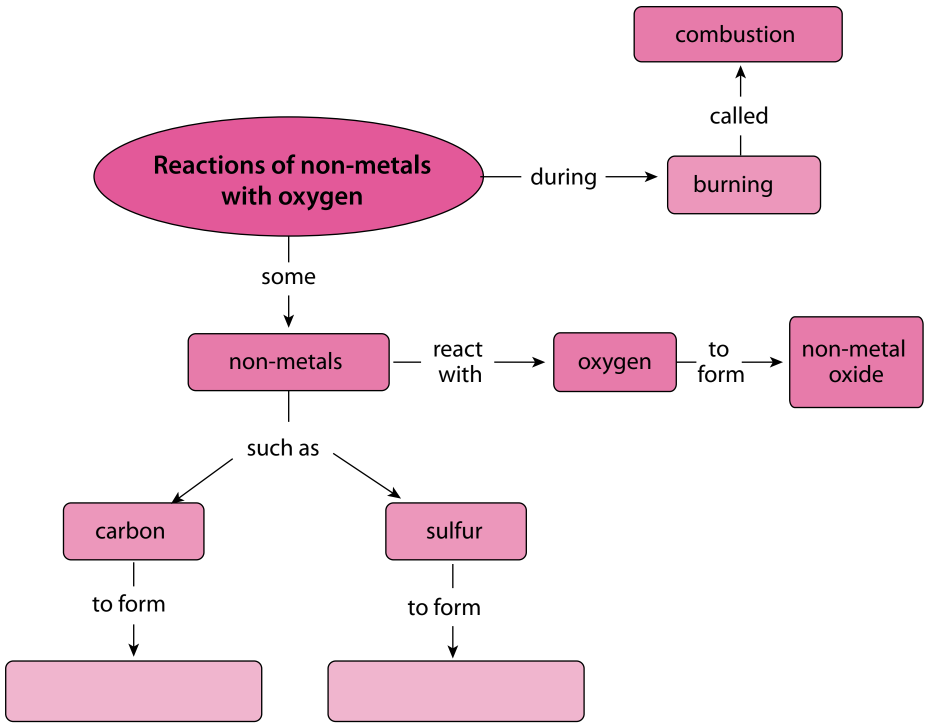
In this unit we have learnt about some of the reactions between non-metals and oxygen. Some of the skills that we practised during this unit were: writing equations (word, picture and chemical equations), and naming compounds.

Key concepts

- Non-metals react with oxygen to form non-metal oxides.
- The non-metal and oxygen gas (O_2) are the reactants in this type of reaction, and a non-metal oxide is the product.
- The reactions of carbon and sulfur with oxygen are examples of non-metals reacting with oxygen.
- Carbon and sulfur both form dioxides with oxygen, but this is not true of all non-metals.

Concept map

Complete the concept map on the following page. What will you fill in for the products when the two different non-metals react with oxygen during combustion?



Revision

1. Fill in the missing words in these sentences. Write the completed sentences in your exercise books. [5]

a) A substance that will react readily with many other substances is called a ___________________ substance.

b) Substances that do not react with other substances and do not change into other compounds are called ___________________ or ___________________.

c) When a non-metal reacts with oxygen the product of the reaction is a ___________________.

d) When a compound reacts with oxygen, we say it has become ___________________.

2. In your books, write a short paragraph (3 or more sentences) to explain what you understand each of the following terms to mean, in your own words. [3 × 3 = 9]

a) systematic name

b) preservative

c) non-renewable energy source

3. For each of the following reactions, write a word equation, a chemical equation, and a picture equation in your exercise books.

a) The reaction between carbon and oxygen. [6]

b) The reaction between sulfur and oxygen. [6]

Total [26 marks]

10 Acids, bases and pH value

Key questions

- What measurement can we use to decide whether something is an acid or a base?
- What does 'the pH scale' refer to?
- How can we measure the pH of a substance?
- What does it mean if a substance has a pH below 7?
- What does it mean if a substance has a pH above 7?
- What does it mean when a substance has a pH equal to 7?
- How does a universal indicator respond to substances that are acidic, basic, or neutral?

Keywords
- unit
- acidity
- pH

10.1 What is the pH value?

In Grade 7 we learnt about acids and bases. Can you remember how to distinguish between them? Here is a table that highlights the main characteristics of acids and bases.

Acids	Bases
• Taste sour • Feel rough between your fingers • Can be corrosive • Can make bases lose their basic character • Turn blue litmus red	• Taste bitter • Feel slippery between your fingers • Can be corrosive • Can make acids lose their acidic character • Turn red litmus blue

We used the criteria in the table above to classify a number of substances as either acids, bases, or neutral substances. The table below contains some examples and shows their classification.

Acids	Bases	Neutral substances
Orange juice Vinegar Lemon juice Citric acid Gastric acid (stomach acid)	Bicarbonate of soda (baking soda) Soaps Bleach Ammonia solution	Distilled water Table salt solution Cooking oil

Finally, we learnt that there are substances that we can use that will show whether we have an acid or a base. Can you remember what they were called? Hint: They indicate, or show, whether we have an acid or base.

Indicators can show us if a substance is an acid or a base. In this unit we are going to link some important new learning to what we already know about acids and bases.

Measuring acidity and basicity

The numerical scale that we use to measure the **acidity** and **basicity** of a substance (how acidic that substance is) is called **pH**. We pronounce the two letters, 'p' and 'H' separately when we say pH.

Have you ever heard the term pH?

Perhaps you have heard of a certain shampoo being 'pH balanced', or a skin soap that is 'neutral'. Perhaps you have heard that it is important for the water in a swimming pool to have 'the right pH'?

The pH scale ranges from the values of 0 and 14.

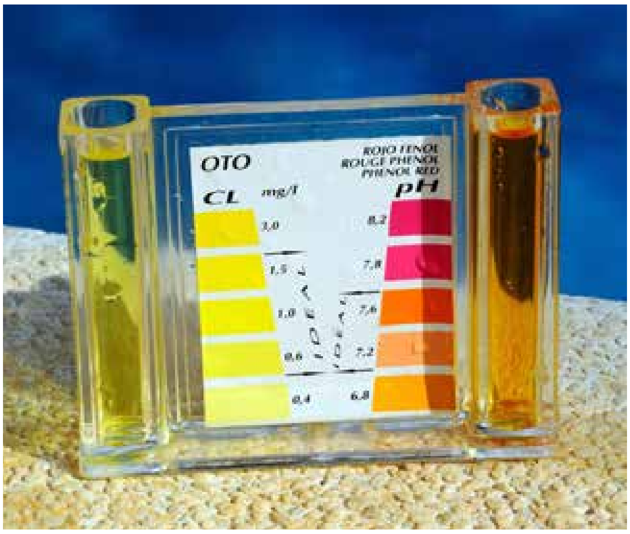


Figure 10.1: A kit for testing swimming pool water pH.

In science and in everyday life, we measure the acidity of substances in pH units. We could say that the 'acidity' of a specific shampoo has a pH of 5,5. pH is the unit of measurement and 5,5 is be the number indicating the relative acidity on the pH scale. It has become acceptable, however, for us to rather say: 'The pH of this shampoo is 5,5.'

In the next activity, we are going to get to know the pH scale a little better.

Did you know?

The term 'pH' was first described by Danish biochemist Søren Peter Lauritz Sørensen in 1909. The definite origin is disputed, but it is widely accepted that pH is an abbreviation for 'power of hydrogen' where 'p' is short for the German word 'potenz' (meaning power or exponent of) and H is the element symbol for hydrogen.

ACTIVITY The pH scale

Instructions

1. In the following picture the pH values of a variety of substances are shown on the pH scale.
2. Use the picture to answer the questions.

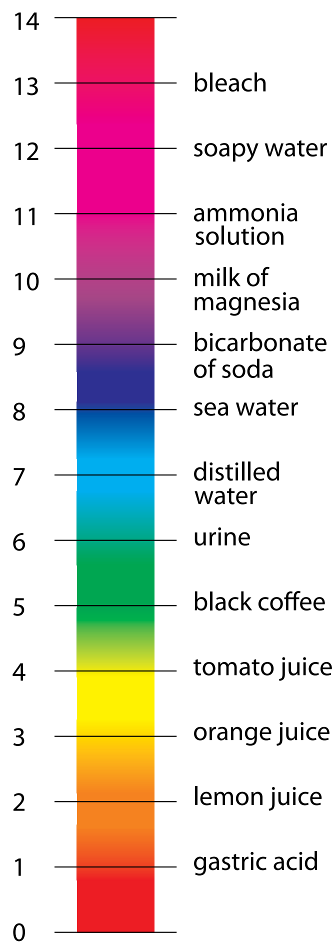


Figure 10.2: The pH scale.

Questions

1. Which of the substances in the table at the start of this unit can you find on the pH scale alongside? Copy the table into your exercise books and write their names and approximate pH values.

Name of substance	Approximate pH

2. Circle the names of all the acids in the table above with a red pen or koki.
3. Write the lowest and highest pH values of these acids. This represents the pH range of the acids on our list.
4. Does this range lie below or above pH 7?
5. Circle the names of all the bases in the table above with a blue pen or koki on the pH scale above.
6. Write the lowest and highest pH values of these bases below. This represents the pH range of the bases on our list.
7. Does this range lie below or above pH 7?
8. Find distilled water on the scale and circle it with a green pen or koki. Is water an acid or a base? Or is it perhaps something else?
9. What is the pH of water?
10. Which do you think is more acidic: orange juice or lemon juice? If you are not sure, ask yourself this question: Which one is more sour?
11. Which one has the lower pH: orange juice or lemon juice?

In the above activity we learnt a number of important things:

- Acids have pH values below 7;
- Bases have pH values above 7; and
- Neutral substances have pH values equal to 7.

This information has been summarised visually in the following diagram.

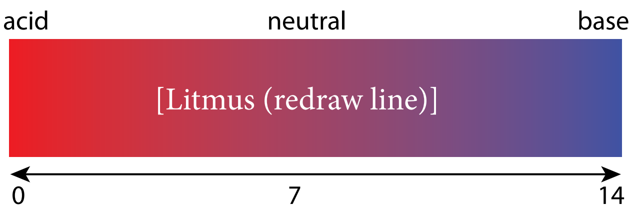


Figure 10.3

We saw in the activity that lemon juice, which is sourer than orange juice, has a lower pH than orange juice. Does that mean that the relative pH of a substance will tell us how acidic or basic it is?

Can we measure how acidic or basic something is?

When we compared orange juice and lemon juice earlier, we learnt something important: The lower the pH of a substance, the more acidic it is. For bases we can state the following: The higher the pH of a substance, the more basic it is.

Here is a summary:

- The closer to pH 1, the more strongly acidic the solution;
- The closer to pH 14, the more strongly basic the solution; and
- pH 7 is a neutral substance.

The pH value of a substance tells us if it is an acid or a base.

But how do we measure pH? One way to measure pH is with the help of acid-base indicators. Can you remember what they are? The next section will refresh your memory.

10.2 Indicators

Keywords

- indicator
- litmus
- universal indicator
- red cabbage indicator

What is an acid-base-indicator?

We know that some substances change colour when they react with an acid or a base. These substances are called acid-base indicators, which can show us if a substance is an acid or a base.

Different indicators change colour at different pH values. The table below shows a selection of acid-base indicators and the colours they will have at different pH values.

Indicator	Colour in acid (pH < 7)	Colour at pH = 7	Colour in base (pH > 7)
Red cabbage water	red, pink	purple	blue, green, yellow
Red onion water	red	violet	green
Tumeric water	yellow	yellow	red
Phenolphthalein	colourless	colourless	pink, red
Bromothymol blue	yellow	green	blue
Red litmus	red	red	blue
Blue litmus	red	blue	blue
Universal indicator	red, orange, yellow	green	blue, violet, purple

We made an indicator from red cabbage and even made some **red cabbage indicator** paper. Can you find red cabbage water on the table above?

- In acids, the red cabbage water will turn red or pink. In neutral solutions it will be purple or violet. Which colours will the red cabbage indicator be when it is mixed with a base?
- If red cabbage indicator is mixed with something that is only slightly basic, it will turn blue. If it is mixed with something that is strongly basic, it will turn yellow.

When you look at the table above and you compare the information given for red cabbage water with the picture on the right, the colour changes you observed in the red cabbage water will make sense!

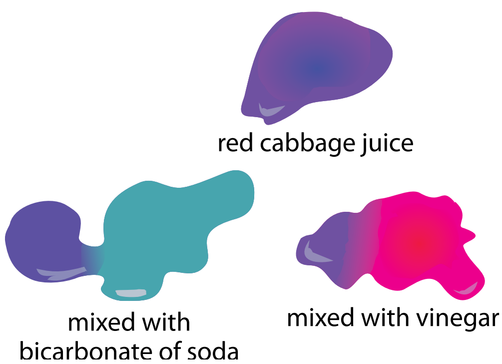


Figure 10.4: Red cabbage water mixed with base (left) and with acid (right). The blue drop at the top is the juice in a neutral solution (water).

You may recall that we also learnt about **litmus**, the most widely used of all acid-base indicators. Can you find litmus on the table of indicators?

Litmus does not change colour in the presence of a neutral substance, but responds to acids and bases in the following way:

- litmus is red in the presence of an acid; and
- litmus is blue in the presence of a base.

Litmus can be bought as a solution or as litmus paper, although the paper is more commonly used.

By changing to different colours in the presence of an acid or a base, indicators can show us if a substance is an acid or a base. In the next section we are going to learn about a special indicator that is so sensitive that it not only tells us whether a substance is an acid or a base, but also what its approximate pH is!

Figure 10.5: Blue and red litmus paper

Universal indicator

Did you know?

Universal indicator can display so many colours because it is actually a mixture of several different indicators.

Unlike litmus, **universal indicator** can show us much more accurately how acidic or basic a solution is. Can you find universal indicator on the previous table of indicators? Universal indicator can change into a whole range of colours, depending on the pH of the solution. In the following picture, solutions of increasing pH were mixed with universal indicator to show its full range of colours.

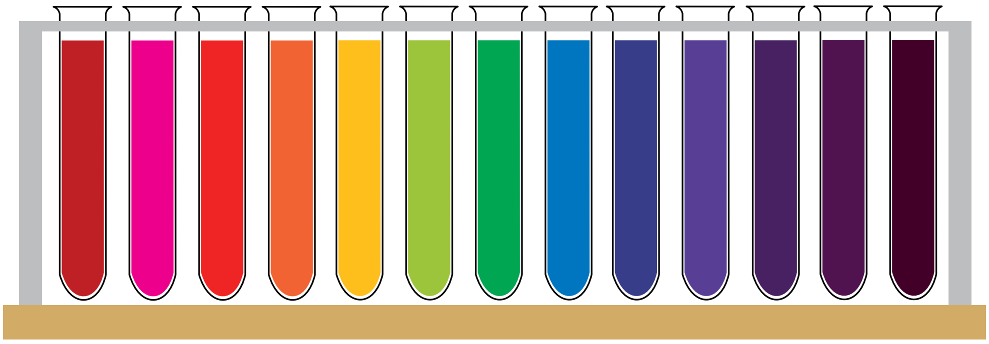


Figure 10.6: Universal indicator can have many different colours, from red for strong acids to dark purple for strong bases. The liquid inside the middle test tube is neutral (pH = 7), which is shown by the green colour of the indicator.

Like litmus, universal indicator also comes in paper form, with the pH colour range of the indicator printed on the packaging.

In the next investigation we will test a number of household substances with red cabbage indicator paper and with universal indicator paper.

Figure 10.7: Universal indicator paper

Investigation: Universal indicator paper and red cabbage indicator paper

The purpose of this investigation is to determine whether universal indicator and red cabbage can be used to show whether one substance is more acidic or basic than another.

Investigative question

What question are we trying to answer with this investigation?

Hypothesis

What do you think the answer to the investigative question is? You should try to make a prediction.

Identify variables

1. What will you be changing in this investigation? What is this variable called?
2. What will you be measuring in this investigation? What is this variable called?
3. What will you keep the same? What is this variable called?

Materials and apparatus

- small containers (test tubes or yoghurt tubs) containing the following substances:
  - distilled water
  - soda water
  - vinegar
  - lemon juice
  - sugar solution (1 tablespoon dissolved in a cup of water)
  - baking soda (bicarbonate of soda) (1 tablespoon dissolved in a cup of water)
  - Handy Andy (1 tablespoon dissolved in a cup of water)
  - aspirin (Disprin) (1 tablet in 2 tablespoons of water)
  - dishwashing liquid (1 teaspoon dissolved in a cup of water)
  - any other substances commonly used at home that are not dangerous.
- universal indicator paper
- red cabbage indicator paper
- glass or plastic rods (plastic teaspoons or straws will also work well)
- white tile or sheet of A4 printer paper.

Method

1. Use a small strip (1 cm long) of universal indicator paper for each substance that you will be testing. Place them on a sheet of printer paper or a white tile.

Take note

Do not use strong acids or bases, or bleach. Suggestions include: tea, coffee, rooibos tea, milk, tartaric acid, salt water, Sprite.

2. Dip the glass rod or straw into the first solution and transfer a drop of it to the first piece of universal indicator paper. Does the paper change colour? Write the colour of the paper with each substance in your table, in the appropriate place.
3. Compare the colour of the test strip with the colour range on the packaging of the universal indicator paper roll to find the pH of the solution. Write this in your table as well.
4. Rinse the straw very thoroughly with tap water before testing the next solution. Do so every time you move from one solution to the next.
5. Test all the solutions and record their colours.
6. Save the solutions to test them again with red cabbage indicator paper.
7. Use a small strip (2 cm long) of red cabbage paper for each substance that you will be testing.
8. Dip a fresh piece of paper into each of the test solutions and place it on the tile or white paper to dry. For each test solution, write the colour of the red cabbage paper in the table in the appropriate place.

Results and observations

Copy the table below into your exercise books and record your observations.

Substance	Colour with universal indicator paper	pH of the substance	Colour with red cabbage paper
Water			
Soda water			
Vinegar			
Lemon juice			
Sugar water			
Bicarbonate of soda			
Handy Andy			
Aspirin			
Dishwashing liquid			

1. Sequence the substances that you tested according to the colour change of the universal indicator, from the most acidic (darkest red) to the most basic (purple).

Questions

1. Which of the test substances are acids?
2. Which of the test substances are bases?
3. Which of the test substances are neutral substances?
4. Which substance is the strongest acid?
5. Which substance is the strongest base?

6. Count all the different colours that were possible with the red cabbage.
7. What colour(s) did the red cabbage paper turn in the test substances that were acids?
8. What colour(s) did the red cabbage paper turn in the test substances that were bases?
9. What colour(s) did the red cabbage paper turn in the test substances that were neutral?
10. Do you think red cabbage indicator can actually be used to measure pH? Why or why not?

Conclusions

What is your conclusion(s)? (Here you should answer the investigative question.)

Something to think about: Extension question

What could we do to make red cabbage indicator suitable for measuring pH?

In the last investigation we explored whether or not universal indicator paper or red cabbage indicator paper could tell us whether a substance is more acidic or basic than another. The advantage of using universal indicator over other indicators is that universal indicator can give us more accurate pH measurements. This is because it has different colours for different pH values. Most other indicators change colour only once or twice over the entire pH range.

Many other colourful foods can be used to make acid-base indicators. Check out the diagram below for some examples. You could even try out a few of them at home!

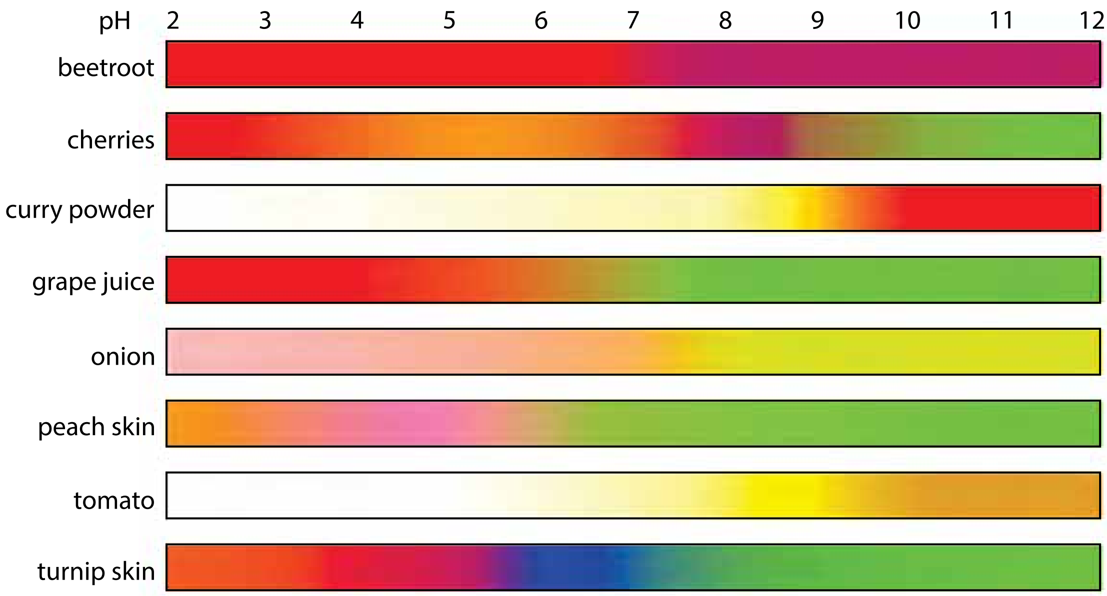


Figure 10.8: pH indicators made from edible substances.

Take note

Universal indicators give a range of colours that can be used to determine the pH of a solution. Litmus paper can indicate only whether a solution is acidic, neutral or basic.

Measuring pH with indicator solutions or paper is easy, economical and convenient if we have only a few measurements to make. If we have many pH measurements to make, tearing and dipping paper strips and matching them up with a colour chart can become quite tedious and time-consuming.

What other quick and easy ways are there to measure pH?

How else can we measure pH?

Scientists use a pH meter to quickly and accurately measure the pH of a substance. While they are much more expensive to purchase than indicator paper or solution, they are a worthwhile investment for a laboratory that has to make many pH measurements daily and needs these measurements to be done quickly.

Figure 10.9: A portable pH meter.

A pH meter is an electronic instrument with a special sensor at the end that is sensitive to acids and bases. This is more accurate than the universal indicator. Help the scientist to read the pH of the solutions in the photos and classify them as acidic, neutral or basic!

In this unit we have learnt about the pH scale. We have also learnt how to make pH measurements and how to interpret pH values.

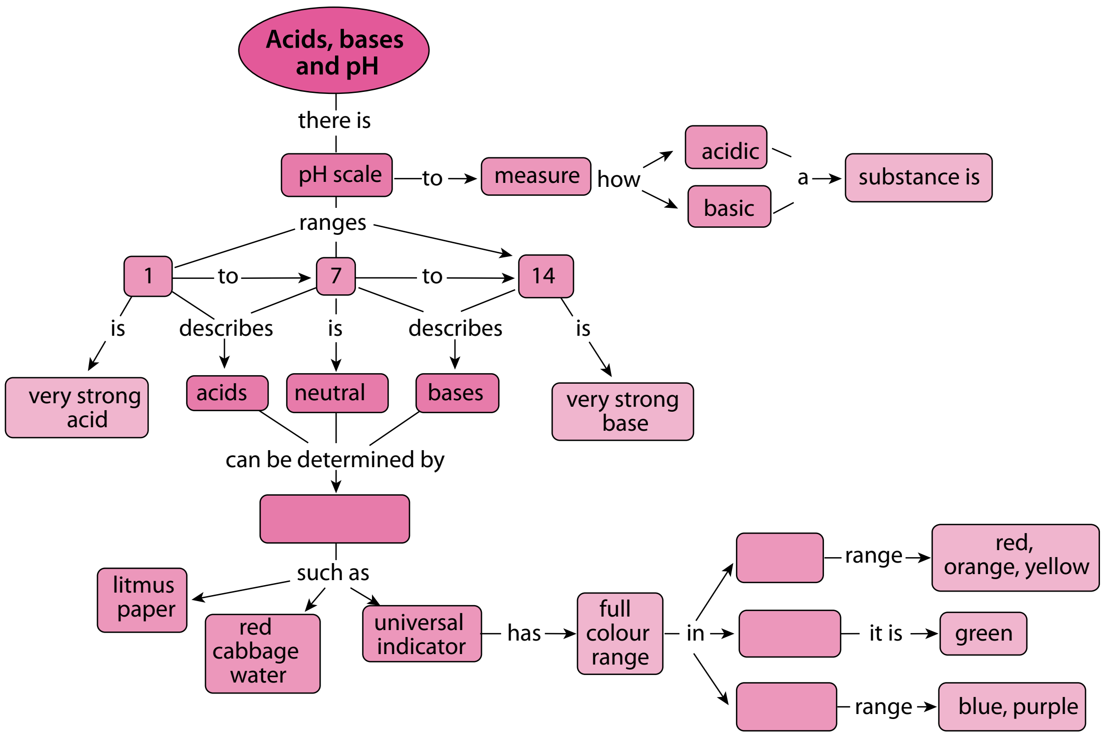
Summary

Key concepts

- When we want to decide whether a solution (in water) is acidic or basic, we can measure its pH.
- One of the ways pH can be measured is with an acid-base indicator, such as a universal indicator.
- An acid-base indicator is a substance that changes its colour depending on the pH of the solution to which it is added.
- The pH scale ranges between 0 and 14:
  - Acids have pH values lower than 7;
  - Bases have pH values higher than 7; and
  - Neutral substances have pH values approximately equal to 7.
- How acidic or basic a solution is, depends on its relative pH value:
  - The more acidic a solution is, the closer its pH value will be to 0; and
  - The more basic a solution is, the closer its pH value will be to 14.

Concept map

What can you use to determine whether a substance is an acid, base or neutral? Fill this in on the concept map. Finally, complete it by completing the information for the universal indicator. Fill in acid, base or neutral, depending on the colours listed.



Revision

1. Fill in the missing words in these sentences. Write the complete sentences in your exercise books. [6]

a) Something which shows whether a substance is an acid or a base, by changing colour when we add it to that substance, is called an ________________.

b) The pH scale ranges between the values ________________ and ________________.

c) ________________ have pH values less than 7.

d) Bases have pH values ranging between ________________.

e) ________________ substances have pH values approximately equal to 7.

2. Imagine we start with a beaker of clean, distilled water. Answer the following questions. [4]

a) What will be the pH of the clean, distilled water?

b) How will the pH change if we add a small amount of acid to the water?

c) How could we get the pH to increase?

d) How could we get the pH to increase to a higher value, for example 13?

3. In the following picture, the three beakers contain three different solutions. Red cabbage water was added to each of the beakers. Answer the following questions. [4 × 2 = 8]

A

B

C

a) Which solution, A, B or C, is the most acidic? Motivate your answer.

b) Which solution, A, B or C, is the most basic? Motivate your answer.

c) Which solution, A, B or C, is neutral? Motivate your answer.

d) What do you think would happen to the colour of solution A if we mixed it with solution B? Motivate your answer.

4. A scientist is given 6 solutions labelled A to F. The scientist tests each solution with universal indicator and records her results as follows:

Solution	Colour of universal indicator
A	Yellow
B	Blue
C	Green
D	Red
E	Purple
F	Orange

Use the results in the table and the colour guide for universal indicator underneath the table to answer the following questions: Copy the table below into your exercise books and answer the questions.

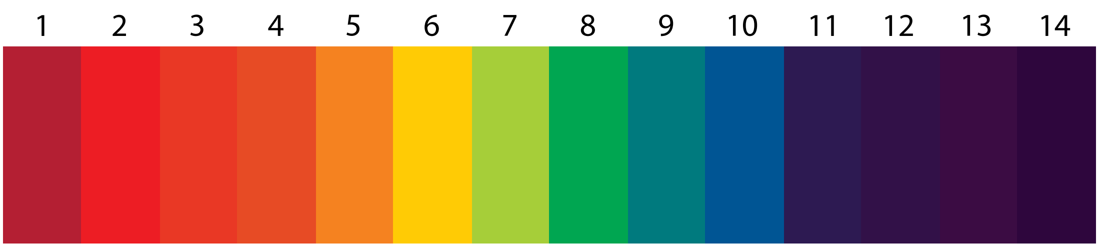
a) Which solutions are acidic? [2]

b) Which solutions are basic? [2]

c) Which solution is neutral? [2]

d) Copy the table below into your exercise books and use it to arrange the solutions in order from most acidic to most basic. Also write the colour and the approximate pH range of each solution. [6]

Solution	Colour of the solution	Approximate pH range of the solution



Total [30 marks]

11 Reactions of acids with bases

Key questions

- What is the reaction between an acid and a base called?
- What happens to the pH when an acid and a base are mixed?
- Does the reaction between an acid and a base always give a neutral mixture, in other words a mixture with pH = 7?
- Which factors will determine the pH of the final solution when an acid and a base are mixed?
- Is there a way to predict which classes of compounds will tend to be acids and which will tend to be bases?
- Are metal oxides, metal hydroxides and metal carbonates acidic or basic? Which pH range will their solutions fall into?
- What products can we expect when a metal oxide, a metal hydroxide or a metal carbonate react with an acid?
- Are there general equations to explain these reactions?
- How does acid rain form?

Keywords

- neutralisation reaction
- neutralise
- neutral solution
- potency
- detour
- exchange reaction
- laboratory acids
- corrosive
- acid rain

11.1 Neutralisation and pH

In the previous unit we learnt about a new concept, namely pH. If we want to know whether something is an acid or a base, we can measure its pH:

- Acids have pH values below 7. The lower the pH value, the more strongly acidic the substance.
- Bases have pH values above 7. The higher the pH value, the more strongly basic the substance.
- Neutral substances have pH equal to 7.

Another useful thing we learnt in the previous unit is that we can use universal indicator to measure the pH of a solution. Universal indicator has different colours at different pH values. Below is a colour chart showing the range of colours for universal indicator and the pH values they correspond to.

You will need it for all the activities of this unit, because we are going to do lots of pH measurements!

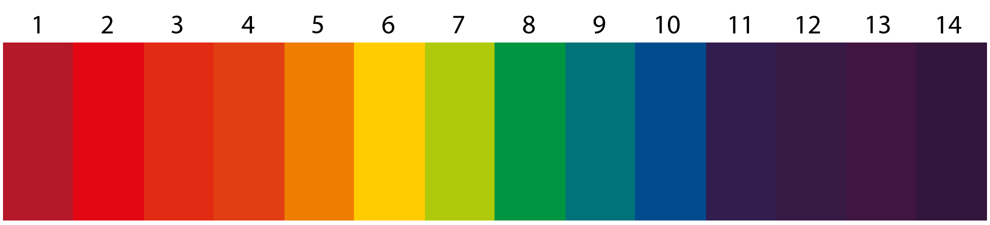


Figure 11.1

Can you remember how we used the universal indicator paper in the previous unit?

Is bicarbonate of soda an acid or a base? If you are not sure, turn back to the previous unit and look at the activity 'The pH scale'.

Investigation: The reaction between vinegar and bicarbonate of soda

The purpose of this experiment is to investigate how the pH changes when vinegar is added to bicarbonate of soda.

Investigative question(s)

What question do you hope to answer with this investigation?

Overview of the investigation

1. We will measure the pH of a solution of bicarbonate of soda with universal indicator paper to confirm whether it is acidic or basic. What range do you expect the pH of this solution to fall in?
2. We will add vinegar to the bicarbonate of soda solution in small portions and measure the pH after each portion has been added. What changes do you expect to observe? Will the pH increase, decrease or stay the same?

Hypothesis

What is your prediction? Your hypothesis should be a prediction of the finding(s) of the investigation. You should write it in the form of a possible answer to the investigative question.

Materials

- bicarbonate of soda
- vinegar
- water
- glass beaker or small yoghurt tub
- universal indicator paper (cut into 1 cm strips)
- sheet of white printer paper
- plastic teaspoon

Method

1. Prepare the universal indicator paper by neatly placing five 1 cm pieces underneath each other on the sheet of paper.
2. Place one teaspoon of bicarbonate of soda in the beaker or yoghurt tub.
3. Add approximately 10 teaspoons of water to the bicarbonate of soda.
4. Use the teaspoon to stir the solution until all the bicarbonate of soda has dissolved.
5. We will be calling this the 'test solution' from now on.
6. Transfer one drop of the test solution onto the first piece of universal indicator paper using the teaspoon or a straw.
7. Compare the colour of the paper with the colour guide given at the start of the unit, to find the pH of the solution. Record this pH in your results table.
8. Add 1 teaspoon of the vinegar to the test solution. Stir it gently and transfer another drop of the solution onto a fresh strip of the universal indicator.

9. Read the pH of the solution off the colour guide and record it in your results table.
10. Repeat steps 6 and 7 until the pH of the test solution drops below 7. You may need more than 5 pieces of universal indicator paper.

Results

Present your results in a neat table. Use appropriate headings for your table. 'Number of teaspoons of vinegar added' and 'Colour of the universal indicator paper' and 'pH of the test solution' are suggested headings for your columns.

Draw a line graph to illustrate your results. What will be on the *x*-axis and what will be on the *y*-axis? Give your graph a heading.

Conclusions

What conclusions can be made from the results of your investigation? Here you can rewrite your hypothesis, but change it to reflect your findings if they are different from what you predicted earlier.

Were you able to confirm or reject your hypothesis?

In this investigation, you probably noticed that the pH of the mixture dropped every time you added more vinegar to the bicarbonate of soda! Why did this happen?

When an acid and a base are mixed (in the right amounts), they will neutralise each other. That means that, together, they will change into something that is neither an acid nor a base. So, the acid will lose its 'acidity' and the base will lose its basicity.

What have we learnt so far? We have learnt that acids and bases neutralise each other:

- If we add a base to an acid, the pH of the resulting solution will increase, because the acid will lose some of its **potency**.
- If we add an acid to a base, the opposite will happen. The pH will decrease, because the base will lose some of its potency.

What are the products of an acid-base reaction? Can we predict what they will be?

The products of acid-base reactions

In order to understand how an acid-base reaction works, we have to take a quick detour and say something about exchange reactions. Acid-base reactions are **exchange reactions**.

In the reaction below, two substances AB and CD are undergoing an exchange reaction:

$$\mathbf{AB + CD \rightarrow AD + CB}$$

Can you see that A and C have exchanged partners so that A is now combined with D, while C combined with B?

What does this have to do with acids and bases? Well, acids and bases undergo exchange reactions too. Here are some examples. See if you can figure out which parts have exchanged with which.

Example 1

HCl + NaOH → NaCl + HOH

In the above equation HOH should actually be written: H_2O. The reaction equation becomes:

$HCl + NaOH \rightarrow NaCl + H_2O$

or, in words:

hydrochloric acid + sodium hydroxide → sodium chloride + water

In this example, the following happened:
- the acid gave its H towards making a water molecule;
- the base gave OH towards making a water molecule; and
- the Na from the base and the Cl from the acid combined to form a salt.

Example 2

$2\ HCl + MgO \rightarrow MgCl_2 + HOH$

In the above equation HOH should actually be written: H_2O. The reaction equation becomes:

$2\ HCl + MgO \rightarrow MgCl_2 + H_2O$

or, in words:

hydrochloric acid + magnesium oxide → magnesium chloride + water

In this example, the following happened:
- the acid gave 2 H atoms towards making a water molecule;
- the base gave OH towards making a water molecule; and
- the Mg from the base and the 2 Cl atoms from the acid combined to form a salt.

Acid-base reactions always produce **water** and a **salt**. In both of the examples above the general equation was:

acid + base → salt + water

There is one class of acid-base reactions that produces an additional product, but we will learn more about that later.

Did you know?

In Grade 11 you will learn that the mechanisms of these reactions are actually slightly more complex than this, but for now, understanding it at this level is good enough.

Which laboratory acids should we know about?

When we investigated acids and bases in the previous unit, we considered only household acids such as lemon juice and vinegar. There are a few **laboratory acids** that you should know the names and formulae of. They are listed in the following table:

Name of the acid	Formula of the acid
hydrochloric acid	HCl
nitric acid	HNO_3
sulfuric acid	H_2SO_4

These acids are very **corrosive**, even when they have been diluted with water, and should always be handled with great care.

Figure 11.2: Hydrochloric acid is the acid we will be using in our investigations in this unit.

Figure 11.3: Look out for this label on bottles which contain corrosive substances, such as strong acids.

In the next sections will discuss the classes of substances that are typically acids or bases. Two important things to remember are the following:

- Non-metal oxides form acidic solutions when they are dissolved in water.
- Metal oxides, metal hydroxides and metal carbonates all form basic solutions when they are dissolved in water.

First, we will look at the non-metal oxides.

Did you know?

Carbonic acid is added to soft drinks to make them fizzy. The carbonic acid decomposes and forms carbon dioxide (CO_2)

Non-metal oxides form acidic solutions

Can you name a few non-metal oxides? Write down their formulae. If you are not sure you can take a peek at the Periodic Table and pick a few non-metals from the right-hand side of the table. Add oxygen and you have a non-metal oxide!

How do we know that non-metal oxides form acidic solutions? Experiments have shown this.

You may not know this, but when CO_2 gas is bubbled through water some of it dissolves in the water to form carbonic acid. Here is the reaction equation:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

To see this happen, try the following quick activity.

ACTIVITY CO_2 bubbled through water

Materials

- tap water
- glass
- straw
- indicator paper

Instructions

1. Test the pH of clean tap water. It should be approximately 7. How would you do that?
2. Now exhale into the water using a straw. Your breath contains CO_2 and some of this will dissolve in the water if you carry on doing this for a few minutes.
3. If you measure the pH of the solution now, you will see that it has decreased! What do you think the pH will be?

Figure 11.5

The pH of the solution is now below 7 because it contains carbonic acid (H_2CO_3). Carbonic acid is not a very strong acid, but still acidic enough to have a pH lower than 7.

When sulfur dioxide (a gas) is bubbled through water it dissolves in the water to form an acid called sulfurous acid:

$$SO_2 + H_2O \rightarrow H_2SO_3$$

These are two of the reactions that produce a phenomenon called acid rain. SO_2 and CO_2 are released as waste products from factories and power stations. For example, burning wood and fossil fuels releases carbon dioxide and sulfur dioxide into the atmosphere. These gases then dissolve in water droplets in the atmosphere to form acids, in a similar way that the CO_2 in your breath dissolved in the water in the last activity to produce an acidic solution. When it rains, these acids are present in the raindrops that fall back to earth. Sulfurous acid (H_2SO_3) is strong enough to damage plant life and to acidify water sources.

Did you know?

Volcanoes also release non-metal oxides into the air (mainly SO_2) that can contribute to acid rain.

Figure 11.6: Acid rain forms when CO_2 and SO_2 from factories and other air pollutants combine with water in the atmosphere.

Figure 11.7: A forest that has been destroyed by acid rain.

ACTIVITY What is acid rain?

For the next activity, you have to do some research on acid rain.

Instructions

1. Study the diagram showing how acid rain forms.
2. Do some extra reading and research about acid rain.
3. Answer the questions about acid rain.

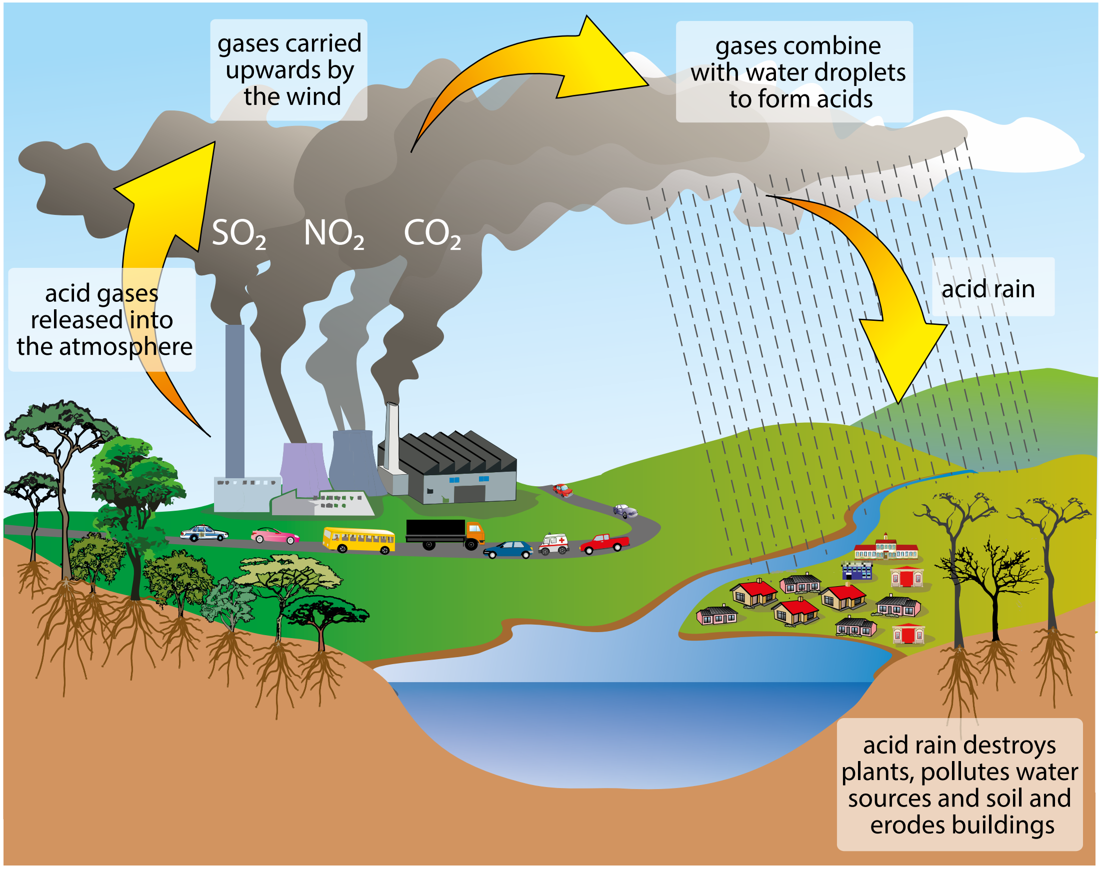


Figure 11.8: Formation of acid rain

Questions

1. Which three gases are shown in the diagram that contribute to the formation of acid rain? Write their names and formulae.
2. What are some of the sources of these gases? You can do some extra reading about this to help you answer this question.
3. Write the equations for how two of these gases which you have learnt about react with the water in the atmosphere to form acids.
4. What are the names of these two acids?
5. What are some of the environmental impacts of acid rain? Study the diagram for some clues and do some extra reading.
6. Acid rain can also damage buildings as it 'eats away' the stone. What property of acids allows it to do this?
7. Factories used to have quite short funnels to let out the smoke, but it was found that this caused many problems in the local towns and cities near the factory as the gases would combine with water in the immediate environment to cause acid rain. Factories then started to build much

higher smoke funnels so that the smoke was let out high enough to be blown further away.
Do you think this is an efficient way to help reduce acid rain? Explain your answer.

8. Do some research to find out about the possible ways to prevent or minimise the formation of acid rain. Write a paragraph to summarise these methods in your exercise books.

We have now learnt about non-metal oxides, but what about metal oxides?

What kind of solutions do they form in water? We will find out more about them and other metal compounds in the next section.

11.2 The general reaction of an acid with a metal oxide

New word

- metal oxide

In the previous section we learnt about two classes of oxides, namely metal oxides and non-metal oxides. Here is what we know about them so far:

- Metal oxides are formed from the reaction between a metal and oxygen.
- Metal oxides are basic. When we dissolve them in water, they form solutions with pH values above 7.
- Non-metal oxides are formed from the reaction between a non-metal and oxygen. Non-metal oxides are acidic. When they dissolve in water, they form solutions with pH values below 7.
- Here is the same summary, in table form, with some examples added:

Metal oxides	Non-metal oxides
metal + oxygen → metal oxide	non-metal + oxygen → non-metal oxide
basic	acidic
$pH > 7$	$pH < 7$
Examples: Li_2O, Na_2O, MgO, CaO	Examples: CO_2, SO_2, NO_2, P_2O_5

In this section, we are going to learn about the reactions between metal oxides and acids.

Investigation: The reaction between magnesium oxide and hydrochloric acid

Aim

- To test whether a solution of magnesium oxide in water is acidic, basic or neutral; and
- to determine whether the reaction between an aqueous solution of magnesium oxide and hydrochloric acid is a neutralisation reaction.

Investigative question(s)

What are the questions you hope to answer with this investigation? Write them in your exercise books. There are a few words to start you off.

1. When magnesium oxide is dissolved in water, will the resulting solution …?
2. When a solution of magnesium oxide is treated with hydrochloric acid, will the pH of the mixture …?

Overview of the investigation

1. We will measure the pH of a solution of magnesium oxide (MgO) with universal indicator paper to confirm whether it is acidic or basic. Within what range do you expect the pH of the magnesium oxide solution to fall?
2. We will add hydrochloric acid (HCl) to the magnesium oxide solution in small portions and measure the pH after each portion has been added. What changes do you expect to observe – will the pH increase, decrease, or stay the same?

Hypothesis

What are your predictions? Your hypothesis should be a prediction of the finding(s) of the investigation. You should write it in the form of a possible answer to the investigative question(s). Here are a few words to start you off:

1. When magnesium oxide is dissolved in water, the resulting solution will…
2. When a solution of magnesium oxide is treated with hydrochloric acid, the pH of the mixture will…

Materials

- magnesium oxide powder
- water
- universal indicator paper (cut into 1 cm strips)
- white tile or sheet of white printer paper
- glass rod (or plastic straw)
- test tube
- dropper
- diuted hydrochloric acid (HCl) solution

Method

1. Prepare the universal indicator paper by neatly placing five 1 cm pieces in a column on the white tile or sheet of printer paper.
2. Place a small quantity (the size of a match head) of the magnesium oxide in a test tube.
3. Add approximately 2 ml of tap water to dissolve most of the magnesium oxide.
4. Use the glass rod (or plastic straw) to stir the solution until most the magnesium oxide has dissolved. We will be calling this the test solution from now on.

5. Transfer one drop of the test solution to the first piece of universal indicator paper.
6. Compare the colour of the paper with the colour guide to find the pH of the solution.
7. Record this pH in the table you prepared beforehand.
8. Add 10 drops of the hydrochloric acid solution to the test solution. Stir it gently and transfer another drop of the solution to a fresh strip of the universal indicator.
9. Read the pH of the solution off the colour guide and record it in your table.
10. Repeat steps 3 and 4 until the pH of the test solution drops below 7. You may need more than 5 pieces of universal indicator paper.

Results

1. Present your results in a table. You should prepare this beforehand. Use appropriate headings for your table. 'Number of drops of HCl added' and, 'Colour of the universal indicator paper', and 'pH of the test solution' are suggested headings for your columns.
2. Draw a graph of your results. Here are some hints to help you decide which variable to put on which axis:
   a) What is your independent variable? (Which variable did you change?)
   This goes on the x-axis.
   b) What is your dependent variable? (Which variable did you measure?)
   This goes on the y-axis.

Conclusions

What conclusions can be made from the results of your investigation? Reflect on your hypothesis, but change it to reflect your findings if they are different from what you predicted earlier.

Were you able to confirm or reject your hypotheses?

Now that we have investigated a reaction between a metal oxide (MgO) and an acid (HCl), we can write an equation for the reaction. We will begin by writing a general equation and end with one that matches the reaction that we have just investigated.

General equation for the reaction of an acid with a metal oxide

Can you remember learning that an acid-base reaction is an exchange reaction?

We learnt that:

- The acid contributes H towards making a water molecule;
- The base contributes O or OH towards making a water molecule; and
- Whatever is left of the acid and the base after making an H_2O molecule combines to form a salt.

The general word equation for the reaction between an acid and a base is:

acid + base → salt + water

Since the base in our reaction is a metal oxide we can write:

acid + metal oxide → salt + water

This is the general word equation for the reaction between an acid and a metal oxide. The type of salt that forms will depend on the specific acid and metal oxide which were used in the reaction.

Equations for the reaction between magnesium oxide and hydrochloric acid

Now we are going to learn how to write equations for our actual reaction.

ACTIVITY Writing the chemical equation

The following steps will guide you:

1. The acid of our reaction was hydrochloric acid. Write its chemical formula.
2. What is the name and formula of the metal oxide we used?
3. Now, let's try to predict the products of the reaction. We know that water will be one of the products.
4. Write what remains of the base (MgO) after we have taken away the O (to make water).
5. Write what remains of the acid (HCl) after we have taken away the H (to make water). (Remember we need two H to make one H_2O).
6. Now put the two remaining fragments together. Place the metal first and remember that 2 HCl will leave 2 Cl after the 2 H has been given to O to make water. One Mg and 2 Cl makes …
   Now, let's put it all together, in the following order.
   $2\ HCl + MgO \rightarrow MgCl_2 + H_2O$
7. Let's check quickly if the reaction is balanced.
   a) How many H atoms on the left-hand side and on the right-hand side? Are they balanced?
   b) How many Cl atoms on the left-hand side and on the right-hand side? Are they balanced?
   c) How many O atoms on the left-hand side and on the right-hand side? Are they balanced?

   Since the numbers of each type of atom is the same on either side of the equation, we can confirm that it is balanced.

Finally, let's use the chemical equation to write a word equation for the reaction:

hydrochloric acid + magnesium oxide → magnesium chloride + water

In the next section we are going to look at the reactions between acids and metal hydroxides.

11.3 The general reaction of an acid with a metal hydroxide

We will start this section with an investigation to illustrate the reaction between an acid and a **metal hydroxide**.

Keywords

- metal hydroxide

Investigation: The reaction between sodium hydroxide and hydrochloric acid

Aim

- Test whether a solution of sodium hydroxide in water is acidic, basic or neutral; and
- determine whether the reaction between an aqueous solution of sodium hydroxide and hydrochloric acid is a **neutralisation reaction**.

Investigative question(s)

What are the questions you hope to answer with this investigation? Write them in your exercise books. You may use the previous investigation (of the reaction between magnesium oxide and hydrochloric acid) as a guideline.

Overview of the investigation

1. We will measure the pH of a solution of sodium hydroxide (NaOH) with universal indicator paper to confirm whether it is acidic or basic. Within what range do you expect the pH of the magnesium oxide solution to fall?
2. We will add hydrochloric acid (HCl) to the sodium hydroxide solution in small portions and measure the pH after each portion has been added.

What changes do you expect to observe – will the pH increase, decrease, or stay the same?

Hypothesis

What are your predictions? Your hypothesis should be a prediction of the finding(s) of the investigation. You should write it in the form of a possible answer to the investigative question(s). If you are unsure, check the previous investigation.

Materials

- sodium hydroxide solution (0,1 M)
- universal indicator paper (cut into 1 cm strips)
- white tile or sheet of white printer paper
- glass rod (or plastic straw)
- test tube
- plastic syringe
- hydrochloric acid (HCl) solution (0,1 M)

Method

1. Prepare the universal indicator paper by neatly placing five 1 cm pieces in a column on the white tile or sheet of printer paper.
2. Use the syringe to transfer 2 ml of the sodium hydroxide solution into the test tube or small glass beaker. We will be calling this the test solution from now on.
3. Rinse the syringe very thoroughly with water and dry it out with a clean tissue. Now fill it with hydrochloric acid solution and set it aside.
4. Transfer one drop of the sodium hydroxide (test solution) to the first piece of universal indicator paper.
5. Compare the colour of the paper with the colour guide to find the pH of the sodium hydroxide solution. Record this pH in your results table.
6. Add 0,5 ml of the hydrochloric acid solution from the syringe to the test solution. Stir it gently with the glass rod or straw and transfer another drop of the test solution to a fresh strip of the universal indicator paper.
7. Read the pH of the solution off the colour guide and record it in your results table.
8. Repeat steps 6 and 7 until the pH of the test solution reaches approximately 7.
9. How much of the hydrochloric acid solution have you used? Write the volume in your exercise books.
10. If you are quite sure that all the base has been neutralised by the acid (the pH should be 7 and the universal indicator paper should have turned green), pour the test solution into a small glass beaker and leave it in the window sill for a few days. Remember to come back to it later to see what has happened to it.

Results

1. Present your results in a neat table. Use appropriate headings for your table.
   The following are suggested headings for your columns:
   - Volume of HCl added
   - Colour of the universal indicator paper
   - pH of the test solution.
2. Draw a graph of your results.
   a) What is your independent variable? (Which variable did you change?)
   b) What is your dependent variable? (Which variable did you measure?)

Conclusion

What conclusion can be drawn from the results of your investigation? Here you can rewrite your hypothesis, but change it to reflect your findings if they are different from what you predicted earlier.

Were you able to confirm or reject your hypotheses?

Now that we have investigated a reaction between a metal oxide (NaOH) and an acid (HCl), we can write an equation for the reaction. We will begin by writing a general equation and end with one that matches the reaction that we have just investigated.

General equation for the reaction of an acid with a metal hydroxide

You learnt that an acid–base reaction can be represented by the following general word equation.

acid + base → salt + water

The base in our reaction was a metal hydroxide, so the general word equation becomes:

acid + <u>metal hydroxide</u> → salt + water

This is the general word equation for the reaction between an acid and a metal hydroxide. The type of salt that forms will depend on the specific acid and metal hydroxide which were used in the reaction.

Equations for the reaction between sodium hydroxide and hydrochloric acid

Now we are going to learn how to write equations for our actual reaction.

ACTIVITY Writing the chemical equation

The following steps will guide you

1. The acid of our reaction was hydrochloric acid. Write its chemical formula.
2. What is the name and formula of the metal hydroxide we used?
3. Now, let's try to predict the products of the reaction. We know that water will be one of the products.
4. Write what remains of the base after we have taken away the OH to make water.
5. Write what remains of the acid after we have taken away the H to make water. Remember we need two H to make one H_2O, but NaOH has already contributed one O and one H. Now put the two fragments together. Place the metal from the base first and the non-metal from the acid. One Na and one Cl makes...
6. Now, let's put it all together, in the following order:
   Acid + metal hydroxide → salt + water
7. Let's check quickly if the reaction is balanced.
   a) How many H atoms on the left and on the right? Are they balanced?
   b) How many Cl atoms on the left and on the right? Are they balanced?
   c) How many O atoms on the left and on the right? Are they balanced?
8. Once you have performed this reaction and you are left with a neutral solution, you decide you want to recover the sodium chloride (table salt). How will you do this?

Finally, let's use the chemical equation to write a word equation for the reaction:

hydrochloric acid + sodium hydroxide → sodium chloride + water

In the next section we are going to look at the reactions between acids and metal carbonates.

Keywords

- metal carbonate

11.4 The general reaction of an acid with a metal carbonate

In this section we will investigate the reaction between an acid and a **metal carbonate**.

Figure 11.9: Blackboard chalk is calcium carbonate, a metal carbonate.

Investigation: The reaction between calcium carbonate (chalk) and hydrochloric acid

Aim

- test whether calcium carbonate is acidic or basic;
- determine whether the reaction between calcium carbonate and hydrochloric acid is a neutralisation reaction; and
- determine the products of the reaction between calcium carbonate and hydrochloric acid.

Investigative questions

What are the questions you hope to answer with this investigation? Write them in your exercise books. You may use your previous investigations as a guideline.

Overview of the investigation

1. We will measure the pH of a suspension of calcium carbonate ($CaCO_3$) with universal indicator paper to confirm whether it is acidic or basic.
   Within what range do you expect the pH of the calcium carbonate to fall?
2. We will add hydrochloric acid (HCl) to the calcium carbonate in small portions and measure the pH after each portion has been added. What changes do you expect to observe? Will the pH increase, decrease, or stay the same?

Hypothesis

What are your predictions? Your hypothesis should be a prediction of the finding(s) of the investigation. You should write it in the form of a possible answer to the investigative question(s). If you are unsure, check the previous investigation.

Materials

- chalk dust (calcium carbonate) suspended in a small quantity of water.
- universal indicator paper (cut into 1 cm strips)

- white tile or sheet of white printer paper
- glass rod or plastic straw
- test tube or small glass beaker
- plastic syringe (2,5 cm capacity) or dropper
- diluted hydrochloric acid (HCl) solution

Method

1. Prepare the universal indicator paper by neatly placing five 1 cm pieces in a column on the white tile or sheet of printer paper.
2. Place approximately 2 ml of the calcium carbonate suspension into the test tube or small glass beaker. We will be calling this the test solution from now on.
3. Rinse the syringe very thoroughly with water and dry it out with a clean tissue. Now fill it with hydrochloric acid solution and set it aside.
4. Transfer one drop of the calcium carbonate (test solution) to the first piece of universal indicator paper.
5. Compare the colour of the paper with the colour guide below, to find the pH of the calcium carbonate solution. Record this pH in your results table.
6. Add 0,5 cm of the hydrochloric acid solution from the syringe to the test solution. Watch very carefully what happens. Do you see anything interesting? (Hint: Look for bubbles!) Stir the test solution gently with the glass rod and transfer another drop of it to a fresh strip of the universal indicator.
7. Read the pH of the solution off the colour guide and record it in your table.
8. Repeat steps 6 and 7 until the pH of the test solution reaches approximately 7. How much of the hydrochloric acid solution have you used? Write the volume in your exercise books.
9. Your teacher will repeat the experiment as a demonstration and will collect the gas that forms during the reaction, for testing with clear lime water.
10. Can you remember which gas we are testing for with clear limewater? Write its name and formula in your exercise books.

Results

1. Present your results in a neat table. Use appropriate headings for your table. Suggested headings for your columns are as follows:
   - Volume of HCl added
   - Colour of the universal indicator paper
   - pH of the test solution
2. Draw a graph of your results.
   a) What is your independent variable? (Which variable did you change?)
   b) What is your dependent variable? (Which variable did you measure?)

Conclusions

What conclusions can be made from the results of your investigation? Reflect your findings if they are different from what you predicted earlier.

Were you able to confirm or reject your hypothesis?

Now that we have investigated a reaction between a metal carbonate ($CaCO_3$) and an acid (HCl), we can write an equation for the reaction. We will begin by writing a general equation and end with one that matches the reaction that we have just investigated.

General equation for the reaction of an acid with a metal carbonate

The general equation for the reaction between an acid and a base is as follows:

acid + base → salt + water

If we replace 'base' with 'metal carbonate', we get:

acid + metal carbonate → salt + water

But wait, there was a third product in our reaction! Can you remember what it was? (Hint: Bubbles formed, so it was a gas.)

We need to make it clear that CO_2 was a product of the reaction, so the correct general word equation would be:

acid + metal carbonate → salt + water + carbon dioxide

The type of salt that forms will depend on the specific acid and metal carbonate which were used in the reaction.

Equations for the reaction between calcium carbonate and hydrochloric acid

Now we are going to learn how to write equations for our actual reaction.

ACTIVITY Writing the chemical equation

The following steps will guide you

1. The acid of our reaction was hydrochloric acid. Can you write its chemical formula?
2. What is the name and formula of the metal carbonate we used?
3. Now, let's try to predict the products of the reaction. We know that water and carbon dioxide will be two of the products.
4. Write what remains of the base after we have taken away the CO to make CO_2 and leave one O_2 to make water.

5. Write what remains of the acid after we have taken away the H to make water. Remember we need two H to make one H_2O and $CaCO_3$ has contributed only one O_2.
6. Now put the two fragments together. Place the metal from the base first and the non-metal from the acid. Ca and 2 Cl makes ...
7. Now, let's put it all together, first the reactants, then the products:
   $2\ HCl + CaCO_3 \rightarrow CaCl_2 + H_2O + CO_2$
8. Let's check quickly if the reaction is balanced.
   a) How many H on the left and right? Are they balanced?
   b) How many Cl on the left and right? Are they balanced?
   c) How many O on the left and right? Are they balanced?
   d) How many C on the left and right? Are they balanced?

Finally, let's use the chemical equation to write a word equation for the reaction:

hydrochloric acid + calcium carbonate → calcium chloride + water + carbon dioxide

Applications for calcium carbonate

Calcium carbonate is found in many places outside of the laboratory. It is found in different types of rocks around the world, for example limestone, chalk and marble.

Figure 11.10: The Cango Caves near Oudtshoorn, South Africa, are situated in a limestone ridge and contain spectacular limestone formations. Such caves are the result of water high in carbonic acid acting upon limestone deposits in ancient rock layers.

Did you know?

Dark green leafy vegetables such as broccoli, kale and cabbage are a dietary source of calcium carbonate, providing the body with calcium. You can also take calcium carbonate in the form of tablet supplements.

Calcium carbonate is also the main part of shells of various marine organisms, snails, pearls, oysters and bird eggshells. It is also found in the exoskeletons of crustaceans (such as crabs, prawns and lobsters).

Calcium carbonate also has many applications. In industry, the main application is in construction as it is used in various building materials and in cement.

Figure 11.11: Chunks of calcium carbonate from various shells.

Calcium carbonate is used in many adhesives, paints and in ceramics. It is also used in swimming pools to adjust the pH. When do you think it would be added? If the pool was too acidic and you wanted to make it more basic, or if the pool was too basic and you wanted to make it more acidic?

Calcium carbonate is also used in agriculture in the form of lime powder. Agricultural lime is made by grinding up limestone or chalk. It is added to the soil if the soil is too acidic to increase the pH. It also provides plants with a source of calcium.

Figure 11.12: This tractor is busy depositing agricultural lime onto a field. This is called liming.

In this unit we have investigated a number of reactions of acids with bases. We have learnt to write word equations for these reactions and practised converting between word and balanced chemical equations.

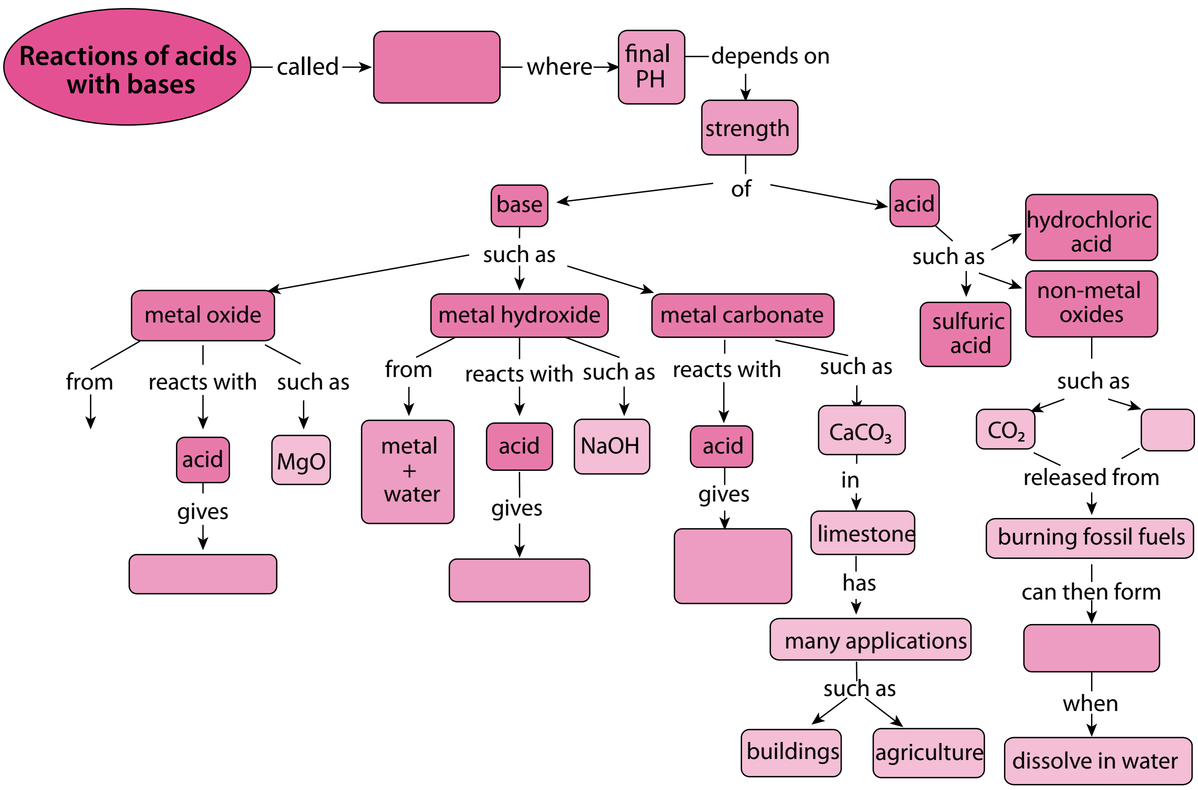
Summary

Key concepts

- The reaction of an acid with a base is called a neutralisation reaction.
- When an acid (pH < 7) is added to a base (pH > 7), the pH of the resulting mixture will lie somewhere between that of the acid and the base. Even though the acid and base will be neutralised, the resulting solution will not necessarily be neutral.
- Some common laboratory acids are sulfuric acid (H_2SO_4), nitric acid (HNO_3) and hydrochloric acid (HCl).
- Non-metal oxides tend to form acidic solutions when they dissolve in water. These solutions will have pH values below 7.
- Metal oxides, metal hydroxides and metal carbonates form basic solutions in water; these will have pH values above 7.
- When a metal oxide or a metal hydroxide reacts with an acid, a salt and water form as products.
- When a metal carbonate reacts with an acid, a salt, water and carbon dioxide form as products.
- The general word equations for the reactions of this unit are the following:
  - acid + metal oxide → salt + water
  - acid + metal hydroxide → salt + water
  - acid + metal carbonate → salt + water + carbon dioxide

Concept map

Complete the concept map provided by your teacher by filling in the blank spaces.



Revision

1. Fill in the missing words in these sentences. Write the complete sentences in your exercise books. [10]
   a) To know if something is an acid or a base, we measure its ___________________
   b) The name of the laboratory acid with the formula H_2SO_4 is ___________________
   c) The formula of the laboratory acid named hydrochloric acid is ___________________
   d) When a metal oxide reacts with an ___________________, a salt and water will be formed.
   e) When a metal hydroxide reacts with an acid, a salt and ___________________ will be formed.
   f) When a metal carbonate reacts with an acid, a salt, water and ___________________will be formed.
   g) Metal oxides, metal hydroxides and metal carbonates all dissolve in water, forming ___________________ solutions. This means the solutions will have pH values ___________________than 7.
   h) The reaction of an acid with a base is called a ___________________reaction.
   i) Non-metal oxides tend to form ___________________ solutions when they dissolve in water.

2. Write a short paragraph (3 or more sentences) to explain what you understand each of the following terms to mean, in your own words. [2 × 3 = 6]
   a) neutralisation
   b) acid rain

3. Copy the following tables in your exercise books. Complete the tables for each of the reactions by providing the missing equations.
   a) The reaction between hydrochloric acid and magnesium oxide. [4]

Word equation	
Chemical equation	
General equation	acid + metal oxide → salt + water

   b) The reaction between hydrochloric acid and sodium hydroxide. [6]

Word equation	
Chemical equation	
General equation	

   c) The reaction between hydrochloric acid and calcium carbonate. [4]

Word equation	
Chemical equation	$2\,HCl + CaCO_3 \rightarrow CaCl_2 + H_2O + CO_2$
General equation	

d) The reaction between hydrochloric acid and magnesium hydroxide. [4]

Word equation	
Chemical equation	$2\ HCl + Mg(OH)_2 \rightarrow MgCl_2 + 2\ H_2O$
General equation	

e) The reaction between hydrochloric acid and calcium oxide. [4]

Word equation	
Chemical equation	$2\ HCl + CaO \rightarrow CaCl_2 + H_2O$
General equation	

f) The reaction between hydrochloric acid and potassium hydroxide. [6]

Word equation	
Chemical equation	
General equation	

g) The reaction between hydrochloric acid and sodium carbonate. [4]

Word equation	hydrochloric acid + sodium carbonate → sodium chloride + water + carbon dioxide
Chemical equation	
General equation	

Total [48 marks]

12 Reactions of acids with metals

Key questions

- What do we get when a metal reacts with an acid?
- What is the general equation for the reaction between a metal and an acid?
- How do we write the word equation and the balanced chemical equation?
- How can we test for the presence of hydrogen gas?

Keywords

- diatomic
- density
- characteristic
- presence
- chemist
- pharmacist

12.1 The reaction of an acid with a metal

In the previous unit we learnt about the reactions of acids with a variety of bases: metal oxides, metal hydroxides and metal carbonates. We learnt how to write general equations, word equations and chemical equations for those reactions.

In this unit we will investigate one final type of reaction, namely the reaction between an acid and a metal.

First, we will do an investigation to observe the reaction and then we will write equations to represent it. Before we do this, however, we have to take a quick detour to learn something interesting about hydrogen gas.

ACTIVITY Testing for hydrogen gas

1. What do you know about hydrogen gas? Perhaps you know its formula? Write it in your exercise books.
2. Hydrogen gas is a diatomic gas. What does this mean?
3. What do you know about the position of hydrogen in the periodic table? Write what you know in your exercise books.
4. The position of hydrogen in the periodic table tells us that it is the lightest of all the elements. It has the smallest atomic mass. Because the element hydrogen is a gas (even though it is a diatomic one), it has one of the lowest densities of any substance.

Figure 12.1: This man is about to launch a weather balloon filled with hydrogen gas. It will float upwards to collect information about the weather in Antarctica.

Can you remember what density means? Write your own definition in your exercise books.

When hydrogen gas is released in a reaction it will immediately rise up, because hydrogen is less dense than air. If you filled a balloon with hydrogen, it would float up and you would need to tie a string to it to prevent it from floating away!

Another interesting thing about hydrogen is that it reacts explosively with oxygen if you bring a flame near it.

You may remember learning about this in Unit 9 about the reactions of non-metals with oxygen. The reaction between a large quantity of hydrogen and oxygen in the air produces a beautiful orange fireball and a very loud boom! Do you remember seeing the following diagram?

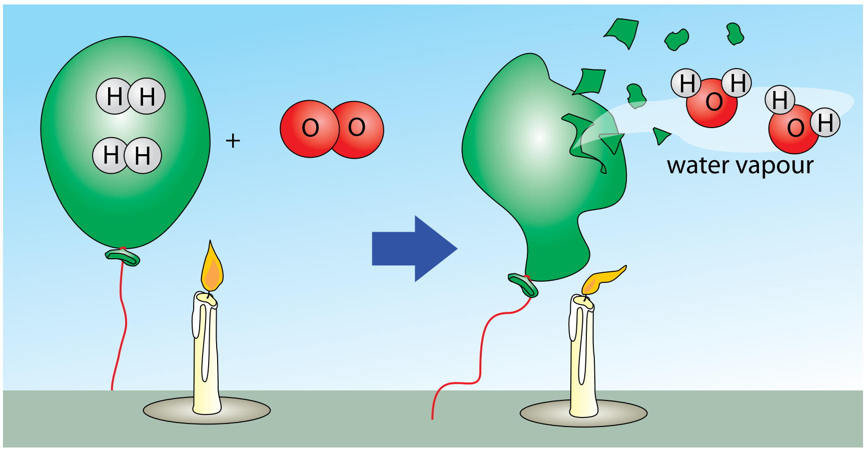


Figure 12.2

5. Write the balanced equation for the reaction between hydrogen gas and oxygen in your exercise books.
The reaction between a tiny amount of hydrogen and oxygen in the air produces a **characteristic** 'pop' sound and this serves as a test for the **presence** of hydrogen. You can watch the short video clip in the visit box in the margin to see this 'pop'.

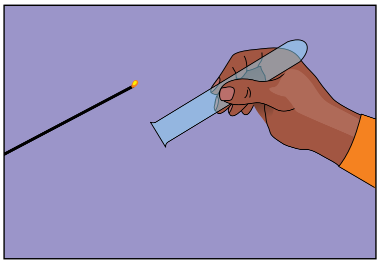


Figure 12.3: When a glowing splint is put into a test tube containing hydrogen gas …

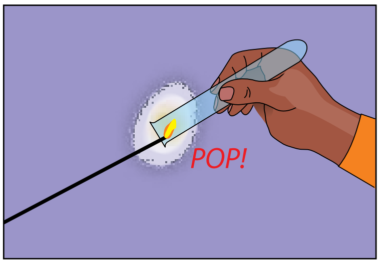


Figure 12.4: it makes a 'pop' sound.

Did you know?

The name 'Hydrogen' comes from the Greek words 'hydro' and 'gen', which means 'water generator'.

Let's now investigate the reaction between an acid and a metal. You should listen carefully for this 'pop' sound during the investigation. If you hear it, it will signal the presence of hydrogen gas!

Investigation: The reaction between magnesium and hydrochloric acid

Aim

- Observe the reaction between hydrochloric acid and magnesium; and
- identify the gaseous product of the reaction between hydrochloric acid and magnesium.

Your teacher will demonstrate the reaction between magnesium and hydrochloric acid, while you make observations. Remember to watch carefully and take detailed notes.

Investigative question

What question(s) do you hope to answer with this investigation?

Hypothesis

What do you predict will happen? Your hypothesis should be a prediction of the finding(s) of the investigation. You should write it in the form of a possible answer to the investigative question(s).

Materials

- magnesium ribbon (cut into smallish pieces)
- concentrated hydrochloric acid (HCl) solution
- large test tube
- retort stand with clamp
- rubber stopper with short length of glass tubing pushed through it
- silicone or rubber tubing (or a glass delivery tube as shown in the set-up below)
- shallow dish filled with soapy water (made by mixing a few teaspoons of dishwashing liquid with water)

Method

1. Use a piece of universal indicator paper to test the pH of the hydrochloric acid solution. Record its pH.
2. Set up the experiment as shown in the following diagram. Ensure that the end of the delivery tube is below the surface of the soap solution in the dish.

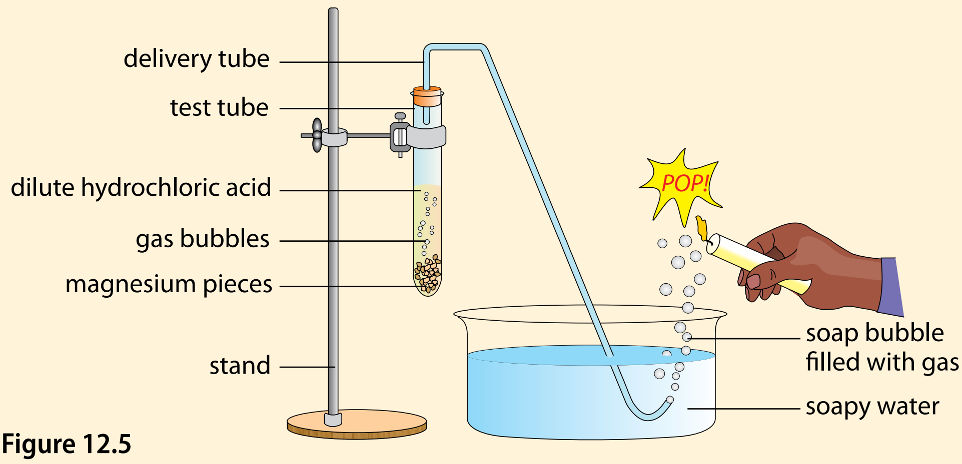


Figure 12.5

3. Place approximately 1 g of the magnesium pieces in the test tube, but do not add the hydrochloric acid until everything else is ready to be assembled.
4. Add approximately 40 ml of hydrochloric acid and immediately place the stopper on the test tube. The first few bubbles of gas that are released from the end of the delivery tube will be air.
5. When the soap bubbles start to float up, hold a burning candle to them and listen carefully for the sound they make when they pop. Do not hold the candle to the end of the delivery tube.
6. When the magnesium stops reacting and no further hydrogen bubbles are released, extinguish the candle and set it aside.
7. Disassemble the experiment and test the pH of the reaction mixture. Record the pH value.

Results and observations

Record your results in the following table:

pH of the hydrochloric acid before the reaction	
pH of the mixture after the reaction	

Write down the observations you make during the investigation in your exercise books.

Conclusions

What conclusions can be made from the results of your investigation? Reflect on our hypothesis, but change it to reflect your findings if they are different from what you predicted earlier.

Questions

1. What did you observe in the test tube when the magnesium and hydrochloric acid were mixed?
2. What did you observe at the end of the gas delivery tube after the magnesium and hydrochloric acid were mixed?
3. Why do you think the soap bubbles floated upwards?
4. Which gas do you think was produced by the reaction? Write its name and formula in your exercise books. What makes you think it was this gas?
5. What happened to the pH of the hydrochloric acid solution during the reaction?
6. What does the increase in pH mean?
7. Were you able to confirm or reject your hypothesis?

In our investigation hydrochloric acid reacted with magnesium (a metal). Our next task is to write an equation for the reaction. We will begin by writing a general equation and end with one that matches the reaction that we have just investigated.

General equation for the reaction of an acid with a metal

The general word equation for the reaction between an acid and a metal is:

acid + metal → salt + hydrogen gas

The type of salt that forms will depend on the specific metal and acid which are used in the reaction.

Equations for the reaction between magnesium and hydrochloric acid

Now let's write equations for our actual reaction from the last investigation.

ACTIVITY Writing the chemical equation

The following steps will guide you

1. The acid of our reaction was hydrochloric acid. Can you write its chemical formula?
2. What is the name and formula of the metal we used?
3. Now, let's try to predict the products of the reaction. We know that hydrogen gas will be one of the products. Write the chemical formula for hydrogen gas.
4. Write what remains of the acid (HCl) after we have taken away the H to make H_2. (Remember we need two H to make one H_2).
5. The two Cl and the Mg are exactly what are needed to make magnesium chloride. Write the formula in your exercise books.
6. Now, let's write the reaction; first the reactants, then the products:

   $$\mathbf{2\ HCl + Mg \rightarrow MgCl_2 + H_2}$$

   Let's check quickly if the reaction is balanced.

   a) How many H on the left and right? Are they balanced?

   b) How many Cl on the left and right? Are they balanced?

   c) How many Mg on the left and right? Are they balanced?

   Since the numbers of each type of atom is the same on either side of the equation, we can confirm that it is balanced.
7. Finally, let's use the chemical equation to write a word equation for the reaction.

Chemist or pharmacist?

When people hear that someone is a 'chemist', they often confuse this with being a 'pharmacist'. In some countries the terms 'chemist' and 'pharmacist' are even used to describe the same kind of person. In South Africa the two words have different meanings. But what is the difference between being a chemist and being a pharmacist?

Look up these careers to identify the main difference between a chemist and a pharmacist and summarise them in your books.

Figure 12.6: Two chemists working in a laboratory.

Figure 12.7: A pharmacist in his dispensary.

ACTIVITY Other careers in chemistry

Instructions

1. Below is a list of different careers that all use chemistry in some way. Have a look through the list and then select the five careers you find most interesting.
2. Do an internet search to find out what each career is.
3. Write a one-line description of this career in your exercise books.
4. If there is a career that really interests you, draw a smiley face next to it and be sure to do some extra reading around the topic and where chemistry may take you! Find out what level of chemistry you will need for this particular career.
5. There are many other careers besides the ones listed here which use chemistry in some way, so if you know of something else which is not listed here and it interests you, follow your curiosity and discover the possibilities!

Some careers involving chemistry

- Agricultural chemistry
- Biochemistry
- Biotechnology
- Environmental chemistry
- Chemical education/teaching
- Chemistry researcher
- Forensic science
- Food science/technology
- Geneticist
- Materials science
- Geochemistry
- Medicine and medicinal chemistry
- Oil and petroleum industry
- Organic chemistry
- Oceanography
- Patent law
- Pharmaceuticals
- Space exploration
- Zoology

Did you know?

Great scientists (including chemists) are observant, curious, patient and eager to learn more about their field every day.

In this unit we have studied the reaction of hydrochloric acid with magnesium, as an example of a reaction between an acid and a metal.

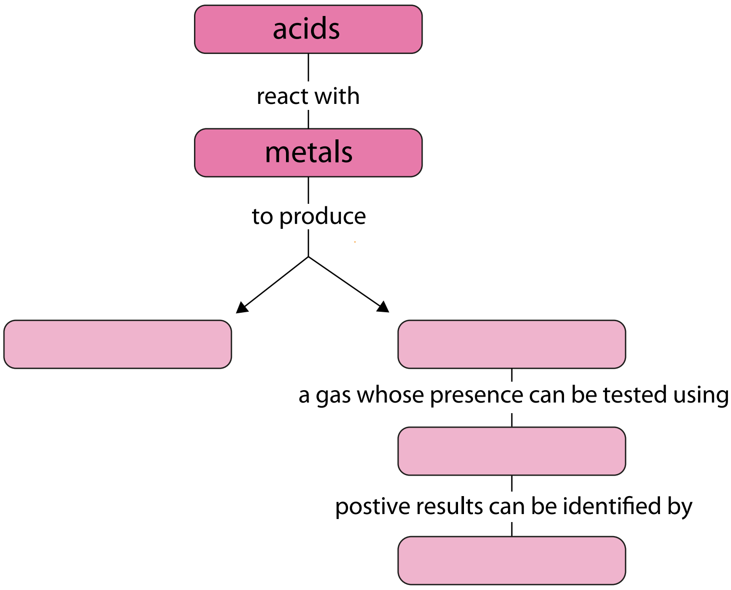
Summary

Key concepts

- An acid will react with a metal to form a salt and hydrogen gas.
- The general word equation for the reaction between an acid and a metal is as follows:
  - acid + metal → salt + hydrogen

Concept map

This was quite a short unit, so the concept map has been left blank for you to do your own. Be sure to include something about the test for hydrogen.



Revision

1. Fill in the missing words in these sentences. Write the word in your exercise books. [3]
   a) When an acid reacts with a metal, a salt and ____________ gas forms.
   b) A molecule that consists of two atoms bonded together is called a ____________ molecule.
   c) The scientific quantity represented by the mass of a substance in a given volume is called the ____________ of that substance.

2. Write a short paragraph (2 sentences or more) to explain why a balloon filled with hydrogen will float upwards. [2]

3. Imagine you are carrying out a reaction and you expect one of the products that will form to be hydrogen. Write a short paragraph (2 sentences or more) to describe how you would confirm the presence of hydrogen gas. [2]

4. When an acid reacts with a metal, do you think the pH of the solution will increase, decrease, or stay the same? Motivate your answer briefly. [3]

5. Copy and complete the following table in your exercise books by providing the missing equations for the reaction between hydrochloric acid and magnesium. [6]

Word equation	
Balanced chemical equation	
General equation	

6. Copy and complete the following table in your exercise books by providing the missing equations for the reaction between hydrochloric acid and zinc. [4]

Word equation	
Balanced chemical equation	$2\ HCl + Zn \rightarrow ZnCl_2 + H_2$
General equation	

7. We have looked at many different chemical reactions this term. As a summary, copy and complete the following table in your exercise books by giving the general equations in words for each of the chemical reactions in the second column, and provide an example for each type as a balanced chemical equation in the third column. [18]

Type of chemical reaction	General word equation	Example (balanced equation)
metals with oxygen		
non-metals with oxygen		
acids with metal oxides		
acids with metal hydroxides		
acids with metal carbonates		
acids with metals		

Total [38 marks]

Glossary

acid rain rainwater that is unusually acidic as a result of dissolved non-metal oxides that have entered the atmosphere

acidity this word is related to the word 'acid', and so is the word 'acidic'; a substance is strongly acidic when it has a high (degree of) acidity

alternative different

atomic number a unique number that represents a given element, and shows its position on the periodic table; the number of protons found in the nucleus

balanced a balanced equation reaction has the same numbers of atoms of a particular type on opposite sides of the reaction equation

barrier a fence or other obstacle that keeps things apart

bond a force between atoms in a compound, holding them together

camera flash a device (usually attached to the camera) that provides a quick burst of light at the instant that the photo is taken

characteristic a quality or feature of an object or item; for example, one of the characteristics of an acid is that it is corrosive

chemical bond a special attractive force that holds the atoms in a molecule together

chemical equation an equation that describes a chemical reaction using the chemical formulae of the compounds involved in the reaction

chemical formula a combination of element symbols that shows the types and number of atoms in one molecule of a given compound; a unique string of symbols (letters and numbers) that represents a chemical compound

chemical reaction a process in which atoms in substances, called reactants, are rearranged to form new substances, called products

chemist a person who has studied chemistry and uses this knowledge to do his/her job

chromed metal metal that is covered by a thin layer of chromium

coefficient a number that is placed in front of a chemical formula in a reaction equation; it shows the number of molecules of that type taking part in the reaction, for example 2 Mg

collide to bump into something

combustion a type of chemical reaction where a substance and oxygen react during burning to form a new product

compound a pure substance in which atoms of two or more different chemical elements are bonded in a fixed ratio

corrosion the gradual destruction of materials (usually metals) by chemical reaction with substances in the environment

corrosive a corrosive substance is something that causes corrosion; substances that are corrosive can cause burns on the skin and damage to certain surfaces

crystal lattice in some compounds, the atoms are arranged in a regular pattern in a fixed ratio to form a lattice structure; a lattice looks like a mesh or trellis

density the mass of a substance in a given space (volume)

detour to take a roundabout route, either to make a visit along the way, or to avoid something

diatomic molecule consists of two atoms; H_2, O_2, F_2, Cl_2, Br_2, and I_2 are all examples of elements that consist of diatomic molecules

dioxide a compound that contains two oxygen atoms in its chemical formula; examples are carbon dioxide (CO_2) and sulfur dioxide (SO_2)

electrons the smallest of the three types of sub-atomic particles; they are negatively charged and are located outside the atomic nucleus

element a pure substance that consists of only one type of atom throughout

exchange reaction a reaction in which the reactants break up into fragments that are then exchanged, or swapped around

exposed when a material is exposed, it is uncovered or unprotected (in this case from oxygen that will react with it)

fossil fuel a fuel that was formed from the prehistoric remains of plant and animal life (fossils); it usually has to be extracted from the earth; examples include oil, coal and natural gas

fuel a substance that will release energy when it reacts with another substance; in this context the other substance is usually oxygen

galvanise to galvanise iron or steel means to cover it with a thin layer of zinc; the zinc reacts with oxygen to form zinc oxide when it is exposed to air and this forms a strong and impenetrable coating

galvanised metal metal that is covered by thin layers of zinc and zinc oxide

generate to produce something; in this case it refers to some other source of energy being converted to electrical energy (electrical power or electricity)

group the vertical columns of the Periodic Table are called groups

identical exactly the same in every way

ignite to set something on fire

indicator a substance that changes colour in the presence of another substance, showing that that substance is present

inert unreactive; these substances do not react with other substances and do not change into other compounds

IUPAC International Union of Pure and Applied Chemistry (acronym)

IUPAC system a system for naming compounds in a way that is unique for each compound

laboratory acids acid commonly found in the laboratory

litmus a well-known acid-base indicator that turns red when mixed with an acid and blue when mixed with a base

macroscopic the macroscopic world includes all the things we can observe with our five senses – things we can see, hear, smell, touch and taste

metal an element that is shiny, ductile and malleable; metals occur on the left and towards the middle of the Periodic Table

metal carbonate a compound with the general formula MCO or M_2CO_3 where M represents a metal atom, C represents a carbon atom and O represents an oxygen atom

metal hydroxide a compound with the general formula MOH or $M(OH)_2$ where M represents a metal atom, O represents an oxygen atom and H represents a hydrogen atom

metal oxide the product of the reaction between a metal and oxygen; a compound with the general formula MO or M_2O where M represents a metal atom and O represents an oxygen atom

molecule two or more atoms that have chemically bonded with each other; the atoms in a molecule can be of the same kind (in which case it would be a molecule of an element), or they can be of different kinds (in which case it would be a molecule of a compound)

neutralisation reaction a reaction in which the reactants neutralise each other

neutralise to neutralise something means to take away its potency

neutral solution a solution with pH = 7

neutrons a type of sub-atomic particle similar to protons in mass and size, but neutral (without charge); neutrons together with protons make up the atomic nucleus

non-metal an element that does not have metallic properties; non-metals (excluding hydrogen) occur in the top right-hand corner of the Periodic Table

non-metal oxide the product of the reaction between a non-metal and oxygen

non-renewable non-renewable energy sources refer to sources that can be used up, such as fossil fuels (coal, oil, or natural gas)

oxidise when a compound reacts with oxygen, we say it is oxidised; in chemistry, the word oxidise means much more than this, but for now, we will limit ourselves to this simple definition

penetrate when liquid or air penetrates into a material, it passes into or through that material (usually because of tiny holes in the material); something that cannot be penetrated is called impenetrable

Periodic Table a table in which the chemical elements are arranged in order of increasing atomic number

period the horizontal rows of the Periodic Table are called periods

pharmacist a person who has studied pharmacy and uses this knowledge in the field of health science

pH pH measures the acidity and alkalinity of a solution as a number on a scale ranging between 0 and 14

picture equation an equation that describes a chemical reaction using diagrams of the particles of the compounds involved in the reaction

porous material that has tiny holes through which liquid or air may pass

potency power

prefix a bit added at the start of a word, usually to indicate number, e.g.,mono-, di-, or tri

presence the state of something existing or being present in a place

preservative a substance that is added to products (usually food or beverages) to make them last longer; most preservatives are toxic to microorganisms, but are added in such small quantities that they do not pose significant harm to humans

product a substance that forms during the reaction; it will be present after the reaction has taken place

protons sub-atomic particles that are positively charged and occur inside the atomic nucleus along with neutrons

reactant the starting substances that undergo change in a chemical reaction

reactive elements and compounds that are reactive will readily react with many other substances

red cabbage indicator An acid-base indicator made from the sap of red cabbage; red cabbage indicator is also capable of displaying a range of colours, depending on the pH of the solution with which it is mixed

renewable a renewable source of energy cannot be used up, such as water, wind, or solar power

rust a reddish or yellowish-brown, often flaky, coating of iron oxide that is formed on iron or steel by oxidation (when it reacts with oxygen in the air)

rust-resistant a rust-resistant material is one that does not rust

semi-metal an element that has properties of both metals and non-metals; the semi-metals occur in a narrow diagonal strip that separates the metals form the non-metals on the periodic table

steel a metal alloy composed of a mixture of iron and other elements (mostly metal); it is very strong and used widely in the construction industry (also in buildings)

submicroscopic the submicroscopic world includes things that exist but that we can't see; atoms and molecules can only be 'seen' as mental pictures and when we draw these, we refer to them as 'submicroscopic diagrams'

subscript a number that is placed inside a chemical formula; it shows the number of atoms of that type in one molecule of that compound, for example O_2

suffix a bit added at the end of a word, for example, -ide

symbol (or element symbol) a unique letter (or letters) that represent a given element

symbolic the symbolic world includes letters and numbers that we use to represent atoms and molecules

systematic name The unique name that will be generated for a given compound, if the IUPAC system for naming compounds is followed correctly

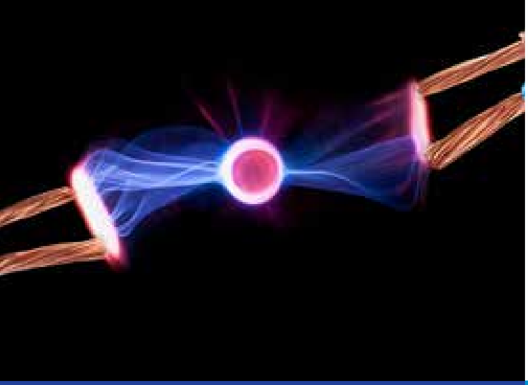
tarnish when a metal surface gets dirty or spotty after reacting with oxygen or other substances in the air, we say it is tarnished

toxic poisonous, harmful to living organisms

unique the only one of its kind; unlike anything else

unit a quantity used as a standard of measurement, for example, units of time are second, minute, hour, day, week, month, year and decade

universal indicator An acid-base indicator that can display a range of colours, depending on the pH of the solution with which it is mixed word equation an equation that describes a chemical reaction using the names of the compounds involved in the reaction



STRAND

Energy and Change











13 Forces

Key questions

- What is a force?
- What effect can a force have on an object?
- Do forces have to be between objects which are touching?

Keywords

- force
- net force
- contact force
- non-contact force
- newton

Did you know?

The Earth's atmosphere has changed overtime. Our oxygen-rich atmosphere was formed by algae millions of years ago.

Did you know?

The Newton is defined as the force needed to accelerate 1 kilogram of mass at 1 metre per second squared (m/s²)

13.1 Forces

What is a force?

Think of the following situation: You are all helping your teacher to rearrange the classroom and she asks you to move her desk from one side of the classroom to the other. How would you do that? The desk is too heavy for you to lift so how do you get it across the classroom?

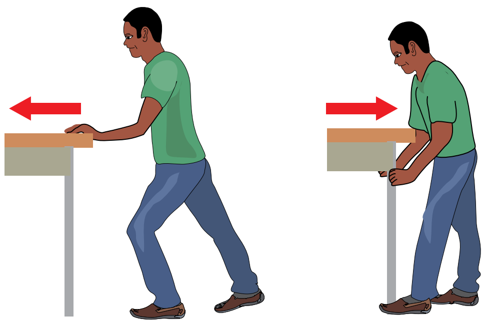


Figure 13.1

That is right, you are going to either push it or pull it across the room. In doing so, you have exerted a force on the desk to get it to move.

A force is a push or a pull on an object. The unit in which we measure force is a **newton (N)**.

The newton is named after Sir Isaac Newton, an English physicist and mathematician. Sir Isaac Newton is recognised as one of the most influential scientists of all times. The unit of force is named after him in recognition of his work in mechanics and his three laws of motion.

Figure 13.2: Sir Isaac Newton (25 December 1642 – 20 March 1727).

We use forces every day of our lives. Our own bodies rely on forces. Our muscles pull on our bones to allow us to move. Our feet push on the ground when we walk. To open doors, to pick up our food – everything we do involves some kind of force.

What can forces do? Let's experiment with forces and see what we can do.

ACTIVITY What can forces do?

This activity is all about experimenting with different objects and seeing what happens to them when we push and pull them.

Materials

- blocks (wooden or metal)
- sponge or piece of foam
- ball
- blown up balloon
- putty or play dough

Instructions

1. Work in groups of 2 or 3 as you follow the instructions and describe the effects of the forces that you are applying.
2. Start with the ball and place it on the ground. Push it towards your partner.
3. What were you able to cause the ball to do by pushing it?
4. When one of you pushes the ball to the other, the third person must give the ball another push at an angle to the direction in which it is already moving. What were you able to do to the direction in which the ball was moving?
5. Exert a force in the opposite direction to its movement while it is already moving. What are you able to cause the ball to do?
6. Exert a force in the same direction to its movement while it is already moving. What are you able to cause the ball to do?
7. Pick up the piece of putty or play dough. Exert pulling or pushing forces on it. Try this out with the blown up balloon too. What are you doing to the shape of the putty or play dough and the blown up balloon?
8. Push and pull the wooden blocks. Are you able to change their motion?
9. Are you able to change their shape?
10. Pick up the piece of sponge and twist it. This is also a type of force which changes the sponge's shape.
11. Press the sponge between both hands. This is called compression.

Did you know?

In 1687, Newton published *Philosophæ Naturalis Principia Mathematica*, which is often thought of as one of the most important books in the history of science. In it he describes universal gravitation and the three laws of motion.

Effects of forces

From the last activity, you should have seen that forces can have the following effects:

- Forces can change the **shape** of an object. This is called deformation.
- Forces can change the **motion** of an object. If an object is stationary, a force can cause the object to start moving. Or, if an object is already moving, a force can cause an object to speed up or slow down.
- Forces can change the **direction** in which an object is moving.

How do we describe the motion of an object? When an object is moving, we say it has a **speed**. Speed is the rate of change of the position of an object. Speed describes only how fast an object is moving.

An object can move at constant speed. This means it travels at the same speed. For example, a car travelling at 100 km/h has a constant speed. However, what happens when the car moves faster or slows down?

Keywords

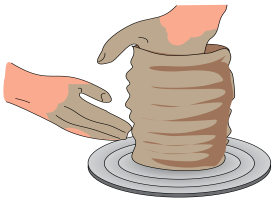
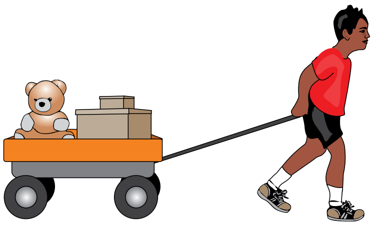
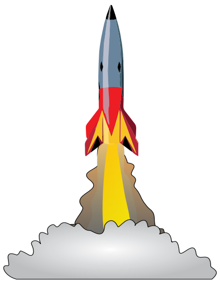
- speed
- acceleration
- deformation

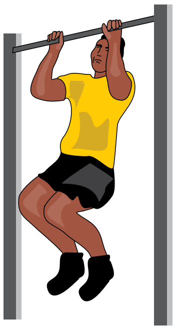
We saw in the last activity that we could change the motion of an object by applying a force to make it speed up or slow down. The speed of the object is changing over time due to a force acting on it. This is called **acceleration**. Acceleration is the rate of change of a body's speed with time. In other words, it is a measure of how an object's speed changes every second.

ACTIVITY Is it a push or a pull?

Instructions

1. Look at the pictures in the table. Copy the table in your exercise books.
2. Describe the action in each image.
3. Decide if the force being exerted is a push or a pull.
4. Describe the effect of the force.

Action	Push or pull?	Effect
 Kicking a ball.		
 Moulding clay.		
 Playing with a toy wagon.		
 A rocket blasting off into space.		

Action	Push or pull?	Effect
 Exercising on a bar.		

Questions

1. In the example of the girl kicking the ball, which is the object experiencing the force and which is the agent of the force (i.e. the body which is applying the force)?
2. When moulding clay, which object is experiencing the force and which object is the agent?

Pairs of forces

We are now going to do another practical activity to investigate another concept about forces.

ACTIVITY Pairs of forces

Instructions

1. Work in groups of three for this activity. First, go up to your classroom wall and push against it. Describe what you feel.
2. When you push on the wall, do you think the wall is pushing back on your hands? How does this force compare to the force you are exerting on the wall?
3. Stand in a triangle with your two partners and hold hands. Pull on each other's' hands. Do you feel your partners' hands pulling back as you pull?
4. Still standing in a triangle, place your palms up against each other and push against each other's' hands. Do you feel your partners' hands pushing back as you push?
5. Next, stand shoulder-to-shoulder with your two partners. The two learners on the outside must push against the shoulders of the learner in the middle.
6. What happens when you both push with the same force?
7. What happens when one of you pushes with a harder force than the other?

Figure 13.3

Did you know?

What we have described here is actually Newton's Third Law of Motion. The law states that when one body exerts a force on a second body, the second body simultaneously exerts a force equal in strength and opposite in direction to that of the first body.

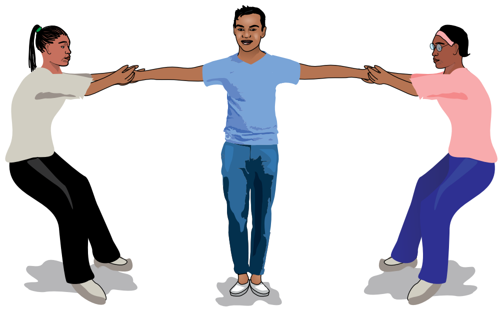


Figure 13.4

8. Next, the learner in the middle must stretch out his or her arms. The learners on the outside must pull on the middle learner's hands in opposite directions.
9. What happens when you both pull with equal force?
10. What happens when one of you pulls with a stronger force than the other?
11. What happens when one of you pulls and the other pushes?

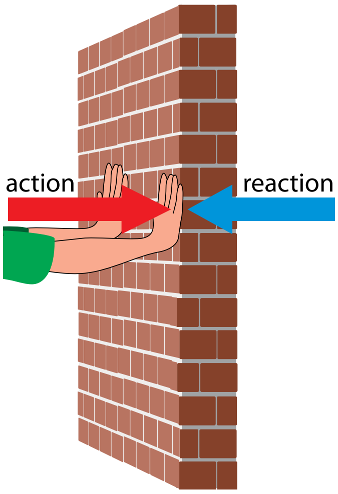


Figure 13.5

What we saw in the last activity is that whenever one object exerts a force on a second object, the second object exerts a force back on the first object. You saw this when you pushed against a wall. We say that forces act in pairs. Newton called the one force the **action**, and the other force the **reaction**, as shown in the following diagram.

We also saw that when you exerted a force on the wall, you experienced the wall exerting a force back on you. Forces act in pairs on different objects. The force exerted by the second object is **equal in strength** and **opposite in direction** to the first force.

Types of forces

So far, we have looked at forces acting on an object when the object causing the force is in contact with the object experiencing the force. Do we always have to be in contact with an object in order to exert a force?

ACTIVITY Can forces act over a distance?

Materials

- bar magnets
- metal paper clips

Instructions

1. Place one of the bar magnets on the table.
2. Bring the north end of another bar magnet close to the south end of the first bar magnet. What happens?
3. Bring the north end of one bar magnet close to the north end of the other bar magnet. What happens?
4. Place the paper clips on the table.
5. Bring a bar magnet over the paper clips. What do you observe?

Questions

1. Did you have to touch the bar magnets together before they would attract each other?
2. Did the paper clips move towards the magnet?
3. What caused the movements?

There were forces exerted by the magnets but they did not have to touch each other. That means that you do not have to be in contact with something in order to exert a force on it.

There are two types of forces:

- **Contact forces**: objects are in contact with each other and exert forces on each other.
- **Non-contact (field) forces**: objects are not in contact with each other and exert forces on each other. We are now going to look at these two broad groups of forces in more detail.

Keywords

- friction
- normal force
- tension
- compression

13.2 Contact forces

Contact forces are forces between objects which are touching each other. Most of the forces that we looked at in the previous section were contact forces, for example, when you push a desk, or pull a go-kart. You are touching the object.

Friction

What happens when you kick a ball across the grass? The ball moves quickly at first but then slows down again. Something has caused the ball to slow and stop moving. If the motion of the ball has changed then a force must have been exerted on it. The force which opposes motion is called **friction**. Friction forces always act in the opposite direction to the motion of the object. Friction resists movement when the object and surface are in contact. What does that mean? It means that if the ball is moving forward then friction acts backwards on the ball.

Take note

As we will see later on, there are also other forces acting on this system such as friction and weight.

The following image shows a ball which has just been kicked. Copy the diagram into your books and draw an arrow to show in which direction friction would be acting.

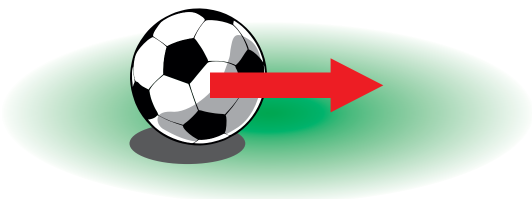


Figure 13.6

There is another force acting on the go-kart. Think of when you stand on the ground: you feel the ground beneath your feet. This contact force is preventing you from penetrating the ground. This is called the **normal force**.

The normal force always acts perpendicularly to the surface that the object is resting on.

In simple situations such as when you are standing on the ground or the go-kart is travelling along a level surface, the normal force is equal to the weight of the object, but in the opposite direction. Think back to what we learnt about forces acting in pairs. On a flat, level surface, the normal force is the reaction force to the weight of the object. This is shown in the diagram for a box resting on the floor.

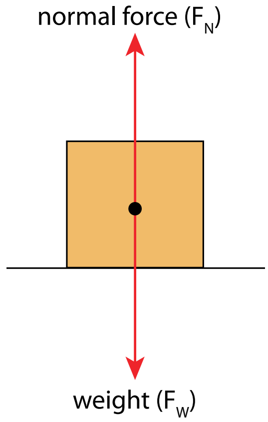


Figure 13.7

Do you think there is a relationship between the friction that a body experiences and the normal force? Let's investigate.

Investigation — What is the relationship between the normal force and friction?

Investigative question

What is the relationship between the normal force and friction?

Aim

To determine the relationship between the normal force and the size of the frictional force.

In the situations that we are going to investigate, the object will be pulled along on a flat, level surface. We will increase its mass and measure the resulting frictional force. But how does this relate to the normal force?

Where the object is on a flat level surface, the normal force is equal to the weight. As you learnt in Grade 8 *Earth and Beyond*, and will see in the next section, we can calculate the weight of an object. We can therefore calculate the normal force acting on the object.

For this investigation, calculate the weight using the formula $W = m \times g$, where m is the mass of the object in kg and g is 9,8 m/s^2. We will learn more about this in the next section.

Take note

We take three readings and then calculate an average. This increases the reliability of the results.

Apparatus

- wooden blocks with different known masses, or mass pieces
- wooden block with a hook
- spring balance
- triple beam balance or electronic scale

Method

1. Measure the mass of the wooden block with a hook with the triple beam balance. Record the mass in the table. Calculate and record the normal force.
2. Put the wooden block with the hook on the table. Attach the spring balance to the hook. Make a small mark on the desk from which to start pulling the block.
3. Pull sideways to the point that the block just starts moving.
4. Copy the table under Results (on the next page) into your exercise book, and record the force readings for each mass. Repeat this three times for the wooden block.
5. Put a mass piece on top of the wooden block. Record the total mass. Calculate and record the normal force. Remember that the normal force acting on the object is equal to the weight of the object.Pull it sideways to the point that it starts to move. Record the force. Repeat this three times. In each case, start the block from the same position and pull gently.

Take note

Remember that the normal force acting on the object is equal to the weight of the object.

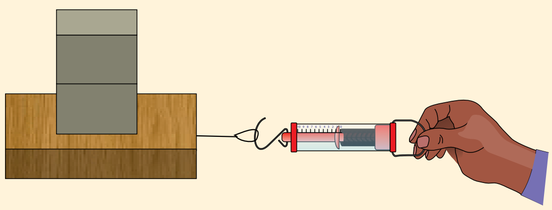


Figure 13.8

6. Repeat the experiment for larger masses.

Results

Table to record the force required to overcome the frictional force and move the block.

Mass (kg)	Normal force (N)	Reading 1 (N)	Reading 2 (N)	Reading 3 (N)	Average (N)

Plot a graph of the average force applied to the block at rest against the normal force of the block in your exercise books.

1. Which is the dependent variable?
2. Which is the independent variable?

Analysis

1. Draw a labelled free-body diagram of all the forces acting on the block just as it is about to start moving.
2. Why is the weight on the block being changed when the aim of the investigation is to find out how the normal force affects frictional force?
3. Why are three readings taken for each setup and an average calculated?
4. What is the shape of your graph?
5. What does the shape of the graph tell us about the relationship between the normal force of the block and the friction force?
6. What do you think would happen if the block was not placed on the smooth desk, but rather on a rough surface, or a much smoother surface? Would this affect the results?

Conclusion

1. Write a conclusion for this investigation.
2. Repeat the investigation and take some readings from the spring balance once the block is moving. How do the readings for the stationary block and a moving block compare? Is there a difference?

The force of friction depends on the type of surface on which an object is moving and the normal force. In order to get an object to move, a force greater than the frictional force needs to be applied in order to overcome the friction between the object and the surface.

Did you know?

We are measuring the static friction, which is the friction between two objects that are NOT moving. We measure it as the minimum force required to start the block moving.

Did you know?

Friction between two surfaces also causes the objects to heat up. Try this out by rubbing your hands vigorously together and then feel your palms afterwards.

Take note

The force applied to the point at which the block starts to move is equal to the frictional force acting on the block.

Friction is advantageous for a number of reasons. For example, the friction between our feet and the ground enables us to move forward and prevents us from slipping. Friction is also involved in keeping cars from skidding as the tyres experience friction between the tread and the roadway.

Tension and compression

There are other forces which are contact forces. Look at the following drawing of a boy pulling on a block with a rope.

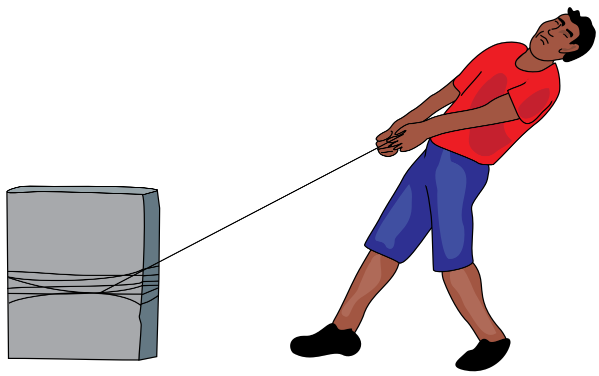


Figure 13.9

The person is pulling the rope which is pulling the block. The person is not touching the block directly. The person is pulling the rope and the block is pulling back on the rope in the opposite direction. This causes a **tension** force to exist in the rope. The rope is tight and so there is tension in the rope. Tension is a contact force. The tension in the rope pulls the block across the floor.

Figure 13.10: Crushing dough.

Another example of a contact force is **compression**. A compression force is a force which acts to deform or squash an object. Let's think of some examples.

If you take a ball of dough and crush it with your fingers, you are exerting a compression force on the dough. The dough changes shape. It deforms. Another example is crushing a tennis ball or a cooldrink can between the palms of your hands.

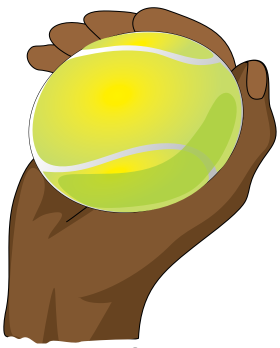


Figure 13.11: Compressing a tennis ball.

Can you think of some other examples?

The following diagram summarises the difference between tension and compression.

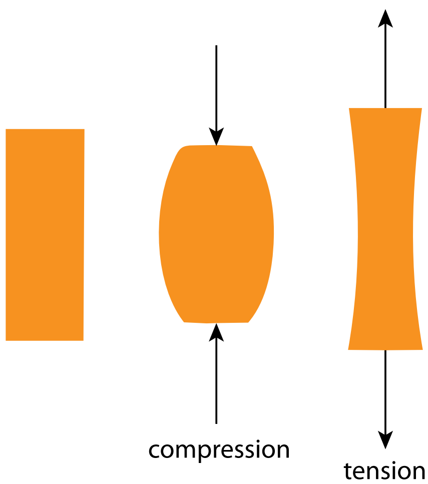


Figure 13.12: Tension forces are two forces acting on one object in opposite directions (away from each other) to stretch the object. Compression forces are two forces acting on one object in opposite directions (towards each other) to compress or deform the object.

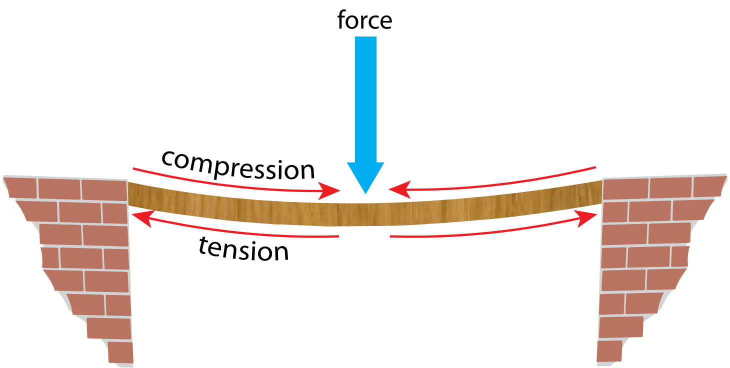


Figure 13.13

There are many other examples of compression forces in everyday life. A bridge experiences both compression and tension due to the weight of the cars and other vehicles which pass over it as shown in the following diagram.

We have been looking at contact forces, which include friction, normal forces, compression and tension. We are now going to look at the forces that act between bodies which do not touch.

13.3 Field (non-contact) forces

A field is a region in space where an object (with certain properties) will experience a force. Field forces are non-contact forces. Non-contact forces are forces which act over a distance. Object's experiencing field forces need not be in contact.

The most common examples of fields are:
- gravitational field
- magnetic field
- electric field

When we discussed contact forces, we spoke about pushes and pulls. However, with field forces, it is better to talk about repulsion and attraction.

Keywords
- gravitational force
- magnetic force
- electrostatic force
- field forces
- attraction
- repulsion

Did you know?

Newton developed his Law of Universal Gravitation, describing the force of attraction between bodies with mass, in 1687. Newton's work on describing a theory of gravitation may have been inspired by watching an apple fall from a tree

Gravitational forces

Have you ever wondered why things fall down and not up?

The force which causes things to fall down towards the Earth and prevents us from falling off the planet is the gravitational force. Gravitational forces exist between any two objects with mass and they are forces of attraction (pull).

The gravitational force is a force that attracts objects with mass towards each other. Any object with mass exerts a gravitational force on any other object with mass. The Earth exerts a gravitational pull on you, the desks in your classroom and the chairs in your classroom, holding you on the surface and stopping you from drifting off into space.

Factors affecting gravitational force

The Earth's gravitational force pulls everything down towards the centre of the Earth which is why when you drop an object like a book or an apple, it falls to the ground. However, do you know that you, your desk, your chair, and the falling apple and book exert an equal but opposite pull on the Earth?

Why do you think these forces on the Earth do not cause the Earth to move noticeably?

Figure 13.14: The arrows show the direction of the gravitational field of the Earth. The arrows all point towards the centre of the Earth because the gravitational force is always attractive

Figure 13.15: These army skydivers have just jumped out of the back of a plane and fall towards the Earth due to gravity.

The Earth attracts us because it has such a large mass and so we are attracted downwards towards the centre of the Earth all the time.

The bigger the mass of the objects, the greater the force between them. This means that two small objects would have a very weak gravitational attraction and so it has no noticeable effect. However, bigger objects such as the Moon and the Earth have a much greater gravitational force.

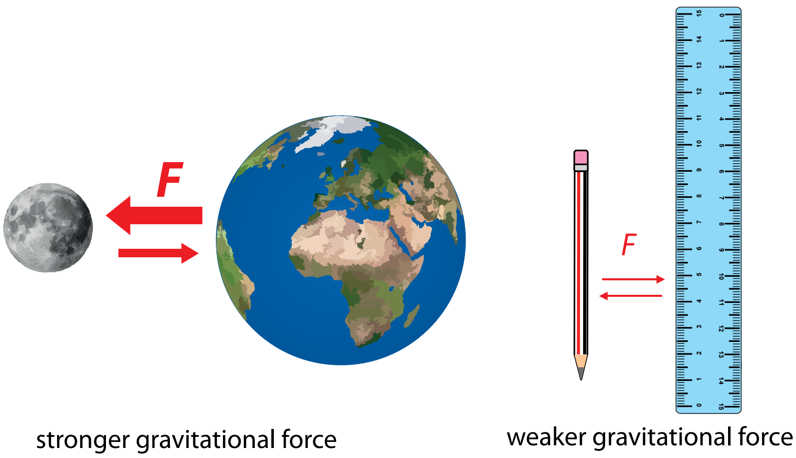


Figure 13.16

As we know from Planet Earth and Beyond, all the planets in our solar system are held in orbit around the Sun by the gravitational force of attraction between the Sun and planets.

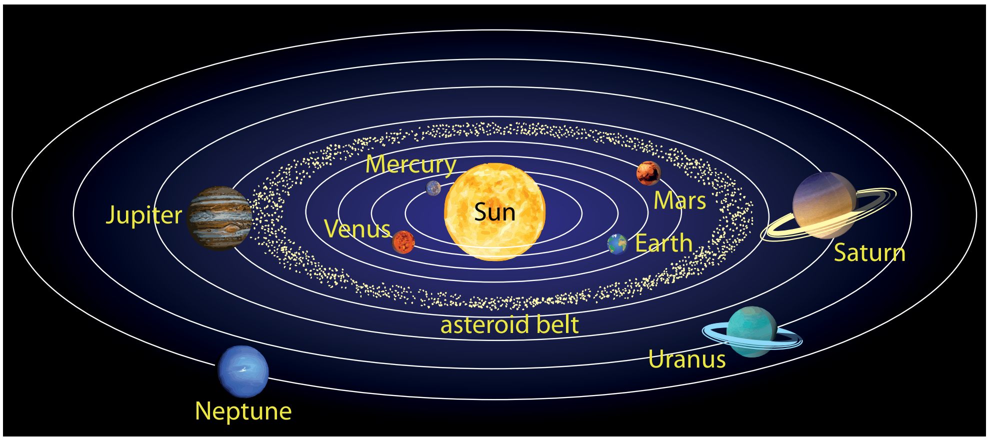


Figure 13.17: The planets move around the Sun in our solar system. There is a gravitational force of attraction between the Sun and planets, and between planets and their moons.

The second factor which affects the gravitational force of attraction between objects is the distance between them. The further objects are away from each other, the smaller the gravitational force.

All the components in our Universe are held together by a gravitational force. There are two factors affecting the gravitational force acting on the object:

- The mass of the object. The bigger the mass, the greater the gravitational force.
- The distance between the objects. The closer the objects, the greater the force.

Did you know?

There is a gravitational force of attraction between us and the Sun, but we do not notice it as we are so far apart, and we are very small.

Investigation Dropping objects

Investigative question

Do different objects fall at the same rate?

Hypothesis

What do you think will happen?

Materials and apparatus

- hammer
- feather
- two balls of the same mass, different volumes (one set per pair)
- two balls of the same volume, different masses (one set per pair)

Method

1. Work in pairs, taking turns to be the person who drops an object (experimenter) and the person who observes the objects dropping (observer).

2. Copy the following table into your exercise book, then complete the 'prediction' column.
3. Experimenter: stand on top of a chair or desk and take the two balls of the same mass, with one in one hand and the other in the other hand.
4. Experimenter: hold the two balls up at the same height in front of you and drop them at exactly the same time.
5. Observer: note what happens, in particular which lands first.
6. Swap positions and repeat the experiment using two balls which have the same volume but different masses.
7. Your teacher will now do a demonstration for you and drop a hammer and a feather. Before your teacher drops the hammer and feather, record the prediction column for the hammer and feather drop.
8. Record what happened with the hammer and feather and answer the questions that follow.

Results and observations

1. What did you keep constant in this experiment?
2. What did you change in this experiment?
3. Before conducting your experiment, assume that you drop each pair of objects from the same height, at the same time. What do you think will happen?
4. Which object do you think will land first? Why?

Objects	Prediction	Observation
Balls: same mass, different size		
Balls: different mass, same size		
Hammer and feather		

Evaluation

How reliable was your experiment? How could you improve your method?

Conclusion

Write a conclusion for this investigation.

Questions

1. Considering the balls of the same mass, which landed first, the larger one or the smaller one?
2. Considering the balls of the same volume, which landed first, the heavier one or the lighter one?
3. Why do you think the two dropped balls always landed at the same time?
4. Why do you think the hammer landed before the feather?

Mass and weight

You have probably heard the term 'weight' used many times before, either in your Natural Sciences classroom, or in conversation with others. Many people use the term weight incorrectly in everyday language. For example, a relative may say to you 'My weight increased by 2 kg over the holiday period as I ate too much food.' What is wrong with this statement? Discuss this with your class and teacher.

The **mass** of an object is the amount of matter in the object. It tells you how many particles you have. Do you remember learning about atoms in Matter and Materials? So, for example, the mass of a wooden block tells us how many atoms there are. Mass is measured in kilograms (kg) and is independent of where you measure it. A wooden block with a mass of 10 kg on Earth also has a mass of 10 kg on the Moon.

However, an object's **weight** can change as it depends on the mass of the object and also the strength of the gravitational force acting on it. Weight is measured in newtons (N) as it is the gravitational force of attraction exerted on an object by the Earth (or Moon or any other planet). Therefore, the weight of an object will change when weighed in different places.

The weight of a 10 kg block on Earth will be different from its weight on the Moon. Why do you think this is? Will the weight be more or less than on the Moon?

Keywords

- weight
- mass
- free-fall
- gravitational acceleration

Did you know?

The word 'mass' comes from the Greek word '*maza*', which means a lump of dough or cake.

Investigation: What is the relationship between the mass of an object and its weight?

Hypothesis

Write a hypothesis for this investigation.

Materials and apparatus

- four mass pieces in increments of 500 g (one of 500 g, one of 1 kg, one of 1,5 kg and one of 2 kg)
- spring balance or force meter
- triple beam balance

Method

1. Measure the mass pieces on the triple beam balance.
2. Measure the weight of each mass piece with the spring balance.

3. Copy the table below in your exercise books and record the mass and matching weight.

Results

Mass (kg)	Weight (N)

1. What is the dependent variable?
2. What is the independent variable?
3. Draw a graph of your results.
4. Your graph should be a straight line. Calculate the gradient of your graph.

Conclusion

Write a conclusion for this investigation.

Weight is the force of gravity pulling you towards the centre of the Earth. It is measured in newtons. On Earth the gravitational force causes us all to accelerate towards the centre of the Earth. The acceleration is called gravitational acceleration.

Did you know?

The mass of the Earth is 5,972 × 10^{24} kg.

On Earth it is 9,8 m/s^2. The gradient that we calculated in the last investigation should have given you a number close to 9,8 m/s^2 which is gravitational acceleration.

Objects are in free-fall when the only force acting on them is the gravitational force.

Weight (W) is calculated by multiplying an object's mass (m) by the gravitational acceleration (g):

$$\mathbf{W = m \times g}$$

But what if you went to the Moon?

The Moon also has its own gravity. The strength of gravity on the surface of the Moon is one-sixth of that on the surface of the Earth, and so you would weigh one-sixth of what you do on Earth on the Moon. On Jupiter you would weigh 2,5 times more than you do on Earth as Jupiter's gravity is 2,5 times that of the Earth's. Even

Figure 13.18: The Moon is 6 times smaller than the Earth.

though you would weigh different amounts (and feel lighter on the Moon and heavier on Jupiter) your actual mass would stay the same in both cases.

An astronaut's mass remains the same wherever it is measured. The astronaut's weight, however, depends on where you measure it.

So how much would an astronaut weigh on the Moon? Suppose that an astronaut has a mass of 120 kg. Your weight on Earth would be $120 \times 9{,}8 = 1\,176$ N. The gravitational acceleration on the Moon is 1,6 m/s^2, so your weight would be $120 \times 1{,}6 = 192$ N on the Moon.

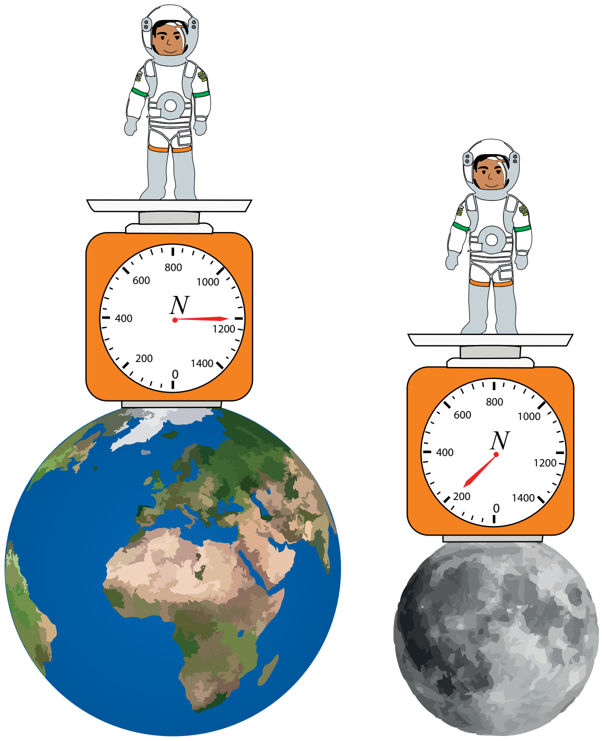


Figure 13.19

> **Take note**
>
> A bathroom scale actually measures weight and converts it to mass.

ACTIVITY Weight and mass calculations

Questions

1. A Ferrari has a mass of 1 485 kg. What is its weight on Earth?
2. Lindiwe has a mass of 50 kg on Earth. What is her mass on the Moon?
3. Ian has a mass of 78 kg. His friend Sam says that he would weigh 24 N on the Moon. Is Sam correct? Explain by using a calculation.
4. You have an apple with a mass of 220 g, what is its weight on Earth and on the Moon?
5. If a cow weighed 1 340 N on the Moon, what is its mass?


Figure 13.20: A Ferrari.


Figure 13.21: A jersey cow.

Have you ever wondered what it would be like to walk around on other planets? Find out how much you would weigh on other planets in the next activity.

ACTIVITY How much would you weigh on other planets?

Materials

- weighing scales
- calculator

Instructions

1. Measure your mass in kilograms. Copy the table below in your exercise books and record the values.
2. Use the values for the acceleration due to gravity on various planets to calculate what you would weigh on that planet.

Planet	Your mass (kg)	Value of g (m/s^2)	Your weight (N)
Earth		9,8	
Mercury		3,6	
Venus		8,8	
Mars		3,8	
Jupiter		26	
Saturn		11,2	
Uranus		10,5	
Neptune		13,3	

Questions

1. On which planets would you feel heavier than you do on Earth?
2. On which planets would you feel lighter than you do on Earth?

Figure 13.22: Astronauts experiencing weightlessness.

Your weight (N)

The weight of a person is the force of gravitational attraction to the Earth that person experiences. Someone in free-fall feels weightless but they have not lost their weight. They are still experiencing the Earth's gravitational attraction.

The only reason the astronauts float is because they are in free-fall and their moving spacecraft is also in free-fall with them, falling at the same rate. Therefore, the astronauts appear to float when compared with the spacecraft because they are both falling at the same rate.

Magnetic forces

Certain materials have strong magnetic fields around them. These are called magnets. All magnets have two poles, a north and a south pole.

Other materials are strongly attracted to magnets. These materials are said to be magnetic. Magnets exert forces on other magnets and magnetic materials.

Which materials are magnetic? Let's investigate.

Keywords

- magnet
- magnetic material
- alloy

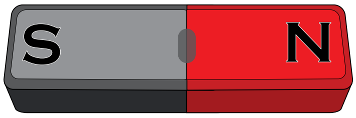


Figure 13.22: An example of a bar magnet with a north and South Pole.

Investigation Magnetic or non-magnetic materials

Investigative question

Which materials are magnetic, and which are not?

Hypothesis

Write a hypothesis for this investigation.

Materials and apparatus

- bar magnets
- paper
- wood
- plastic
- iron
- aluminium
- steel

Method

1. Hold the different items close to the bar magnet (not touching) to see if they are attracted to the magnet.
2. Complete the table indicating whether or not the items are attracted to the magnet.

Results

Copy and complete the following table in your exercise books.

Material	Magnetic (YES/NO)
paper	
wood	
plastic	
iron	
aluminium	
steel	
copper	

Conclusion

What can you conclude from your results?

Not all metals are attracted to magnets. Those that are attracted to magnets are known as magnetic materials. There are very few magnetic materials. They are iron, nickel and cobalt. Alloys which include any of the magnetic materials can also be attracted to magnets. Steel is an alloy which contains iron so steel can be attracted to a magnet.

So now we know that magnetic forces can act over a distance, but can they still act if there is something in the way? Let's find out.

Take note

An alloy is a mixture of metals.

ACTIVITY Can a magnetic force act through substances?

Materials

- bar magnets
- paper
- thin piece of wood
- thick piece of wood
- foil
- paperclips

Instructions

1. Hold two north poles close together. What do you notice?
2. Hold two south poles close together. What do you notice?
3. Hold a north pole and a south pole close together. What do you notice?
4. Put the paper clips on the desk.
5. Try to pick up the paperclips with the magnet but put one of the other materials between the magnet and the paper clips. Are the paperclips still attracted to the magnet?
6. Try each of the different materials between the magnet and the paper clip.

Questions

1. Which materials prevented the magnet from picking up paper clips?
2. What does this activity tell us about the nature of the magnetic force?

In the last activity we saw that like poles repel each other but opposite poles attract each other. We have also seen that the magnetic force acts over a distance. The magnet does not need to touch something in order to exert a force on it. So a magnetic force is a non-contact or a field force.

What is a field of a force? Can we see it? Let's investigate if it is possible to see a magnetic field.

ACTIVITY Visualising magnetic fields

Materials

- iron filings
- two bar magnets
- paper

Instructions

1. Put one of the bar magnets on the table.
2. Put the paper over the magnet.
3. Shake the iron filings onto the paper.
4. Take note of the pattern and draw it in your exercise books.
5. Lift the paper away from the magnet.
6. Place a second magnet next to the first so that different poles are facing each other.
7. Put the paper back over the magnets.
8. Move the iron filings around the two magnets, especially between the magnets..
9. Draw the pattern in your exercise books.
10. Lift the paper away from the magnet.
11. Move the second magnet so that the same poles are facing each other.
12. Put the paper back over the magnets.
13. Move the iron filings around the two magnets, especially between the magnets.
14. Draw the pattern in your exercise books.

Take note

In the last activity, the iron filings showed a two-dimensional view of the field but the field is actually all around the magnet, in three dimensions.

As we have seen, it is possible to visualise the magnetic force field around a magnet. We know from our previous activities that the magnetic force acts over a distance. The field is the space around a magnet in which it can attract or repel another magnet.

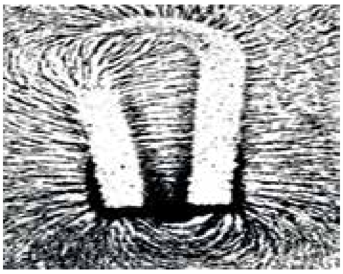


Figure 13.23: The magnetic field around a horseshoe magnet.

How do we draw a force field? The pattern you saw with your magnets can be represented by **field lines**. Field lines are used to show something we can't actually see. The closer the field lines are drawn together, the stronger the field being described. The more field lines that are drawn, the stronger the field. The field lines go from the North Pole to the South Pole. The following diagram shows the field lines around a bar magnet.

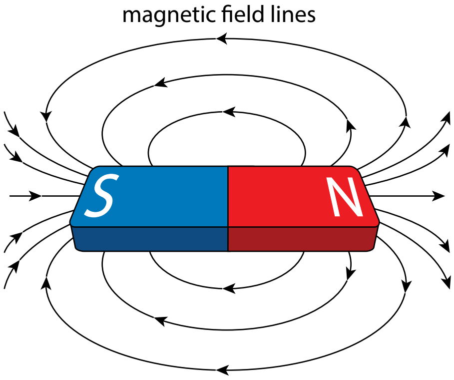


Figure 13.24

The next diagrams show the field lines between bar magnets which are attracting and those which are repelling.

Opposite poles attract.

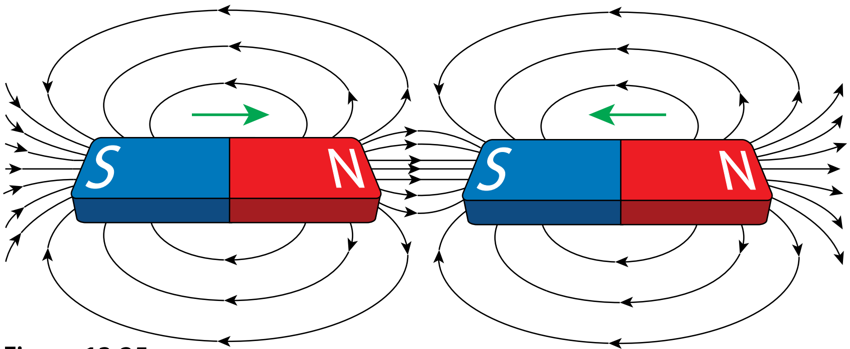


Figure 13.25

Like poles repel.

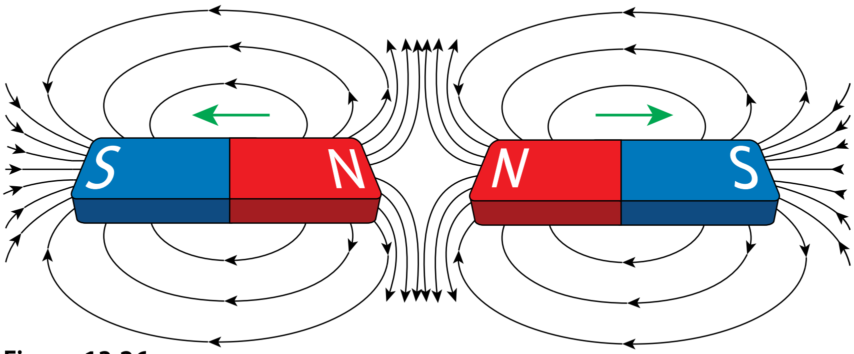


Figure 13.26

A field is strongest next to the magnet and gets weaker further away from the magnet.

Did you know that the Earth is like a bar magnet with a North and a South Pole? The Earth has a magnetic field. You can imagine Earth's magnetic field as though there is a bar magnet running through the core with the magnet's South Pole under Earth's North Pole. No one knows for sure, but the theory is that the superhot liquid iron in the Earth's core moves in a rotational pattern, and these rotational forces lead to the weak magnetic forces around the Earth's rotational axis.

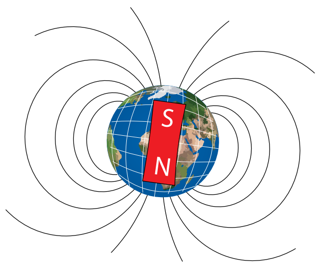


Figure 13.27: Earth has a magnetic field, as though there is a big bar magnet running through the core, with its South Pole below Earth's magnetic North pole.

The Earth's magnetic field is the reason why we can use compasses to tell direction.

A plotting compass has a needle with a small magnet. The needle points to magnetic north because the small magnet is attracted to the opposite magnetic field and can be used to determine direction.

Figure 13.28: A compass with the needle pointing North.

Have you heard of the Southern or Northern Lights before? Do you know how these phenomena occur?

Take note

The Southern lights are also called the Aurora Australis and the Northern lights are called the Aurora Borealis.

Figure 13.29: The Southern Lights, viewed from the International Space Station.

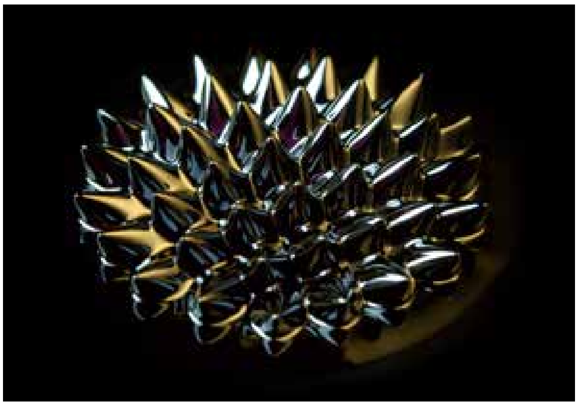


Figure 13.30: An example of a ferrofluid, a liquid that can become magnetised in a magnetic field.

For enrichment

- Charged particles escape from the surface of the Sun and move outwards in all directions. When the charged particles reach Earth, some are trapped by Earth's magnetic field in areas in space around Earth's atmosphere, called belts.
- Sometimes the charged particles escape the belts and spiral along the magnetic field lines towards the magnetic poles where they enter Earth's atmosphere. They then interact with atmospheric gas particles, causing beautiful light shows.
- Some liquids can also become magnetised in the presence of a strong magnetic field. They are called ferrofluids.

Electrostatic forces

Do you remember learning about static electricity in Grade 8? Let's do a quick activity to revise some of the concepts we already know.

ACTIVITY Charging objects

Materials

- balloons (or a plastic comb)
- glass rod
- piece of knitted fabric (wool)
- PVC rod
- plastic ruler
- small pieces of paper
- water tap

Instructions

1. Work in pairs.
2. Blow up a balloon and tie it closed so that the air does not escape.
3. Hold the balloon a short distance away from your hair. What do you notice?
4. Rub your hair with the balloon.
5. Now hold the balloon a short distance away from your hair. What do you see?

6. Next, hold the glass rod over the small pieces of paper. What do you notice?
7. Rub the glass rod with the knitted fabric.
8. Hold the glass rod over the pieces of paper. What do you notice?
9. Rub the glass rod with the knitted fabric again.
10. Open the tap so that a thin stream of water is flowing.
11. Hold the glass rod close to the stream of water. What do you notice?

Questions

1. What did you do to make your hair stick to the balloon?
2. What happens when you rub the glass rod with the knitted fabric?
3. Why did the glass rod attract the stream of water?

Let's look at the example of brushing your hair in more detail to understand what is happening. You have dragged the surface of the plastic comb against the surface of your hair. When two surfaces are rubbed together there is **friction** between them. The friction between two surfaces can cause electrons to be transferred from one surface to the other.

In order to understand how electrons can be transferred, we need to remember what we learnt about the structure of an atom.

- Where are the electrons positioned in the atom?
- What is the type of charge on a proton?
- What is the type charge on an electron?
- What is the charge on a neutron?

The atom is held together by the **electrostatic attraction** between the positively charged nucleus and the negatively charged electrons. Within an atom, the electrons closest to the nucleus are the most strongly held, while those further away experience a weaker attraction.

Normally, atoms contain the same number of protons and electrons. This means that atoms are normally **neutral** because they have the same number of positive and negative charges, so the charges balance each other out. All objects are made up of atoms and since atoms are normally neutral, objects are also usually neutral.

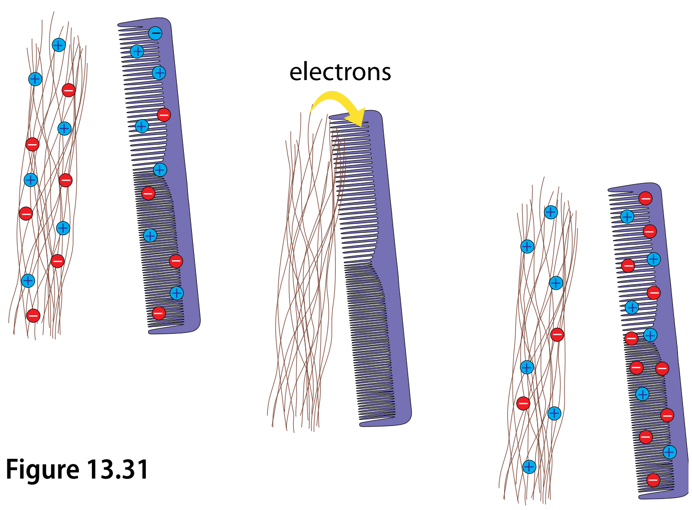


Figure 13.31

However, when we rub two surfaces together, such as when you comb your hair or rub a balloon against your hair, the friction can cause electrons to be transferred from one object to another. Remember, the protons are fixed in place in the nucleus and so they cannot be transferred between atoms. Only electrons can be transferred between atoms. Some objects give up electrons more easily than other objects. Look at the following diagram which explains how this happens.

Which object gave up some of its electrons in the diagram?

Does this object now have more positive or more negative charges?

Which object gained electrons in the diagram?

Does this object now have more positive or more negative charges?

- When an object has more electrons than protons, we say that the object is **negatively charged**.
- When an object has fewer electrons than protons, we say that the object is **positively charged**.

Have a look at the following diagrams which illustrate this.

> **Take note**
>
> Remember it is only the outer electrons which move, and not the protons, which are located in the nucleus of the atom.

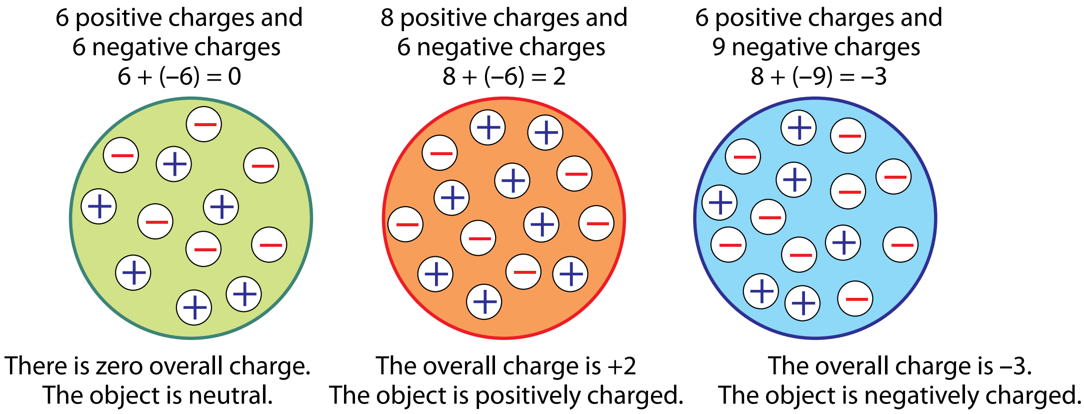


Figure 13.32

We now understand the transfer of electrons that takes place as a result of friction between objects. But how did that result in your hair rising when you brought the charged balloon close to your hair in the last activity? Let's look at what happens when oppositely charged objects are brought together.

ACTIVITY Turning the wheel

Materials

- two curved watch glasses
- two Perspex rods
- cloth: wool or nylon
- plastic rod
- small pieces of torn paper

Instructions

1. Place a watch glass upside down on the table.
2. Balance the second watch glass upright on the first watch glass.
3. Rub one of the Perspex rods vigorously with the cloth.
4. Balance the Perspex rod across the top of the watch glass.
5. Rub the second Perspex rod vigorously with the same cloth.
6. Bring the second Perspex rod close to the side of the first Perspex rod that was charged. What do you see happening?

> **Take note**
>
> Remember, like charges repel and opposite charges attract.

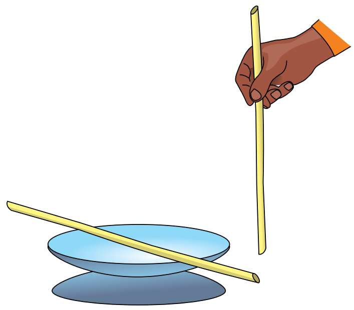


Figure 13.33

7. Repeat the activity but instead of the second Perspex rod, use the plastic rod. What do you see happening?
8. Next, bring a rod that you have rubbed closer to small pieces of torn paper on the table. What do you observe?

Questions

1. What happened when you brought the second Perspex rod close to the first Perspex rod?
2. What happened when you brought the plastic rod close to the first Perspex rod?
3. What happened when you brought the plastic rod close to the pieces of paper?

When we rubbed the Perspex rods with the cloth, electrons were transferred from the Perspex to the cloth. What charge do the Perspex rods now have?

Both the Perspex rods now have the **same** charge. Did you notice that objects with the same charge tend to push each other away? We say that they are **repelling** each other. It is an electrostatic force of repulsion.

When we rubbed the plastic rod with the cloth, electrons were transferred from the cloth to the plastic rod. What charge does the plastic rod now have?

The perspex rod and the plastic rod now have **opposite** charges. Did you notice that objects with different charges tend to pull each other together? We say that they are **attracting** each other. It is an electrostatic force of attraction.

As with gravitational and magnetic force, the distance between charged objects affects the strength of the electrostatic force. The closer the charged objects are, the stronger the force. The more charged the objects are, the stronger the electrostatic force between them.

We have now observed the fundamental behaviour of charges. In summary, we can say:

- If two negatively charged objects are brought close together, then they will repel each other.
- If two positively charged objects are brought close together, then they will repel each other.
- If a positively charged object is brought closer to a negatively charged object, they will attract each other.
- Have you ever wondered where lightning comes from? Let's demonstrate an electrostatic spark.

Did you know?

The fundamental idea of using friction in a machine to generate a charge dates back to the 17th century, but the generator was invented by Robert Van de Graaff only in 1929 at Princeton University.

ACTIVITY Van de Graaff generator

Materials

- Van de Graaff generator

Instructions

1. Turn on the generator.
2. Bring the small metal globe close to the generator. What do you see?

Did you see sparks? The Van de Graaff generator can be used to demonstrate the effects of an electrostatic charge. The big metal dome at the top becomes positively charged when the generator is turned on. When the dome is charged it can be discharged by bringing another insulated metal sphere close to the dome. The electrons will jump to the dome from the metal sphere and cause a spark.

Figure 13.34: A Van de Graaff generator.

How does this little spark relate to a massive lightning strike?

During a lightning storm, clouds become charged. Friction between the clouds and the moisture in the clouds cause the clouds to become charged. The bottom of the clouds (closest to the ground) become negatively charged and the top of the cloud becomes positively charged. When the build-up of charge becomes too large, the electrons move from the bottom of the cloud to the ground where they are 'earthed'. The energy transfer is massive and results in extremely bright light, heat and sound. A lightning flash is a massive discharge between charged regions within clouds, or between clouds and the Earth. The thunder-clap, which we hear, is the air moving as a result of electrons moving.

Figure 13.35: Lightning is a huge electrostatic discharge.

Lightning is extremely dangerous. If the electrons move through a person on their way to the ground, then the large amounts of energy cause significant damage. That person can suffer serious injury, even death.

What precautions should we take during a lightning storm? Lightning can strike far from the rain shadow of the storm. This means that even if the storm seems to be far away, it is better to take precautions anyway. The safest place to be in a lightning storm is indoors. Stay away from windows and metal objects. If you cannot get inside, avoid standing next to tall objects or metal objects because if lightning strikes it will usually hit the tallest object in the area. If you are travelling in a car during a storm, stay inside the car until the storm subsides.

Did you know?

South Africa has one of the highest incidences of lightning strikes in the world.

Summary

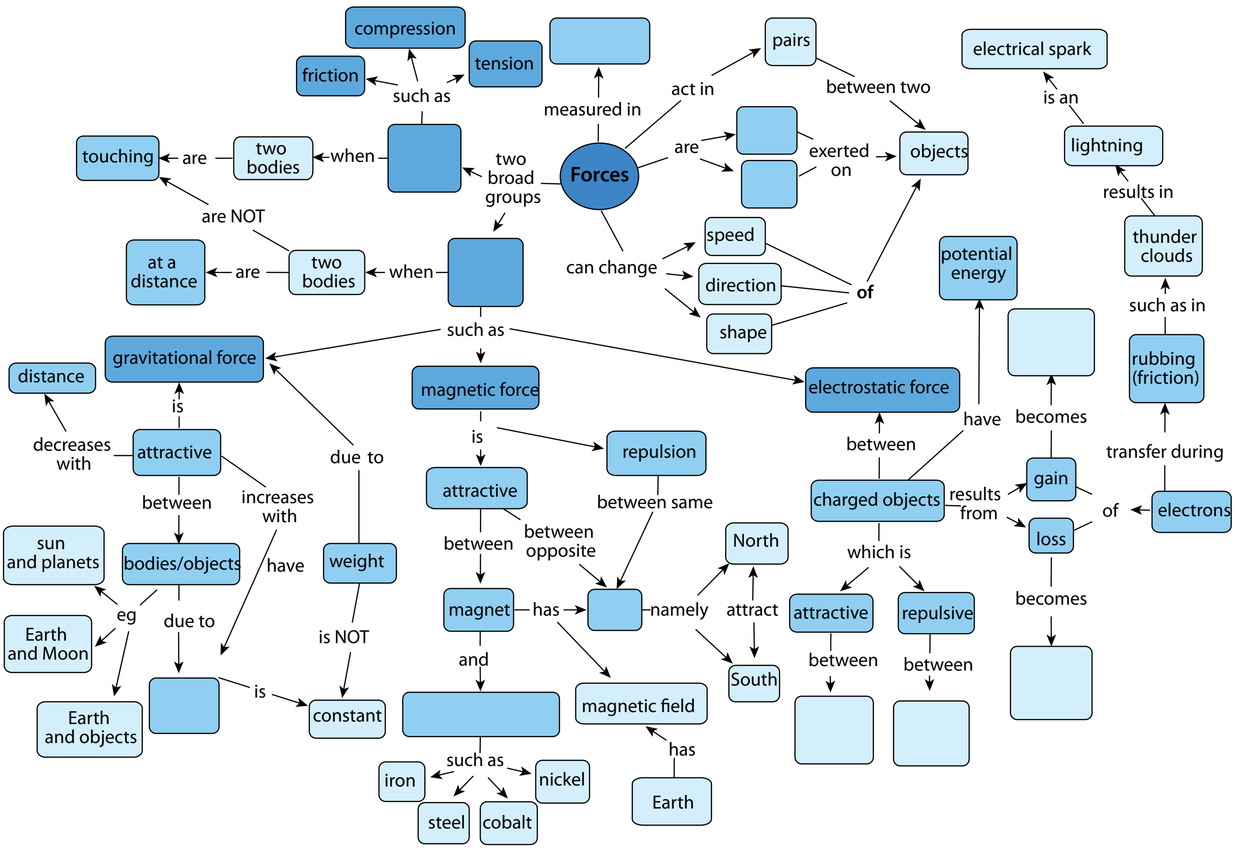
Key concepts

- A force is defined as a push or a pull on an object.
- Forces are measured in newtons (N).
- A force can change the shape, direction and motion of an object.
- Forces act in pairs. The force acting on the object is called the action and the force that the object exerts back in the opposite direction and equal in magnitude is the reaction.
- More than one force can act on an object. The net or resultant force is the sum of all the forces acting on the object.
- The forces acting on a body can be represented as a free-body diagram where the arrows indicate the direction and magnitude of the different forces.
- There are two main groups of forces: contact and non-contact (field) forces.
- Contact forces act when objects are in contact (touching) with each other. Friction, tension and compression are examples of contact forces.
- Friction is the force opposing motion between two surfaces as they rub against each other.
- Compression forces are two forces acting on one object, moving in opposite directions (towards each other) to compress or deform the object.
- Tension forces are two forces acting on one object, moving in opposite directions (away from each other) to stretch the object.
- Non-contact forces can act over a distance and objects do not have to be touching each other. Common examples of field forces are magnetic, electrostatic and gravitational forces.
- Non-contact forces are known as field forces. A field is a region in space where a certain object with certain properties will experience a force.
- Gravitational force is a force of attraction between two bodies due to their mass. The gravitational force increases with mass and decreases with the distance between the bodies.
- The weight of a body is the gravitational force exerted on an object by the Earth (or Moon or other planet). The weight will vary depending on where it is measured.
- The mass of an object is a measure of how much matter it contains. The mass stays constant no matter where it is determined.
- Weight is calculated as $W = m \times g$, where g is the gravitational acceleration. On Earth, $g = 9{,}8\ m/s^2$.
- A magnet is a material which has a strong magnetic field around it.
- Magnetic forces of attraction exist between a magnet and a magnetic substance, such as iron, steel, cobalt and nickel.
- A magnet has two poles, a north and south pole. Opposite poles attract each other and like poles repel each other.
- The Earth has a magnetic field around it. We can use compasses to tell direction as the needle is a magnet which points to magnetic North.
- When certain materials are rubbed together, the friction between them causes electrons to move from one material to the other. The objects then have an electrostatic charge, due to either the loss or gain of electrons.
- A charge is a fundamental property of matter. Electrons carry negative charges and protons carry positive charges.
- An object which has gained electrons will be negatively charged. An object which has lost electrons will be positively charged.

- There is an electrostatic force of attraction between objects with opposite charges, and repulsion between objects with like charges.
- Thunder clouds can become charged as the water and air particles rub against each other. A lightning strike occurs when there is a huge discharge between the thunderclouds and the ground.
- Lightning is dangerous and safety precautions should be adhered to during lightning storms.

Concept map

- Complete the concept map to summarise what you have learnt about forces in this unit. You can also use the space around the concept maps to add some of your own notes on these to help form more comprehensive summaries. This will help you prepare for exams when you need to revise everything from the year.



Revision

1. Give one term for each of the following descriptions. [5]
   a) An influence that can deform a flexible object or change the motion of an object with mass.
   b) A region in space where an object with certain properties will experience a force.
   c) When the only force acting on an object is the force due to gravity.
   d) The two opposite ends of a magnet.
   e) A fundamental property of matter that comes in two types and is carried by protons and electrons.

2. Four possible answers are given for each of the following questions. There is only one correct answer. Write the letter in your exercise books. [6 × 2 = 12]
   a) Which ONE of the following statements is FALSE?
      A. In order for a non-moving object to start moving, a net force must act on that object.
      B. Contact forces are strongest when the objects experiencing the force are touching.
      C. Field forces act over distances, but they can also act when objects are touching.
      D. Forces always act in pairs of equal strength, but these pairs act on different objects.
   b) Which ONE of the following is NOT a field force?
      A. Gravitational force
      B. Frictional force
      C. Electrostatic force
      D. Magnetic force
   c) The correct unit for gravitational force is:
      A. the newton
      B. the kilogram
      C. the newton per kilogram
      D. the kilogram per newton
   d) Which ONE of the following substances is magnetic?
      A. aluminium
      B. copper
      C. cobalt
      D. tin
   e) The electrostatic force between two charged objects is F. The distance between them is increased. How does the electrostatic force change?
      A. It increases
      B. It decreases
      C. It remains the same
      D. Not enough information has been provided.
   f) An astronaut has a mass of 80 kg on Earth. Which ONE of the following regarding mass and weight of the astronaut on the Moon is correct?
      A. The mass will be the same and the weight will also be the same.
      B. The mass will be less and the weight will also be less.
      C. The mass will be the same and the weight will be less.
      D. The mass will be less and the weight will be the same.

3. Decide which of the following statements are True or False. If they are False, rewrite them to make true. [5 × 2 = 10]
   a) A force cannot make a motionless object move.
   b) A force can make a moving object change direction.
   c) A force can change the shape of an object.
   d) A tension force slows down or stops an object because of the surfaces rubbing against each other.
   e) Lightning is an application of a magnetic force.

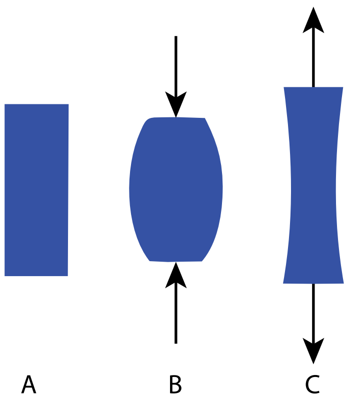
4. Have a look at the following images.

   a) Which situation shows a push and which situation shows a pull? [1]
   b) The boy is pulling the desk with a force of 70 N. There is a frictional force of 20 N. Draw a free-body diagram to show these forces acting on the desk. [4]
   c) What is the net force acting on the desk? [1]

5. A force of 50 N and 80 N act on a block. Calculate the net force acting on the block if:
   a) the forces are acting in the same direction [1]
   b) the forces are acting in opposite directions. [1]

6. Write down three different effects that a force can have on an object. [3]

7. What is the following diagram illustrating? Explain your answer. [4]



8. Tabulate the distinction between mass and weight by making use of definitions of mass and weight and comparing the units they are measured in. [5]

9. Write down the formula that relates the weight of an object to its mass. Explain what each symbol represents. [4]

10. What TWO factors affect the gravitational force experienced between two objects? Explain the relationship. [2]

11. An astronaut performs an experiment to determine the relationship between mass and weight on different planets. He takes a scale and sets off in a spaceship and measures his own weight on different planets in the solar system. The following table indicates his results.

Planet	Weight (N)
Mercury	287
Venus	710
Earth	?
Mars	302

Planet	Weight (N)
Jupiter	2 076
Saturn	886
Uranus	854
Neptune	1 126

a) Calculate the astronaut's weight on Earth if his mass is 80 kg. [3]

b) Plot an appropriate graph of the astronaut's weight on different planets of the solar system. Your graph will need a suitable heading and labels for the axes. [8]

c) On which planet is Kevin's weight the smallest? What does this tell you about the size of this planet in relation to the other planets? [2]

12. Draw a diagram to illustrate the magnetic field around a bar magnet. [3]

13. You do an experiment in class to investigate the bar magnets. You place two magnets next to each other on the table and place a sheet of paper over the magnets and sprinkle iron filings over the paper. You then turn one magnet around and do it again. You see the following patterns. What does each photo (A and B) show us? [2]

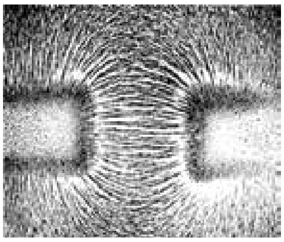


Photo A.

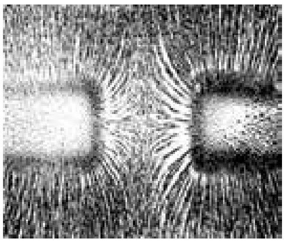
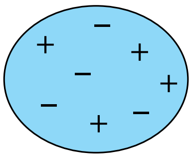
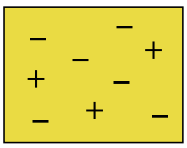
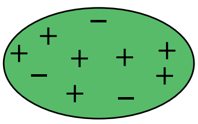


Photo B.

14. Complete the table by determining the overall charge on each object. Show your calculations. State whether the object is positively charged, negatively charged, or neutral, and why. [9]

Object	Overall charge	Why is it positive, negative or neutral?
		
		
		

15. A balloon is rubbed against a jersey and the balloon picks up a negative charge.

a) Explain where this negative charge comes from. Make reference to both protons and electrons in your answer. [3]

b) Name the type of force that the balloon and jersey will experience DURING rubbing. [1]

c) Name the type of force that the balloon and jersey will experience AFTER rubbing. [1]

d) Will the force referred to in (c) be attractive or repulsive? [1]

16. What do you think these two girls are touching on the left of the photo? Explain your answer and what is happening to them. [3]

17. Write a short paragraph to explain how lightning forms. [4]

18. What is wrong with the following scene? Explain your answer. [2]

Total [95 marks]

14 Electric cells as energy systems

Key questions

- Where does an electrical circuit get its energy from?
- What is inside a battery?
- How can we build our own electric cells?
- How does an electric cell supply energy?

This term we will be investigating electricity and electrical circuits in more detail. We are going to pay attention to electric cells. You have already come across electric cells in previous grades when looking at electrical circuits. What is the circuit symbol for an electric cell? Draw it in your exercise books. Indicate the positive and negative terminal.

14.1 Electric cells

Keywords

- electric cell
- battery
- electrode
- electrolyte
- half cell
- salt bridge

What is the source of energy in an electrical circuit?

We use electric cells to supply the energy needed for electrons to move around an electrical circuit. We often talk about batteries in electrical circuits or appliances. A battery is a group of two or more electric cells that are connected together. Where does the energy in a cell come from?

In Grade 8 we spoke about the transfer of energy within electrical systems. We can also call an electric cell a system. Write your own definition of a system in your exercise book.

Take note

Last term in Matter and Materials we looked at many different types of chemical reactions.

The electric cell system works to generate electricity. We have spoken before about how electricity is generated using moving parts, such as in a power station, where the moving parts in a generator produce electricity. A cell does not have moving parts to generate electricity. An electric cell generates electricity from **chemical reactions**.

Did you know that we can create our own cell using a fruit? Let's try this out in the next activity.

ACTIVITY Fruit cell

Materials

- lemon (or potato)
- zinc strip or galvanised nail
- copper strip or coin
- LED bulb
- ammeter
- insulated copper conducting wires

Instructions

1. Gently squeeze the lemon to soften the fruit so that the juice is released inside. Be careful not to crush the lemon or break the peel. If you are using a potato, you do not need to squeeze it first.

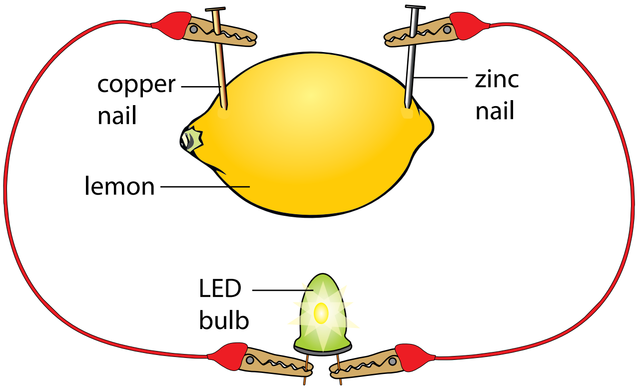


Figure 14.1

2. Next, puncture the peel of the lemon with the two different nails (or strips) of **different** metals. If you are using a copper coin, then push it carefully into the lemon so that it breaks the skin.
3. Insert each nail slowly and carefully into either side of the lemon. Push the nails into the lemon so that they almost reach the centre of the lemon, but are not touching.
4. Attach one wire to the zinc (or iron) nail and the other wire to the copper nail or copper coin.
5. Connect the wires to the LED bulb and ammeter if you are using one as shown in the diagram. What do you notice?

Questions

1. If your light bulb does not glow, connect your fruit cell with your partner's cell and reconnect the LED light bulb. Does it glow now? If not, connect several more fruit cells in a series until the LED bulb glows as shown in the diagram. How many cells did you connect in series to cause the LED to emit light?

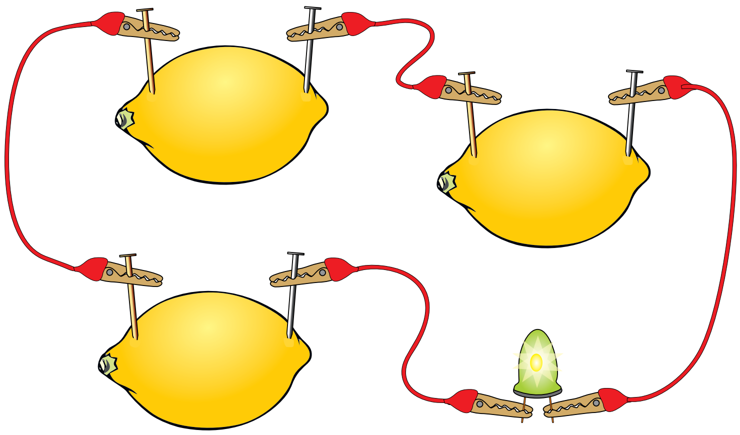


Figure 14.2

2. What do we call the cells connected together?
3. What happens if you replace the copper nail with another zinc nail, so that you have two electrodes of the **same** metal? Are you able to light up the LED light?
4. Experiment further by investigating the effects of pushing the nails deeper into the lemon and placing them at different positions in the lemon (closer together and further apart). Record some of your observations here.

Did you know?

The lemon battery is very similar to the first electrical battery invented by Alessandro Volta in 1800. He used salt water instead of lemon juice.

In the last activity we created a simple electric battery. A chemical reaction takes place inside the lemon which produces electricity. The components in the lemon battery are very similar to those used in a normal battery. The copper and zinc nails (or strips of metal) are called **electrodes**. The lemon juice acts as the **electrolyte**. Citrus fruits, such as lemons, are acidic, which helps their juice to conduct electricity.

Take note

An electrolyte is a special type of solution which is able to conduct electricity.

When the electrodes are connected in a circuit, a chemical reaction takes place within the electrolyte in the lemon, which causes electrons to move in the external circuit. This flow of charge is **electric current**. The chemical reaction causes a potential difference which causes the flow of electrons in the external circuit. This will occur only when the cell is connected in a circuit. Think of a normal battery that you may use in a torch. You can store this battery for a long time, and it will not go flat, as the chemical reactions take place only when it is connected in a circuit.

We are now going to build a more complex cell.

ACTIVITY Zinc-copper cell

Materials

- two 250 ml beakers
- copper sulphate solution
- zinc sulphate solution
- concentrated sodium sulphate or sodium chloride solution
- salt bridge made with a U tube (this can be made from a plastic tube which is bent) or filter paper soaked in the salt bridge solution
- cotton wool
- copper electrode
- zinc electrode
- insulated copper conducting wires with crocodile clips
- LED bulb
- ammeter

Take note

If you do not have a U-tube or plastic tubing, you can use strips of filter paper or a cloth soaked in the sodium sulfate solution with the ends dipped into each beaker.

Instructions

1. Pour about 200 ml of the zinc sulphate solution into a beaker and put the zinc electrode into the solution.
2. Pour about 200 ml of the copper sulphate solution into the second beaker and place the copper electrode into the solution.
3. Fill the U-tube with the sodium sulphate solution and seal the ends of the tubes with the cotton wool. This will stop the solution from flowing out when the U-tube is turned upside down.
4. Connect the zinc and copper electrodes to the ammeter. Does the ammeter record a reading?
5. Place the U-tube so that one end is in the copper sulphate solution and the other end is in the zinc sulphate solution, as shown in the diagram.

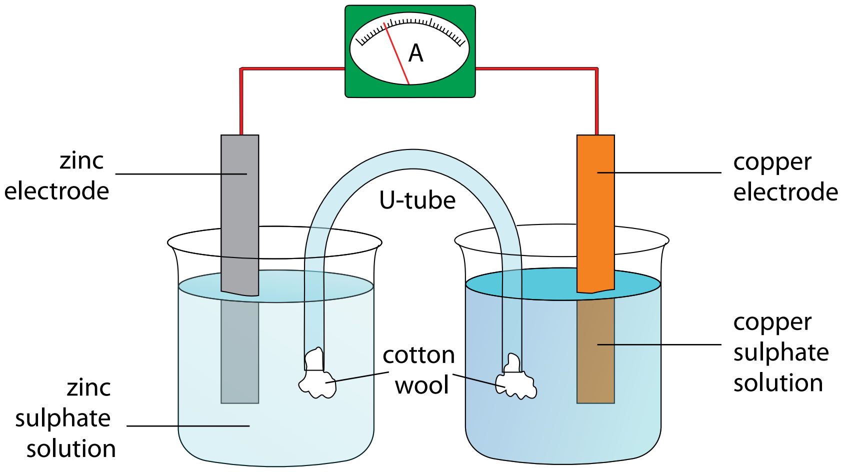


Figure 14.3

6. Remove the ammeter and insert the LED bulb in the circuit. Does it glow? If not, try connecting a few cells in series until the LED lights up.
7. Observe what is happening at the copper electrode and at the zinc electrode. Is there a reading on the ammeter?

Questions

1. What did you notice on the ammeter (or voltmeter) when you connected the circuit with the U-tube?
2. What does the ammeter reading tell us?

In the last activity, we demonstrated a zinc-copper cell. This is made up of a zinc half-cell and a copper half-cell. Together, they make up the whole cell. The purpose of the U-tube is to connect the two half cells. It is called the salt bridge.

How do we explain the chemical reactions taking place in the zinc-copper cell?

When a zinc sulphate solution containing a zinc plate is connected by a U-tube to a copper sulphate solution containing a copper plate, reactions occur in both solutions.

- At the zinc electrode, the zinc metal has gone into the zinc sulphate solution as zinc ions.
- At the copper electrode, copper ions from the solution have deposited onto the electrode as wcopper metal atoms.

In the zinc-copper cell the important thing to notice is that the chemical reactions that take place at the two electrodes cause an electric current to flow through the outer circuit. In this type of cell, **chemical energy** is converted to **electrical energy**.

As we have said before, an electric battery used in appliances such as a torch consists of two or more electric cells connected together. There are many different battery cell types such as zinc-carbon, nickel-cadmium and nickel-zinc batteries.

Did you know?

An ion is an atom or molecule in which the total number of electrons is not equal to the total number of protons. If there are fewer electrons than protons, this gives an atom a positive charge. If there are more electrons than protons, this gives an atom a negative charge.

Take note

You can also use a voltmeter to measure the potential difference across the cell. The voltmeter will replace the ammeter and LED light.

Did you know?

Rechargeable batteries are recharged by applying an electric current which reverses the chemical reactions that take place during their use in a circuit.

Summary

Key concepts

- An electric cell is a system in which chemical reactions take place to convert chemical energy into electrical energy.
- An acidic fruit can be used to construct a simple cell. The lemon juice acts as the electrolyte.
- An electric cell can be made using two beakers with an electrolyte and electrode in each. The electrolyte solutions in each half-cell are connected by a salt bridge.
- When the electrodes are connected to an external circuit, chemical reactions will take place in each of the beakers, causing a current in the external circuit.
- A battery is a group of cells which are connected together.
- There are many different types of cells, such as zinc-carbon, nickel-cadmium and nickel-zinc batteries.

Concept map

This was a short unit on electrical cells, demonstrating how we can make cells. Draw your own concept map summarising what was covered in this unit. You can refer back to previous units and concept maps from this Learner's Book when thinking about how to construct this concept map.

Revision

1. Write a short paragraph to describe, in your own words, what an electrical cell is and how it causes a current in an external circuit. [3]
2. What is the difference between a cell and a battery? [2]
3. You made an electrical cell from a lemon. How could you generate enough energy from lemons in order to make a light bulb glow? [2]
4. How would you test whether or not a battery or cell is producing energy? [2]
5. Draw a diagram to show how to set up a zinc-copper cell. Include an ammeter in the external circuit. You must use the following labels: zinc electrode, copper electrode, salt bridge/U-tube, zinc-sulphate solution, copper sulphate solution. [8]

Total [17 marks]

15 Resistance

Key questions

- What is resistance?
- What do we use resistors for?
- Does length affect resistance?
- Does temperature affect resistance?
- Does the type of resistor material affect resistance?
- Does the thickness of a resistor affect the resistance?

Keywords

- resistance
- resistor
- electric current
- electric charge
- delocalised
- conductor

15.1 What is resistance?

Think about your school break time. All of the learners are outside on the field, sitting in groups and relaxing. Some of you will be moving around the field from group to group as you greet your friends. The school bell rings, signalling the end of break. You all get up and start moving toward the school building. You are all able to move easily because there is a great deal of space, but what happens as you enter the corridor of the school building?

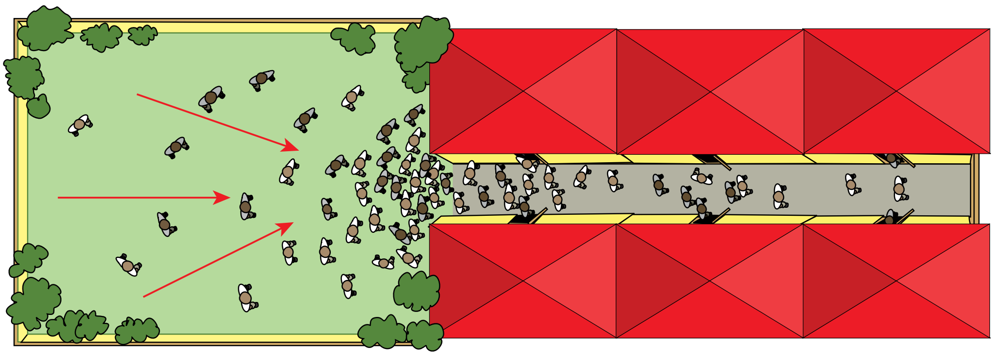


Figure 15.1

Everyone now has to fit through a narrow corridor. Everyone is trying to get to class and so some learners will bump into other learners. As you try to enter your classroom it becomes even more difficult because the doorway is even narrower than the corridor and so only one or two learners can pass through at a time.

The movement of the learners is very similar to the movement of electrons in an electrical conductor. The field offers a very low resistance to the movement of the learners and so the learners are able to move freely. The corridor has a higher resistance to the movement of the learners because fewer learners can now pass through the corridor than through the field. The classroom doorway offers the highest resistance as it only allows a few learners through at a time.

Resistance in an electrical circuit opposes the passage of electrons. The unit of measurement for resistance is the **ohm**, with the symbol Ω.

Do you remember what an electrical conductor is? Write your own definition.

All electrical conductors have some resistance. Some conducting materials have a particular resistance and are used to add electrical resistance to a circuit. An electrical component which adds resistance to a circuit is called a **resistor**.

Resistors are electrical components and have a symbol to represent them in an electric circuit diagram. Do you remember the symbol from Grade 8? Draw it in your exercise books.

Figure 15.2: Different types of resistors are used to add resistance to an electric circuit.

On a microscopic level, electrons moving through the conductor collide (or interact) with the particles of which the conductor (metal) is made. When they collide, they transfer kinetic energy. This leads to resistance. The transferred energy causes the resistor to heat up. You can feel this directly if you touch a cellphone charger when you are charging a cell phone – the charger gets warm because its circuits have some resistors in them.

15.2 Uses of resistors

Resistors can be used to control the current in a circuit. Think back to some of the work that you did in Gr 8. If you increase the resistance in a circuit, what happens to the current? Explain your answer.

Another way in which we can use resistors is to provide useful energy transfers. Do you remember looking at energy transfers in a system in Grade 8? The input energy enters the system and then provides an output energy. Some of the output energy is useful to us, and some is wasted energy. For example, a resistor can be used to transfer electrical energy into light (light bulb) or into heat (kettle element). Energy is wasted as it is lost to the surroundings. Resistors are used to provide useful energy transfers.

ACTIVITY Useful resistance

Why do we want to resist the movement of electrons? Resistors can be extremely useful. Think about a kettle. If you look inside you will see a large metal coil.

This metal coil is the heating element. If you plug in and switch on the kettle, the element heats up and heats the water. The element is a large resistor. When the electrons move through the resistor, they release a lot of energy in overcoming the resistance. This energy is transferred to the water in the form of heat. This transfer of energy is useful to us as the thermal energy is used to boil water in the kettle.

Figure 15.3: Looking inside a kettle.

Take note

Can you see that there are different coloured bands on the resistors? This isn't just to make them look pleasing to the eye. The coloured bands are actually a code that tells us the strength of the resistance of the resistor.

Keywords

- LED
- motor
- variable resistance
- rheostat
- Sankey diagram
- input energy
- output energy

Did you know?

The ohm gets its name from the German physicist Georg Simon Ohm, who noticed that the potential difference across a conductor and the electric current are directly proportional (Ohm's Law).

1. What is the input energy in this system?
2. What is the useful output energy?

Look at the photograph of a light bulb on the left. Can you see there is a small coiled wire in the glass bulb? This is called the filament. The filament is made from tungsten wire. This is an element with high resistance.

Take note

Incandescent means emitting light as a result of being heated.

Figure 15.4: The tungsten filament glowing brightly.

Figure 15.5: An incandescent light bulb.

Did you know?

The inventor Thomas Edison, experimented with thousands of different resistor materials until he eventually found the right material that allowed the bulb to glow for over 1 500 hours.

When the electrons move through the filament they experience high resistance. This means that they transfer a lot of their energy to the filament when they pass through. Describe the energy transfer taking place.

1. What is the useful energy output and what is the wasted energy output in this light bulb?
2. The filament is tightly coiled. Why do you think this is? Discuss this with your class and teacher. Look at the following photo of a toaster.
3. Can you see the glowing filament inside? Why does the element glow?
4. What is the useful output energy in this system?
5. What is the wasted output energy in this system?

Figure 15.6: An electric toaster.

Rheostats are another form of resistor which are commonly used. A **rheostat** is a device which is able to offer a **variable** resistance. Rheostats are used in electric circuits where you want to adjust the current, for example in sound equipment to adjust the volume, in dimmer switches for lights, and in controlling the speed of **motors**. Let's look at how rheostats can be used in a circuit.

Figure 15.7: An example of a rheostat.

ACTIVITY Make your own rheostat

Materials

- graphite rod or graphite pencil
- torch light bulb
- battery (AA)
- insulated copper conducting wires with crocodile clips
- ammeter

Instructions

Set up a circuit as in the diagram below with the battery, ammeter, light bulb and graphite rod connected in series. Use crocodile clips to attach the wires to each end of the graphite rod.

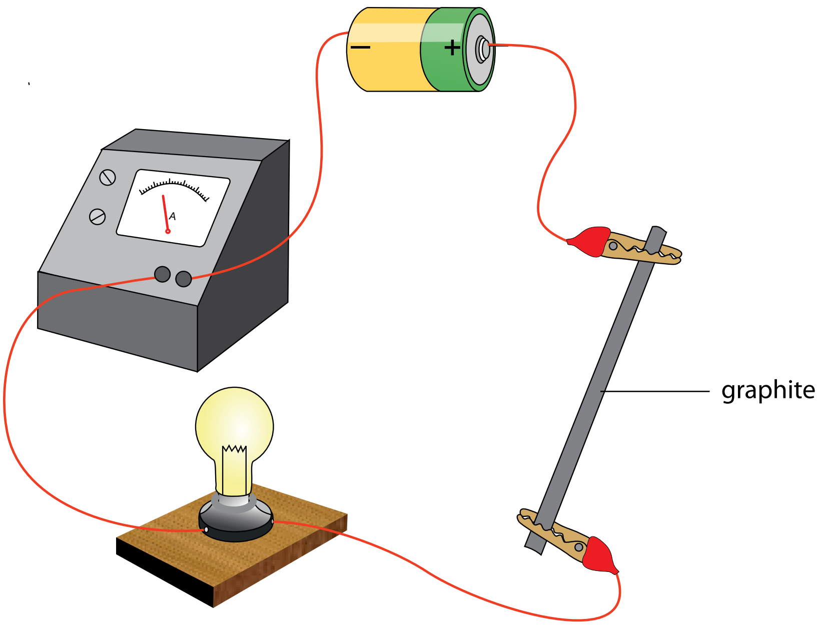


Figure 15.8

1. Does current flow through the circuit? How do you know?
2. The crocodile clips are connected on either end of the graphite rod. Predict what you think would happen if you moved the crocodile clips closer towards the centre of the piece of graphite.
3. Move the crocodile clips closer towards the centre of the graphite rod. What do you observe?
4. How do you think the length of the graphite connected to the circuit has affected the current strength?
5. Draw a circuit diagram to represent this set-up.

Did you know?

The first electric light was made in 1800 by a man called Humphry Davy. He invented an electric battery, to which he connected wires and a piece of carbon. Being a resistor, the carbon glowed and produced light.

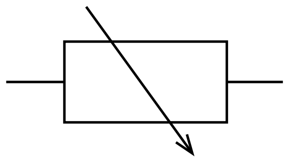


Figure 15.9: The symbol for a variable resistor.

The graphite rod was behaving as a rheostat. The resistance of the graphite rod was changed by changing the length connected to the circuit. A dimmer switch often has a dial which can be turned. Turning the dial increases the resistance of the circuit and makes the light dim. Why do you think this happens?

> **Take note**
>
> A diode is an electrical component that has a very low resistance to current flow in one direction, and high resistance in the other direction. Therefore, current can move only in one direction.

Figure 15.10: A small LED light.

> **Did you know?**
>
> Sankey diagrams are named after the Irish Captain Matthew Sankey, who first used this type of diagram in 1898 in a publication on the energy efficiency of a steam engine.

Turning the dial in the opposite direction causes the resistance to decrease and so the light burns brighter. Turning the dial changes the resistance of the rheostat in the switch.

Another device which demonstrates the useful application of resistance is in an **LED**. LED stands for light emitting diode.

An LED is a diode because it only allows current to pass through it in one direction. This means that it has to be put into a circuit in a very specific way. LEDs are very sensitive to high currents so when they are connected in a circuit, they need to be protected by a large resistor. The resistor is used to control the current which is allowed to travel through the LED. This is another useful application of resistance.

Many households are choosing to replace incandescent light bulbs with LEDs.

Are LEDs a more efficient form of lighting?

ACTIVITY Comparing an LED to a filament light bulb

We can use a **Sankey diagram** to show how the energy is transferred in a system. This gives us a picture of what is happening and shows the input energy and how the output energy is made up of useful energy (arrow at the top) and wasted energy (arrow going to the bottom). Have a look at the following general example.

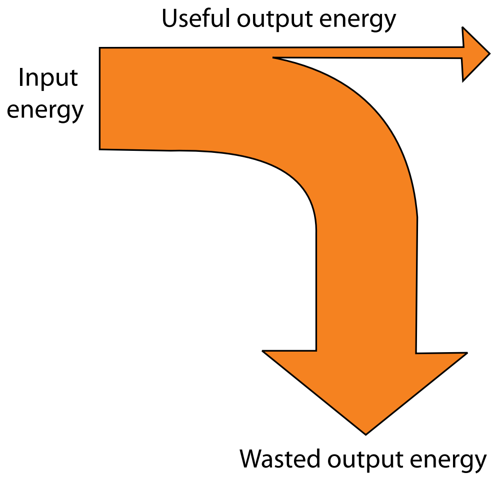


Figure 15.11

The width of the arrows tell us something in these diagrams. The input energy is the width of the original arrow. The width of both the output energy arrows (useful and wasted) add up to the width of the input arrow. Why do you think this is so?

Sankey diagrams are drawn to scale so that the width of the arrows gives us a visual idea of how much energy is useful and how much is wasted.

Questions

1. The Sankey diagram for an LED is shown below.

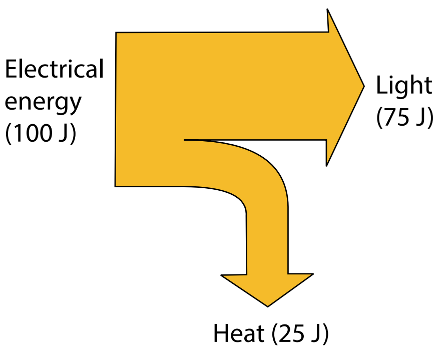


Figure 15.12

a) Describe the energy transfer which takes place in an LED, based on the given Sankey diagram.
b) Is the LED efficient or inefficient? Explain your answer.

2. The Sankey diagram for an incandescent light bulb is shown below:

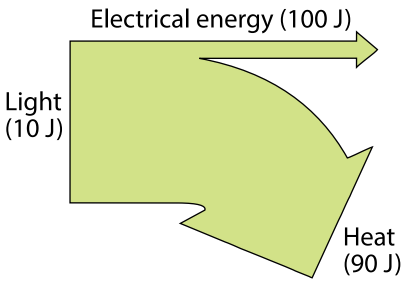


Figure 15.13

a) Explain the energy transfers in the incandescent light bulb.
b) Is the incandescent light bulb efficient? Explain your answer.

3. If you are trying to reduce your electricity consumption in order to save money, which light source would you choose? Why?

When we built our own rheostat, we were able to vary the resistance by changing the length of the graphite rod. This tells us that the length of the rod affected the amount of resistance. Let's look at what other factors which affect the resistance of a conductor.

15.3 Factors that affect the resistance of a conductor

What determines the resistance of a component? Let's investigate some of the factors. There are four different factors which affect resistance:

- The type of material of which the conductor is made
- The length of the conductor
- The thickness of the conductor
- The temperature of the conductor.

Type of material

Conductors can be made of different materials. Do different materials have different resistances?

Investigation **How does the material of the conductor affect the resistance?**

How can we measure resistance? Do you remember that in a series circuit, if we increase the resistance, then the strength of the current decreases? This means that we can use the strength of the current in the circuit as an indication of the amount of resistance in the circuit.

Aim

To determine whether different types of conducting materials have different resistances.

Take note

We can say that resistance and current in an electric circuit are inversely proportional, because as the one increases, the other decreases, and vice versa.

Hypothesis

Write a hypothesis for this investigation.

Variables

- Which variables would we need to keep constant in an investigation such as this?
- Which variable is the independent variable?
- Which variable is the dependent variable?

Materials and apparatus

- three 1,5 V cells
- insulated, conducting wires with crocodile clips
- conductors of different materials to test
- ammeter
- light bulb

Method

1. Set up a circuit with the three cells, ammeter and light bulb connected in series.
2. Test each of the conductors by adding each to the circuit individually. Use crocodile clips to connect each conductor to the circuit, as shown below.

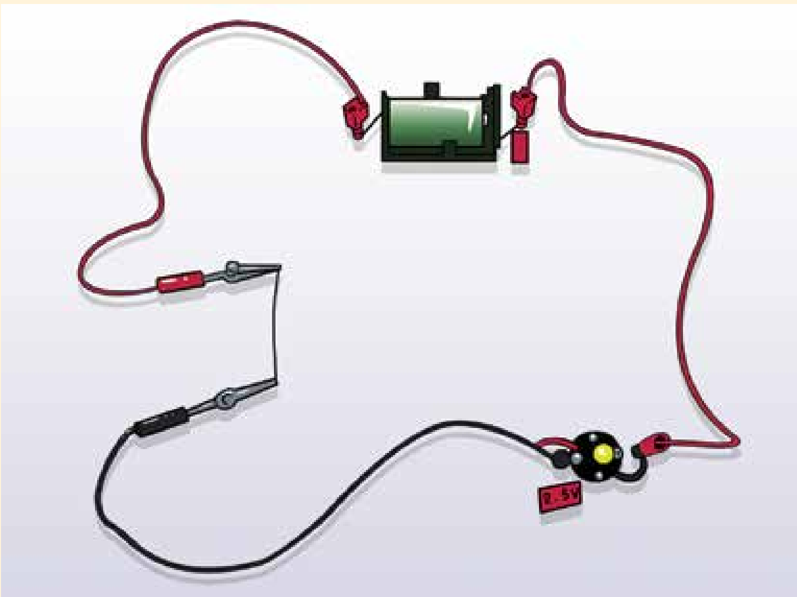


Figure 15.14: A similar setup showing a light bulb, one cell, and a piece of copper wire connected in series.

3. Read the ammeter and record the reading for each test material.
4. Draw a bar graph to show your results.

Results

1. Draw a circuit diagram of the setup.
2. Draw a table showing your results.
3. Draw a bar graph of your results in your exercise books.

Analysis and evaluation

1. Which material offered the most resistance in the electric circuit? How do you know this?
2. Which material offered the least resistance in the electric circuit? How do you know this?
3. Are there any potential problems with the way in which this investigation was set up, or are there any ways in which you could have improved the design?

Conclusions

1. What conclusion can you reach from this investigation?
2. Why must the different conductors have the same length and thickness?

Thickness of the conductor

When we investigate the thickness of a conductor, we are looking at the cross-sectional area of the wire, called the gauge. This is shown in the diagram on the right.

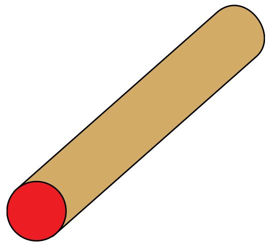


Figure 15.15: The cross-sectional area of a wire is indicated by the red circle.

Do you think the thickness of a wire will affect the resistance? Let's do an investigation to find out.

Investigation: How does the thickness of the conductor affect the resistance?

Aim

To determine whether the thickness of the conductor will affect the resistance.

Hypothesis

Write a hypothesis for this investigation.

Variables

1. Which variables would we need to keep constant in an investigation such as this?
2. Which variable is the independent variable?
3. Which variable is the dependent variable?

Materials and apparatus

- three 1,5 V cells
- insulated, conducting wires with crocodile clips
- conductors of different thickness
- ammeter
- light bulb

Method

1. Assess the lengths of wire that you have and arrange them in order from thickest to thinnest. Label the thickest wire as 1, the next thickest as 2, and so on, so that you can easily record the results.
2. Set up a circuit as in the previous investigation with the three cells, ammeter and light bulb connected in series.
3. Test each of the different wires by adding each to the circuit in turn. Use the conducting wires with crocodile clips attached at the ends to join each conductor to the circuit.
4. Read the ammeter and record the reading for each wire.

Results

Draw a table showing your results.

Analysis and evaluation

1. Which thickness of wire offered the most resistance in the electric circuit?
2. Which thickness of wire offered the least resistance in the electric circuit?
3. Are there any potential problems with the way in which this investigation was set up, or are there any ways in which you could have improved the design?

Conclusions

1. What conclusion can you reach from this investigation?
2. Can you accept or reject your hypothesis?

The thinner the wire, the more resistance it offers. Thicker wires offer less resistance. This is easy to understand if you think back to the example of all the learners filing back into the classrooms after break. If the corridor is narrow (or thin) then it is more difficult for all the learners to move through. A very wide corridor would be easier to move through as it would offer less resistance. This is the same in a conducting wire. A thinner wire is more difficult for electrons to move through than a thicker wire.

Length of the conductor

In each of the previous investigations, we have used the same length for each conductor. It was a controlled variable. Let's now investigate how the length of a conductor affects the resistance.

Investigation — How does the length of a conductor affect the resistance of the conductor?

Hypothesis

Write a hypothesis for this investigation.

Materials and apparatus

- piece of resistance wire (110cm) long
- ammeter
- two 1,5 V cells
- metre ruler
- tape
- insulated copper conducting wires

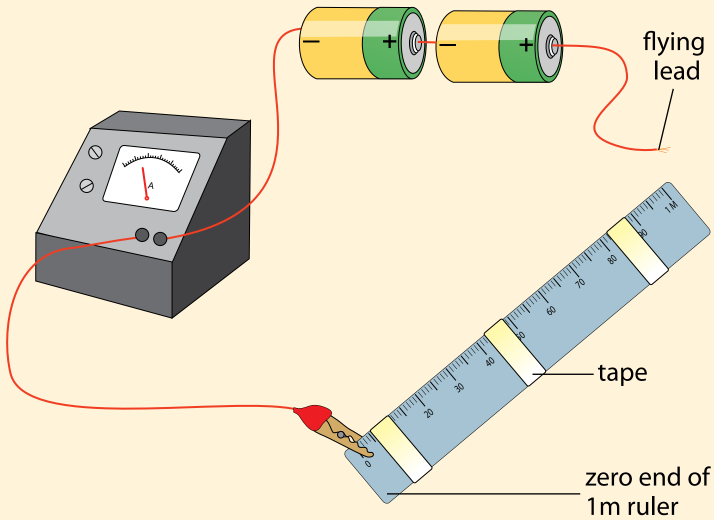


Figure 15.16

Variables

1. Which variables would we need to keep constant in an investigation such as this?
2. Which variable is the independent variable?
3. Which variable is the dependent variable?

Method

1. Tape the resistance wire to the metre ruler. Make sure the wire is stretched flat and that the numbers on the ruler are still visible.
2. Assemble a circuit according to the diagram on the next page.
3. Use the flying lead and touch it to the resistance wire at the 1 m mark. Record the ammeter reading.
4. Use the flying lead and touch it to the resistance wire at the 0,9 m mark. Record the ammeter reading.
5. Move the flying lead in 10 cm intervals until you have 10 readings. Record the ammeter reading each time.

Results

Copy the table and record your results in your exercise books..

Draw a graph to show the relationship between the length of the resistor and the ammeter readings.

Length of wire (m)	Ammeter reading (A)
1,0	
0,9	
0,8	
0,7	
0,6	
0,5	
0,4	
0,3	
0,2	
0,1	

Conclusions

1. Look at your table and graph. What conclusion can you draw?
2. What is causing the decrease in current strength?
3. What can you conclude about the relationship between the length of the resistor and the resistance of the resistor?

The length of the resistor affects how much resistance it offers to the circuit.

The longer the resistor, the more resistance it has. The shorter the resistor, the less resistance it has.

Figure 15.17: A close-up photograph of the tungsten filament in an incandescent light bulb.

Longer wires have more resistance than shorter wires. Let's take a close-up look at the filament of an incandescent light bulb.

You can see that the filament is made up of coils of tungsten wrapped up tightly. We want to fit a very long wire into a small space. The electrons have to travel through this very long, high-resistance wire. How is this more beneficial compared to having a shorter wire? Discuss this with your class.

Temperature of the conductor

The last factor which affects resistance is the temperature of the conductor. The hotter a resistor becomes the more resistance it has. The atoms of the conductor vibrate much more quickly when they are hot because of the increase in kinetic energy. This makes it more difficult for the electric current to move through. Cold resistors offer less resistance to the circuit.

Take note

We are not going to investigate this factor as it is difficult to control the temperature of a wire in an investigation.

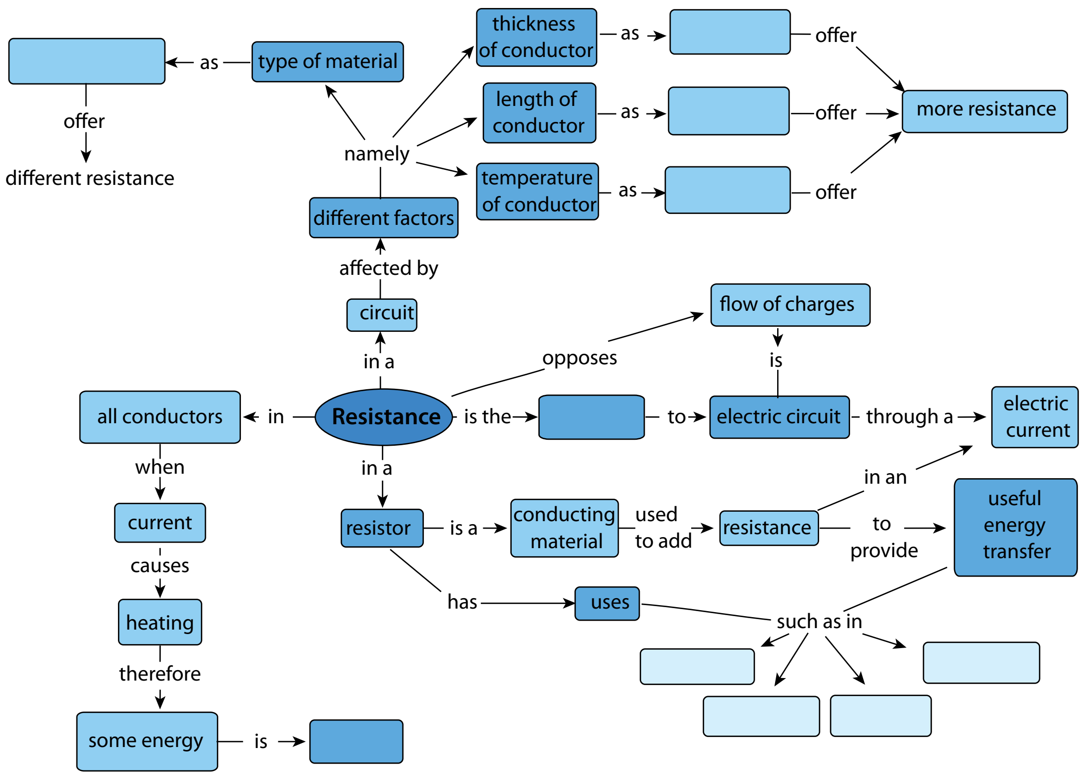
Summary

Key concepts

- Resistance is the opposition to electric current in a circuit.
- A resistor is an electrical component used to add resistance to an electrical circuit.
- Resistance can be useful. For example, the filament in a light bulb and a toaster have a high resistance.
- There are four factors which influence the amount of resistance of a conductor: type of material, length, thickness and temperature.
- Different materials will offer different amounts of resistance.
- Longer resistors will offer more resistance than shorter resistors.
- Thicker resistors offer less resistance than thinner resistors.
- Hot resistors offer more resistance than cold resistors.

Concept map

Complete the following concept map to summarise what you have learnt about resistance in this unit. For example, when looking at the factors that affect resistance, you need to describe the relationship by completing the sentences.



Revision

1. There are many useful applications of resistance. Give two examples of appliances which require large resistances in order to function. [2]

2. Look at the following photograph of an electric toaster.

An electric toaster.

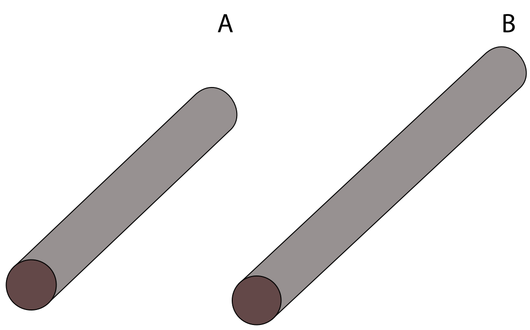
a) Do you think the element in the toaster has a low or high resistance? Explain your answer. [2]

b) Explain the energy transfers which take place within the heating element of the toaster. [3]

c) Is there wasted energy in this system? If so, what is it, and why can we consider it 'wasted energy'? [2]

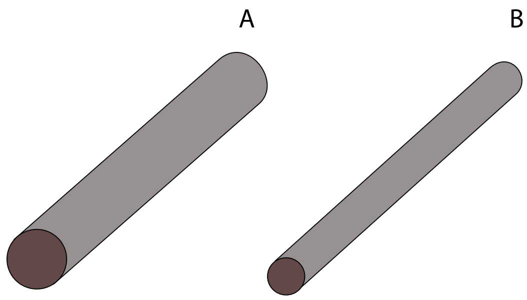
3. List the factors which affect the amount of resistance in a resistor. [4]

4. The pictures below show two pieces of the same type of metal wire with the same diameter.



Which piece has the higher resistance? Explain why. [2]

5. The pictures below show cross-sections of two pieces of the same type of metal wire. The pieces are the same length but have different diameters.



Which piece has the lower resistance? Explain why. [2]

6. Look at the image of a stove-top heating element. The heating element offers a large resistance to the flow of electric current.

a) Why is the heating element in the shape of a coil? [2]
b) What is the input energy in this system? [1]
c) What is the output energy? [2]
d) Is all of the energy transferred to the heating element useful? [2]

Total [24 marks]

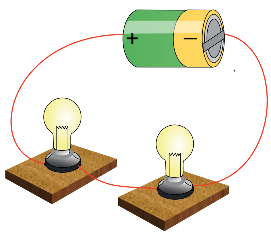
16 Series and parallel circuits

Key questions

- What happens when we add cells in series or parallel?
- What happens when we add resistors in series or parallel?
- What is potential difference?
- How do we connect ammeters and voltmeters in circuits?
- What is electric current?

16.1 Series circuits

A series circuit provides only one path for electric current to move through the circuit.

Series circuit	Draw a circuit diagram for this circuit in your exercise books
	

How many cells and how many resistors are in the above circuit?

What happens when more cells or resistors are added into a series circuit? We are going to investigate the effects on the current and the potential difference in series circuits.

What is potential difference?

Potential difference is the difference in potential energy per charge between two different points in an electric circuit. Here is a simpler explanation: potential difference tells us how much energy per charge the electrons are losing when they pass through a resistor or how much they are gaining when they pass through the cell or battery. The electrons 'lose' energy because they have transferred it to the resistor in the form of heat, light or sound. Electrons 'gain' energy when they pass through the cell or battery because of the chemical energy from the battery being transferred to the electrons.

The potential difference is measured by a **voltmeter**. The unit of potential difference is the **volt**.

The voltmeter has a very high internal resistance and must be connected in parallel with the component you are measuring. You therefore need to connect it to two different points (which are usually before and after a resistor). The voltmeter calculates the potential difference between those two points. An example illustrating the placement of a voltmeter at two points (A and B) is indicated in the diagram.

Keywords

- potential difference
- voltage
- voltmeter
- electric current strength
- ammeter

Take note

Remember that a battery is a group of cells connected together.

Take note

You may have learnt about potential difference in Technology already, but this is the first time we are investigating it in Natural Sciences.

Take note

People often use the term 'voltage' to describe the potential difference. This is based on the fact that we measure potential difference in volts. Voltage is not the scientific term, and potential difference is the more correct term of use.

Did you know?

The volt is named in honour of the Italian physicist Alessandro Volta (1745-1827), who invented the voltaic pile, the first electric battery which could deliver a continuous electric current.

Figure 16.1: A voltmeter.

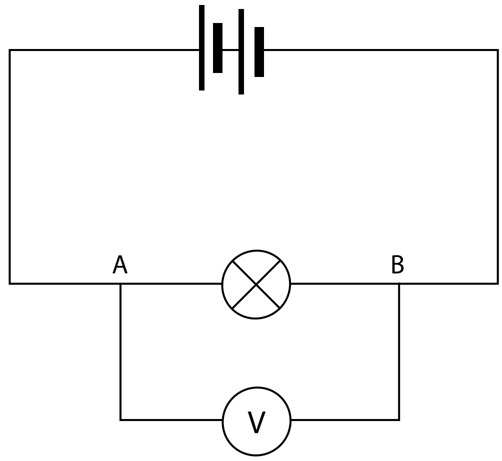


Figure 16.2: This voltmeter is connected in parallel with the bulb and measures the potential difference between points A and B.

Alternatively, a multimeter can be used to measure the current strength across a resistor, and the potential difference across the resistor. A multimeter is a device that can be used to measure the potential difference across a resistor, and the current strength through the resistor.

Activity

1. If you connect the voltmeter in series, there will not be two different points as you connect it to the same wire with the same potential. What do you think would happen if you connected the voltmeter in series in the circuit? Explain your answer.
2. What instrument do we use to measure the current strength in a circuit?
3. How do we connect the device named in number 2 in a circuit? Explain why this is so.
4. Draw a circuit diagram in your exercise books to illustrate an ammeter, a light bulb and a cell will should be connected in a circuit.

Electric Current

Electric current is a flow of charges in a circuit. An atom is made up of electrons arranged in the outer space around a central nucleus which comprises of protons and neutrons. The nucleus of the atom is held together by strong electrostatic forces, such that it's almost impossible to move the protons. Therefore, it is the flow of electrons that gives rise to the electric current.

Figure 16.3: an ammeter

An **ammeter** (shown in Figure 16.3) is an instrument used to measure the strength of the electric current at any point in the electric circuit. Because of its relatively lower resistance, an ammeter allows the charges to flow through with ease. An ammeter should, therefore, always be connected in series with the components of the circuit.

The measuring SI unit of electric current strength is an **ampere** (denoted by A).

Conditions for the electric current to flow in a circuit

- For any circuit to function, that for the electric current to flow, there has to be a **source of energy** in a form of a **cell** or a **battery**.
- There has to be a **complete**, **cyclic pathway** that connects the components of the circuit to the energy source.

The illustration below summarizes these two conditions through a virtually performed experiment.

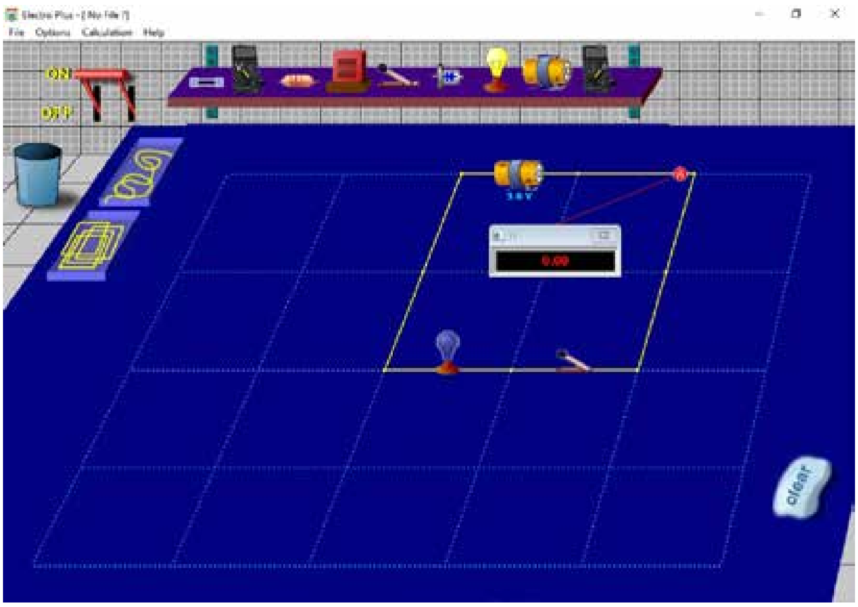


Figure16.4: Source, switch open (no complete pathway), no current flows

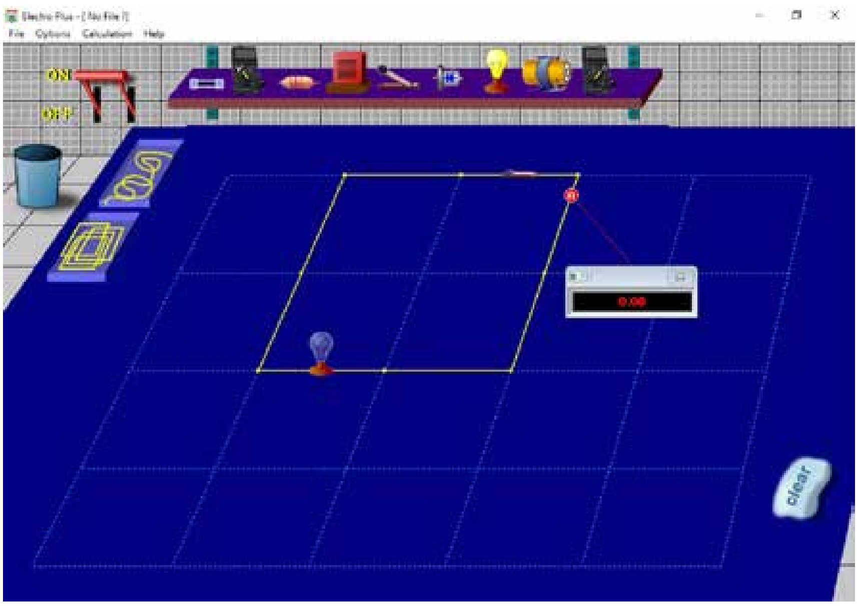


Figure 16.5: No source, switch closed, complete pathway, no current

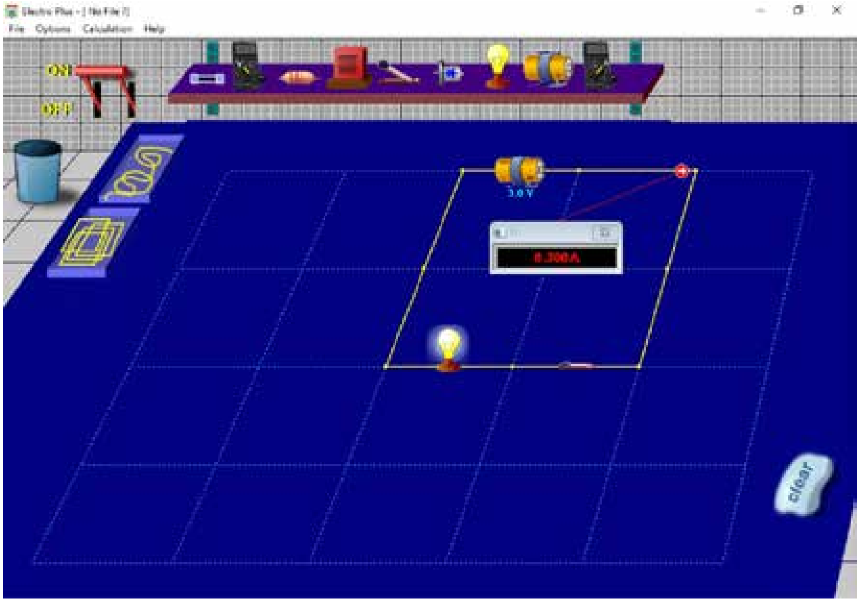


Figure 16.6: Source, switch closed, complete pathway, current flows

Measuring electric current strength in a circuit

We have already discussed that an ammeter is used to measure the electric current strength in the circuit. We have further discussed that an ammeter should be connected in series with the components of the circuit. We even looked at the conditions for the electric current to flow in the electric circuit.

In the next practical activity, we are going to measure the strength current flowing in the circuit.

Practical Activity | **Measuring the electric current strength**

Aim

Measuring the electric current strength

Apparatus

- 2 x 1,5 V cells
- 1 x Bulb
- Conducting wires
- Switch
- Ammeter

Precautions

- Always keep the switch open if you're not making any observations or taking any measurements. This saves the battery life of the cells.
- Ask for the teacher's assistance to connect the ammeter.

Procedure

1. Construct a circuit as shown in the picture below, but keeping the switch open.

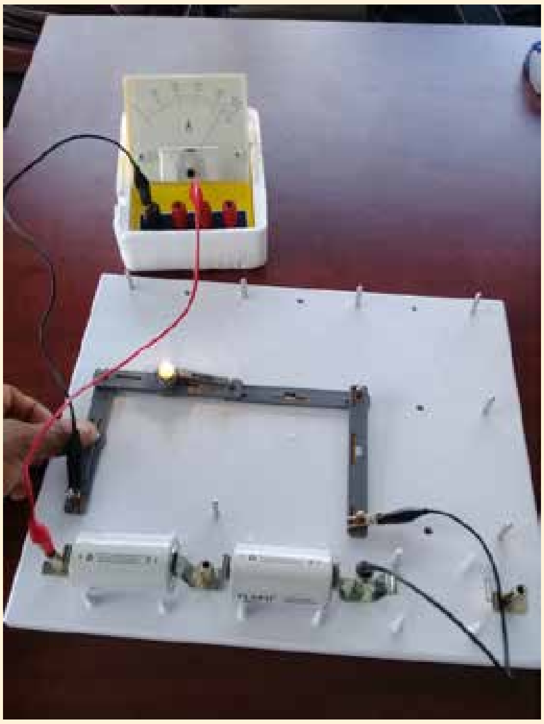


Figure 16.7

2. Observe the bulb and the ammeter reading with the switch open.
3. Closed the switch and observe the bulb lights.
4. Record the ammeter reading and the bulb observation in the table of results below.

Results

	Switch open	Switch closed
Does the bulb light up?		
Ammeter Reading		

Discussion and Conclusion

From the observations you have made when the switch is open and when it is closed, what can you conclude about flow of current in a circuit?

Questions

1. Draw a circuit diagram representing the circuit you have built.
2. What is electric current?
3. What is the name of measuring SI unit of electric current?
4. What instrument is used to measure electric current?
5. How should this instrument be connected in a circuit?
6. List two conditions necessary for the electric current to flow in an electric circuit.

The following photo shows a voltmeter connected in parallel and an ammeter connected in series.

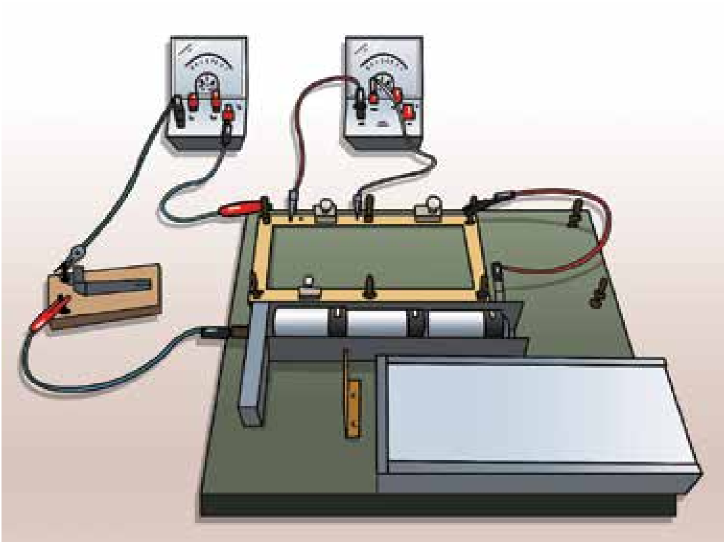


Figure 16.8

Cells in series

When cells are connected together they are called a battery. What happens when we put more than one cell in a circuit? Let's investigate what happens when we add cells, in series, to a circuit.

Take note

If you are using a light bulb and not an ammeter to see the effect, then take note of the brightness of the bulb as you add more cells in series.

Investigation: What is the effect of the number of cells connected in series on current and potential difference?

Hypothesis

Write a hypothesis for this investigation.

Materials and apparatus

- three 1,5 V cells
- insulated copper conducting wires with crocodile clips
- ammeter
- voltmeter
- resistor or light bulb

Precautions

- If you using bulbs instead of a resistor, make sure that you use two bulbs. Bulbs have a lower resistance and may blow up as you add more cells in series.
- Always use a switch to control the flow of electric current when you're not taking any readings.

Method

1. Construct a series circuit with 1 cell, a resistor and the ammeter in series.

2. Connect the voltmeter in parallel with the cell as shown in the following circuit diagram.

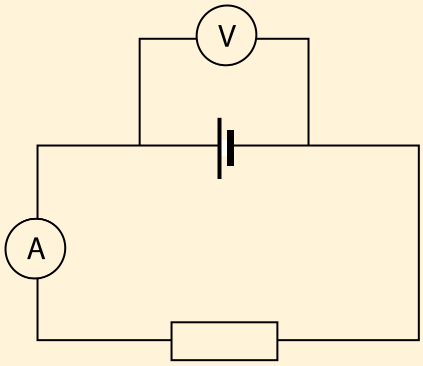


Figure 16.9

3. Record the readings on the ammeter and voltmeter in your exercise books.
4. Add a second cell in series with the first cell.

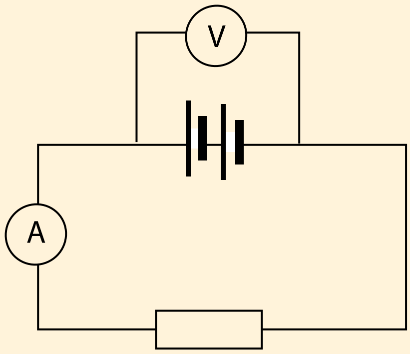


Figure 16.10

5. Record the new readings on the ammeter and voltmeter in your exercise books.
6. Add the third cell in series with the other two cells.

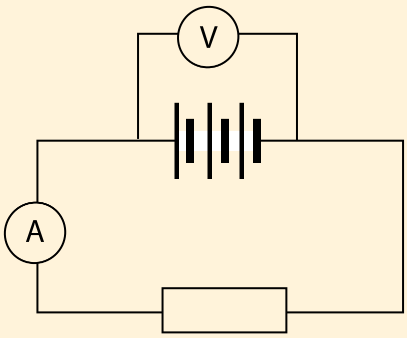


Figure 16.11

7. Record the new readings on the ammeter and voltmeter in your exercise books.
8. Draw a graph of your results.

Take note

Remember that the units of measurement are noted in the heading for a column in a table and not written in each cell in the table.

Take note

A line of best fit (or 'trend' line) is a straight line that best represents the data on a scatter plot. To draw a line of best fit, balance the number of points above the line with the number of points below the line. This line may pass through some of the points, none of the points, or all of the points.

Results

Copy and complete the following table in your exercise books:

Number of cells	Ammeter reading (A)	Voltmeter reading (V)
1		
2		
3		

Use your table to draw two line graphs on the same set of axes. One graph should be the number of cells against the current (ammeter reading) and the other graph should be the number of cells against the potential difference (voltmeter reading). Decide which are your independent and dependent variables in this investigation. Draw a line of best fit through the data points.

If you used a light bulb instead of a resistor, what happened to the brightness of the bulb as you added more cells in series? If you did not do this, predict what would happen.

Conclusion

What can we conclude happens to the current strength and potential difference as more cells are added in series?

What have we learnt? Increasing the number of cells connected together in series increases the strength of the current in the circuit and the potential difference across the cells.

Investigation: The effect of the number of cells connected in series on current strength and potential difference

This is an optional investigation using PhET (Physics Education Technology) online simulations. You might do this in class with your teacher or else you can visit the website and interact with the simulation in your own time.

Hypothesis

Write a hypothesis for this investigation.

Materials and apparatus

- PhET circuit construction kit (DC only) bit.ly/19eKTHf

Method

1. Construct a series circuit with one cell, a resistor and the ammeter in series in the PhET simulation. Drag and drop each component to create the circuit.
2. Connect the voltmeter in parallel with the cell.
3. Record the readings in your exercise books.

4. Add a second cell in series with the first cell.
5. Record the new readings in your exercise books.
6. Add the third cell in series with the other two cells.
7. Record the new readings in your exercise books.
8. Draw a graph of your results.

Results

Copy and complete the following table in your exercise books:

Number of cells	Ammeter reading (A)	Voltmeter reading (V)
1		
2		
3		

Use your table to draw two line graphs in your exercise books. One graph should be the number of cells against the current (ammeter reading) and the other graph should be the number of cells against the potential difference (voltmeter reading). Decide which are your independent and dependent variables in this investigation.

Conclusion

What can we conclude regarding the effect on the current strength and potential difference of adding cells in series into a circuit?

Resistors in series

Let's revise some of the work we covered in Grade 8 about series circuits.

ACTIVITY Increasing the resistance in a series circuit

Materials

- 1,5 V cell
- 3 torch bulbs
- insulated copper conducting wires
- switch
- ammeter

Instructions

1. Construct the circuit with the cell, the ammeter, one bulb and the switch in series.
2. Close the switch.
3. Note how brightly the bulb is shining and record the ammeter reading. Draw a circuit diagram.
4. Open the switch.
5. Add another light bulb into the circuit.
6. Close the switch.

7. Note how brightly the bulbs are shining and record the ammeter reading. Draw a circuit diagram.
8. Open the switch.
9. Add the third light bulb into the circuit.
10. Close the switch.
11. Note how brightly the bulbs are shining and record the ammeter reading. Draw a circuit diagram. Copy the table below in your exercise books and record the ammeter readings:

Number of bulbs (resistors)	Ammeter reading (A)
1	
2	
3	

Questions:

1. What happened to the brightness of the bulbs and the ammeter reading as more light bulbs were added to the circuit?
2. Explain the observations you made in question 1.

If we increase the resistance in a series circuit, by adding more resistors, then the total current decreases. We say the current is inversely proportional to the resistance.

We are now going to look at the potential difference of each resistor.

Investigation: Measuring the potential difference across components in a series circuit

Investigative question

What is the relationship between the potential difference across the battery and the potential difference across the resistors in a series circuit?

Materials and apparatus

- three 1,5 V cells
- insulated copper conducting wires with crocodile clips
- two resistors of different resistances
- three voltmeters
- a switch

Method

1. Construct a circuit with three 1,5 V cells, two resistors and the switch in series with each other.
2. Connect a voltmeter, in parallel, across the three cells. This is voltmeter V_1.

3. Connect a second voltmeter, in parallel, across one resistor. This is voltmeter V_2. Take note of whether this is the resistor with the higher or lower resistance.
4. Connect the third voltmeter, in parallel, across the other resistor. This is voltmeter V_3. Take note of whether this is the resistor with the higher or lower resistance.
5. Record the readings on the 3 voltmeters.

Results and observations

Draw a circuit diagram to illustrate your circuit. Take note of which resistor has the highest resistance.

Reading on V_1:
Reading on V_2:
Reading on V_3:

Record these readings on your circuit diagram as well.

1. What do you notice about the readings on V_2 and V_3 when compared to V_1?
2. Add the readings together. What do you notice?
3. Which resistor has the highest potential difference, the one with the higher or lower resistance?

Conclusions

Write a conclusion for this investigation.

What have we learnt? The **sum** of the potential differences across the resistors in a series circuit is equal to the potential difference across the battery. If a resistor has a high resistance, then it will have a large potential difference.

If a resistor has a low resistance, then it will have a small potential difference. We can explain this because the battery provides the electrons with potential energy. The electrons travel through the resistors and lose some of that energy to each resistor in the form of heat, light or sound. There is only one path for the electrons to travel, so they transfer energy to each resistor through which they pass. The higher the resistance of the resistor, the more energy is transferred within the resistor. Therefore, there will be a greater difference in potential energy per charge from before to after the resistor in the series circuit.

Let's look at the example on the right:

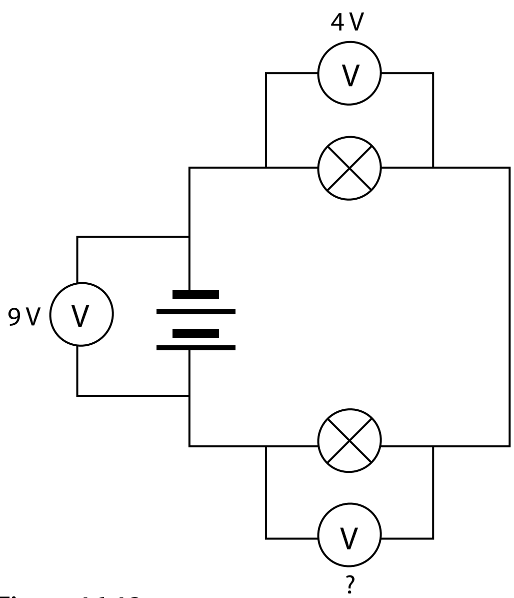


Figure 16.12

If the potential difference across the cells or battery is 9 V and the potential difference across one of the bulbs is 4 V, what would the reading on the third voltmeter be?

We say that resistors in series are **potential dividers**.

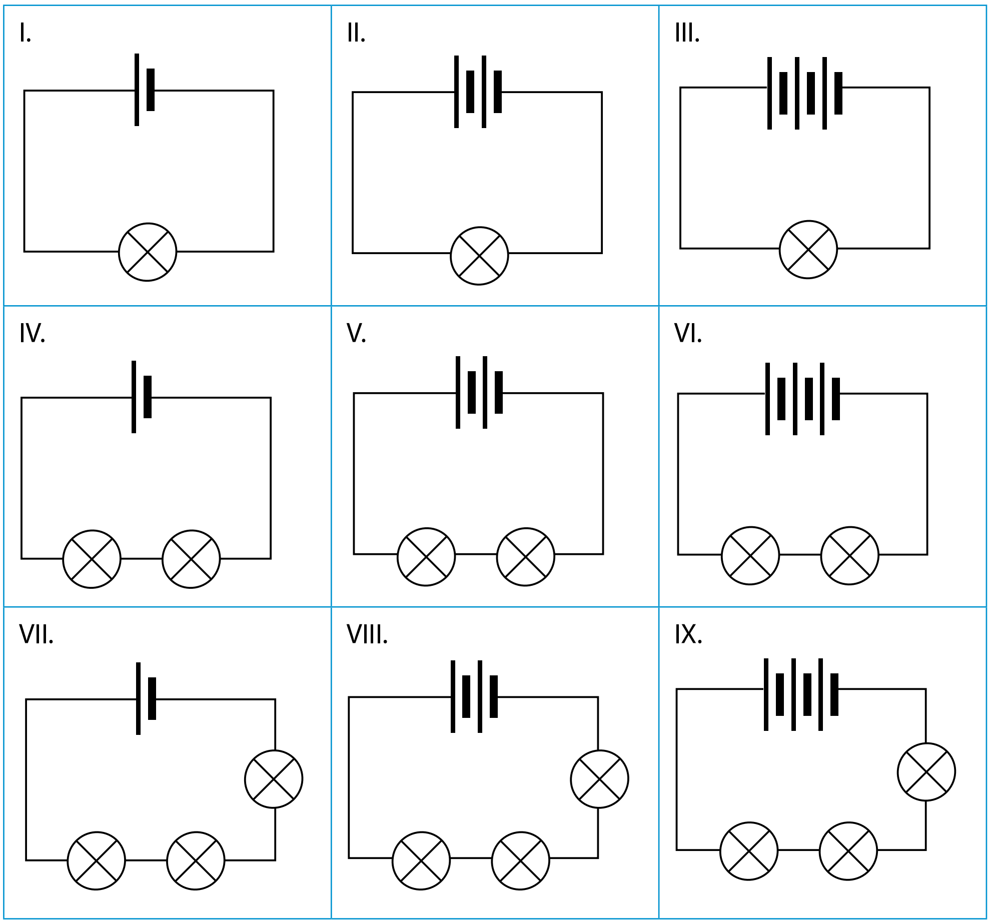
ACTIVITY Check your knowledge of series circuits

Materials

- batteries (or cells)
- torch bulbs
- insulated copper conducting wires
- ammeters

Instructions

Look at the circuit diagrams in the table. Assume that each bulb is the same.



1. Predict in which circuit each bulb will glow the brightest. On what did you base your prediction?
2. Predict in which circuit each bulb will glow the dimmest. On what did you base your prediction?
3. Why will the brightness of bulbs I, V and IX will be the same?
4. Now test each of your predictions by building the different circuits. Include an ammeter in the circuits in order to measure the current.

We have now seen that the current is affected by adding more cells and resistors in series, but so far we have only measured the current at one point in the circuit. Let's see how the current compares at different points in the circuit.

ACTIVITY Current in a series circuit

Materials

- insulated copper conducting wires
- two 1,5 V cells
- two torch light bulbs
- ammeter

Precautions

The longer the cells are used for, the more energy they transfer to the bulbs and that might affect the reading. Always keep the switch closed when you are not taking any readings.

Instructions

1. Set up a series circuit with two cells and two torch light bulbs in series with each other.
2. Insert an ammeter in series between the positive terminal of the cells and the first torch bulb.
3. Measure the current strength using the ammeter. Draw a circuit diagram of this set-up.
4. Insert the ammeter, in series, between the two torch bulbs.
5. Measure the current strength using the ammeter. Draw a circuit diagram of this set-up.
6. Insert the ammeter, in series, between the last torch bulb and the negative terminal of the battery.
7. Measure the current strength using the ammeter. Draw a circuit diagram of this set up.

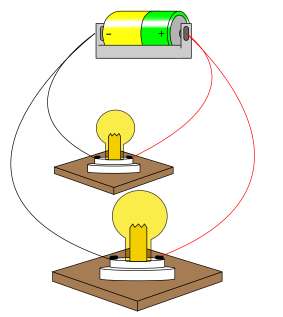
Copy and complete the following table in your exercise books:

Position of ammeter in circuit	Ammeter reading (A)
Between positive terminal of battery and first bulb	
Between two bulbs	
Between negative terminal of battery and last bulb	

What can you conclude from this about the current in a series circuit?

16.2 Parallel circuits

A parallel circuit provides **more than one** path for the electric current to move through the circuit.

Parallel circuit	Draw a circuit diagram for this circuit in your exercise books
	

Cells in parallel circuit

We saw that connecting cells in series increases the amount of energy supplied to the electrons. The potential difference increases. Let's investigate what happens when we add cells in parallel in a circuit.

Investigation **What happens to the current and potential difference in a circuit when adding cells in parallel?**

Hypothesis

Write a hypothesis for this investigation.

Materials and apparatus

- three 1,5 V cells
- insulated copper conducting wires with crocodile clips
- ammeter
- voltmeter
- resistor

Method

1. Construct a series circuit with 1 cell and the ammeter in series.
2. Connect the voltmeter in parallel with the cell as shown in the circuit diagram.

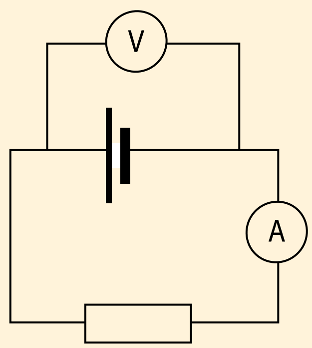


Figure 16.13

3. Copy the table on the next page, then record your results.
4. Add a second cell in parallel with the first cell as shown in the diagram.

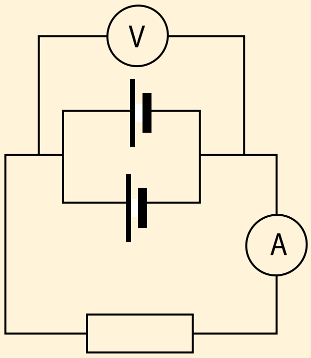


Figure 16.14

5. Record the new readings in your table.
6. Add the third cell in parallel with the other two cells. Draw a circuit diagram for this in the space below.
7. Record the new readings in your table.

Results

Copy and complete the following table in your exercise books:

Number of cells in parallel	Ammeter reading (A)	Voltmeter reading (V)
1		
2		
3		

Conclusion

What can we conclude regarding the effect of adding cells in parallel into a circuit?

What have we learnt?

When we connect two cells in parallel with each other, the overall potential difference is the same as if we had only one cell. Therefore, if both cells are 1,5 V, the overall potential difference for the circuit is still 1,5 V. The current is the same as if there was only one cell because the electrons travel through only one of the cells.

What advantage would we get from connecting cells in this way? Discuss this with your class.

Resistors in parallel

Parallel circuits have more than one pathway for the current. Let's look at how adding resistors in parallel affects the current strength.

ACTIVITY Adding resistors in parallel

Materials

- 1,5 V cell
- 3 torch bulbs
- insulated copper conducting wires
- switch
- ammeter

Instructions

1. Construct the circuit with the cell, ammeter, one bulb, and the switch in series.
2. Close the switch.
3. Note how brightly the bulb is shining, and write down the ammeter reading. Draw a circuit diagram of your circuit.
4. Open the switch.
5. Add another light bulb, in parallel to the first, into the circuit.
6. Close the switch.
7. Note how brightly the bulbs are shining, and write down the ammeter reading. Draw a circuit diagram of your circuit.
8. Open the switch.
9. Add the third light bulb, in a parallel to the first two, into the circuit.
10. Close the switch.
11. Note how brightly the bulbs are shining, and write down the ammeter reading. Draw a circuit diagram of your circuit.

Questions

1. What happened to the brightness of the bulbs and the ammeter reading as more light bulbs were added in parallel?
2. Explain your observations from question 1.

In the last activity, we measured only the current in the main branch of the circuit. What happens to the current in a parallel circuit?

ACTIVITY Current in a parallel circuit

Materials

- insulated copper conducting wires
- two 1,5 V cells
- three identical torch light bulbs
- ammeter

Method

1. Set up a parallel circuit with two cells in series with each other and three torch light bulbs in parallel with each other.
2. Insert an ammeter in series between the cells and the first pathway as shown in the diagram.

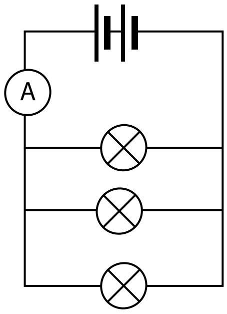


Figure 16.15

3. Measure the current strength using the ammeter.
4. Remove the ammeter and close the circuit again. Insert the ammeter, in series, in the first pathway.

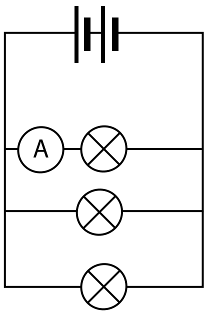


Figure 16.16

5. Measure the current strength using the ammeter.
6. Insert the ammeter, in series, in the second pathway.

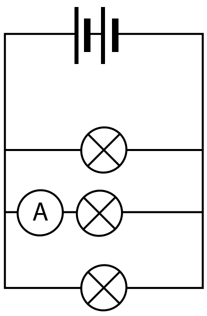


Figure 16.17

7. Measure the current strength using the ammeter.
8. Insert the ammeter, in series, in the third pathway.

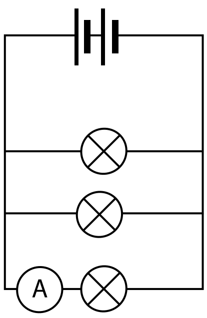


Figure 16.18

9. Measure the current strength using the ammeter.
10. Insert the ammeter, in series, between the first pathway and the batteries on the opposite side to the first reading.

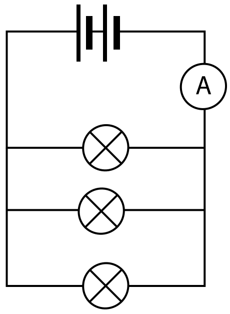


Figure 16.19

11. Measure the current strength using the ammeter.

Draw a table in your exercise books to record your readings.

Questions

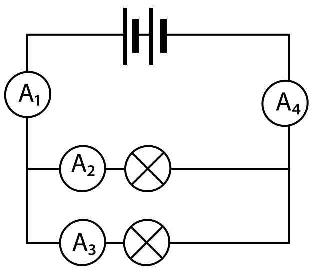


Figure 16.20

1. What do you notice about the current in the main branch and the current in the pathways?
2. Add up the currents in each pathway through a bulb. What do you notice?
3. Use the diagram on the right and write an equation to illustrate the relationship between:
   a) A_1 and A_4.
   b) A_1, A_2 and A_3.
   c) A_4, A_2 and A_3.

When we add resistors in parallel to each other the total resistance decreases and the current increases. Why does this happen? Adding resistors in parallel provides more alternative pathways for the current. Therefore, it is easier for current to move through the circuit than if all the current had to move through one resistor. In conclusion; a parallel circuit is a current divider and that voltage is the same in all the resistors.

As the electrons approach the branch in the parallel circuit, some electrons will take the first path and others will take the other path. The current is divided between the two pathways. We say that resistors in parallel are current dividers. Although both pathways provide resistance, the total resistance is less than if there were just one pathway.

We are now going to look at the potential difference across each resistor in a parallel circuit.

Investigation — Measuring the potential difference across components in a parallel circuit

Investigative question

What is the relationship between the potential difference across the battery and the potential difference across the resistors in a parallel circuit?

Hypothesis

Write a hypothesis for this investigation.

Materials and apparatus

- three 1,5 V cells
- insulated copper conducting wires with crocodile clips
- two torch light bulbs or resistors
- three voltmeters
- a switch
- three ammeters

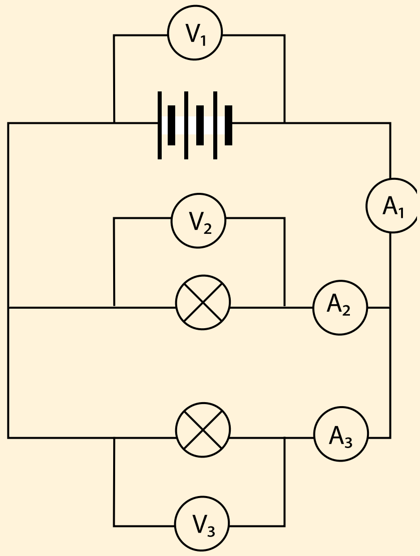


Figure 16.21

Method

Construct the circuit.

Note the readings on the three voltmeters and ammeters.

Results

Copy the circuit diagram above and the table into your exercise books. Record the readings on both.

Voltmeter	Reading (V)	Ammeter	Reading (A)
V_1		A_1	
V_2		A_2	
V_3		A_3	

1. What do you notice about the readings on V_2 and V_3 when compared to V_1?
2. Add the readings on A_2 and A_3 together. What do you notice?
3. Explain the behaviour of the electrons in the circuit based on the ammeter readings.

Conclusion

Write a conclusion for this investigation based on the investigative question.

Extension

Do you know that we can calculate the resistance of each light bulb in the circuit used in this investigation? We have seen that the current (I) through a resistor is inversely proportional to the resistance (R) and the potential difference across a resistor (V) is directly proportional to the resistance. This relationship is summarised in the following equation:

$$R = \frac{V}{I}$$

The unit of resistance is the ohm (Ω), which is defined as a volt per amp of current. This can be written as:

$$1 \text{ ohm} = \frac{\text{volt}}{\text{amp}}$$

We can therefore calculate the resistance. An example is shown here using the values in this circuit diagram:

$$R = \frac{V}{I}$$

$$= \frac{3\text{ V}}{2\text{ A}}$$

$$= 1{,}5\ \Omega$$

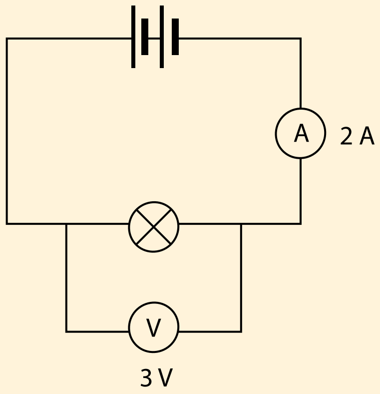


Figure 16.22

Did you know?

The relationship described here between current through a resistor and the potential difference across the resistor, is called Ohm's Law.

In this investigation, you measured the potential difference (in volts) and the current (in amps) for each bulb. Use these measurements to calculate the resistance for each bulb in your circuit.

What have we learnt from this investigation?

- The current in a parallel circuit divides when it enters the separate branches. The total current is the sum of the current in the branches.
- The potential difference across the branches of the circuit is the same as the potential difference across the battery.

Investigation Testing current strength

Investigative question

Is the current strength the same at all points in a series circuit?

Hypothesis

Write a hypothesis for this investigation. What do you think will happen in this investigation?

Materials and apparatus

- insulated copper connecting wires.
- two 1,5V cells
- two torch light bulbs
- ammeter

Method

1. Set up a series circuit with two cells and two torch light bulbs in series with each other.
2. Insert an ammeter in series between the positive terminal of the batteries and the first torch bulb.
3. Measure the current strength using the ammeter. Draw a circuit diagram of this setup.
4. Remove the ammeter and close the circuit again.
5. Insert the ammeter in series between the two torch bulbs.
6. Measure the current strength using the ammeter. Draw a circuit diagram of this setup.
7. Remove the ammeter and close the circuit again.
8. Insert the ammeter in series between the last torch bulb and the negative terminal of the batteries.
9. Measure the current strength using the ammeter. Draw a circuit diagram of this setup.

Results

Copy and complete the following table in your exercise books:

Position of ammeter in circuit	Ammeter reading (A)
Between positive terminal of cell and first bulb	
Between two bulbs	
Between negative terminal of cell and last bulb	

Conclusion

1. Write a conclusion based on your results.
2. Is your hypothesis true or false?

ACTIVITY Series and parallel circuits

Materials

- two 1,5 V cells
- insulated copper conducting wires
- two torch light bulbs

Instructions

1. Set up a series circuit with the two cells and the two torch light bulbs. Are both torch lights shining?
2. Disconnect one of the torch light bulbs. What happens?
3. Set up a parallel circuit with two cells and the two torch light bulbs in parallel with each other. Are both torch lights shining?
4. Disconnect one of the torch light bulbs. What do you notice?

Questions

1. Why did the series circuit stop working when one of the light bulbs was removed?
2. Why did the light bulb in the parallel circuit keep shining after you removed the other bulb?
3. Which type of circuit, series or parallel, would be more useful in a household circuit? Why?

Parallel circuits are useful in household circuits because if one pathway stops working then the other pathways can still work. So if your bathroom light bulb breaks, the rest of the lights or appliances in the house can still be used. If your house used a series circuit then all the lights and appliances in the house would stop working if one item broke. You can also turn lights on in different rooms at different times without having to turn all the lights on in the whole house at once.

An example of a series circuit is a set of tree lights. Each light bulb is connected in series with the others. This means that if even one breaks, all will stop working. To find the broken one and fix it, you would have to test every bulb.

Figure 16.23: Tree lights are sometimes connected in series.

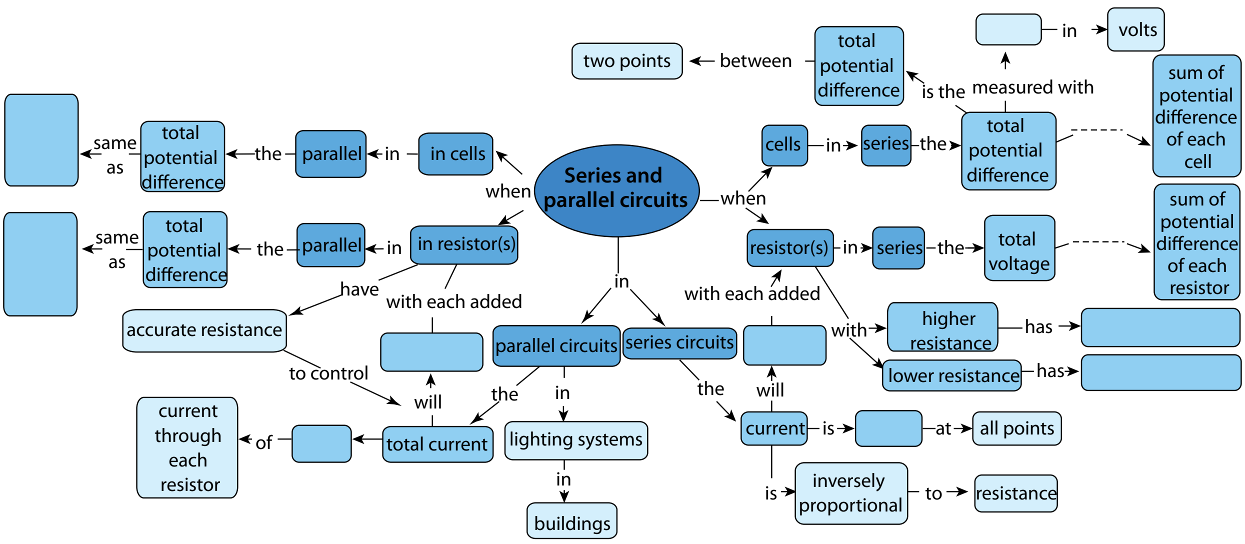
Summary

Key concepts

- A series circuit provides only one pathway for the electrons to move through the circuit.
- Increasing the number of cells connected in series increases both the current strength through the circuit and the potential difference across the cells.
- Increasing the number of resistors in a series circuit increases the overall resistance of the circuit and decreases the current strength.
- Resistors connected in series are potential dividers. The sum of the potential differences of the resistors is equal to the potential difference of the battery.
- The current strength in a series circuit is the same throughout the entire circuit.
- A parallel circuit provides more than one pathway for the electrons to move through the circuit.
- Increasing the number of cells connected in parallel with each other has no effect on the current strength and the potential difference of the circuit.
- Increasing the number of resistors connected in parallel decreases the overall resistance of the circuit.
- Resistors connected in parallel are current dividers. The current has more than one pathway to move along and so the current divides between the paths. The sum of the current strengths in the pathways is equal to the current strength before and after the branch in the pathway.
- The potential difference across each pathway is equal to the potential difference across the battery.
- Parallel circuits are used in the lighting systems in buildings.

Concept map

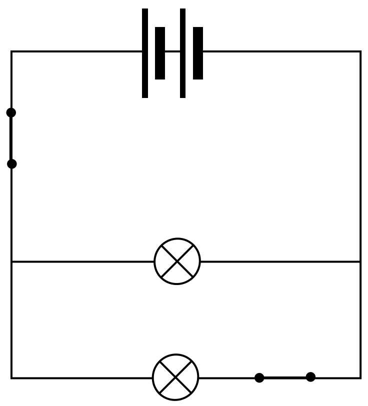
Complete the concept map on the next page in your exercise books. Remember that you can also add your own notes on this page to make your summary more comprehensive and easier for you to study from for tests and exams.



Revision

1. Draw the following circuit diagrams.
   a) A closed circuit with one cell, two light bulbs and a switch in series. [2]
   b) An open circuit with two cells, two light bulbs and a switch in series. [2]
   c) A closed circuit with 1 cell and a resistor in series, with an ammeter to measure the current and a voltmeter to measure the potential difference of the cell. [2]
   d) A closed circuit with two cells in series and two light bulbs in parallel. [2]
   e) A closed circuit with an ammeter and resistor in series and three cells in parallel, with a voltmeter connected to measure the potential difference across the three cells. [2]

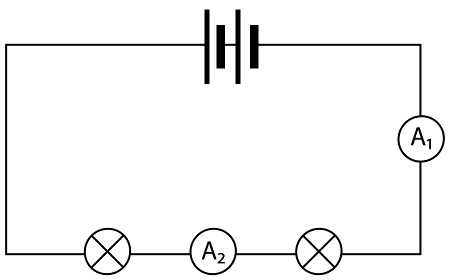
2. Look at the following circuit diagram. Identify the number of bulbs, switches and cells in this circuit. Identify whether they are in series or parallel. [3]



3. Ian has bought a string of Christmas tree lights and has hung them in the tree and plugs them in. One of the light bulbs breaks.
   a) What happens to the rest of the light bulbs? [1]
   b) Explain your answer to question a. [2]

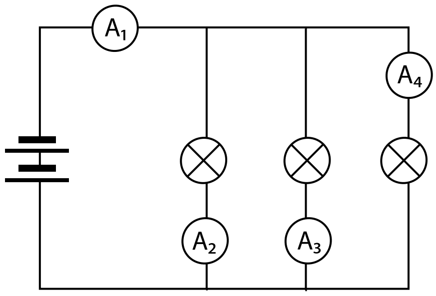
4. Household circuits are parallel circuits. Explain why it is better to use a parallel circuit in a house than a series circuit. [2]

5. Answer the following questions on the circuit below.

Circuit	Values for each reading
	A_1 = 3 A A_2 =

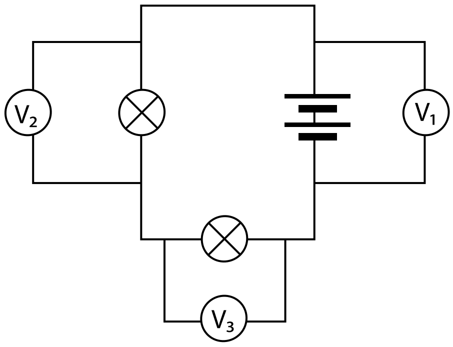
   a) Calculate the missing values. [2]
   b) Explain your answer above. [1]

6. Answer the following questions on the circuit below.

Circuit	Values for each reading
	A_1 = A_2 = 3 A A_3 = 3 A A_4 = 1 A

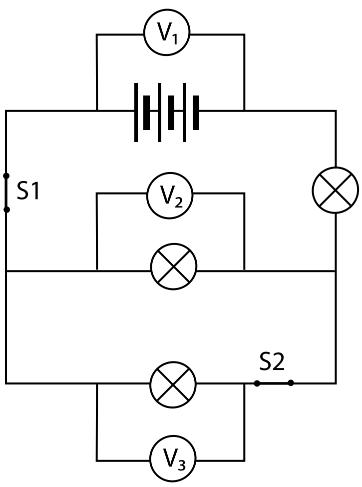
a) Calculate the missing values. [2]
b) Explain your answer above. [2]

7. Answer the following questions about the circuit below.

Circuit	Values for each reading
	V_1 = 12 V V_2 = 8 V V_3 =

a) Calculate the missing values. [2]
b) Explain your answer above. [1]

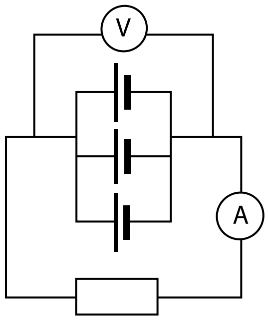
8. Answer the following questions about the circuit below.

Circuit	Values for each reading
	V_1 = 10 V V_2 = V_3 =

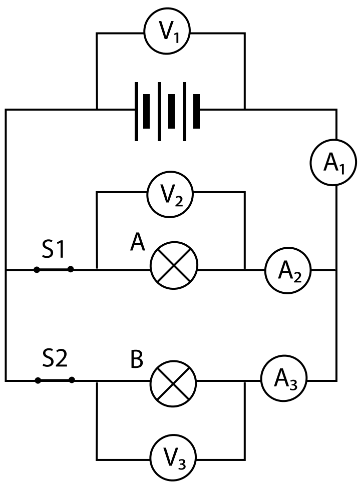
a) Calculate the missing values. [2]
b) Explain your answer above. [1]

c) How many bulbs will still glow if switch S_1 is opened? [1]
d) How many bulbs will still glow if switch S_2 is opened? [1]

9. Calculate the missing values below. [2]

Circuit	Values for each reading
	Each cell in this circuit is 1,5 V. What is the reading on V?

10. Answer the following questions about the circuit below. [4]

Circuit	Values for each reading
	V_1 = 9 V V_2 = V_3 = A_1 = 6 A A_2 = 2 A A_3 =

a) Work out the missing values. [4]
b) What would the reading on A_2 show if switch S_2 is opened? [2]
c) Explain your answer to the previous question. [2]
d) Which bulb, A or B, has the higher resistance? [2]
e) Explain your answer to the previous question. [2]
f) **Extension question:** Calculate the resistance of Bulb A and Bulb B.
Show your working. [4]

Total without extension [47 marks]
Total with extension [51 marks]

17 Safety with electricity

Key questions

- How safe is my electricity connection?
- What is a short circuit?
- Why do plugs have three wires?

17.1 Safety practices

Imagine you are at home, it is dark and you have switched on one of the overhead lights. You then switch on a second light. Does the first light become dimmer? No, it does not. This is because the electrical circuits in houses are parallel circuits.

Despite the advantages of using parallel circuits in the electrical wiring in buildings, there is a disadvantage. Parallel circuits can become overloaded with too many branches and become a safety hazard. The overloading can cause too much heat which could lead to a fire starting. The fire could spread throughout the house and cause a lot of damage.

Keywords

- armature
- reset
- excess
- fuse
- circuit breaker
- earthing
- earth leakage
- short circuit

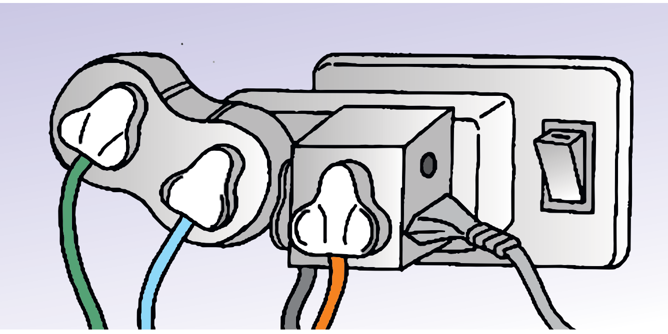


Figure 17.1: This plug is overloaded and is a safety hazard.

Let's now look at some of the safety practices which are followed and employed.

Earthing

What does it mean to **earth** an electrical appliance? Let's consider the example of a washing machine.

The electric circuit inside the washing machine has three different wires:

- a brown **live wire**
- a blue **neutral wire**
- a green-and-yellow striped **earth wire**.

The live and neutral wires provide the potential difference needed for the motor inside the washing machine to turn. The

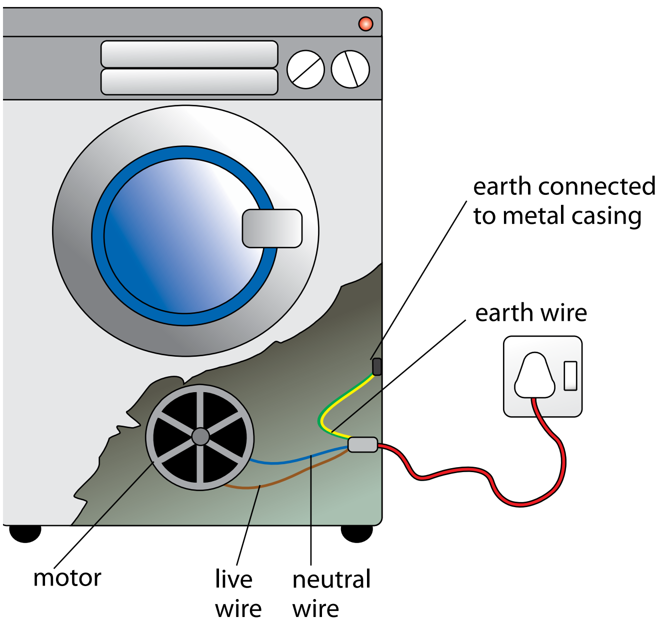


Figure 17.2: The electric circuit inside a washing machine.

earth wire is connected to the metal case of the washing machine. The three wires are encased in a plastic insulation to form one cord, which is plugged into the mains electricity supply at the wall.

The earth wires from all the electric sockets end up in one thick earth wire which is connected to a big metal spike driven into the ground. The earth wire usually does nothing. The only time it is used is when something goes wrong inside the machine.

If the live wire is exposed and touches the metal casing of the washing machine, you could get an electric shock if you touch the metal casing. However, the earth wire is connected to the metal casing so that the current goes through the earth wire and into the ground instead of shocking you. The earth wire has a very low resistance and so a strong current will easily go through it.

Did you know?

The colours for the different wires are used universally, so no matter where you are in the world, you will be able to identify the different wires by their colours.

The earth wire completes the circuit and connects the live wire to the ground.

This is a **short circuit**. The washing machine will stop working because none of the electricity will flow through the motor.

If there were no earth wire, the metal casing of the washing machine would become part of the electrical circuit and anyone who touched it would get an electrical shock. That is why an earth wire is an important safety feature on any electrical appliance.

Figure 17.3: The green-and-yellow earth wire connected to the metal casing inside an electric motor.

Take note

The earth wire is sometimes just green or just yellow instead of striped.

What are short circuits? A short circuit usually happens by mistake. An extra electrical pathway is made. This pathway has very low resistance and so the current increases. This increased current can damage appliances and cause overheating. Overheating can lead to fires. There are several safety devices which are used to stop the flow of current if a short circuit occurs. Let's look at some of the safety devices which are commonly used.

Take note

How to deal with an electrical shock from an appliance. bit.ly/1c9pGDg

ACTIVITY Making your own fuse

Materials

- three 1,5 V cells (large voltage battery)
- copper conducting wires with crocodile clips
- steel wool
- heat resistant mat or piece of wood
- torch light bulb
- variable resistor
- ammeter

Instructions

1. Set up a circuit according to the picture on the next page.
2. Twist a few strands of steel wool into a wire. This must not be very thick. Just a few strands will do.
3. Use the steel wool to complete the circuit.
4. Set the variable resistor to its highest resistance.

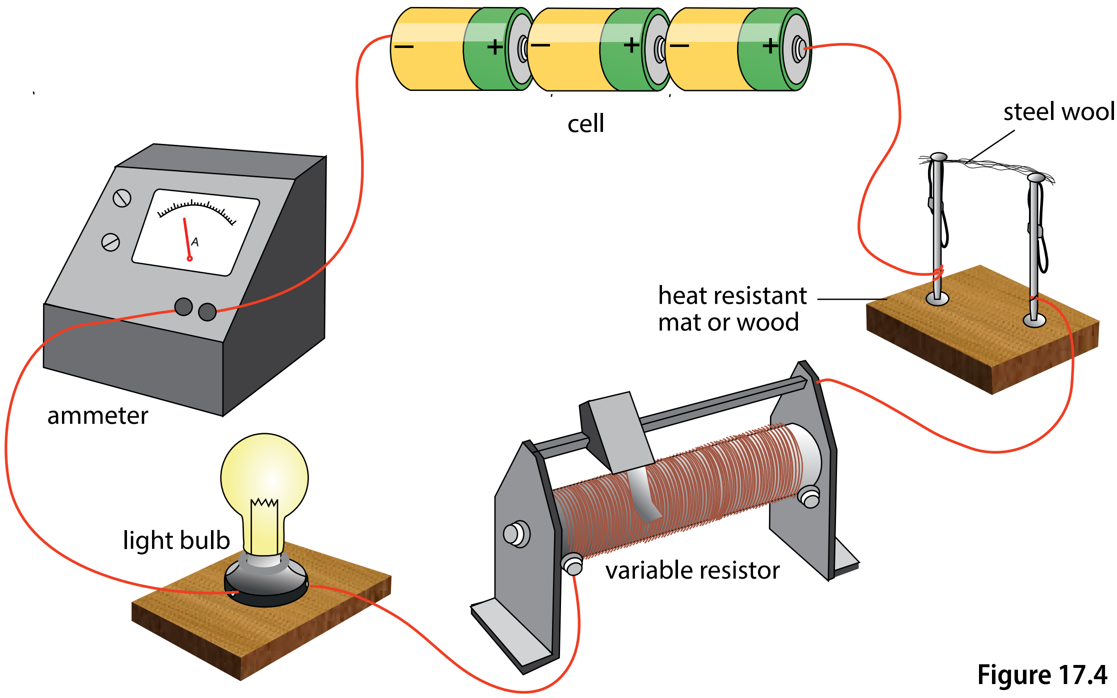


Figure 17.4

5. Close the switch. What do you observe?
6. Take note of the reading on the ammeter which measures the current in the circuit.
7. Open the switch.
8. Set the variable resistance to its lowest resistance.
9. Close the switch. What do you observe?


Figure 17.5: Motor cars also have fuses. Can you see the fuse in this photo showing the battery in a motor car?

Questions

1. Draw a circuit diagram for your circuit.
2. Why is the light bulb included in the circuit?
3. When you decreased the resistance, what happened to the current? In other words, what happened to the reading on the ammeter?
4. What do you think happens to the electric current when the steel wool has burnt? Explain your answer.

A fuse is a wire which will melt if the current travelling through becomes too large due to a fault, such as a short circuit or overload. When the fuse wire melts it breaks the circuit and current stops flowing. This disconnects the appliance to prevent any further damage. Fuses are stamped with the maximum current that they can handle. The photo is of a 5-ampere fuse. It will melt if a current of more than 5 amperes passes through it.


Figure 17.6: A 5-ampere fuse.

ACTIVITY Drawing circuit diagrams with fuses

Instructions

Draw the following circuit diagrams to show various places to insert fuses in circuits.

1. A circuit diagram with two cells and two light bulbs in series with each other. Insert a fuse into the circuit so that if the fuse breaks all the light bulbs will switch off.
2. A circuit diagram with a cell and two light bulbs in parallel with each other. Insert a fuse into the circuit so that if the fuse breaks, only one of the light bulbs will switch off.
3. A circuit diagram with a cell and two light bulbs in parallel with each other. Insert a fuse into the circuit so that if the fuse breaks, both bulbs will switch off.

Figure 17.7: This fuse has blown and has to be replaced.

Circuit breakers

When a fuse melts, it has to be replaced each time. There are other devices which are now more commonly used in households rather than fuses, such as circuit breakers.

Circuit breakers are one of the most important safety devices in our homes today. Without circuit breakers, electricity in our houses and buildings could be dangerous because of the risk of fires and other safety hazards resulting from electrical wiring faults and equipment failures.

Figure 17.8: An example of circuit breakers showing the switches.

A circuit breaker is similar to a fuse except that it can be reset. Once a fuse has melted it is thrown away and a new fuse is put into the circuit. A circuit breaker acts in the same way that a switch would and breaks the circuit if the current surges. You may have seen these switches before on a circuit or distribution board in your home or school.

New word

- electromagnet

Let's take a look at how a circuit breaker functions. Do you remember learning about **electromagnets** in Grade 8 when we looked at the effects of an electric current? An electromagnet is a type of magnet which forms due to an electric current around a bar. The strength of the magnet depends on the electric current. The more current, the stronger the magnet.

A basic circuit breaker consists of a switch connected to an electromagnet. Have a look at the diagram on the right.

When the switch is on, the current flows through the device, from the left through the moving contact and across to the stationary contact. It then goes around the electromagnet and out the other side. The iron catch is holding the moving contact in place so that the circuit is complete. If the current passing through the circuit breaker increases, the electromagnet becomes stronger. If the current gets to unsafe levels, the electromagnet becomes strong enough to pull the iron catch lever. This releases the moving contact so that the circuit breaks and the electricity is shut off, as shown in the diagram on the right.

There is a reset button which can be pushed in order to push the contacts back together when the fault has been fixed and it is safe to reconnect the electricity.

Earth leakage

We have mentioned the dangers of electric charge in previous units. An electric charge will move from where there is a lot of potential energy to where this is less potential energy. Do you remember learning about lightning? The excess electrons from the clouds move to the ground and transfer a large amount of energy in the process.

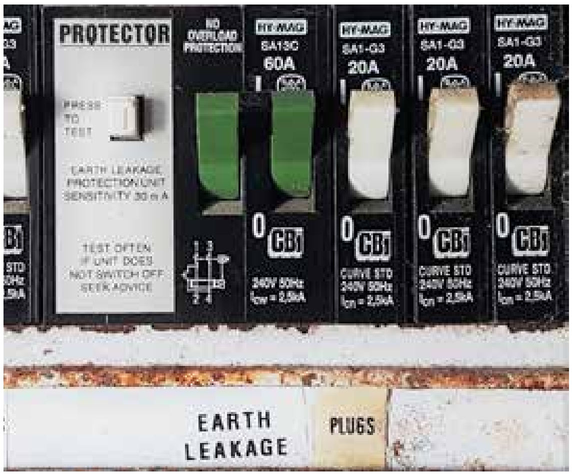


Figure 17.9: An example of the earth leakage and main switch on a distribution board in a house.

The earth leakage circuit breaker is used in the electrical circuits of households and businesses. The circuit breakers for the different parts of the circuit are put into the electrical distribution board. The earth leakage circuit breaker is also on the distribution board.


Figure 17.10: A lightning rod on the roof of a house.

The earth leakage circuit breaker is a safety device which can switch off the electricity supply to the house. The earth leakage is able to detect if any current is moving through the earth wire. If current is moving through the earth wire, there is a short circuit somewhere, as explained with the washing machine. The earth leakage circuit breaker then shuts down all the current as a safety measure.

Lightning is always a danger to an electric circuit. In areas where lightning strikes are common, a lightning spike is often used. This is a metal pole which is connected to the house with one end buried in the ground.

If lightning strikes the house then the surge in current will flow through the metal spike and go safely into the ground. This helps to prevent electric fires in households due to a lightning strike.

Wiring a 3-pin plug

In the first section of this unit, we learned about the three wires that are attached to most electrical appliances. In your exercise books, copy and complete the following table to identify the colours of these three wires.

Wire	Colour
Neutral wire	
Earth wire	
Live wire	

Figure 17.11: The three wires that form the cable leading to a plug.

Why are there three wires? For a complete circuit we have wires coming into the house and wires leaving the house. The wire which enters our homes is the live wire. The neutral wire leaves our homes and is earthed as it leaves the house. The earth wire has a very low resistance and is connected through the plug socket to the earth cable of the house. The earth cable leads into the ground. If an electrical appliance becomes charged because of an electrical fault, it can discharge through the earth wire and earth cable and into the ground. This prevents someone from getting an electric shock from a fault in an appliance.

Take note

The neutral wire is earthed as it leaves the house, as shown in the diagram, to protect the national grid from lightning strikes. If lightning strikes the overhead cables or transmission lines, then the current flows into the ground rather than burning up the entire network.

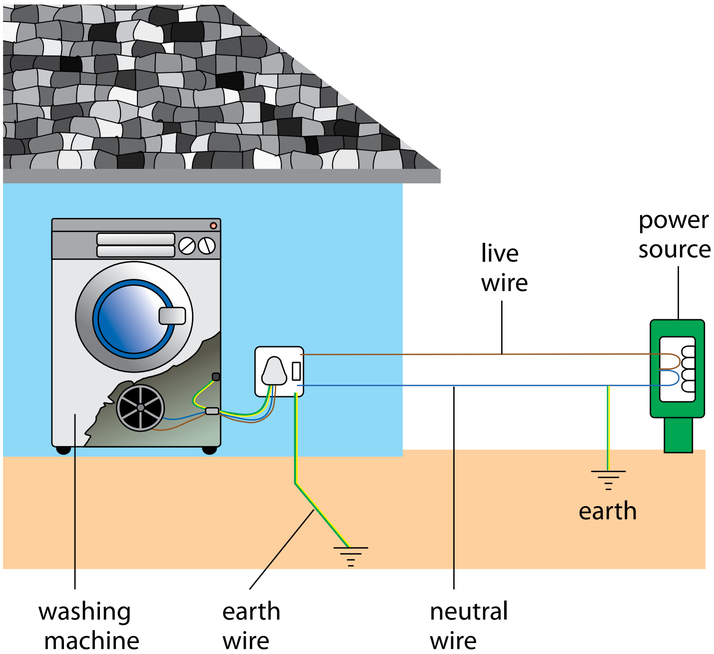


Figure 17.12: Houses and other buildings are connected to the national grid by the live wire entering the house and the neutral wire leaving the house.

The electrical plug has three metal pins. Each pin has a hole in it with a small metal screw. Loosening the screw opens the hole, tightening the screw closes the hole. Let's take a look inside a plug to see how to wire it.

ACTIVITY Wiring a 3-pin plug

Materials

- piece of insulated electrical cord
- wire strippers or craft knife
- 3-pin plug
- small screwdriver

Have a look at the photo of a 3-pin plug.

Figure 17.13: A 3-pn plug.

1. Which pin is the green-and-yellow cable connected to?
2. Which pin is the blue neutral wire attached to?
3. Which pin is the brown live wire always attached to?

We are now going to wire our own plugs.

Instructions

1. Cut about 2 cm of the white insulation off the electrical cord to expose the three wires within it. Do not slice directly into the wire as though you are cutting a loaf of bread. Move the blade carefully around the cord in a circle until you have cut through the insulation.
2. Once you have exposed the three different-coloured wires, cut away about half a centimetre of insulation from each of these three smaller insulated wires to expose the copper wire inside.
3. Twist the copper wires gently with your fingers so that the strand is tight.
4. Open the plug cover.
5. Unscrew the little screws on the 3 metal pins.
6. Insert the copper wire into the metal pins. The green and yellow wire goes into the top pin (often labelled 'E' for earth, or with the symbol for earthing). The blue wire must go into the pin on the right when viewed from the bottom (often labelled 'N' for neutral). The brown wire must go into the pin on the left when viewed from the underneath of the plug (often labelled 'L' for live).
7. Tighten each of the little screws to trap the wires in place.
8. Replace the plug cover.
9. You have now correctly wired a 3-pin plug and attached it to the electrical cable.
10. When you wire a 3-pin plug of an actual appliance, what safety precautions do you think you need to follow? Discuss this with your partner or class and write down your answer here.

Take note

When viewed from the underneath with the pins facing towards you, the green-and-yellow earth wire is always connected to the uppermost pin, the blue neutral wire to the pin on the right and the brown live wire to the pin on the left.

Now that we know more about the safety practices in electrical wiring in buildings, let's practise by designing the wiring for a house.

PROJECT Wiring a house

Instructions

You have made a doll's house for a neighbour's little girl. The doll's house has 2 bedrooms, a bathroom, a lounge and a kitchen. You want to make a simple electrical circuit for the doll's house.

Start off by drawing the floor plan of the house. Once you have this, draw in the wiring system to show how you would put a light bulb in every room. Each light must be able to switch on and off without affecting the other lights in the house. There must be a mains switch located in the kitchen and a fuse to prevent overload.

You should practice this on rough paper before drawing the final design in your exercise books on the next page. Include the labels for each room.

Keywords

- illegal
- provision

17.2 Illegal connections

An illegal electricity connection is made when a person attaches their home's electrical circuit to the national grid without a meter. This is done without the consent or knowledge of Eskom. Eskom cannot monitor the electricity consumption, so the electricity is stolen because these consumers do not pay for the electricity.

Some people make money supplying **illegal** connections and others have no legal way to access electricity and so they resort to illegal connections. Others have access to legal electricity, but prefer not to have to pay for it. Not only are these types of electrical connections illegal and considered energy theft, they are also very dangerous, as you will see in the next activity.

Figure 17.14: Electricity theft is illegal and also very dangerous because of the insecure connections

ACTIVITY Case study on illegal electricity connections

Instructions

1. Read the following newspaper article.
2. Answer the questions that follow.

Doornbach informal settlement celebrates electricity provision

WestCapeNews, July 2012 and fire risks.

There was much celebration in Doornbach, an informal settlement just outside of Cape Town, when the City switched on about 200 new electrical connections over the period of a few months in 2012. The illegal electricity connections had previously been the only supply of electricity to the area. Authorities often encounter fierce opposition when trying to cut down illegal electricity connections in informal settlements. But the Doornbach residents immediately took it upon themselves to cut down the massive web of illegal wires in response to finally receiving formal, legal electricity provision.

Besides the mass of wires running through the informal settlement, many of the wires had been strung across Potsdam Road, the main road running through the settlement. This was very dangerous as the wires hung very low and would often catch on trucks passing through and snap. Fire threats and electrical shocks to passers-by and vehicles were also a safety concern. The use of legal electricity would also help to prevent shack fires as residents would rely less on candles and paraffin stoves.

A fifty-two-year-old Doornbach resident, celebrating the end of illegal connections in the settlement, said that she had lived there for 18 years and had never received any municipal services from the City because they had originally settled on privately owned land, which meant that the City could not, in terms of national legislation, install services on privately owned land. However, the City had bought the land in May 2011, and Eskom could therefore begin the process of providing electricity to households in Doornbach. The fifty-two-year old was very excited about being able to use an electric iron and installing a refrigerator.

As a symbolic gesture, the residents took it upon themselves to remove the illegal wires. Many of the young people climbed up the dangerous makeshift poles in order to collect the wire which they would then sell to scrap yards. Not everyone was celebrating the switching on legal electricity connections in Doornbach. Many residents in neighbouring settlements, living in formal housing, were making money by selling and supplying electricity illegally to Doornbach. Street lighting had also been installed in Doornbach, and it was hoped this would help to reduce the crime rate.

Lastly, the City of Cape Town extended their sincere thanks to the community of Doornbach, as without their support, involvement and cooperation, such a project would not have been possible.

Questions

1. What is an informal settlement?
2. After reading this article, what do you think is the main reason that the people of Doornbach originally set up illegal connections?
3. Why is it dangerous for young people to climb the makeshift electricity poles?
4. What were some of the physical dangers of the illegal connections in Doornbach?
5. Aside from the physical dangers associated with illegal electrical connections, why else are they illegal?

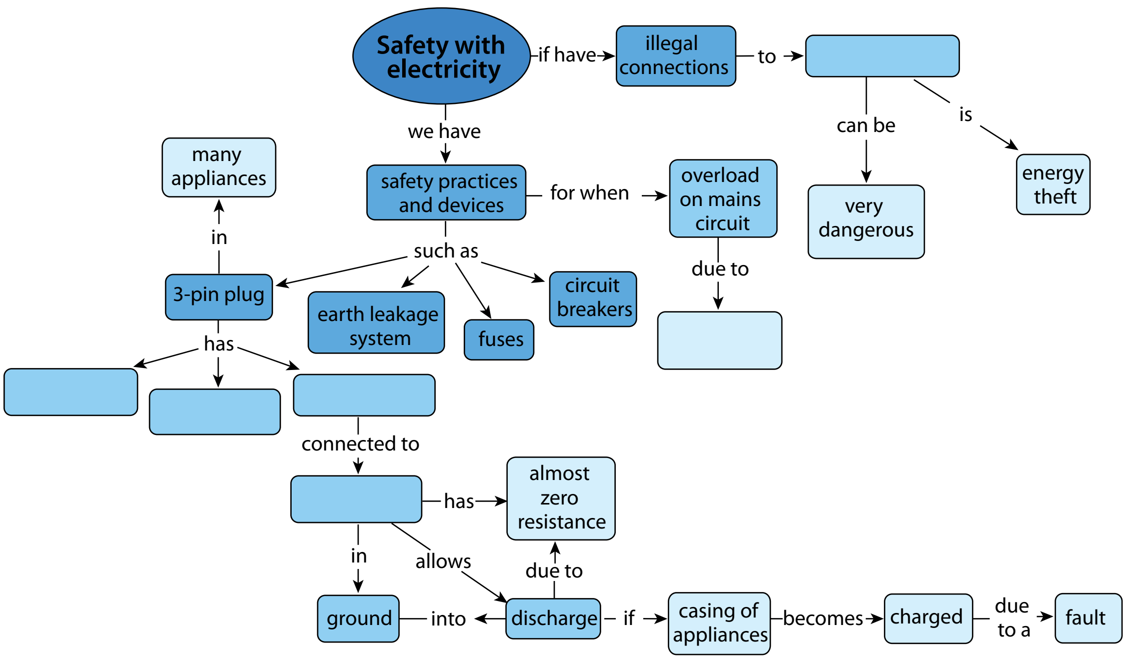
Summary

Key concepts

- Electricity can be dangerous, so we need safety devices such as fuses, circuit breakers and earth leakages to reduce risk.
- A fuse is a safety device with a very low resistance wire, designed to melt if it experiences a large enough current. This breaks the circuit and protects the appliance, as well as preventing a possible fire hazard.
- A circuit breaker is like a fuse, but acts as a switch which breaks the circuit in response to an electrical fault or overload. It can be reset.
- Many electrical appliances with a metal casing have an earth wire attached to prevent electric shocks if there is a short circuit.
- A three-pin plug has three wires: a brown live wire, a blue neutral wire and a green and yellow striped earth wire.
- The earth wire has a very low resistance and is connected through the plug socket to the earth leakage system of the house, and into the ground.
- A plug must be connected properly in order to make sure that it is safe to use.
- Illegal electricity connections are both dangerous and illegal. It is a crime to steal electricity.

Concept map

Complete the concept map in your books on the following page to summarise what you know about safety with electricity.



Revision

1. Explain how a fuse functions to protect an electric circuit. [4]
2. What would happen if you used a 3-amp fuse in an electrical fan heater that needs a current of 8-amps to function? [1]
3. What type of fuse should you use in the 8-amp fan heater? [1]
4. Why are circuit breakers more convenient to use than fuses? [2]
5. When a fuse 'blows', why do you think it is important to fix the problem before replacing the fuse? [2]
6. What is a short circuit? [3]
7. Why is a short circuit dangerous? [2]
8. What is the colour of the live wire in an electrical cable? [1]
9. Write down one safety precaution that should be followed when wiring a 3-pin plug. [1]
10. What is the purpose of the green-and-yellow wire in an electrical cable? [2]
11. Draw an outline of a 3-pin plug and label where each wire is connected and what colour each wire is. [6]
12. Draw a circuit diagram for the following circuits:
    a) A series circuit with 2 cells and three light bulbs. Insert a fuse that will break the circuit and where all the bulbs won't work if there is a short circuit. [3]
    b) A circuit with a cell and two light bulbs in parallel with each other. Insert a fuse into the circuit so that if the fuse breaks, only one of the light bulbs will switch off. [3]

Total [31 marks]

18 Energy and the national electricity grid

Key questions

- How is electricity generated in a power station?
- What energy sources are used in South Africa to generate electricity?
- Is nuclear energy the best way to solve the energy crisis?
- What are the advantages and disadvantages of nuclear power?
- How is electricity distributed from power stations to our homes?

18.1 Electricity generation

Electricity is generated in a power station. In previous grades, we have looked at how electricity is generated within coal-powered power stations and distributed to the country in the national electricity grid. We are going to revise some of these concepts.

The general method for producing electricity is to turn a turbine which will turn a generator. In South Africa most of the power stations use coal for fuel. The coal is mined out of the earth. The coal is transported to the power station in large trucks or trains.

Let's take a closer look at what happens inside a coal-powered power station.

Keywords

- turbine
- generator
- alternative energy
- power station

Figure 18.1: A coal-powered power station.

Have a look at the following diagram.

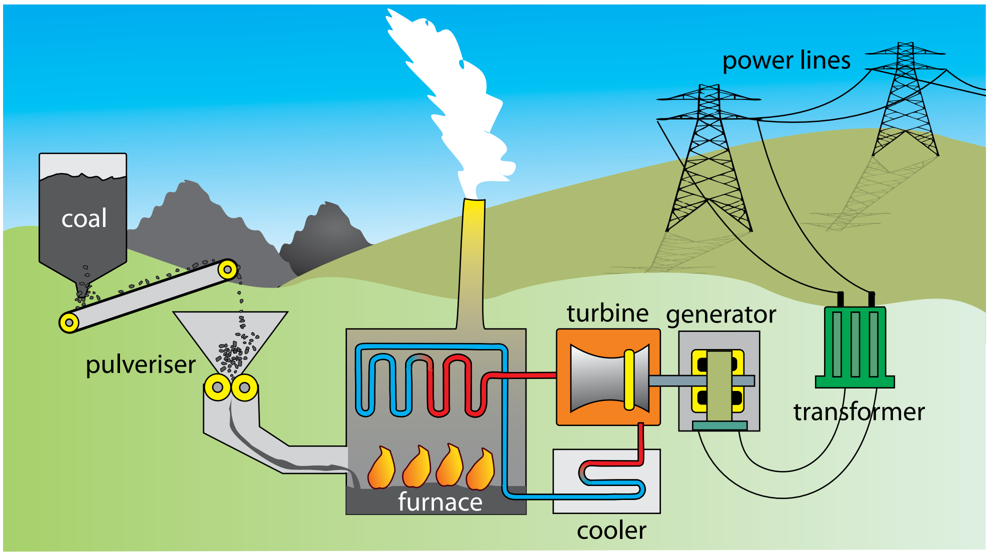


Figure 18.2: Diagram of a coal-powered power station.

An overview of the steps in a coal-powered station:

1. The large chunks of coal are first crushed into a fine powder. This is called pulverisation.
2. The coal is then transported to a **furnace** where it is burnt.
3. The thermal energy from the burning coal is used to boil water and generate **steam**.
4. The steam pushes the blades of the **turbine** and so the turbine spins.
5. The turbine is connected to the shaft of the **generator** which then rotates large magnets within wire coils, which generates electricity.
6. The **electric current** is sent through the **power lines** to businesses and homes.

Did you know?

The cooling tower on the left in the photo is covered in the largest mural painting in South Africa.

Figure 18.3: This is the Orlando Power Station in Soweto, which served Johannesburg for 50 years from 1951. It is not used any more. The painted cooling towers are seen the most prominently, but the building to the right is also part of the power station.

Is coal a renewable or a non-renewable energy source? Explain your answer.

What are the disadvantages of South Africa's reliance on coal as the main source of energy in power stations?

Figure 18.4: A modern-day steam turbine connected to a generator.

Alternative sources of electrical energy

There are many different ways to get enough energy to turn the turbine. What are some of the alternative energy sources which can be used instead of coal?

List them in your exercise books.

The Gariep Dam on the border of the Free-State and Eastern Cape provinces is a hydroelectric power station which uses the water falling out of the dam to turn the turbine. How does the falling water make the turbine turn? Let's investigate that a little more.

ACTIVITY Hydroelectric power

Materials

- aluminium foil plate or cooking tray
- scissors
- pencil
- adhesive tape or packaging tape
- piece of string about 45 cm long
- eraser
- nut, bolt, or other small mass piece
- source of running water, such as a tap

Instructions

1. Cut out the circular bottom of an aluminium foil plate. If it isn't circular, use a compass to draw a circle in the base and cut it out.
2. Make eight equally spaced cuts toward the centre of the foil circle, as shown with the solid lines in the diagram. End each cut about 2 cm from the centre. You now have eight triangular sections.

Take note

In Grade 8 you might have made miniature turbines and seen how steam is able to make the blades of the turbine turn. You can refer back to this by looking online at www.curious.org.za

Take note

Do you remember how coal is formed? Coal is a fossil fuel, formed over millions of years as prehistoric swamps and vegetation were covered in layers of sediment and compressed.

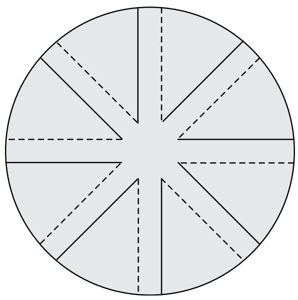


Figure 18.5

3. Fold each of the sections upwards. Use a ruler to help you get a straight edge. Use the dotted lines in the diagram as a guide.
4. Make a small hole in the centre of the plate. Push a pencil through the hole. The pencil should fit tightly into the hole. Use adhesive tape to stick the wheel to the pencil so that if you rotate the pencil, the wheel rotates.
5. Tie a piece of string around one end of the pencil. Tie the small nut or bolt to the other end of the string.
6. Hold each end of the pencil lightly between your thumbs and index fingers.
7. Hold the wheel under a slow stream of water from a running tap. Make sure to hold the wheel so that the blades are in the water, as shown in the a diagram.

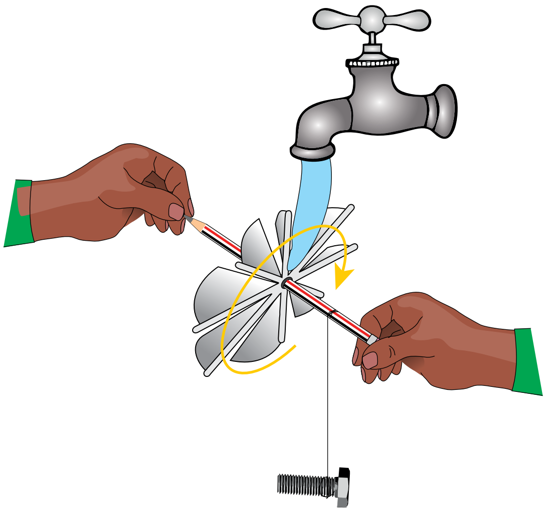


Figure 18.6

Questions

1. What happens to the aluminium wheel when it is placed in the stream of water?
2. What happens to the mass piece when the aluminium wheel is in the water stream?
3. Explain the energy transfers between the falling water and the mass piece lifting.
4. The following diagram shows an example of a hydroelectric power station. Answer the questions that follow.

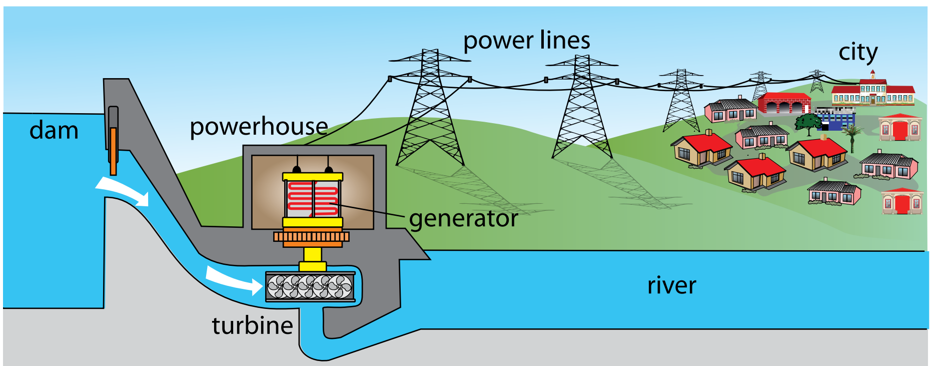


Figure 18.7: A diagram of a hydroelectric power station.

a) The water in the dam on the left is high up. It has the ability to fall down. What kind of energy does the water have?
b) As the water flows down the outlet from the dam, describe the transfer of energy.

c) The flowing water then turns the turbine. This is a mechanical system. What kind of energy does the turbine have?
d) The generator then transfers the energy between two systems. The kinetic energy in the mechanical system is transferred to electrical energy in the electrical system as it generates electricity. What parts make up the electrical system in the diagram?
e) What is the output from this whole system? In other words, what does the city get?

A large dam wall is often built to collect water. The water then flows through the hydroelectric power plant.

Figure 18.8: A large dam wall with a hydroelectric power plant.

Figure 18.9: The generators inside the hydroelectric power plant.

Figure 18.10: The water flows out the bottom of the power station and continues down the river.

A turbine can be used to transfer kinetic energy from the falling water to the generator. A generator is a device which converts mechanical energy to electrical energy. A generator consists of large metal coils which move within a magnetic field. In some generators the coils are stationary and the magnet is rotated and in other generators the magnets are stationary and the coil is rotated.

Turning a set of conducting metal coils inside a magnetic field generates an electric current. The modern-day generator works on the principle of

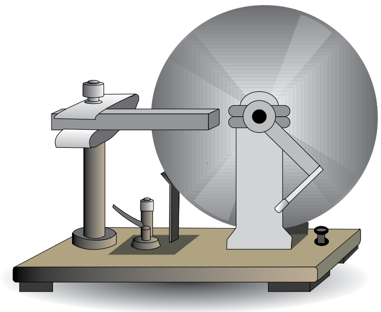


Figure 18.11: A drawing of the Faraday Disk, the first electromagnetic generator. It consisted of a copper disk rotated between the poles of a horseshoe-shaped magnet to generate electricity.

Did you know?

The Faraday Disk was the first electromagnetic generator invented by British scientist Michael Faraday in 1831.

Take note

Portable generators produce exhaust fumes which contain poisonous gases that can kill if they are present in high enough levels. When using a portable generator, make sure it is in a well-ventilated area, and away from water as far as possible.

electromagnetic induction discovered by Michael Faraday in 1831–1832. Faraday discovered that you could cause an electric current to flow by moving an electrical conductor, such as a wire that contains electric charges, in a magnetic field. The movement creates a potential difference between the two ends of the wire or electrical conductor. This then causes the electric charges to flow through the conductor as current.

There are many different types of generators used in different situations, not only in power stations. Some yachts and boats use water or wind-powered generators to charge their batteries through the use of small propellers in the water or a wind turbine. Portable generators are often used in homes and businesses when there are power outages to keep certain appliances running, such as the lights and refrigerator.

Figure 18.12: A portable generator used in a home.

Portable generators run on fuel, such as
shaft and generate electricity.

Small generators, called dynamos, can be rotated by a person rotating a crank, and are used in devices such as portable radios and torches, and especially mining helmets. Dynamos are also used in bicycle lights. The dynamo in a bicycle consists of a permanent magnet and some surrounding coils of wire and is attached to the wheel, which rotates as the bicycle moves. As the dynamo rotates it generates a changing magnetic field that generates electricity in the surrounding coils of wire.

Figure 18.13: A dynamo on the wheel of a bicycle.

Figure 18.14: Wind turbines out at sea are an alternative energy source.

As we have seen, most of the electricity generated in South Africa uses the burning of coal to provide steam to turn the turbines. Some of the electricity is generated using alternative energy sources. Why are they called alternative energy sources? This is because they are not the main source of energy. Most alternative energy sources are renewable forms of energy.

RESEARCH PROJECT Alternative energy power stations

Instructions

1. Research the different types of power stations in South Africa.
2. Choose one of the alternative energy sources used in South Africa.
3. Alternatively, your teacher may ask you to do this as a research project and present a poster.
4. Write a paragraph here where you discuss the alternative energy source power station you have researched. In your paragraph, include the following information:
   a) Compare the alternative energy power station to a coal-powered station in terms of sustainability and environmental impact.
   b) Discuss the advantages and disadvantages of using the alternative energy source rather than coal for generating electricity.
   c) Include your references.

18.2 Nuclear power in South Africa

Keywords

- nuclear power
- nuclear fission
- nuclear fusion
- radioactive

For enrichment

South Africa has only one commercial nuclear power station, the Koeberg Power Station in Cape Town. We are going to take a closer look at nuclear power.

Figure 18.15: The Koeberg Nuclear Power Station outside Cape Town.

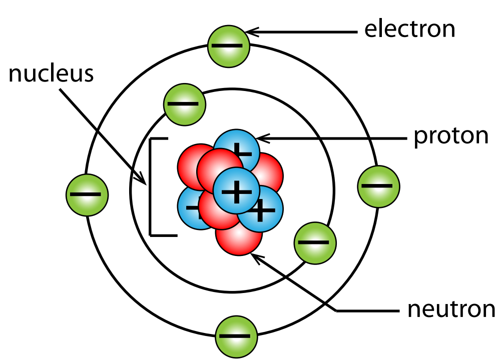


Figure 18.16: The structure of an atom

Before we look at nuclear fission, let's revise the model of an atom which we have already learnt about. Copy and label the diagram of the model of an atom.

Most atomic nuclei are stable. But there are some elements which are not stable. The nuclei in these unstable elements

> **Did you know?**
>
> Atomic bombs use the processes of nuclear fission or nuclear fusion. The devastating effects of nuclear bombs are still seen today in Hiroshima and Nagasaki in Japan where two nuclear bombs were dropped during World War 2.

spontaneously emit particles, referred to as radiation. A nucleus that emits radiation is said to be radioactive. Radioactive decay is the process when an unstable nucleus of an atom emits particles. It then 'decays' into another type of atom with a different mass.

Nuclear power was first pursued for electricity generation in the beginning of the 20th century when researchers discovered that radioactive materials, such as radium and uranium, release large amounts of energy when they decay. For a long time, however, the use of nuclear power was not seen as practical or possible to generate electricity.

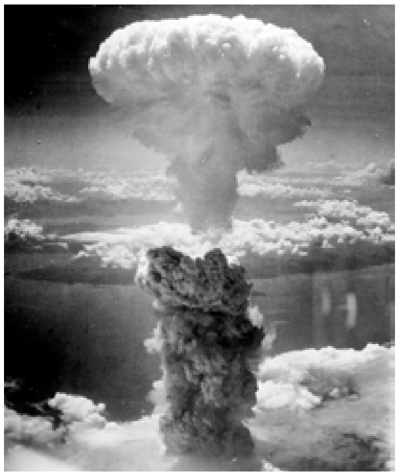


Figure 18.17: Atomic bombing of Nagasaki on 9 August 1945.

This changed in the 1930s with the discovery of nuclear fission. During nuclear fission, scientists split the nucleus of an atom into two smaller atoms. This releases a huge amount of energy. There is also another way in which the energy in an atom can be released during nuclear fusion. Nuclear fusion occurs when two atoms are brought together to make a new, bigger atom. During both of these nuclear reactions, huge amounts of heat and radiation are released.

Nuclear power uses nuclear fission, nuclear fusion and nuclear (radioactive) decay. Uranium is an element which is unstable and undergoes radioactive decay at a very slow rate. This makes uranium a good choice to use as a fuel in nuclear power stations. Nuclear power stations therefore use uranium and induce nuclear fission to release the heat and radiation. Let's take a look inside a nuclear power plant, such as Koeberg Power Station.

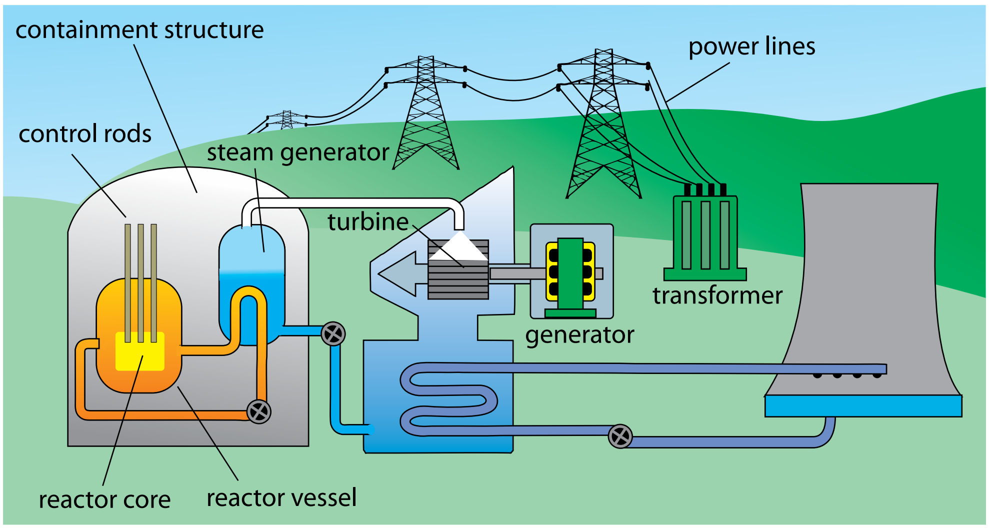


Figure 18.18: Diagram of a nuclear power plant.

The main difference between a nuclear power station and other power stations, such as coal power stations, is the way in which the water is heated to produce the steam.

A nuclear power station has a nuclear reactor vessel. The nuclear power station needs to control the huge amount of energy given off during nuclear fission of uranium in order to generate electrical energy. The nuclear reactor is the device in which the nuclear reactions take place and are controlled. The uranium is formed into pellets which are arranged into long rods, called the reactor core. The rods together make a bundle which is inserted into water to prevent overheating and melting. The bundle of uranium rods also contains control rods which help to control the process.

The large amounts of energy produced by the nuclear fission reactions in the uranium fuel rods heat the water to produce steam. The steam is used to turn large turbines which transfer the kinetic energy to generators, which produce electricity in the same way as in other power stations.

Most of South Africa's power stations use the burning of coal to produce enough heat to boil the water. The only difference in a nuclear power station is how the energy is produced to heat the water and produce steam.

As was mentioned before, the nuclear fuel is radioactive. The radiation that the fuel emits is dangerous and can be very harmful as it can enter our bodies and damage our cells. The workers in nuclear power plants therefore need to take extra precautions. The nuclear reactor is also contained within a special container that acts as a barrier to radiation.

You may have heard some of the debate surrounding the use of nuclear fuel in power stations. There are many supporters but also many critics. Let's look at some of the advantages and disadvantages of using nuclear fuel.

> **Did you know?**
>
> In March 2011, thousands of Japanese citizens evacuated the area surrounding the Fukushima-Daiichi nuclear power plant after a powerful earthquake and resulting tsunami seriously damaged the power station. The water leaked out of the reactor, resulting in overheating and a partial nuclear meltdown.

ACTIVITY Advantages and disadvantages of nuclear power

Instructions

1. Discuss and answer the questions that follow.
2. You will then be divided into groups to do some extra reading and research and host a debate for and against the advancement and development of nuclear power in South Africa.

Questions

What are some of the advantages of nuclear fuel? Discuss this with your partner and write down your answers in your exercise books.

One of the major disadvantages is that once the nuclear fuel has been used, it cannot just be thrown away in a city dump. The spent nuclear fuel is high-level radioactive waste. The radiation can also damage animals and plants. This nuclear waste needs to be disposed of carefully and correctly so that the radiation is not able to cause a lot of damage. Over time, the nuclear waste will decay to safe levels of radioactivity, but this takes thousands of years. In the meantime, it has to be stored so that it does not cause any damage or fall into the hands of nuclear arms manufacturers. This adds to the cost of using nuclear fuels. Some people also have reservations about nuclear power plants as the potential for a nuclear reactor meltdown is catastrophic.

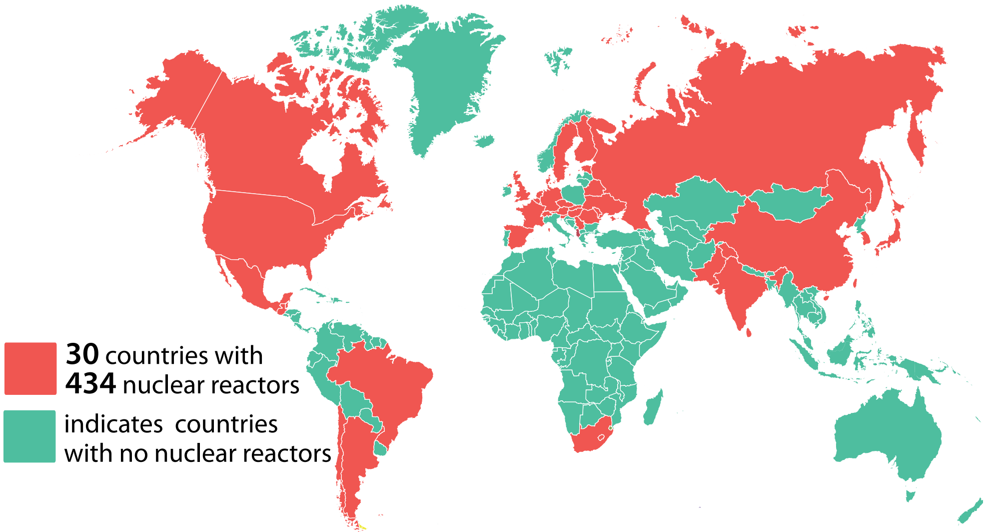


Figure 18.19: Operating nuclear power stations worldwide.

Did you know?

Nuclear fission produces roughly a million times more energy per unit mass than fossil fuel alternatives.

Research and debate

You need to conduct further research into the advantages and disadvantages of nuclear power. Your teacher will put you into a group which is either in favour or not in favour of using nuclear power, and developing it further in South Africa. Debate, with your classmates, whether or not nuclear power is the solution to our developing energy crisis. You need to substantiate your point of view and justify your statements either in support of or against nuclear power.

We are now going to look at what happens to the electricity that is generated in a power station, whether it is coal, nuclear, or a hydroelectric power plant.

Keywords

- national electricity grid
- transformer
- transmission lines
- pylon
- power surge

18.3 National electricity grid

Figure 18.20: The national power lines transmit electricity across the country from the power stations.

The national energy grid is a network of interacting parts which form one big system to provide electricity to all sectors of the economy. It starts at the power stations where the electricity is generated. The power stations then feed the electric current into large power lines called transmission lines. There is a massive network of transmission lines that extends throughout the entire country. The transmission lines are supported by pylons.

Very high currents are generated at the power stations. The transmission lines have some resistance. If the power stations transferred electricity at high currents, what do you think would happen in the transmission lines? Hint: Remember what we learnt about the effects of resistance.

The following diagram illustrates a coal-powered power station connected to the national electricity grid.

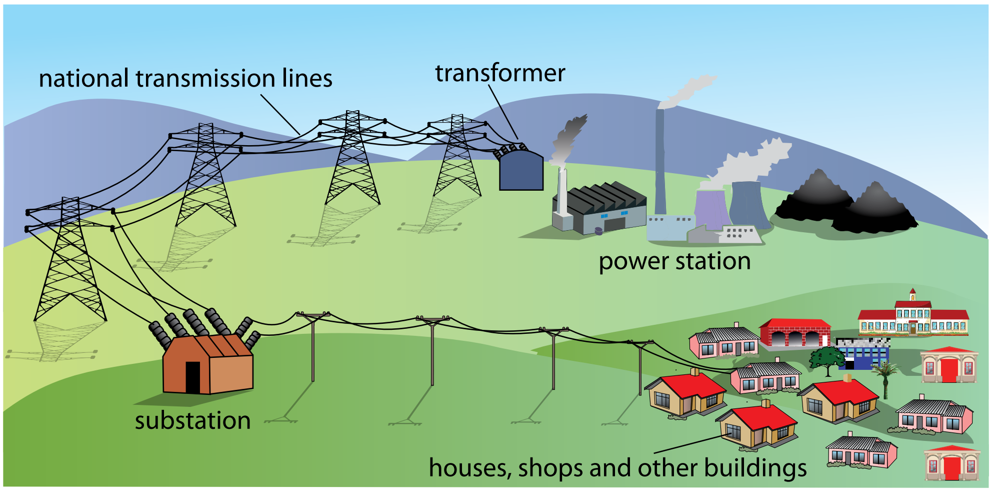


Figure 18.21: A coal-powered power station connected to the national electricity grid.

To prevent the waste of energy, the electric current is rather sent through the transmission lines at very high voltages and low current.

However, these voltages are too high for use in both private homes and commercial buildings. In our homes and buildings we need low voltage and high current.

Transformers are used to change the voltages at different points in the grid. As you can see in the previous diagram, the electricity first goes through a transformer before entering the national transmission lines. This is a step-up transformer as it increases the voltage and lowers the current. When the electricity reaches the substation to be distributed locally, there is a step-down transformer which decreases the voltage again and increases the current.

All the systems in the national electricity grid are connected and this means that a power surge or a grid overload can cause blackouts and disruptions throughout the network.

Did you know?

In 1986, the Ukrainian nuclear reactor in Chernobyl exploded and released 50 tonnes of radioactive material into the area, destroying forests and causing 30 000 people to evacuate the area. Thousands of people subsequently died from cancer and other illnesses.

Take note

In a debate, each person must be given a chance to voice his or her opinion and a chance to respond to other opinions.

Power surge

What is a power surge? A power surge is a sudden increase in the voltage somewhere in an electric circuit. The power surge causes an increase in the current strength. This sudden increase in the current strength can damage sensitive circuits.

Lightning strikes near a transmission line can cause a power surge. Other causes of power surges or a grid overload include faulty wiring, or appliances or equipment that require a lot of energy when they are switched on and off. These sudden demands or excesses of energy cause brief changes in voltage that can cause a surge. There are several points in the national grid which can detect a power surge or grid overload. If these are detected, the power supply to that area is cut off.

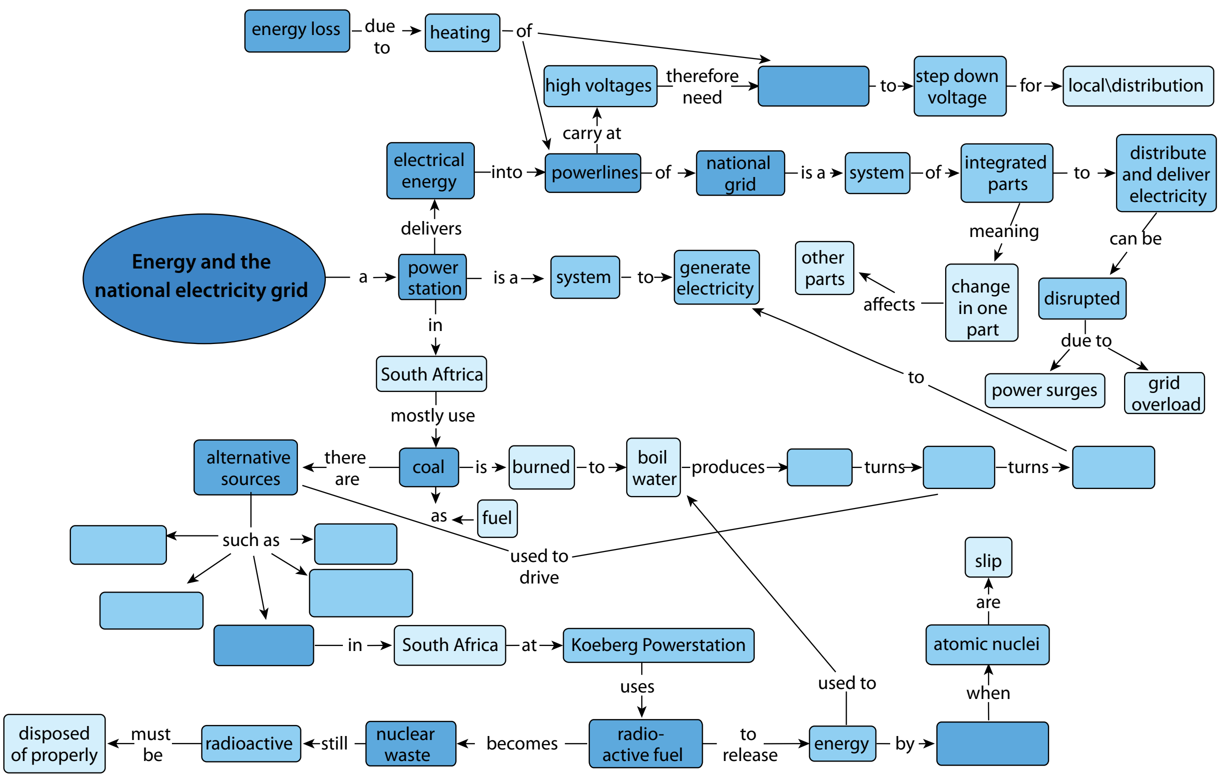
Summary

Key concepts

- The national grid is a network of interacting parts. If one part of the system is damaged, it will affect the entire network.
- Electricity in South Africa is mainly produced using coal-fired power stations.
- In a coal power station, coal is burned to heat water to produce steam. The steam turns a turbine, which turns a generator to produce electricity.
- There are alternative sources of energy besides coal to drive turbines, such as wind, hydropower, sun-heated steam, nuclear power, and tidal energy.
- Koeberg is the only nuclear power station in South Africa.
- Nuclear power stations use nuclear fuels, such as uranium, to generate heat and radiation by nuclear fission. This heats the water to produce steam to turn the turbine.
- Nuclear fuels are very energy-efficient as a large amount of energy is obtained from a very small mass of nuclear fuel. There is no emission of greenhouse gases in the use of nuclear fuels.
- Nuclear power stations generate radioactive waste materials which need to be properly disposed of. There is much debate around the use of nuclear fuels.
- The national electricity grid is a system to deliver electricity around the country.
- Electricity is carried at high voltages and low current through the national transmission lines to reduce the heating effect of the wires and minimise the energy wasted.
- Transformers are needed to step-up the voltage as the electricity leaves the power station and enters the national grid, and to step-down the voltage for local distributors and consumers.

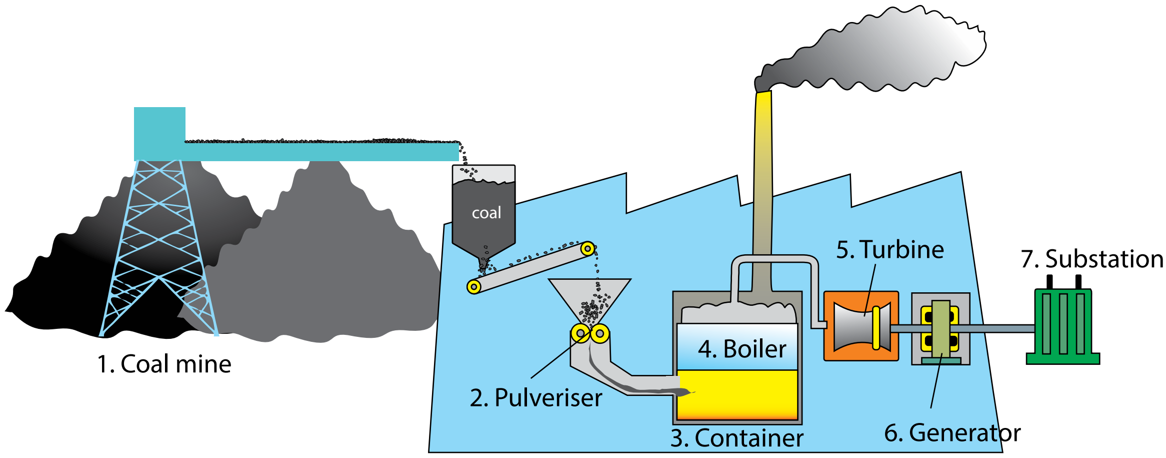
Concept map

Complete the concept map on the following page to summarise this unit on electricity production and delivery.

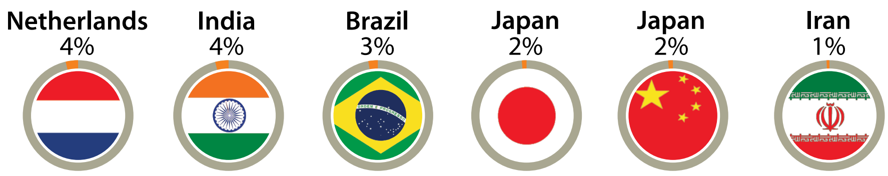


Revision

1. Why do you think we can refer to the national electricity supply as a grid? [2]
2. What is the main source of energy for power stations in South Africa? [1]
3. Why are renewable sources of energy referred to as alternative forms of energy? [2]
4. Look at the diagram of a power station. Write a paragraph to describe the process by which electricity is produced in a coal power station. [6]



5. With the aid of a flow diagram, explain the energy transfer that occur in a coal fired power station. [4]
6. What is nuclear power? [2]
7. Where is South Africa's nuclear power station? [1]
8. What is the difference between nuclear fission and nuclear fusion? [2]
9. Write a paragraph to explain the differences and similarities between a coal-fired power station and a nuclear power station. [4]
10. Write a paragraph to compare how the use of coal impacts on the environment when compared to how the use of nuclear fuels impacts the environment. [4]
11. Study the following diagram below and on the opposite page and answer the questions that follow.



The proportion of electricity generated using nuclear fuels in each country in 2013.

a) Which country has the highest percentage of its electricity being produced using nuclear fuels? [1]

b) What is the percentage of South Africa's energy generated using nuclear fuels? [1]

c) Why are all the countries in the world not shown here in this diagram? [1]

d) Draw a bar graph to compare the percentage of electricity generated using nuclear fuels to compare South Africa, France, United States of America, United Kingdom, India and China. [6]

12. Why can we consider the national electricity grid a system? [2]

13. We can divide the national electricity grid into four main stages. These are:

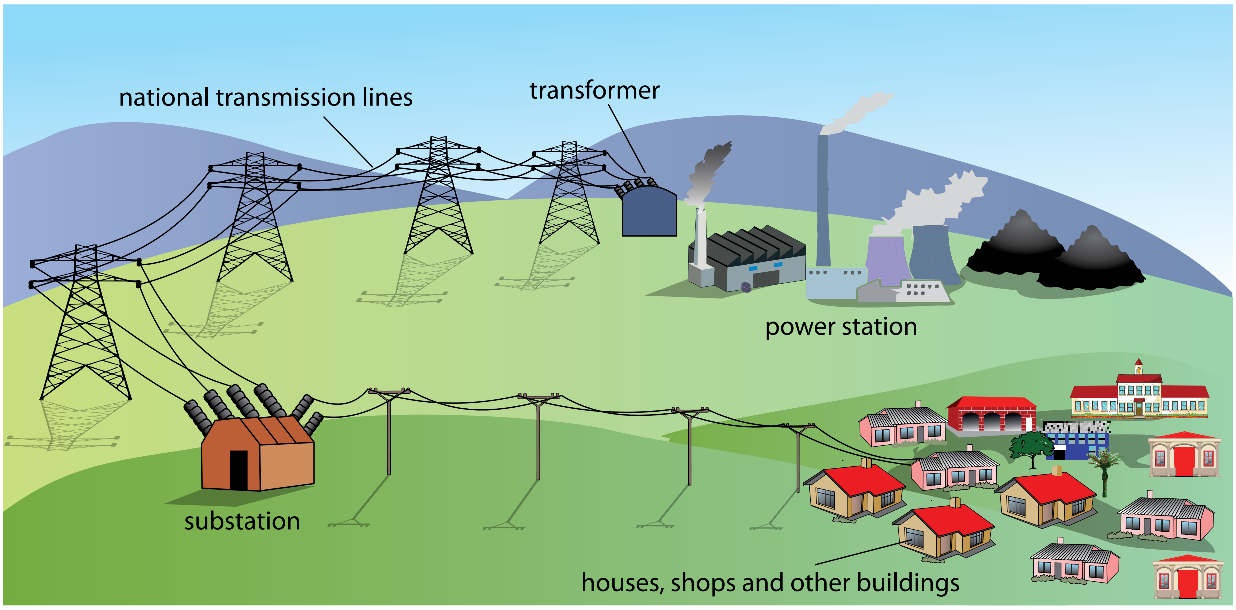
A: **Generation** (this is where electricity is generated)

B: **Transmission** (the electricity enters the power lines of the national grids and is transmitted)

C: **Distribution** (the electricity is distributed from substations to various towns and areas)

D: **Consumers** (this is where the electricity is transferred to useful energy outputs)

Use this information to write the letters A, B, C and D on the diagram of the national electricity grid to label these stages. [4]



14. Why is electricity transmitted through the power lines at high voltages and low current strength? [3]

15. Most household appliances need a voltage of 220–240 V. If the electricity in the transmission lines is very high, how are we able to use it? [2]

16. Why should you protect your computer from power surges? [2]

Total [50 marks]

19 Cost of electrical energy

Key questions

- What is electrical power?
- How do we measure electrical power?
- Do different appliances use different amounts of energy?
- How do we know how much power we are using?
- How do we measure our use of electrical energy?
- How can we work out how much our electricity costs?
- How can we reduce our energy consumption?

Keywords

- electrical power
- watt
- rate

19.1 What is electrical power?

Electrical power is the rate of electrical energy supply. It is the amount of energy supplied per unit of time. In simpler terms, it is how fast the electrical energy is supplied.

Power is measured in **watts (W)**. We can calculate the power using the formula:

$$\text{power} = \frac{\text{energy}}{\text{time}}$$

Energy is measured in joules and so this means that power is the amount of joules supplied in a certain period of time. When doing calculations of power, you need to have the energy measured in joules and time measured in seconds.

1 watt is the same as 1 joule of energy transferred in a second.
(1 watt = 1 joule per second)

There are 1000 watts in 1 kilowatt (kW).

Take note

A rate is a ratio where one quantity is compared to time, for example km/h, which compares distance (in kilometres) to time (in hours).

Different appliances use different amounts of power, depending on their function. All electrical appliances have a stamp or a sticker which indicates the power rating. If you look at your hairdryer or kettle you should find it easily.

Figure 19.1: The label on an electric pan indicating a power rating of 1400 W.

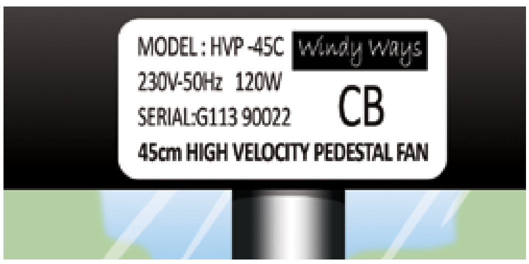


Figure 19.2: The label on a fan indicating a power rating of 120 W.

Which of the above two appliances uses more power to operate?

ACTIVITY Power rating of different appliances

Instructions

1. Depending on your class and teacher, you may be able to walk around the school or your classroom and look at different appliances.
2. You may also have advertisements from newspapers or magazines to study.
3. Write down the power rating of each appliance that you find. Complete the table to record your findings.
4. Some photographs of the labels on various appliances have been given below. Include these power ratings in your table.
5. Answer the questions that follow.

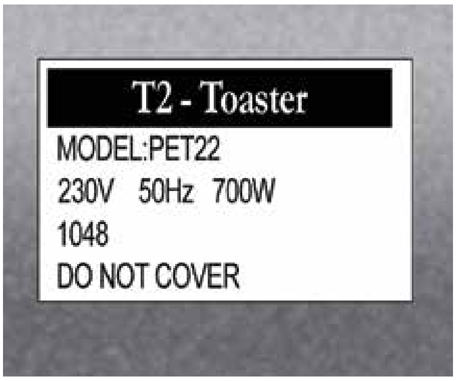


Figure 19.3: The label on the underside of a toaster.

Figure 19.4: The box for an electric beater.

Figure 19.5: The label on the back of a television set.

Figure 19.6: The label on an urn for heating water.

Copy the following table in your exercise books and fill in the power ratings of the various appliances.

Appliance	Power (W)
Toaster	
Electric beater	
Television	
Urn	

Questions

1. Copy the following table in your exercise books and complete the conversions between joules and kilojoules:

joules (J)	kilojoules (kJ)
120	
	34
1 230	
	24,6

Take note

If you are given the amount of energy transferred in kilojoules, you need to convert it to joules to calculate the power in watts.

2. Copy the following table in your exercise books and complete the conversions between watts and kilowatts:

watts (W)	kilowatts (kW)
1 760	
	4,56
25	
	0,56

3. Sequence the appliances listed in your table above from those that use the most power to those that use the least power.
4. Did you record the power ratings of any other appliances which involve heating? What do you notice about the power for these appliances?
5. The following questions involve calculations based on the equation:

$$\text{power} = \frac{\text{energy}}{\text{time}}$$

   a) If 180 kJ of energy is transferred to your bedroom lamp in half an hour, what is the power rating of your lamp? Show your calculations.
   b) 100 000 kJ of energy passes through a power station every minute. What is the power rating of the power station? Show your calculations.

Keywords

- Eskom
- power consumption
- tariff
- tiered tariff
- electrical appliance
- survey
- estimate
- VAT
- lumens
- kilowatt-hour

We pay for the electricity that we use in our homes. How do we calculate how much we pay based on our energy consumption?

19.2 The cost of energy consumption

Eskom charges us for the electrical energy we use in our homes. Eskom charges us based on our energy consumption. The more electrical energy we use to run our household electrical appliances, the more Eskom charges us.

How do we work out how much energy we use? Think for example of using a 1 000 W microwave to warm your food for 1 minute. How much energy is transferred?

We can rearrange the following equation:

$$\text{power} = \frac{\text{energy}}{\text{time}}$$

So that we have:

$$\text{energy} = \text{power} \times \text{time}$$

In this formula, energy is measured in joules, time is measured in seconds and power in watts.

Therefore, to calculate the energy consumption when using a 1 000 W microwave, we can calculate it as follows:

$$\begin{aligned}\text{energy} &= \text{power} \times \text{time}\\ &= 1\ 000\ \text{W} \times 60\ \text{s}\\ &= 60\ 000\ \text{J}\end{aligned}$$

Eskom now wants to work out our energy consumption for the whole month for all the appliances in your home. If 60 000 J of energy were used to warm food for 1 minute, then you can see that we would calculate an extremely large number for our energy consumption for the whole month in joules. This is not practical for electricity bills. We therefore have an alternative unit for energy consumption.

The quantity used for energy consumption is the **kilowatt-hour** (kWh). 1 kWh is the energy used if a 1 000 W appliance is used for 1 hour.

We can calculate the energy consumption of different appliances by multiplying the power rating by the amount of time it was used in hours.

Take note

The kilowatt-hour is a measure of energy consumption as it is calculated by multiplying power in kilowatts by time in hours.

Take note

1 kWh is equal to 3 600 000 joules.

Take note

A kilowatt-hour requires the unit of time to be in hours. You must therefore convert any times that you are given into hours for your calculations.

ACTIVITY Calculating energy consumption

Instructions

1. Complete the following table to convert between seconds, minutes and hours.
2. Answer the questions on power consumption showing your calculations.

Seconds (s)	Minutes (min)	Hours (h)
620		
120		
	127	
	940	
		4,5
		12,25

Questions

1. An oven with a power rating of 3 600 W is used to bake a cake for 1 hour. What is the energy consumption?
2. A kettle with a power rating of 2 200 W is used to boil water for 6 minutes. What is the energy consumption?

3. You use a 3 600 W oven to bake a cake for 1,5 hours. What is the energy consumption?
4. A 120 W light bulb is left on for 2 hours. A 60 W light bulb is left on for 3,5 hours. Which light bulb has a higher energy consumption? Show your calculations.

The cost of energy consumption

We are charged for the number of kilowatt-hours that we use. The cost of energy consumption is charged in cents per kilowatt-hour (c/kWh). The following table gives us the rates at which homeowners are charged for purchasing their power directly from Eskom. As you can see, there are different 'blocks'. The more energy you use per month, the more you pay per kilowatt-hour. This is called a **tiered tariff** system.

Eskom Home Power Tariffs 2013

Different energy consumptions per month	Energy charge (c/kWh)	Environmental levy charge (c/kWh)	Total (c/kWh)
Block 1 [≤ 50 kWh]	67,07	2,28	69,35
Block 2 [51 – 350 kWh]	83,32	2,28	85,60
Block 3 [351 – 600 kWh]	124,74	2,28	127,02
Block 4 [> 600 kWh]	137,03	2,28	139,31

In order to calculate your electricity costs, choose the block that applies to your home. For example, if your home uses 252 kWh of electricity in a month, you fall into Block 2.

Let's calculate the cost if your home used 252 kWh in April 2013.

The first 50 kWh were charged at the lower rate so:
50 × 69,35 = 3 467,5 cents

The rest of the units were charged at the block 2 rate:
(252 – 50) = 202

Therefore, 202 × 85,60 = 17 291,2 cents

So, in total you would have had to pay 3 467,5 + 17 291,2 = 20 758,7 cents

Remember, the tariffs are quoted in cents, not rands, so you need to do a conversion.

20 758,7 ÷ 100 = R207,59

This means that your total bill would have been R207,59 for the month of April 2013.

Take note

The tiered tariff system is used to encourage people to save electricity and use it wisely as the less you use, the less you pay per unit of electricity.

What if you do not want to work out your entire bill, but just want to find out how much one particular appliance was costing you? The average per unit price of electricity in 2013 was 71,65 c/kWh. This is the per unit price we will use for our calculations.

If we want to know how much we will pay for using a particular appliance we would use the following calculation: cost = power rating of appliance × number of hours it was used for × unit price of electricity

Let's try an example calculation for the microwave.

We want to work out the cost of using a small oven (1 500 W) for a total of 1 hour in a day. The following steps outline what you should do.

Step 1: Write down the formula
cost = power rating × time × price

Step 2: List all the given values in a problem
power rating = 1 500 W = 1,5 kW
time = 1 hour
price = 71,65 c/kWh

Step 3: Substitute the given values into the formula to find the unknown
cost = 1,5 kW × 1 hour × 71,65 c/kWh
= 107,475 cents
= R1,07

Step 4: Write down the solution on its own line with the units.
The cost is R1,07 to run a small oven for one hour.

Lets's try another example.

Have you ever notice your fridge start humming after a period of silence? Fridges are extremely energy-expensive electrical appliances. To keep the temperature at a constant cool temperature, fridges contain a thermostat that measures how cool the air is inside your fridge. When the temperature inside the fridge warms beyond a certain point, the thermostat will switch on the energy-expensive compressor and condenser. Fridges are specially insulated to keep cool air inside, and the energy demands of a fridge vary greatly depending on how often the doors are opened, and what is kept inside.

Imagine now, that you left the fridge door open by accident as you rushed to school and didn't notice until the next day! We now want to work out how much it costs to run a fridge with a power rating of 2 200 W for a day.

cost = power rating × time × price
power rating = 2 200 W= 2,2 kW
time = 24 hours
price = 71,65 c/kWh

cost = 2,2 kW × 24 hours × 71,65 c/kWh
= 3 783,12 cents
= R37,83 per day

The cost is R37,83 to run a fridge for one day.

Take note

Remember that we can find the power rating for an appliance on the labels. Did you notice that both of the labels indicated power in watts (W) and not kilowatts (kW)? That means that if you use them to calculate the cost of electricity you must first convert them to kilowatts.

ACTIVITY Calculating the cost of energy consumption

Instructions

1. Use the information in the following table to answer the questions that follow.
2. Use a cost per unit of electricity of 71,65 cents/kWh in all your calculations.

Appliance	Power rating
Microwave oven	1 360 W
Conventional oven	6 000 W
Television	105 W
Geyser	4 800 W
Incandescent light bulb	100 W
Fluorescent light tube	40 W
Vacuum cleaner	1 600 W
Washing machine	2 200 W

Questions

1. Imagine that your family has used 320 kWh of electricity this month. Calculate the cost of the 320 kWh.
2. A potato takes about 1 hour to cook in a conventional oven. In a microwave it takes approximately 12 minutes. Calculate the cost of cooking the potato in each appliance and write down which one is the cheaper option.
3. Which light bulb is cheaper to run for an hour, the incandescent light bulb or the fluorescent light bulb? Justify your answer with a calculation.
4. If you have a prepaid electricity voucher for R15, how long could you watch TV?
5. You need to vacuum your room and it takes you 30 minutes to do this. What does this cost?
6. It takes the geyser to two and a half hours to heat water from 20 °C to 65 °C. How much does it cost to heat the water?
7. What alternative appliance could a family use to heat water which would not demand such a high use of electricity?

Did you know?

The actual cost per unit depends on whether or not you buy your electricity directly from Eskom or from your local municipality. In fact, the tariff differs from municipality to municipality as well.

We can see that different appliances have different power ratings and so require more electricity to run. This means that some appliances are more expensive to run than others. An incandescent light bulb, for example, is more expensive to use than a fluorescent light bulb. If you remember, an incandescent light bulb loses most of its energy as heat, instead of light.

Do you know how much electricity your family consumes? Let's find out.

ACTIVITY Home survey

Instructions

1. List, in a table similar to the one above, all the electrical appliances in your home. The 4 column headings should read: Appliance, Power rating, Number of hours and Cost.
2. Estimate the number of hours for which each appliance is used on a typical day.
3. Calculate the daily cost of each appliance, using 71,65 c/kWh as the unit price. Remember to count the number of light bulbs you have in your home and multiply that by the cost for 1 light bulb.

Questions

1. What was your total estimated electricity cost for one day?
2. If there are 30 days in an average month, what would your estimated monthly bill be?
3. Can you think of any ways that your family could reduce the amount of electricity you use?

There are many different ways in which we can try to conserve electricity in order to save money. Our choice of light bulbs can affect our electricity bills. LED light bulbs are the most energy efficient. They have lower power ratings than normal light bulbs, but most of their energy is transferred as light and very little as heat (unlike incandescent light bulbs). Light transmitted from the bulb is measured in lumens.

ACTIVITY Comparing the energy efficiency of different light bulbs

Instructions

Read the information in the table and use it to answer the questions.

	LED	Compact Fluorescent Light bulbs (CFLs)	Incandescent light bulbs
Example			
Average life span (in hours)	50 000	8 000	1 200
Watts	8	15	60
Lumens	800	800	800

Did you know?

LEDs and incandescent light bulbs also do not contain mercury, which is poisonous, while fluorescent light bulbs do.

1. Which of the three light bulbs will last the longest?
2. Which of the three light bulbs has the highest power rating?
3. How do the three light bulbs compare in terms of how much light they can provide?
4. Calculate how much it would cost to run each light bulb in a house for 5 hours a day for an entire year (365 days). Use 71,65 cents/kWh.
5. Which light bulb would you choose to use? Explain your choice.
6. Which bulb is the best for the environment? Explain your choice.

Using light bulbs which use less electricity can have a knock-on effect. If everyone is using less electricity, then there is less demand for electricity to be produced in our coal-powered power stations in South Africa. If less electricity is produced then fewer fossil fuels are burnt, and this would lead to a reduction in the production of excess greenhouse gases.

There are many important and rewarding careers in the electrical energy sector.

Let's take some time to research some of them.

ACTIVITY Career research

Instructions

1. Divide into groups of 3.
2. Use the library or the internet to research a career from the following list:
   a) electrician
   b) electrical engineer
   c) IT specialist.
3. Try to find information about what someone in that career spends their day doing and what qualifications are needed to do the job.
4. Report your findings to the class.

Questions

1. Write down the career path that you found the most interesting.
2. What did you like about that particular career path?

Summary

Key concepts

- Electrical power is the rate of energy supply, measured in watts (W).
- 1 watt of power is equal to 1 joule per second.
- Different appliances use different amounts of power.
- Electrical energy is sold in units called kilowatt-hours (kWh), a measure of the energy consumption.
- 1 kWh is the energy used by a 1000 W appliance in 1 hour.
- Eskom sells electricity using tiered tariffs to discourage people from using too much electricity.
- We can calculate the cost of using a single appliance by multiplying the power rating by the number of hours and the unit cost of electricity.

Concept map

Design your own concept map to summarise this unit on the cost of electrical energy.

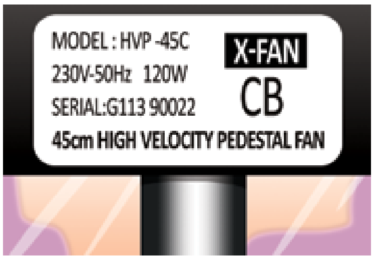
Cost of electrical energy

Revision

1. What is the power rating on the following two appliances? [2]

a) A frying pan

b) A fan



2. Refer to the table of power ratings for common appliances. List the appliances in sequence from those that use the least power to those that use the most. [2]

Appliance	Power rating (W)
Stove	3 600
Microwave	1 200
Washing machine	2 200
Kettle	2 200
Fridge	230
Toaster	750
Energy-saver globe	40
Incandescent light bulb	120
Vacuum cleaner	1 600

3. What is electrical power? Explain in your own words. [2]

4. Explain what is meant by 1 watt of power. [2]

5. What does it mean that a stove has a power rating of 3 600 W and a microwave has a power rating of 1 200 W? Compare these two appliances in terms of the energy supplied. [3]

6. Copy and complete the following table in your exercise books. [8]

Joules (J)	Kilojoules (kJ)
145	
	134
1 650	
	32,12
Watts (W)	Kilowatts (kW)
1 850	
	3,79
32	
	0,485

7. An electric iron is rated at 1 500 W. If the iron is used for 3 hours every day, find the number of units of electrical energy it consumes in the month of February. [3]

8. An electric kettle is rated at 1 000 W. If it is used for 1 hour every day, find the number of units of electrical energy it consumes for the month of August. [3]

9. Your house's electricity meter reading in March was 3 456 and in April it was 4 566.

a) How much electrical energy did your household use in that one month period? [2]

b) If electrical energy is charged at 71,65 c/kWh, what will your bill be for that one month period? [3]

10. A 120 W electric blanket is left on for 8 hours.

a) How many kilowatt hours of electrical energy is used by the blanket? [3]

b) If the unit cost of electricity is 71,65 cents, what is the cost, in rands, of using the electric blanket for 8 hours? [3]

11. A 2600 W kettle in a school staffroom is used 8 times a day for five minutes each time.

a) What is the total time that the kettle is switched on during each 5-day school week? [2]

b) How much energy is consumed to run the kettle for this period (in kilowatt hours)? [2]

c) If the cost of a unit is 71,65 cents per kilowatt, what is the cost of running the kettle for this period? [3]

12. If you had a prepaid electricity voucher with a value of R35, calculate the following.

a) How long could you run a 230 W fridge for if electricity costs 71,65 cents per kWh? [5]

b) How long could you run six 60 W incandescent light bulbs? [5]

13. Which light bulb, 15 W CFL or 8 W LED, would you choose to use? Explain your answer. [3]

14. A tumble dryer has a power rating of 4 500 W. How long did it take to dry a load of wet washing if electricity costs 71,65 cents per kWh and the cost of running the dryer is R4,84? [6]

Total [62 marks]

Glossary

acceleration the rate of change of velocity with time, as an object speeds up or slows down

alloy a mixture of different metals; the alloy will have properties from the different metals in the mixture

alternative energy a form of energy which is different to the main energy source used in the country

armature any moving part of an electrical machine in which a current is produced by a magnetic field

attraction a force which causes objects to move towards each other

battery a group of two or more electric cells connected together

circuit breaker like a fuse, a circuit breaker switches off the current in the case of an electrical fault

compression a force which attempts to flatten or deform (squash) an object

conductor a substance which allows heat, sound or electric charge to pass through it easily; a good conductor allows free passage whilst a poor conductor allows partial passage

contact force objects are in contact with each other and exert forces on each other

deformation to cause an object to change its shape

delocalised not limited to a particular place, free to move

earth leakage is a circuit breaker which will switch off all the electricity to a household or business if there is an electrical fault

earthing a circuit is earthed when there is a direct connection to the ground; this connection is usually through the earth wire in an electrical socket

electric cell a system in which chemical reactions occur to generate electricity

electric charge the physical property of matter that causes it to experience a force when close to other electrically charged matter; there are two types of electric charges positive and negative

electric current the rate of flow of charge in an electric circuit

electrical appliance an electrical device

electrical power the rate at which energy is transferred

electrode an electric conductor used to make contact with a non-metal part of the circuit, such as a copper coin or iron nail in a lemon, or zinc or copper plates in a cell

electrolyte a special type of solution which is able to conduct electricity

electrostatic force force of attraction or repulsion between electrostatic charges

Eskom Electricity Supply Commission of South Africa

estimate a value which is not exact

excess more than is needed

field forces non-contact forces

force a push or a pull exerted on an object by an agent

free-fall when the only force acting on an object is the gravitational force

friction a force that opposes or tries to oppose the motion

fuse a safety device which switches off an appliance if the current in the circuit is too strong

generator a machine which produces an electric current by rotating a conducting coil in a magnetic field

gravitational acceleration a measure of how an object changes its speed every second; on Earth gravitational acceleration is 9,8 m/s^2

gravitational force force of attraction between two objects because of their masses

half cell a setup that consists of an electrode surrounded by an electrolyte; for example, a zinc half cell could consist of a zinc metal plate (the electrode) in a zinc sulphate solution (the electrolyte)

illegal forbidden by law; against the law
input energy the energy that enters a system and is altered by the system to produce an output energy

kilowatt-hour a unit of energy that is useful for measuring energy consumption

LED light emitting diode (a diode is an electrical component that allows current flow in one direction only and blocks the flow in the opposite direction)
lumens the units of measurement for light output from an LED bulb

magnet a material with a strong magnetic field around it
magnetic force a force exerted by a magnet on a ferromagnetic material
magnetic material a material which is strongly attracted to a magnet
mass a measure of the amount of matter making up an object
motor a device that can convert electrical energy into mechanical energy

national electricity grid the network of cables, pylons and transformers which transfer electricity throughout the country
net force the overall result of several forces acting on the same object at the same time
newton the unit of measurement of a force
non-contact force a force which can act over a distance without touching the object experiencing the force
normal force the reaction force of the surface to an object
nuclear fission when an atomic nucleus is split to produce two separate atomic nuclei; a large amount of energy is released during the separation
nuclear fusion when two small atomic nuclei are combined to produce one atomic nucleus; a large amount of energy is released as the nuclei are fused together
nuclear power the use of nuclear reactions to generate useful heat and electricity

ohm unit of measurement for resistance (Ω)
output energy the energy that a system produces due to an input energy

potential difference the difference in potential energy per charge between two points in an electric circuit
power consumption the amount of electrical power used by an appliance or household
power station a system for generating electricity
power surge a sudden increase in the voltage somewhere in an electric circuit which can disrupt the power supply
provision supplying something
pylon a large vertical steel tower which supports electrical power cables

radioactive the spontaneous release of a stream of particles or electromagnetic waves from an unstable nucleus
rate a ratio where one quantity is compared to time, for example km/h or m/s
repulsion a force that causes objects to move apart
reset to start something again from its start
resistance the opposition to the flow of electrical current through a material
resistor an electrical component in a circuit that opposes the flow current in the circuit
rheostat a variable resistor. The amount of resistance offered by the rheostat can be adjusted

salt bridge a device that is used to connect the two half cells in an electric cell so that their electrolytes do not mix
Sankey diagram a Sankey diagram is used to show the difference between input and output energy
series circuit a circuit which provides only one path for electric current
short circuit a short circuit is a low resistance path which causes all of the current to flow through the low resistance path and not through the rest of the circuit
speed the rate of change of distance of an object
survey information gathered from a wide range of people

tariff the amount of money charged for every unit
tension the force transmitted through a rope, string or chain. It is a contact force

tiered tariff the amount of money charged changes if more units are used; there are different levels of tariffs

transformer an electrical device to transfer energy between two parts of a circuit in the national electricity grid

transmission lines power cables which transmit electricity across the country

turbine a machine which consists of a large wheel that is made to turn by using steam

variable resistance resistance which is able to be changed

VAT Value Added Tax; this is a tax imposed by the government on all consumable goods

velocity the rate of change of the position of an object, specifying the object's speed and direction

voltage the difference in potential energy per charge between two points in an electric circuit

watt unit of measurement for power; 1 watt is 1 joule per second

weight the gravitational force of attraction exerted on an object by the Earth (or Moon or any other planet)



STRAND

Planet Earth and Beyond












20 The Earth as a system

Key questions

- What are the different parts of the Earth?
- How do these parts interact?
- Why can we refer to the Earth as a system?

Keywords

- biosphere
- hydrosphere
- lithosphere
- atmosphere
- yield
- pollution

In Grade 7 you learnt about the relationship between the Earth and the Sun and the importance of the Sun for life on Earth. In Grade 8 you looked at the relationship between the Earth and other planets in our solar system. This year we will look at the Earth as a system and all the parts of this system.

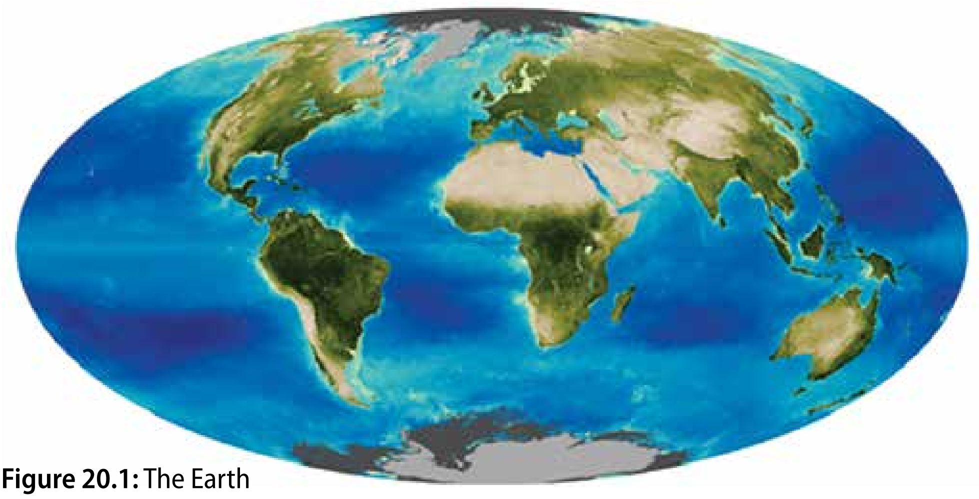


Figure 20.1: The Earth

20.1 Spheres of the Earth

You have learnt about systems and cycles throughout your studies of Natural Sciences over the past 5 years. For example, you have learnt about the life cycle of a butterfly, energy systems in food webs or electric circuits, and the solar system. Much of what we observe in nature is part of one or many systems or cycles. In this unit we are going to learn about the Earth as a closed system and the four different parts (spheres) of this system.

Earth's four spheres

The Earth is made up of four systems, or spheres. The biosphere (life), the lithosphere (land), the hydrosphere (water) and the atmosphere (air). On Earth land, water, air and life interact with one another. As humans, we are also part of this interaction. There is a fine balance between these four systems – if the one becomes altered, it has an effect on all the others.

The Biosphere

The biosphere includes all life on Earth – plants, animals and humans. Most of what is studied in *Life and Living* is about the biosphere. The biosphere also includes life in the oceans, and under the soil.

Did you know?

Scientists built a self-contained facility called Biosphere 2, to study the interactions between living things and the environment.

For example, bacteria living on decaying plant material and the smallest sea creatures and plants are part of the biosphere. Almost all the life on the planet is found between 3 metres below the surface of the Earth, up to 30 metres above the ground, and in the top 200 metres of the oceans.

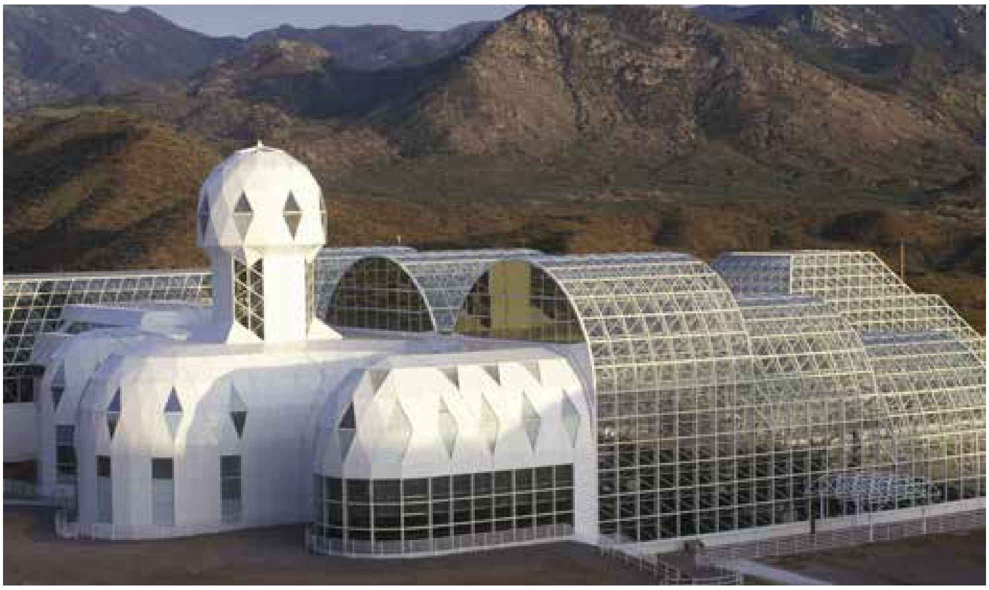
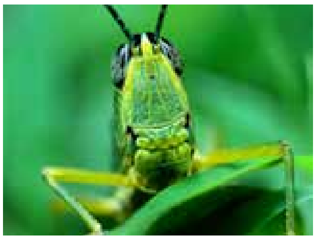


Figure 20.2: Biosphere 2 is a man-made research centre in America, in the Arizona Desert, where scientists have built a large enclosed artificial biosphere.

All living things and their habitats form part of the biosphere. The following photographs provide examples of different organisms in their habitats, living in the biosphere.



Grasshopper.

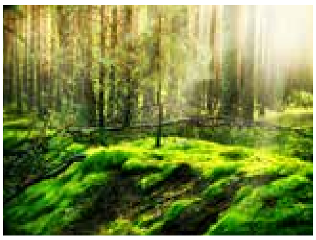
Dolphins in the sea.

Escherichia coli bacteria.

Sugarcane fields

An earthworm in the soil.

Limpets in a rock pool.



Moss in a forest.

Mushrooms in a field.

Phytoplankton in the sea.

Children at school.

A blue crane on the river's edge.

Figure 20.3: Organisms in their habitats.

The hydrosphere

The hydrosphere includes all water on the planet – the oceans, lakes, rivers, groundwater, rain, clouds, glaciers and ice caps. About 70% of the surface of the Earth is covered with water. The oceans contain most of this water, with only a small portion of it being fresh water. All the water on Earth forms part of the hydrosphere.

An iceberg.

A river.

Clouds.

The sea.

Figure 20.4: All the water on Earth forms part of the hydrosphere.

Did you know?

The names of the four spheres are derived from the Greek words for stone (*litho*), air (*atmo*), water (*hydro*), and life (*bio*).

The atmosphere

The atmosphere includes all the air above the surface of the Earth all the way to space. All the gases that are present in the air are included in the atmosphere. Most of the atmosphere is found close to the surface of the Earth, where the air is most dense. The air contains 79% nitrogen, less than 21% oxygen, and a small amount of carbon dioxide and other gases. We will look more closely at the atmosphere later on in this unit.

Did you know?

The first person to use the term 'biosphere' was the geologist Eduard Suess in 1875 when he wrote a definition for the biosphere as 'the place on Earth's surface where life dwells'.

Figure 20.5: The top of Earth's atmosphere.

Figure 20.6: The region of space occupied by Earth's atmosphere.

The lithosphere

The lithosphere includes the Earth's crust and the upper part of the mantle. All mountains, rocks, soil and minerals included in the Earth's crust are part of the lithosphere. Even the seafloor is part of the lithosphere, because it is also made up of sediments of sand and rock. We will look more closely at the lithosphere in the next section.

All the rocks, soil and sand on Earth form part of the lithosphere, as shown in the following photographs.

Rock formations.

Sand dunes.

Soil.

Mountains.

Minerals.

Seafloor.

Figure 20.7: All the rocks, soil and sand on Earth form part of the lithosphere.

The following collage shows the four spheres of the Earth.

Figure 20.8: The four spheres of the Earth.

Did you know?

The total mass of the hydrosphere is approximately 1,4 × 10 tonnes! The volume of one tonne of water is approximately 1 cubic metre (this is about 900 A4 textbooks).

Take note

The word 'sphere' is used in Mathematics to describe a round shape. The Earth has the shape of a sphere. When we talk about the four spheres of the Earth, we do not mean a ball shape, but rather we refer to the touching and overlapping layers within Earth.

ACTIVITY Exploring the spheres of the Earth

Instructions

1. Find an example on your school ground or at home where all four spheres are present, for example a tree growing in your garden.
2. Describe the location and what you have included in your example.
3. Identify each of the spheres in a short paragraph.
4. Your teacher might also ask you to present your example as a poster with illustrations and short descriptions, identifying each sphere.

Interaction between the spheres

The different spheres of the Earth are closely linked and interact with each other. Let's investigate this in the following activity.

ACTIVITY Interaction between the spheres

Instructions

1. Study the photo of thorn trees on the savannah.
2. Answer the questions that follow.

Figure 20.9: Thorn trees.

Questions

1. Identify the four different spheres of the Earth in the example.
2. What will happen if the trees do not get enough water?
3. Describe the interaction between the hydrosphere and the biosphere in this example.
4. What will happen if the carbon dioxide levels change dramatically?
5. Describe the interaction between the atmosphere and the biosphere in this example.

6. Is there any interaction between the lithosphere and the hydrosphere in this example?
7. Use the example you have chosen in the previous activity (Exploring the spheres of the Earth) and describe three different interactions between the different spheres.

There is an interaction between the tree and other plants (biosphere) and the air (atmosphere) as they use carbon dioxide from the air during photosynthesis and give off oxygen. There is an interaction between the plants (biosphere) and the soil (lithosphere) when they absorb water (hydrosphere) and minerals (lithosphere) from the soil (lithosphere). The soil is also used to anchor the plants. The tree (biosphere) produces flowers and then fruit. Animals eat the fruit and the leaves of the trees and other plants.

ACTIVITY Identifying the interactions of the spheres on Earth

Instructions

1. The following picture is of the dam wall that was built for the Gariep Dam on the border between the Free State and the Eastern Cape. The wall is used to generate hydroelectric power, as we learnt in *Energy and Change*.
2. Answer the questions below.

Figure 20.10: Gariep Dam in the Orange River.

Questions

1. Discuss in pairs all the possible interactions between the spheres of the Earth.
2. Work on your own to complete the following map. Write a description of the interaction on each of the arrows. One example has been done for you:

Take note

Think back to the definition of a system which we discussed in Energy and Change. A system is a set of parts working together where a change in one part affects other parts. This also applies when talking about the Earth as a whole system.

There is an interaction between the lithosphere and the atmosphere in that the wind (moving air) will cause erosion of the rocks surrounding the dam. Where possible include more than one interaction on the arrow linking the spheres.

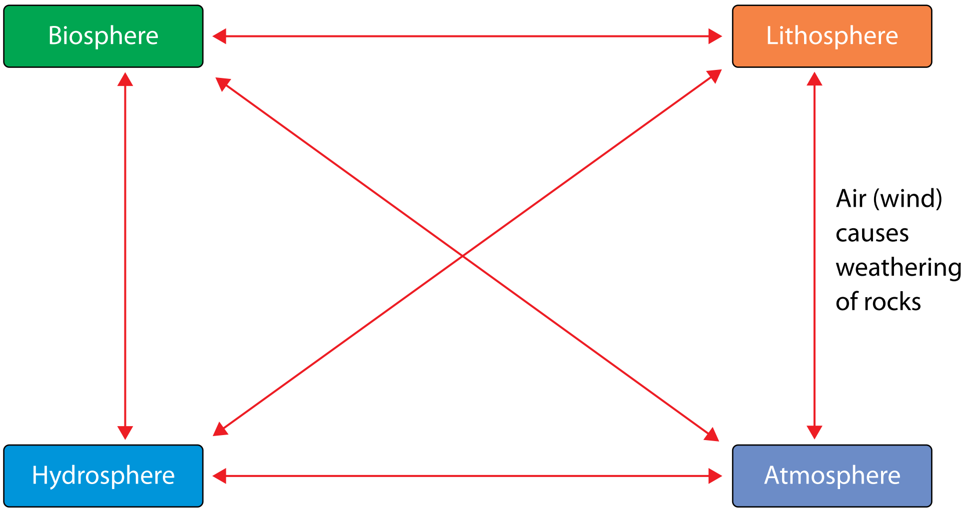


Figure 20.11: Interaction between the lithosphere and the atmosphere

The pictures below show how crops are harvested. The process of growing and harvesting crops are good examples of how the different spheres of the Earth interact. The hydrosphere provides water for the crops to grow. The soil provides minerals for the crops to give a good yield. The air provides carbon dioxide to the crops for photosynthesis and in return the plants give off oxygen to the air. The people (biosphere) make use of the materials from the lithosphere to build machinery or make sharp tools (metal from the lithosphere) for cutting wheat for example. Many interactions play a role in ensuring a healthy crop.

Figure 20.12: Growing wheat in fields.

Figure 20.13: A harvester cutting and gathering the wheat.

Upsetting the balance in the ecosystem

Let's look at our example of the thorn trees in a savannah ecosystem again. If the balance in any part of the system is changed, it affects the whole system. For example, if there is not enough water, the tree won't flourish and produce fruit (in this case, seed pods). If the air is polluted, it affects the availability of carbon dioxide to the tree. If there are not sufficient minerals in the soil, the plants cannot grow.

ACTIVITY Upsetting the balance

Figure 20.14: Interactions between the spheres of Earth.

Questions

1. Identify the four spheres of the Earth from the photograph.
2. Predict what the influence of the following scenarios on each sphere would be:
   a) Large deposits of coal are found here.
   b) The average temperature rises considerably as a result of global warming.
3. What is our responsibility as humans in the two scenarios in the previous question?

As you have seen in the activity, all the spheres on Earth interact closely with each other. When there is a change in one of the spheres, the others are also affected. The changes can be due to natural causes, for example floods or earthquakes, but more often these changes are due to human influence. As humans we have a responsibility to understand the interactions on Earth and to look after the planet so that future generations will be able to live on Earth.

Summary

Key concepts

- The Earth is a complex system where all the parts (spheres) interact.
- The Earth consists of four spheres: the lithosphere, the hydrosphere, the atmosphere and the biosphere.
- The lithosphere consists of solid rock, soil and minerals.
- The hydrosphere consists of water in all its forms.
- The atmosphere is the layer of gases around the Earth.
- The biosphere consists of all living plants and animals and their
- interactions with the rocks, soil, air and water in their habitats.

Concept map

Draw your own concept map for this unit.

Spheres of the Earth

Revision

1. Identify the four spheres of the Earth. What is each sphere composed of? List only three components for each. [8]

2. How does the lithosphere interact with the hydrosphere, biosphere and atmosphere in the photographs below? [6]

A large open copper mine.

A sand dune in the Namib Desert

3. You have a wet towel which you hang outside to dry. Describe and compare the interaction between the hydrosphere (water droplets on your towel) and the atmosphere (temperature and air movement around you), if you live in a dry area, and if you live in a humid area. [2]

Total [16 marks]

21 The lithosphere

Key questions

- What does the centre of the Earth look like?
- Why is it important to know about the structure of the Earth?
- Why is there so much variety in the rocks you see around you?
- How do rocks form?
- Why do we need to know about rocks?
- Why are rocks important?

Keywords

- geosphere
- lithosphere
- continental crust
- oceanic crust
- crust
- mantle
- core
- composition

The Earth is a system consisting of many parts. In the previous unit we looked at how these parts or spheres interact. In this section we are going to look more closely at one of these spheres, namely the **lithosphere**.

21.1 What is the lithosphere?

On Earth, water, air, stone and life interact. Let's think about the stone part of this statement. Where on Earth do we find stone? What are the different forms of stone that are found on Earth? Why is it important to know about this part of the Earth? Let's investigate these questions.

Sand.

Pebbles.

Stones.

Large boulders.

Figure 21.1: Examples of different forms of stone.

ACTIVITY Investigating stones

Materials

- magnifying glasses
- hammers
- paper towel
- samples collected, as described below

Questions

1. Collect the following items and bring them to school: sand, pebbles, a small stone/rock, a larger rock.
2. When you collect sand, stones or rock, look for the samples that look interesting and different and bring these to class.
3. Find at least four different items from different locations.
4. Study the different samples and complete the following table. If you have magnifying glasses available, use these to study the detail of the different samples.
5. Wrap some of the samples in paper towel and see if you can crush them with a hammer. Your teacher might instruct you to do this outside.

	Location Describe where you have found your sample.	Shape and colour Describe the size, shape and colour	Texture Describe the texture and hardness.	Composition Is it made of more than one material? Describe what it is made up of.
Sand				
Pebble				
Small stone/rock				
Larger rock				

In the last investigation you would have seen a lot of variety amongst the types of stone that are found in the area around your school. There is variation in shape, colour and texture amongst the different rocks on Earth.

The lithosphere consists of all the mountains, rocks, stones, top soil and sand found on the planet. In fact, it also includes all the rocks under the sea and under the surface of the Earth. The lithosphere is found all around us and we interact quite closely with it every day.

Inside the Earth

The lithosphere is considered the outer layer of the Earth. The Earth is made up of concentric layers called the crust, the mantle and the core.

Take note

All the 'Keywords' listed in the boxes in the margin are defined in the Glossary at the end of this strand.

Take note

Concentric objects share the same point as their centre.

Imagine that we cut away a slice of the Earth, as shown here:

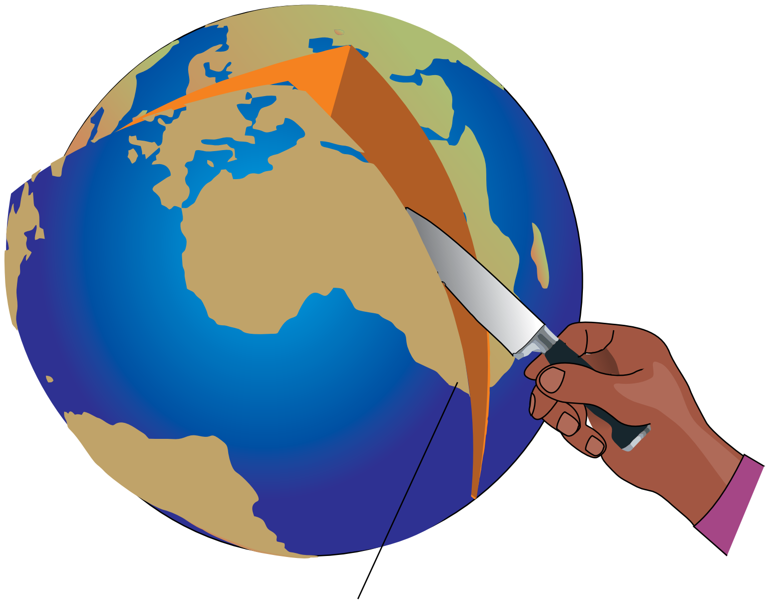


Figure 21.2

Inside, we would then be able to see the layers of the Earth, as shown in the next diagram:

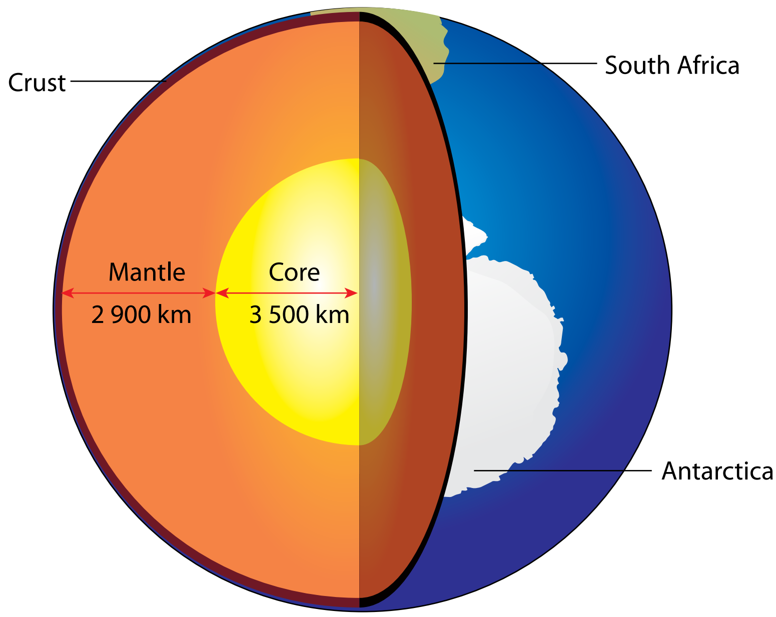


Figure 21.3

Did you know?

The centre of the Earth is 6 371 km deep.

The core has two parts, the **inner core** which is solid and the **outer core** which is liquid. The mantle can also be divided into two parts, the **lower mantle** and the upper mantle. Some parts of the crust are found under the oceans. This is called the **oceanic crust**. Other parts of the crust form part of the continents and is called **continental crust**.

The brittle upper part of the mantle and the crust form the **lithosphere**. The lithosphere, the mantle and the core are sometimes called the **geosphere**. The geosphere is also one of the parts of the Earth, just like the **hydrosphere**, **atmosphere** and **biosphere** that you learnt about in the previous unit.

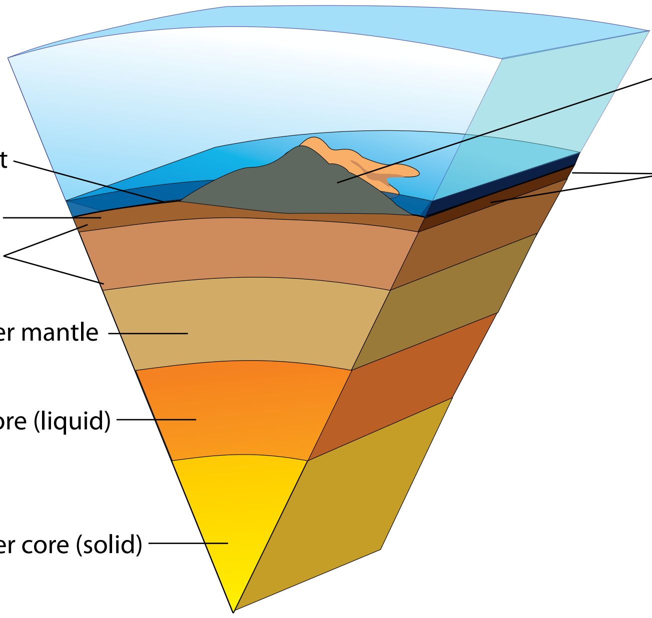


Figure 21.4: The layers inside the Earth.

ACTIVITY Build a 3D-model of the Earth

Instructions

1. Use recycled material and modelling clay to build a three-dimensional model of the inside of the Earth.
2. All the layers of the Earth need to be included and accurately labelled on your model.
3. Write a one-page summary on the layers of the Earth. Read about each of the layers to be able to answer the following questions in your write-up. You can use the internet and library books, or ask knowledgeable people in your community.
   a) Thickness of each layer
   b) State of matter
   c) Temperature
   d) Composition (what it is made up of).

Did you know?

The temperature of the Earth's inner core is about the same temperature as the surface of the Sun, more than 5 000 °C.

ACTIVITY The layers inside the Earth

Instructions

Use all the words in bold in the previous section to complete the following map:

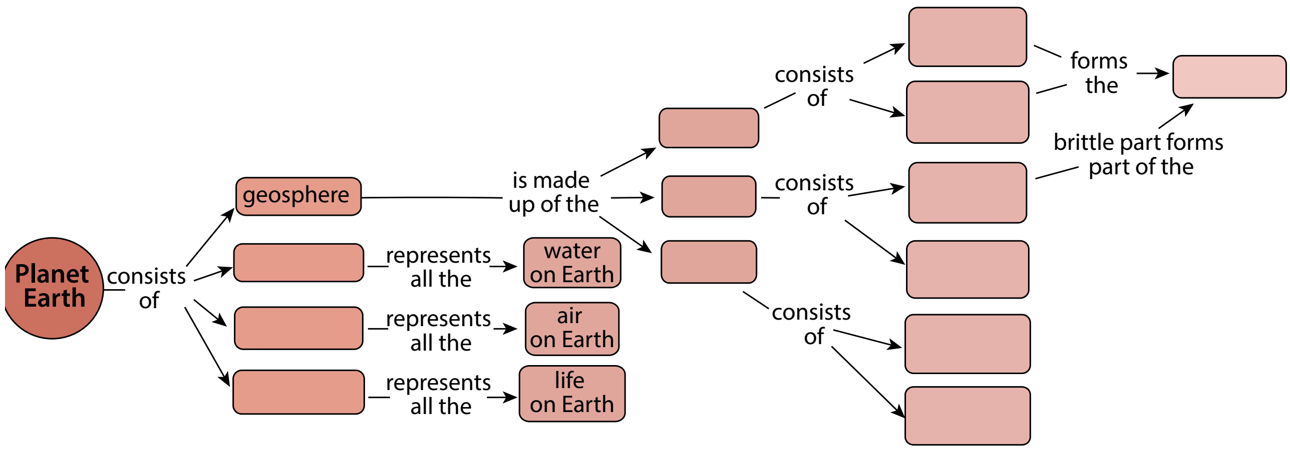


Figure 21.5

In the first activity of this unit we collected different rocks. Why are there different types of rocks, and why do they look different? These are the questions we will answer in the next section.

21.2 The rock cycle

Keywords

- cycle
- weathering
- compaction
- erosion
- deposition
- melting
- cooling
- solidify
- sedimentary rock
- metamorphic rock
- igneous rock
- sediment
- sedimentation
- cementation

In previous grades you learnt about the water cycle. A cycle is a combination of processes that take place in a certain sequence and which repeat over and over again from the beginning. Processes in a cycle do not stop and are therefore said to be continuous. For example, the **water cycle** which is part of the biosphere describes how water forms clouds, rain, rivers and clouds again.

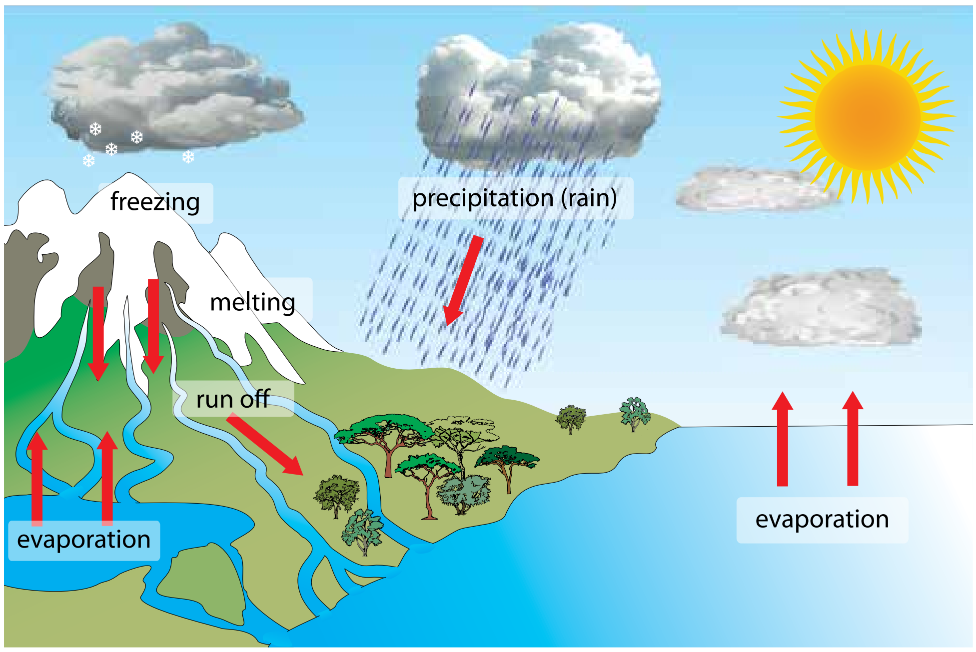


Figure 21.6: An example of a cycle with which you are familiar is the water cycle.

The **carbon cycle**, which takes place as part of the biosphere, describes the movement of carbon through carbon dioxide, fossil fuels and carbohydrates.

The **rock cycle** is part of the lithosphere and it describes how rocks change from one form into another and eventually back into the first form.

How does the rock cycle work?

Rocks on Earth are divided into three broad categories:
1. sedimentary rocks
2. metamorphic rock
3. igneous rock

This classification is based on where the rocks were formed. The following diagram summarises the rock cycle.

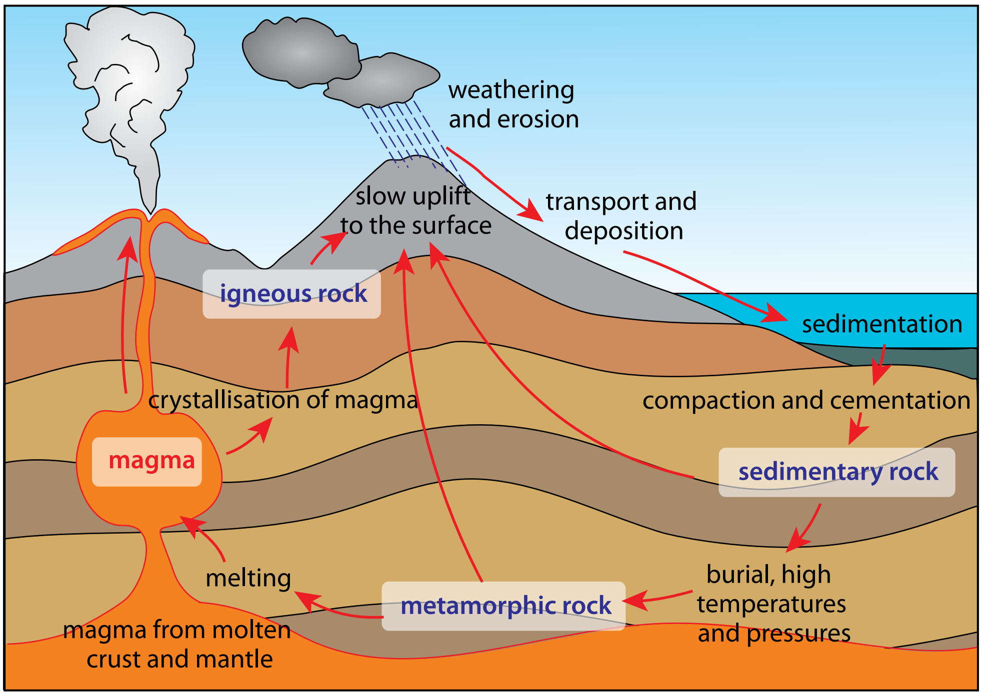


Figure 21.7: The rock cycle.

> **Take note**
>
> Not all rock on Earth is recycled. Thousands of tons of rock fall to Earth from space every year.

The rock cycle is a natural continuous process in which rocks form, are broken down, and re-form again over long periods of time. The process can be described as follows:

- Wind, water, heat and cold cause the weathering of rocks on the surface of the Earth. The rocks are broken up into smaller and smaller pieces and form sand.
- Wind and water wash the sand and small stones away and deposit them as **sediments** into lakes and the ocean. This process is called **deposition**.
- The sediments settle at the bottom of the oceans, lakes and rivers. Over time they get covered with more layers of sediment. The pressure from the additional layers causes the sediments to compact and solidify to form sedimentary rock.
- The sedimentary rock may be buried deeper and deeper beneath the surface of the Earth through movement in the Earth's crust (where oceanic plates and continental plates meet). The rocks can also be pushed deeper (subducted) into the Earth. As the rocks move deeper into the Earth, temperature and pressure increase.

Take note

Heat causes expansion of rocks and cold causes contraction.

Did you know?

A geologist is a scientist who studies the Earth, the rocks from which it is made, and the processes and history that have shaped it.

Take note

Magma and lava are both molten rock, but refer to different locations. Magma is molten rock that forms beneath the Earth's surface. When magma erupts out of a volcano onto the surface, it is referred to as lava.

- Rocks become more compact as processes of compaction and cementation occur. As the chemical compounds in the rocks change, due to heat and pressure, metamorphic rock is formed.
- Over time the metamorphic rock can move deeper into the Earth, melt, and become **magma**.
- Magma moves towards the surface of the Earth through volcanic pipes. The hot magma cools slowly on its way to the surface and forms **igneous rock**. Magma can also break through the surface as lava in volcanoes. In this case, the lava will solidify quickly on the surface to form igneous rocks. Igneous rock can form in the crust or on the surface.
- Igneous rocks get eroded by wind and water and the whole process starts again.

Metamorphic rock is formed deeper under the surface and becomes exposed to the surface only when the layers above it are removed by erosion. Igneous rock, just like sedimentary rock, can move deeper into the Earth and form metamorphic rock because of the increase in pressure and temperatures. As you can see in the previous diagram, rocks of all types may move down through the mantle, melt, and mix with magma. The Earth's crust is continually recycled. This is why we refer to the process as the **rock cycle**.

ACTIVITY Summarising the rock cycle

Questions

1. Copy and complete the diagram in your exercise books by filling in which type of rock belongs where: Sedimentary rock, Metamorphic rock, Igneous rock.

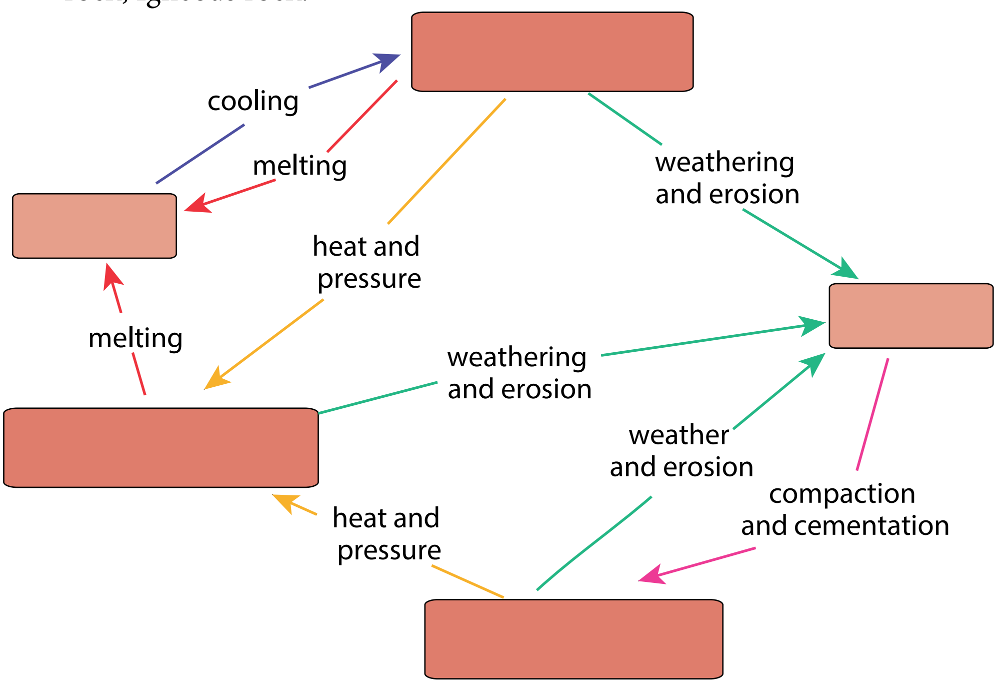


Figure 21.8

2. Name the process by which igneous rock is formed.
3. Which type(s) of rock form sediment?
4. What conditions are needed for metamorphic rock to form?
5. Explain what 'weathering and erosion' of rock mean.

6. Explain what 'compaction' means.
7. What type of rock is formed through compaction?
8. What is magma? Explain the role of magma in the rock cycle.

ACTIVITY Explaining the rock cycle

Instructions

Write a paragraph to explain the rock cycle in your own words. Start the explanation with the formation of igneous rock. Use full sentences and include the following key words in your write-up.

The words can be used more than once, and you should add your own keywords as well. You should also include a labelled diagram in your write-up.

Keywords

- melting
- deposition
- erosion
- cooling
- compact
- temperature
- pressure
- metamorphic rock
- igneous rock
- sedimentary rock

We are now going to take a closer look at each of the three main types of rocks.

Sedimentary rock

Sedimentary rocks are formed when layers of sediment solidify over time. Sediments are layers of particles from pre-existing rock or once-living organisms, for example, shells. Rocks on the surface of the Earth are weathered by expansion and contraction due to changes in temperature, wind and water, and also by erosion caused by animals. Bigger rocks break up into smaller and smaller particles through the process of erosion.

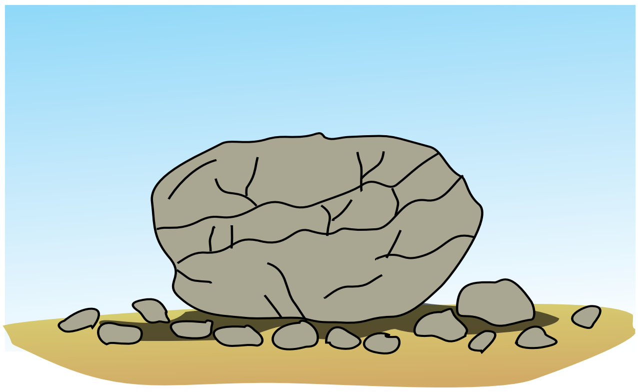


Figure 21.9: Changes in temperature cause rocks to crack and break up. Plants may grow in the cracks, causing them to break up further.

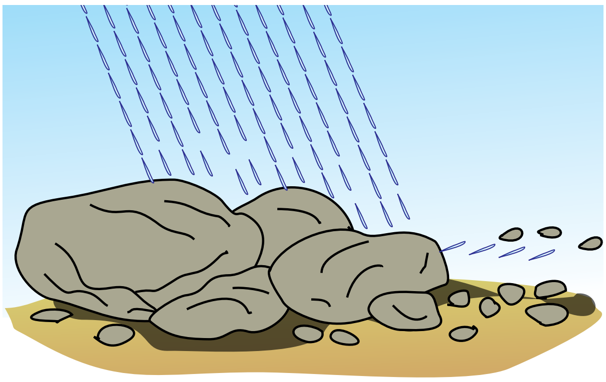


Figure 21.10: Rain wears down rocks and causes smaller pieces to break off.

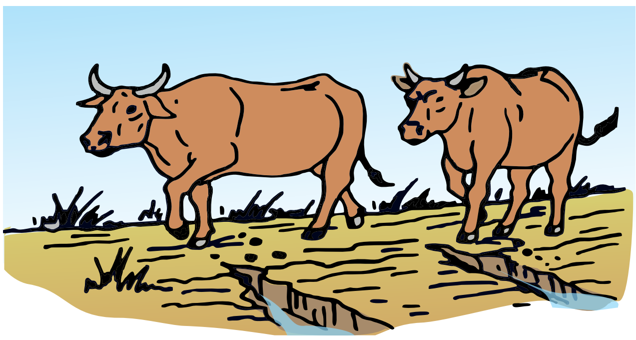


Figure 21.11: Animals break up rocks into smaller particles as they walk along.

Did you know?

The Hoba Meteorite landed in what is now Namibia around 80 000 years ago. It is the largest known meteorite still in a single piece, and the most massive naturally occurring piece of iron known at the Earth's surface. It has a mass of over 60 tons.

Wind and water transport the loose, smaller particles, along with debris from living organisms, and some large stones, eventually depositing them on flood plains and in the sea. This is called erosion.

The material accumulates at the bottom of oceans, rivers, lakes and swamps. The sediment settles and forms layers. These layers build up on each other and cause the compaction of the lower layers.

Figure 21.12: Soil erosion caused by water.

Over time, the bottom layers eventually solidify and form layers of sedimentary rock, as is shown in the following diagram.

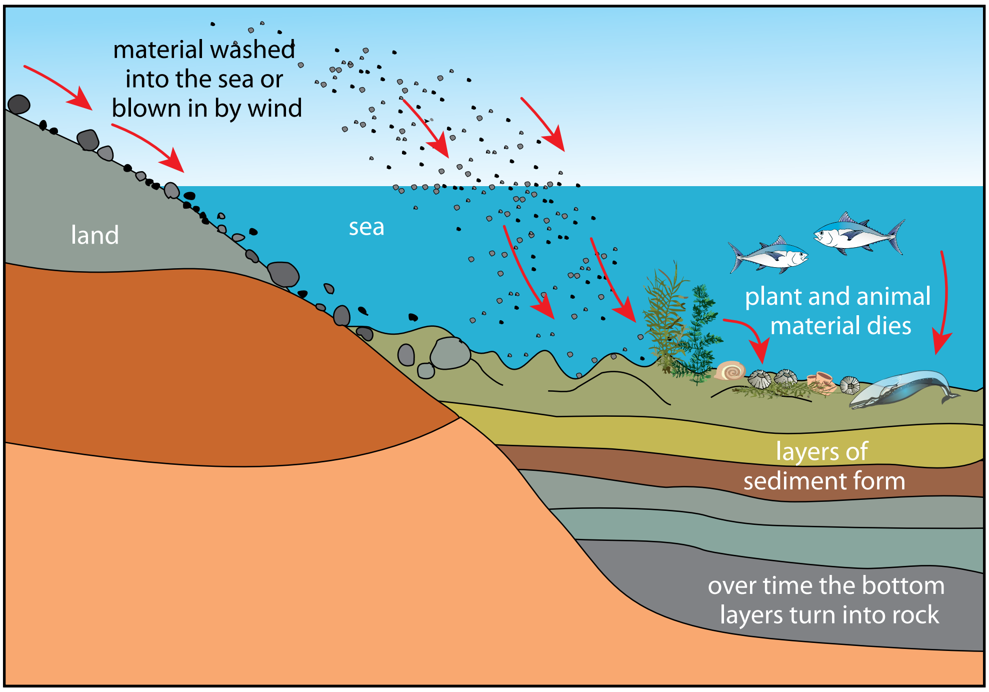


Figure 21.13: The formation of sedimentary rock.

Did you know?

The oldest layers of sedimentary rock visible in the Grand Canyon are believed to be nearly 2 billion years old.

Although sedimentary rock is found in most places on Earth, these rocks make up only 8% of the Earth's crust. Different layers of sedimentary rock may be seen in the mountains and rocks around us on a daily basis.

In the photograph you can clearly see the layers of sediment which have solidified over millions of years to form the sedimentary rocks of the Grand Canyon.

In the photograph below, you can see the layers in the sedimentary rock making up Table Mountain in Cape Town.

Figure 21.14: The layers in the sedimentary rock in the Grand Canyon.

Figure 21.15: The sandstone layers of Table Mountain.

There are different types of sedimentary rock, including sandstone, limestone, dolomite, coal, shale and conglomerate.

Figure 21.16: Sandstone rock in the Cederberg in the Western Cape.

Figure 21.17: Layers of limestone sedimentary rock.

> **Did you know?**
>
> Lime is the word used for calcium-containing compounds like calcium oxide (CaO), calcium hydroxide ($Ca(OH)_2$) and calcium carbonate ($CaCO_3$).

Limestone

Limestone is a sedimentary rock made from the mineral calcium carbonate ($CaCO_3$), often formed from the remains of the skeletons of marine animals. We use limestone as building stone in the manufacture of lime (calcium carbonate), and cement.

Dolomite

Dolomite is a sedimentary rock made from calcium magnesium carbonate ($CaMg(CO_3)_2$). Coal is another example of sedimentary rock formed from the solidified remains of ancient plants at the bottom of swamps. Shale is a very fine-grained sedimentary rock formed from the deposition of mud and silt. It is made up of very thin layers all stuck together. Conglomerate is a sedimentary rock made up of small stones, shells and other pieces of sediment. **Cementation** is the process whereby sand and associated shells, pebbles, and other sediment become cemented together to form sedimentary rock.

Sedimentary rock is softer than the other types of rock. It is eroded by the actions of wind, water or ice (glaciers). Fossils, especially of sea creatures, are often found in sedimentary rocks, lying cemented in the sediments in which they fell when they died. When plants or animals die, they are often covered in sand, which later becomes rock, capturing the fossil inside.

Dolomite mountains.

Fossils in sedimentary rock.

Limestone (creamy-brown) on top of shale (dark grey).

Conglomerate showing the layers with small pebbles embedded in the rock.

Figure 21.18: Examples of sedimentary rock.

Let's take a look at how the layers of sediment are compressed and become harder over time as a result of pressure.

ACTIVITY Modelling the formation of sedimentary rock

Materials

- three slices of white bread
- three slices of brown bread
- heavy books or object

Instructions

1. Cut off the crust from all the sides.
2. Layer the slices on top of each other, alternating the white and brown slices. Each slice represents a different layer of sediment.
3. Draw a labelled diagram of what the stack looks like.
4. Place a piece of plastic on top of the bread stack to protect the bottom book in your bookstack, then place a pile of books on top of the bread stack. Observe what happens to the layers. Write your observations here.
5. Add more books to the pile and observe. What happens to the layers?
6. Remove the books from the bread pile. Can you distinguish the different layers now?
7. Draw a labelled diagram of the bread layer.
8. Explain how this model demonstrates the formation of sedimentary rock.

Figure 21.19

Metamorphic rock

Metamorphic rock makes up a large part of the Earth's crust. Metamorphic rocks are formed when sedimentary or igneous rocks are exposed to heat and pressure. Metamorphic rocks do not form on the surface of the Earth, but rather deeper underneath the surface where the temperatures and pressures are much higher. When other types of rock experience higher pressures and temperatures, the rock crystals are squashed together. They undergo changes in crystal structure to form metamorphic rock.

Metamorphic rocks may move deeper into the Earth where they melt, forming magma. The magma may then cool and form igneous rock.

Some examples of metamorphic rocks are slate, marble, soapstone, and quartzite.

Slate is a metamorphic rock formed from shale (sedimentary rock) that was metamorphosed. Slate is often used for roofing or flooring. Since it can be cut into shapes and does not absorb moisture, it makes a good material for tiles.

Figure 21.20: Examples of metamporphic rock

Did you know?

'Metamorphic' refers to metamorphosis – a process where one thing is transformed into a completely different thing, like a pupa becoming a butterfly.

Marble

Marble is a metamorphic rock that is produced from the metamorphosis of limestone. It is used for countertops, flooring and tombstones, and is a very durable building material.

Roof tiles are made from slate, which was formed from shale (a sedimentary rock).

Figure 21.21: Marble blocks in a wall.

Figure 21.22: A marble arch in London.

Keywords

- extrusive rock
- intrusive rock

Soapstone

Soapstone is a relatively soft metamorphic rock. It is often used as an alternative natural stone countertop instead of granite or marble, for example in kitchens and laboratories. In laboratories it is unaffected by acids and alkalis. In kitchens it is not stained or altered by tomatoes, wine, vinegar, grape juice and other common food items. Soapstone is unaffected by heat. That means that hotpots can be placed directly on it without fear of its melting, burning or other damage. Many statues and carvings are also made from soapstone.

Figure 21.23: Soapstone carvings.

Figure 21.24: A pot made from soapstone.

Quartzite is formed through the actions of heat and temperature on sandstone. If you compare the texture of sandstone with quartzite in the pictures shown here, you will see that the process of metamorphism changes the texture from sandy to more glossy.

The crystals in the quartzite are bigger and the layers have disappeared. Quartzite is much harder than sandstone.

Figure 21.25: Sandstone.

Figure 21.26: Quartzite.

Igneous rock

Igneous rock is formed when magma cools down. Three factors play a role when igneous rocks are formed:

1. **Where it is formed**: If rocks are formed on the surface, they are called intrusive rocks. If they are formed under the surface they are called extrusive rocks.
2. **How quickly it cools**: When magma cools quickly, small crystals are formed and the resulting rock has a fine-grained texture. When it cools slowly, larger crystals form, resulting in a more coarse-grained rock. Sometimes the individual crystals can be seen with the naked eye.
3. **How much gas is trapped**: Magma contains molten rock and lots of gas. The gas is under pressure deep in the Earth. When the magma breaks through the surface, the gas is released. Depending on how quickly the magma cools down, some of the gas may have time to escape. When the magma cools down very quickly, lots of gas is trapped, resulting in cavities and openings forming in the rock.

Take note

Molten refers to liquids which are extremely hot, and whose usual form is a solid (e.g. rock). However, something melted need neither be hot, nor a complete liquid (e.g. butter).

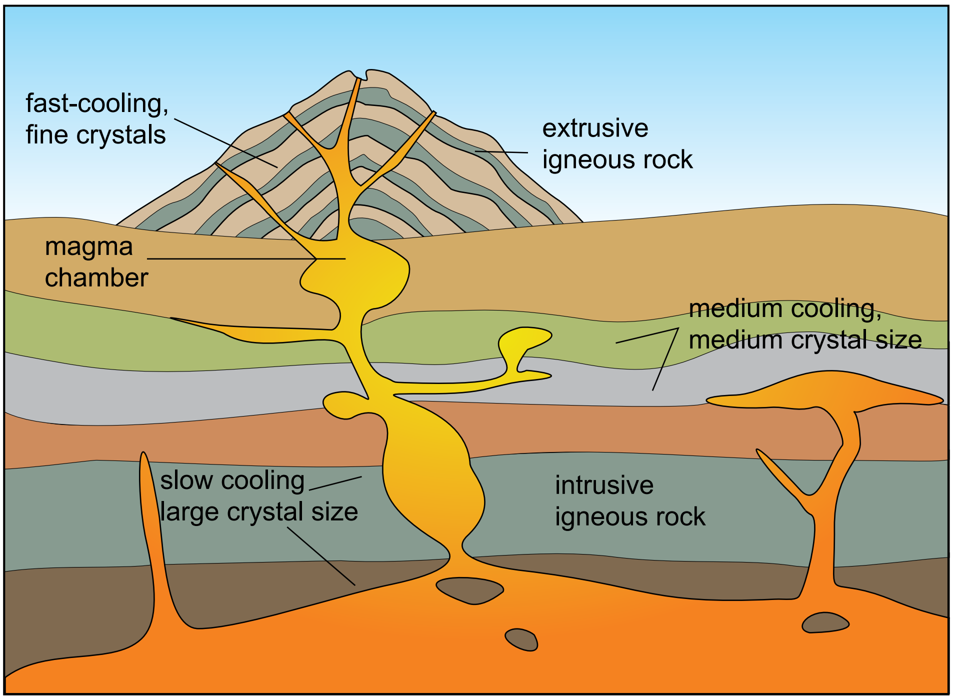


Figure 21.27: The structure of a volcano.

A volcano is an opening or rupture in the surface of the Earth's crust (or another planet) which allows hot lava and volcanic ash to escape in an eruption from the magma chamber below.

Did you know?

Pompeii was an ancient Roman city that was completely destroyed and buried under as hand pumice in the eruption of Mount Vesuvius in 27 AD. The town and objects were preserved for thousands of years and have now been excavated. Today it is visited by millions of tourists annually.

Figure 21.28: The Cleveland Volcano eruption in 2006 in Alaska, photographed from the International Space Station.

Figure 21.29: An eruption from Mount Etna in Italy in 2007.

Examples of igneous rock are basalt, granite and pumice.

Basalt is the most common igneous rock and makes up a large part of the rocks just under the surface of the Earth. Most of the oceanic crust is basalt rock. It is a dark-coloured rock and is used as building material, particularly in building stone walls.

Basalt is found not only on Earth, but also on the Moon and Mars! The highest mountain on Mars, and also the biggest-known volcano in our solar system, Olympus Mons, was formed from basaltic lava flows.

Figure 21.30: Basalt.

Figure 21.31: Olympus Mons, a volcano on Mars.

Granite is an igneous rock with large grains. It was formed from magma which slowly crystallised below the surface of the Earth. Granite is one of the best-known types of rock. It is used to make numerous objects such as tabletops, floor tiles and paving stone.

Figure 21.32: Various colours and patterns of granite rock.

Pumice rock is an example of extrusive igneous rock. It is formed from the lava emitted during volcanic explosions. Because the lava cools down very quickly, a lot of gas is trapped in the rock. As a result, pumice is a very porous rock, with lots of holes in it, making it the only rock that can float on water. Pumice stones are used in lightweight concrete and as an abrasive in industries and in homes.

Figure 21.33: Pumice stone used as an exfoliator.

ACTIVITY Comparing the properties of igneous rocks

Questions

Study the following igneous rocks and compare their similarities and differences in the following table.

Figure 21.34: Sample 1.

Figure 21.35: Sample 2.

Figure 21.36: Sample 3.

Figure 21.37: Sample 4.

Sample	Where was the sample formed? Extrusively or intrusively?	How quickly did it cool? What evidence do you have for your answer?	Was air trapped when it was formed? What evidence do you have for your answer?	Describe the colour
Sample 1				
Sample 2				
Sample 3				
Sample 4				

Keywords

- mineral

ACTIVITY Classifying rocks

Instructions

1. In this project you will be working in pairs. You need to collect rocks from your neighbourhood, or borrow some rocks from someone's rock collection.
2. You will need at least 12 different samples of rock.
3. Try to find as much variety as possible, applying what you now know about the three different rock types.
4. You could also ask a geologist to provide you with a variety of rock samples to identify.
5. Go to the website provided in the Visit margin box and follow the flow diagram to identify all your rock samples.
6. You need to create a display of the rocks and how you have identified them using the flow diagram and their properties.

Rocks contain minerals

We started this unit by collecting rocks and looking closely at their characteristics. We then looked at how rocks were formed. The questions now are why do we need to know about rocks, and why are rocks important. Let's look at what makes rocks so valuable.

Rocks contain minerals. A mineral is a chemical compound which occurs naturally, for example in rocks. There are several thousand types of minerals which are found in different combinations in rocks. They consist of metal and non-metal atoms combined in various ratios.

Let's look at some examples. Copper is a valuable metal because it is a good conductor. It is used in electrical cabling and other electrical applications. There are about 15 different types of rock which contain copper compounds. One such compound is copper(I)sulfide or Cu_2S. When this compound is found in rocks it is called a mineral, named chalcocite. Copper can also be found as the compound $CuFeS_2$ or chalcopyrite. The minerals chalcocite and chalcopyrite can be found in many different types of sedimentary, metamorphic or igneous rocks.

If we would like to use the copper from these rocks, we need to find a way to get it out of the rock and into the metal form. This we will discuss in the next unit.

Figure 21.38: Chalcocite crystals.

Figure 21.39: Chalcopyrite ore.

Figure 21.40: Chalcopyrite crystals.

Figure 21.41: Chalcocite ore.

Quartz and feldspar are the two most abundant minerals in the crust. Quartz is the mineral form of silicon dioxide (SiO_2). Potassium feldspar has the formula KAl_3SiO_8. A rock may be composed almost entirely of one mineral or could be made of a combination of different minerals. Different combinations of different minerals in rock will result in a different types of rock.

ACTIVITY What minerals are found on Earth?

Instructions

In this unit you have learnt about the Earth's crust and minerals that occur in rocks. Read more about the Earth's crust and answer the following questions:

1. What are the most abundant elements in the Earth's crust?
2. Why are these elements so abundant?
3. How did the elements get into the Earth's crust?
4. Why are the elements important?
5. What do you think are the most important element(s) in the Earth's crust? Give a reason for your answer.

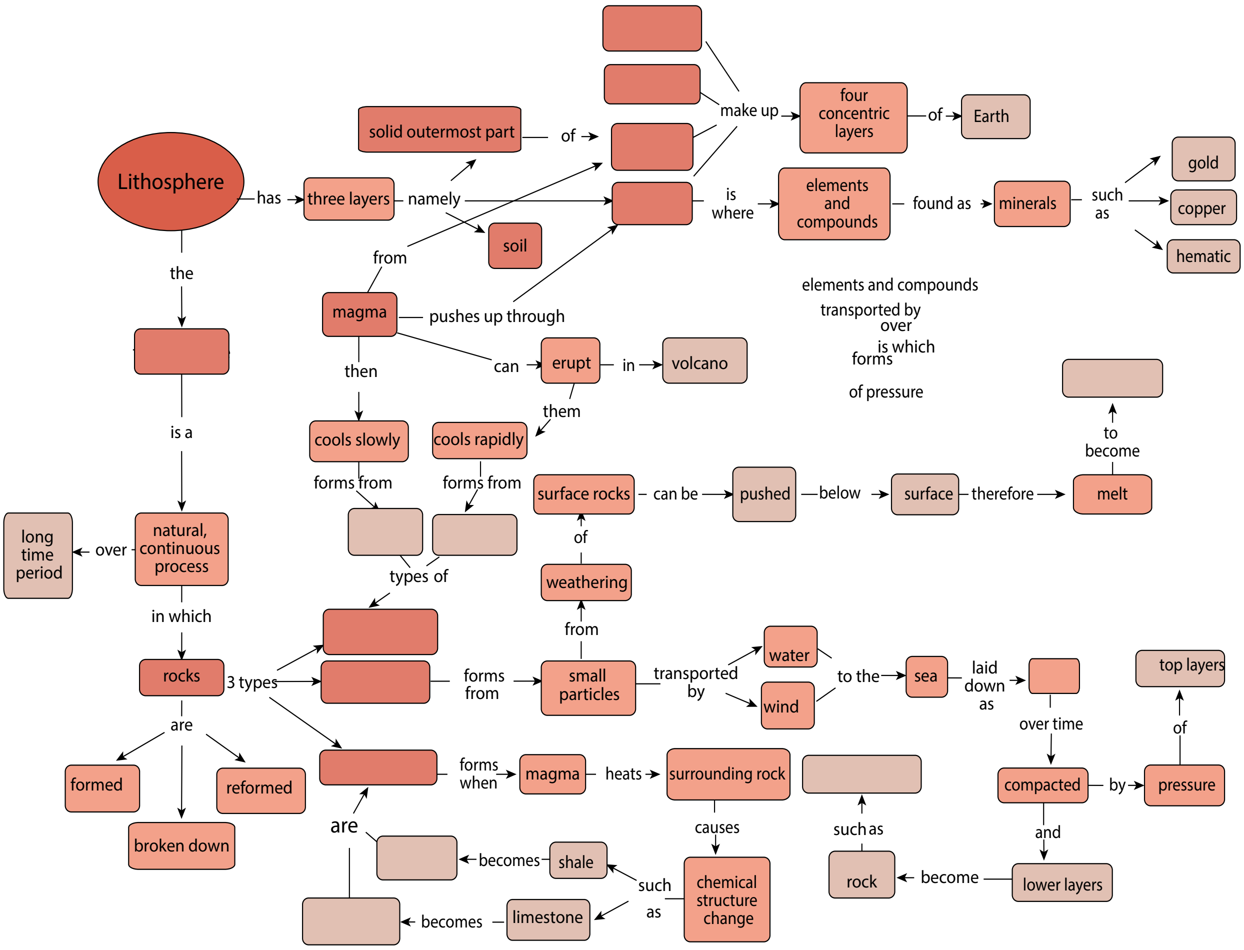
Summary

Key concepts

- The Earth consists of four concentric layers called the inner core, the outer core, the mantle, and the crust.
- The lithosphere consists of the solid outermost part of the mantle, the crust, and sediments covering it.
- The rock cycle is the natural continuous process in which rocks form, are broken down and re-form over long periods of time. The rock cycle has a number of steps.
- There are three rock types: igneous rock, sedimentary rock and metamorphic rock.
- Sedimentary rock is formed when rocks on the surface are weathered and the small particles, along with plant and animal material, are deposited in sediments at the bottom of lakes, oceans and rivers. Over time, more and more layers of sediment are deposited. The resulting increase in pressure causes compaction and the formation of hard layers of sedimentary rock.
- Fossils are often found in sedimentary rock as when some organisms die, they become incorporated into the layers of sediment.
- Hot magma is found deep below the surface of the Earth. When magma cools slowly, below the surface of the Earth, it forms intrusive igneous rock. When the magma pushes up through the crust (for example in a volcano), it cools rapidly and forms extrusive igneous rock.
- Hot magma can heat the surrounding rock and change other types of rock into metamorphic rock.
- Different combinations of elements and compounds form the minerals in the crust.

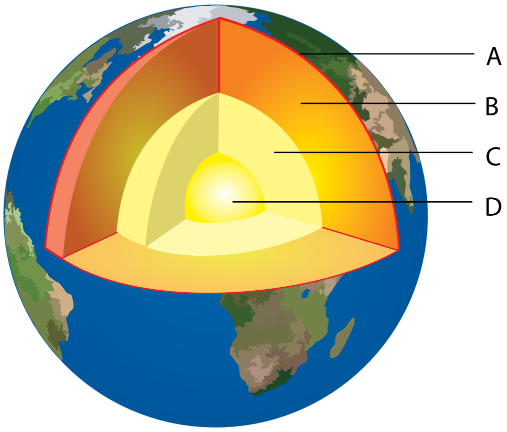
Concept map

Use the concept map on the next page to summarise what you learnt about the lithosphere and rock cycle in this unit. If you want to add more links or information into the concept map, you should do so.



Revision

1. The Earth consists of different layers.
   a) Label the following diagram: [4]

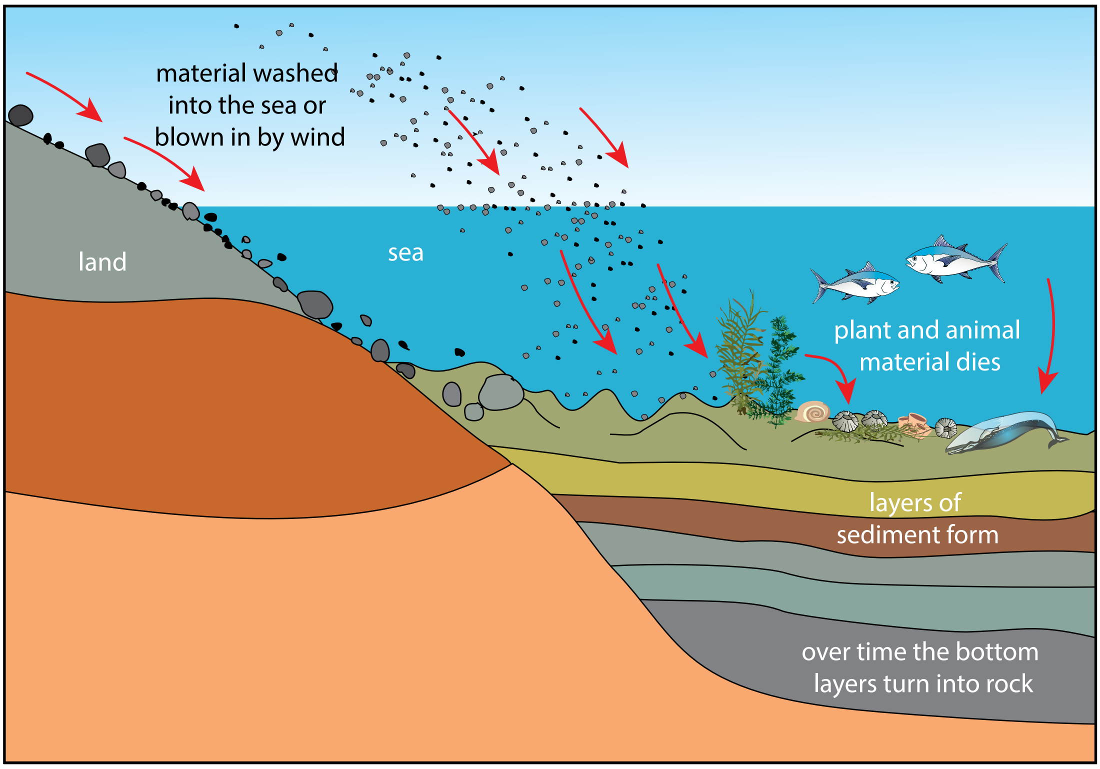


   b) What is the difference between parts C and D? [2]
   c) What does part B consist of? [1]
   d) Give three examples of things found around your school that form part of part A. [3]

2. Why are there so many different rocks found on Earth? [2]

Beyond

3. The diagram below shows the formation of one of the rock types. Study the diagram and answer the question that follow.



a) What type of rock formation is shown in the diagram? Give a reason for your answer. [2]
b) What processes are involved in the formation of this type of rock? [2]
c) What will happen if the rocks formed here move deeper into the Earth? [3]

2. Fossils are often found in sedimentary rocks. Explain why this is the case. [4]

3. Explain the difference between the formation of igneous rock, such as granite, and igneous rock, such as pumice. [4]

4. Iron is an element found abundantly on Earth, especially in the core of the Earth. Iron combines with oxygen to form haematite, the mineral form of iron(III)oxide. Haematite is present in sedimentary rocks, for example in the Sishen area in the Northern Cape.
   a) What is the formula for iron(III)oxide? [1]
   b) How does iron end up in sedimentary rock? [3]
   c) Why is hematite an important mineral? [1]

Total [32 marks]

22 Mining of mineral resources

Key questions

- How do we know where to mine?
- How do we get the valuable ore-rich rocks out of the ground?
- How do we get the minerals or metals out of the ore?
- How do we separate minerals from waste rock?
- How do we refine minerals?
- Where in South Africa are the mineral-rich deposits suitable for mining?
- What do we mine in South Africa?
- What is the impact of mining?

Keywords

- mineral
- ore
- PGM

In the previous two units you have learnt about the spheres of the Earth especially the lithosphere. The lithosphere consists of rocks, which contain minerals. Minerals are natural compounds formed through geological processes.

A mineral could be a pure element, but more often minerals are made up of many different elements combined. Minerals are useful chemical compounds for making new materials that we can use in our daily lives. In this unit we are going to look at how to get the minerals out of the rocks and in a form that we can use. This is what the mining industry is all about. Mining is a very important industry in South Africa. We have a lot of mineral resources in our country and a lot of people depend on mining for a living.

You already know that minerals in rocks cannot be used. Many processes are used to make minerals available for our use. We need to locate the minerals. We must determine whether these concentrations are economically viable to mine. Rocks with large concentrations of minerals are called **ores**. Mining depends on finding good quality ore, preferably within a small area.

The next step is to get the rocks which contain the mineral out of the ground. Once the ore is on the surface, the process of getting the mineral you want out of the rock can start. Once the mineral is separated from the rest of the rock, the mineral needs to be cleaned so that it can be used.

This process can be represented by the flowchart on the left.

In this unit we will look at each of the steps in more detail. You will also apply what you learn about mining to one specific mining industry. This is explained in the research project below.

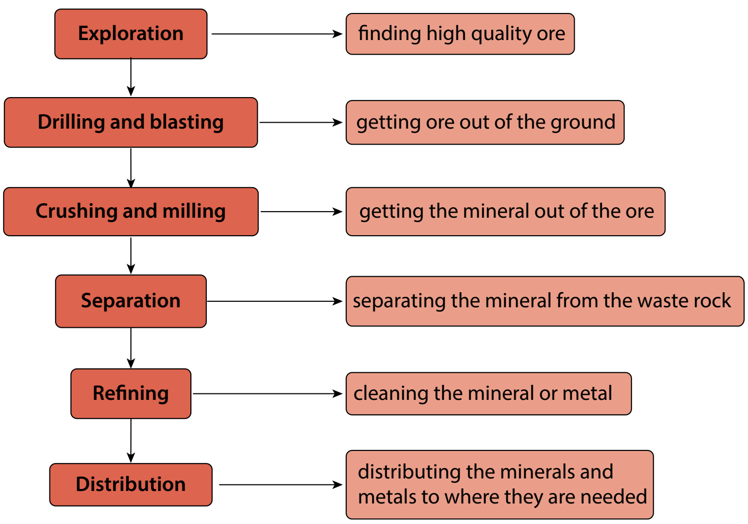


Figure 22.1

ACTIVITY Mining in South Africa

Instructions

1. Work in groups of three.
2. Choose one mining industry in South Africa and find information about the industry of your choice.
3. Choose from the following list: gold, iron, coal, phosphate, manganese, diamond, chromium, copper and the platinum group metals (PGMs).
4. Present your findings to the class in an oral and a poster.
   a) Use the following questions to guide your research:
   b) How do geologists and engineers know where to mine for the mineral of your choice?
   c) What type of mining method is used in this industry?
   d) What processes are used to get the rock out of the ground?
   e) What processes are used to reduce the size of the rocks?
   f) How is the mineral removed from the ore?
   g) How is the mineral separated from its compound?
   h) How is the mineral refined?
   i) Where in South Africa is this mineral mined?
   j) What has the impact of this mining industry been on South Africa?
   k) What has the impact of this mining industry been on the environment?
   l) What careers are involved in this mining industry?

Keywords

- exploration
- remote sensing
- geophysical methods
- geochemical methods

22.1 Exploration: Finding minerals

One of the most important steps in mining is to find the minerals. Most minerals are found everywhere in the lithosphere, but in very, very low concentrations, too low to make mining profitable. For mining to be profitable, high-quality ore needs to be found in a small area. Mining **exploration** is the term we use for finding out where the valuable minerals are.

Today technology helps mining geologists and surveyors to find high-quality ore without having to do any digging. When the geologists and surveyors are quite sure where the right minerals are, only then do they dig test shafts to confirm what their surveying techniques have suggested.

Methods of exploration

In all these methods we use the properties of the minerals and our knowledge of the lithosphere to locate them underground, without going underground ourselves. For example, iron is magnetic, so instruments measuring the changes in the magnetic field can give us clues as to where pockets of iron could be. Exploration methods are used to find and assess the quality of mineral deposits, prior to mining. Generally, a number of explorative techniques are used, and the results are then compared to see if a location seems suitable for mining.

Did you know?

The rare earth elements are a set of 17 elements on the Periodic Table, including the fifteen lanthanides and scandium and yttrium. Despite their names, they are found in relatively plentiful amounts in the Earth's crust.

Did you know?

Kimberlite pipes are the most important source of diamonds in the world. They are named after the town of Kimberley, where a where a 16,7 g diamond was found in 1871, starting the diamond rush.

Remote sensing is the term used to gain information from a distance. For example, by using radar, sonar and satellite images, we can obtain images of the Earth's surface. These images help us to locate possible mining sites, as well as study existing mining sites for possible expansion.

Figure 22.2: This image covers an area of 15 × 19 km and was taken from the NASA research satellite, Terra. It shows the mine at Baiyun Ebo, China, which is the site of almost half the world's rare earth element production.

Geophysical methods make use of geology and the physical properties of the minerals to detect them underground. For example, diamonds are formed deep in the Earth at very high temperatures, in kimberlite pipes of igneous rock. The kimberlite pipe is a carrot shape. The first kimberlite pipe to be detected was in Kimberley in South Africa. The pipe was mined, eventually creating the Big Hole.

Figure 22.3: The Kimberley Big Hole was a diamond mine until 1914 when it closed down, and is now a tourist attraction.

Geochemical methods combine the knowledge of the chemistry of the minerals with the geology of an area to help identify which compounds are present in the ore and how much of it is present. For example, when an ore body is identified, samples are taken to analyse the mineral content of the ore.

Did you know?

The Kimberley Big Hole is considered to be the largest hand-dug excavation on Earth at 463 m wide and 240 m deep. About 22 million tons of earth were excavated, which yielded 3 000 kg of diamonds.

ACTIVITY Minerals and the right to own them

Many indigenous people, such as the San, share the same central belief that the land and all it produces are for all the people to use equally.

When colonialists arrived, they realised the potential mineral wealth of South Africa as gold, and later diamonds, were discovered. They ruthlessly took land from the local people wherever minerals were found, completely ignoring their right to ownership and access.

De Beers purchased the mining rights and closed all access to diamond mining areas. Anyone entering the area would be prosecuted and the sale of so-called 'illegal' diamonds was heavily punished. Other large mining companies have tried to claim the right to the minerals that they mine.

In groups or as a class discuss the following:

1. Should a few select people hold the right to the land and the minerals in it?
2. Who owns the minerals?
3. Should big corporations hold these rights?
4. What role should government play in allocating/administering mining rights?
5. Write down some of the main points of your discussion.

22.1 Extracting ores

Once the ore body has been identified, the process of getting the ore out of the ground begins. There are two main methods of mining – surface mining and underground mining. In some locations a combination of these methods is used.

Keywords

- topsoil
- overburden
- excavation
- rehabilitation
- slurry

Surface mining

Surface mining is exactly what the word says – digging rocks out from the surface, forming a hole or pit. In South Africa, this method is used to mine for iron, copper, chromium, manganese, phosphate and coal. Surface mining is also known as open pit or open cast mining.

Let's look at coal as an example. For surface mining, the minerals need to be close to the surface of the Earth. Most of the coal found in South Africa is shallow enough for surface mining. Usually the rocks are present in layers.

Figure 22.4: An open pit coal mine.

Did you know?

South Africa is one of the seven largest coal-producing countries in the world. A quarter of the coal mined in South Africa is exported, mostly through Richards Bay.

To expose the coal layer, the layers above it need to be removed. The vegetation and soil, called the **topsoil**, is removed and kept aside so that it can be re-deposited in the area after mining.

If there is a layer of rock above the coal face, called the **overburden**, this is also removed before the coal can be **excavated**. Once all the coal has been removed, the overburden and topsoil are replaced to help in restoring the natural vegetation of the area. This is called **rehabilitation**. There is a growing emphasis on the need to rehabilitate old mine sites that are no longer in use. If it is too difficult to restore the site to what it was before, then a new type of land use might be decided for that area.

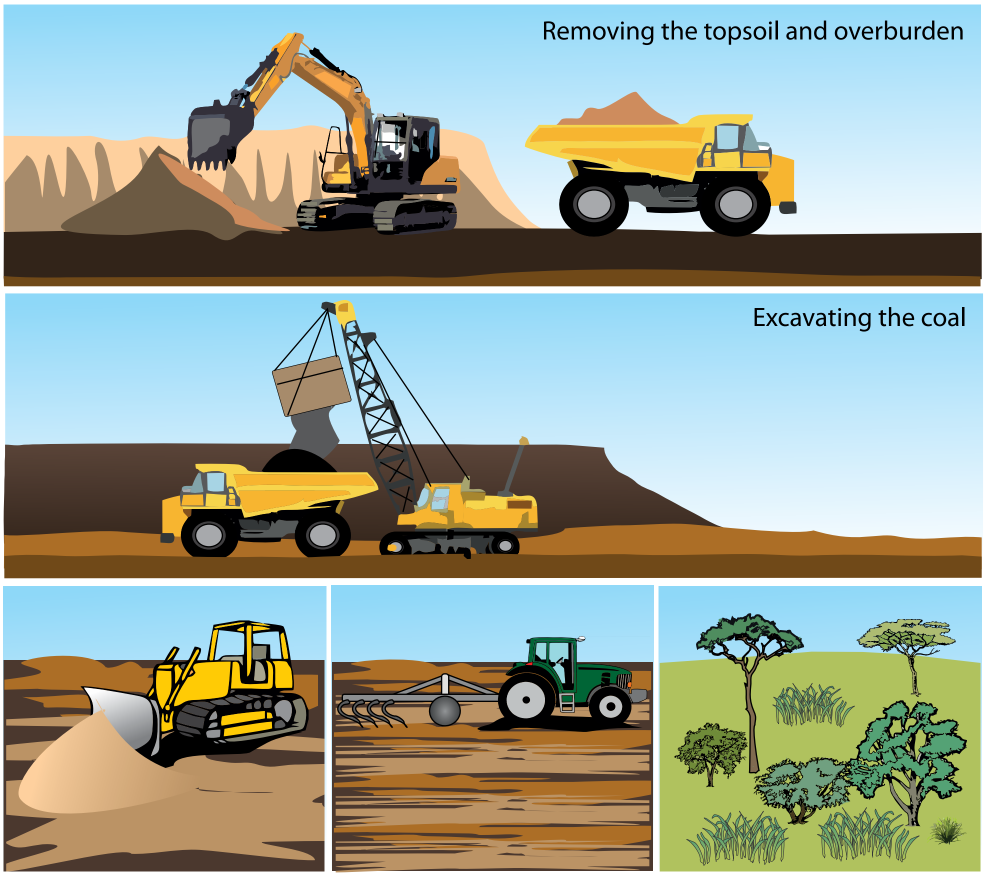


Figure 22.5: Surface mining coal and mine rehabilitation

Figure 22.6: Copper ore from Phalaborwa Mine.

In Phalaborwa in Limpopo province, copper ore is mined using open-pit mining.

The Phalaborwa open pit is one of the world's largest open pit mines. It is 2 km across and is the largest man-made hole in Africa.

When you mine you are digging into solid rock. The rock needs to be broken up into smaller pieces before it can be removed. Holes are drilled in the rock and explosives, like dynamite, are placed inside the holes to blast the rock into pieces. The pieces are still very large and extremely heavy. The rocks are loaded onto very large haul trucks and removed. Sometimes the rocks (ore) are crushed at the mining site to make them easier to transport.

Do you remember learning about how coal is formed? What is coal made from?

> **Did you know?**
>
> Mining trucks are enormous. They are up to 6 metres tall. That's higher than most houses. These trucks can carry 300 tons of material and their engines have an output 10 – 20 times more powerful than a car engine.

Figure 22.7: A mining haul truck being loaded with coal.

Underground mining

Shaft mining

Often the minerals are not found close to the surface of the Earth, but deeper down. In these cases, underground mining, also called shaft mining, is used. Examples of underground mining in South Africa are mining for diamonds, gold, and sometimes the platinum group metals (PGM).

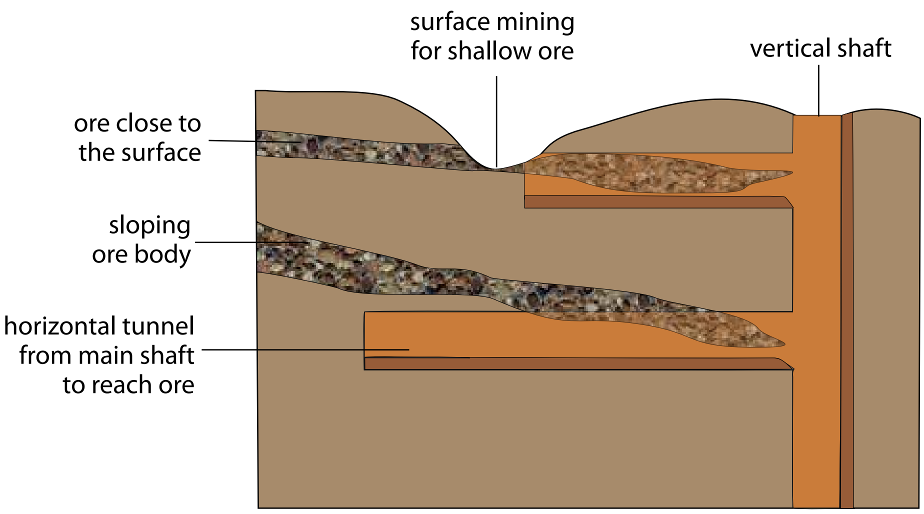


Figure 22.8: Extracting ore.

Take note

Igneous and metamorphic rocks are found where gold is mined.

Did you know?

South Africa is a leader in the field of deep underground mining as we have several mines deeper than 3 km.

Sometimes the ore is very deep, which is often the case with diamonds or gold ore. In these cases mine shafts go vertically down and side tunnels make it possible for the miners and equipment to reach the ore.

A structure called the headgear is constructed above the shaft and controls the lift system into the vertical shaft. Using the lift, it can take miners up to an hour to reach the bottom of the shaft.

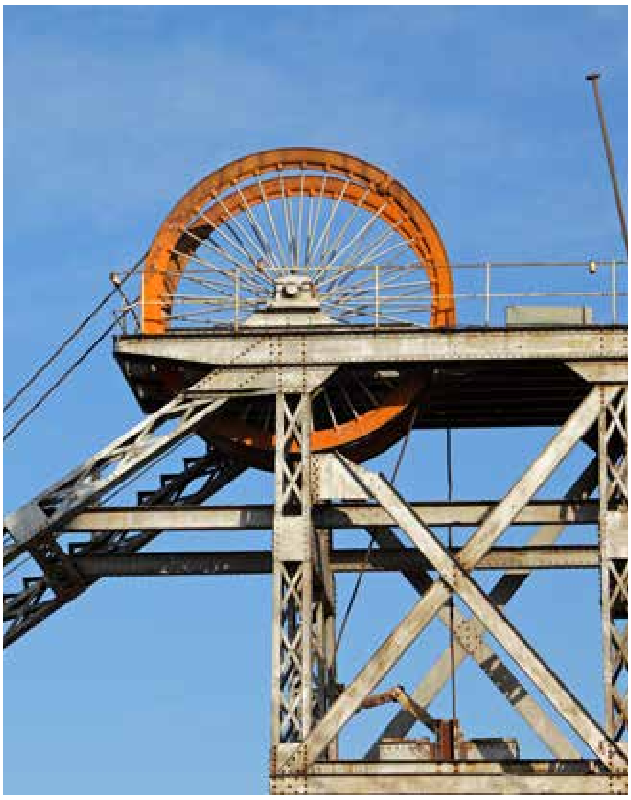


Figure 22.9: Old headgear at the Kimberley Mine in the Northern Cape

The TauTona Mine in Carletonville, Gauteng is the world's deepest mine. It is 3,9 km deep and has 800 km of tunnels. Working this deep underground is very dangerous. It is very hot, up to 55 °C. To be able to work there, the air is constantly cooled to about 28 °C using air-conditioning vents.

ACTIVITY Gold mining in South Africa

South Africa is a world leader in the gold mining industry. We have been mining gold for more than a century and our mines are the deepest in the world. Until 2010 we were the leading producer of gold in the world. Gold is a lustrous, precious metal, which has very high conductivity.

Questions

1. What mining method is used to mine for gold?
2. What type of rock is found where gold is mined?
3. What is gold used for?
4. Do you think gold mining is dangerous? Why do you say so?
5. Provide labels for numbers 1 – 7 in the following diagram.

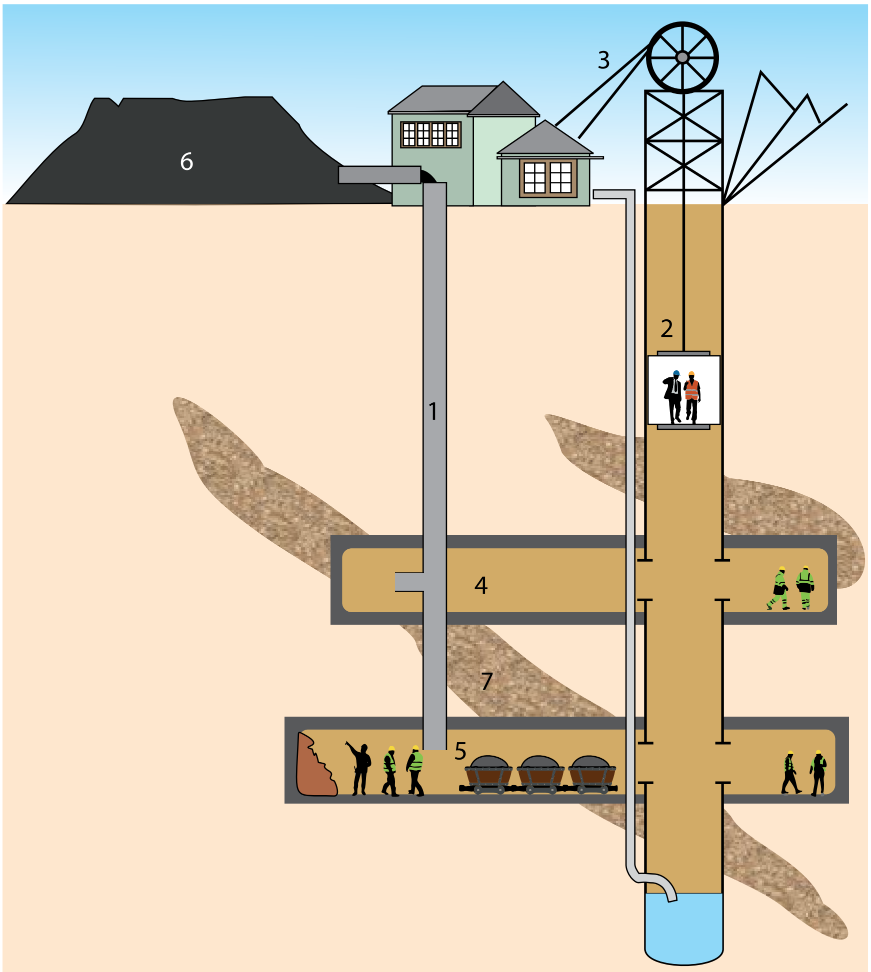


Figure 22.10: Gold mining

Did you know?

The PGMs are six transition metals usually found together in ore. They are ruthenium (Ru), rhodium (Rh), palladium (Pd), osmium (Os), iridium (Ir) and platinum (Pt). South Africa has the highest known reserves of PGMs in the world.

Room-and-pillar method

One of the methods used in underground mining is called room and pillar, and is often used for mining coal. Part of the mine is open to the surface and part of it is underground. The coal face is dug out, but pillars of coal are left behind to keep the tunnels open and support the roof. Machines called continuous miners are used to remove the coal. The coal is loaded onto conveyor belts and taken up to the surface for further crushing.

Figure 22.11: A machine called a continuous miner at work at the coal face.

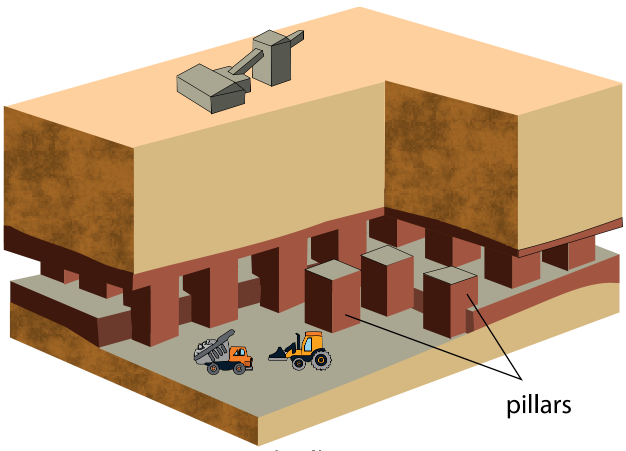


Figure 22.12: Room-and-pillar mining

What happens once the ore has been removed from the crust by mining?

> **Did you know?**
>
> Coal miners used to take a canary with them down the mines. If the canary died, they knew that oxygen levels were being dangerously depleted and that it was not safe to remain underground.

22.2 Crushing and milling

Figure 22.13: Ore is like choc chip biscuits where the minerals are spread through the rocks.

Mineral crystals are spread throughout rocks, just as chocolate chips are spread throughout a choc chip biscuit. Sometimes we can see the chocolate chips from the outside, but most of the time the chips are not visible because they are inside the biscuit.

Figure 22.14: The ore needs to be crushed, such as a choc chip biscuit, to get the minerals out.

The only way to find out how many choc chips there are is to crush the biscuit. In the same way we can sometimes see mineral crystals from the outside of the rock, but mostly we don't know what minerals there are and what concentrations are inside the rock. The only way to find out is to break the rock into smaller and smaller pieces.

Figure 22.15: The choc chips are separated from the rest of the biscuit, just as minerals are extracted from the rock.

Once we have crumbled the choc chip biscuit, the chocolate pieces can be separated from the crumbs. In the same way, in the mining process, the valuable minerals can be separated from the unwanted rock. The unwanted rock is called waste rock.

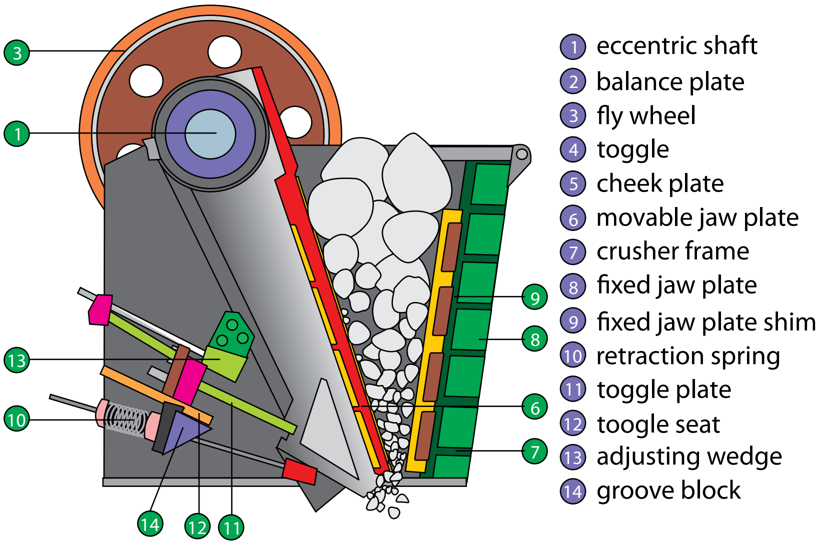


Figure 22.16: Jaw crusher at a mine. The rocks are fed into the funnel and crushed as the two sides move back and forth.

Let's look at an example. You have learnt in the previous unit that copper minerals are found in rocks. In South Africa, the Bushveld Igneous Complex is an area which stretches across the North West and Limpopo Provinces. Igneous rock with high mineral content is found here. Here they mine for PGMs, chromium, iron, tin, titanium, vanadium and other minerals using open pit and underground mining. The rocks from the mines are transported by conveyor belts to crushers. Jaw crushers and cone crushers break the huge rocks into smaller rocks.

The smaller rocks are then moved to mills where large rod mills and ball mills grind them further into even smaller pieces until they are as fine as powder.

Figure 22.17: A ball mill.

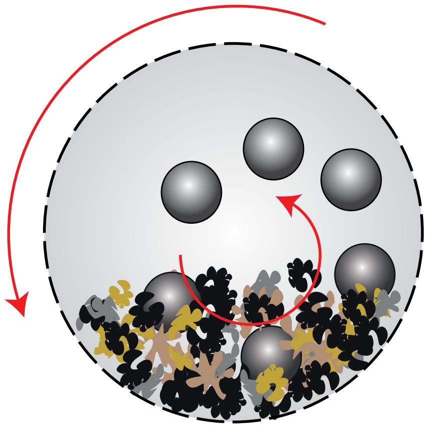


Figure 22.18: Inside a ball mill, the balls move round in a circle as the mill turns, crushing the ore into a powder.

This process of reducing the size of the rocks requires a lot of energy. Just image how hard it is to break a rock. How much more energy do you think is needed to crush a rock until it is like sand? This is one of the steps in the mining process that is very expensive because energy is needed to drive the process.

Most minerals are found as compounds in rocks. Only a few minerals are found in their pure form, in other words not bound to any other element. Examples of minerals found in their pure form are gold and diamonds (diamonds consist of the element carbon).

Figure 22.19: A rough diamond crystal embedded in rock.

Some rocks are used as is, and do not need to be crushed into powder, or involved in minerals extraction. For example, phosphate rock itself can be used as a fertiliser, or it can be used to make phosphoric acid. Sand, or the mineral silicon dioxide (SiO_2), is used in the building industry.

Figure 22.20: A gold nugget.

Coal found in sedimentary rock is crushed into the appropriate size and used as fuel for electricity generation or the iron-making process.

Figure 22.21: Lumps of coal can be used directly as a fuel. However, some coal is first washed to make it into 'high-grade coal'. It can also be sorted into various sizes, depending on what the fuel is required for.

22.3 Separating minerals from waste

Before the minerals can be used, they need to be separated from the waste rock. A number of different separation techniques are used. These techniques are based on the properties of the minerals. Different minerals are often found together, for example copper and zinc, gold and silver, or the PGMs. A combination of techniques is used to separate the minerals from the waste and then the minerals from each other.

> **Take note**
>
> An electro-magnet, as we have learnt in Energy and Change, is a type of magnet in which the magnetic field is produced by electric current.

Hand sorting

Sorting by hand is not a very effective method to separate out the minerals you want. It can be used only in exceptional situations or by individuals; for example many people mine for alluvial diamonds by hand in rivers in Angola. It is a cheap and easy process to do individually, but it is not feasible on an industrial scale.

> **Keywords**
>
> - magnetic separation
> - panning
> - size separation

Magnetic separation

Iron is a metal with magnetic properties. Iron ore can be separated from waste rock by using magnetic separation techniques. Conveyor belts carry the ore past strong electromagnets which remove the magnetic pieces (containing the iron) from the non-magnetic waste. How do you think this works? Study the following diagram:

> **Take note**
>
> You may remember some of the different methods of physical separation from previous grades. This was covered in *Matter and Materials*.

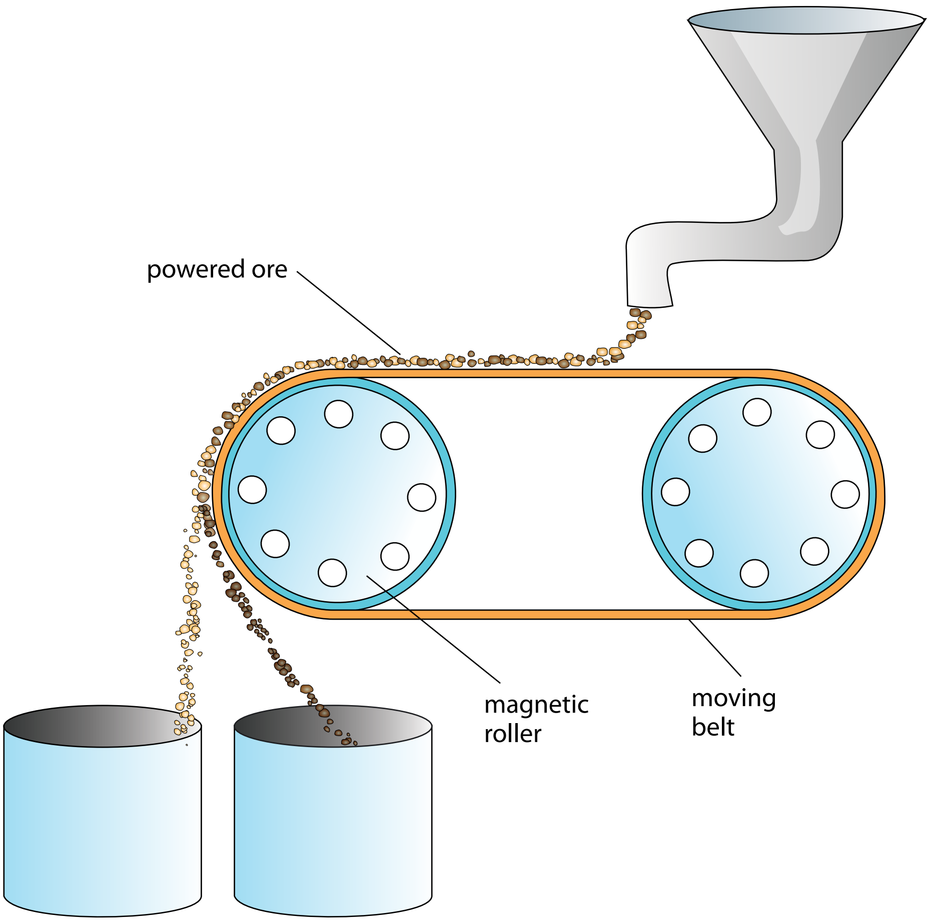


Figure 21.22

Which container, the left or the right, will contain the magnetic iron ore and which one will contain the non-magnetic waste? Copy this diagram into your exercise book, then label it providing a reason for your answer.

Density separation

One of the first methods for mining gold was that of **panning**, a technique where ore is mixed with water and forms a suspension. When it is shaken, the dense particles of gold sink to the bottom and can be removed.

Figure 21.23: Panning.

ACTIVITY Separating beads

In this activity you are going to separate beads as an analogy for separating minerals in the mining industry.

Materials

- collection of beads, different shapes, sizes, densities and magnetic properties
- paint tray
- piece of carpet
- plastic cup and mesh
- magnet
- water

Figure 21.24: Different plastic and metal beads.

Instructions

1. Work in groups of three.
2. Your teacher will indicate to you which bead is the valuable mineral. You need to design a process to separate the valuable mineral from the waste rock.
3. Draw a flow diagram for the process you have designed. Consider using a number of steps in different orders. You may use the same technique more than once.
4. Also remember that repeating a technique improves the efficiency of it. Think about changing the order in which you separate the beads to see if you can find a more efficient process.

Did you know?

When gold was discovered in Pilgrim's Rest in Mpumalanga in the 1840s, they mostly used panning to separate the gold nugget ore from sand and stones in rivers.

5. Hand sorting may NOT be used.
   Use your exercise books to draw a final flow diagram of the process your group has designed.

Questions

1. How did you sort the beads based on size?
2. How did you sort the beads based on shape?
3. How did you sort the beads based on density?
4. How did you sort the beads based on magnetic properties?

Take note

Although hand sorting is an effective method, it is very time consuming, which makes it an expensive process. So it is almost never used in the mining industry, except for diamond sorting.

Keywords

- flotation
- physical separation methods
- slurry

As you have seen in the activity, separating a mixture can be done using different properties, depending on the different properties of the beads. There could be a number of different ways to separate the beads depending on which type of bead you want to select (considered to be the most valuable ones). Size separation is used frequently in mining to classify ore. For example, when iron ore is exported, it needs to be a certain size to be acceptable to the world market. Coal that is used in power stations also needs to be a certain size so that it can be used to generate electricity effectively.

Density separation is used widely in mining, and you will see why in the next section.

Flotation

Flotation makes use of density separation, but in a special way. Chemicals are added to change the surface properties of the valuable minerals so that air bubbles can attach to them. The minerals are mixed with water to make a **slurry**, almost like a watery mud. Air bubbles are blown through the slurry and the minerals attach to the bubbles. The air bubbles are much less dense than the solution and rise to the top, where the minerals can be scraped off easily.

Figure 21.25: Separating minerals by flotation

ACTIVITY Separating peanuts and raisins

You will be working in pairs for this activity. You need to observe carefully and explain your observations.

Materials

- peanuts
- raisins
- soda water
- tap water
- two tall glasses or beakers

Instructions

1. Pour tap water into the first glass until it is about $\frac{3}{4}$ full.
2. Add a handful of the peanuts and raisins mixture to the water and note what happens.
3. Pour soda water into the second glass until it is about $\frac{3}{4}$ full.
4. Add a handful of the peanuts and raisins mixture to the soda water and note what happens.
5. Write down your observations.
6. Explain your observations.

Peanuts and raisins.

Separating peanuts and raisins.

Looking down into the water-filled beaker.

Figure 21.26

Record and explain your observations.

The methods mentioned so far are all **physical separation methods**. Sometimes they are sufficient to separate minerals for use, such as coal or iron ore. But more often the element that we are looking for is found as a chemical compound, and so will have to be separated by further chemical reactions, for example, copper in Cu_2S or aluminium in Al_2O_3.

What is the name for the force that is holding atoms together in a compound?

Once the compound is removed from the ore, the element we want needs to be separated from the other atoms by chemical means. This process forms part of refining the mineral, as you will see in the next section.

Keywords

- bloomery
- bellows
- blast furnace
- brittle
- slag

Did you know?

Iron appears to have been smelted in the West as early as 3000 BC. The start of the Iron Age in most parts of the world coincides with the first widespread use of bloomeries.

22.4 Refining minerals

There are many different methods used to concentrate and refine minerals. The choice of methods depends on the **composition** of the ore. Most of the methods, however, make use of chemistry to extract the metal from the compound or remove impurities from the final product. We will discuss the extraction of iron from iron ore as an example.

Extraction of iron

Iron atoms are found in the compounds FeO, Fe_2O_3 and Fe_3O_4 and in rocks such as haematite and magnetite. South Africa is the seventh-largest producer of iron ore in the world. Iron has been mined in South Africa for thousands of years. South African archaeological sites in KwaZulu-Natal and Limpopo provide evidence of this. Evidence of early mining activities was found in archaeological sites dating mining and smelting of iron back to the Iron Age around 770 AD.

The first iron mining techniques used charcoal which was mixed with iron ore in a **bloomery**. When heating the mixture and blowing air (oxygen) in through **bellows**, the iron ore is converted to the metal, iron. The chemical reaction between iron oxide and carbon is used here to produce iron metal. The balanced chemical equation for the reaction is:

$$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$$

This extraction method is still used today using the chemistry. However, the bloomery is replaced with a **blast furnace**, a huge oven where iron ore is burned with oxygen and coal to produce the metal, iron. Iron ore, a type of coal called coke (which contains 85% carbon), and lime are added to the top of the blast furnace. Hot air provides the oxygen for the reaction. The temperature of a blast furnace can be up to 1 200 °C.

Figure 21.27: A small bloomery.

The reaction takes place inside the furnace and molten iron is removed from the bottom. Lime (calcium carbonate or $CaCO_3$) is added to react with the unwanted materials, such as sand (silicon dioxide or SiO_2). This produces a waste product called **slag**. The slag is removed from the bottom and used for building roads. Iron is used to make steel. Hot gases, mainly carbon dioxide, escape at the top of the furnace.

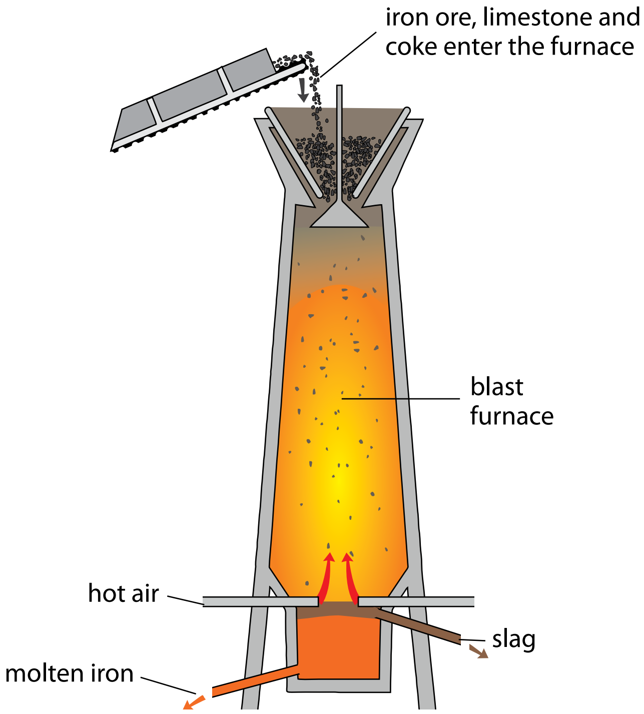


Figure 21.28: Blast furnace.

ACTIVITY Separating lead from lead(II)oxide

In this demonstration you are going to react lead(II)oxide with carbon. This is similar to the process used in iron mining where iron ore is reacted with coke (carbon) to form iron metal.

Materials

- lead(II) oxide (red)
- charcoal block
- Bunsen burner
- blowpipe
- spatula
- safety glasses

Instructions

1. Use safety glasses in this experiment.
2. Use the spatula to scrape a hollow in the charcoal block. Ensure that the loosened carbon remains in the hollow.
3. Add an equivalent amount of lead oxide to the carbon in the hollow.
4. Add a drop or two of water to make a paste.
5. Use a blowpipe to direct the flame of the Bunsen burner into the hollow where the lead(II)oxide-carbon paste is. Create a steady flow of air through the flame.
6. Keep the flame directed onto the paste for 2 – 3 minutes.
7. Observe if any changes have taken place. If not, continue blowing for another minute.

Take note

Remember from Matter and Materials that lead (II) oxide is formed from the reaction between lead (a metal) and oxygen.

Questions

1. What have you observed? Were there any colour changes? Describe your observations.
2. Write a balanced equation for the reaction that has taken place.
3. Carbon dioxide is formed in this reaction. What would the impact of this be if the reaction is done on large scale?

In this experiment carbon was used to remove the oxygen from the lead(II)oxide. The carbon and oxygen form carbon dioxide, and the lead is left behind as a metal. This is the same process that is used in iron extraction in the blast furnace that we discussed above. Coke, which is mainly carbon, removes the oxygens from the iron(III)oxide to form carbon dioxide and leaves behind the iron metal.

Refining iron

The iron that is formed in the blast furnace often contains too much carbon – about 4%, where it should contain not more than 2%. Too much carbon makes the iron **brittle**. To improve the quality of the iron, it needs to be refined by lowering the amount of carbon. This is done by melting the metal and reacting the carbon with pure oxygen to form carbon dioxide gas. In this way the carbon is burned off and the quality of the iron improves. The iron can now be used in the steel-making process. Carbon reacts with oxygen according to the following chemical equation:

$$C + O_2 \rightarrow CO_2$$

Most minerals go through chemical extraction and refining processes to purify them for use in making materials and other chemical products. These are then distributed to where they are needed, for example, coal is distributed to coal power stations and slag is distributed to construction groups for building roads. The mining industry supplies the manufacturing industry and the chemical industry with its raw materials, for example iron is distributed to steel manufacturing industries.

22.5 Mining in South Africa

Long before diamonds were discovered in the Kimberley area and the Gold Rush started in Pilgrim's Rest and the Witwatersrand areas in the late 1800s, minerals were mined in South Africa. At Mapungubwe in the Limpopo Province evidence of gold and iron mining and smelting was found which dates back to the early 11th century AD. However, it was the large-scale mining activities that accelerated the development of the country.

South Africa has a wealth of minerals. We are the world's largest producers of chromium, manganese, platinum, vanadium and alusite; and the second-largest producer of ilmenite, palladium, rutile and zirconium. We are the third-largest coal exporter, fifth-largest diamond producer and seventh-largest iron ore producer. Up to 2010 we were the world's largest gold producer, but our gold production has declined steadily over a number of years. We are currently fifth on the list of gold producers.

Figure 21.29: The Okiep Copper Mine, South Africa, established in the 1850s, is one of the richest bodies of copper ore ever found to this day.

Minerals are mostly found in the northern part of the country. They are often concentrated in specific areas which are linked to the geology of the area.

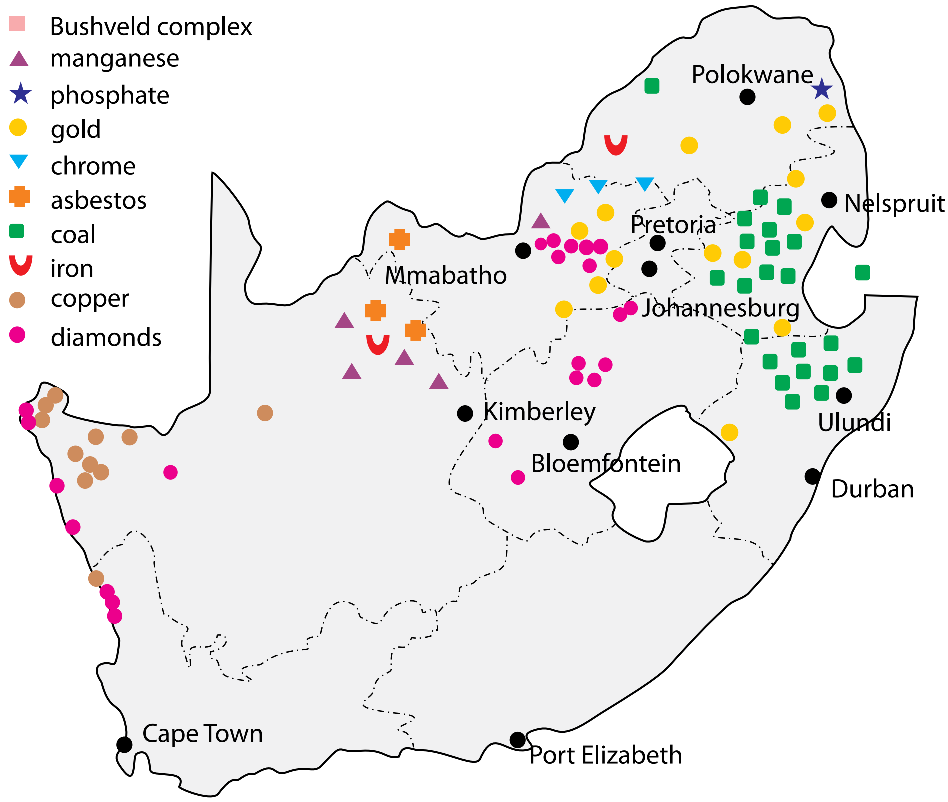


Figure 21.30: Minerals in South Africa

Did you know?

In South Africa in 2012, miners were striking because of dangerous working environments and low wages. A series of devastating and violent incidents followed, resulting in the deaths of 44 people.

The Bushveld Igneous Complex has the world's largest primary source of platinum group metals, indicated on the map in light blue. It is one of the most important mining areas in South Africa because of its abundance of minerals.

Figure 21.31: The Cullinan Premier Diamond Mine, near Pretoria, Gauteng.

ACTIVITY Create your own mining map

Instructions

1. Use the map of South Africa and the data provided in the table below to draw your own map of where mining in South Africa takes place. You will need to find out where the towns are located in South Africa and indicate them on the map.
2. Your teacher will indicate whether you must show all the locations, or a selection of the ones provided.
3. You need to decide on a key for your map and appropriate labels.
4. Also complete the table by filling in the chemical symbols or formulae and answer the questions that follow.

Mineral	Chemical symbol/formula	Where it is found
Lead		Aggenys
Andalusite	Al_2SiO_5	Namakwaland; north of Lydenburg; Eastern Bushveld Complex
Zinc		Aggenys; between Vryburg and Kuruman
Iron		Vredendal; Postmasburg; Sishen/Kathu, Thabazimbi
Salt		Port Elizabeth; Velddrif; between Prieska and De Aar; Douglas; Koffiefontein; Jacobsdal; Petrusburg, Upington

Mineral	Chemical symbol/formula	Where it is found
Limestone		Port Elizabeth; Port Shepstone; Saldanha; Lichtenburg; Mahikeng; Zeerust; between Christiana and Bloemhof; West of Thabazimbi
Vermiculite	$(Mg,Fe^{2+},Al)_3(Al,Si)_4O_{10}(OH)_2 \cdot 4(H_2O)$	Between Pietermaritzburg and Durban; east of Musina; west, south and east of Makhado; Phalaborwa
Diamonds		Kimberley; northwest of Kimberley; Alexander Bay; Luderitz; Port Nolloth; on the west coast north of Vredendal; Mahikeng; north of Ventersdorp; Cullinan; west of Musina
Titanium		West coast north of Saldanha Bay; Richards Bay
Manganese		North of Kuruman; northeast of Ventersdorp
Zirconium		West coast north of Saldanha Bay; Richards Bay
Gold		Virginia; Welkom; Stilfontein; Klerksdorp; Potchefstroom; Carletonville; Johannesburg, Vereeniging; Vryheid, Barberton; west of Phalaborwa; Evander
Chromium		Western Bushveld Complex; Eastern Bushveld Complex
PGMs		Western Bushveld Complex; Eastern Bushveld Complex; Northern Bushveld Complex
Phosphate		Phalaborwa
Coal		Virginia; Welkom; Bothaville; Kroonstad; Vereeniging; Sasolburg; Vanderbijlpark; Dundee; Newcastle; Utrecht; Vryheid; Ermelo; Standerton; Secunda; Evander; Witbank; Middleburg; Carolina; Lephalale
Nickel		West of Barberton
Copper		Aggenys/Springbok; Phalaborwa; Western Bushveld Complex; Eastern Bushveld Complex
Antimony		West of Phalaborwa

Questions

1. What mineral(s) are mined closest to where you live?
2. What do you notice about the gold mines in South Africa?
3. There are two types of diamond mining, alluvial (which is found on the coast or in inland rivers which have washed through kimberlite pipes) and kimberlite (which is found inland). What is the link between these two types of diamond mining?
4. Which mining industry do you think is the best or most important one in South Africa? Give a reason for your answer.

ACTIVITY Drawing a mining flow diagram

Instructions

1. Choose one mining industry mentioned in this unit. It can be the one you are doing your research project on.
2. Draw a flow diagram to show the different steps in the mining of the chosen mineral.
3. End your flow diagram with something or somewhere where this mineral is used in real life. Look at the beginning of the unit for a generic flow diagram for mining. Draw your flow diagrams in your books.

The impact of mining

Mining has played a major role in the history of South Africa. It accelerated technological development and created infrastructure in remote areas in South Africa. Many small towns in South Africa started because of mining activity in the area. It also created a demand for roads and railways to be built. Most importantly, it created job opportunities for thousands of people. Even today many households are dependent on mining activities for jobs and an income. Mining is an important part of our economic wealth. We export minerals and ore to many other countries in the world.

Mining activities also have a negative impact on the environment. In many cases the landscape is changed. This applies particularly to surface mines (open pit mines), where large amounts of soil and rock must be removed in order to access the minerals.

Take note

Tailings are the materials left over after separating the valuable minerals from the ore.

The shape of the landscape can be changed when large amounts of rocks are dug up from the Earth and stacked on the surface. These are called mine dumps. Open pit mines also create very large unsightly and dangerous holes (pits) in the ground that change the shape of the land.

Air and water pollution can take place if care is not taken in the design and operation of a mine. Dust from open pit mines, as well as harmful gases such as sulphur dioxide and nitrogen dioxide, could be released from mining processes and contribute to air pollution. Mining activities produce carbon dioxide. Trucks and other vehicles give off exhaust gases. If the mining process is not monitored properly, acid and other chemicals from chemical processing can run into nearby water systems such as rivers. This is poisonous to animals and plants, as well as to humans, who may rely on that water for drinking.

An example are pollutants (dangerous chemicals), called tailings, left over from gold mining, which pose a threat to the environment and the health of nearby communities. Dangerous waste chemicals can leak into the groundwater and contaminate water supplies if the tailings are not contained properly.

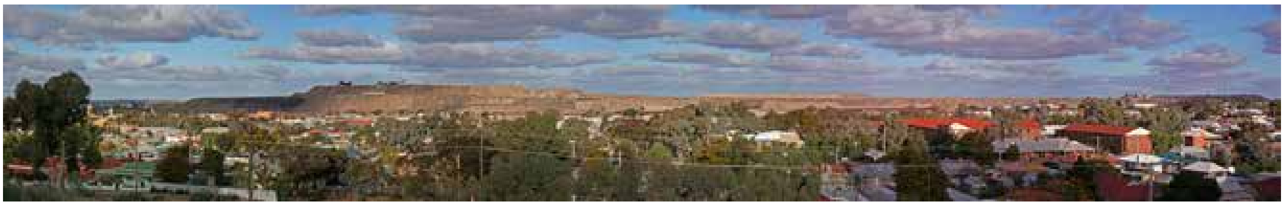


Figure 21.32: An aerial photograph of Primrose Gold Mine. Can you see the piles of gold tailings on the left of the photograph?

ACTIVITY What would we do without mining?

Instructions

1. Imagine that all the mines in South Africa close down. What do you think would be the impact on the points outlined below?
   a) Carbon emissions
   b) Jobs
   c) Economy
   d) Future of small towns
   e) Add one of your own issues here.
2. Discuss the following aspects with your group.
3. Present your discussion to the class in a few short sentences on each issue.

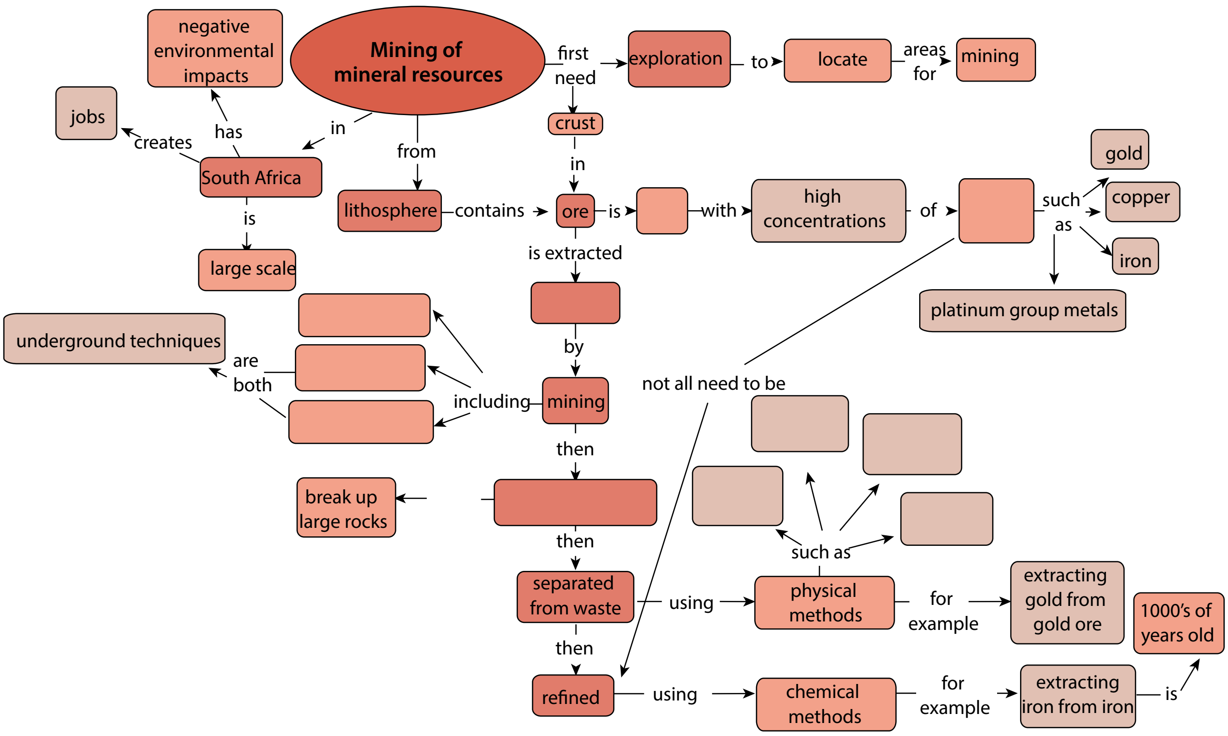
Summary

Key concepts

- People extract valuable minerals from the lithosphere.
- Rock that contains high concentrations of valuable minerals are called ore.
- Various methods are used to locate potential sites for mining.
- Ore is removed from the crust by mining, either on the surface (open-pit mining) or underground (shaft mining or room-and-pillar mining).
- Some minerals can be used in their natural form, for example sand in the building industry, phosphate rock for fertilisers, and diamonds in jewellery.
- Some minerals require a physical and/or chemical process to remove them from the ore.
- Large rocks containing minerals need to be crushed and milled.
- The valuable minerals are then separated from the rock using a variety of physical and chemical separation methods.
- People have extracted minerals, for example iron and copper, from ores for thousands of years.
- Examples of how minerals were mined long ago can be found at archaeological sites in South-Africa, such as Mapungubwe.
- Today iron is extracted using coke (carbon) to make steel.
- South Africa has a large mining industry.
- The industry creates jobs and contributes to the economy.
- The mining industry has a significant impact on the environment.

Concept map

Use the following concept map to summarise what you have learnt in this unit about mining of mineral resources. What are the three types of mining that we discussed in this unit? Fill these into the concept map. Remember that you can add in your own notes to these concept maps, for example, you could write more about the environmental impacts of mining.



Revision

1. Bauxite is an aluminium ore that contains four different minerals: Al, SiO_2, TiO_2 and Fe_2O_3.
   a) What are the chemical names of each of these minerals? [4]

Bauxite.

   b) Bauxite is found close to the surface of the Earth. What type of mining would you expect to be used in bauxite extraction? [1]
   c) What is the common name for SiO_2? [1]
   d) SiO_2 is present as unwanted material in the iron blast furnace and needs to be removed. How is it removed and what is the waste product used for? [2]
   e) Bauxite also contains iron(III)oxide. Write down the common name for iron(lll)oxide. [1]
   f) Suggest one way of separating the iron(III)oxide from the rest of the minerals in bauxite. Give a reason for your answer. [2]

2. Explain how iron is extracted from iron ore. [6]

3. Write a balanced equation for the extraction of iron from its ore. [3]

4. What is the environmental impact of the iron mining process? [2]

5. Case study: Read the following article and answer the questions that follow.

The story of Loolekop

Phalaborwa is home to one of the largest open-pit mines in the world. The original carbonate outcrop was a large hill known as Loolekop. Archaeological findings at Loolekop revealed small-scale mining and smelting activities carried out by people who lived there long ago. An early underground mine shaft of 20 metres deep and only 38 centimetres wide were also found. The shafts contained charcoal fragments dating the activities to 1 000 – 1 200 years ago.

In 1934 the first modern mining started with the extraction of apatite for use as a fertiliser. In 1946 a well known South African geologist, Dr. Hans Merensky, started investigating Loolekop and found economically viable deposits of apatite in the foskorite rock. In the early 1950s a very large low-grade copper sulfide ore body was discovered.

In 1964 the Phalaborwa Mine, an open-pit copper mine, commenced its operations. Today the pit is 2 km wide. Loolekop, the large hill, has been completely mined away over the years. A total of 50 different minerals is extracted from the mine. The northern part of the mine is rich in phosphates and the central area, where Loolekop was situated, is rich in copper. Copper with the co-products of silver, gold, phosphate, iron ore, vermiculite, zirconia and uranium are extracted from the rocks.

The open-pit facility closed down its operation in 2002 and has now been converted to an underground mine. This extended the lifetime of the mine for another 20 years. The mine employs around 2 500 people.

2 000 million years ago this area was an active volcano. Today the cone of the volcano is gone and only the pipe remains. The pipe is 19 km^2 in area and has an unknown depth, containing minerals such as copper, phosphates, zirconium, vermiculite, mica and gold.

This mine was a leader in the field of surface-mining technology with the first in-pit primary crushing facility. This meant that ore was crushed by jaw crushers before being taken out of the mine. They also used the first trolley-assist system for haul trucks coming out of the pit. Today the mine has secondary crushing facilities, concentrators, and a refinery on site.

In 1982 a series of cavities with well-crystallised minerals were discovered, for example calcite crystals up to 15 cm on edge, silky mesolite crystals of up to 2cm long and octahedral magnetite crystals of 1 – 2 cm on the edge.


Mesolite crystals


Hematite crystals


Calcite crystals

a) What type of rock would you find in the Phalaborwa mine? Give a reason for your answer. [2]

b) Why did the open pit facility closed down in 2002? [2]

c) What is phosphate rock used for? [1]

d) What has the impact of the Phalaborwa Mine been on the landscape? How was it possible for very large crystals to form? [2]

e) What are the environmental impacts of open pit mining? Name any three. [3]

Total [32 marks]

23 The atmosphere

Key questions

- What is the atmosphere?
- What makes up the atmosphere?
- Does the atmosphere change as you go further from the Earth's surface?
- Can the atmosphere be divided into different layers?
- Where does the atmosphere end?
- What important aspect of the atmosphere allows life to exist on earth?
- What is the greenhouse effect?
- How do humans contribute to the greenhouse effect?

In the first unit of *Earth and Beyond*, you learnt about the different spheres of the Earth. The atmosphere was mentioned briefly in Unit 20. In this unit we will look at the atmosphere in more detail.

Keywords

- atmosphere
- troposphere
- stratosphere
- mesosphere
- thermosphere
- exosphere
- altitude
- temperature gradient
- density

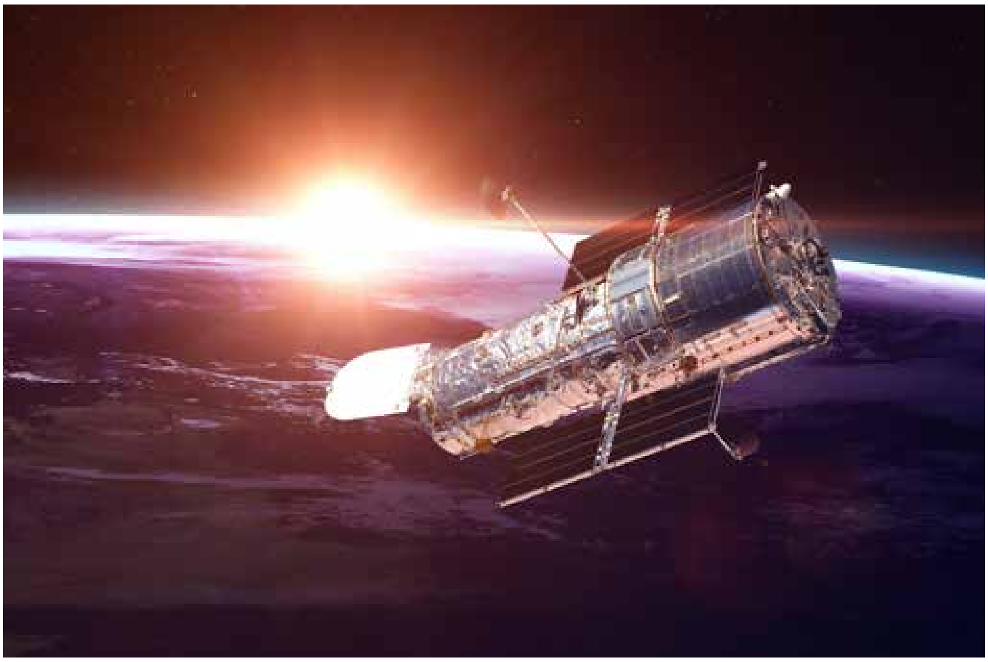


Figure 23.1: Photograph of the Earth's atmosphere taken from the International Space Station. You can see the curved Earth below the bright atmosphere – a very thin layer of gases around the Earth. Above and beyond the atmosphere is where we find outer space. The bright spot is the Sun just going below the horizon.

23.1 The atmosphere

The atmosphere is the layer of gases which surrounds the Earth. It contains the following mixture:

- nitrogen (78,08%)
- oxygen (20,95%)
- argon (0,93%)
- carbon dioxide and other trace gases (0,04%).

Take note

The exosphere is not considered part of the atmosphere because of the very low density of gases, but it is still briefly discussed in this unit. In some other resources which you may look at, the exosphere is sometimes discussed as a layer or upper limit of the atmosphere.

The gas molecules in the atmosphere are kept close to the Earth by gravity. The effect of gravity means that there will be more gas molecules closer to the Earth's surface than further away. As you move further and further away from the surface of the Earth, the gas molecules become fewer and the spaces between the molecules become larger, until there are no more gas molecules and only spaces are left. The atmosphere therefore does not have a set boundary, but rather fades away into space.

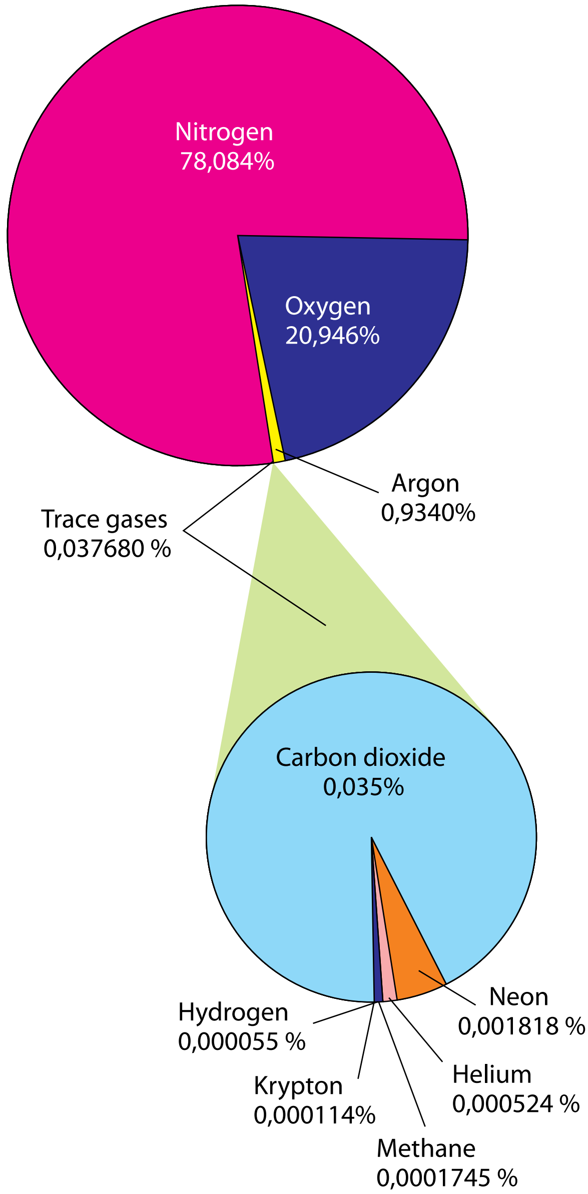


Figure 23.2: The composition of the atmosphere by volume.

Density and altitude

When we walk up a very high mountain, there is less oxygen present. We may feel out of breath. People sometimes say that the air is thinner higher up. When they say this, they mean that there is a lower concentration of oxygen molecules.

The **density** of the atmosphere decreases with an increase in the height above sea level (altitude).Density is an indication of how many particles are present in a specific volume of gas. When the density is high, there are lots of gas molecules present. If the density is low, there are fewer gas molecules present.

Take note

Sports teams and athletes need to acclimatise before performing when they get to a new location at altitude, so that their bodies can get used to the lower level of oxygen.

The atmosphere is a very important part of the Earth. It keeps the planet warm and protects us from the harmful radiation of the Sun. It also ensures a healthy balance between oxygen and carbon dioxide so that life can be sustained on the planet.

The layers of the atmosphere

The atmosphere has four main layers. We start measuring these from sea level and move towards space. The diagram alongside illustrates this. The surface of the Earth is at the bottom of the diagram, with Mount Everest drawn in. The first layer is the **troposphere**, then the **stratosphere**, the **mesosphere** and the **thermosphere**. Above the thermosphere, the atmosphere merges with outer space in the layer known as the exosphere.

The atmosphere is actually a very thin layer compared to the size of the Earth. It is almost like the skin of an orange, relative to the size of the orange.

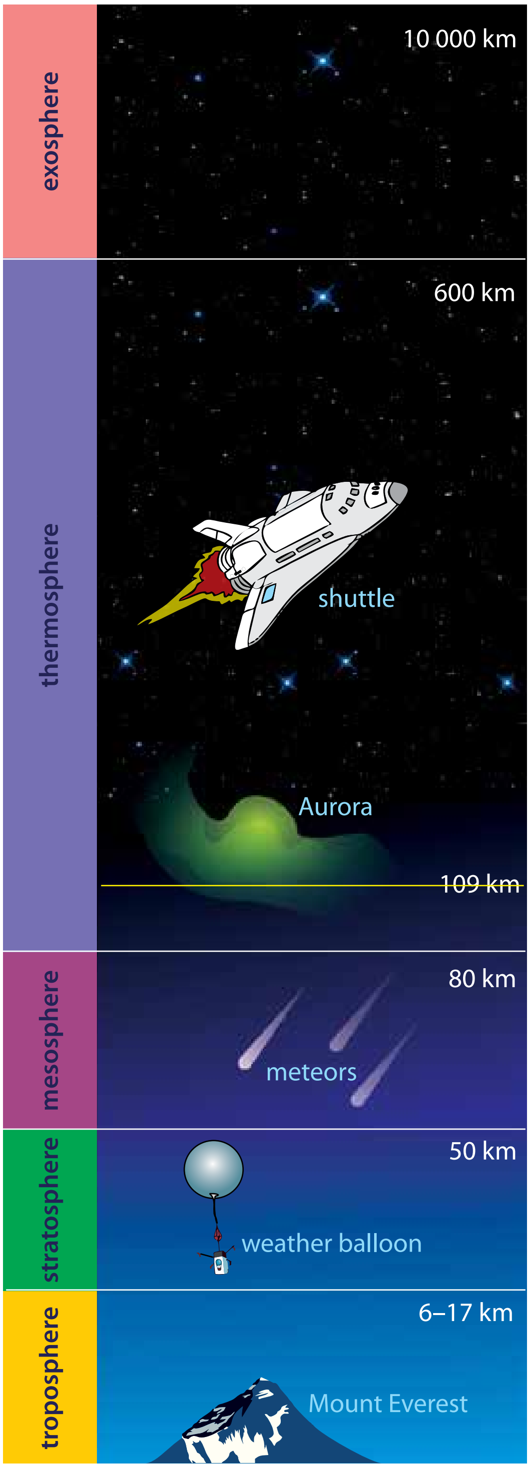


Figure 23.3: Space Shuttle Endeavour in between the stratosphere (white layer) and mesosphere (blue layer). The orange layer is the troposphere.

Figure 23.4: The layers of the atmosphere, and the exosphere.

ACTIVITY How thick is the atmosphere compared to the size of the Earth?

Questions

1. You need to draw a scale diagram to show how thick (or thin) the atmosphere is in comparison to the size of the Earth. Use graph paper.

Did you know?

Some endurance athletes spend several weeks training at high altitudes, preferably 2 400 m above sea level, so that their bodies adapt by producing more red blood cells. This gives them a competitive advantage when returning to a lower altitude to compete.

Take note

Altitude is a measure of height above sea level.

2. Answer the following questions to help you draw the diagram.
   a) What is the radius of the Earth? Choose an appropriate scale and draw a circle in your notebook to represent the Earth.
   b) How thick is the atmosphere in km? Use the same scale as above and draw the atmosphere around the Earth.
   c) Indicate the atmosphere density gradient on your diagram.

Each layer of the atmosphere has a different **temperature gradient**, in other words, the temperature changes gradually as you move through each layer. The following graph shows how the temperature changes as you move through the atmosphere. The layers of the atmosphere are also indicated on the graph.

Temperature is on the *x*-axis and altitude is on the *y*-axis. The red line shows the change in temperature. Note that as you move further to the left on the graph it is colder, dropping far below 0 °C, and further to the right is hotter, reaching over 1 000 °C.

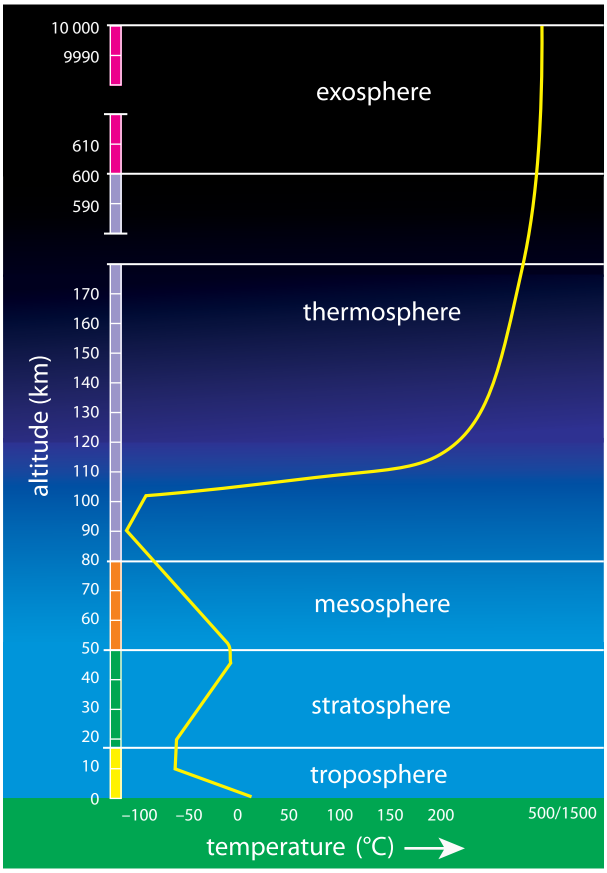


Figure 23.5: The average temperature profile of the Earth's atmosphere and the exosphere.

Now let's look at each of the layers of the atmosphere.

23.2 The troposphere

The troposphere is the lowest layer in the atmosphere. It stretches from sea level up to about 9 km at the poles and 17 km at the equator. As a result of the Earth's rotation, the atmosphere is thicker at the equator than at the poles. On average it is about 12 km thick.

The density of air decreases as you move further away from the surface of the Earth. The first two layers of the atmosphere contain most of the mass of the atmosphere. The bottom part of the troposphere has a high enough density for us to breathe and is the layer of the atmosphere in which we live.

Figure 23.6: Shown here is the orange-coloured troposphere, the lowest and most dense portion of the Earth's atmosphere above the Earth's surface, with the Moon above.

The air in the troposphere is in constant motion. As it is warmed by the Earth, the warm air moves away and gets replaced by cooler air which travels in convection currents. This is the basis for cloud formation and weather patterns.

All the Earth's weather systems take place close to the Earth in the troposphere.

Figure 23.7: Cloud formations typical of a tropical cyclone. This one was photographed approaching the south-eastern coast of Brazil.

Figure 23.8: Clouds forming in the troposphere.

The temperature in the troposphere decreases with altitude – the further you move away from the surface, the colder it becomes. The temperature decreases about 6,4 °C for every kilometre increase in altitude. In the following activity you will investigate the change in temperature as height above sea level increases.

Take note

Troposphere comes from the Greek word 'tropein', meaning to change, circulate or mix.

ACTIVITY Drawing a graph of the temperature gradient in the troposphere

Questions

1. Using the information in the previous text, set up your own table displaying the temperature change in the troposphere from 0–12 km.
2. Then draw a neat, accurate graph of this data.
3. Assume that the average temperature on the surface of the Earth is 16 °C.
4. Choose an appropriate scale for the *x*- and *y*-axes of your graph.
5. Label the axes and give the graph a heading.
6. Draw a table for your data.
7. Draw your graph.

The temperature in the troposphere decreases steadily until it reaches about –60 °C at about 10 – 12 km above sea level. The temperature here stabilises before it increases again. This is the transition zone between the troposphere and the stratosphere. This layer forms an invisible barrier which prevents the warmer moist air from escaping from the troposphere. Beyond this region air does not circulate much and weather patterns are not found any more.

Keywords

- ozone
- CFCs

23.3 The stratosphere

The stratosphere is the layer above the troposphere. It stretches from 12 km to 50 km above the surface of the Earth. 90% of the mass of the atmosphere is found in the troposphere and the stratosphere.

Aeroplanes fly in the lower stratosphere because the air is much more stable than in the troposphere. The density of the air in the stratosphere is very low and decreases with altitude.

Scientists use **weather balloons** to gather information on the temperature and pressure as they move up from the Earth's surface to the stratosphere. A weather balloons carries a small device, called a radiosonde, which sends back information on atmospheric pressure, temperature, humidity and wind speed.

Did you know?

Weather balloons were first used 70 years ago, and are still the key instrument for meteorologists to assess and predict the weather. This information is used in many ways, for example, to compile the weather report on TV or to warn of flooding or hurricanes.

Figure 23.9: A weather balloon being released from a US Navy ship.

Figure 23.10: A photograph taken by a weather balloon 30 km above Earth in the stratosphere.

Weather balloons are filled with helium or hydrogen and rise higher and higher into the atmosphere. Do you think they continue rising up for ever? What do you think happens to the balloon as it increases in altitude? Hint: Think of what happens to the gas inside the balloon as the altitude increases. Discuss this with your class and write some notes in your exercise books.

Ozone gas (O_3) is found in the stratosphere. Ozone gas is made up of ozone molecules. Each molecule consists of three oxygen atoms. Ozone plays an important role in absorbing harmful UV rays from the Sun by forming, breaking down and reforming ozone molecules over and over again. When UV light reaches the Earth, it can cause cancer and affect plant growth, and the life cycles of species.

Take note

Although ozone is considered a pollutant in the troposphere, in higher altitudes in the stratosphere, ozone is considered vital as it protects Earth from too much ultraviolet radiation.

What happens to ozone in the atmosphere?

The formation and destruction of ozone is a natural process that takes place in the stratosphere. Oxygen forms ozone, and ozone breaks apart again to form oxygen. The following diagram shows the reactions that take place.

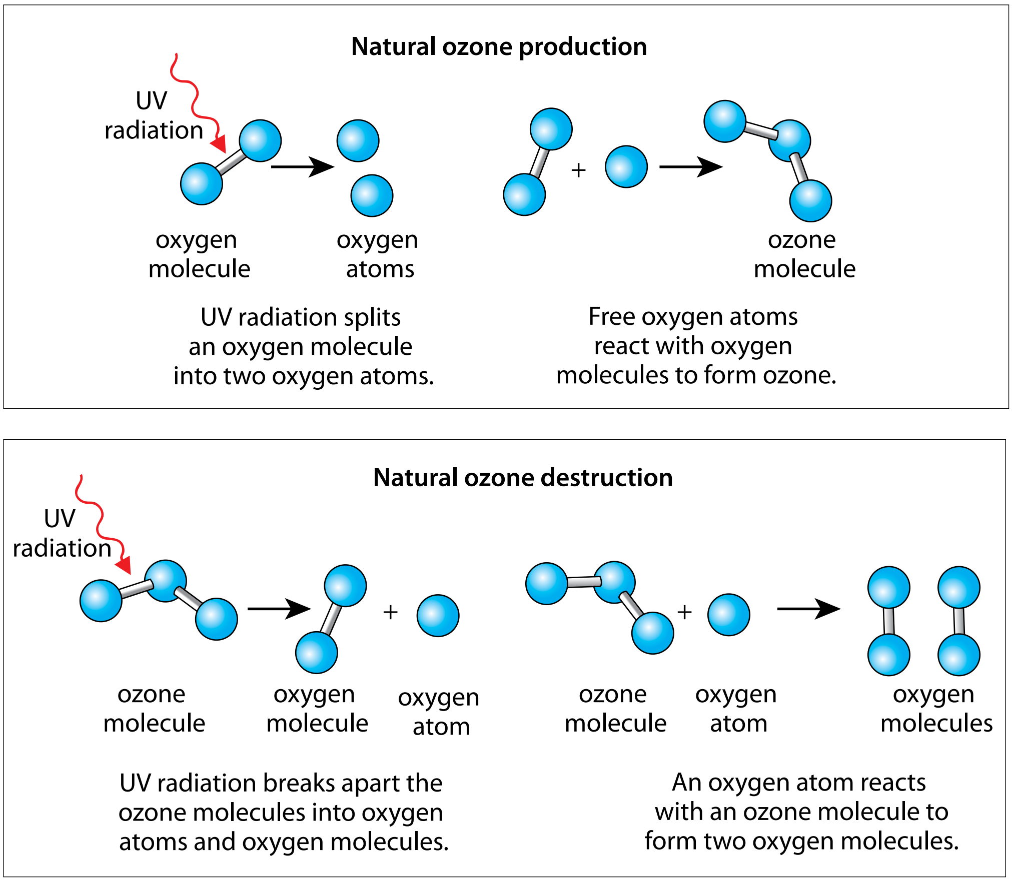


Figure 23.11: Production and destruction of ozone.

Did you know?

The ozone hole is an annual thinning of the ozone layer over Antarctica, caused by chlorine from CFCs in the stratosphere.

What holds the oxygen atoms together in a molecule?

What is the term given to a molecule of oxygen which consists of two atoms of the same element bonded together?

The ozone reactions lead to the heating of the stratosphere, increasing the temperature from –60 °C to about 0 °C. As a result, the air becomes warmer as you move further away from the Earth in the stratosphere. The problem arises when there are molecules present which interfere with these natural

Did you know?

NASA is thinking of sending high-altitude weather balloons to probe the atmosphere of Mars.

processes. Chlorofluorocarbons, or CFCs, are molecules which release chlorine atoms into the stratosphere. Chlorine atoms react with ozone, destroying it before it can absorb harmful UV rays. The following diagrams show how CFCs react with ozone.

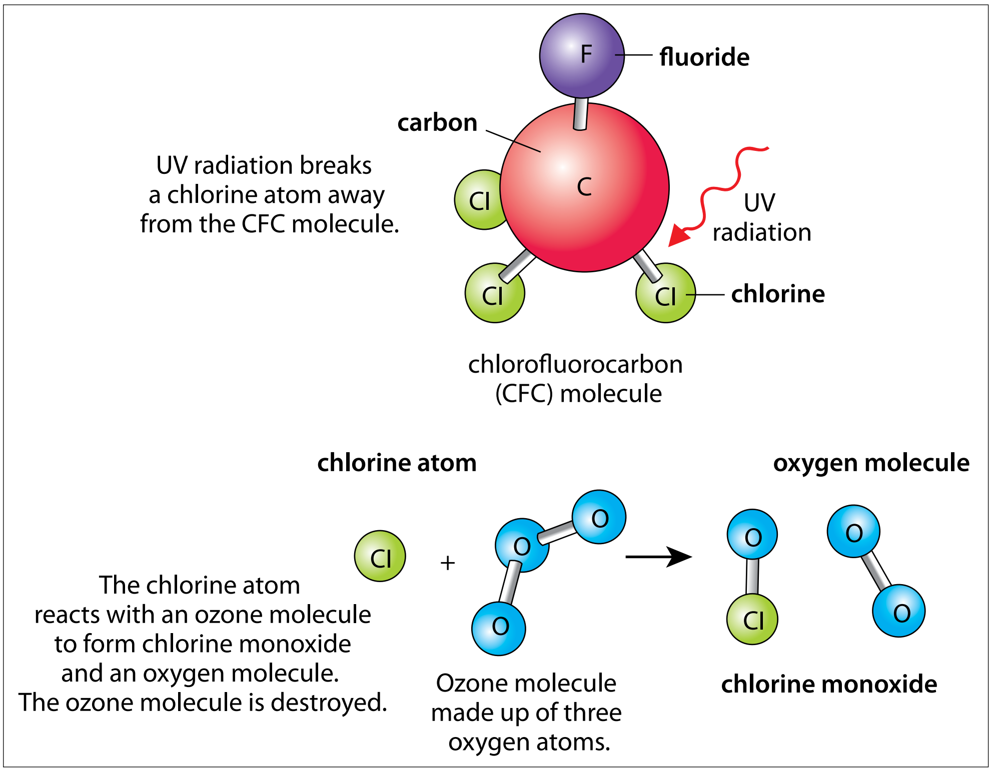


Figure 23.12: CFC's react with ozone.

CFCs used to be found in aerosols and refrigerator gas, and were given off by industrial processes. Scientists noticed that these gases interfered with ozone. This could have had a serious impact on life on Earth and the use of CFCs was banned.

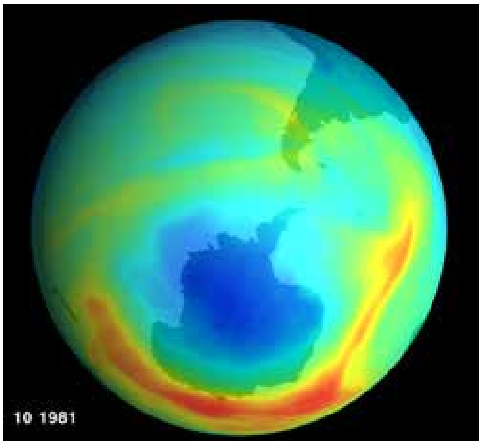


Figure 23.13: In 1985, a British scientist working in Antarctica discovered a 40 percent loss in the ozone layer over the continent. In the 1990s, this prompted a worldwide ban on CFCs. In this image, the blue/purple areas show low ozone, while the red areas indicate higher ozone levels.

Did you know?

On 14 October 2012 Felix Baumgartner set a world record by jumping from an altitude of about 39 km – from the stratosphere to the Earth. He is the first man to jump from the stratosphere.

23.4 The mesosphere

The mesosphere extends from around 50 km to 80 km above the Earth's surface. The atmosphere reaches its lowest temperature (–90 °C) in the mesosphere. The air density is extremely low, but there is still enough air to burn up rocks and dust entering from space.

A **meteor** is a rock that enters the atmosphere from space. It travels at extremely high speed, up to 30 000 m/s. As a meteor enters the atmosphere, the air in front of it is compressed. The air heats up and the meteor burns up as a result of heat and friction. When we look up at the night sky, we may see a streak of light flashing for a brief moment. This is commonly called a shooting star, but is in fact a meteor burning up in the mesosphere.

Figure 23.14: A meteor is a rock burning up in our atmosphere.

Most meteors are fairly small and burn up completely while whizzing through the mesosphere. Some of the larger, denser meteors can reach the Earth and are then called **meteorites**. When the meteorite strikes the ground, it kicks up dust and soil and leaves an impact crater on the Earth's surface. The size of the crater depends on the size, density and speed of the meteorite.

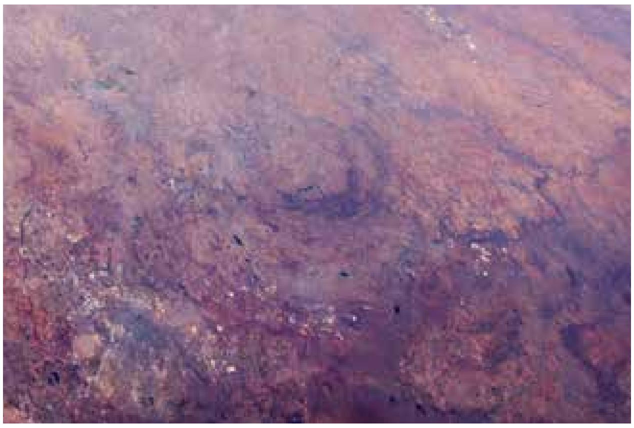


Figure 23.14: The impact crater at Vredefort in South Africa has a diameter of 300 km, and nearly fills the complete aerial photograph shown here.

Figure 23.15: The Tswaing Crater, just north of Pretoria, is 1,1 km wide and formed as the result of a meteorite impact about 200 000 years ago.

23.5 The thermosphere

The thermosphere is the layer of the atmosphere from 80 km upwards. The density of the air is extremely low. The further away you move from the Earth, the less dense the concentration of molecules becomes until the atmosphere becomes space. Most satellites that we depend on every day are in Low Earth Orbit (LEO), orbiting the Earth at an altitude between 160 km and 2 000 km. The **International Space Station** (ISS) is situated at 370 km into the thermosphere. This is an international facility in space that is used for research purposes.

Keywords

- meteor
- meteorite
- ionosphere
- aurora
- northern lights (Aurora Borealis)
- southern lights (Aurora Australis)
- International Space Station

Did you know?

In 2002, Mark Shuttleworth became the first South African in space when he launched with a Russian space mission. He spent eight days on board the International Space Station, participating in experiments related to AIDS and genome research.

Figure 23.16: The International Space Station orbits the Earth in the thermosphere.

The temperature in the thermosphere increases from –90 °C to as high as 1 500 °C. The thermosphere is very sensitive to an increase in energy, and a small change in energy results in a high temperature increase. At times of increased solar activity, the temperature can easily increase up to 1 500 °C. However, the thermosphere will feel cold as there are few particles present to collide with our skin and transfer enough energy for us to feel the heat.

High energy light (for example, UV light) can cause atoms or molecules to lose electrons, forming ions. The region where this takes place is called the **ionosphere**. The ionosphere is found mainly in the thermosphere. The Sun also gives off charged particles (the solar wind), which can enter the Earth's atmosphere (mostly near the poles) and react with the ions and electrons in the ionosphere, causing a phenomenon called an **aurora**. It is a colourful display of light in the sky at the poles. In the northern hemisphere, it is called the **northern lights** or **Aurora Borealis**, and the **southern lights** or **Aurora Australis** in the southern hemisphere.

The ionosphere reflects longer wavelength radio waves, for example the radio waves we use for radio and surface-broadcast television (not satellite television), allowing the signal to be broadcast over a larger distance. The ions in the ionosphere also absorb ultraviolet radiation and X-rays. The region beyond the thermosphere is called the **exosphere**. This layer has very few molecules and extends into space.

Figure 23.17: Sunset from the International Space Station. The troposphere is the deep orange and yellow layer. Several dark clouds are visible within this layer. The pink-white layer above is the stratosphere. Above the stratosphere, blue layers show the mesosphere, thermosphere (dark blue) and exosphere (very dark blue), until it gradually fades to the blackness of outer space.

ACTIVITY How thick are the layers of the atmosphere?

In this activity you will build a model to represent the different layers of the atmosphere. In addition to the model, you need to draw an accurate diagram in your workbook to represent the thickness of each layer. Use a ruler to draw an accurate scale diagram.

Figure 23.18: Beans, samp, popcorn and dried peas.

Materials

- large measuring cylinder or tall drinking glass
- corn kernels (popcorn)
- samp
- dried peas
- beans
- ruler

Instructions

1. Add a 0,5 cm layer of dried split peas to represent the troposphere (1 layer of peas thick).
2. Add a 1,5 cm layer of corn kernels on top of the peas to represent the stratosphere.
3. Add a 1,5 cm layer of samp on top of the corn kernels to represent the mesosphere.
4. Add a 24 cm layer of beans on top of the samp to represent the thermosphere.

Your column should look something like this.

A close-up photograph of the layers.

Figure 23.19

You will notice that the area where the two layers meet is not always clear cut. The kernels may have mixed a little bit. The atmosphere is the same. There is a not a clear line separating two layers, but they mingle in the area of contact.

Table showing the heights of the layers in Earth's atmosphere and in the model:

Layer	Represented by	Height of layer (km)	Height of layer (cm)
Troposphere	Dried split peas	10	0,5
Stratosphere	Corn kernels	30	1,5
Mesosphere	Samp	30	1,5
Thermosphere	Beans	480	24

Questions

1. Draw a labelled diagram of the model using a graph paper. Include a scale. The density of the atmosphere decreases with altitude. Show this on your diagram as well.
2. What atmospheric layers are represented by the different grains in the model?
3. In the model in the activity, how many kilometres does 1 cm represent?
4. How much thicker is the stratosphere compared to the troposphere?
5. How much thicker is the thermosphere compared to all the other layers combined?
6. Where in this model would you expect to find clouds?
7. Where in this model would you expect to find the Drakensberg Mountains?
8. Where in this model would you expect to find a satellite?
9. Where in this model would you expect to find meteors burning up?
10. In which layer is there life? What is different about this layer?

Keywords

- greenhouse gases
- greenhouse effect
- global warming
- climate change
- carbon dioxide
- methane
- water vapour
- radiation

23.6 The greenhouse effect

You have learned a lot about greenhouse gases in Natural Sciences. In this section we will be looking at how important greenhouse gases are to sustain life on Earth.

Earth's atmosphere contains mostly (99%) nitrogen and oxygen, but a small percentage (1%) of the atmosphere contains gases such as **water vapour** (H_2O), **carbon dioxide** (CO_2), and **methane** (CH_4). Carbon dioxide is a product of respiration in all organisms and also a gas given off by industrial processes and the burning of fossil fuels and vegetation.

Methane is a gas, also called natural gas, which occurs in reservoirs beneath the surface of the Earth. It is also given off by decomposing plant and animal material, and animals give off methane as part of their digestion. Water vapour is formed when water evaporates on Earth.

Water vapour, methane and carbon dioxide are gases which let through incoming visible light from the Sun. The incoming radiation from the Sun is absorbed by the Earth's surface and warms it. The Earth's surface emits **infrared radiation**. Infrared radiation is absorbed by the greenhouse gases and re-emitted in all directions. This increases the temperature of the Earth's surface and lower atmosphere, above what it would be without the gases, called the **greenhouse effect**. These gases play a very important role in regulating the Earth's temperature.

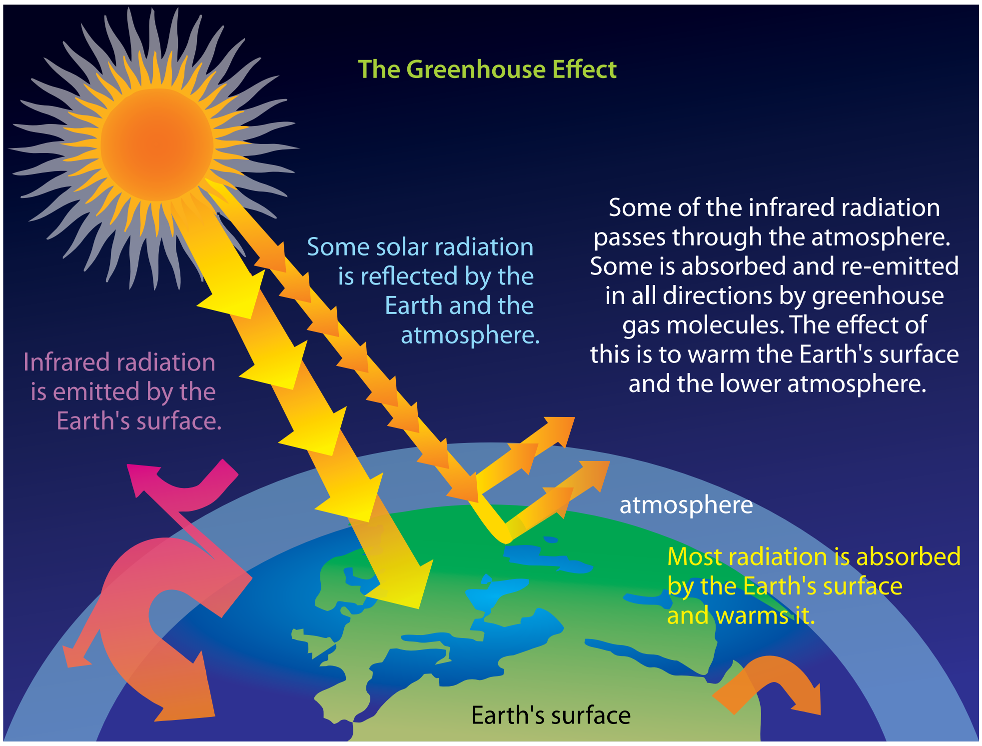


Figure 23.20: The greenhouse effect.

As you can see in the diagram, the radiation from the Sun is able to reach the Earth and warm it up. The energy that is given off by the Earth is trapped by the water vapour, carbon dioxide and methane. This ensures that the Earth stays warm. It is almost as if the gases form a blanket around the Earth keeping some of the heat inside. The gases are referred to as **greenhouse gases**. A greenhouse is a glass structure that is used to grow plants. The glass lets the heat of the Sun through, but then keeps the heat inside the structure so that the plants have a moderate climate in which to grow. Water vapour, carbon dioxide and methane act in the same way.

The Earth is a very unique planet because of the make-up of its atmosphere. In this unit you have learned about the composition of the Earth's atmosphere. Let us compare the atmosphere of Earth to its neighbouring planets, Mars and Venus.

ACTIVITY Comparing Venus, Earth and Mars

Figure 23.21: Venus, Earth and Mars.

Instructions

1. The table below gives information about the gases in the atmospheres of the three planets: Venus, Earth and Mars.
2. Study the table and answer the questions that follow. Percentage of gases making up the atmospheres of Venus, Earth and Mars.

	Venus	Earth	Mars
Carbon dioxide (CO_2)	96,5%	0,03%	95%
Nitrogen (N_2)	3,5%	78%	2.7%
Oxygen (O_2)	Trace	21%	0,13%
Argon (Ar)	0,007%	0,9%	1,6%
Methane (CH_4)	0	0,002%	0

Questions

1. Compare the data for Venus and Earth. What similarities and differences do you notice?
2. Compare the data for Venus and Mars. What similarities and differences do you notice?
3. What is the biggest difference between Earth's atmosphere and the atmospheres of the other two planets?
4. Why is the level of oxygen so much higher on Earth than on the other two planets?
5. Why do you think there is no methane gas on Venus and Mars?
6. Predict whether you think the temperature on the surface of Venus will be low or high. Give reasons for your answer.

The atmospheres of Venus and Mars are very similar. Both planets have mainly carbon dioxide in the atmosphere, and very few other gases. However, the two planets are quite different.

Did you know?

Venus is the hottest planet in the solar system; the temperature is hot enough to melt lead.

Venus has a very dense atmosphere which results in a high concentration of carbon dioxide on its surface. This causes an extreme greenhouse effect and very high temperatures on the surface of Venus. Venus has an average surface temperature of 462 °C. This is too high to sustain life as we know it.

Mars, on the other hand, has almost no atmosphere, so, although there is carbon dioxide present, the density is very low and almost no greenhouse effect takes place. Mars is also much further away from the Sun. It is a very cold planet, with an average temperature of –55 °C. This is too low to sustain life as we know it.

Earth has the right composition of atmospheric gases to sustain life. It has the right balance between oxygen and nitrogen so that plants and animals can breathe, and just enough carbon dioxide and methane to keep the planet warm enough so that life can be sustained. Many scientists think that it is the life on Earth that keeps the atmosphere in this perfect balance. Plants produce oxygen and re-circulate carbon dioxide on Earth. They believe that if life were to disappear from Earth, the atmosphere would become like Mars or Venus.

Investigation A model of the greenhouse effect

In the greenhouse effect, carbon dioxide traps the heat of the Sun. In this investigation, you will use bottles with air and carbon dioxide, respectively, to model the greenhouse effect. You are going to investigate the following question: Does air or carbon dioxide absorb more heat?

Aim

Write an aim for this investigation.

Hypothesis

Write a hypothesis for this investigation.

Materials and apparatus

- two glass bottles or clear cold drink bottles with lids
- 2 thermometers
- Prestik
- heat source (two study lamps)
- vinegar
- bicarbonate of soda
- small cold drink bottle with lid

Method

Set up the experiment as in the photograph.

Figure 23.22: Experimental set-up

1. Mark one bottle as 'Air' and the other bottle as 'CO_2'.

2. If the lids do not have the thermometers in them already, prepared by your teacher, make a hole in each of the lids. You can do this using a hammer and nail and hammering the nail through the lid into a wooden block. Secure the thermometer in each lid. You can use Prestik to do this.

3. Fill the first bottle with air, secure the thermometer, and close the lid tightly.
4. Fill the second bottle with carbon dioxide:
   a) To collect a bottle of carbon dioxide, add one tablespoon of bicarbonate of soda to the small bottle.
   b) Add 10–20 ml of vinegar and place the lid back on.
   c) Hold the mouth of the small bottle over the large CO_2 container and pour the CO_2 collecting in the small container into the large container.
   d) Hold the small bottle horizontal so that the vinegar does not spill into the bigger bottle; only the heavier carbon dioxide gas pours into the large container.
   e) Add more vinegar when the effervescence stops. Repeat 2–3 times until the bottle is full. If a burning match at the mouth of the bottle goes out immediately, the bottle is full.
   f) Secure the thermometer and close the lid tightly.

Figure 23.23: Pour carbon dioxide from the small bottle into the large bottle. Your teacher will prepare the carbon dioxide for you.

5. Measure and record the starting temperature of both bottles.
6. Switch on the heat source and measure the temperature increase in both bottles. You need to decide for yourself what time increments are appropriate and record these in the table.

Figure 23.24: The CO_2 container with the light positioned to shine on it.

Results

Copy and complete the table below in your exercise books.

Time (minutes)	Temperature of air bottle (°C)	Temperature of CO_2 bottle (°C)

Represent your results by drawing a graph for each of the experiments to show how the temperature for each bottle changed over time. You need to decide what values to use for each axis. Label the axes clearly and provide a heading for each graph.

What have you observed?

Conclusion

What do you conclude for your experiment?

Extension investigation

What factors make the temperature of the atmosphere increase faster?

Design your own investigation to answer one or more of the following questions. Use the experiment above to guide your experimental set-up.

1. Does dark soil make the temperature increase more quickly?
2. Does water vapour make the temperature increase more quickly?
3. Does the thickness of the layer of gases make the temperature increase more quickly?
4. Does the presence of dust/aerosols make the temperature increase more quickly?
5. Does the distance of the Sun make the temperature increase more quickly?

Global warming

What do you think will happen if the levels of carbon dioxide and other greenhouse gases increase? Think about what you discovered in the last investigation and look at the diagram of the greenhouse effect again. Write down your answer.

If there are more greenhouse gases in the atmosphere, more ultraviolet radiation will be trapped and the Earth will heat up. This will result in more of the polar ice melting than usual. Even a difference of one degree in the average temperature has an effect on the melting of polar ice. If more ice than usual melts, the water levels in the oceans will rise and low-lying areas could flood.

> **Take note**
>
> An **ice core** is a core sample from the accumulation of snow and ice over many years that have recrystallised and have trapped air bubbles from previous time periods

A change in the temperature will also result in a change in weather patterns.

More rain will fall in some areas, and less in others. If this change is permanent, it is called **climate change**, and if it occurs on a worldwide scale, it is called global climate change, which is what is being discussed here.

Global warming affects weather patterns, which in turn has a knock-on effect on agriculture and food production. The impact on food production can lead to food shortage for humans and animals. Long-term climate change can lead to the extinction of plants and animals, which are unable to adapt to changed conditions.

The levels of greenhouse gases vary naturally over time. A question that scientists often ask is whether the concentration of greenhouse gases is rising more than it would naturally as a result of human activities. How do you think this can be investigated?

Since the industrial revolution humans have burned more fossil fuels than ever before. Human activities have resulted in the increase of carbon dioxide emissions over time. Carbon dioxide is therefore the main greenhouse gas under discussion amongst scientists and environmentalists. The following investigation will look at the levels of carbon dioxide over thousands of years.

> **Take note**
>
> The expression 'ppm' is short for 'parts per million'.

Investigation Ice core analysis

Carbon dioxide is trapped in the ice which forms at the poles. As the ice is compacted and becomes thicker over thousands of years, the carbon dioxide remains trapped. The levels of carbon dioxide in ice can be determined by analysing the ice cores. A research team in Antarctica drilled an ice core containing ice from 160 000 years ago. They analysed the ice for carbon dioxide and presented their data in the following table.

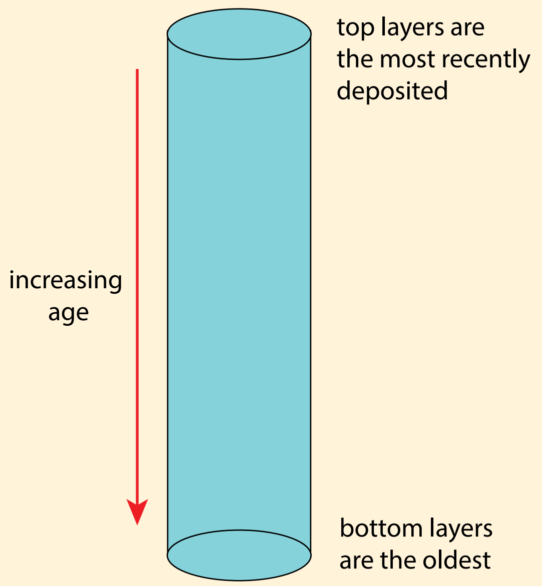


Figure 23.25: Ice cores trap carbon dioxide over time periods.

Figure 23.26: Drilling through the ice to obtain ice cores.

Figure 23.27: Sawing through the ice core to obtain samples for analysis.

Results from the ice core analysis.

Number of years ago	CO_2 levels (ppm)	Number of years ago	CO_2 levels (ppm)
160 000	190	70 000	250
150 000	205	60 000	190
140 000	240	50 000	220
130 000	280	40 000	180
120 000	278	30 000	225
110 000	240	20 000	200
100 000	225	10 000	260
90 000	230	8 160	280
80 000	220	0	387

Investigative question

Write down an investigative question for this study.

Analysis

1. Draw an accurate graph to represent your data. You need to choose your own set of axes, and label them appropriately.
2. What is the link between the levels of CO_2?

Conclusion

1. Write down a conclusion for this investigation.
2. What is the impact of global warming on the planet?

Summary

Key concepts

- The layer of gases around the Earth is called the atmosphere.
- The density of the gas molecules decreases as the distance from the Earth increases – the further away from the Earth you travel, the fewer gas molecules there are.
- The atmosphere can be divided into different layers – the troposphere, stratosphere, mesosphere and thermosphere.
- The exosphere is the uppermost layer directly above the thermosphere, where the gases thin out and the atmosphere merges with space. It is considered part of outer space.
- The troposphere is the densest layer, has the highest air pressure, and is closest to the surface of the Earth. It is on average about 12 km thick, and temperature decreases with altitude.
- Meteorites usually burn up in the mesosphere. Temperature decreases with altitude from 0 °C to −90 °C
- The thermosphere stretches up to 480 – 600 km. It absorbs ultraviolet light and X-rays. Temperature increases with altitude and can reach 1 500 °C.
- The ionosphere is the layer where molecules are ionised by the Sun's ultraviolet light. Radio waves can be transmitted and reflected as a result of the ionised layer.
- The greenhouse effect is a natural phenomenon – it warms the atmosphere sufficiently to sustain life.
- Greenhouse gases trap the re-radiation from Earth's surface and reflect it back to the Earth (like inside a greenhouse).
- The most common greenhouse gases are carbon dioxide, water vapour and methane.
- An increase in greenhouse gases leads to global warming.
- Global warming is an increase in the average temperature of the atmosphere.
- Global warming is a potentially life-threatening situation on Earth. It can lead to climate change, rising sea levels, food shortages and the extinction of organisms on Earth.
- The stratosphere stretches from 12 – 50 km and contains the ozone layer.
- Aeroplanes fly in this layer because the air is more stable. Temperature increases with altitude, from −60 °C to 0 °C.
- The mesosphere stretches between 50 – 80 km. The air is very thin.

Concept map

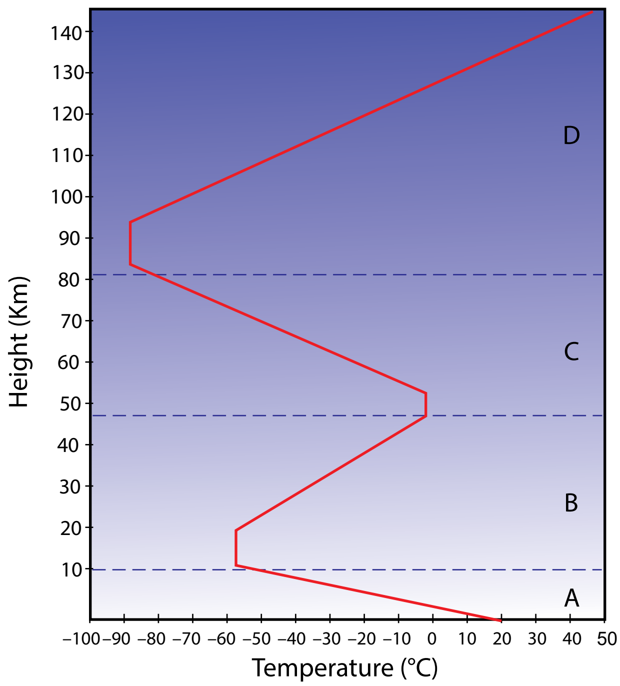
Through the past 2 – 3 years you have come across concept maps in Natural Sciences. Use what you know about concept maps and design a map for this unit. You must add terms and examples to the list. Remember to use linking words between concepts, and arrows to indicate the direction in which information is read. Plan your concept map on rough paper first before drawing the final one into your workbook. Use the following terms to help you with your map:

- atmosphere
- layers
- mesosphere
- thermosphere
- troposphere
- stratosphere
- weather
- ozone
- satellites
- radio waves
- global warming
- greenhouse gases
- greenhouse effect
- oxygen
- carbon dioxide
- water vapour

The atmosphere

Revision

1. The following graph shows the variation in temperature as you move further away from the Earth. Study it and answer the questions that follow.



a) Give labels for A-D, the layers of the atmosphere. [4]
b) Describe the temperature change in each of the layers. [4]
c) Explain why the temperature changes as you move further away from the Earth in Layer A? [2]
d) In which layer is the density of gas the highest? Give a reason for your answer. [2]
e) In which layer(s) can life survive? Give two reasons for your answer. [3]
f) In which layer are satellites found? Write only A, B, C or D. [1]
g) In which layer are meteors found? Write only A, B, C or D. [1]
h) In which layer radio waves reflected? Write only A, B, C or D. [1]
i) In which layer is weather observed? Write only A, B, C or D. [1]
j) In which layer is the aurora found? Write only A, B, C or D. [1]
k) In which layer do jet aeroplanes travel? Write only A, B, C or D. [1]
l) In which layer are lightning and storms found? Write only A, B, C or D. [1]
m) In which layer is ozone found? Write only A, B, C or D. [1]

2. Venus and Mars contains equal amounts of carbon dioxide, yet the temperature on the surfaces of these two planets are very different. Explain why. [4]

3. Earth is the only planet that we know of that sustains life. What makes Earth's atmosphere suitable to sustain life? [2]

4. Scientific evidence seems to point to the fact that carbon dioxide levels have increased steadily over the past 200 years.
   a) Why would the levels of carbon dioxide have been increasing over the past 200 years? [2]
   b) What is global warming? [1]
   c) What are the long term effects of an increase in carbon dioxide on life on Earth? [4]

Total [36 marks]

24 Birth, life and death of a star

Key questions

- Where are stars born?
- Can we talk about a star as 'living'?
- How long do stars like the Sun live?
- How do stars spend most of their life?
- Why are stars different colours?
- How do stars die?

Keywords

- stellar
- evolution
- nebula
- protostar
- constellation
- nuclear fusion
- stellar wind

Stars do not live forever, just like people. Stars are born, live their lives, changing or *evolving* as they age, and eventually they die. Often stars do this in a much more spectacular way than humans do!

Scientists speak of **stellar evolution** when talking about the birth, life and death of stars. The lifetime of individual stars is way too long for humans to observe the evolution of a single star, so how do scientists study stellar evolution? This is possible as there are so many stars in our galaxy, so we can see lots of them at different stages of their lives. In this way, astronomers can build up an overall picture of the process of stellar evolution. In this unit you will discover how stars are born, how they evolve, and how they die.

24.1 The birth of a star

Stars are born in vast, slowly rotating, clouds of cold gas and dust called nebulae (singular **nebula**). These large clouds are enormous, they have masses somewhere between 100 thousand and two million times the mass of the Sun and their diameters range from 50 to 300 light years across.

Take note

The collapse of a star can be triggered when the cloud is squeezed. For example, if a cloud passes through a spiral arm in a galaxy, it will be slowed down and compressed. This explains why lots of stars are formed in the spiral arms of galaxies.

Figure 24.1: The 'Pillars of creation'. These giant, dense dusty clouds of hydrogen gas are vast stellar nurseries where new stars are born. (NASA)

A famous example of one of these huge clouds is the Orion nebula in the constellation of Orion. It is visible with the naked eye if the sky is dark enough. These clouds are so massive that they can collapse under their own gravity if they are disturbed.

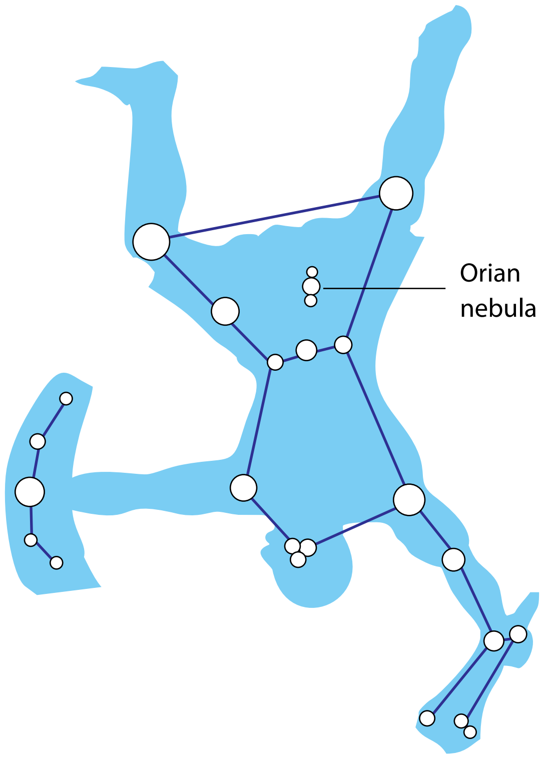


Figure 24.2: The constellation of Orion as viewed from the southern hemisphere. The Hunter Orion is 'upside down' when viewed from the south, and his sword lies above the three stars in his belt. The jewel in his sword which looks like a white-pink smudge is the Orion nebula.

Take note

A light year is the distance that light travels in one year. Light travels extremely fast at 299 792 458 m/s. One light year is equivalent to 10 trillion kilometers

Over time the clouds contract, become denser, and slowly heat up. The clouds also break up into smaller clumps. As the clumps get smaller they begin to flatten out into a disk shape. The centre of each clump will eventually contain a star and the outer disk of gas and dust may eventually form planets around the star.

This diagram shows how the stars make up the constellation of Orion, as seen in the southern hemisphere.

Figure 24.3: Hubble Space Telescope Image of the Orion Nebula showing different protostars surrounded by a dark disk of gas and dust. These disks (called protoplanetary disks) may eventually form planets around the star.

Take note

Do you remember that we learned about nuclear reactions last term in Energy and Change when looking at nuclear power plants?

As the contracting clump continues to heat up, a **protostar** is formed at the centre. A protostar is a dense ball of gas that is not yet hot enough at the centre to start nuclear reactions. This stage lasts for roughly 50 million years.

As the collapse continues, the mass of the protostar increases, squeezing it further and increasing the temperature. If the protostar is massive enough for the temperature to reach 10 million degrees Celsius, then it becomes hot enough for nuclear reactions to start and the protostar will technically be referred to as a star.

Not as well-known as its star formation cousin Orion, the Corona Australis region, with the Coronet cluster at its centre, is one one of the nearest and most active star formation regions to us. The image on the right shows the young stars at the centre, with gas and dust emissions.

Figure 24.4: The Coronet cluster.

The young star starts converting hydrogen to helium via **nuclear fusion** reactions. Nuclear reactions in stars produce vast amounts of energy in the form of heat and light, which is radiated into space. This energy production prevents the star from contracting further. As the star shines, the disk of dust and gas surrounding the star is slowly blown away by the star's **stellar wind** which leaves behind any planets if they have already formed.

Did you know?

Just as the Sun loses particles into space in the form of the solar wind, other stars also have winds, called stellar winds.

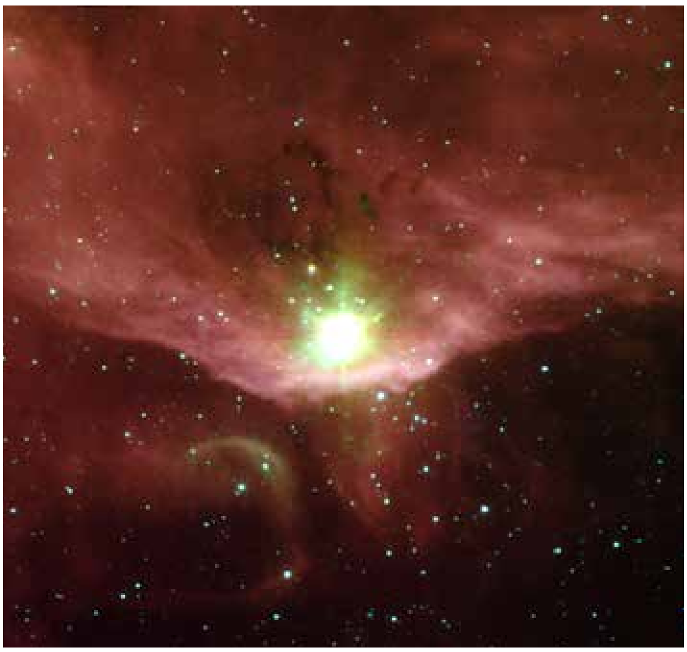


Figure 24.5: A large bubble of hot gas rising from glowing matter in a galaxy 50 million light years from Earth. Astronomers suspect the bubble is being blown by stellar winds, released during a burst of star formation.

Take note

In the upper left of the image of Large Magellanic Cloud, you can see a collection of blue and white young stars. They are extremely hot and are some of the most massive stars known anywhere in the Universe.

Figure 24.6: Star formation in the nearest galaxy outside the Milky Way, called the Large Magellanic Cloud (LMC), taken with the Hubble Space Telescope. This image shows glowing gas, dark dust clouds and young, hot stars.

24.2 Life of a star

This section covers the main stages of a star's life, from infancy to old age. Learners will also discover why stars do not all look the same and why they evolve at different rates and have different lifetimes: it is a consequence of having different masses. They will learn how important the mass of a star is in determining its evolution and observable characteristics.

A star is considered to be 'born' once nuclear fusion reactions begin at its centre. Initially hydrogen is converted to helium deep inside the star. A star that is converting hydrogen to helium is called a **main-sequence star**. Stars spend most of their lives as main-sequence stars, converting hydrogen to helium at their centres or cores. A star may remain as a main-sequence star for millions or billions of years.

Main-sequence stars are not all the same. They have different masses when they are born, depending on how much matter is available in the nebula from which they formed. These stars can range from about a tenth of the mass of the Sun up to 200 times as massive. Stars of different mass have different observable properties.

Keywords

- main-sequence star
- red giant star

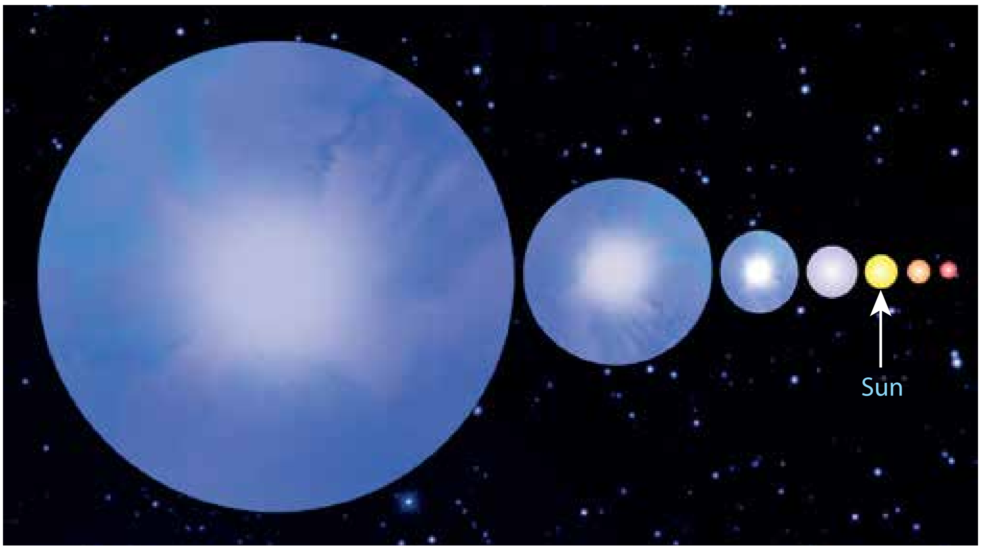


Figure 24.7: Main sequence stars come in different sizes and colours. Their sizes range from around 0,1 to 200 times the size of the Sun. Their surface temperatures determine their colours and can range from under 3 000 ˚C (red) to over 30 000 ˚C (blue).

Did you know?

Most of the stars in the Universe, about 90%, are main-sequence stars. The Sun is a main-sequence star.

Main-sequence stars also have different colours, depending on the temperatures of their surfaces.

Look at the following picture and correctly label the temperatures of all the stars using the list of temperatures below. Which star represents our Sun?

Temperature list: 3 000 ˚C, 4 500 ˚C, 6 000 ˚C, 10 000 ˚C, 40 000 ˚C

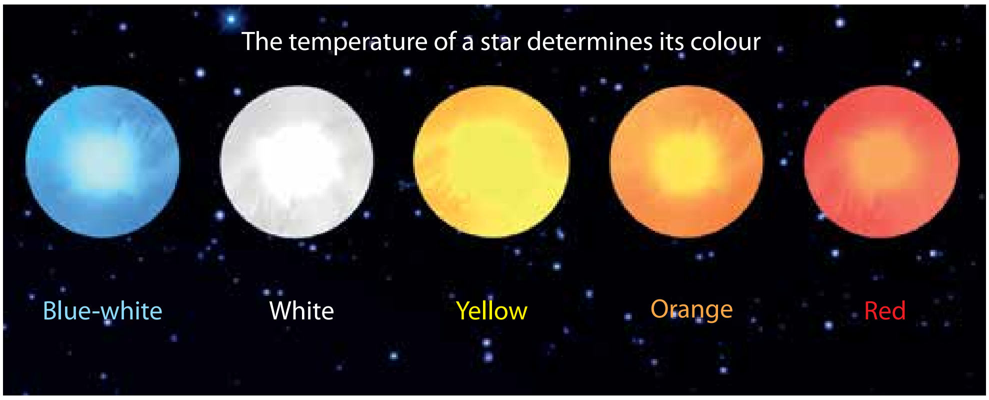


Figure 24.8: The termperature of a star determines its colour

Why are hotter stars bluer in colour? Can you remember what you learnt about the spectrum of visible light in Grade 8? The colour blue corresponds to light at shorter wavelengths (higher frequencies) than the colour red. Shorter wavelengths (higher frequencies) correspond to higher energies and thus hotter temperatures. This is also seen in the flames of a fire or candle. If you look at the flames, the central regions are bluer (and hotter) than the outer regions, which are orange and yellow.

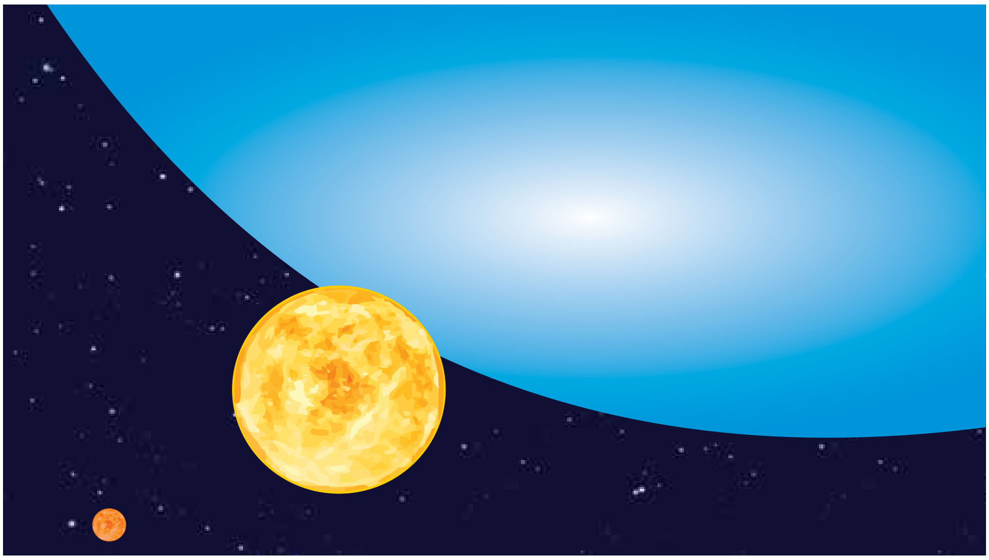


Figure 24.9: This artist's impression shows the relative sizes of young stars, from the smallest 'red dwarfs', at about 0,1 solar masses, low mass 'yellow dwarfs' such as the Sun, to massive 'blue dwarf' stars weighing eight times more than the Sun, as well as the 300 solar mass star named R136a1.

ACTIVITY Observing Orion in the spring sky

Orion is an easily recognisable constellation visible in cities as well as in dark skies. In this activity learners will have to look at the night sky to spot the constellation and identify the stars Betelgeuse and Rigel and note their difference in colour. Orion is up in the east from around 00:30 at the beginning of October, however, as the months progress, it rises earlier. By the beginning of December Orion is visible from around 20:30 in the east. If observing the constellation is unfeasible, you could ask learners to look at the image of the constellation in this unit instead.

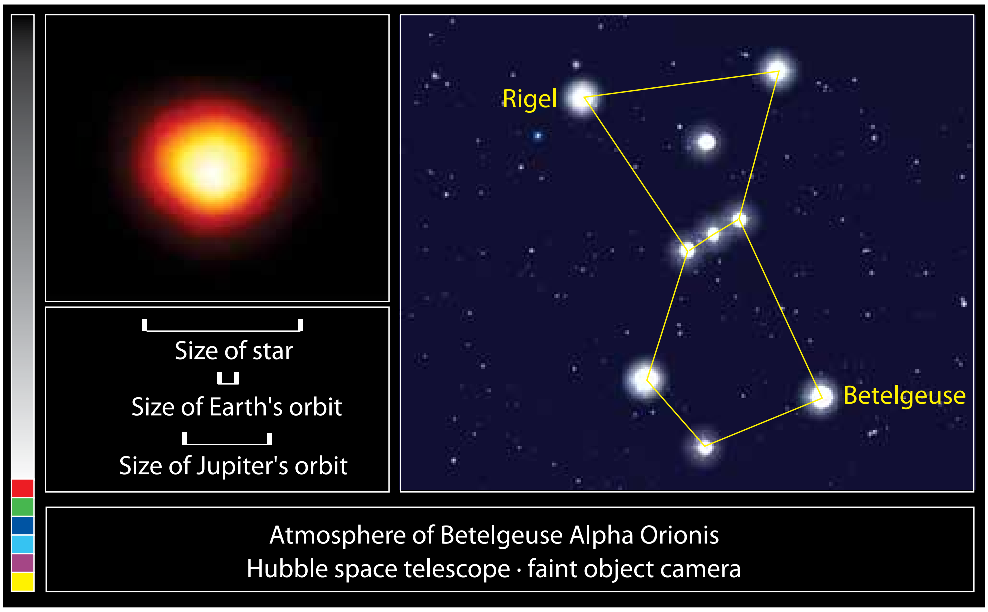


Figure 24.10: This is the first direct image of a star other than the Sun, made with NASA's Hubble Space Telescope. This is Betelgeuse, the star marking the shoulder of Orion, which we see in the bottom right of the constellation, when viewing Orion in the southern hemisphere.

Materials

- sky map

Instructions

1. A clear sky is necessary for this task. Look outside at night towards the east and identify the constellation of Orion. A photograph of the constellation is included in this unit for reference.
2. Identify the stars Betelgeuse and Rigel.

Questions

1. What did you notice about the colour of the two stars Betelgeuse and Rigel?
2. Why do you think the stars look different? Hint: Look back at the colours of stars in the diagram before this activity to see what this tells us about their temperatures.

Take note

At the beginning of October Orion is visible in the east from around 00:30 until morning. From the beginning of November Orion is visible in the east from around 22:30 and from the beginning of December it is visible in the east from around 20:30.

Did you know?

Betelgeuse is so huge that, if it replaced the Sun at the centre of our solar system, its outer atmosphere would extend past the orbit of Jupiter (see the scale at lower left of the image).

How long a main-sequence star lives depends on how massive it is. More massive stars move onto the next stages of their lives more quickly than lower mass stars. In fact, they are main-sequence stars for a shorter time than lower mass stars.

A higher-mass star might have more material, but it also uses up the material more quickly due to its higher temperature. For example, the Sun will spend about 10 billion years as a main-sequence star, but a star 10 times as massive will last for only 20 million years. A red dwarf, which is half the mass of the Sun, can last 80 to 100 billion years.

Red Giant Star

When the hydrogen in the centre of the star is depleted, the star's core shrinks and heats up. This causes the outer part of the star, the star's atmosphere, which is still mostly hydrogen, to start to expand. The star becomes larger and brighter and its surface temperature cools so it glows red. The star is now a **red giant star**. Betelgeuse, as you observed in the last activity, is a red giant star.

Why does a red giant glow red?

Why do you think red giants are called 'giant' stars?

Did you know?

Globular clusters are particularly useful for studying stellar evolution, since all of the stars in the cluster have the same age (about 10-15 billion years), but cover a range of stellar masses.

Figure 24.11: A colourful view of the globular star cluster NGC 6093 in the Milky Way, containing hundreds of thousands of ancient stars. Especially obvious are the bright red giants, which are stars similar to the Sun in mass that are nearing the ends of their lives.

Eventually the core of the star becomes hot enough for the next nuclear reaction to start: atoms of helium collide and fuse into heavier elements such as carbon and oxygen. However, eventually the helium in the core will also be depleted. From this point onwards, the fate of the star is determined by its mass.

For medium-sized stars, such as the Sun, the temperature in their centres will never get high enough to fuse the newly-formed carbon and oxygen into heavier elements and so they do not evolve much further. Following the red giant phase, the star becomes unstable and will eventually die, as you will discover in the next section.

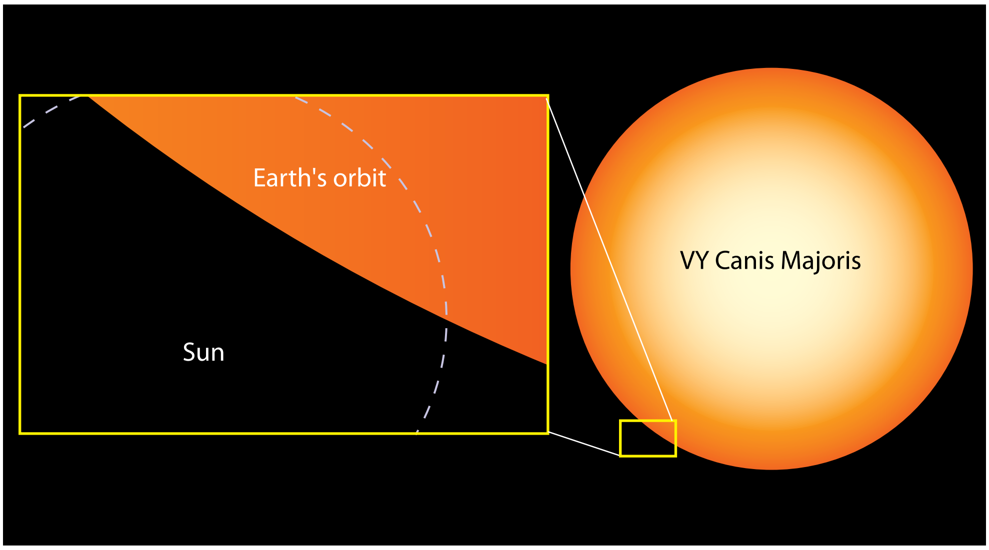


Figure 24.12: The relative sizes of the Earth, the present-day Sun, and a red super-giant star, *Canis Majoris*, in the constellation. The Sun will eventually evolve into a red giant star in about 4,5 billion years' time.

24.3 Death of a star

As a star enters the final stages of its life, after it has become a red giant, the star becomes unstable and expands and contracts over and over. This causes the star's outer layers to become detached from the central part of the star and they gently puff off into space. When the last of the gas in the star's outer layers is blown away, it forms an expanding shell around the core of the star called a **planetary nebula**. Planetary nebulae glow beautifully as they absorb the energy emitted from the hot central star. They can be found in many different shapes, as shown in the following images.

Keywords

- planetary nebula
- white dwarf
- black dwarf
- supernova
- neutron star

Figure 24.13: The beautiful Ring Nebula. The gas is lit up by the light from the central star which is the faint white dot in the centre of the nebula.

Figure 24.14: The Boomerang Nebula is a young planetary nebula and the coldest object found in the Universe so far.

Did you know?

The Butterfly Nebula is a dying star that was once five times the mass of the Sun. What resembles the butterfly wings are actually hot clouds of gas tearing across space at almost 1 million km an hour – fast enough to travel from Earth to the Moon in 24 minutes!

Figure 24.15: Kohoutek 4-55 Nebula contains the outer layers of a red giant star that were expelled into interstellar space when the star was in the late stages of its life.

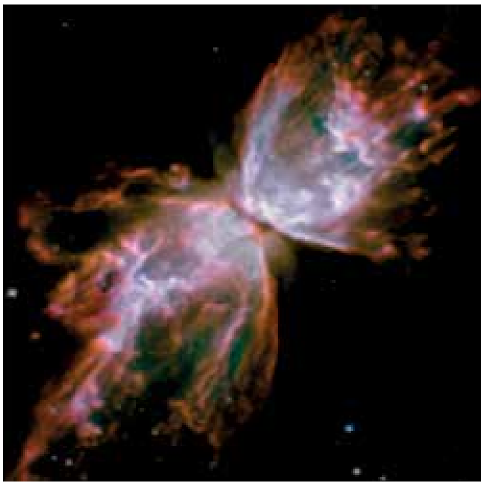


Figure 24.16: The Butterfly Nebula. The dying central star itself cannot be seen, because it is hidden within a doughnut-shaped ring of dust.

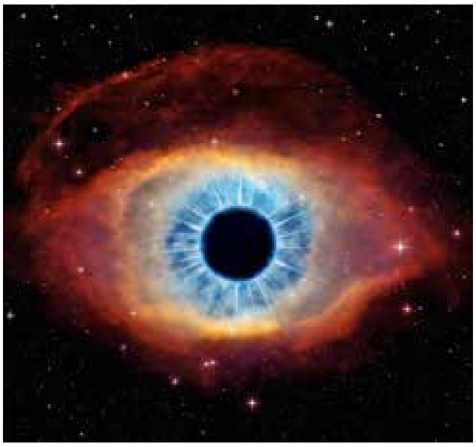


Figure 24.17: The Helix Nebula

Figure 24.18: The Dumbbell Nebula.

Some time after puffing off its outer layers, the central star will run out of fuel. When this happens, the central star begins to die. Gravity causes the star to collapse inwards, and the star becomes incredibly dense and compact, about the size of the Earth. The star has then become a **white dwarf** star.

Figure 24.19: An ultraviolet image of the Helix Nebula. As the star in the centre approaches the end of its life and runs out of fuel, it shrinks into a much smaller, hotter and denser white dwarf star.

White dwarfs have this name because of their small size and because they are so hot that they shine with a white hot light. The central parts of stars are much hotter than their surfaces, and a white dwarf is made from the remaining central parts of a star which explains why they are so hot.

The following image shows the relative size of Sirius B, a nearby white dwarf star, compared to some of the planets in our solar system. Stars and stellar remains can be smaller than planets.

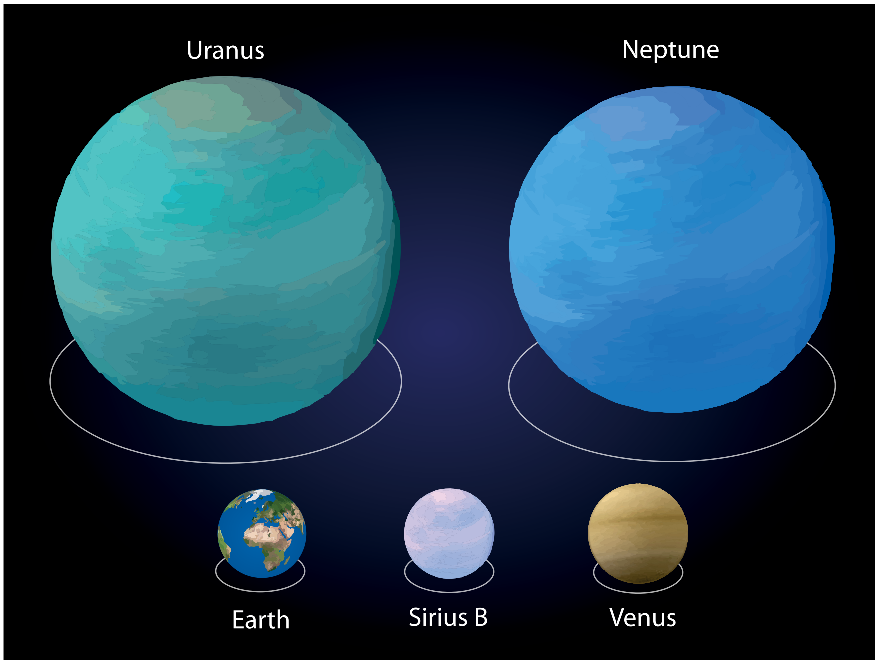


Figure 24.20: Comparitive size of Sirius B.

White dwarfs no longer produce energy via nuclear reactions so they radiate their energy into space in the form of light and heat. They slowly cool down over time. Eventually, once all of their energy is gone, they no longer emit any light. The star is now a dead **black dwarf** star and will remain like this forever.

> **Did you know?**
>
> White dwarf stars are so dense that one teaspoon of material from a white dwarf would weigh up to 100 000 kg.

ACTIVITY: Life cycle of a Sun-like star

Materials

- yellow round balloon – one per pair or group
- black marker
- red marker
- scissors
- 2 cm small white Styrofoam ball – one per pair

Instructions

1. In this activity you will work in pairs. One of you will instruct your partner using the instructions below. Your partner will follow your

instructions. Decide which of you will be the instructor and which of you will be the experimenter.

2. Experimenter: Insert the white Styrofoam ball into the deflated balloon
3. Instructor: Read out the step-by-step instructions from the table below (listed in order). First state the time from the star's birth which is given in the left hand column, then tell your partner what to do with the balloon.
4. Experimenter: Follow the instructions from your partner very carefully. You will be demonstrating how a Sun-like star evolves over time.

Step Number	Instructions
1) Star is born	Blow up the balloon to about 6 cm in diameter
2) 5 million years	Wait
3) 10 million years	Wait
4) 500 million years	Wait – planets are being formed around the star.
5) 1 billion years	Blow the balloon up a little bit
6) 9 billion years	Blow up the balloon some more and colour it red – it is now a red giant star
7) 10 billion years	Blow the balloon up a little bit. The outer layers are now being blown off. To simulate this, slowly allow the balloon to deflate. Cut the balloon into pieces and scatter them around the white ball. The star has now become a white dwarf (the ball) surrounded by a planetary nebula (the pieces of balloon).
8) 50 billion years	Move the planetary nebula farther away from the white dwarf.
9) 500 billion years	Remove the planetary nebula and colour the ball black – the star is now a black dwarf.

The different stages of evolution of a star like the Sun are summarised in the diagram below and compared to the lifecycle of a person.

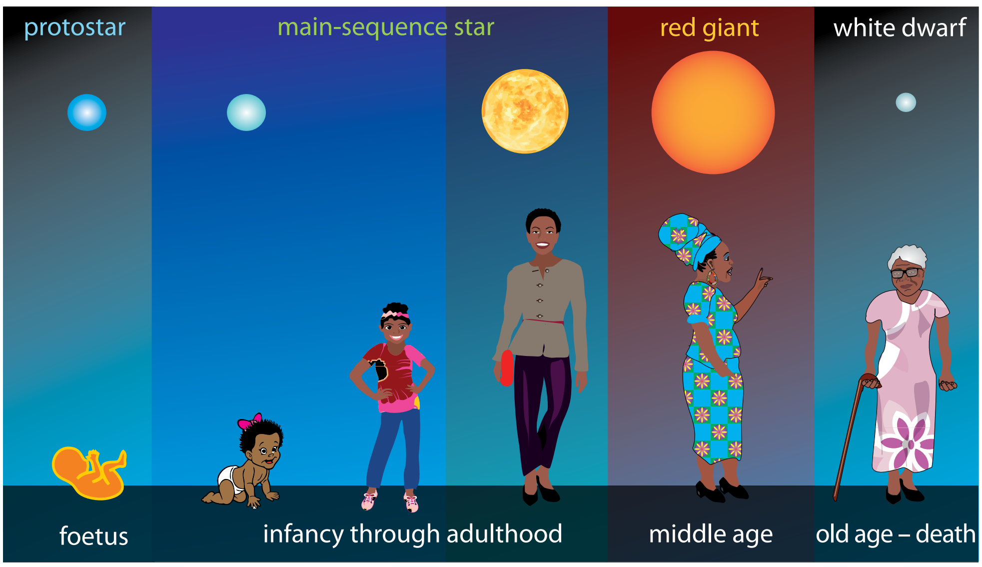


Figure 24.21: Evolution of a star.

Let's take a closer look at the life of our star, the Sun.

ACTIVITY The life cycle of the Sun

Instructions

1. The diagram below shows the life of our Sun. The Sun is a common type of star of average size and mass.
2. Copy and complete the sentences by filling in the gaps which summarise the evolution of our Sun over time.

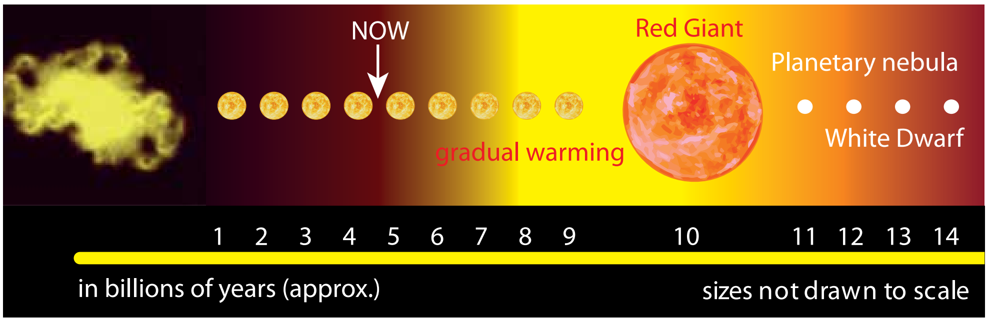


Figure 24.22: The life of our Sun.

Questions

1. The Sun is currently about halfway through its lifetime as a ______________star. In about 4.5 billion years' time the Sun will swell up to form a ______________star engulfing the Earth as it does so.
2. After the Sun has become a red giant, it will eventually become unstable and puff off its outer layers forming a beautiful ______________. The central core of the Sun will be left exposed in the centre of the planetary nebula.
3. Once the fuel runs out in the core of the Sun, nuclear reactions will______________. The Sun will then have become a hot ______________star, left behind at the centre of the planetary nebula.
4. As there are no ongoing nuclear reactions, as the white dwarf shines, it slowly cools and will eventually form a ______________dwarf.

Take note

The plural of nebula is nebulae. Planetary nebulae have nothing to do with planets but were named like this in the 1700s because they resembled planets when observed with the telescopes of the time.

ACTIVITY Flow diagram poster showing the life of a Sun-like star

Materials

- paper or card for the poster
- pencils, crayons or paint for drawing
- printouts of photographs or pictures of the various stages in the Sun's life

Questions

1. Draw a flow diagram showing the key stages in a Sun-like star's life.
2. Include the birth, life, ageing and death of the star. If you have access to printouts of photos or drawings of the key stages, you could paste them onto the poster instead of drawing the key stages.

Take note

Here we are not talking about bigger stars, but rather stars that are more massive. It is not the size that counts, but the mass of the star.

3. Label each stage and indicate clearly with arrows the direction of flow in the evolutionary stages.
4. *Advanced*: Write down approximately how long each stage lasts. You can use the timeline of the Sun's evolution in this unit to help you.

Questions

1. Where are stars born?
2. Why is a red giant so named?
3. What kind of stellar remnant is left behind once a star like the Sun dies?
4. What is a planetary nebula?
5. How big is a white dwarf?

So far we have looked at stars that are about the same mass as our Sun. But what about stars that are more massive? How do they die?

Stars more than eight times the mass of the Sun end their lives spectacularly.

When the hydrogen at their cores becomes depleted, they swell into red super-giants which are even larger than red giants.

A red super-giant can fuse successively heavier and heavier elements for a few million years until its core is filled with iron. At this point, nuclear reactions stop and the star collapses rapidly under its own gravity. The collapsing outer layers of the star hit the small central core with such a force that they rebound and send a ripple outwards through the star, blowing the outer layers of the star into space in a huge explosion called a **supernova**.

Did you know?

Japanese and Chinese Astronomers recorded the violent supernova event that led to the Crab Nebula nearly 1 000 years ago in 1054 AD.

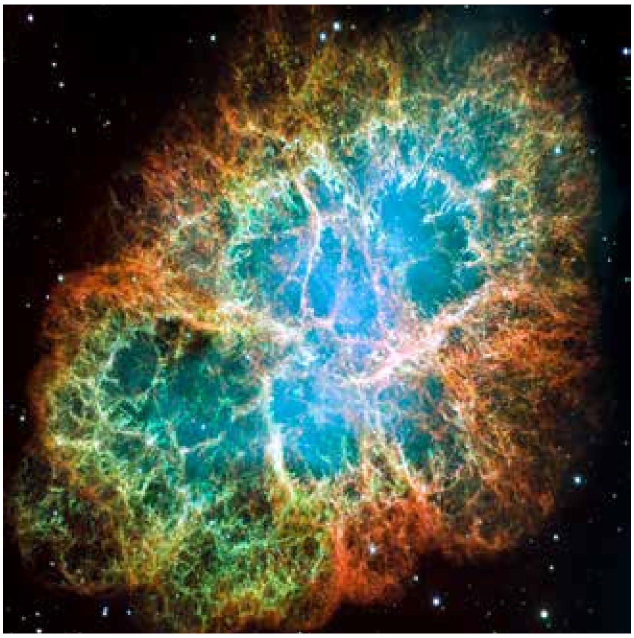


Figure 24.23: The Crab Nebula. This giant glowing cloud of gas is the remains of the outer layers of a star that exploded in a supernova explosion. In the centre is a rapidly spinning neutron star.

For a week or so, a supernova can outshine all of the other stars in its galaxy.

However, they quickly fade over time. The central star left behind is either made of neutrons and it is called a **neutron star**, or if the initial star was really massive, a **black hole** forms. The leftover neutron star or black hole is surrounded by an expanding cloud of very hot gas.

In February 1987, astronomers observed a supernova explosion, called Supernova 1987A. It is one of the brightest stellar explosions observed since the invention of the telescope 400 years ago. The supernova belongs to the Large Magellanic Cloud, a nearby galaxy about 168 000 light-years away. Even though the stellar explosion took place around 166 000 BC, its light arrived here less than 25 years ago.

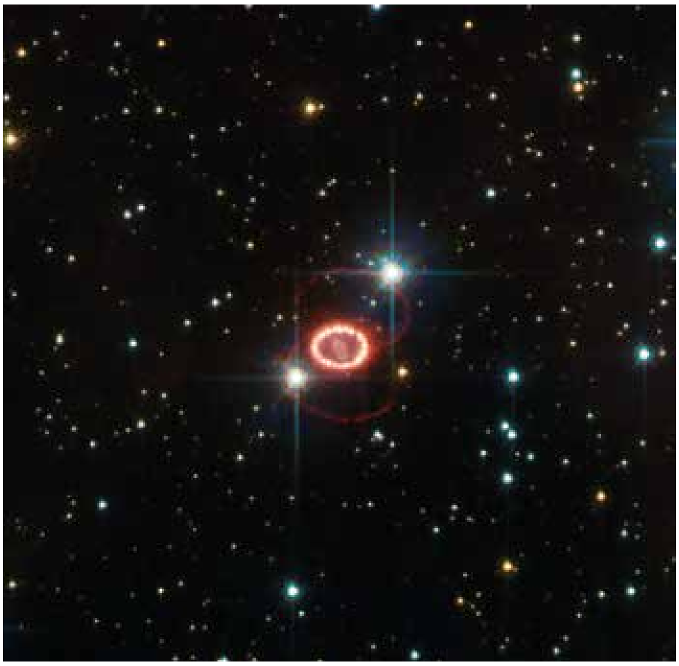


Figure 24.24: An image of the supernova called Supernova 1987A. The outer layers of the star have formed beautiful rings expanding into space.

Supernovae have also been observed previously with the naked eye before the invention of the telescope. On 9 October 1604, sky watchers, including astronomer Johannes Kepler, spotted a 'new star' in the sky. Now, we have images of the remnants of the supernova and know that it is not a new star, but rather the death of a massive star.

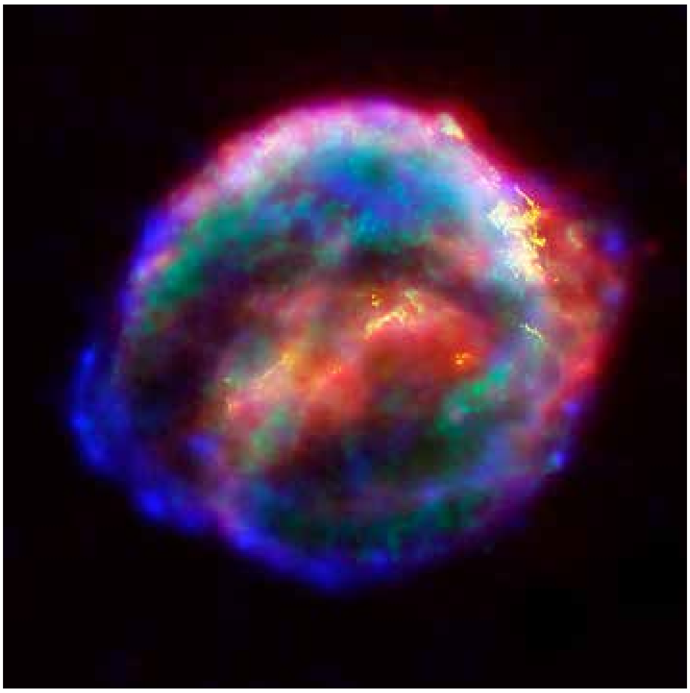


Figure 24.25: The remnants of Kepler's supernova. The explosion was observed in 1604.

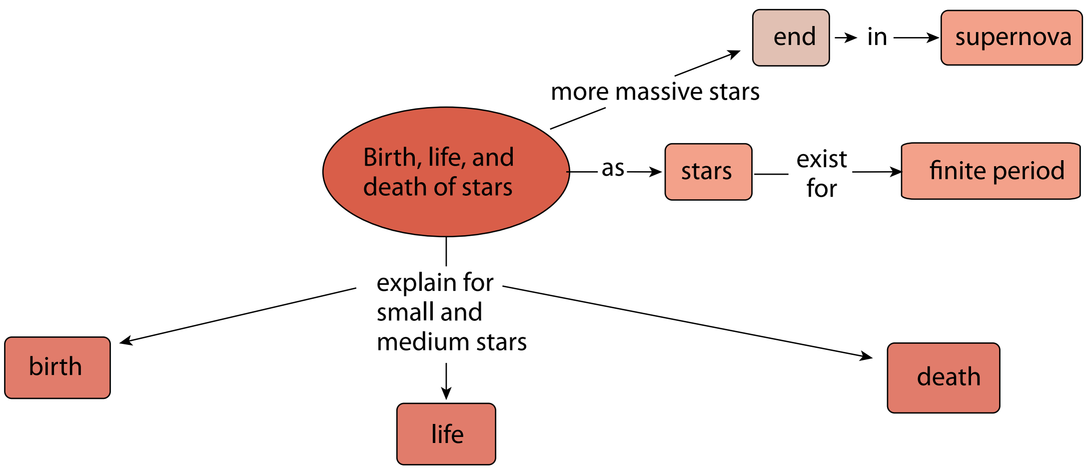
Summary

Key concepts

- Stars are born in giant, cold clouds of gas and dust called nebulae.
- A star is born once it becomes hot enough for fusion reactions to take place at its core.
- Stars spend most of their lives as main-sequence stars fusing hydrogen to helium in their centres.
- The Sun is halfway through its life as a main-sequence star and will swell up to form a red giant star in around 4,5 billion years.
- Stars similar to the Sun end their lives as planetary nebulae and leave behind a small hot white dwarf star at the centre of the planetary nebula.

Concept map

The concept map on the life cycle of stars has been started, but you need to finish it by summarising the concepts for each stage, namely birth, life, and death of a star.



Revision

1. What is the name of the giant clouds where stars are formed? [1]

2. In the human life cycle, a foetus is the unborn baby in a mother's womb. What is the equivalent stage in a star's life called? [1]

3. Under what conditions do astronomers technically say a star has been born? [1]

4. Which star colour is hotter, white or yellow? [1]

5. What nuclear reaction does a main-sequence star undergo? [2]

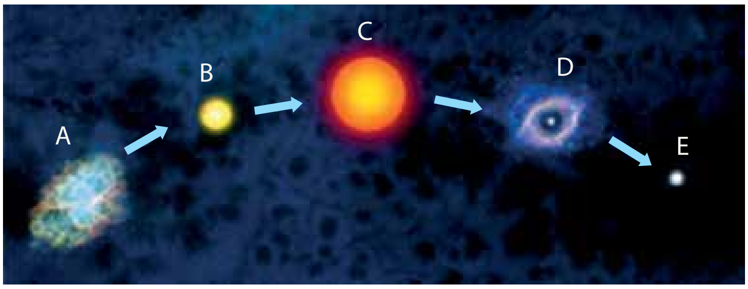
6. Once the Sun has exhausted its hydrogen fuel supply, it will swell up to form what type of star? [1]

7. Low mass stars like the Sun eject their outer layers. What is the name of the object they form when they do this? [1]

8. What kind of star is left behind after a planetary nebula? [1]

9. What is the difference between a stellar nebula and a planetary nebula? [2]

10. Study the following diagram showing a star's evolution.



a) Copy the table below in your exercise books and provide labels for the different stages. [5]

Label	Stage
A	
B	
C	
D	
E	

b) What changes occur from stage B to form C? [2]
c) Sometime after puffing off its outer layers at stage D, the fuel of the central star will have become depleted. What causes the star to collapse inwards to become E? [1]
d) What eventually happens to the star after stage E? [1]

11. Massive stars die in powerful explosions. What are these explosions called? [1]

Total [21 marks]

Glossary

altitude height above sea level
atmosphere the layer of gases surrounding the Earth and held in place by gravity
aurora a natural phenomenon whereby charged particles from the Sun interact with atmospheric particles; this is observed as bright, coloured 'lights' in the sky, mostly in polar regions

bellows a device that produces a stream of air when it is squeezed
biosphere the part of the Earth and its atmosphere in which living organisms exist or that is capable of supporting life
black dwarf a white dwarf that has sufficiently cooled and used up all of its energy so that it no longer emits any heat or light; the star is now dead and will remain like this
blast furnace used in the extraction of iron from iron-ore, a high temperature oven in the form of a tower into which compressed air can be introduced from below
bloomery a type of oven used for purifying iron from iron ore
brittle hard, but can break or shatter easily

carbon dioxide a gas with the chemical formula CO_2
cementation the process of solidifying sediments by chemical compounds acting as glue
CFCs chlorofluorocarbons are molecules which release chlorine atoms due to solar radiation in the stratosphere
climate change a significant and lasting change in weather patterns; if there is a change in the world's weather patterns, it is a global climate change
compaction an increase in the density of something
composition what makes up a substance or a mixture
constellation a group of stars in a recognisable pattern
continental crust the thick part of the Earth's crust that forms the continents
cooling lowering the temperature
core innermost layer of the Earth
crust the thin, solid, outermost layer of the Earth
cycle a continuous process where the last step feeds into the first again

density separation a separation method where the differing densities of particles are used to separate them out
deposition the process where sediments, rocks and and sand are deposited (laid down) by wind or water

electromagnets a soft metal core made into a temporary magnet by passing current through a coil surrounding it
erosion the breakdown and movement of the Earth's surface by natural agents such as wind and water
evolution (of stars) the changes a star undergoes as it is born, lives and dies
excavation the process of removing rock containing ore from the surrounding rock
exosphere considered part of outer space; the uppermost layer directly above the thermosphere, where the gases thin out and the atmosphere merges with space
exploration the process of finding out where profitable mineral deposits are located
extrusive rock igneous rock which forms when magma flows out onto the surface of the Earth as lava

flotation a separation method by which hydrophobic particles are separated from hydrophilic particles by blowing air through the mixture

geochemical methods exploration methods using knowledge of geology and the chemistry of minerals
geophysical methods exploration methods using knowledge of geology and the physical properties of minerals
geosphere the core, mantle and crust of the Earth
global warming a gradual increase in the temperature of the Earth's atmosphere

greenhouse effect the trapping of the Sun's energy in the lower part of the atmosphere due to the presence of greenhouse gases

greenhouse gases gases such as water vapour, carbon dioxide and methane, which let through sunlight but reflect ultraviolet radiation

hydrosphere all the water, in all its forms, found on Earth

igneous rock a rock type formed by magma or lava

International Space Station a multinational space station, used for research purposes, which orbits the Earth at 370 km above the surface

intrusive rock igneous rock which forms from magma deep below the surface of the Earth

ionosphere the region mainly in the thermosphere where high energy light (UV light) can cause atoms, molecules or substances to form an ion or ions, typically by removing one or more electrons

lithosphere the outer part of the Earth consisting of the crust and the upper part of the mantle; it includes all rock, soil and minerals found on Earth

magnetic separation a separation method based on the magnetic properties of the mixture

main-sequence star a star that has hydrogen undergoing nuclear fusion reactions into helium in its core

mantle the middle layer of the Earth

melting the change from a solid to a liquid as a result of heating

mesosphere the layer of the Earth's atmosphere above the stratosphere, extending to about 80 km above the surface of the Earth

metamorphic rock a rock type formed through the transformation, or metamorphosis, of other rock types

meteor a small body of mass entering the Earth's atmosphere from space which emits light as a result of friction and heat, and appears as a streak of light

meteorite a meteor which has collided with the Earth

methane a gas with the chemical formula CH_4

mineral a natural compound formed through geological processes; the term 'mineral' includes both a material's chemical composition and its structure

nebula a vast cloud of gas and dust in space

neutron star an extremely dense star made of neutrons about the size of a small town in diameter

northern lights the aurora in the northern hemisphere; also called the Aurora Borealis

nuclear fusion process in which two light nuclei of atoms combine to produce a heavier single nucleus, with a total mass slightly less than that of the total initial material, the difference in mass is radiated as energy

oceanic crust the thinner part of the Earth's crust that underlies the oceans

ore a naturally occurring solid material from which a metal or valuable mineral can be extracted

overburden the layer of rock or sand overlying a mineral deposit

ozone a gas molecule found in the stratosphere consisting of 3 oxygen atoms (O_3)

panning a separation method based on the density gradient of the mixture

PGM platinum group metals, which includes ruthenium, rhodium, palladium, osmium, iridium and platinum, and are elements on the Periodic Table

planetary nebula a cloud of gas (the remains of the original star's atmosphere) surrounding an old star; these have a confusing name because they actually have nothing to do with planets at all

protostar a contracting mass of gas that will become a star once it is hot enough for nuclear fusion to start

radiation the transfer of energy from a source that does not require physical contact or movement of particles

red giant star an old, bright, very big, cool star; main-sequence stars evolve to become red giant stars once the hydrogen in their cores has been depleted

rehabilitation an area is restored to certain specifications, for example an area that has been mined is rehabilitated by planting trees or grass

remote sensing gathering information from a distance, without making physical contact

sediment particles, for example those that arise from erosion and weathering, settle in layers

sedimentary rock a rock type formed from solidifying sediment

sedimentation the deposition and solidification of sediment

size separation a separation method based on the size of the particles

slag the waste product extracted from a blast furnace after extracting iron from iron-ore

slurry a watery mixture of solids and liquids

solidify becoming a solid

southern lights the aurora in the southern hemisphere; also called (Aurora Australis)

stellar of stars, such as a stellar nebula

stellar wind a flow of neutral or charged gas ejected from a star (the solar wind refers specifically to the stellar wind of our Sun)

stratosphere the layer of the Earth's atmosphere above the troposphere, extending to about 50 km above the surface of the Earth

supernova an explosion in a high mass star where the outer layers of the star are flung off into space

temperature gradient how much the temperature changes as height above sea level (altitude) increases

thermosphere the layer of the Earth's atmosphere above the mesosphere, extending from about 480 to 600 km above the surface of the Earth

topsoil the upper surface of the Earth consisting of a layer of vegetation and soil

troposphere the lowest layer of the Earth's atmosphere, extending from sea level to about 9 – 17 km

water vapour a gas with the chemical formula H_2O; water in its gaseous form

weathering the wearing away of rocks as a result of exposure to wind, water and ice

white dwarf a small, hot, very dense star that is the size of a planet