



Physical Sciences

Learner's Workbook

Grade 11

Learning Channel (Pty) Ltd
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2001

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Contents

How to use the Learning Channel Physical Sciences programme for Grade 11	iv
Using this book	vi
What the icons mean	vii
Your Learning Channel presenters	viii
Other Learning Channel products	ix
LESSON 1 FORCES AND EFFECTS OF FORCES	1
LESSON 1A CONSERVATION OF MOMENTUM	8
LESSON 2 NEWTON'S THIRD LAW	10
LESSON 3 THE FORCE OF FRICTION	17
LESSONS 3A & B COMBINING NEWTON'S LAWS OF MOTION	23
LESSON 4 THE FORCE OF GRAVITY	26
LESSON 4A GRAVITATION	33
LESSON 5 THE TURNING EFFECT OF FORCES	35
LESSON 5A THE TURNING EFFECT OF FORCES	46
LESSONS 6 & 7 TRANSVERSE AND LONGITUDINAL WAVES	50
LESSON 8 GEOMETRICAL OPTICS	60
LESSON 8A SOUND AND LIGHT	67
LESSONS 9 & 10 ELECTRICAL CHARGE, FORCE BETWEEN CHARGES AND CAPACITANCE	75
LESSON 10A FORCES, FIELDS AND CAPACITANCE	92
LESSONS 11 & 12 ELECTROMAGNETISM, INDUCED CURRENT AND TRANSFORMERS	95
LESSON 12A TRANSFORMERS	112
LESSONS 13 & 14 ELECTRIC CIRCUITS: POTENTIAL DIFFERENCE, ELECTRIC CURRENT AND RESISTANCE TO THE FLOW OF CHARGE	114
LESSONS 14A & B ELECTRIC CIRCUITS TO ANALYSE	125
LESSONS 15 & 16 BASIC CHEMICAL CONCEPTS: THE NUCLEUS, ATOMS, BONDING AND MOLECULES	128
LESSONS 17 & 18 ELECTRON INTERACTIONS (1): MULTIPLE BONDS, OXIDATION STATE, MOLECULAR SHAPE AND CONDUCTION	150
LESSONS 17A & B EXERCISES ON BASIC CHEMICAL CONCEPTS	164
LESSONS 19 & 20 NUCLEAR REACTIONS AND INTERACTIONS	167
LESSONS 21 & 22 KINETIC THEORY, IDEAL GASES AND GAS LAWS	178
LESSON 21A INTERPRETING GRAPHS: HOW GRAPHS REPRESENT THEORY; BOYLE'S LAW	187
LESSON 22A IDEAL GASES, DEVIATIONS FROM IDEAL GAS BEHAVIOUR AND IDEAL GAS CALCULATIONS	192
LESSONS 23–27 ELECTRON INTERACTIONS (2): AN OVERVIEW OF CHEMICAL REACTIONS	196
LESSON 27A BASIC STOICHIOMETRIC CALCULATIONS	211
LESSON 27B ENERGY IN CHEMICAL AND PHYSICAL REACTIONS	214
LESSON 27C ACID-BASE REACTIONS	220
LESSON 27D REDOX REACTIONS	223
LESSONS 28–30 LO3 ISSUES IN SCIENCE, TECHNOLOGY AND SOCIETY	228
LESSON 30A CHEMICAL REACTIONS IN THE ATMOSPHERE AND MINERAL PROCESSING	255
LESSON 30B A SCIENCE, TECHNOLOGY AND SOCIETY (STS) ISSUE	261
ANSWERS AND ASSESSMENT	265
TEACHER TIPS	325



How to use the Learning Channel Physical Sciences programme for Grade 11

Congratulations and thank you for choosing this Learning Channel Physical Sciences Grade 11 programme.

This Physical Sciences programme is comprehensive and covers all the Learning Outcomes, Assessment Standards, knowledge, key concepts and skills for this subject as stated in the National Curriculum Statement – everything you need to make a success of your world. However, it does not replace your teacher or textbook!

This Learning Channel programme is for everyone ... you may be using this at home or in your classroom with your teacher and classmates. You may have chosen this programme because you are struggling with Physical Sciences and as a result you're not achieving the grades you know you deserve. Or, you may be using it because it will help you earn the distinction you've set as your goal. Wherever you are and whatever your reason, this programme will give you the head start you need.

The Learning Channel programme consists of three components:

- Lessons to watch on DVD;
- A learner workbook, with exercises and activities for you to complete; and
- If you are connected to the Internet, the Learning Channel website.



COME

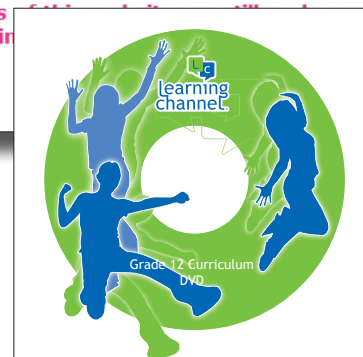
Learning Channel (in conjunction with Liberty Life, Bank, SABC Education and the Department of Education) is one of the world's leading televised educational resources, broadcast on SABC1 on weekdays from 11:00am to 12:00pm.

Our new-generation content – reflecting the latest curriculum – has been developed in close collaboration with SABC Education and the Department of Education.

Our best broadcasting endeavours are also supported by a potent digital strategy – including web, newspapers, hi-tech audio-visual aids, and social media – to ensure it maximizes its much-needed reach to South African learners.



sections
for mailing



Here are some tips on how to make the most of this programme

Before sitting down to study, make sure you have the following at hand:

- The Learning Channel Physical Sciences for Grade 11 DVD;
- The Learning Channel Physical Sciences for Grade 11 Workbook;
- Pen and paper; and
- Your DVD remote control – if you are watching this on a DVD player.
 - Insert the Learning Channel Physical Sciences for Grade 11 DVD disc into your computer or DVD player. Press play.
 - The subject name and grade will appear followed by the title of the lesson, the lesson number, and the duration of the lesson.
 - Next, you will be told what page to turn to in your workbook.
 - The Learning Outcomes and Assessment Standards will appear, followed by the lesson overview. This will tell you exactly what you will be expected to do by the end of the lesson.

We suggest that you watch the entire lesson before working in the workbook. While watching the lesson you can stop the DVD when you need to review or refresh what has been said or if you want to take down notes.

While watching the lesson you will also see the PAUSE icon. This alerts you to an activity you can complete in the workbook. If you feel that you are ready to try this concept or skill related activity press the PAUSE button on your remote control, television or computer screen. Press PLAY once you have completed the activity.

At the end of the lesson you will see a summary of the key concepts covered. If you've been taking notes you can jot these down or find them in your workbook.

- All the exercises and activities are designed so that you can complete them on your own. Some activities, however, can also be completed with a partner, in a group or as a class. These opportunities are clearly indicated with icons (see page 3).
- Check your answers against the solutions provided at the end of the workbook. Errors may indicate that you have missed or not understood key concepts. Watch the lesson again, refer to any notes you have made and redo the activities you did not master.

The Learning Channel website offers extra features, like subject glossaries, past exam papers, study tips and the National Curriculum Statement. Visit the website to make use of the extra features.

If you are a teacher using this programme with your class, you will find teacher tips at the end of the Learner's Workbook. These tips will help you facilitate the use of the AV lesson and convey its content to your learners.



Using this book

The new FET Physical Sciences curriculum is exciting as it covers much more ground than did the old one. The National Curriculum Statement document: “Physical Sciences Content (DoE June 2006)” sets out, in great detail, the requirements for the new curriculum. Features of the new curriculum are that it introduces students to important concepts in modern science (e.g. quantum theory); rapidly developing areas of applied science (e.g. materials science); important technologies (e.g. lasers and electron microscopes); science-based industries (e.g. mining and the chemical industry); and social issues (e.g. drugs in sport). But while it is an exciting curriculum it will also be demanding both in terms of the quantity of information and conceptual demand.

So how do the Learning Channel materials address these problems?

Here are some pointers that suggest how to use them.

- **The video and printed notes do not replace your textbook.** Use them in addition to your textbook and not instead of it. Time and space available for the video and text materials make it impossible to cover every single aspect of the new curriculum. Our materials try to help you to understand the basic concepts in the curriculum.
- **The video lessons** (numbered #1 to #30) **explain key concepts.** Some explanations are purely verbal but others include demonstrations and calculations. The aim here is to clarify key concepts. Once you have done so, doing more advanced calculations and applications will be much easier. *You will normally watch each video in its entirety before proceeding to the notes.*
- **The 20 “additional” video lessons** (numbered #1a, #3a, #3b ... #30a and #30b) **contain additional explanations and information; extension work; calculations; and other background material - especially on “STS”** (Science, Technology and Society) **issues** which cover the criteria for Learning Outcome 3. *Watch these videos together with the notes on additional lessons.*
- The notes on each video lesson **specify Learning Outcomes (LOs) and Assessment Standards (ASs).** Additional lesson notes specify **the required curriculum content** for the section covered in the materials. While all key areas of the curriculum are touched on in the materials they may not deal with these in the detail required by examiners.
- **Understand the basic concepts first and then move on to applications.** You may find that the additional lessons help you to understand the subtleties of the key concepts better but remember: we cannot effectively apply concepts which we do not first understand!
- The Grade 12 curriculum relies on an understanding of concepts found in the Grade 11 curriculum. For this reason **the Grade 11 notes will be referred to frequently in the Grade 12 course.** Similarly, Grade 11 work relies on a good understanding of the basic concepts that were studied in Grade 10.



What the icons mean



DVD – watch the lesson



Individual work – do this activity on your own



Pair work – do this activity with a partner



Group work – do this activity in a group



Class work – do this activity as a class



Self-assessment – assess yourself



Baseline assessment – what I know before starting (prior knowledge)



Formative assessment – how I am progressing



Summative assessment – a check on what I know



Project – a project to research and present



Collection of evidence activity – include in your portfolio



Your Learning Channel presenters

Afrikaans FAL

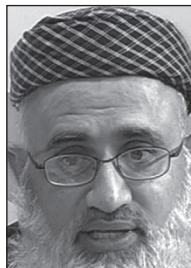


Melinda Lawrence



Donovan Lawrence

Accounting

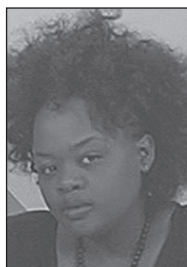


Ashraf Patel



Eurika Fourie

English Home Language/FAL



Casandra Gudhluza



Janet Unterslak



Mary Adams



Pule Hlabane

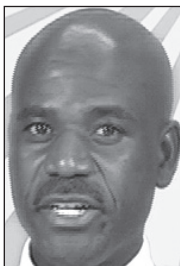
Business Studies



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Nelson Mogodi



Moira Clarke



Mvelo Phungula



Mark Phillips

Mathematics

Life Sciences



Cathy Hastie



Farida Cassim

Life Orientation

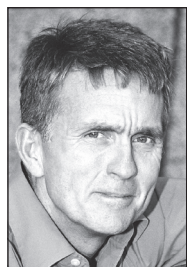


Zikhona Ntsangani

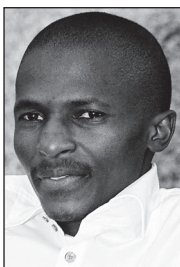


Juliet Glover

Mathematical Literacy

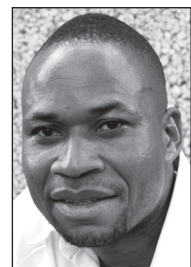


Aarnout Brombacher

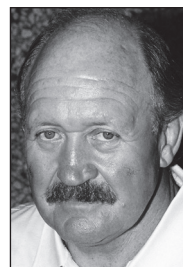


Eric Taba

Physical Sciences



Tinyiko Khosa



Peter Glover

Other Learning Channel products

Other products in the Learning Channel Grade 11 series

- Learning Channel Life Sciences for Grade 11 DVD lessons and Learner's Workbook
- Learning Channel Mathematics for Grade 11 DVD lessons and Learner's Workbook
- Learning Channel Mathematical Literacy for Grade 11 DVD lessons and Learner's Workbook
- Learning Channel English Home Language for Grade 11 DVD lessons and Learner's Workbook
- Learning Channel Life Orientation for Grade 11 DVD lessons and Learner's Workbook
- Learning Channel Business Studies for Grade 11 DVD lessons and Learner's Workbook
- Afrikaans First Additional Language for Grade 11 DVD lessons and Learner's Workbook
- Learning Channel Accounting for Grade 11 DVD lessons and Learner's Workbook
- Learning Channel English First Additional Language for Grade 11 DVD lessons and Learner's Workbook

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Learning Channel's latest broadcasting endeavours are also supported by a potent mix of delivery platforms – including the web, newspapers, hi-tech audio-visual aids, workbooks and SMS – to ensure it maximizes its reach to South Africa's learners.



Learning Channel offers an extensive range of educational material on video or DVD. You can order 15-20 hours of interactive learning with a tutor, accompanied with a workbook to be used in the privacy of your own home or school.

CDs with digitised video lessons are also available.

To order your Learning Channel CDs, DVDs, videos and workbooks, please contact Takalani. E-mail: info@learn.co.za Phone: (011) 639-0170



FORCES AND EFFECTS OF FORCES

Learning Outcomes and Assessment Standards:

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 1:

Conducting an investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Learning Outcome 3: The nature of science and its relationship to technology, society and the environment.

Assessment Standard 1:

Evaluating knowledge claims.



Part 1

Overview

INTRODUCTION

This lesson is an introduction to forces and will familiarise you with the concept of “force”. A force can cause something to move or it can prevent something from moving. A force can make something move in a particular way (e.g. accelerate) or it might just change the shape of an object (distort it). The basic definition of a force is a “push” or a “pull”. This is the simple definition you learnt in the junior grades but it is still valid.

In this lesson you will focus on identifying forces in various contexts and recognising their effects. We will study Newton’s First and Second Laws of Motion and see how they relate to important quantities such as momentum, impulse and acceleration. There is very little calculation in this lesson. There will be more calculation in Lessons 2–5 of the mechanics series.

EXAMINATION TIP

The golden rule of problem solving in the physical sciences is: first understand the physics behind a problem or question and **then** answer it.

WHERE ARE THE FORCES?

Start with a qualitative understanding of forces (that means, no numbers and calculations yet). For the moment, we will simply analyse the forces that must be acting in images of the action, e.g. in pictures from magazine and newspapers.





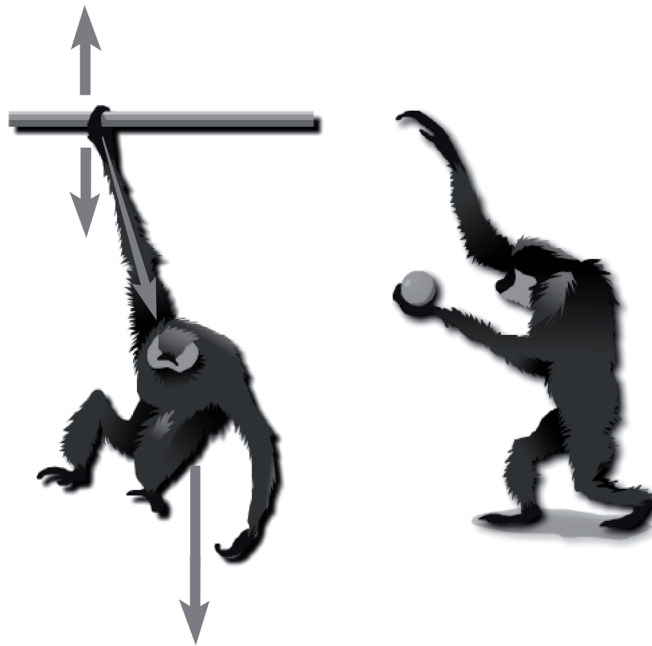
Activity 1.1

ANALYSING THE FORCES ACTING

Take photographs from magazines or newspapers and draw in forces that you think must be acting, e.g. in a picture of a dog running or a cat just sitting. Do not try to be too specific – just draw in the obvious forces.

The force of gravity (the force with which bodies near the earth are attracted towards it) always acts on bodies near the earth. If you try to analyse bodies in orbit around the earth, gravity will still be present, even though the forces will be smaller. (The force of gravity will be dealt with in detail in Lesson 4 of the Mechanics section.)

Look at the pictures of the apes below. Read the description and do the analysis of the forces acting in the picture on the right.



The ape on the left hangs from a bamboo pole. The force of gravity acts downwards on the ape. This force (the ape's weight) acts downwards on the pole at the point where the ape grips the pole. The pole does not break so it is strong enough to produce a force that is equal in size but opposite in direction to the force exerted by the ape's hand on the pole. If you were to hang like this, you would feel tension in your arm. How does this tension relate to the weight of the hanging body? Does the tension in the arm change if the ape is swinging from side to side? Try it yourself and discuss the question with your friends.

The ape on the right is walking and holding a ball in its left hand. Its left foot may be off the ground so its weight is on its right foot, which is also pushing the ape forward. Draw in the forces exerted by the ape's foot and hand on the floor and the ball as well as the forces exerted by the floor and the ball.



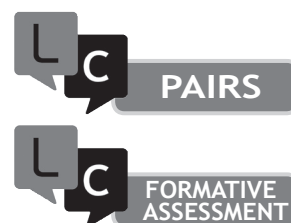
Activity 1.2

THE EFFECTS OF SMALL FORCES

Forces can be very large or very small. The easiest forces to detect are those that make things move but, as you will see later, bodies at rest also have forces acting on them, even if they are not moving.

You will remember this fact when you recall Newton's First Law of Motion.

Now write down five examples of very tiny forces being exerted in nature, e.g. when a leaf moves slightly in a breeze.

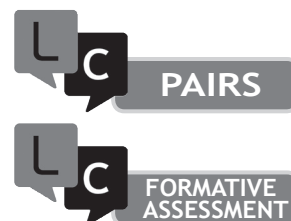


Activity 1.3

THE EFFECTS OF LARGE FORCES

Forces in nature can also be extremely large. Write down five examples of very large “forces of nature”, e.g. heavy winds that can lift roofs off houses or uproot large trees.

Now write down five examples of very large forces being exerted in nature, e.g. volcanoes projecting lava into the air.



Part 2

Overview

INTRODUCTION

When a force acts, we must be able to analyse where it acts, what the effects of the action are and what the nature of the force is. We will study different kinds of forces and effects in the five lessons on forces.

WHAT KINDS OF FORCES ARE THERE?

The first kind of force we will deal with is the contact force. As the name implies, these are forces that are exerted when bodies are in contact. (The true origin of contact forces will be discussed again when we study electrostatics later in the course.)

Activity 2

CONTACT FORCES

Note these instances of contact forces and identify the bodies that are exerting the forces on one another. When you do this activity you will find it useful to draw pictures of the situations you are trying to describe, e.g. when a wave strikes the side of a boat, *the boat rocks in the water from the force of the wave and the water reflects off the boat.*

1. a cricket bat hits a ball
2. an axe strikes a piece of wood
3. a car remains stationary on the road
4. a nail in the road pierces a car tyre
5. a worker stands on a ladder



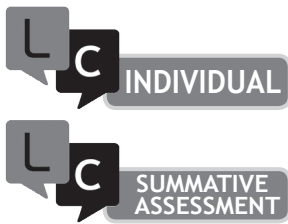
(Forces at a distance will be dealt with in Lesson 4 on gravitation. This is a type of force that is exerted without any contact being made between bodies. It must have occurred to you that this is happening when gravity acts on a body even when it is not in contact with the ground.)

Part 3

Overview

WAYS OF REPRESENTING FORCES

Use arrows to represent forces. The convenience of an arrow is that it has length and direction. The length of an arrow can be used to represent the size of a force and the direction of the line (shown by the arrow head) can represent the direction in which a force acts. We can use arrows to represent what are called “vector quantities”.

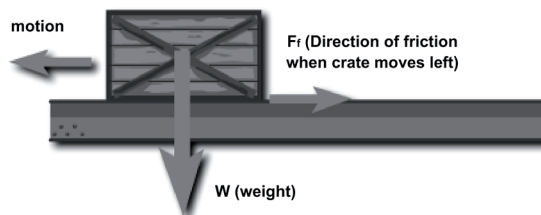


Activity 3

WHAT SIZE MUST THE FORCE BE?

Regard the following information as being “the rules of the game”. Study the rules and then do the set task.

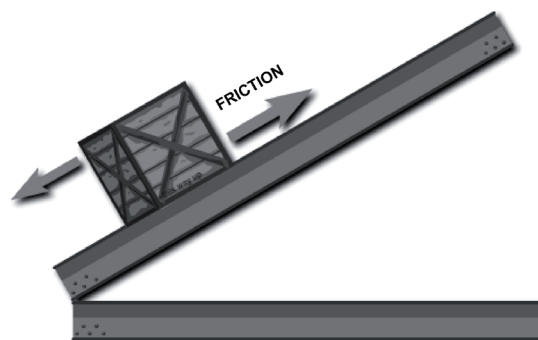
- The diagram below is of a crate on a warehouse floor.



- The crate’s weight is the force of gravity exerted on it by the earth.
- The force of gravity (weight) is represented by the large black arrow pointing downwards from the centre of the box.
- The frictional force between the crate and the floor is represented by the smaller arrow pointing to the right.
- The force of friction (see box below) always acts opposite to the direction of motion of a body.

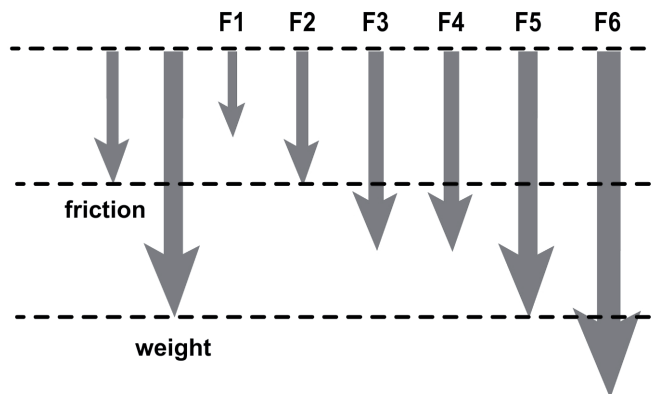
Friction acts when a body is moving on a surface or when a body would move if it were not for the frictional force. In this case the resultant force is zero.

Think of a box at rest on a slope. If there is no friction, the box will slide down the slope. If there is friction, when the slope is increased eventually the box will slide down the slope.



When the body starts to move, it has overcome the frictional force. (Friction will be dealt with in more detail in Lesson 3.)

- The arrows below represent forces $F_1 - F_6$ that can be applied to the crate.
- A comparison of the size of these arrows with the weight and friction is given to scale.
- These forces could be applied by ropes and pulleys, people or any lifting or pushing equipment.
- The forces shown can be applied singly or in combinations.
- The forces can be applied in any direction.



Use all the information provided to answer the following six questions. It will help you to draw diagrams showing the forces that would enable you to perform the following tasks.

In your diagrams, show where the forces would be exerted.

Use the fewest number of forces and the smallest possible force to:

1. Get the crate moving to the right.
2. Get the crate moving to the left and keep it sliding to the left at a constant speed.
3. Lift the crate off the ground.
4. Keep the crate rising off the ground at a steady speed.
5. The largest possible resultant force applied to the right.
6. Apply the smallest possible force that will reduce the frictional force between the crate and the floor.

Part 4

Overview

This section is a summary of Newton's First and Second Laws and some of the quantities involved, e.g. inertia and momentum. There are no activities as such but there is some work to be done to become familiar with the mathematics of the Second Law.

NEWTON'S FIRST LAW OF MOTION

Newton's First Law of Motion is sometimes called "the Law of Inertia". Newton's First Law uses the conclusion which Galileo Galilei drew from his famous "thought experiment" and describes the property of inertia. See if you can find out more about Galileo and his thought experiment.



INERTIA

Inertia is the property of a body that makes it remain in its rest position or keep on moving with uniform velocity in a straight line **unless** it is acted upon by another force.

Discuss this important property of matter with some friends to make sure you understand it. It seems quite simple, and it is. But it is a very important property of matter and must be understood clearly.

Newton's First Law of Motion

A body
will remain at rest
or continue moving with uniform velocity (in a straight line)
unless it is acted upon
by another force.

MOMENTUM

In order to describe the motion of a body when acted on by a force, Isaac Newton defined a quantity that he called *quantitas motus*, Latin for “quantity of motion”. He did so because he wanted a quantity that combined the amount of matter in a body (its mass) with its motion (its velocity). We call this quantity **momentum**.

*The momentum (**p**) of a body is given by the product of its mass **m** and its velocity **v**.*

$$\mathbf{p} = \mathbf{m} \times \mathbf{v} \quad [\text{the units of momentum are } \text{kg}\cdot\text{m}\cdot\text{s}^{-1}]$$

NEWTON'S SECOND LAW

A nett or “resultant” force causes an object’s momentum to change. Newton’s Second Law of Motion is stated in terms of the change of momentum. According to Newton’s Second Law, the change in a body’s motion or, more correctly, the change in a body’s momentum, is proportional to the size of the force that causes the change.

The rate of change of momentum (i.e. the change in momentum per second) of a body is proportional to the resultant (or nett) force acting on the body.

We can show this using a series of mathematical equations that say the same thing, but in symbols:

$$\mathbf{F} = \frac{\Delta \mathbf{p}}{\Delta t} \quad \text{the rate of change of momentum}$$

$$\mathbf{F} = \frac{\Delta(\mathbf{mv})}{\Delta t} \quad \text{the rate of change of momentum}$$

If the mass of the body experiencing the force remains constant (i.e. it does not change), then the change in momentum is only caused by the change in the body’s velocity. This is called a **special case** and leads to a familiar equation that you can use in many calculations. *But remember: the equation only applies when mass remains constant!*

$$\mathbf{F} = \mathbf{m} \times \frac{\Delta \mathbf{v}}{\Delta t}$$

In Grade 10 you learnt that acceleration is the “rate of change of velocity”. Therefore:

$$\mathbf{F} = \mathbf{m} \times \mathbf{a} \quad (\text{because } \mathbf{a} = \frac{\Delta \mathbf{v}}{\Delta t})$$

which can also be written as:

$$\mathbf{a} = \frac{\mathbf{F}}{\mathbf{m}}$$



This equation gives us the version of Newton's Second Law of Motion for the special case when the mass of the accelerating body remains constant.

Newton's Second Law of Motion

When a force acts on a body,
it causes the body to accelerate
in the direction of the force.

The magnitude of the acceleration
is proportional to the magnitude of the force
and inversely proportional to the mass of the body.



CONSERVATION OF MOMENTUM

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 1:

Conducting an the investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

INTRODUCTION

What you must know in this section of the curriculum is:

- Momentum
 - Define momentum; calculate the momentum of a moving object using $p = mv$.
 - Describe the vector nature of momentum and illustrate with some simple examples.
 - A net force on an object causes a change in momentum – if there is no net force on an object or system, its momentum will not change, i.e. momentum will be conserved.
 - State Newton's Second Law (N2) in terms of change of momentum: the net (or resultant) force acting on an object is equal to the rate of change of momentum.
 - In the absence of an external force acting on a system, momentum is conserved.
 - Apply the conservation of momentum to collisions of two objects moving in one dimension (along a straight line).
 - Explain the relationship between net force and change in momentum for a variety of motions.
 - Calculate the change in momentum when a resultant force acts on an object and its velocity.
 - increases in the direction of motion (e.g. 2nd stage rocket engine fires)
 - decreases (e.g. brakes are applied)
 - reverses its direction of motion, e.g. a soccer ball kicked back in the direction it came from
 - Draw vector diagrams to illustrate the relationship between the initial momentum, the final momentum and the change in momentum in each of the above cases.
- Impulse (product of net force and time for which it acts on an object)
 - Define impulse as $F\Delta t$ and ...
 - Know that $F\Delta t$ is a change in momentum, i.e. $F\Delta t = \Delta p$



- Use the relationship between impulse and change in momentum to calculate the force exerted, time for which the force is applied and change in momentum for the motion of an object in one dimension.
- Apply the concept of impulse to safety considerations in everyday life, e.g. airbags, seatbelts and arrestor beds.

Activity 1

A toy railway truck with a mass of 5 kg moves along its track at $6 \text{ m}\cdot\text{s}^{-1}$. Another truck which is stationary and which has a mass of 3 kg is standing in the path of the first truck. The two trucks collide. After the collision, the lighter truck moves off with a speed of $5 \text{ m}\cdot\text{s}^{-1}$.

Calculate the velocity of the heavier truck after the collision.



Activity 2

An 800 g rubber ball is dropped to the ground. Immediately before colliding with the ground, it is moving at $15 \text{ m}\cdot\text{s}^{-1}$. It bounces on the ground and as it starts to move upwards it is moving at $10 \text{ m}\cdot\text{s}^{-1}$.

Calculate

- The magnitude and direction of the momentum of the ball immediately before colliding with the ground;
- The magnitude and direction of the momentum of the ball immediately upon leaving the ground on its upward journey;
- The magnitude and direction of the change in momentum of the ball;
- The average force exerted on the ball by the ground during the collision if the ball and the ground remain in contact for 0,16 s.



Activity 3

A boy with a mass of 40 kg lies on a sled with a mass of 20 kg on a frozen lake. He holds a gun with a mass of 10 kg and fires a bullet with a mass of 20 g at a velocity of $300 \text{ m}\cdot\text{s}^{-1}$.

The bullet embeds itself in a block of wood with a mass of 1,98 kg lying on the ice some distance away.

Calculate

- The speed with which the boy and the sled begin to move immediately after the gun is fired;
- The speed with which the block of wood moves when the bullet enters it.

When you have completed Activity 3, work through the answer with a friend. Discuss your understanding of the problem and make sure that you both understand the physics behind it.



NEWTON'S THIRD LAW

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



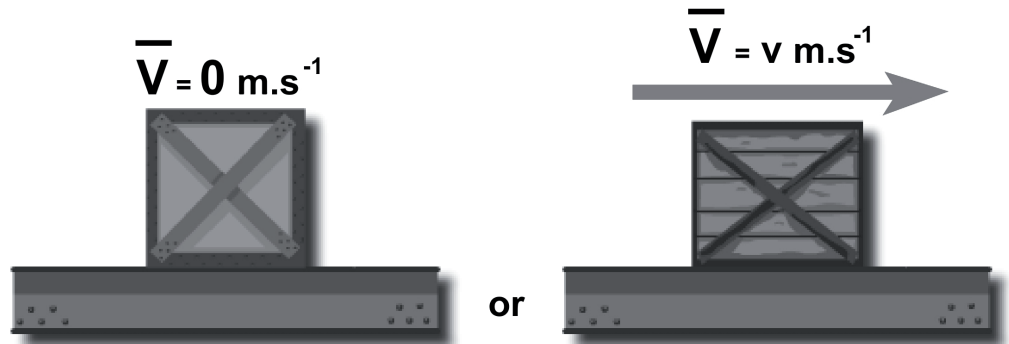
Part 1

INTRODUCTION

In this lesson we will study the meaning of Newton's First and Second Laws. We will also find that there is a gap which needs to be filled by a third law. Newton's Third Law tells us that forces always occur in pairs. With a third law to complement the first two, we now have a "package deal" that enables us to analyse forces and their effects.

RECAP OF NEWTON'S FIRST LAW OF MOTION

Every body continues in its state of rest OR moves at a constant velocity in a straight line unless it is acted on by another force.



Newton's First Law describes the property of inertia: that property of matter which causes it to remain at rest or continue to move with uniform velocity unless acted upon by another force.

RECAP OF NEWTON'S SECOND LAW OF MOTION

The rate of change of momentum (i.e. the change in momentum per second) of a body is proportional to the force acting on the body. The change in momentum is in the same direction as the force itself.

We can show this using a series of mathematical equations that say the same thing, but in symbols:

$$\mathbf{F} = \frac{\Delta \mathbf{p}}{\Delta t} \quad \text{the rate of change of momentum}$$

Since

$$\Delta \mathbf{p} = \Delta(\mathbf{mv}) \quad \text{the definition of the momentum, what Newton called "the quantity of motion"}$$

So Newton's Second Law can also be written:

$$\mathbf{F} = \frac{m\Delta \mathbf{v}}{\Delta t} \quad \text{when the mass of a body remains constant}$$



Acceleration is “the rate of change of velocity”:

$$\mathbf{a} = \frac{\Delta \mathbf{v}}{\Delta t}$$

If we place acceleration into the force equation, we see that Newton's Second Law can also be written:

$$\mathbf{F} = m\mathbf{a}$$

or more correctly:

$$\mathbf{a} = \frac{\mathbf{F}}{m}$$

This equation, stated in words, gives us the version of Newton's Second Law for the **special case when the mass of the accelerating body remains constant**.

Newton's Second Law of Motion

When a force acts on a body, it causes the body to accelerate in the direction of the force. The magnitude of the acceleration is proportional to the magnitude of the force and inversely proportional to the mass of the body.

DEPENDENT AND INDEPENDENT VARIABLES

Look at the way the equation for the special case is written. Acceleration is given in terms of the result of force on a body and the mass of the body being accelerated.

Thus we say that the acceleration:

- depends on the size of the force;
- is in the same direction as the force because a force can only cause a movement in the same direction in which it acts; and
- is inversely proportional to the size of the mass.

The third of those statements can be explained as follows: if a number of forces of *exactly the same size* act on a number of bodies, as the masses of those bodies increase so the accelerations being caused by the similarly sized forces will get smaller.

Acceleration is known as the **dependent variable** and the force is the **independent variable**, meaning that the force is the **cause** and the acceleration is the **effect**.

Part 2

INTRODUCTION

If we start from the general form of Newton's Second Law, we can define a new quantity called “impulse”. Think of what that word means to you. The way we use the word in everyday language suggests “the cause of change”. That is the same way it is used in mechanics. But in mechanics it refers specifically to “the cause of a change in momentum.”

RECAP OF MOMENTUM

In order to describe the motion of a body when acted on by a force, Isaac Newton defined a quantity that he called *quantitas motus*, Latin for “quantity of motion”. We call this quantity momentum and define it as follows: The momentum (**p**) of a body is given by the product of its mass **m** and its velocity **v**. So $\mathbf{p} = m \times \mathbf{v}$ (the units are $\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$).



IMPULSE

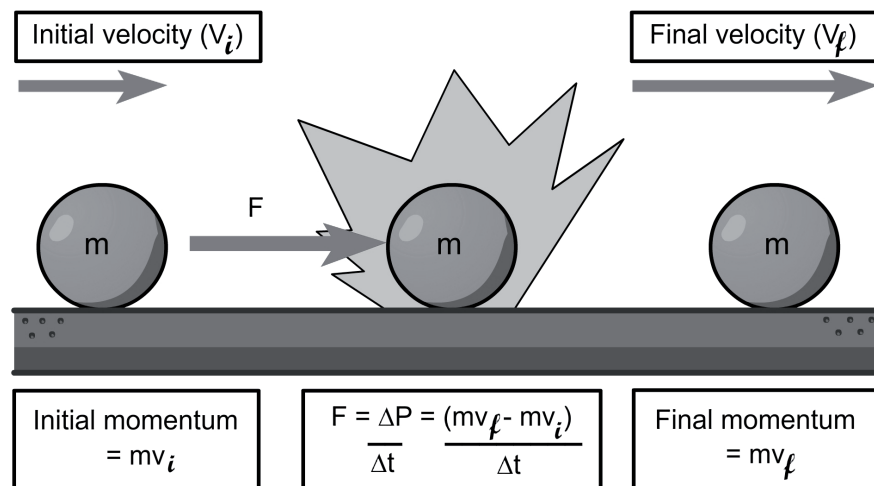
As we have seen, according to Newton's Second Law, the rate of change in a body's momentum is proportional to the magnitude of the force that causes the change:

$$\mathbf{F} = \frac{\Delta \mathbf{p}}{\Delta t}$$

Whenever we see the words "rate of change", it means that we divide the change in some quantity by the time taken for that change to happen. If we draw this in a diagram, we see how the action of a force causes a body's velocity, and therefore its momentum, to increase.

Because we talk about "rate" of change, the time it takes for the force to act is also important.

Remember that "change" is always calculated by subtracting the initial condition from the final condition.



We define an **impulse** as the product of a force (\mathbf{F}) and the length of time (Δt) in which it acts. An impulse on a body causes a change in its momentum.

$$\mathbf{F} \cdot \Delta t = \Delta p = (mv_f - mu) = \mathbf{m} \Delta \mathbf{v}_i$$

Example

A force of 200 N acts on a **resting** body whose mass is 2 kg. If the action of the force on the body lasts for 0,01 s, by how much will its velocity change?

$$\begin{aligned} \mathbf{F} \cdot \Delta t &= (\mathbf{m} \mathbf{v}_f - \mathbf{m}_i)(v_i = 0 \text{ m} \cdot \text{s}^{-1} \therefore \text{body is initially at rest.}) \\ (200 \text{ N}) \cdot (0,01 \text{ s}) &= (2 \text{ kg}) \cdot (v_f - 0) \quad (\text{the mass of the body remains constant.}) \\ \therefore \mathbf{v}_f &= 2,0 \text{ N} \cdot \text{s} / 2 \text{ kg} \\ &= \mathbf{1 \text{ m} \cdot \text{s}^{-1}} \end{aligned}$$

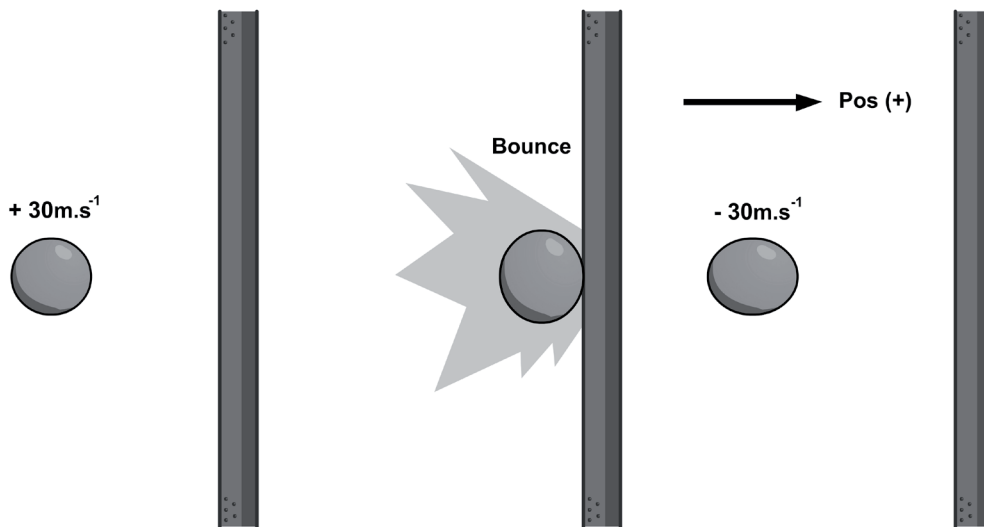
The body's velocity changes from rest ($v_i = 0 \text{ m} \cdot \text{s}^{-1}$) to $1 \text{ m} \cdot \text{s}^{-1}$.

When a force acts on a body, it will seldom be constant. This is because a force, when acting on a body, may deform the body slightly (i.e. squash it or push it out of shape in some way). Therefore we always regard the forces in these examples as being **average** forces. This means that the value of \mathbf{F} remains constant for the entire duration of its action, i.e. for Δt seconds.



Activity 1

A ball with a mass of 500 g strikes a wall at a velocity of $30 \text{ m}\cdot\text{s}^{-1}$ and rebounds at a velocity of $30 \text{ m}\cdot\text{s}^{-1}$. If the ball was in contact with the wall for 0,4 s, what was the size of the average force exerted by the wall on the ball?



NOTE: Because the direction of the change of momentum is important, we must decide on which direction is to be taken as positive. Here we choose left to right as being positive.

Part 3

NEWTON'S THIRD LAW OF MOTION

Examine again the example of the ball bouncing off the wall.

If it is the ball whose momentum is changing, the force causing the change in the ball's momentum must be acting **ON THE BALL**. (Otherwise the ball's momentum **WOULD NOT CHANGE!**) Therefore it is the wall's force on the ball that we must calculate.

But something odd is happening! The incoming ball must be exerting a force on the wall. And the wall must be exerting a force on the ball because the ball's momentum is changing.

So it seems that we have a pair of forces acting!

This brings us to the third of Sir Isaac Newton's three laws of motion – the final part of the “package deal”, the part that completes the picture. Together, the three laws give us the tools to understand how and why bodies remain at rest or move.

The First Law describes why a body either remains at rest or moves with constant velocity *and what needs to be done to change that situation*.

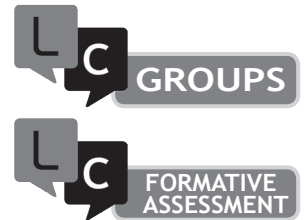
The Second Law tells us about the *effect* an external resultant force *causes* on a body.

What the first two laws **DO NOT TELL US** is the response of a body to a force when that force acts on it.

Newton's Third Law of Motion tells us that, when one object applies a force on a second object, the second object applies an equal and opposite force on the first object.

Newton's Third Law of Motion:

To every action there is an equal and opposite reaction.



We call an action and its reaction an “**action-reaction pair**” of forces, as in the case of a boot and a ball.

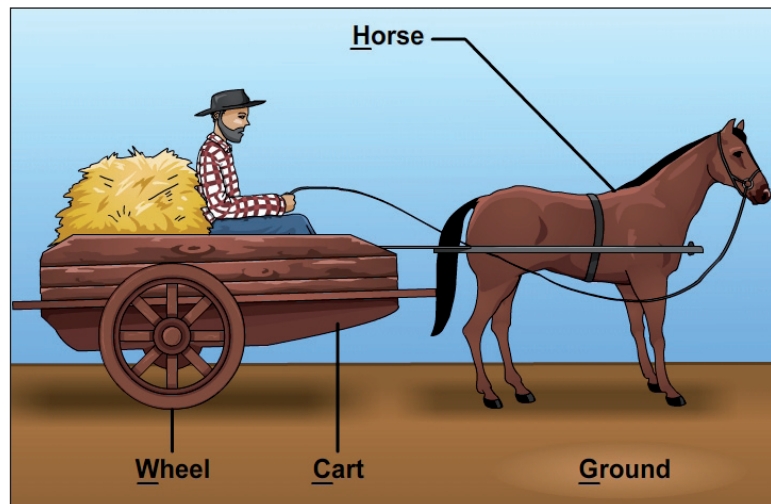


Five things to remember about action-reaction pairs:

- The **two** forces: have the same magnitude;
- act in opposite directions;
- act on different objects;
- are the same kind of force (e.g. both are contact forces);
- act simultaneously.

The last feature of action-reaction pairs is very important. When we speak of “action” and “reaction”, it almost sounds as though the reaction follows the action. This is a **WRONG IDEA!** There can be no reaction without an action, so the two forces arise at exactly the same time! In other words, the action and reaction are **SIMULTANEOUS**.

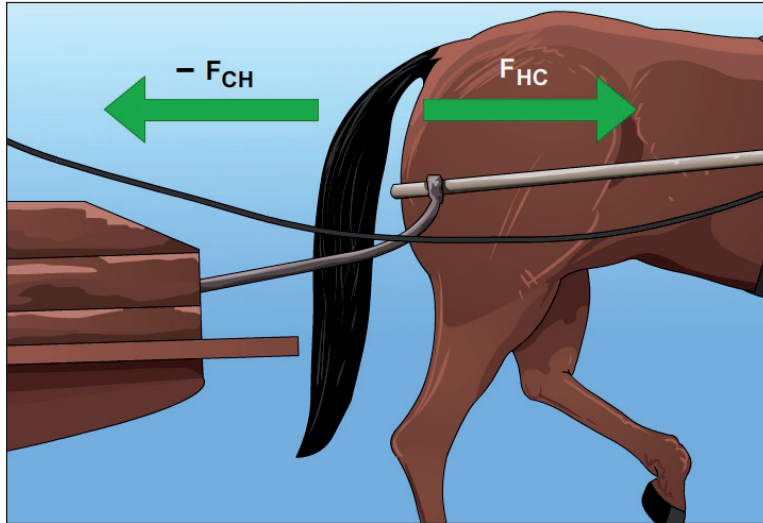
We can examine another situation: a horse and cart. Is it the pull the horse applies on the cart that causes the cart to move? Newton’s Third Law is subtle and gives us some surprising results – including the answer to that simple question.



There are many forces acting on a horse and cart, including friction between wheels and axle, etc. But we will concentrate on just three **action-reaction pairs (A-R pairs)**, as shown in the diagram. Imagine that the cart is accelerating. This means that there must be a **resultant force** in the direction of the acceleration (because the force is the cause and the acceleration is the effect).

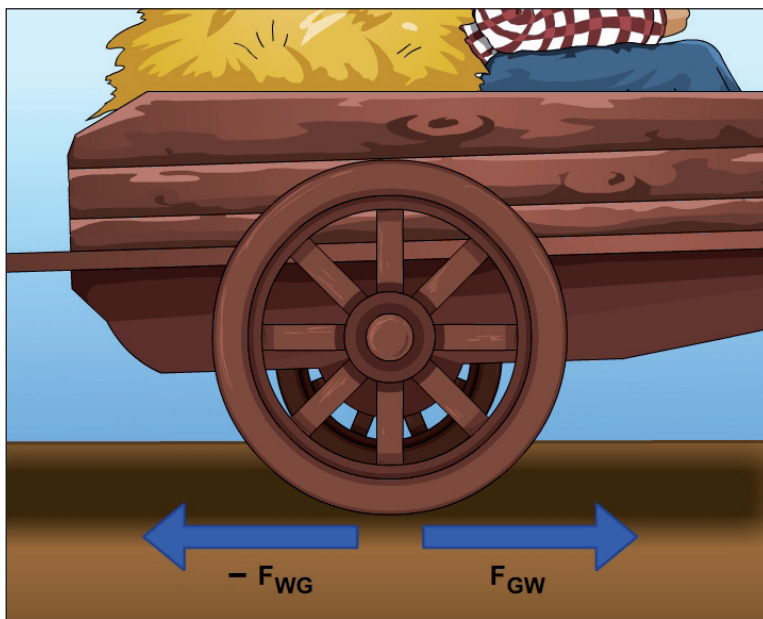


The first A-R pair is the pull of the horse on the cart and the equal and opposite pull the harness exerts on the horse.



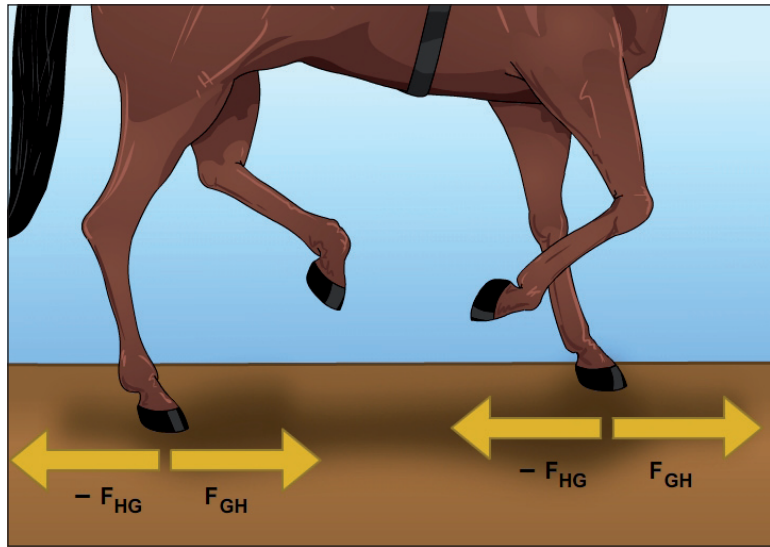
These can be considered “internal forces” and won’t affect the acceleration. *You wouldn’t try to push a car stuck in the mud by sitting in the front seat and pushing on the dashboard!*

If we examine the force between the wheel and the ground, we see the action of the wheel as it tries to move in a forward direction and the reaction of the ground on the wheel. This force of reaction is what we would call “resistance” or the frictional force that the surface (the ground) exerts on the body (the cart) that is moving over it.



Finally, we look at the force that we are fairly certain causes the cart to move forward. BUT LET’S BE CAREFUL HERE AS THERE IS A LITTLE TRAP FOR YOU UNLESS YOU ARE WIDE AWAKE! If the horse’s hoof pushes backwards on the ground, there is a reaction from the ground that pushes forwards. The cart accelerates forwards, so which of those two forces causes the acceleration? **The answer is that the force of the ground on the horse’s hoof is what propels the cart forward!!**





How can we decide if the cart actually accelerates forwards? We must find the resultant of all the forces that can either propel the cart forward or resist attempts to do so. If the magnitude of F_{GH} is greater than the magnitude of the oppositely directed resistance (F_{GW}) then the cart will accelerate forwards. And it is the force of the ground on the horse that is mainly responsible!

(Does this make sense to you? If not, go through the reasoning again.)

L C PAIRS

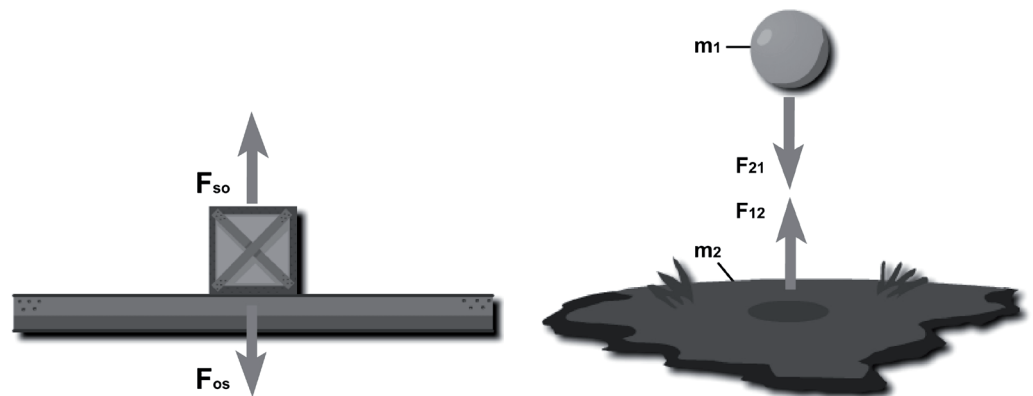
L C SUMMATIVE ASSESSMENT

Activity 2

EXPLAINING ACTION-REACTION PAIRS

Explain the forces acting in these two cases. In the left-hand diagram, an object (**O**) is resting on a table. Identify the action-reaction pair and explain its origin.

In the right-hand diagram, two masses attract one another. The nature of this “gravitational attraction” will be explained in Lesson 4. For the moment, all you need to know is that masses do attract one another. Of course, you know this from seeing how an object falls towards Earth. You could imagine that m_1 was a ball falling towards the Earth and that m_2 was the Earth.



THE FORCE OF FRICTION

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

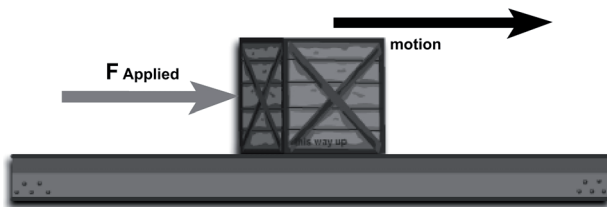
Indicating and explaining relationships.



Part 1

INTRODUCTION

Friction is something we have all been aware of since long before we could give it a name. Sometimes we are aware of friction because it is reduced, like when we slip on a well-polished floor or when a car skids on a wet or icy road. Friction is usually a retarding force that acts against the direction of motion and results in the motion being retarded.



We can reason that there must be retarding forces acting when bodies move on a surface. Look at this diagram. An applied force (F_{Applied}) acts on a block resting on a surface. If we want it to move we must apply a force. When the block goes from rest to some velocity, it has accelerated and therefore we know, from Newton's Second Law, that the force has acted on the body.

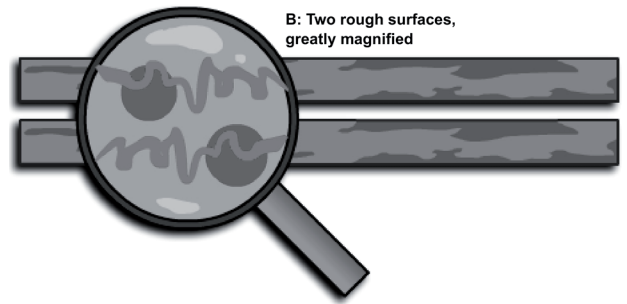
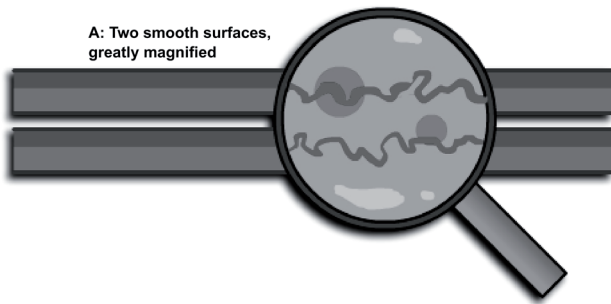
Now imagine that, once the body has begun to move, the applied force is adjusted so that the block now moves with constant velocity. This, we know from Newton's First Law, means that the resultant force acting on the body is zero. But if we are pushing (i.e. applying a force), there must be some opposing force counterbalancing our pushing. And, in the case of our block being pushed along a surface, this is what we call "the force of friction".

THE FRICTIONAL FORCE: A BRIEF EXPLANATION

Friction occurs when two surfaces are in contact. It actually consists of electromagnetic forces (we will deal with these in Lessons 9 and 11) that exist between atoms and molecules. If you think about it and try to imagine yourself looking at two touching surfaces greatly magnified (imagine you could see the atoms and molecules), the forces that exist between the surfaces will come from electric charges, won't they? Even surfaces that seem smooth to the naked eye actually have many imperfections, bumps and depressions. So even two very smooth-looking surfaces will not have every part of one surface in contact with every part of the other.

Where surfaces are very rough, one will find many spikes or peaks from one surface interlocking with fissures or troughs on the other surface, and vice versa. This will explain why rough surfaces have a great deal of friction.





Part 2

THE FORCE OF FRICTION

The first person to study friction scientifically was Charles-Augustin Coulomb, whom we will meet again in Lesson 9. He came up with an equation to describe the force of friction between two surfaces. The equation is:

$$F_f = \mu N$$

μ is a constant known as the **coefficient of friction**.

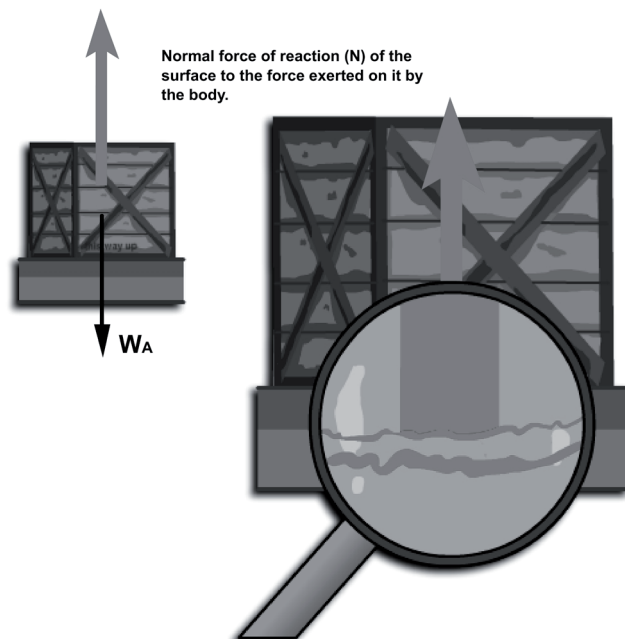
(This is just a number i.e. it has no dimensions, as in newtons, kilograms or seconds. But the coefficient of friction contains information about the nature of the two surfaces that are sliding relative to one another.)

N is the normal force exerted between the surfaces and is explained in the next paragraph.

F_f is either the force exerted by friction or the maximum possible size that this force can attain under a given set of conditions.

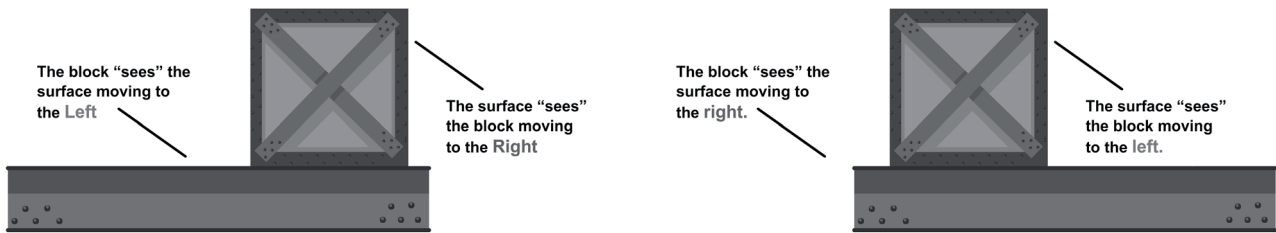
NORMAL FORCE OF REACTION

A surface will exert a normal force (**N**) in reaction to the action of a body on that surface. The action will usually be because of the weight of the body (i.e. the force that the Earth exerts on the body – the gravitational pull on the body, as discussed in Lesson 4) and any other forces acting downwards on the body (e.g. if someone or something is pressing down on it).



COEFFICIENTS OF FRICTION: WHY ARE THERE MORE THAN ONE?

When two surfaces are in relative motion, i.e. when a body moves along a surface, from that surface's point of view, the body is moving in the opposite direction.



In this case, the coefficient of friction is called “the coefficient of kinetic/dynamic friction” (μ_k / μ_d). The force of friction (F_f) on each surface is exerted in the direction opposite to its motion relative to the other surface.

When surfaces are at rest relative to each other, μ_s is the coefficient of static friction. This coefficient is usually greater than μ_k . (See Teacher Tips for a method that can be used to demonstrate this fact.)

The force of friction can be any value from zero up to F_f . What this statement means is that, in the static case, the frictional force is exactly what it must be in order to prevent motion between the surfaces. F_f (**static**) balances the net force that tends to cause the motion. The direction of the frictional force on a surface is always opposite to the motion of that surface or the direction a body would move in if there was no friction.

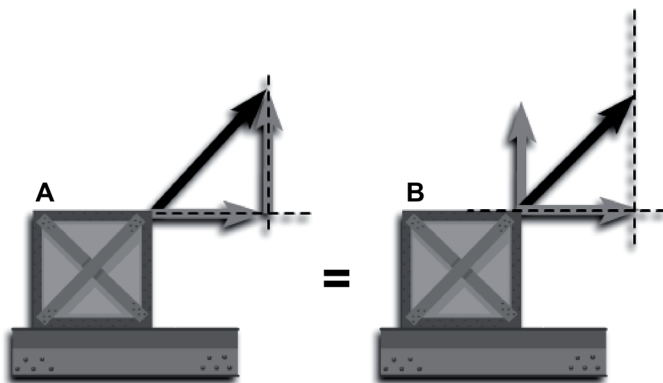
We say that μ_s gives us the maximum value for the frictional force above which sliding would start.

MEASURING THE COEFFICIENT OF FRICTION

When calculating the friction on a slope, when the incline is at an angle Θ , we first divide the force into **components**. This is a convenient way of dealing with forces and we usually choose the directions of the components so that they are at right angles to one another.

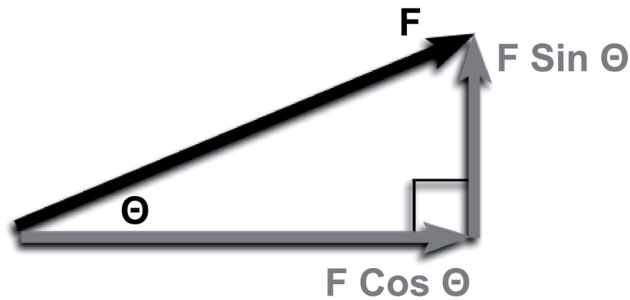
Because both the size and direction of a force is important (force is a **vector quantity**), we must take both into account when dealing with the effects of a force.

But the beauty of breaking forces down into two conveniently directed components is that we are then **finding two forces which, when they act together, have a combined effect that is the same as the original force**.

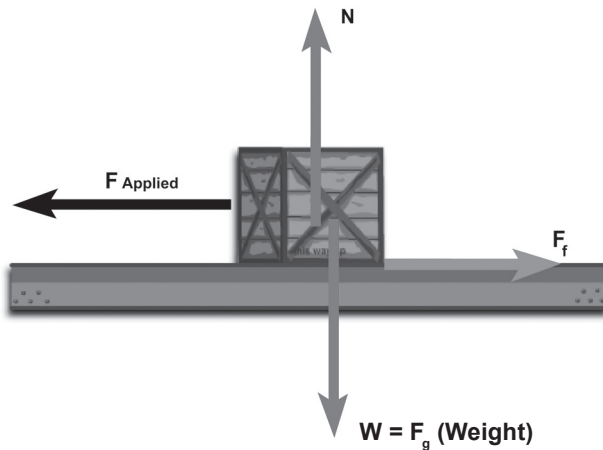


In Diagram A, we see how the black force can be broken down into a force acting horizontally to the right and a force acting vertically upwards.

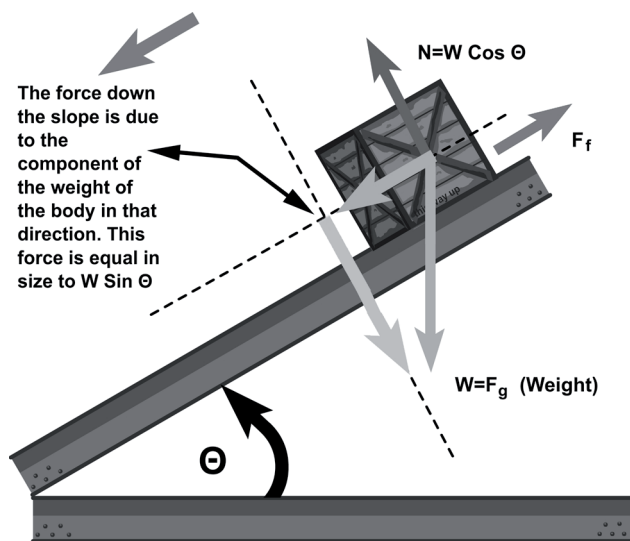
Diagram B shows us what this means: if we replace the black force acting at an angle with two forces (a force acting upwards and a force acting to the right), the effect on the body will be exactly the same. Think of this in terms of ropes pulling on a body: first a black one pulling at an angle on its own; and then one pulling upwards while another one pulls to the right. **In both cases, the motion of the body would be exactly the same!**



If a body with a weight W lies on a horizontal surface, the normal force of reaction to the weight of the body on the surface is N and is equal in size to the weight W .



As the surface is tilted or inclined at an angle Θ to the horizontal so the normal force of reaction (which is now only a component of the weight, $W \cos \Theta$) gets smaller as Θ increases.



Now for the final part of the story of simple friction on a slope. As Θ increases (i.e. the slope becomes more inclined), the value of $W \sin \Theta$ (the applied force down the slope) increases while the value of $W \cos \Theta$ (the normal force, N) decreases. If N decreases then the frictional force (μN) also decreases. At a



certain slope (or value of Θ), the force down the slope just exceeds the force of friction and the body will begin to slide.

At the moment before the body slides, i.e. when the frictional force up the slope is equal to the component of the weight down the slope, the following condition occurs:

$$\begin{aligned}
 \mathbf{F}_{\text{friction}} &= \mathbf{F}_{\text{down slope}} \\
 \text{or when } \mu W \cos \Theta &= W \sin \Theta \\
 \text{i.e. when } \mu &= \tan \Theta
 \end{aligned}$$

CALCULATING THE FORCE OF FRICTION

The equation for the frictional force, $\mathbf{F}_f = \mu \cdot \mathbf{N}$, consists of two forces and a constant which is a plain number without any dimensions. μ actually tells us what the size of the frictional force is between two kinds of surfaces and also between two kinds of surfaces with a lubricant between them. Here are some coefficients of friction.

Materials	Coefficient of friction	
	Static (μ_s)	Kinetic (μ_k) or dynamic (μ_d)
Steel on steel	0,7	0,6
Aluminium on steel	0,6	0,5
Glass on glass	0,9	0,4
Copper on glass	0,7	0,5
Heel on road	0,15	0,10
Rubber/concrete	1,0	0,8
Teflon/air	0,04	0,04
Synovial joints	0,01	0,01
Ball bearings	<0,01	<0,01

REDUCING FRICTION

- Devices such as wheels, ball bearings or rollers can affect friction by causing rolling instead of sliding.
- One technique used on trains is to reverse the train slightly to create slack in the linkages between trucks. This allows the train to pull forward and only take on the static friction of one truck at a time, instead of all of them at once. This spreads the static frictional force out over a longer period of time.
- A common way to reduce friction is by using a lubricant, such as oil or water, which is placed between the two surfaces.
- Graphite and talcum powder are very good lubricants and they demonstrate that not only liquids can be lubricants. Graphite is a good dry lubricant so it is used in locks. It can also be used in situations where temperatures are high.





GROUPS



SUMMATIVE ASSESSMENT

Activity 1

A thick steel sheet lies on the back of a flat-bed truck. The sheet has a mass of 250 kg.

- What force must be applied to lift the sheet?
- What force must be applied to start sliding the sheet off the back of the truck?



PAIRS



SUMMATIVE ASSESSMENT

Activity 2

A block of wood begins to slide down a wooden slope when it is inclined at 30° .

- Calculate the coefficient of static friction for wood on wood.
- Could we say that this coefficient applies for any two wooden surfaces?



INDIVIDUAL



SUMMATIVE ASSESSMENT

Activity 3

- Calculate the normal force of reaction of the surface when a 10 kg block rests on a slope that is angled at 45° to the horizontal.
- Use the table above to discuss which materials would not slide in this situation.



COMBINING NEWTON'S LAWS OF MOTION

Learning Outcomes and Assessment Standards



Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 1:

Conducting an investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

INTRODUCTION

What you must know in this section of the curriculum is:

Pairs of interacting objects exert equal forces on each other.

- Newton's Third Law
 - State Newton's Third Law (N3): When pairs of objects interact, they exert forces on each other.
 - These forces are the same size and point in opposite directions.
 - You can't touch without being touched; you can't pull without being pulled.
 - Differentiate between contact and non-contact forces.
 - Apply Newton's Third Law (N3) to contact and non-contact forces.
 - Identify N3 pairs, e.g. donkey pulling a cart, a book on a table.
- Solving problems involving forces in a straight line.
- Combining Newton's three laws of motion.

Lesson 3a

Activity 1



Study the graphic on the DVD showing a series of graphs describing the motion of a ball thrown vertically upwards.

Understanding the problem

Understand the meaning of the arrows (vectors) and how the pictures translate into graphs. It is most important that you understand why the force on the ball and its acceleration remain constant during the upwards and downwards motions.

Draw your own diagrams showing the vectors and explain your understanding to other members of your group.





Activity 2

With a partner study a graphic of the forces acting when a horse and cart travel along a horizontal road. Force diagrams and free-body diagrams can be used to understand better any situation involving forces.

Understanding the problem

Remember that if you want to determine the acceleration of the horse and cart you must look at all the forces – both “driving” and “retarding” forces – acting on the horse and cart as a whole. In this case, the action-reaction pair where the horse and cart are joined (F_{HC} and $-F_{CH}$) become so-called “internal forces” and they can be discounted. An example of internal forces is that if your car is stuck in mud, you can’t get it out by sitting inside the car and pushing on the dashboard!

If you want to determine the acceleration of the cart alone then the force F_{HC} becomes significant and the resultant force that is causing the acceleration is the difference between F_{HC} and any retarding forces on the wheels and axles. To determine the acceleration we take into account only the mass of the cart and anything in/on it. The fact that the horse’s acceleration must be equal to that of the cart and the horse and cart as a whole does not matter. There is only one golden rule here: if you want to determine the acceleration of a body then look at ONLY those forces that are acting ON IT and take only ITS MASS into account. This is true even though the body is connected to other parts of a more complex system.



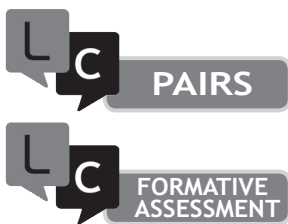
Lesson 3b

Activity 3

A cricket ball (mass 250 g) is bowled at $40 \text{ m}\cdot\text{s}^{-1}$.

A bat strikes the ball with an average force of 120 N.

If the bat and the ball are in contact for 0,1 s, with what speed will the ball leave the bat?

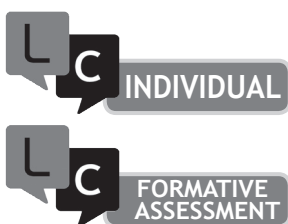


Activity 4

A 950 kg lift is moving upwards and slowing down with an acceleration of $2 \text{ m}\cdot\text{s}^{-2}$.

The lift is carrying a single passenger with a mass of 500 kg.

Calculate the tension in the cable.



Activity 5

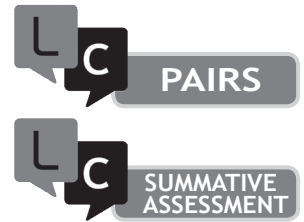
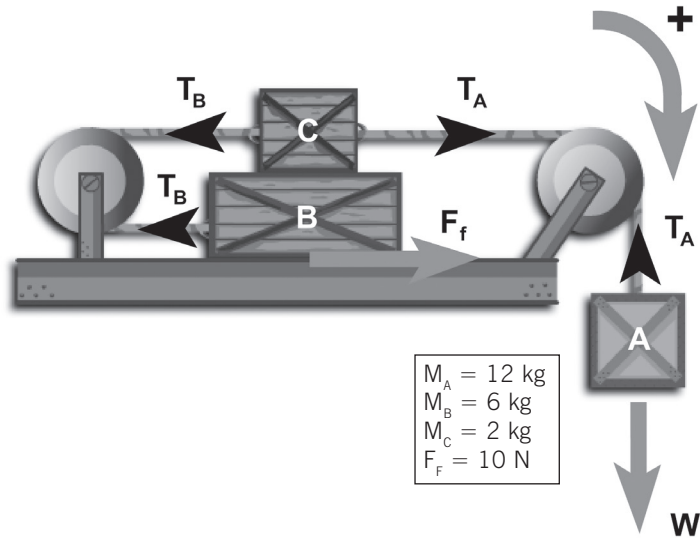
A 4 kg rock falls to the ground from a height of 45 m.

As it reaches the ground, it is moving at $30 \text{ m}\cdot\text{s}^{-1}$.

The rock sinks into the ground and comes to a stop 18 cm into the ground in 0,012 s.

Calculate the average force exerted by the ground on the rock.

Activity 6



Three blocks of wood **A** (12 kg), **B** (6 kg) and **C** (2 kg) rest on a table top and are connected as shown in the diagram.

The strings are light and inextensible and there is a frictional force of **10 N** between the table and block **B**. There is no friction between **B** and **C**.

6.1. Draw free body diagrams for the three bodies that make up the system.

6.2. Calculate

- the **acceleration** of the system; and
- the **tensions** in the strings.



THE FORCE OF GRAVITY

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

In the most simple terms, we regard a force as a push or a pull that may cause a body to accelerate (and hence change its momentum), rotate (we see this effect as a “torque”) or deform (we see this as stresses and strains within solid structures). If a force does cause acceleration then the motion is determined by Newton’s Second Law of Motion. Forces may not always cause motion, as we know from Newton’s First Law, and from the Third Law we know that forces always occur in pairs.

The ancient Greek philosopher-scientist, Archimedes, recognised that something had to cause movement and he was the first to describe forces. He didn’t get it quite right, however, and Galileo improved on Archimedes’ theory by describing the property of matter we now call “inertia”. Newton, the great English genius, gave the first really complete account of forces and we still use his laws very successfully today.

Charles Coulomb, who described friction (see Lesson 3), also discovered the relationship between the size of electrical charges, the distance between them and the force they exert. (This will be dealt with in Lesson 9). Another reclusive English genius, Henry Cavendish, showed that a force of attraction existed between bodies with mass. His work gave direct, experimental evidence for Newton’s explanation of the motion of the planets around the sun and the moon around the earth. More importantly, the work of Newton, Coulomb and Cavendish began the process of identifying the different kinds of forces in nature.

The greatest explosion of knowledge about the nature of forces came about in the early 20th century, thanks largely to the work of one of the greatest scientific geniuses of all time, Albert Einstein. Because of his work and that of others who followed him and expanded on his highly original ideas, we now have a very different picture of what a force is. We now know about four fundamental forces that act as the universe’s “glue” because they hold matter together in all its forms and govern the interactions between the forms of matter.

The relative size of the fundamental forces varies enormously. This lesson deals with the weakest of the four, gravity. The next two are electromagnetism (including the forces between static electrical charge) and the weak interactions that govern the way some atomic nuclei can break up spontaneously, emitting radioactive particles. The fourth force is the strongest of all and is responsible for binding together the positively charged particles (protons) in the nucleus. The modern view of these forces (or interactions between forms of matter) is that they are “mediated” by particles themselves, i.e. a force is the result of a very rapid exchange of particles between the interacting bodies.

This idea is very exciting, although w-a-a-a-y beyond the scope of school physics! Still, as the poet Robert Browning said: “A man’s reach must exceed his grasp or what’s a heaven for?” He was talking about the advent of the automobile but the



sentiment still applies. It should be terribly exciting to a young, enquiring mind to know what fascinations lie ahead. In fact, Sir Isaac Newton put it as well as anyone could have:

“I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.”

There are four fundamental forces of nature. And who knows? There might be others. The ones we know of so far are:

Interaction	Current Theory	Mediating particles	Relative Strength
Strong	Quantum chromodynamics	gluons	10^{38}
Electromagnetic	Quantum electrodynamics	photons	10^{36}
Weak	Electroweak theory	W and Z bosons	10^{25}
Gravity	Einstein's General Theory of Relativity	gravitons	1

Note how relatively weak the force of gravity is. We will consider later why gravitational forces are still so important. And we will also come back to this table when we begin to talk about the nucleus of the atom where protons are pushed very close together and yet can be held in those positions. Do you have any theories about how this happens?

For more fascinating reading on forces, consult: <http://en.wikipedia.org/wiki/Force>

Part 1

INTRODUCTION

We all know, from first-hand, empirical evidence, that a body that is released from near the Earth's surface will fall. But what does “fall” actually mean? We see “falling” in terms of an object dropping towards the ground, don't we? But, as we will see, when we remember what was said in Newton's Third Law of Motion, the truth is slightly different.



Here is a snowboarder. He has just ramped off the edge of a snowdrift.

Although he still has forward momentum, he is also falling under the influence of Earth's gravitational pull.

*But, according to Newton's Third Law of Motion, for every action (Earth's pull on the snowboarder) there must be an equal (in size) but opposite (in direction) force of reaction. **What is the force of reaction here?***



GRAVITY: A FORCE OF MUTUAL ATTRACTION

Newton also formulated a fourth law that tells us about the attractive force between two objects having mass.

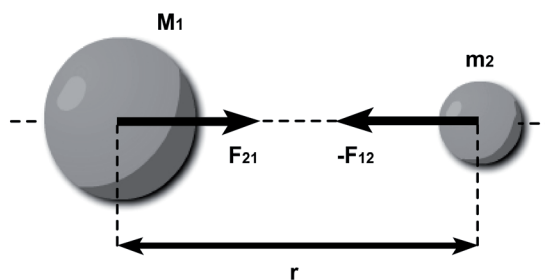
A common and often-told legend tells of an apple falling on Newton's head and Newton thinking: "Eureka! That's why the apple falls: because the Earth attracts it!" (Actually, "eureka" is what Archimedes is *supposed* to have shouted as he ran naked down the road after realising how to determine specific gravity while sitting in his bath. Another story.) Well, Newton and the apple probably didn't happen exactly as the legend tells it either, although there is still an apple tree in the grounds of Newton's house, Woolsthorpe Manor in Lincolnshire, England. It may be a daughter of the tree that existed when Newton had his great thought there in 1665. He had just received his degree from the University of Cambridge and, when the university closed because of an outbreak of bubonic plague, he went home to escape the terrible contagion.

Most probably what happened was this: Newton had read the works of the great astronomers and scientists Copernicus, Galileo, Descartes and Kepler while at Cambridge even though most of the teachers in his college, Trinity College, were still followers of the physics of Aristotle. Through his readings and his own observations and measurements, Newton realised that the force that kept the planets in their orbits was **the same force** that caused objects such as apples to **appear** as though they were falling towards the ground.

Moreover, Newton also realised that the force in evidence when a body "falls" is actually a force between the two bodies: **each of the pair of bodies experiences the same force!** If such a force acts on both the Earth and an apple, which of these two bodies will appear to move? Surely the apple, because it is so much smaller than the Earth and the same sized force acting simultaneously on both an apple and the Earth will have a far more noticeable effect on the little apple. Won't it?

Newton said that because two bodies close enough to one another will attract each other with forces that are equal in size but opposite in direction, we speak of a **MUTUAL force of (gravitational) attraction**. Such a pair of forces is an **action-reaction pair**.

When two masses (M_1 and m_2), whose centres are a distance r apart, exert a gravitational force on each other, the force (F_{12}) with which the first mass (M_1) attracts the second mass (m_2) is equal in magnitude but opposite in direction to the force with which the second mass attracts the first mass, i.e. $-F_{21}$.



When two masses (M_1 and m_2), whose centres are a distance r apart, exert a gravitational force on each other, the force (F_{12}) with which the first mass (M_1) attracts the second mass (m_2) is equal in magnitude but opposite in direction to the force with which the second mass attracts the first mass, i.e. $-F_{21}$.

The force between two bodies depends on the size of their respective masses and their distance apart. Newton identified how these quantities were related. But the first and most important point to realise is that the force arises because there are **two** masses. The force will not occur unless both are attracting one another.



Part 2

NEWTON'S LAW OF UNIVERSAL GRAVITATION

The force between two bodies depends on the respective size of the two masses and their distance apart. Newton identified how these quantities were related:

$$F_g \text{ (gravitational force)} = \frac{m_1 \times m_2}{r^2} \quad \begin{array}{l} \text{(the **product** of the masses)} \\ \text{(the **reciprocal of the square of the distance}** \\ \text{between their centres)} \end{array}$$

When we have something that is proportional to more than one variable, the variables can be combined. If we have identified all the variables, we can then rewrite the relationship in the form of an equation by introducing what is called a “constant of proportionality”.

Mass and distance apart **are** the only variables that affect the force of attraction between two bodies. By introducing a constant of proportionality, “**G**”, known as the “universal gravitational constant”, we get this equation:

$$F = \frac{G \cdot m_1 \times m_2}{r^2}$$

$$G \cdot \frac{m_1 \times m_2}{r^2}$$

This is **Newton's Law of Universal Gravitation**. An important aspect of the equation is that when the centres of two masses (m_1 and m_2) are r metres apart, they experience a mutual force of attraction that **obeys an “inverse square law”**. If the distance between the bodies is doubled, the force between them becomes one quarter of its initial strength (and **not** one half). Newton also showed that when a body such as the Moon orbits another body such as the Earth, the orbiting body will follow an elliptical path.

A WORKED EXAMPLE

A man stands on the surface of the Earth and then jumps into the air. He is certainly aware of the force that the Earth exerts on him as it brings him down to Earth. What he is probably not aware of is the force that HE (the man) exerts on the EARTH.

If he considers Newton's Second Law, he might realise that the Earth's mass is so huge compared to his own that the acceleration caused by his force on the Earth wouldn't even be noticed. We even have a name for the Earth's force on the man: we call it his **weight**!

As we also know, the force of the Earth's gravity on an object is explained by “mass \times the acceleration caused by the gravity of the Earth (**g**)”, i.e. $W = m \cdot g$.



We know that g_E is about $10 \text{ m}\cdot\text{s}^{-2}$. The “acceleration caused by gravity” means that, when a body falls into the Earth's gravitational field, it will increase its downward velocity by $10 \text{ m}\cdot\text{s}^{-1}$ each second. We also know that the Earth's circumference (C) is about 40 000 km (or $4 \times 10^7 \text{ m}$) so we can calculate the Earth's radius (from $C = 2\pi r$).

Using the formula for Newton's Law of Universal Gravitation, the mass of the Earth can also be calculated provided that we know the value of the universal gravitational constant. Fortunately, Henry Cavendish



devised an ingenious method of doing this so we know that the value of $G = 6,67 \times 10^{-11} \text{ N}\cdot\text{m}^2\cdot\text{kg}^{-2}$.

$$F_{\text{Earth on man}} = m_{\text{man}} \cdot g_E = \frac{G \cdot M_{\text{Earth}} \times m_{\text{man}}}{r_{\text{Earth}}^2}$$

$$\therefore g_E = \frac{G \cdot M_{\text{Earth}}}{r_{\text{Earth}}^2}$$

and $M_{\text{Earth}} = \frac{g_E \cdot r_{\text{Earth}}^2}{G}$

From the final equation, we can calculate a value for M_{Earth} at approximately $6,4 \times 10^{24} \text{ kg}$. (Can you work out this answer?) Now can you also see why the mutual force of attraction between the man and the Earth has so little noticeable effect on the Earth?

The equation for the acceleration caused by gravity on or near the surface of the Earth (g_E) also tells us that it depends only on the Earth's mass (M_{Earth}) and its radius (r_{Earth}). This means that a tennis ball and a large iron ball will accelerate towards the Earth at exactly the same rate of acceleration, i.e. large objects and small objects fall at the same rate of acceleration. (Galileo discovered this surprising result through careful experimenting.)

When we do the section on electrostatics and Coulomb's Law (Lesson 9), we will find that the equation for forces of electrostatic attraction and repulsion is very similar to the equation for the Law of Universal Gravitation. In Coulomb's Law, we have a constant of proportionality $k = 9 \times 10^9 \text{ N}\cdot\text{m}^2\cdot\text{C}^{-2}$. Comparing k (about 10^{+10}) with G (about 10^{-10}) we get an idea of how much stronger the electrostatic force is than the force of gravity. Look at the table of relative strengths of the fundamental forces again.

Part 3

THE GRAVITATIONAL FIELD

We will deal with the concept of a field again in the section on electricity and electrostatics (Lesson 9). **A field refers to a region in space where a force can be felt.** So, when we have a mass positioned somewhere in space, there is a gravitational field associated with that mass.

The concentric rings diagram below represents a field in which the field strength drops off as we get further from the mass which gives rise to the field. To find out how the strength of the field drops off, we need to look at how it varies with "r" – the distance from the mass. Look at the equations in the box in Lesson Part 2. We can see that

$$g_E = \alpha \frac{1}{r_{\text{Earth}}^2}$$

This means that as "r" gets bigger (as we get further from the mass) so the strength of the field decreases "as the square of the distance". This means, for instance, that if the distance doubles then the field drops to $\frac{1}{4}$ of its strength at a distance of one radius from the centre of the mass. (NOTE: The diagram is not quite accurate because we see rings going from darker to lighter instead of a smooth and gradual change in field strength.)





The obvious question to ask is, if there is a field in this theoretical “region in space” around a mass, how do we know? How can we tell? Well, the answer is that we must place another mass in that region (i.e. IN the field) to test it. If our “test mass” experiences a force then we know that a field exists. We also know that somewhere relatively close by there must be a mass that is causing the field.

In gravitational fields, the field strength can be measured by the acceleration of our test mass. If we place a unit mass (1 kg) in the Earth’s gravitational field (quite close to the Earth’s surface), that mass will accelerate towards the Earth at approximately $10 \text{ m}\cdot\text{s}^{-2}$. We can also say that masses will experience a force of 10 N for each kilogram of their mass. So, if you are asked what the strength of the Earth’s gravitational field near the surface of the Earth is, you can reply with confidence: “Very nearly $10 \text{ N}\cdot\text{kg}^{-1}$ ”. (This is the same as saying that any mass placed near the surface of the Earth will accelerate towards it with an acceleration of $10 \text{ m}\cdot\text{s}^{-2}$).

We can also explain this in another, slightly different way. If we take the alternative expression for Newton’s Second Law of Motion – the one that talks about a resultant force acting on an object with a mass **m** – we know that the acceleration can be calculated by dividing the force (**F**) by **m**, or **F/m**. If acceleration is constant then N2 tells us that it is the ratio **F/m** that is constant. If we say that the acceleration caused by gravity is constant near the Earth, then it follows that all bodies, regardless of their mass, fall at the same rate. **When you explain this to a friend (see ASSESSMENT below), think about how the force of gravity must vary for different masses in order to ensure a constant acceleration.**

The mass of Earth’s satellite, the Moon, is much less than the Earth’s. The Moon’s radius is also very different from the Earth’s. These two factors combine to give a gravitational field strength of approximately $1,6 \text{ N}\cdot\text{kg}^{-1}$, or one sixth that of the Earth. A mass near the surface of the Moon accelerates towards it at $1,6 \text{ m}\cdot\text{s}^{-2}$.

GRAVITATIONAL ACTION-REACTION PAIRS

We know from Newton’s Third Law of Motion that forces exist in pairs and that every force has an equal and opposite reaction to itself. We call the pairs of forces “action-reaction pairs”. When mass A attracts mass B, mass B attracts mass A with a force equal in size but opposite in direction. So, as the Earth attracts the Moon, the Moon also attracts the Earth. These two forces are an action-reaction pair.





GROUPS



FORMATIVE ASSESSMENT



INDIVIDUAL



FORMATIVE ASSESSMENT



INDIVIDUAL



FORMATIVE ASSESSMENT

Activity 1

An astronaut with a body mass of 80 kg stands on a bathroom scale on the surface of the Earth. The scale measures his weight (which is a force) and it shows 800 N. If he travels in a rocket to a height of one Earth radius above the Earth's surface, what will the reading on his scale be now?

Activity 2

Two masses, one of 5 kg and another of 60 kg, are placed a distance of 20 cm apart.

- Calculate the mutual force of attraction between the two masses.
- What will the force on the masses be if their centres are made 10 cm apart?
- By what factor will the mutual force of attraction change if the 5 kg mass is replaced by a 10 kg mass?

Activity 3

Two masses exert a force of 100 N on each other.

- The masses are doubled and the distance between them is halved. What is the new force between them?
- Now the masses are halved and the distance is doubled. What is the force between them now?



GRAVITATION

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 1:

Conducting an investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

INTRODUCTION

What you must know in this section of the curriculum is:

- Masses can exert forces on each other (gravitational attraction) without being in contact.
- Force between two masses (Newton's Law of Universal Gravitation)
 - State Newton's Law of Universal Gravitation.
 - Use the equation for Newton's Law of Universal Gravitation to calculate the force two masses exert on each other.
 - Understand that objects can interact with a field, which is how masses can exert forces on each other without touching.
 - Know that gravitational field strength "g" is the force per unit mass:
 - $g = F/m$, with an approximate value of $9.8\text{m}\times\text{s}^{-2}$ on or near the surface of the Earth.
 - Know that weight of an object is the force the Earth exerts on the object on or near the surface of the Earth ($w = mg$).



Lesson

Activity 1

Explain why the "acceleration because of gravity" is actually a measure of the gravitational field strength at a point in a gravitational field.

Understanding the problem

We define the strength of electrical field as $\mathbf{E} = \mathbf{F}/q$, or the force per unit charge. If we place a "positive test charge" at a point in an electric field it will experience a force. Therefore the electric field strength at a point in the field is the size of the force exerted divided by the size of the positive test charge.





PAIRS

Activity 2

Why is the gravitational field strength at the surface of the moon less than the gravitational field strength at the surface of the Earth?



FORMATIVE ASSESSMENT

Activity 3

Work out your answer without doing any paper and pencil calculations and choose one of the answers below. **Then** do the calculation on paper before looking at the answers to check on both your reasoning and your calculations.



INDIVIDUAL



FORMATIVE ASSESSMENT

Question: If the mutual force of attraction between two masses is 100 N, what will the force be if the **distance between them is doubled** and the **size of one of the masses is halved**?

Answer from:

- a) The force is doubled.
- b) The force remains the same.
- c) The force is halved.
- d) The new force is a quarter of the original size.
- e) The force is now one-eighth what it was before.



INDIVIDUAL

Activity 4

At some point between the Earth and the moon, a space capsule will be travelling at a constant velocity. Where is this point?



FORMATIVE ASSESSMENT

[The average distance between the moon and the Earth is 384 000 km. Use this as the Earth–Moon distance.]

Understanding the problem

For this kind of problem, it is important to draw a diagram so that one sees the physical/spatial aspects of the problem at a glance.



THE TURNING EFFECT OF FORCES

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

We have seen that when a force acts on a body in a straight line, it causes a change in the body's momentum. This is true whether the body was initially at rest or moving with some velocity.

A change in momentum can come about in three ways. First, there can be an increase or a decrease in a body's speed without its direction changing. (In other words, a body speeds up or slows down but the direction of its movement remains unchanged, i.e. it continues on its path in a straight line.) Secondly, there can be a change in direction with or without a change in its speed. And, thirdly, if a body's mass changes while it is moving, then its momentum may also undergo a change (i.e. if a body's mass increases or decreases but its velocity does not, its momentum also increases or decreases.)

Forces act in each of these cases where momentum changes in some way. And in each case, we know from Newton's Second Law of Motion that a force has acted. But if a force acts on a body and its momentum does not change, it is possible that the effect of the force can be a change in the body's shape. This can happen in several ways, the details of which need not concern us at this point.

In this lesson we will deal with the particular case in which force causes a body to turn (or rotate). In this situation, even if the speed of the body remains unchanged, there will be a change of direction, indicating that a force is acting on the body in question.

Rotation is an important form of motion. Most machines include some form of rotation in their action. A simple bicycle; the winding gear at the top of a mineshaft with its cables, pulleys and axles; and complicated machines used to make products in a factory all involve forces that cause something to turn.

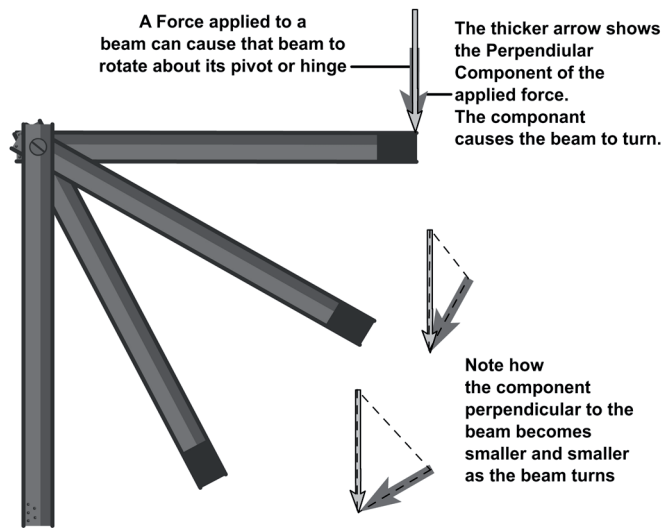
Part 1

TURNING EFFECT

You must know that when an object is fixed or supported at one point and a force acts on it a distance away from the support, that force tends to make the object turn.

BUT only components of the force perpendicular to an object will cause turning. Any component of a force exerted parallel to an object will not cause the object to turn.





Now it also makes sense when we say that a force which is exerted parallel to an object cannot make it turn.

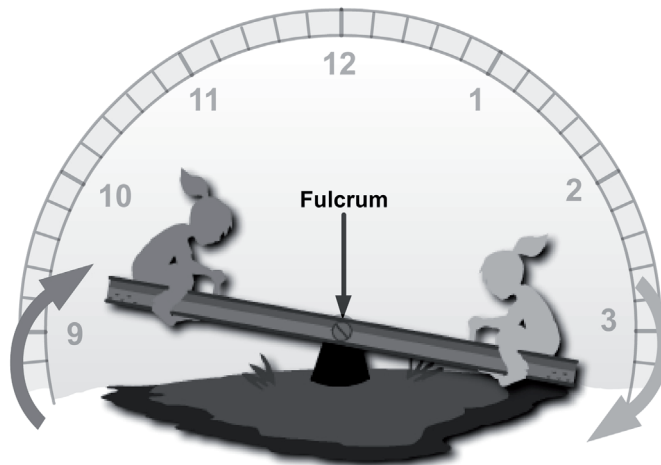


TURNING EFFECTS IN CLOCKWISE AND ANTICLOCKWISE DIRECTIONS

The **direction of a TORQUE** or the **MOMENT of a force**, (the names given to the turning effects of a force), is **either clockwise or anticlockwise**. This can be seen clearly in a playground seesaw.

The downward force due to the red girl's weight at some distance from the fulcrum causes an anti-clockwise torque or moment

The downward force due to the blue girl's weight at some distance from the fulcrum causes a clockwise torque or moment



CALCULATING TORQUE OR THE MOMENT OF A FORCE

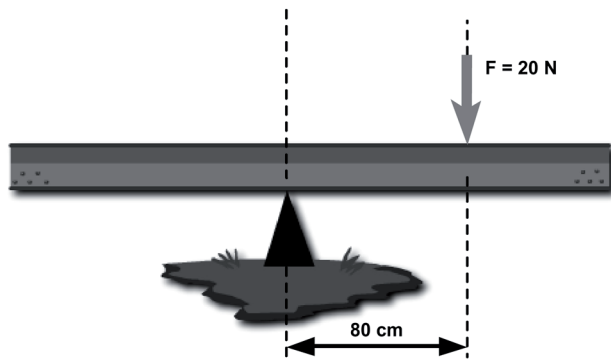
The size of a torque is the product of the distance of a force from the support (also called a pivot or a fulcrum in the case of our seesaw) and the component of the force perpendicular to the turning object.

The symbol sometimes used for torque is the Greek letter τ , known as "tau".

$$\tau = F_{\perp} r$$

A simple application of this formula is as follows:





The unit of force is the newton (**N**) and the unit of length is the metre (**m**). Notice that the distance from the pivot/fulcrum is given here in centimetres. Before we can use that figure in our calculation, we must convert it to metres, i.e. 80 cm = 0,80 m.

$$\begin{aligned}
 \tau &= F_{\perp} r \\
 &= 20 \text{ N} \times 0,80 \text{ m} \\
 &= 16 \text{ Nm}
 \end{aligned}$$

The units of torque are newton metres (Nm). To put torque into perspective, here are some of the specifications for the SLK range of Mercedes-Benz roadsters, the fast sports models.

*The range of engines available for the SLK class is also quite unique in this market segment. For the SLK 350, Mercedes-Benz has developed a new six-cylinder engine with around 25% more power (200 kW) **and 13% extra torque (350 Nm)**. The four-valve unit is one of the most powerful V6 engines in its class and reinforces its sporting credentials with a pleasing, full-throated sound.*

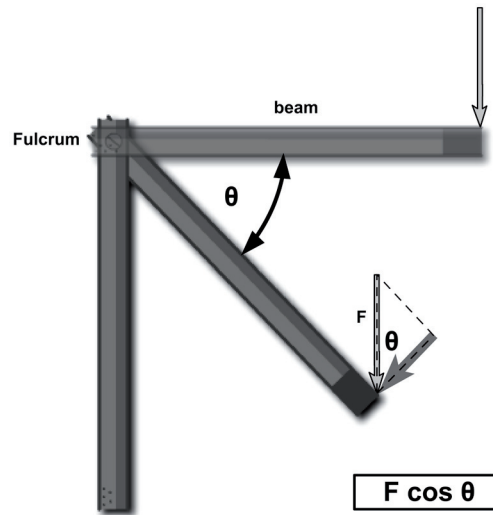
***Peak torque is available as low down as 2400 r/min and remains constant up to 5000r/min.** This provides the key to powerful acceleration and impressive mid-range sprints. The SLK 350 automatic with 7G-TRONIC reaches 100 km/h from a standstill in just 5,5 seconds and accelerates from 60 to 120 km/h in 5,1 seconds ...*

*Sometimes, we all wish time would stand still. But a 0 to 100 km/h time of 4,9 seconds is calculated to dispel such thoughts pretty quickly. With its AMG 5,5-litre VS engine, the SLK 55 AMG Roadster is unique in its class, delivering a sonorous 265 kW of power **and peak torque of 510 Nm**.*

Torque in cars is related to the transferring of the engine's power through the "drive train" (i.e. crankshaft) and to the wheels. It is obvious that more powerful cars will be capable of producing greater torque and this is indeed so. But remember that, although a car's power and the torque an engine can produce are related, **they are NOT the same thing!**

Next is a calculation of torque using the components of a force.





As we saw before, when an object turns because of the action of a force, if the force continues to act along the same lines then the component of force at right angles (perpendicular) to the object (in this case it is a beam) will decrease as the angle of turn (θ) increases.

If the same force acted as before ($F = 20 \text{ N}$) at the same distance ($r = 0,80 \text{ m}$) from the fulcrum (the point about which the turning motion happens), then we can see how the torque changes as **angle θ** changes.

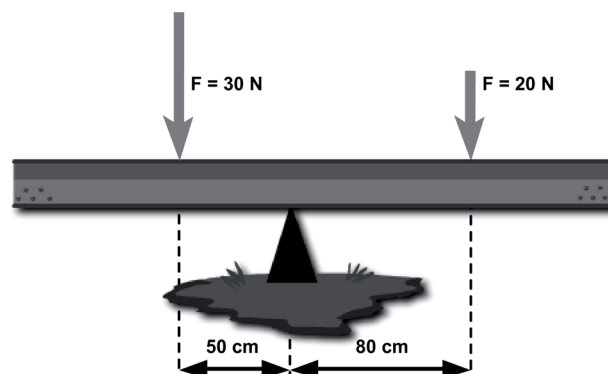
θ	$\cos \theta$	$F \cos \theta$	$\tau = F \cos \theta r$
10°	0,9848	19,7	15,8 Nm
20°	0,9397	18,8	15,0 Nm
30°	0,8660	17,3	13,8 Nm
45°	0,7071	14,1	11,3 Nm
60°	0,5000	10,0	8,0 Nm
75°	0,2588	5,2	4,2 Nm
90°	0,0000	0,0	0 Nm

Do the calculations yourself to confirm the values given in the table. **What is the significance of the zero value for torque when the beam has turned through 90° ? Explain why it has this value.**

EQUILIBRIUM

When this term is used in relation to forces on a body, we say that a number of forces are in equilibrium when their resultant (i.e. their sum) is zero. We can also define the equilibrium condition for a body which has forces acting on it but which is not turning.

Here is a simple example:



When these two forces act on the beam, they are on opposite sides of the fulcrum. The 20 N force will produce a clockwise torque or moment. The 30 N force will produce an anticlockwise turning effect (or torque or moment). If the two torques are equal in size, we see that the beam would remain stationary, i.e. there is no nett turning effect. If we calculate the torques/moments we can determine whether or not the beam will turn, and in which direction.

Clockwise moment/torque = 20 N × 0,8 m = 16 Nm

Anticlockwise torque = 30 N × 0,5 m = 15 Nm

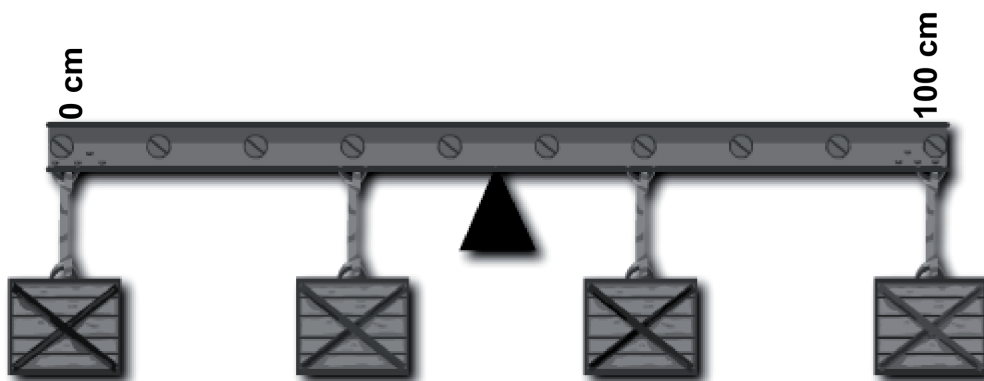
You can see from this that the clockwise turning effect (caused by the 20 N force) is greater (even though only slightly) than the anticlockwise turning effect (caused by the 30 N force). In this case, the beam turns in a clockwise direction.

What would you expect the nett/overall turning effect to be? Would you expect the beam to turn vigorously? Can you explain your answer?

Activity 1

A metre rule is used as a beam and is suspended at the position we call the fulcrum, i.e. the point around which any rotation can take place.

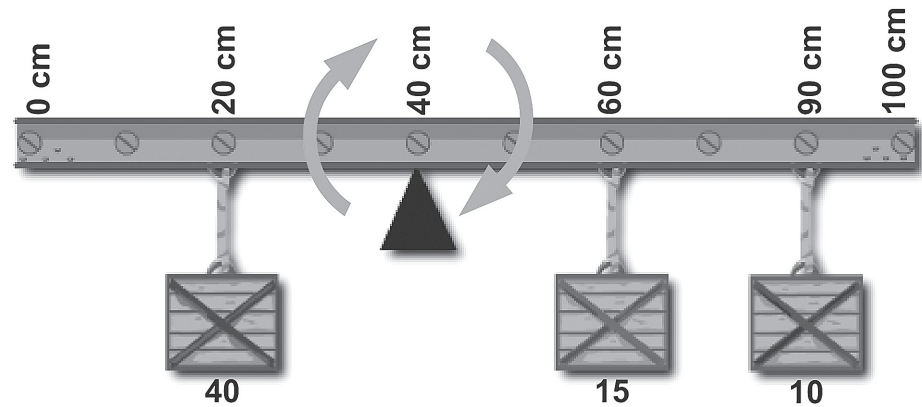
- Draw each of the following beams showing the positions of the loads and the fulcrum.
- Calculate the moments of each of the forces acting on each beam.
- Decide whether each individual load will lead to a clockwise or anticlockwise moment.
- Decide whether the beam will turn or not and, if it does turn, decide in which direction it will turn.



	Position of fulcrum (cm)	Size and position of load 1 (N, cm)	Size and position of load 2 (N, cm)	Size and position of load 3 (N, cm)	Size and position of load 4 (N, cm)
Beam 1	40	40 N @ 20 cm	15 N @ 60 cm	10 N @ 90 cm	–
Beam 2	20	50 N @ 0 cm	10 N @ 30 cm	25 N @ 40 cm	5 N @ 100 cm
Beam 3	50	30 N @ 20 cm	15 N @ 40 cm	30 N @ 75 cm	12 N @ 80 cm
Beam 4	60	40 N @ 10 cm	40 N @ 50 cm	0 N @ 80 cm	60 N @ 100 cm
Beam 5	75	40 N @ 10 cm	60 N @ 50 cm	30 N @ 70 cm	160 N @ 100 cm



Example – Beam 1



Load 1 will turn the beam in an anticlockwise direction.

Loads 2 & 3 will turn the beam in a clockwise direction.

$$\begin{aligned}\text{Clockwise moments} &= (15 \text{ N} \times [60 - 40] \text{ cm}) + (10 \text{ N} \times [90 - 40] \text{ cm}) \\ &= (15 \times 0,20 \text{ m}) + (10 \text{ N} \times 0,50 \text{ m}) \\ &= 3 \text{ Nm} + 5 \text{ Nm} \\ &= 8 \text{ Nm}\end{aligned}$$

$$\begin{aligned}\text{Anticlockwise moments} &= (40 \text{ N} \times [40 - 20] \text{ cm}) \\ &= (40 \times 0,20 \text{ m}) \\ &= 8 \text{ Nm}\end{aligned}$$

The clockwise and anticlockwise moments are equal. Therefore the beam is in equilibrium, i.e. it will be balanced and will not turn.

Part 2

SO WHICH WAY WILL IT TURN?

When a particular force acting on a body is zero, this does not mean that there are NO forces acting on the body. It means that ALL the forces in action add up to zero. So, when we study Newton's First Law of Motion, we see that "no force acting" means that the forces on a body are "in equilibrium" and their combined effect is zero. This allows a body to continue in its "state of rest" or to continue "moving with constant velocity".

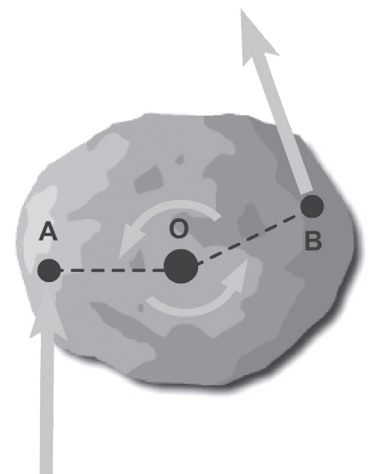
As we now know, forces can also cause a body to turn. If a body is not turning (we could call this "rotational equilibrium") then we can say that, whatever the turning effects might be present, they must be balancing one another.

Look at the diagram on the right.

The force pushing the body at point A will tend to rotate the body clockwise. We say that this force has clockwise moment or torque.

The force pulling the body at point B will tend to rotate the body anti-clockwise. We say that this force has an anticlockwise moment or torque.

Can we decide from what we see here whether the grey body will rotate clockwise or anticlockwise



around the pivot point at O? Possibly it won't rotate at all. **But how can we tell?**

The way to do this is to compare the clockwise and anticlockwise moments.

If they are equal – NO ROTATION.

If they are unequal – ROTATION IN ONE DIRECTION OR THE OTHER.

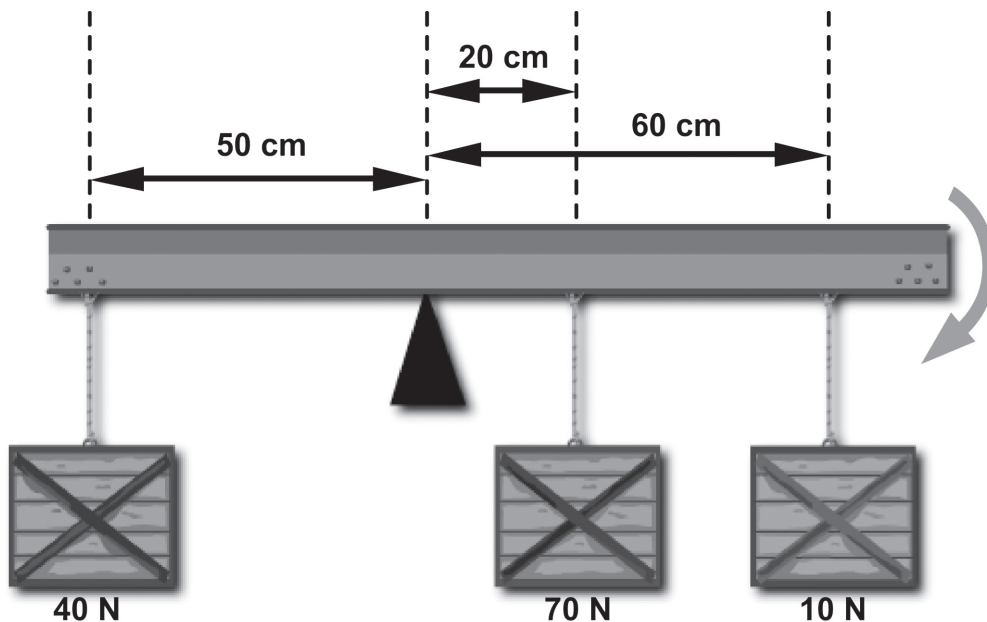
THE LAW OF MOMENT

The Law of Moment can be stated as follows:

When a body is in equilibrium then the sum of the clockwise moments will be equal to the sum of the anticlockwise moments.

It is also common in physics (and geometry) for a law (or theorem) to be stated as a converse – “the other way around”, so to speak. In this case, we can also say:

When the sum of the clockwise moments and the anticlockwise moments of forces acting on a body are equal, then the body is said to be in equilibrium.



Here is a balance beam which has been loaded at various points with different sized **loads**. Will the beam turn and, if so, in which direction: clockwise or anticlockwise?

The way to determine this is calculate the clockwise moments and the anticlockwise moments separately and then compare them.

$$\begin{aligned}\text{Anticlockwise moments} &= 40 \text{ N} \times 0,50 \text{ m} \\ &= \mathbf{20 \text{ Nm}}\end{aligned}$$

$$\begin{aligned}\text{Clockwise moments} &= (70 \text{ N} \times 0,20 \text{ m}) + (10 \text{ N} \times 0,60 \text{ m}) \\ &= 14 \text{ Nm} + 6 \text{ Nm} \\ &= \mathbf{20 \text{ Nm}}\end{aligned}$$

We see from these calculations that the clockwise and anticlockwise moments are equal. In other words, this beam is in equilibrium and there will be NO TURNING. You can use this method of calculating moments for any number of forces or loads.

SIMPLE MACHINES



In the study of mechanics, we refer to a machine as a device which uses an applied force to do work. Work is done when an applied force causes something to move for some distance. There are six traditional simple machines. Look at their names and match them with the pictures in the six blocks shown below.

Remember that machines make it easier to do work. In each case, see how the simple machine makes our work easier.

- Inclined plane
- Wheel and axle
- Lever
- Pulley
- Wedge
- Screw



Think about this: A screw is an inclined plane wrapped around an axle. Use a pencil and an inclined plane cut from a piece of paper. Wrap the paper around the pencil. Can you see how this relates to what we know as a screw?

LEVERS AND MECHANICAL ADVANTAGE

Who is reputed to have said “Give me the place to stand, and I will move the Earth”? This person was referring to levers. Read on and you will find out who it was!

A lever is a rigid object **usually** used with a fulcrum or pivot point to increase the mechanical force that can be applied to another object. This is what is known as **mechanical advantage**. (Occasionally a lever will have a mechanical advantage of less than one but the distance through which the second force moves is multiplied. Read about this kind of lever in **third-class levers** below.)

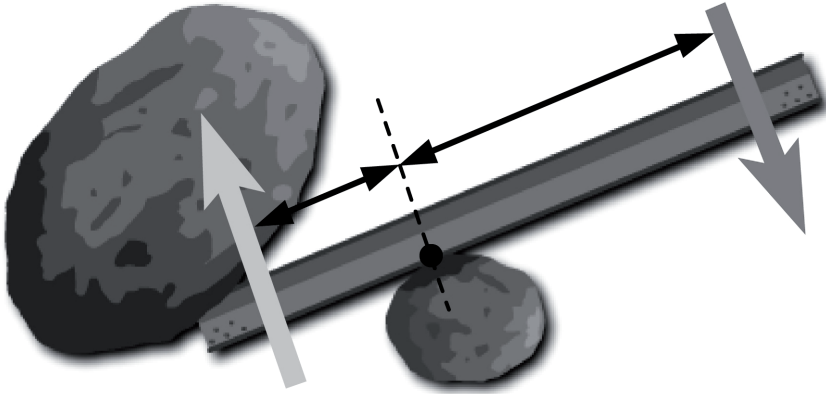
The amount of work done is given by force times distance. So most levers – remember that they are examples of simple machines – allow the user to apply less effort in order to move the object on which the work is being done through a greater distance. For example, we can use a lever to lift a weight by applying a force (our effort) which is much less than the size of that weight.

The principle of mechanical advantage is explained in the diagram below.



This large force is the **LOAD or RESISTANCE** that the user of a simple machine wants to overcome with the small force that is applied

This small force is the **EFFORT** applied by the user of a simple machine or, in this case, the **LEVER**, in order to "move a load" or "overcome a resistance"



The work done by the person applying the effort is given by the size of the force (**f**) multiplied by the distance between the effort and the fulcrum (**D**). Since energy (i.e. *the ability to do work*) is always conserved (energy cannot be created or destroyed, it can only be transferred from one place to another and/or transformed from one form to another), the work that is done by the person using the lever is equal to the work done by the lever in moving the load! In simple mathematical terms, we can show this as follows:

$$f \times D = F \times d$$

By rearranging this equation we get this:

$$F = f \times D/d$$

The term **D/d** is called the mechanical advantage. We can work out logically what this means. **D** is larger than **d** (see the diagram) so that means **D/d** is greater than one (>1). This means that **F** (the load that is to be moved) can be bigger than the applied effort (**f**) by this same factor. **D/d** is called the **mechanical advantage (MA)**. We call the distance between the effort and the fulcrum the **effort arm** and the distance between the load/resistance and the fulcrum the **resistance arm**.

$$MA = \frac{\text{EFFORT ARM (D)}}{\text{RESISTANCE ARM (d)}}$$

THE THREE CLASSES OF LEVERS

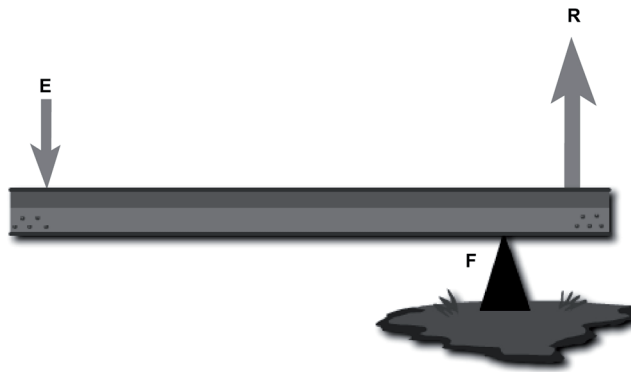
The earliest writings on levers were by the Greek scientist and philosopher, Archimedes. He is supposed to have made the famous claim: *Give me the place to stand, and I will move the Earth*. He showed the mathematical principle of levers that we derived from the diagram above. He also identified three different classes of levers that represent the order in which we find the **effort (E)**, **load/resistance (R)** and **fulcrum (F)**.

- **First-class levers: fulcrum between effort and resistance**

A first-class lever has the fulcrum between the effort (the "input force") and the load/resistance (the "output force"). The effort is applied by pushing or pulling one side of a bar so that it turns around the fulcrum and overcomes the resistance force on the far side of the fulcrum.

(This would normally be constructed to ensure that MA is >1)



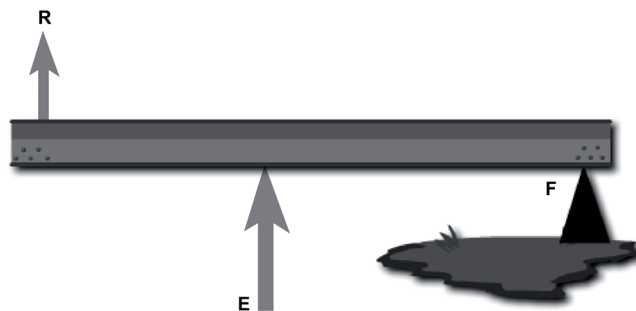


Examples:

1. seesaw
2. crowbar
3. pliers and scissors (these are also called “double levers”)
4. oars in a rowing boat
5. some can openers
6. bicycle brakes
7. a claw hammer (can be used to remove nails)

● **Second-class levers: resistance between effort and fulcrum**

With second-class levers, the load is between the effort and the fulcrum (**MA always > 1**)



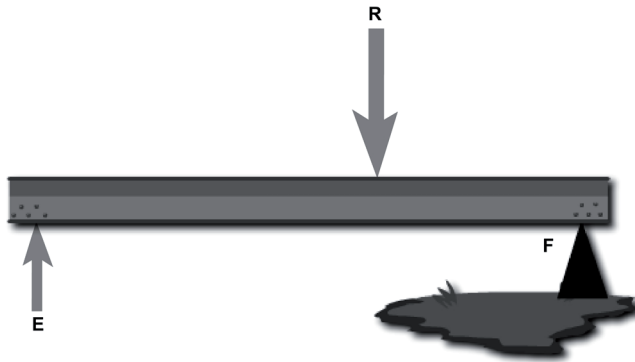
Examples:

1. nutcracker
2. door
3. crowbars (when pivoted around the end resting on the ground)
4. paper stapler
5. diving board at a swimming pool
6. some can openers
7. canoe paddles
8. wheelbarrows



- **Third-class levers: effort between resistance and fulcrum**

With third-class levers, the effort is between the resistance and the fulcrum. Intuitively, we can see that the effort must therefore be a larger force than the resistance which is not the case in first-class and second-class levers. The usefulness of third-class levers lies in the fact that the input effort will move a much shorter distance than the load or resistance. This makes certain tasks easier to do. (**MA always <1**)



Examples:

1. the human arm (especially the attachment of the bicep muscle)
2. tools such as spades and hoes (look at how a hoe is held)
3. a hockey stick or a cricket bat (again, look at how they are held)
4. nail clipper
5. broom
6. the jaw bone

Activity 2

- Using the notes on the three classes of levers, draw diagrams of the following showing the position of the effort (E), the load (R) and fulcrum (F).
 - State, in each case, whether the mechanical advantage is greater than or less than 1.
- a) A wheelbarrow
 - b) A bicycle pedal and the main cog
 - c) The bicep muscle in the arm (*Explain why the position of the attachment of the biceptal tendon is important in determining the strength of the arm*)
 - d) A hockey stick



THE TURNING EFFECT OF FORCES

Learning Outcomes and Assessment Standards:

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 1:

Conducting an investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

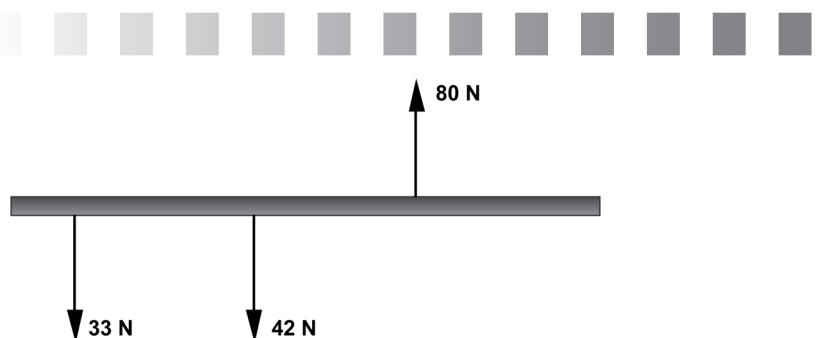
INTRODUCTION

What you must know in this section of the curriculum is:

- Moment of force
 - Know that when an object is fixed or supported at one point and a force acts on it a distance away from the support, it tends to make the object turn.
 - Know that the moment of a force, or torque, is the product of the distance from the support and the component of the force perpendicular to the object.
 - Calculate the moment of the force, or torque, caused by each force when several forces act on the same object using the equation: $\tau = F_{\perp} \cdot r$.
 - Know that for an object to be in equilibrium both the sum of the forces acting on the object and the sum of the moments of the forces must be zero.
 - Solve problems involving objects in equilibrium.
- Mechanical advantage (MA)
 - Describe the terms “load” and “effort” for a lever.
 - Define “mechanical advantage” as the ratio of “load/effort” and calculate the mechanical advantage for simple levers.
- Apply the concept of mechanical advantage to everyday situations.

Lesson

Activity 1



- Will the light one-metre rod in the diagram move upwards or downwards?

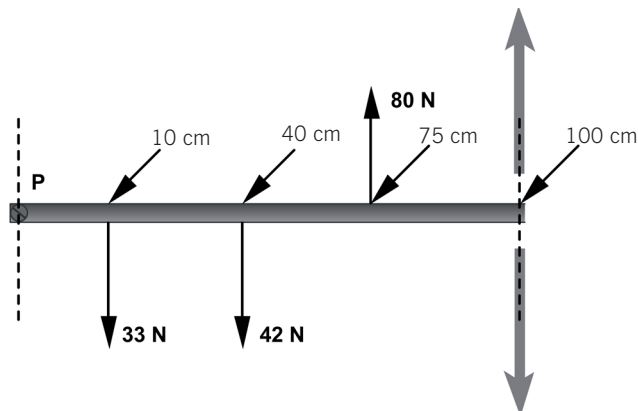


- Add one force (use a labelled arrow to indicate where you are adding the force) that will bring the forces into equilibrium.
- Draw some rods with forces acting on them and then challenge other members of the group to draw in a single force that will bring the forces on the rod into equilibrium.

Understanding the problem

Review the concept of forces in equilibrium. When we have several forces acting on a rod, it can move up or down depending on which forces (the “upward” forces or the “downward forces”) are greater. OR the rod can remain stationary IF the upward and downward forces are the same.

Activity 2



The one-metre rod that was used in Activity 1 is replaced by a light metre rule. The metre rule is pivoted at one end (point P) and the same forces act as before, at the distances from the pivot as shown.

What upwards or downwards force must be applied at the far end of the metre rule (at the 1 m mark) in order to bring it into equilibrium?

Understanding the problem


The way to solve this problem is to bring the “Law of Moments” into play. The Law of Moments says that when a body is in (rotational) equilibrium then the sum of the moments of the forces (or the **torques**) will be zero.


The convention is that anticlockwise moments or torques are considered to be positive.

$$\text{Torque } (\boldsymbol{\tau}) = \text{force perpendicular to the distance } (\mathbf{F}_{\perp}) \times \text{distance to the pivot } (\mathbf{r})$$

In other words, when a body is not turning then the sum of the clockwise moments around any point will be equal to the sum of the anticlockwise moments about the same point.




PAIRS

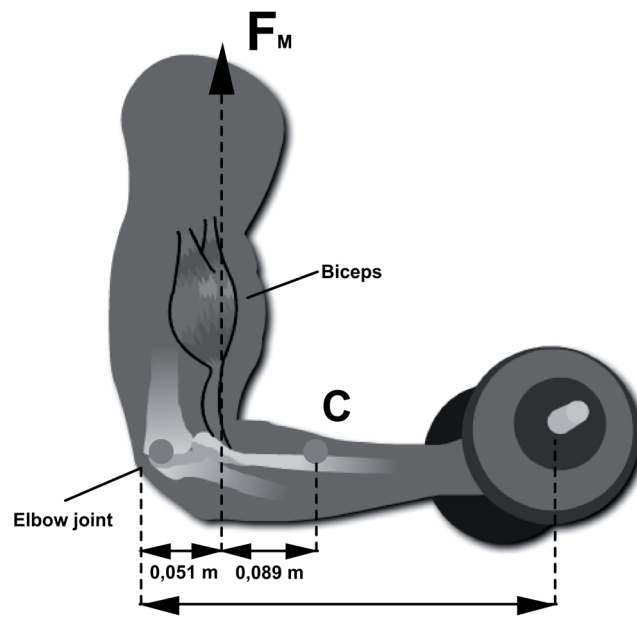

SUMMATIVE ASSESSMENT

Activity 3

(This question was set in the National Department of Education's Grade 11 exemplar examination paper for June 2007.)

An athlete is preparing for a fitness competition. In order to develop the biceps muscle, she embarks on a training programme. This programme entails holding a 176 N weight steady in the palm for some minutes at a time.

The forearm weighs 24 N. It is held horizontally as shown in the sketch, and can be regarded as a rod. In the diagram below, the elbow joint is the pivot. The weight of the forearm acts through the point C. The maximum force developed in the biceps muscle, due to weight, is represented by F_M .

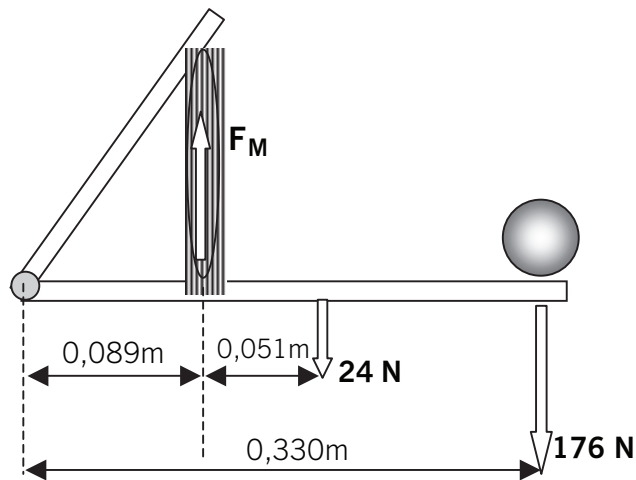


1. What do you understand by the term *torque*?
2. Represent the forearm as a bar and indicate ALL the forces acting on the forearm. **Hint:** Assume that the elbow joint exerts a downward force F_E .
3. Calculate the force F_M developed in the biceps muscle and the force F_E exerted by the elbow joint. Assume the force F_E acts downwards.
4. Is the direction assigned to the force on the elbow joint correct? Give a reason for your answer.



Activity 4

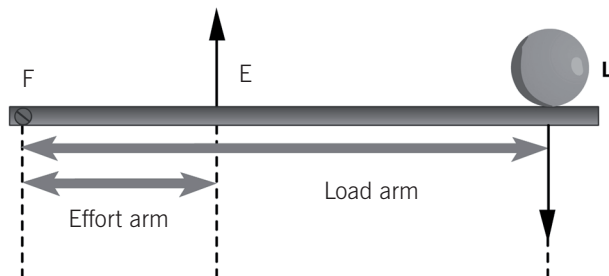
If a 176 N weight is held horizontal by a chimpanzee, does the chimpanzee with these forearm dimensions exert as much force in his biceps as the athlete in the previous example?



Understanding the problem

This problem involves the concept of **mechanical advantage** which depends on the lengths of the load and effort arms in a lever such as the forearm.

When we look at a lever we can identify two quantities: the effort arm and the load arm, i.e. the distance between the fulcrum (or pivot) and the effort and the distance between the fulcrum (or pivot) and the load. (This is always true and it does not matter whether it is a first-, second- or third-class lever, i.e. whether it is **Effort – Fulcrum – Load**; **Fulcrum – Load – Effort**; or **Fulcrum – Effort – Load**.)



$$\text{Mechanical advantage} = \frac{\text{Effort arm}}{\text{Load arm}}$$

$$= \frac{0,089 \text{ m}}{0,330 \text{ m}}$$



TRANSVERSE AND LONGITUDINAL WAVES

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

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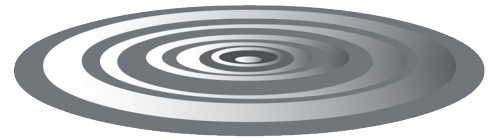


Overview

WAVES TRANSFER ENERGY

Waves are disturbances that move through a medium or through space, as in the case of electromagnetic waves such as visible light or radio waves.

Waves transfer energy from one place to another. Just think about how you can disturb water with your finger and then watch as a wave travels away from your finger until it reaches some object floating in the water.



- When the wave arrives, the object moves up and down.
- To make an object move, work must be done.
- To do work requires energy.
- If the object moves, energy must have been expended to do the work.

(Remember that the energy is not “used up” but merely transferred from the water wave to the object – as can be seen from the object’s motion.)

- Where does the energy come from? – From the work done on the water to disturb it!
- Don’t be fooled into thinking that, because you felt no effort when disturbing the water, no work was done to disturb the water. That is not true!

We may only notice forces when they are large and we may only feel the work we do (and thus the energy that is being transferred from us because we get tired) when the work is “hard”. But the laws of nature apply as much to the small and the subtle as they do to the big and the noticeable. We see forces acting and work being done and energy being transferred even in the tiny movement of air that causes leaves to rustle!

HOW A MEDIUM BEHAVES WHEN A WAVE PASSES THROUGH IT

When disturbances move through some physical medium such as air or water, **it is the wave that moves** from its source (for instance, a finger dipping into the water) to other parts of the medium. **The medium itself does not move permanently from one place to another in the medium.** Instead, the particles that make up the medium (these could be gas molecules in the air or water molecules in water) **oscillate** – that is, they move *back and forth* or *up and down* or *around and around*. The important thing to realise here is that when a material medium (i.e. one that is composed of many particles) is disturbed, the parts of the medium that are disturbed move as though they are attached to many tiny springs. As the springs are stretched, at some point they reach the limit of their stretchiness. When our tiny springs reach this limit, they pull the medium back. The medium then moves faster and faster, back to the point where it started from



and then past that point and away to the other side. When it reaches the limit of its stretch in that direction, the process repeats itself.

Imagine now that the medium is made of billions and billions of tiny particles (which it is), all behaving as though they were attached to little springs (which they appear to be). As a disturbance passes through the medium, the particles oscillate or vibrate or repetitively rotate but always return to their original, fixed position (which is called the equilibrium position).

If you understand this simple picture of a medium and what happens when a wave passes through it, you will find wave phenomena, especially in physical (also called mechanical) media, then you will find the concept of waves and the effects they can have much easier to grasp.

TYPES OF WAVES ...

Waves are regular and repetitive (periodic) motions in a medium. Waves can be characterised by crests (highs) and troughs (lows) or by large or small movements of the particles in a medium away from some stable or equilibrium position.

Waves may also be divided into two categories: **longitudinal** and **transverse waves**. Longitudinal waves are those in which the particles in the medium vibrate parallel to the direction of the wave (e.g. sound waves) and transverse waves are those in which the medium vibrates perpendicularly to the direction of the wave (e.g. waves on water or on a guitar string).

... AND WHERE ARE THEY FOUND

We know about waves on the oceans. They are caused by tidal effects, mainly of the Moon, and can be made bigger by the action of the wind on the water's surface. The destructive seas on the Kwazulu-Natal coastline in March 2007 in which waves of up to 8 metres in height crashed on to the coast were related to two factors. First there were abnormally high tides because of the alignment of the Earth, the Moon and the Sun. And, secondly, there were large waves that had rolled in from strong, cyclonic winds far to the east in the Indian Ocean.

Then, every so often, a great, destructive wave called a tsunami occurs, like the one that devastated the coasts of Sumatra and coastal areas for thousands kilometers from the epicentre of the shock on 26 December 2004. Those waves were caused by an undersea earthquake of 9,1–9,3 on the Richter Scale (a scale for measuring the strength of earthquakes). In modern memory, very few earthquakes have reached this intensity.

Apart from ocean and water waves, the most common form of waves in our lives is the electromagnetic wave which accounts for visible light, infrared and ultraviolet rays, microwaves, X-rays and radio waves. These waves can travel through a vacuum, which is why we can receive such radiation from outer space. Electromagnetic waves (or radiation, as it is sometimes called) travel through a vacuum at $299\,792\,458\text{ m}\cdot\text{s}^{-1}$ or approximately $3 \times 10^8\text{ m}\cdot\text{s}^{-1}$. One of the predictions of Albert Einstein's Special Theory of Relativity is that the speed of light is a constant throughout the universe, regardless of the speed of the light source.

Waves in liquids (e.g. water), gases (e.g. air) and solids (e.g. the Earth) are called mechanical waves because the waves require a material medium in which to move. The particles in the medium bump or knock rhythmically against their neighbours and, as a result of this, the wave travels backwards and forwards because of mechanical bumping between molecules. So, for waves in air, one talks of pressure waves because where the molecules of air are close together the pressure is high. And where the molecules are further apart the pressure is low. As you will see in the lesson, sound waves in air can be thought of as pressure waves travelling through the air.



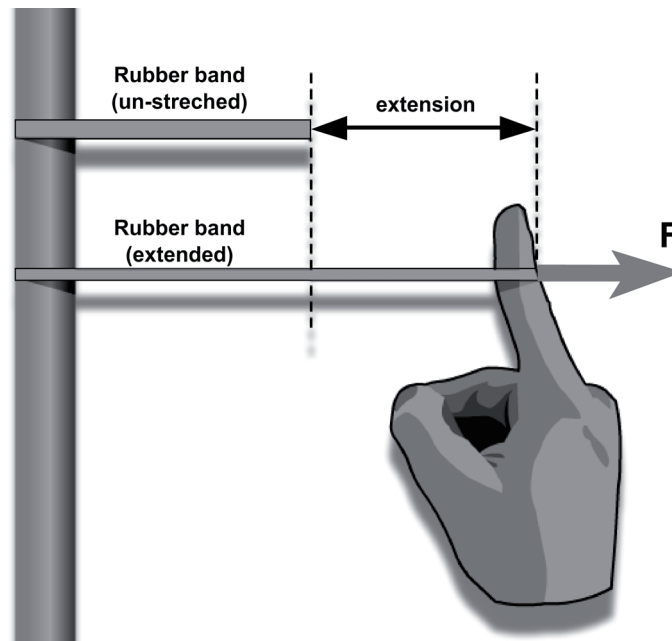
Although different kinds of waves move in different mediums, they all have one thing in common: their motion can be explained in the same way.



Part 1

THE ELASTICITY OF MATTER

The word “elastic” describes something that, when it is deformed by a force, can then return to its original position. Springs and rubber bands are like this. If a rubber band experiences a stretching force, it can restore itself to its original form once the force is removed.

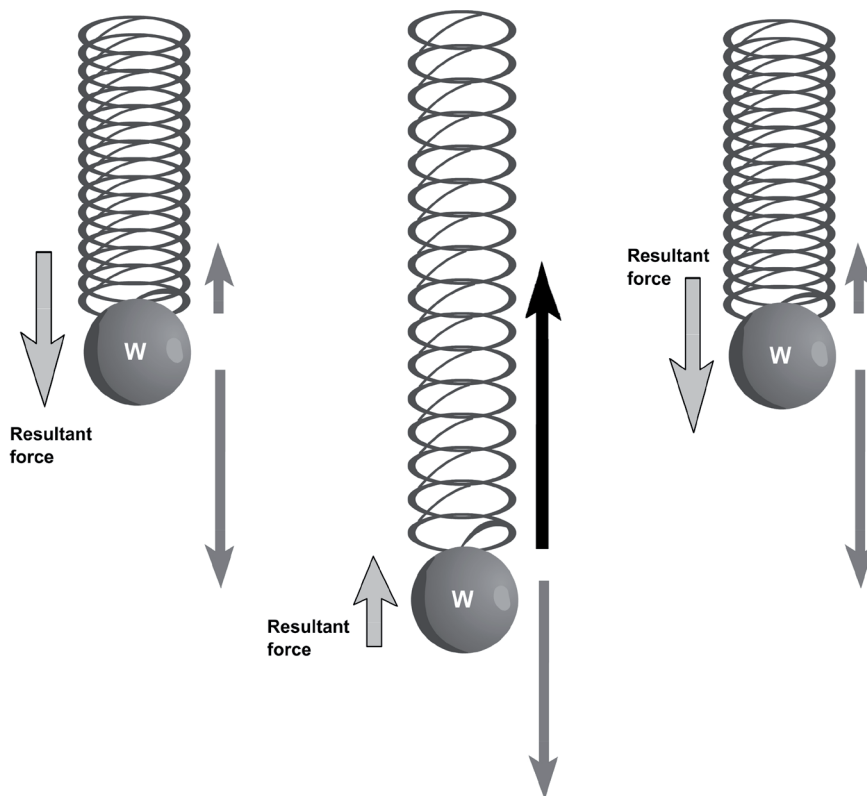


Now imagine that the force on the medium (the rubber band) varies from a maximum in one direction to zero to a maximum in the other direction. This would cause a rhythmic backwards and forwards motion in the medium. If the whole medium is affected by a rhythmic, varying force, then we see wave motion.

For example, take a small weight hanging on the end of a spring. Lift the weight until the spring is unextended. Now release the weight. What happens?

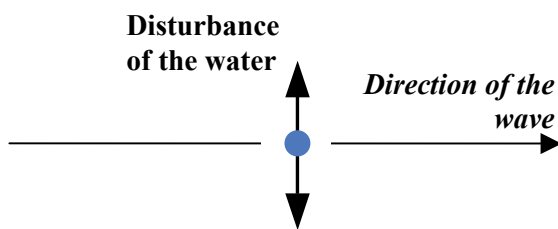
- The weight falls – fast at first.
- The spring extends.
- As the spring extends, it also pulls back on the weight.
- The weight’s rate of fall slows down.
- After a time, the weight stops momentarily or “instantaneously”.
- The weight then starts moving upwards.
- It moves upwards – fast at first.
- It then slows down until it stops momentarily.
- At this point, it begins to fall again and ...
- ... the cycle repeats itself.



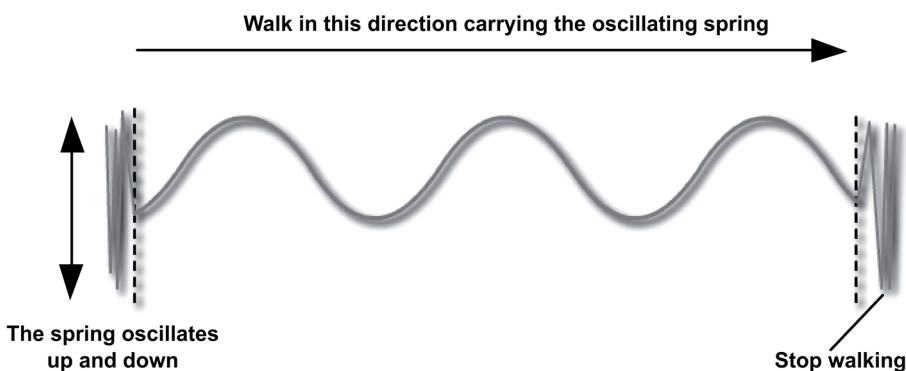


TRANSVERSE WAVES

Transverse waves travel along the surface of a medium or occur at the interface between two mediums. So, when we have an air/water interface, we can get waves moving on the water surface. (Water waves also cause disturbance in the air above the water.) What we see in water is a wave-like pattern moving across the surface of the water. But what we also know, from seeing a light object in the water bobbing up and down, is that the disturbance in the medium is perpendicular to the direction of the wave. This is the definition of a transverse wave.

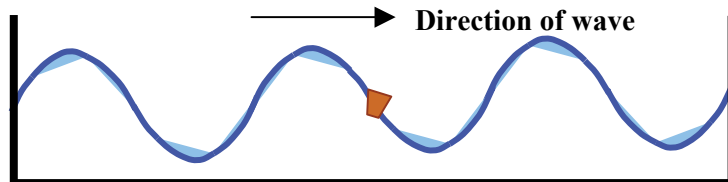


Imagine now that we take the bouncing weight on the spring (we call this bounce the “oscillation”) and walk past a long piece of paper on the wall. If the weight is covered in ink so that it can leave a trace on the paper, what will the trace look like?



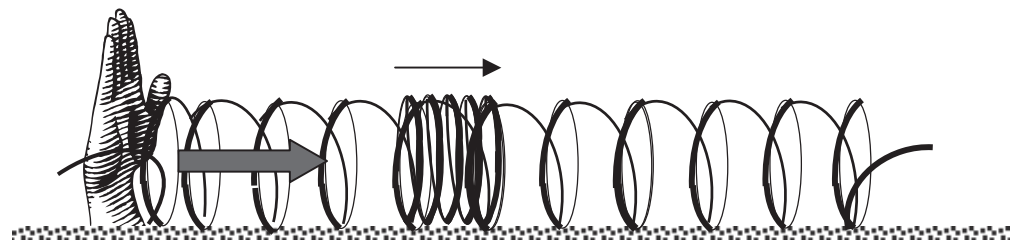
The wavy line traced out by the bouncing or oscillating spring gives the shape of a transverse wave. A point to remember here is that the spring, which is elastic, keeps on restoring itself to its original shape as the weight bounces. In this case, the spring is the medium in which the wave moves.

If we make waves in water in a glass tank and watch them go by, we will see the same shape, i.e. we are seeing a transverse wave in action. And if we place a cork in the water, we will see it going up and down as successive waves pass it, in the same way that the medium (the spring) went up and down in the previous example. And, once again, we notice that the medium, the water, is always restored to its original position as the wave passes by. The water, too, is an elastic medium.

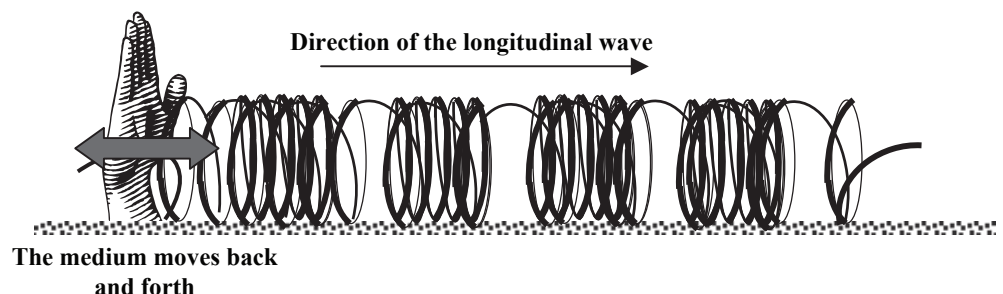


LONGITUDINAL WAVES

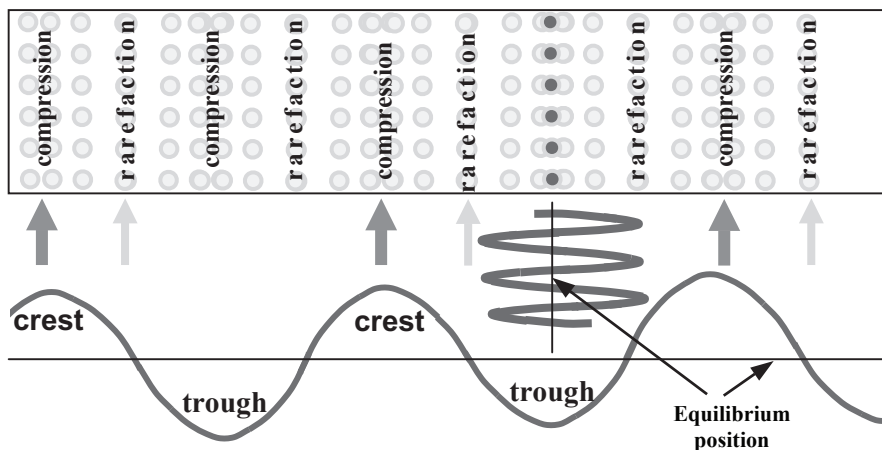
A good way to generate longitudinal waves is to take a long, soft spring which is resting on a surface (a table top or the floor) and move one end back and forth in a rhythmic, repetitive motion. If we start off by giving the spring a single quick push we get a single "pulse" travelling down the spring. The spring (our medium) is elastic, so each part of the spring oscillates back and forth as the pulse passes by and keeps being restored to its original position. (You can easily draw a single transverse pulse in water.)



Now let the hand move backwards and forwards along the direction of the spring in a regular, rhythmic, repetitive way and we will see a longitudinal wave being generated.



A CLOSER LOOK AT TRANSVERSE AND LONGITUDINAL WAVES



This diagram contains a great deal of information about waves. As you read the explanations that follow, refer to the diagram. Waves behave in a wave-like manner no matter whether they are variations in pressure in the air (longitudinal waves as in sound waves through air) or variations in water level (transverse waves as in ocean waves on the surface of the sea). Therefore we will take longitudinal and transverse waves together when we consider some of the terms that apply to wave motion. The definitions of the wave terms that follow apply to both transverse and longitudinal waves.

In **longitudinal waves**, the particles in the medium move back and forth around their starting or **equilibrium position**. Look at the line of red particles and see how they move back and forth – always returning to the equilibrium position. Also notice how we can turn their backwards and forwards movement into a picture that looks like another transverse wave!

So, as the first part of the wave arrives, particles move with it. They then bump into the particles just beyond them, and so on. This creates the first **compression**. When the first set of particles has moved as far as it can, it begins to move back to where it started. The particles to the right of the set, as we look at the diagram, have not begun to return yet so the particles are now as far apart as they can be. This is called a **rarefaction**. These same particles now move as far as they can to the left and at some point they meet particles coming back towards them because of another, incoming pulse. This causes another **compression**. At every second compression, the particles have returned to their original position and are now ready to repeat the **cycle**.

One complete cycle of a longitudinal wave is from the one compression, past the next compression and up to the third compression. The same is true for rarefactions i.e. a complete wave is the length from the first to the third rarefaction.

The starting position of a particle before it is disturbed and to which it returns after one cycle is called **the equilibrium position**.

In **transverse waves**, the particles in the medium move up and down around their starting or **equilibrium position**. **What we appear to see** if we concentrate on a single crest is that the crests move at a certain speed. But now we also know that it is actually the wave and not the medium that is moving.

One complete cycle for a transverse wave is when a part of the medium has gone from its highest point (or its furthest **displacement** from the **equilibrium position** in one direction) past its **maximum displacement** in the other direction (i.e. the **trough**) and **back to** the **crest** position.



The **maximum displacement** of the medium when a wave passes through it is called the **amplitude** of the wave.

In a similar way to longitudinal waves, **one cycle of a transverse wave** is **from crest to trough to crest**. Therefore one wavelength is the distance from crest to crest or from trough to trough.

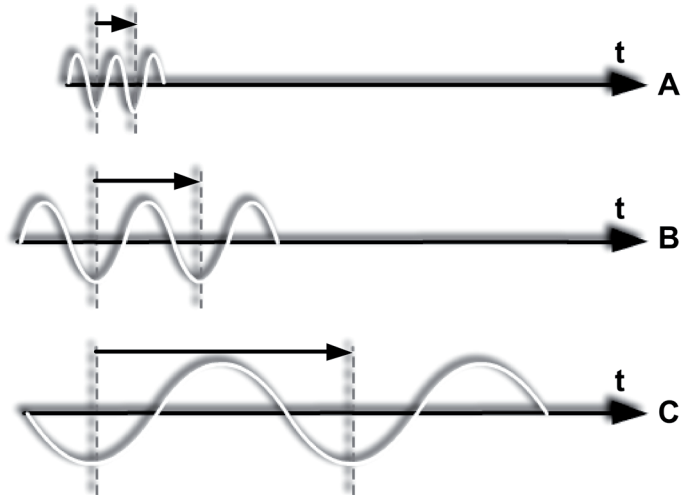
The time taken for a particle in the medium to complete one cycle is called the **period of the wave**. This period is given the symbol **T** and is measured in **seconds**.

The last characteristic of a wave we must define is called **the frequency of a wave**. Frequency (**f**) is defined as the number of waves that pass a point in one second.

To understand the terms **period** and **frequency**, examine the diagram of three waves below. In the first wave, the period is one second, i.e. $T_A = 1 \text{ s}$. That means that one wave or cycle (marked in the diagram as “trough to trough”) is completed in one second.

The next wave takes twice as long to complete one cycle, i.e. $T_B = 2 \text{ s}$.

The third wave takes twice as long again to complete one cycle, i.e. $T_C = 4 \text{ s}$.



Activity 1

QUESTION 1.1

Complete the following summary table of definitions for waves terms.

Term	Symbol	Description	Definition	Measure in units of
Displacement				
Amplitude				
Crest				
Trough				
Equilibrium				
Period				
Frequency				
Wavelength				



QUESTION 1.2

Using the definitions of period and frequency,

- a) verify that the relationship between period (T) and frequency (f) is the following:

$$f = \frac{1}{T}$$

- b) calculate the frequency of the three waves A, B and C in the diagram above.

Part 2

THE SPEED OF A WAVE

We know that when waves travel they move at a certain speed. We can see a crest moving and, as it travels a certain distance in a certain time, we can measure these quantities and calculate the speed from an equation we know well:

$$\text{speed} = v = \frac{\text{distance}}{\text{time}}$$

We know that, for a complete wave, the distance it travels is called its “wavelength”. **Wavelength** is represented by the Greek letter for “L” or “lamda” – λ . We also know that **one wavelength is the distance travelled in the time taken for one cycle** – the **period** of the wave (**T**).

So now, for a wave, we can write: $v = \frac{\lambda}{T}$

But we also have another relationship: the **frequency** of a wave is **the number of waves that pass a point in one second** OR it is one wave per period, i.e.: $f = \frac{1}{T}$

Now we can write down what is known as “**the wave equation**”:

$$v = \lambda \times \frac{1}{T}$$

$$v = \lambda \times f$$

The beauty of this simple equation – which explains the **speed, frequency** and **wavelength** of waves – lies in the fact that when we know two features of a wave, we can calculate a third important feature.

Example: A fisherman standing on the rocks watches the waves on the surface of the sea moving past him at a velocity of $12 \text{ m}\cdot\text{s}^{-1}$. If the distance from the crest of a wave to the trough that follows it is 10 m, how many waves pass the fisherman in one minute?

If crest to trough is 10 m, then crest to crest (i.e. λ) is 20 m.

$$\begin{aligned} f &= \frac{v}{\lambda} \\ &= \frac{12 \text{ m}\cdot\text{s}^{-1}}{20 \text{ m}} \\ &= 0,6 \text{ Hz} \end{aligned}$$

A frequency of 0,6 Hz means that six waves pass the fisherman every 10 seconds.

Therefore, 36 waves will pass the fisherman in one minute.

SOUND WAVES AND THE SPEED OF SOUND

Sound is a phenomenon which we detect using our ears and our organs of hearing. This much is obvious. But only when one knows the nature of sound waves and how they are propagated is one able to appreciate the amazing sense of hearing from a mechanical point of view.



The **speed of sound** is a term used to describe how fast sound waves pass through elastic mediums. The speed varies with the type of medium employed (for example, sound waves usually move faster through liquids than through gases) and the properties of the medium, **especially temperature**. Sound usually travels more slowly with greater altitude but this is mainly from reduced temperature and not the fact that air is more rarefied (thinner) there. Humidity can also have a small effect on the speed of sound. Sound travels slightly faster in humid air.

At sea level, under normal atmospheric conditions and at a temperature of 21°C, the speed of sound is **344 m·s⁻¹** (1238 km·h⁻¹). Speed of sound is usually designated **c**.



Activity 2

QUESTION 2.1

Use this table to calculate the approximate wavelength of a 1000 Hz sound at sea level and at 12°C.

MEASURED VALUES OF THE SPEED OF SOUND AT SEA LEVEL									
Temperature (°C)	-10	-5	0	+5	+10	+15	+20	+25	+30
Speed of sound (m·s ⁻¹)	325,2	328,3	331,3	334,3	337,3	340,3	343,2	346,1	349,0

QUESTION 2.2

A mosquito's buzzing is produced by the beating of its wings at a frequency of approximately 600 Hz. What wavelength of sound would the wings produce if the speed of sound was 340 m·s⁻¹?

QUESTION 2.3

Is it true to say that the doubling of the frequency of a wave also doubles its speed? Explain.

QUESTION 2.4

A Middle C tuning fork produces a sound wave with a frequency of 256 Hz. What is the wavelength of this sound at sea level when the temperature is 20 °C?

QUESTION 2.5

The upper limit of human hearing is about 20 000 Hz. If the speed of sound in air is 333 m·s⁻¹, what is the wavelength of this sound? (Before calculating the value, try to reason out whether it will be a long or short wavelength.)

QUESTION 2.6

Elephants can communicate with one another using very low frequency sounds of about 10 Hz. On the other hand, dogs and cats can hear sounds of up to 45 kHz and 60 kHz respectively.

- Determine the wavelengths of the low sound made by elephants as well as the sounds at the upper limits of canine and feline hearing. (Assume a speed of sound of 345 m·s⁻¹.)
- The human auditory response is from 20 Hz–20 000 Hz. Discuss with a friend why elephants, cats and dogs should be so different and how their actual auditory mechanisms differ to enable them to hear sounds at these limits. [You may need to consult the Life Sciences teacher.]



QUESTION 2.7

Two sound waves travel through a tube filled with nitrogen gas. Wave X has a wavelength which is one third that of Wave Y. The speed of Wave Y is:

- a) One-third that of Wave X
- b) The same as the speed of Wave X
- c) Three times greater than the speed of Wave X



Lesson 8

GEOMETRICAL OPTICS

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

Although the connection between waves and light is not immediately apparent to us, the behaviour of light is consistent with a “wave phenomenon”. This means that the way light behaves (it can be reflected, refracted and diffracted) suggests very strongly that light is carried by waves. In fact, light that is visible to our eyes is only one type of what are known as electromagnetic waves. We speak of the visible spectrum or the visible part of the electromagnetic spectrum and this is the series of colours we all know as the colours of the rainbow, or red, orange, yellow, green, blue, indigo and violet (ROYGBIV).

The wavelengths of light on the red side of the spectrum are longer than those on the blue side. Because the speed of light is a constant ($c = 3 \times 10^8 \text{ m}\cdot\text{s}^{-1}$ or 300 000 km in ONE SECOND!), this means that the frequencies of the different colours of light will vary. From the wave equation ($v = f \lambda$), we can see that, if the speed of a wave (v) is constant, when the wavelength (λ) gets larger, so the frequency of the waves gets lower. Red light is low-frequency light. Blue light is high-frequency light and also higher energy light because the energy of the light is proportional to its frequency. So, when you are warmed by the sun, that is caused by the longer red wavelengths of light. But while that is happening, it is the shorter wavelength but higher frequency and higher energy electromagnetic waves at the blue end of the spectrum (the so-called “ultraviolet radiation”) that are actually damaging skin cells and causing sunburn.

In this section of the work, the required content is as follows:

- Geometrical optics
- Lenses and the formation of an image
- Spectacles and the eye
- Optical telescopes and microscopes
- Radio telescopes and SALT
- Gravitational lenses

In this lesson the emphasis will be on geometric optics, the most important aspect of the section on waves and optics.



Lesson

Part 1



GEOMETRIC OPTICS

The term comes from the fact that when light rays pass through lenses the paths they take form geometric patterns which make the calculation of image sizes very simple. This approach also enables the design of optical instruments such as microscopes and telescopes.

One important fact to be remembered in studying lenses is that **the approximations we make in the geometrical optics of lenses are only true for thin lenses**. In this section we will only consider the geometry of simple lenses. Lenses fall into two types: simple and compound lenses. Simple lenses are either convex or concave while compound lenses are combinations of both. The lenses making up compound lenses may also have different curvatures.

The curvature – or the amount of “roundness” in a lens – is what gives it its specific ability to redirect rays of light. Normally, the more curved a lens surface, the greater the angle through which it redirects a ray of light.

Eye glasses or spectacles are almost always compound lenses and the manufacture of such lenses is complicated by the fact that the spectacle lenses must match the very specific specifications of one person’s eyes and correct whatever problems exist. In addition to this, the optometrist and his or her lens-maker will often have to make the lenses slightly differently for the left and right eyes. (We aren’t always as symmetrical as we think we are!)



Thin, conVEX lens



Thin, conCAVE lens



A compound lens:
CONCAVO-CONVEX

THE BENDING OR REFRACTION OF LIGHT

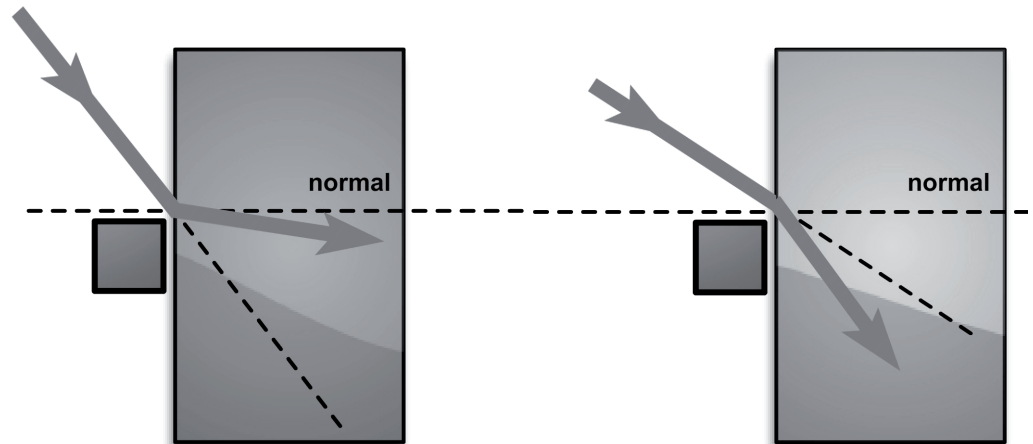
When light passes from one medium to another it can be bent one way or another. To understand this, we must be introduced to the term “optical density”. This refers to how easily light passes through the medium or material. Obviously, the material must be transparent or optically clear, i.e. light must be able to pass through it without being disturbed.

In fact, if light travels at a speed of $300\,000\,000\text{ m}\cdot\text{s}^{-1}$ in a vacuum (a vacuum is the least optically dense medium there is because it offers no hindrance at all to the passage of light) then the speed of light in anything more dense than a vacuum will be less than $300\,000\,000\text{ m}\cdot\text{s}^{-1}$. So, for instance, the speed of light in water is about $2,25 \times 10^8\text{ m}\cdot\text{s}^{-1}$ and the speed of light through glass can vary



between about $1,6 \times 10^8 \text{ m}\cdot\text{s}^{-1}$ and $2 \times 10^8 \text{ m}\cdot\text{s}^{-1}$, depending on the type and composition of the glass.

Here are the rules for the bending of light.



When a ray of light enters an **optically more dense** medium **from an optically less dense** medium, the ray is **bent towards** the normal. (The **normal is a line drawn perpendicular to the boundary between the two media.**)

When a ray of light enters an **optically less dense** medium **from an optically more dense** medium, the ray is **bent away from** the normal.

OBJECTS AND IMAGES

An object is whatever is being observed through a lens. But what we actually see with our eyes is an image of the object. This means, in the case of a **real** image, that light that was reflected off the actual object has passed through the lens and entered the eye. The way the lens bends the light and the position of both the object and the eye in relation to the lens will determine the nature of the image. If the eye isn't at the same position as the image (i.e. where the image is formed) then the image may appear blurred.

In fact, this is why our eyes see objects as blurred when we are in need of spectacles. Spectacles adjust the position of the image so that it falls directly on the retina, from where the information is carried to the brain. When we see things as blurred, it is because the lens in our eyes cannot form the correct shape to focus the image of an object exactly on the retina. The spectacle lenses can compensate for or correct such errors.

RAY DIAGRAMS AND SOME OPTICAL TERMS

A ray of light is a convenient "tool" to use when we investigate the characteristics of lenses. In fact, when light from some source (the sun or a light bulb) is reflected as a point on an object, the so-called "rays" will move off **in straight lines** in all directions. In ray diagrams (we will deal with convex lenses only), we choose to work with only those rays that are of interest to us. In fact, there are only two:

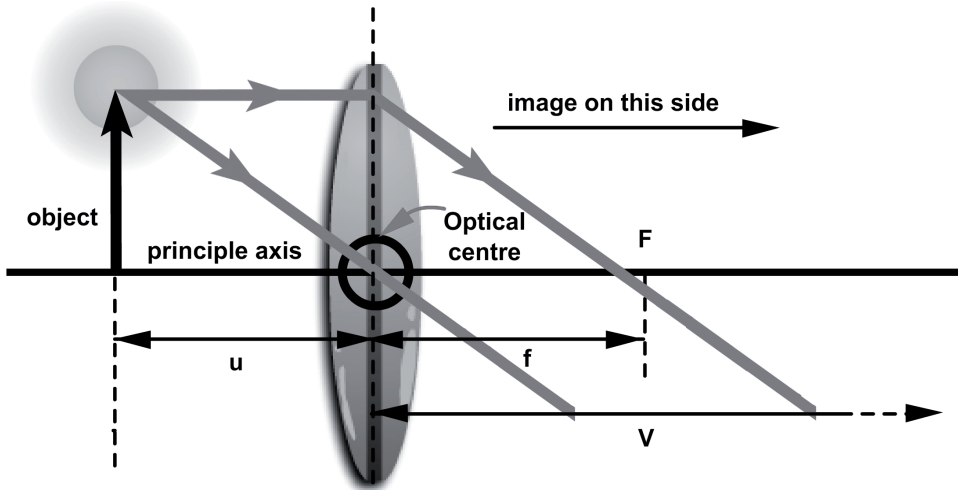
- A ray that travels parallel to the principal axis (a line at right angles to the lens that passes through the optical centre of the lens); and
- A ray that passes directly through the optical centre of the lens.

These two rays behave in the following way:

- The first (parallel to the principal axis) will be bent so that it passes through the focus of the lens; and



- The second passes through the optical centre as though it is not bent (the correct word is “refracted”) at all.



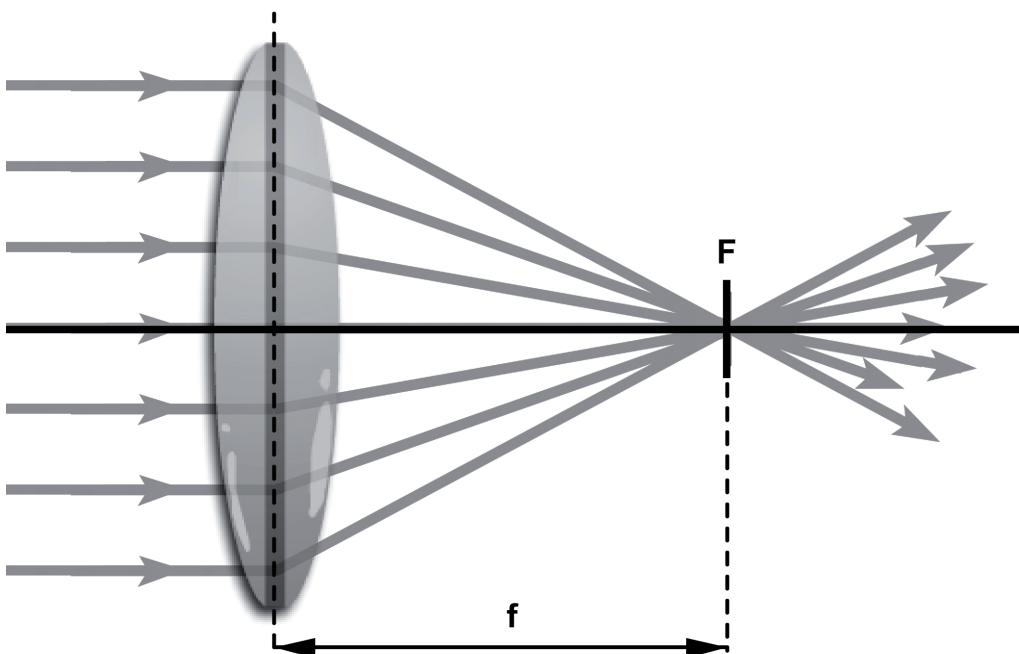
THE LENS EQUATION

This equation relates the positions of an object and its image for a particular lens. Also look at the diagram above to see where the measurements must be taken.

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

The three values that we must know in the equation are:

- The distance between the object and the centre line of the lens (u);
- The distance from the centre of the lens to the image (v); and
- The distance from the centre of the lens to the focus of the lens (f). (The focus of the lens is the point at which a set of parallel rays will converge.)



Just by inspecting the equation, we can tell some things about it.

For a particular lens with its characteristic curvatures, the value of f will be a constant. So one can see that if f (and hence $1/f$) has a fixed value for a particular lens, as the object is moved closer to or further from the lens (i.e. u changes), the value of v will also change.

A slightly more complex version of the lens equation is known as the **lensmaker’s equation** as it allows more details about a lens to be calculated. This is necessary



for the grinding of very accurate lenses for very specific requirements, such as the lenses in an individual's spectacles.

MAGNIFICATION

We all know that lenses can magnify (make larger) and also diminish (make smaller) the image of an object. Obviously, the lens can't make an object smaller or bigger but it can make the image of the object **seem** smaller or bigger.

The simple definition of magnification is the factor by which the size of the image differs from the size of the object. Magnification can be given by a number which is calculated as follows:

$$\text{Magnification} = \frac{\text{size of image}}{\text{size of object}} = \frac{\text{distance from the image to the lens (v)}}{\text{distance from the object to the lens (u)}}$$

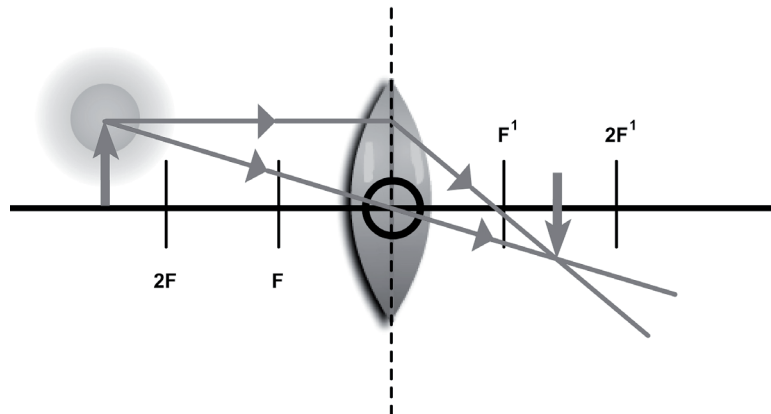
The second part of that equation can be verified geometrically using similar triangles.

Part 2

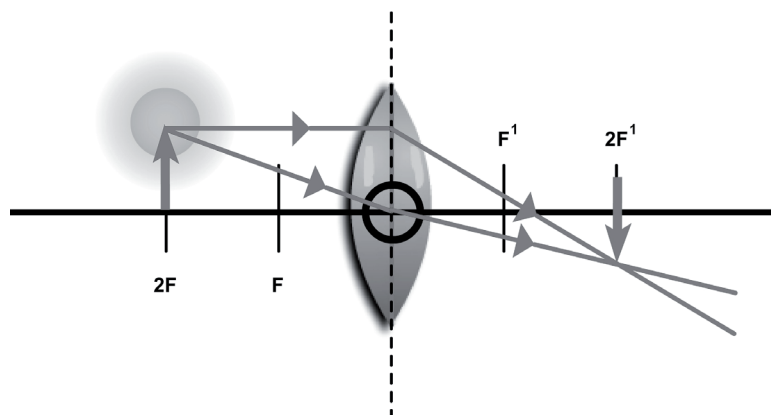
RAY DIAGRAMS FOR SIMPLE, THIN, CONVEX LENSES

By using the information and rules described above, it is possible to work out where the image will be found for various positions of the object. The magnification of the images always depends on the focal length (**f**) of the lens. In the following diagrams, we see how the position of the image varies with the position of the object. As you will see, there are only a certain number of variations.

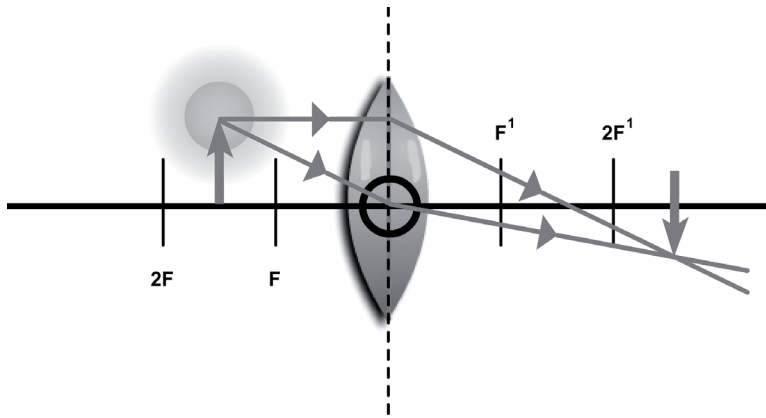
OBJECT FURTHER THAN TWO FOCAL LENGTHS FROM THE LENS



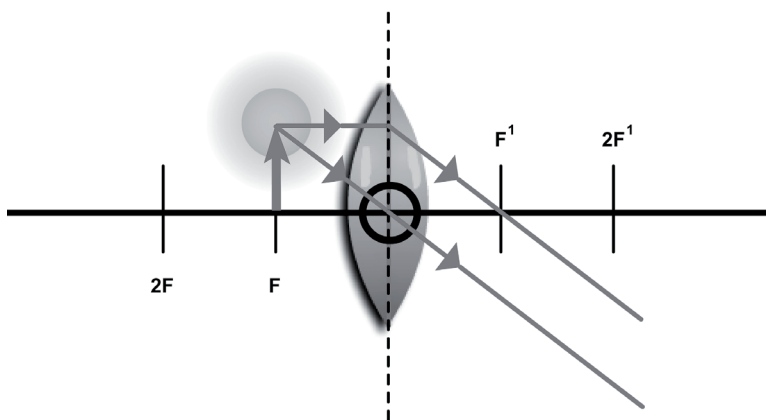
OBJECT AT TWO FOCAL LENGTHS FROM THE LENS



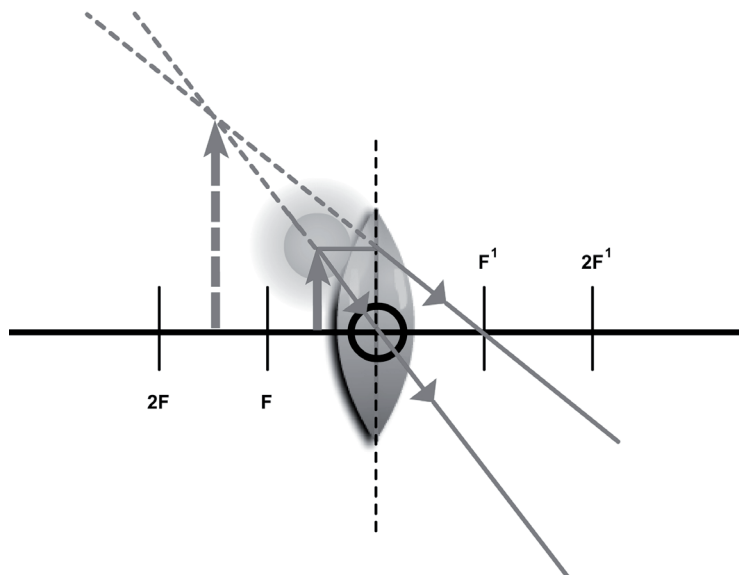
OBJECT BETWEEN ONE AND TWO FOCAL LENGTHS FROM THE LENS

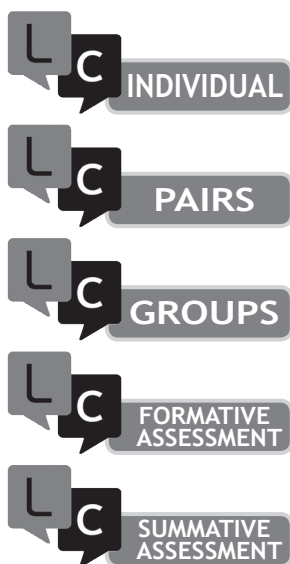


OBJECT AT ONE FOCAL LENGTH FROM THE LENS



OBJECT CLOSER THAN ONE FOCAL LENGTH TO THE LENS





Activity

Using the geometrical diagrams above, complete the table for thin convex lenses.

Position of object	Orientation of object	Position of image	Compared to object	Orientation of image	Magnification (<math>< 1</math>; = 1; or > 1)
<i>Beyond 2F</i>	<i>Upright</i>	<i>Between F and 2F</i>	<i>On opposite side of lens</i>	<i>Inverted</i>	< 1
<i>At 2F</i>					
<i>Between 2F and F</i>					
<i>At F</i>					
<i>Between F and lens</i>					

Now examine the diagrams again and answer these questions.

QUESTION 1

- When the object is at one focal length from the lens, there is no image.
- We also see that the two rays drawn in the diagram emerge from the lens parallel to one another.
- Why does this situation result in no image?
- And why do we get an image when two rays intersect?

QUESTION 2

- When the object is at two focal lengths, the image is exactly the same size as the object (i.e. magnification = 1).
- Can you use geometry to show why this is so?

QUESTION 3

- When the object is between the lens and the focal length of the lens, the image is on the same side of the lens as the object.
- Why do we draw the image in dotted lines?
- Do the rays come from the image or do they only appear to do so? Look at the other diagrams. When we have an image, are there light rays at the image?



SOUND AND LIGHT

Learning Outcomes and Assessment Standards:

Learning Outcome 1: Practical Scientific Inquiry and Problem-solving Skills

Assessment Standard 1:

Conducting an the investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and Applying Scientific Knowledge

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

INTRODUCTION

What you must know in this section of the curriculum is:

- Particle motion, position, displacement, velocity, and acceleration
- Longitudinal waves on spring
 - Wavelength, frequency, amplitude, period, wave speed
- Sound: Quality of sound (tone), pitch, waves, loudness, and ultrasound
- The ear and hearing
 - Sound waves
 - Pitch, loudness, quality (tone)
- Geometric optics
- Lenses
 - image formation

This lesson will focus on some interesting applications and extensions of the basic knowledge in this section:

- Longitudinal and transverse waves in nature
- Physics of the ear and hearing
- Ultrasound
- Spectacles
- Radio telescopes and SALT
- Gravitational lenses.





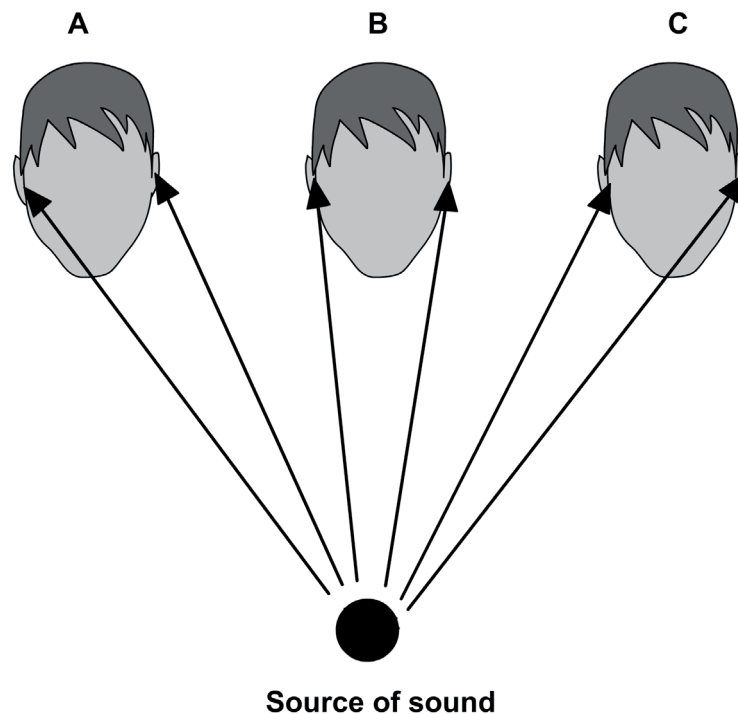
Activity 1

- Write down as many examples of wave phenomena in nature as you can.
- Divide your wave examples into transverse and longitudinal waves.
- When you have done so compare your list with other groups until you have as many examples as possible.

Activity 2

Discuss why you think we have two ears.

- What examples of adaptations for very good hearing do we have from the animal kingdom?
- What are the particular features of the animals that help their hearing?



Preparation for Activity 3

The ear

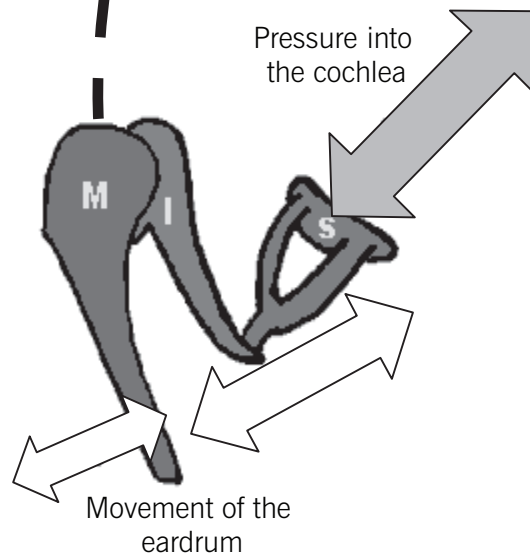
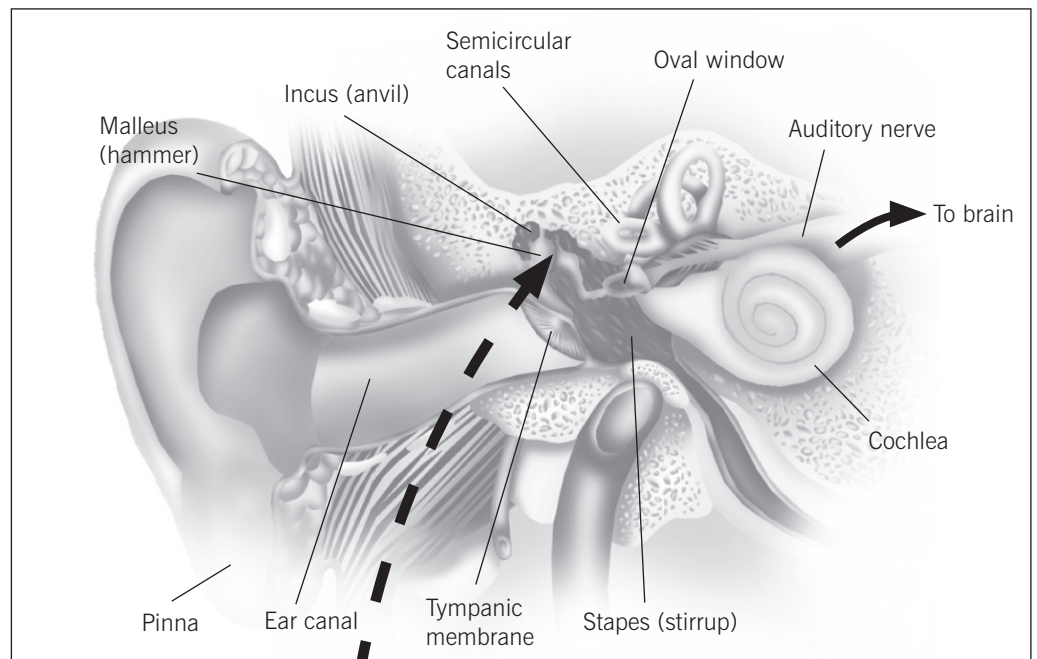
- No electronic instrument has the capabilities of the ear.
- It contains a high fidelity sound detection system that can pick up a huge range of frequencies and intensities.
- It can be tuned to be sensitive to very quiet sound.
- It can also be adapted to exposure of very loud sounds in order to minimise damage to the sensitive membranes, linkages and nerve endings.
- It can discriminate particular sounds from within a cacophony (mixture) of loud sounds and noise. (Noise is pattern-less sound.)
- It is also important for maintaining balance which is due to the fluid levels in the inner ear.



The structure of the ear

- The pinna acts as collecting device that funnels the sound waves into the ear canal. Many animals the pinna of the ear (the outer flap) can be moved about to funnel the sound into the ear to get a more accurate location.
- The ear canal increases the intensity of the sound by reducing the area.
- The sound causes the tympanic membrane (ear drum) to vibrate.
- This vibrates the ossicles;
- [The ossicles are three small bones that amplify the sound by increasing the movement through a system of levers. Their names are:
 - malleus (the hammer)
 - incus (the anvil)
 - stapes (the stirrup)]
 - Which in turn strike the oval window of the cochlea.
 - The cochlea – the snail-like coiled tube - has nerve cells that detect the sound to convert it into electrical impulses for processing by the brain.





The cochlea

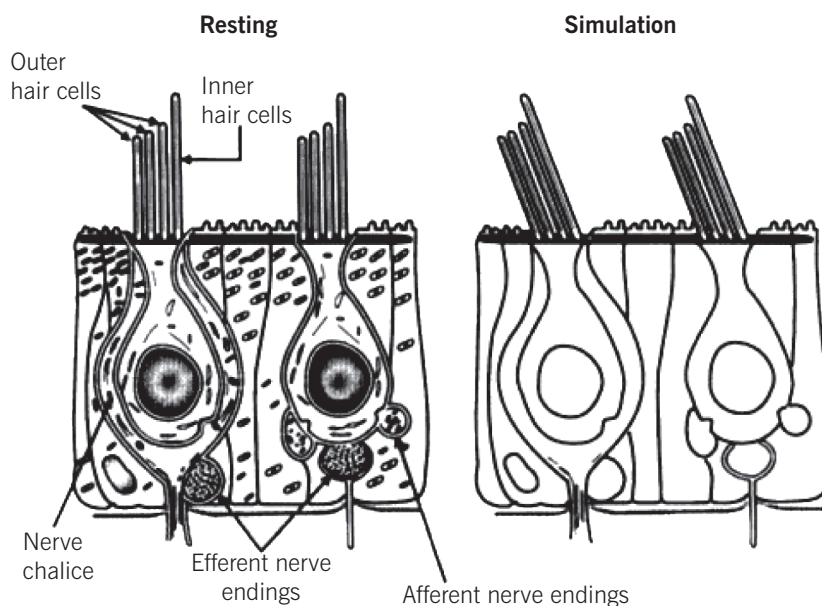
The cochlea is a fluid filled canal which is lined with **hair cells, or cilia**. Sound impulses are sent through the fluid because of the vibrating of the oval window. The longitudinal pressure waves moving through the fluid in the cochlea vibrate the cilia. The picture below shows the hair cells. At the base of the cilia are tiny muscles which are stretched when the cilia move.

TASK: Assessing a theory on how sound becomes nerve impulses to the brain.

Study and discuss the theory below. Decide whether it is **plausible** (i.e. consistent with principles of physics) and **feasible** (i.e. it could happen like this). Also do your own research and decide whether this theory agrees with current theories of hearing.



- When the muscles at the base of the cilia are stretched they react by contracting.
- The stretching and contraction of muscles is associated with a small electric currents or impulses.
- The louder the sound, the greater the movement of the cilia; the greater the muscle reaction the larger the electrical impulse.
- The current generated in the muscle is conducted by the nerves that lie alongside the muscles.
- The current being conducted by the nerve becomes a nerve impulse in the nerve cell, or neuron.
- The neurons at the base of the many, many cilia in the cochlea fire together.
- The nerves now join like many, tiny bundles of electrical wires to make a “cable” called the auditory nerve.
- This nerve will carry the electrical impulses to the appropriate part of the brain.
- There the electrical impulses are interpreted as a sound.
- If we recognize the sound it is because the pattern of electrical impulses matches something we have heard before.
- If the brain is unable to match the sound it is stored as a new memory.



While we're talking about neurons, try these numbers for size!

The human brain has a huge number of synapses (the bulb at the end of a neuron which connects to other neurons). Each of the 10^{12} (one trillion) neurons in the brain has on average 7,000 synaptic connections to other neurons. It has been estimated that the brain of a three-year-old child has about 10^{16} synapses (10 quadrillion). This number declines with age, stabilizing by adulthood. Estimates vary for an adult, ranging from 10^{15} to 5×10^{15} synapses (1 to 5 quadrillion).

[Reference: <http://en.wikipedia.org/wiki/Neuron>]

Frequency response of the ear

The human ear can detect sounds of frequency about 20 Hz.

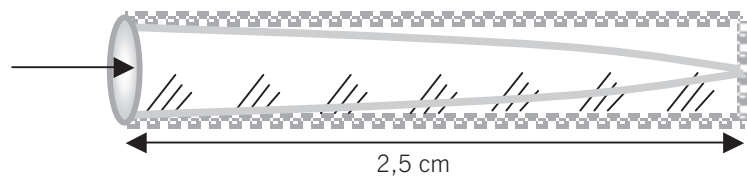


Sounds below this frequency are called **infrasound** and are felt rather than heard.

In a young person, the upper limit of hearing is sound of about 20 000 Hz. However the upper limit reduces with age so that a middle-aged person hears frequencies up to only about 15 000 Hz. An elderly person could have an upper limit of as low as 10 000 Hz.

The human ear has a peak sensitivity at about 3 000 – 3 400 Hz. This frequency causes a sense of unease and discomfort in the listener. A human scream is at this frequency, and alarms are designed to produce sound of about 3 000 Hz.

The reason for this is that the cochlea has a tube length of about 2.5 cm, closed at one end and open at the other. Since the sound is a maximum at the open end and a minimum at the closed end, we know that the fundamental in the cochlea will be a one-quarter wavelength i.e. $\frac{1}{4}\lambda$.



$$\text{If } \frac{1}{4}\lambda = 2,5 \text{ cm}$$

$$\text{then } \lambda = 10,0 \text{ cm} = 0,1 \text{ m.}$$

Now if $v_{\text{sound}} = 336 \text{ m}\cdot\text{s}^{-1}$ and if $v = f\lambda$

$$\text{then } f = \frac{336}{0,1} = \mathbf{3\ 360 \text{ Hz.}}$$



Activity 3

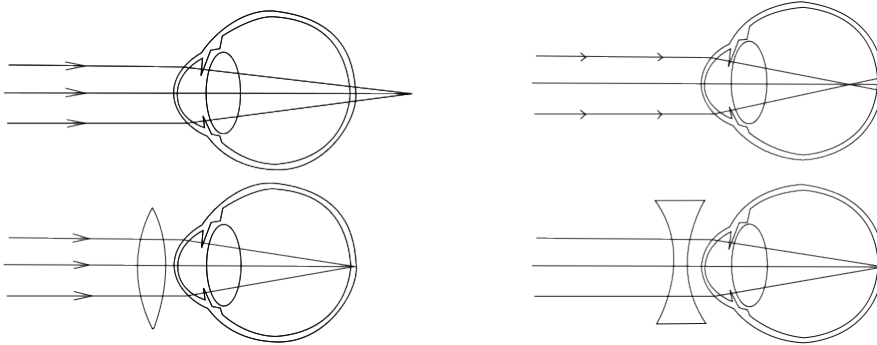
When you have read the notes above and studied the diagrams, get together with a group of friends and discuss the physics of hearing. In particular, use the information in the notes and your understanding of the points there to explain:

- where we find a lever operating in the ear;
- where longitudinal waves in the air are transformed into vibrations in the ear;
- where you think “hearing” actually takes place; and
- why long exposure to very loud sounds can impair one’s hearing i.e. damage the structures which enable us to hear?



Preparation for Activity 4

Look at these two sets of ray diagrams to decide which applies to myopia and the spectacles to remedy the condition and which applies to hyperopia.



Condition A & remedial spectacles

Condition B & remedial spectacles

Activity 4

Myopia is “near sightedness” and is a condition where a person can focus on things close by but where things far away seem blurred. The problem normally lies with the lens of the eye. Either the lens can be too curved, causing the light entering the eye to be focused at a point that falls short of the retina. Or the lens material can become more optically dense, resulting in incoming light being bent too much by the lens. Either way, by the time rays of light reach the retina they are already diverging. This causes a blurred, indistinct image on the retina.

Hyperopia is “far sightedness”. Use the explanation for myopia to explain hyperopia.

Preparation for Activity 5

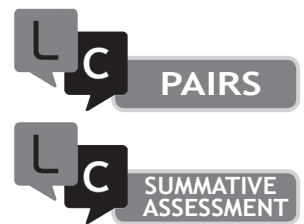
SALT

The Southern African Large Telescope (SALT) is the largest single optical telescope in the southern hemisphere, with a hexagonal mirror array 11 metres across. Although very similar to the Hobby-Eberly Telescope (HET) in Texas, SALT has a redesigned optical system using more of the mirror array. It will be able to record distant stars, galaxies and quasars a billion times too faint to be seen with the unaided eye - as faint as a candle flame at the distance of the moon.

Eventually the sharpness of SALT’s images will be improved when its active optical controls are working perfectly. Unlike radio telescopes SALT has a spherical mirror and not a parabolic mirror as is the case in the usual reflecting telescopes. This is why the special optical controls are so important.

Gravitational lenses

Gravitational waves are ripples in “**spacetime**” – a concept introduced in Einstein’s theory of general relativity in 1916. A mass cause a curvature in spacetime and the bigger the mass the greater the curvature it causes. The curvature of spacetime is another way of explaining the effect of gravity. Massive bodies even cause light to bend, which is the basis for gravitational lenses. In 1919 Sir Arthur Eddington led an expedition to St Helena Island to observe an eclipse of the Sun. They were able to see a star that would normally have been invisible because it lay behind the Sun. But because its light was bent (or curved) by the Sun’s gravity they were able to observe it. This is an illustration of the notion of a **gravitational lens**.

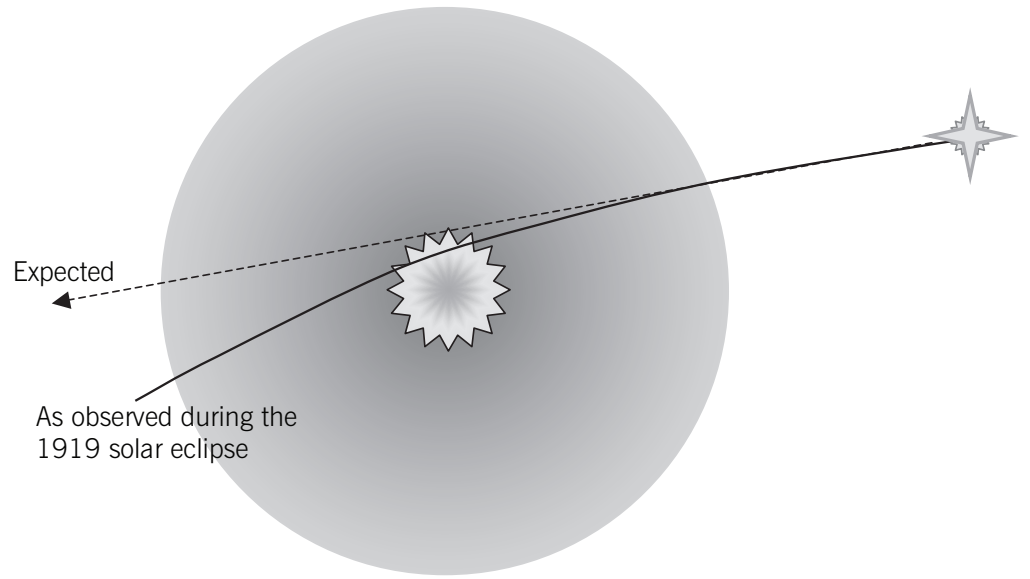


L C PAIRS

L C SUMMATIVE ASSESSMENT

Activity 5

Read the explanation in the notes above and listen to the explanation given on the DVD. Then explain this diagram to a friend.



ELECTRICAL CHARGE, FORCE BETWEEN CHARGES AND CAPACITANCE

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Lessons

9–
10

Overview

This lesson is about charge and the behaviour of charge under various circumstances. Remember that physics is a study of the interactions of inanimate matter in the universe. That's a fancy way of saying "how bodies interact." We aren't immediately interested here in the organic causes of motion, e.g. what makes the muscles work. (Muscle physiology is about the chemistry of living systems and chemistry is simply physics on a microscopic scale so it's all physics in the end – even though biologists and chemists may not agree!). What we are interested in here is forces – the agency of movement – and the origins of forces. In this lesson we will deal, in particular, with electrostatic charge, how it behaves, the nature of fields and what forces arise when charges interact.

FORCES

Forces and the effect of forces have been discussed in depth in Lessons 1–5. One must remember that regardless of the source of the force on a body with mass (any body with mass can be referred to as "massive" without meaning "huge" or "large in size"):

- Any force has the ability to make something move: keep it moving, or change its motion.
- Motion can be in a line, along a curve, or a combination of these two. (How do we get movement which is the combination of a line and a curve? Think of a spiral. If something spirals, it is moving along a line while moving in a circle!)
- See the "Overview" of Lesson 4 for the different kinds of forces to be found in nature.

CHARGE: A PROPERTY OF MATTER

- Charge can be described as a fundamental property of matter, just as mass is.
- In this lesson we will look at the force involved when charges interact.
- In the same way that matter interacts with other matter because of its mass (the gravitational interaction), matter can also interact with other matter because of its charge.
- When charges interact we get either repulsion or attraction because two kinds of charge exist. By contrast, there is only one kind of mass, which is why there is only gravitational attraction and no gravitational repulsion.

In the early 1700s, in the town of Leyden in Holland, a device called a Leyden jar was invented. The Leyden jar was used to store what was called "electricity". These days we call it "electrical charge". Although electrical charge is difficult to describe, we can say that (a) it is an **accumulation of electrical matter** and (b) when this "electrical matter" accumulates it can give rise to electrical effects that

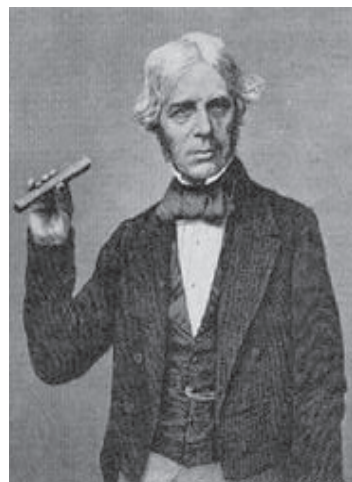


75

we can observe. Charge is unlike the matter that we know has mass and that causes a gravitational force of attraction between bodies with mass.

SOME FACTS ABOUT CHARGE

- Charge comes in two varieties: positive charge and negative charge.
- Charge is measured in units of coulombs (C). (1 C is a very large charge!)
- A body can have both its gravitational mass (m) and an electrostatic charge caused by any electrical charge (q) that is at rest on it at the same time.
- Unlike (different to each other) charges (+ and -) attract and like (the same as each other) charges (+ & + or - & -) repel.
- Charge can flow from one place to another in materials called conductors. Flowing charge is referred to as current ($q = I \times t$).
- Moving/flowing electrical charge (i.e. current) causes magnetic effects: a current in a wire will cause a magnetic needle on a compass to deflect.
- Atoms are electrically neutral but are known to consist of a positively charged nucleus surrounded by moving negative charges called electrons.
- Ions are atoms or groups of atoms that have had one or more electrons removed or on which one or more additional electrons are at rest. (Ions can exist in solutions, in the air or in a vacuum.)
- The charge on a negative ion is $-1,6 \times 10^{-19}$ C for every electron that has been added or $+1,6 \times 10^{-19}$ C for every electron that has been removed. So, although we write Fe^{2+} for the iron (II) ion, we know that the charge resting on that ion is actually $(2 \times +1,6 \times 10^{-19}$ C) or $+3,2 \times 10^{-19}$ C.



Michael Faraday (1791–1867) did much research on electricity. To explain his understanding of charge in the regular lectures he gave to the public and to children, Faraday used special diagrams to illustrate **electric fields**. The idea of an electrical field arose through the work of Faraday and other scientists. **An electric field** was defined as **a region (or a “space”) in which electrical effects can be observed or felt**. The words “region” or “space” are used rather than “area” because an area refers to flat surfaces only. Faraday also developed rules for his diagrams to show magnetic fields. These rules are now also used to draw representations of electrical fields around static electrical charges.

THE CONSERVATION OF CHARGE

“Charge can neither be created nor destroyed.” This statement is known as the **principle of conservation of charge**. Note the similarity of this principle to the principle of conservation of energy. Both are so-called “conservation laws”. In physics there are several conservation laws including energy-matter, charge and angular momentum.

When a single positive charge and a single negative charge combine, they neutralise each other’s charge and we get a net charge of zero. But this does not mean that charge has been destroyed!

When an electrically **neutral** body becomes positively charged, it does so because some negative charge has left it. That negative charge still exists, i.e. it has not



been destroyed. If the negative charge returns to the positively charged body, the body becomes neutral once again.

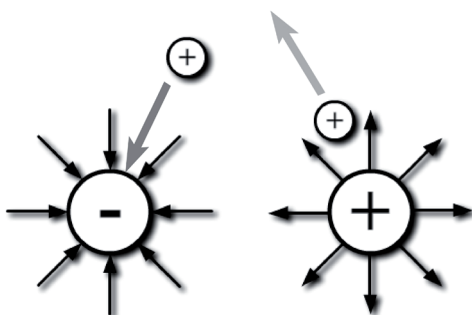
The basic amount of negative charge is the charge carried by one electron, i.e. $-1,6 \times 10^{-19}$ C. This means that when an electron leaves a body it has a positive charge equal to $+1,6 \times 10^{-19}$ C. So the charge on an ion is $-1,6 \times 10^{-19}$ C for every electron that is added or $+1,6 \times 10^{-19}$ C for every electron that has been removed. Therefore, although we write Fe^{2+} for the iron (II) ion (when two electrons are removed from a neutral iron atom), we know that the charge resting on it is actually $2 \times (+1,6 \times 10^{-19} \text{ C})$ or $+3,2 \times 10^{-19} \text{ C}$.

Lesson

DIAGRAMS OF ELECTROSTATIC FIELDS

When we use field diagrams to represent electric fields, we follow certain rules:

- Field lines have a direction.
- The direction of a field line is given by the path a positive charge would move along in that field, i.e. towards a negative charge and away from a positive charge. [Note: this is also the direction of the force that would act on that positive charge.]
- Field lines are always drawn perpendicular (i.e. at 90°) to a charged surface.
- Field lines are drawn closer together where the field is stronger, e.g. closest to the charged body. [Note: the negatively charged body below has a greater charge on it than the positively charged body. Note the difference in the field lines as a result.]
- The strength of the field decreases with the distance away from the charged body.



TASK

Apply the rules and draw lines around each of these three pairs of charges. A useful hint is to place an imaginary positive test charge at points around the charges. Imagine the direction and magnitude of the resultant force on the test charge. That will be the direction of the field line at that point.

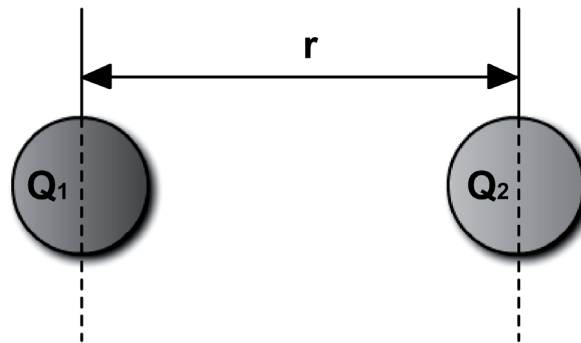
(a)	+	+
(b)	2-	+
(c)	2-	2-

(Field diagrams for the pairs of charges can be found on page 287 in ANSWERS AND ASSESSMENT at the end of these lesson notes.)



THE FORCE BETWEEN TWO CHARGED BODIES

Coulomb's Law states that: *The force of attraction or repulsion between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them.*



We write Coulomb's Law as
$$F = k \cdot \frac{Q_1 Q_2}{r^2}$$

The law speaks of “point charges” and the way we use the formula when we apply the law is to assume that all of the charge on a body acts as though it were concentrated at the centre of the body. So the distance “*r*” is taken as the distance between the centres.

The value of the proportionality constant is taken as $9 \times 10^9 \text{ N}\cdot\text{m}^2\cdot\text{C}^{-2}$. The units of *k* can be seen from the formula. We have seen a similar formula before: when we studied the gravitational force in Lesson 4.

The electrostatic and the gravitational forces are both “inverse square laws”. Inverse square laws behave in the following way: as we get further from the matter causing the field, the strength of the field gets smaller and smaller by a fixed ratio related to distance. For every doubling of the distance from the charge (or mass), the force is reduced in strength by the square of one half, i.e. the strength is quartered. So, if we move two charges to three times the distance apart, the force will become one-ninth the strength, and so on.

COMPARING *G* AND *k*

The difference between the strengths of the electrostatic field and the gravitational field can be seen in the size of *G* and *k*, and in particular by examining the powers of ten involved in the constants. If we ignore the units for the moment, we see that while $G = 6,67 \times 10^{-11} \text{ N}\cdot\text{m}^2\cdot\text{kg}^{-2}$, the value of *k* has a factor of 10^9 in it. 10^{-11} is a very, very small number (one divided by one hundred thousand million, to be exact!) whereas 10^9 is a billion. The difference between the two factors gives us a clue to the relative strengths of the electrostatic and gravitational forces.

The reasons we usually see the gravitational force as being so impressive (the weight of a heavy object makes it difficult to lift) while static electricity causes a tiny spark and just a brief moment of discomfort is this: the Earth has a mass of approximately $6 \times 10^{24} \text{ kg}$ and this more than makes up for the fact that the gravitational force is so weak. The charge on an electron, on the other hand, is incredibly tiny ($1,6 \times 10^{-19} \text{ C}$) so, even though the value of *k* is large and there are a few billion electrons in a spark of static electricity, we are still dealing with a very small force indeed.



USING COULOMB'S LAW TO CALCULATE ELECTROSTATIC FORCE

One coulomb is a very large charge. Problems of this kind, therefore, usually speak of **nanocoulombs** (nC) or 10^{-9} coulombs or **microcoulombs** (μC) or 10^{-6} C because these charges are more realistic. (One nC of charge still represents many, many electrons. If the charge on a single electron is $1,6 \times 10^{-19}$ C, **can you show that, when there is one nC of negative charge on a body, there must be an excess of about six billion electrons?**)

PROBLEM

Two identical charged bodies are brought into contact (i.e. they touch) and are then moved apart to a distance of 20 cm. If the bodies have initial charges of $+10 \mu\text{C}$ and $-2 \mu\text{C}$, what is the size of the force on each body after they have touched and been separated?

Answer: In problems like this, we must first determine the charges on the two bodies AFTER they have touched. When they touch the electrons from the negatively charged body will move on to the positively charged body. Because the bodies are identical, the negative charge will continue to flow until the charges on the two bodies are equal.

To calculate how much charge is on each body when they are separated we do two simple calculations: (a) How much charge is available altogether? (b) What is half of the total charge?

$$\begin{aligned}Q_{\text{TOT}} &= +10 \mu\text{C} + -2 \mu\text{C} \\ &= +8 \mu\text{C}\end{aligned}$$

Half of this charge will be left on each body i.e. $+4 \mu\text{C} = +4 \times 10^{-6}$ C

When the two bodies holding this amount of charge are separated by 20cm, the force between them is:

$$\begin{aligned}F &= \frac{k \cdot Q_1 Q_2}{r^2} = 9 \times 10^9 \times 4 \times 10^{-6} \times 4 \times 10^{-6} \div (20 \times 10^{-2} \times 20 \times 10^{-2}) \\ &= \mathbf{3,6 \text{ N}} \text{ (This force is equal to the gravitational force, i.e. the weight of a } \\ &\quad \mathbf{360 \text{ g mass.)}}\end{aligned}$$

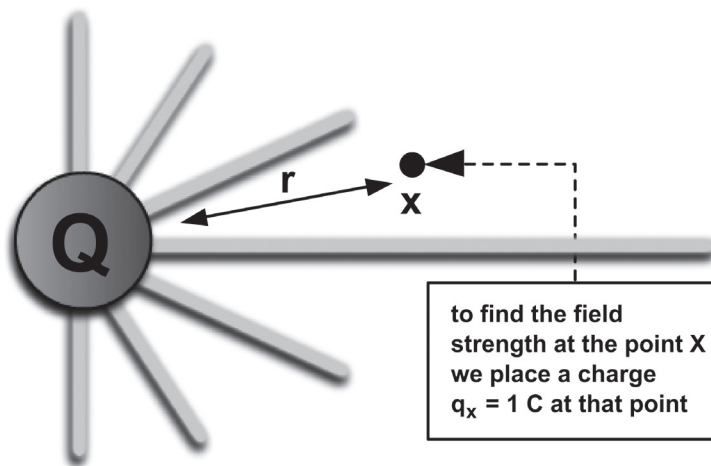
THE STRENGTH OF A FIELD

A field's strength can be found by measuring the size of the force acting at that point. This could be done by measuring the force on a mass placed at a point in a gravitational field or a charge at a point in an electric field. To measure either of these forces in a consistent way, we **must measure the force on one unit of either mass or charge**.

As we know, a unit of mass is the kilogram. Therefore, a convenient way to measure the strength of the field at a point in that gravitational field is by measuring the force per unit mass, i.e. the force of gravity per kilogram at that point.

The principle is exactly the same when we measure **electric field strength** (also called **electric field intensity**) at a point in an electric field. The symbol is **E** and it denotes "the force per unit charge" or force per coulomb.





Having placed the 1 C charge at **X**, we define the strength of the field at that point as:

$$E = \frac{F}{q_x}$$

But we know, from Coulomb's Law, the force that both **Q** and **q_x** will experience. (Remember that the force of repulsion or attraction – we don't know which because we have not specified the signs on the two charges – is the same on both charges as we have an action-reaction pair.) So we know that the electric field strength at **X** is:

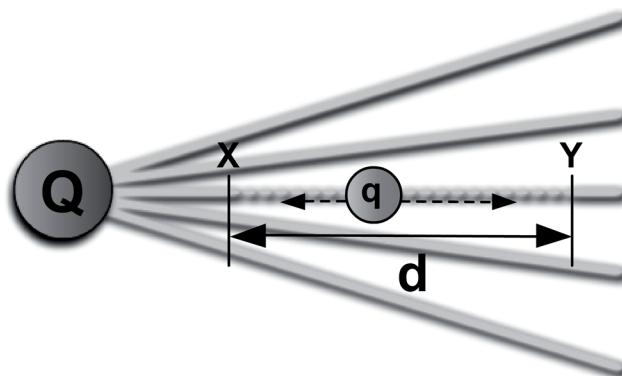
$$E = \frac{\frac{kQq_x}{r^2}}{q_x} = \frac{kQ}{r^2}$$

Now, as you can readily see, the electric field strength (**E**) at point **X** (which can be a point anywhere in the field at a distance or **r** from **Q**) depends only on the size of **Q**, the charge whose field we are interested in, and **r²**, the square of the distance from the charge **Q**. Again we note that there is an inverse square relationship so the electric field strength or intensity decreases rapidly as **r** increases.

ELECTRIC POTENTIAL AT A POINT IN AN ELECTRIC FIELD

When we hear the word “potential” mentioned in physics we are immediately on the alert for something to do with work and energy. Here is the test: **Was work done in order to move something from one point to another?** If the answer is “yes” then we have a field. If it is a gravitational field then somewhere there is a mass that is causing the field. And if it is an electric field then somewhere there is a charge causing the field. (If we place a “test mass” or a “test charge” at a point, then if there is a gravitational or an electric field there, the test objects will experience a force.)

Now, if we are dealing with an electric field and we move a charge from one point to another in the field like this: then we must do work on the small positive charge.



Study the following table and make sure you understand the information it gives and how the conclusions are arrived at. The **three important facts** you must remember are:

1. If an outside agent (like you) does work on a charge by exerting a force on the charge and moving it some distance (**d**), then the work done is stored **IN** or **BY THE ELECTRIC FIELD** as electrical potential energy.
2. If a charge moves in a field without an outside agent applying a force, then **WORK IS DONE ON** the charge **BY THE FIELD** (and the charge will probably gain in kinetic energy [**E_k**] because it will increase its velocity).
3. If the field does work on a charge then the field loses an amount of energy equal to the work it has done.

	q goes from X to Y	q goes from Y to X
q positive Q positive	q experiences a force away from Q (in the direction X to Y) so work is done BY the field on q as its kinetic energy increases.	Work is done ON q against the repulsive force (in the direction X to Y) and the work done is stored IN the field as potential energy.
q positive Q negative	Work must be done ON q to move it in the direction X to Y, and the work done is stored IN the field as potential energy.	q experiences a force towards Q (in the direction Y to X) so work is done BY the field on q and its kinetic energy increases.
q negative Q positive	q experiences a force towards Q (in the direction Y to X) so work is done ON q and this is stored IN the field as potential energy.	q experiences a force towards Q (in the direction Y to X) so work is done BY the field on q and its kinetic energy increases.
q negative Q negative	q experiences a force away from Q (in the direction X to Y) so work is done BY the field on q as its kinetic energy increases.	Work is done ON q against the repulsive force (in the direction X to Y) and work done is stored IN the field as potential energy.

Make sure that you can follow the logic in each case and understand the difference between work done **ON** the field (in which case, energy is stored **IN** the field as potential energy) and work done **BY** the field, in which case the field loses potential energy and the charge gains kinetic energy.

	q goes from X to Y	q goes from Y to X
q positive Q negative	Work must be done ON q to move it in the direction X to Y, and the work done is stored IN the field as potential energy.	
q negative Q positive	q experiences a force towards Q (in the direction Y to X) so work is done ON q and this is stored IN the field as potential energy.	

Read the bold text in the two blocks again. The wording is different. Are they saying the same or different things? Which wording do you think is preferable?

POTENTIAL DIFFERENCE IN AN ELECTRIC FIELD

The term “potential difference” in physics is just as simple as it seems. If work is done on a charge to move it from **X** to **Y** then the work done per unit charge in getting it from **X** to **Y** is the **potential difference**. In fact, this is how we define potential difference.

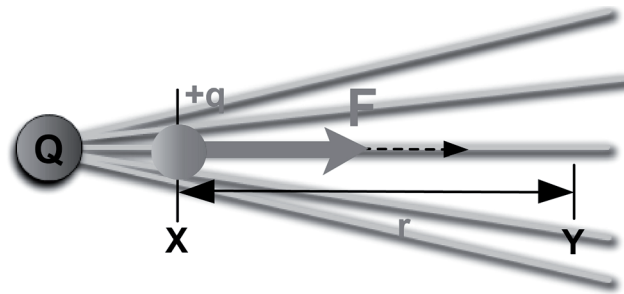
$$P.d = \frac{\text{Work done}}{\text{Charge}}$$

$$V = \frac{W}{Q}$$

- We say that if two points in the field are at different potentials then there is a potential difference between them.



- Work must be done to move charge from a low potential to a high potential – in other words, if we do work on a charge (as in a battery) we will increase its potential.
- When a charged body has had work done on it we say that potential energy has been stored in the field.



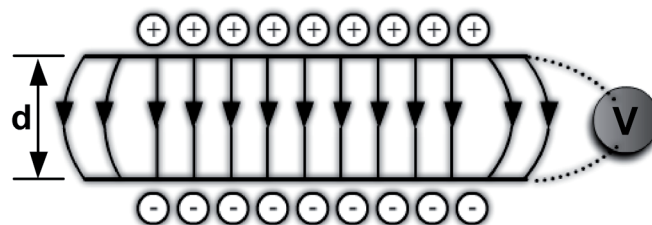
$$W = F \cdot r = \frac{kQq}{r^2} \times r \frac{kQq}{r}$$

The potential energy of a charge (**q**) because of other charges (**Q**) can be given as $U = \frac{kQq}{r}$ and can be used to calculate the potential energy of a charge because of other charges. We can also say that “the electric potential at a point is the electrical potential energy per unit charge”, i.e. **the potential energy a positive test charge would have if it were placed at that point.**

UNIFORM FIELDS

So far we have only looked at fields around single charges or pairs of charges. Those fields are called “radial fields” because the field lines “radiate” outwards from the charge. If we look at the field between charged, parallel plates, we get a different and surprising picture. Instead of the field getting weaker as we get further from the charge, we get a field of uniform strength. This means that wherever we go in the field between the plates, the field strength is the same. (The exception is that when we are close to the edges of the plates, the field becomes “non-uniform”.)

Note that we use the word “constant” to denote something that does not vary with time, i.e. as time elapses the quantity or characteristic remains unchanging and invariable. The word uniform is better used when we are not dealing with time elapsing. A uniform field is one in which the field strength is the same **at every point** in that field. A constant field is one that is the same no matter **when** you measure it. In the next lesson you will see that transformers rely on changing electrical and magnetic fields: fields that are neither constant nor uniform.



ELECTRIC FIELD STRENGTH IN A UNIFORM FIELD

It is a little more difficult to derive an equation for the strength of a uniform electric field. But the equation is a simple one:

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

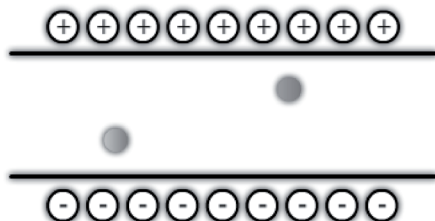
where **V** is the potential difference across a pair of parallel plates and **d** is the separation of the plates (the distance between them), as one sees in the diagram above. The unit of electric field strength when calculated in this way is “volts per



metre” or Vm^{-1} . This is the official, SI unit but NC^{-1} is still acceptable, especially when using $\mathbf{E} = \mathbf{F}/\mathbf{q}$.

CAPACITANCE

As we know, two parallel conducting plates can store charge. We represent this in the familiar way:



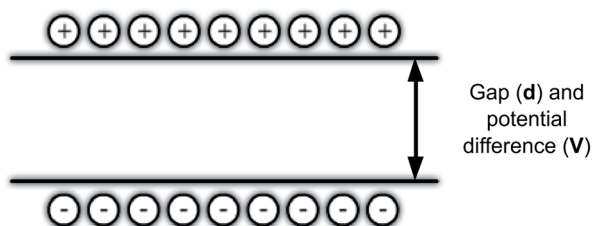
You know from experience that we can get small electric shocks during dry weather. Static charge builds up on one’s body from the friction of cloth on cloth or cloth on plastic surfaces, etc. When one gets close enough to a conductor (say a door handle), the static charge will move off the body, suddenly, as a spark.

The important thing to realise here is that the spark jumps when there is a combination of two factors: a sufficient amount of charge and a small enough gap to spark (or “arc”) across. It is also important to remember that when two plates hold charge (as in the diagram above), there will be a measurable potential difference across the plates. This also means that by applying a potential difference across the plates it is possible to maintain charge on the plates.

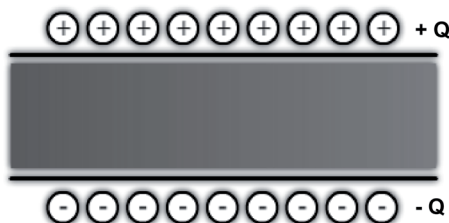
Question: If we carry on increasing the potential difference across to parallel plates, will the charge build-up just keep on increasing and increasing?

The answer to the question lies in ... capacitance.

Capacitance is a measure of the amount of electric charge that can be stored or kept separate (without sparking or arcing across the separating gap) for a given electric potential (or potential difference). (Obviously, the word “capacitance” is related to “capacity”.)



When the potential difference (\mathbf{V}) increases, the strength of the field increases. This makes it easier for the charge (\mathbf{q}) to move. Similarly, if \mathbf{V} remains constant and the separation (\mathbf{d}) decreases, electric field strength increases and charge will move.



It is also obvious that any non-conducting material (it could be an insulator) between the plates will affect the amount of charge that can be held on the plates. We call any material that is placed between two charged plates a **dielectric**. The type of material can be anything from air to carbon to leather to paper. Every



type of material will have a different effect on capacitance because the molecular structure of every type of material is different and hence its effect on charge is different. (We would not place a metal between the plates. Why not?)

A set of parallel plates which can store electrical charge is called a **capacitor**. In capacitors there are two electrodes or conductors which are insulated from one another. The charge on the conductors (they could be plates or concentric cylinders, for example) is $+Q$ and $-Q$. V represents the potential difference between the electrodes/conductors.

The relationship between **capacitance (C)**, **charge (Q)** and **potential difference (V)** is given as:

$$C = \frac{Q}{V}$$

Capacitance, therefore, can be defined as the charge stored per volt. The unit of capacitance is **one farad (1F)**. 1 farad = 1 coulomb per 1 volt.

Remember that capacitance is telling us about the amount of electrical energy that can be stored because that is the amount of energy that is released when we have a **discharge** of charge.

Capacitance tells us the maximum charge that can be contained on two plates for a given potential difference. $Q = CV$ (from the formula for the definition of capacitance) tells us that if the capacitance of a pair of plates is C , then for a potential difference V , the maximum charge the plates can hold is Q .

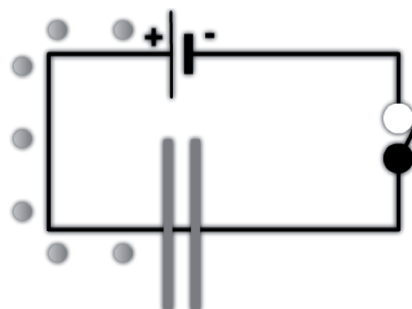
CAPACITORS

The capacitance of the majority of capacitors used in electronic circuits is much smaller than one farad, mainly because the size of one coulomb of charge is ENORMOUS. ($6,25 \times 10^{18}$ electrons, i.e. 6 250 000 000 000 000 000!). The most common units of capacitance in use in the electronics industry are the millifarad (**mF**), microfarad (**μ F**), the nanofarad (**nF**) and the picofarad (**pF**). A capacitor's capacitance can be calculated if the dielectric properties of the insulator between the conductors are known.

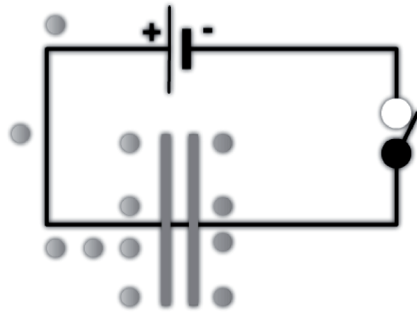
A CAPACITOR IN A CIRCUIT

As we have seen, a capacitor in a circuit will store energy and when a capacitor is used as a circuit device that will be its main function. When the value of Q/V for a capacitor is exceeded, it discharges. That means there is a sudden surge of charge in the circuit, i.e. a sudden current. You will see that as the charge builds up and then discharges, we get a current that pulses. The amount of resistance in the circuit (**R**) and the size of the capacitance (**C**) can be used to determine the length of time it takes for the capacitor to discharge ($t = RC$). By adjusting **RxC** to a desired value, one can build a simple circuit that "pulses" at very regular intervals.

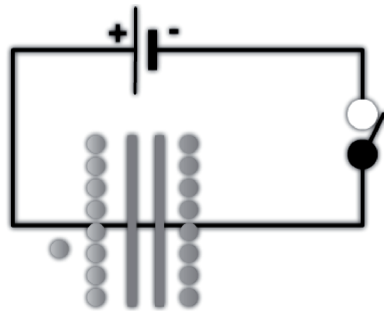
Study these diagrams to get a picture of the flow of charge in a capacitive circuit.



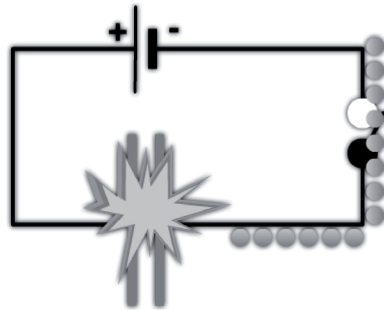
The switch is closed and positive charge begins to flow from the battery towards the positive plate of the capacitor.



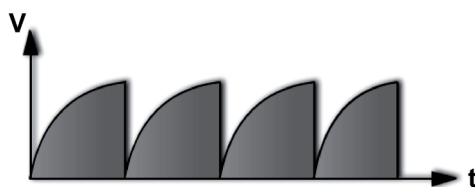
As charge builds up on the left hand plate, opposite charge will build-up on the right hand plate. As this happens, the potential difference across the capacitor plates builds up. As charge builds up on the left plate, it becomes more and more difficult for positive charge to leave the positive terminal of the battery and current decreases.



At some point, the capacity of the capacitor to hold charge on its plates is achieved and the capacitor discharges, releasing a large amount of charge very suddenly. This will be shown on an ammeter as a surge in the current.



A graph of potential difference across the capacitor plates vs time. Make sure that you can match the parts of the graph with the diagrams of the build-up of charge.



SOMETHING INTERESTING ABOUT MECHANICAL FORCES

When you sit on a chair, why don't you fall through it? After all, Earth's gravity attracts you towards its centre so there is a contact force acting downwards on the chair seat. The simple answer is that the chair is able to exert an equal and opposite reaction to the action that you exert on the chair. The reason the chair can exert an action is that it has the strength to do so.

All of this is pretty obvious so far. But as we look at the contact forces acting downwards on the chair's seat (and upwards on the sitter's seat!), we come to a startling realisation. All the contact forces in nature are electrostatic! What we



refer to as the strength of the chair comes down to the strength of the bonds between molecules in the wood or the plastic of the chair seat. (Think about this statement: **All chemistry is about the forces between charged bodies.**)

MILLIKAN'S OIL DROP EXPERIMENT

This work, sometimes jokingly referred to as “Millidrop’s oil can”, is not included in the Grade 11 Physical Sciences curriculum. Yet it is an interesting and important application of the electrostatic theory which you have been studying. Robert Millikan is regarded as one of the finest experimental physicists of the 20th century. He made contributions in many areas of physics but is most famous for his experimentation that gave us the accurate value of the charge on an electron. As far as we can tell about the accuracy of the experimental methods used, the charge on electrons and protons is identical.

In recent years, there has been some suspicion cast on the unerring accuracy of Millikan’s results and the fact that his determinations of the electronic charge varied so little from experiment to experiment.

A suggestion has been made – though certainly *not* proved – that Millikan may have made accurate estimates of the correct value and then made sure that any experimental measurements outside of a desired range of values were excluded from his calculations. This kind of suspicion arises from time to time and is taken very seriously by the scientific community. The reason the community is so sensitive to the issue is that the integrity of the entire community is damaged when the accusations – be they true or false – surface into the public domain. The scientific community polices itself very strictly on matters of integrity and transparency.

LO3 TASK: SCIENTIFIC ETHICS

Debate or write an essay on the issue of honest reporting of scientific results and scrupulous care in adhering to accepted scientific methods and procedures. Why should the scientific community be so careful to avoid this kind of behaviour by scientists that it leads to such accusations? What effect do scientific scandals have on (a) the scientific community and (b) the public perception of scientific inquiry?

CHARGED PARTICLES

By the end of the 19th century, the English scientist JJ Thompson had proposed a model of the atom involving negative charge stuck into a positively charged mass. This was his famous “plum pudding model” of the atom. Early in the 20th century, Ernest Rutherford had advanced the model to that of a tiny positive nucleus surrounded by negative charge. The negatively charged particle, called an electron, was known from so-called cathode rays: negatively charged particles that flowed from a negatively charged electrode. It was guessed that the negative particles in the atom were electrons, but it remained for Robert Millikan to measure their charge.

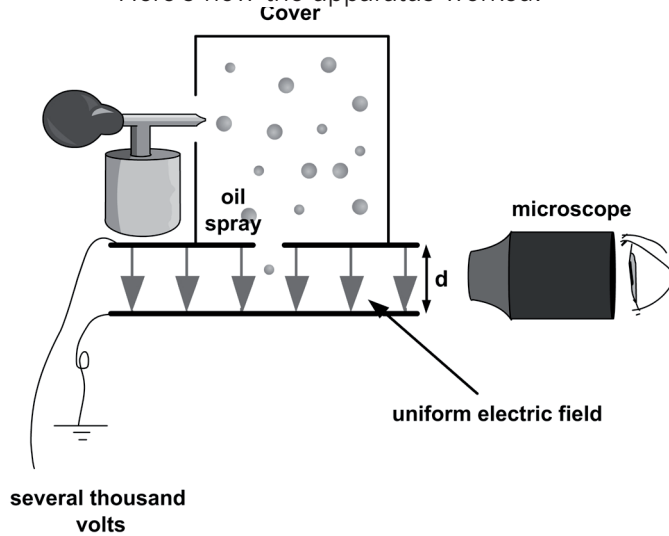
THE EXPERIMENT

Millikan performed this in 1909 to determine the size of the charge on a single electron. What he did was to charge tiny drops of oil and measure how strong an applied electric field had to be in order to stop the oil drop from falling. Millikan was able to determine the mass of the oil drop. From this he could calculate the force of gravity on the drop and hence the electric charge that the drop must have. By varying the charge on different drops, he noticed that the charge was always a multiple of about $-1.6 \times 10^{-19}\text{C}$. He correctly deduced that this was the charge on a single electron. We now realise what this meant: electrons carry this **unit** of charge.



MILLIKAN'S OIL DROP APPARATUS

Here's how the apparatus worked:

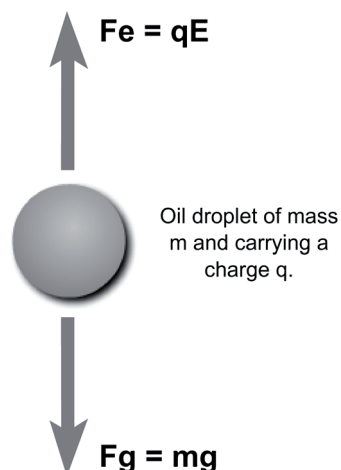


(The diagram is taken from www.wikipedia)

1. An atomiser sprays a fine mist of tiny oil droplets into a chamber.
2. Some of the tiny droplets fall through a hole in the upper of two parallel charged plates which were a distance (**d**).
3. As the droplets fall, they reach terminal velocity. Using a microscope, their terminal velocity is measured and by using a suitable formula, the mass (**m**) of an oil drop can be calculated.
4. Next, Millikan applied a charge to the falling drops by illuminating the space between the parallel plates with x-rays. X-rays can ionise the air and electrons attach themselves to the oil drops.
5. By attaching a battery to the parallel plates, he was able to apply an electric potential difference (**V**).
6. The electric field produced between the plates by the **pd** acted on the charged oil drops. When the **pd** was just right, the electromagnetic force just balanced the force of gravity on a drop, and the drop would remain stationary.

HOW MILLIKAN CALCULATED THE ELECTRONIC CHARGE

When a drop is suspended (zero velocity) or moving with a constant velocity, the weight (**mg**) of the oil droplet is exactly equal to the applied electric force (**qE**).



The value of **E**, the applied electric field, can be calculated because the uniform field strength between two parallel plates is $E = V/d$ and both **V** and **d** can be measured accurately; **m**, the mass of the oil droplet, can be calculated by measuring its density and its diameter (and hence its volume); and **g**, the acceleration caused by gravity at the location of the laboratory, can be determined very accurately. Thus one can solve, for **q**, the charge on the drop:

$$q \times E = m \times g$$

$$\therefore q = \frac{mg}{E}$$

$$\therefore q = \frac{mgd}{V}$$

Using this equation, Millikan determined the charge on a drop of oil. He repeated the experiment many times. By varying the strength of the x-rays used to ionise the air, differing numbers of electrons would arrive on the oil droplets. But, although he obtained different values for **q**, the value was always very close to a multiple of $-1.6 \times 10^{-19}C$. He deduced that this was the charge on a single electron.



Activity

QUESTIONS

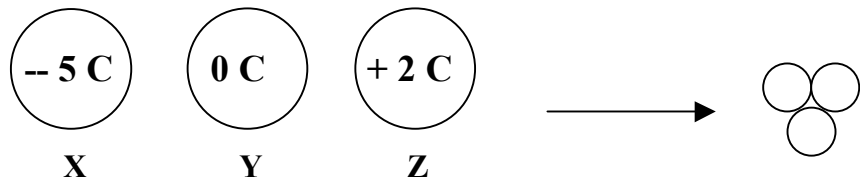
1 Which of the following is a vector quantity?

- (a) Charge (b) Field strength
(c) Potential difference (d) Current

2 The electrostatic force on a charge between two charged parallel plates, where the symbols have their normal meanings and units, is given by:

- (a) ma (b) q/E (c) QV/d (d) $k \cdot Q_1 Q_2 / r^2$

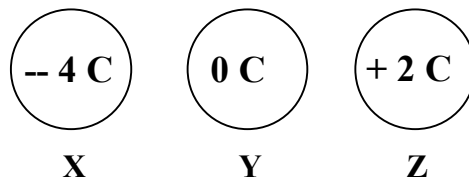
3



If three identical charged spheres, X, Y and Z, are placed together in a triangular arrangement (i.e. each sphere touches the other two) and are then separated, the charge on each sphere, in coulombs, after contact has been broken is:

- (a) -1 (b) +1 (c) -2 (d) -3

4



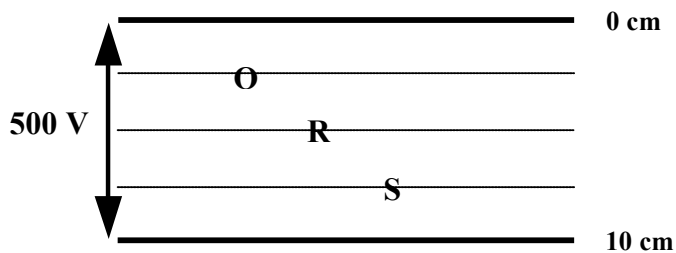
X, Y and Z are three identical charged spheres, as shown. First X and Y are brought into contact and then separated. Then Y and Z are brought into contact and separated. The charge on Y will now be:

- (a) -1 (b) 0 (c) +1 (d) +2



- 5 The electrostatic force, in newtons, on a positively charged particle ($Q = +5 \text{ mC}$) when placed in a field with an electric field strength of 20 V.m^{-1} is:
- (a) 0,1 (b) 0,25 (c) 100 (d) 20
- 6 An α -particle (He^{2+}) is a Helium atom with two electrons removed, i.e. it is an ion. The repulsive force between two α -particles is F when they are at a distance r metres apart. When an α -particle and an electron are $0,5 r$ apart, the magnitude of the force between them is:
- (a) $8 F$ (b) $4 F$ (c) $2 F$ (d) $1 F$
- 7 When an electron and a proton are at a distance of r metres apart, the force between them is F . When the distance between the two particles is increased to $2 r$, the magnitude of the force between them is:
- (a) $4 F$ (b) $2 F$ (c) $1 F$ (d) $0,25 F$

8



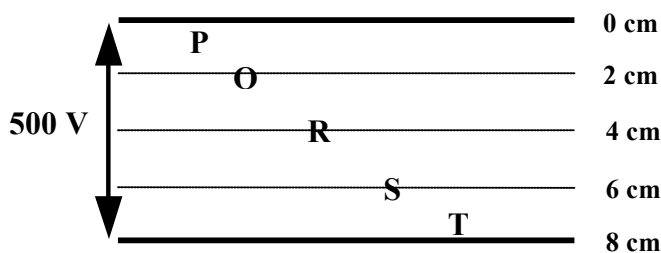
Two parallel metal plates (shown as dark lines) are exactly 10 cm apart. If the potential difference across the plates is a steady 500V, which of the following statements concerning electric field strength is the most accurate?

E , in appropriate units, at ...

- (a) point Q has a lower value than at S
- (b) point R is 250 Vm^{-1}
- (c) point S is $5\,000 \text{ Vm}^{-1}$
- (d) points Q, R and S have the same magnitude



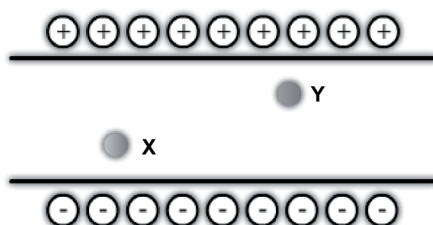
9



Two parallel metal plates (shown as dark lines) are exactly 8cm apart. If the potential difference across the plates is a steady 500V, which of the following statements concerning electric field strength is the most accurate?

- (a) E at point P is less than E at point T
- (b) E at point R is $12\,500\text{ Vm}^{-1}$
- (c) E at point S is $6\,333.33\text{ Vm}^{-1}$
- (d) E at points P and T is $6\,250\text{ Vm}^{-1}$

10



In this diagram, two charged particles, X and Y, are pictured between two charged parallel plates. X is stationary and Y moves upwards at a constant velocity. What are the charges on X and Y respectively?

- (a) positive, negative
 - (b) pos, pos
 - (c) neg, neg
 - (d) neg, pos
- 11 The potential difference between two conducting plates, A (at a positive potential) and B (at a negative potential), is 2 volts. If an electron (charge = $-1,6 \times 10^{-19}\text{C}$) is moved from A to B at a constant speed, its potential energy will:
- (a) remain unchanged
 - (b) decrease by 2 J
 - (c) increase by $1,6 \times 10^{-19}\text{ J}$
 - (d) increase by $3,2 \times 10^{-19}\text{ J}$
- 12 The potential difference between two charged plates, A (positive) and B (negative), is 2 volts. If a proton (charge = $+1,6 \times 10^{-19}\text{ C}$) is moved from A to B, its potential energy will:
- (a) remain unchanged
 - (b) decrease
 - (c) increase
- 13 Two vertical parallel plates are 20mm apart. The electric field strength between the plates is $2,5 \times 10^{-4}\text{ Vm}^{-1}$. Calculate the horizontal and vertical forces acting on the proton.
- 14 Two point charges of $+8 \times 10^{-2}\mu\text{C}$ and $-4 \times 10^{-2}\mu\text{C}$ are placed 120 mm apart.
- (a) What is the resultant field intensity at a point midway between the two charges?
 - (b) If a charge of $4\mu\text{C}$ is placed at the midpoint, what force will it experience?



15 Two parallel charged plates have a separation of 40mm and a potential difference of 400V between them.

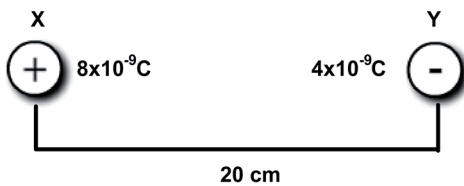
- (a) What is the electric field strength between the two plates?
- (b) An electron starts from rest at the negative plate. What is its speed when it reaches the positive plate? (Use the formula for kinetic energy gained.)

$$[m_e = 9,0 \times 10^{-31} \text{ kg} ; q_e = 1,6 \times 10^{-19} \text{ C}]$$

16 The flat base of a thunder cloud is 150 m above the ground. Lightning originating from the cloud base strikes the ground. The charge being discharged from the cloud is estimated to be 20 C and the duration of the strike (i.e. the time taken for all the charge to move from the cloud to Earth) is measured at 0,5 s.

- a) What is the average size of the electrical current between the cloud and Earth during the strike?
- b) If the potential difference between the cloud base and Earth is estimated to be 1MV (one million volts), what is the approximate average electric field strength in the space between the cloud base and the ground?
- c) How much energy is released as a result of the lightning strike?

17



Two small, identical metallic spheres are placed 20 cm apart. They are then charged with +8 nC and -4 nC of charge, respectively.

- a) Calculate the magnitude and direction of the force exerted by X on Y.
- b)
 - i) Calculate the magnitude and direction of the electric field intensity at X.
 - ii) What is the origin of the electric field at X?
- c) Calculate the magnitude of the force between the spheres if they are brought into contact and then removed to a distance of 60 cm apart.

18 A capacitor discharges when a charge of $2,4 \times 10^{-10} \text{ C}$ accumulates on one of its plates at a potential difference of 36 V.

What is the capacitance of the capacitor?

19 A 1,5 A current in a capacitive circuit flows for 2 ms before the $12 \mu\text{F}$ capacitor in the circuit discharges. Assuming that all the charge that flowed in the circuit is on one of the capacitor plates when it discharges:

- a) How much charge accumulates on the plates?
- b) What is the pd across the plates of the capacitor when it discharges?

FORCES, FIELDS AND CAPACITANCE

Lesson

10a

Learning Outcomes and Assessment Standards:

Learning Outcome 1: Practical Scientific Inquiry and Problem-solving Skills

Assessment Standard 1:

Conducting an the investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and Applying Scientific Knowledge

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

INTRODUCTION

What you must know in this section of the curriculum is:

- Coulomb's Law
- Electric field around charges
- Electrical Potential Energy and Potential
 - Force between charges (Coulomb's Law)
 - Electric field around single charges and group of charges
- Capacitor and capacitance on a circuit
- Stored energy
- Relationship between capacitance, charge and potential difference
 - Electrical potential energy and potential
 - Capacitance, physics of the parallel plate capacitor, relation between charges, potential difference and capacitance
 - Capacitor as a circuit device

This lesson will focus on calculations using the basic knowledge in this section:

- Solving problems involving electrostatic fields.
- Solving problems involving capacitors.



Activity 1

Compare Coulomb's Law of electrostatic attraction and Newton's Law of universal gravitation.

How are they similar?

How do they differ? (*Hint: compare the values of G and k .*)

What does this table suggest to you?

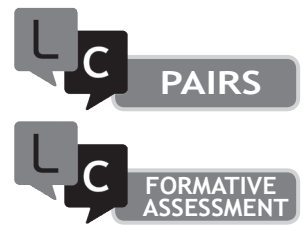
The force holding the nucleus of the atom together	1
Electromagnetic force (including electrostatic forces)	$\frac{1}{137}$
Weak nuclear force that must be overcome during radioactive decay	10^{-5}
Gravitational force	10^{-39}

Activity 2

- Two bodies, A and B, are placed 1 m apart.
- Some electrical charge is placed on A.
- Twice as much charge is placed on B.
- The charges on A and B are both positive.
- The electrostatic force between A is +1 unit. Draw a diagram of the system described above.

What is the new force between A and B in each of the following cases?

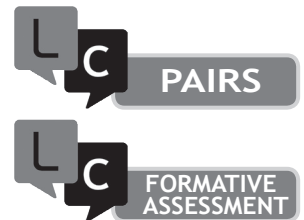
- Body A's charge is replaced by the same amount of charge, but of the opposite charge.
- The bodies are now separated to 2 m apart.
- A and B are brought into contact and then separated to 1 m again.
- The charge on B is removed. A and B are brought into contact again and then separated to 0,5 m apart.



Activity 3

Two metal bodies, each with a mass of 1 tonne, are positioned so that their centres are 500 cm apart. The bodies each have a charge of $-4 \mu\text{C}$.

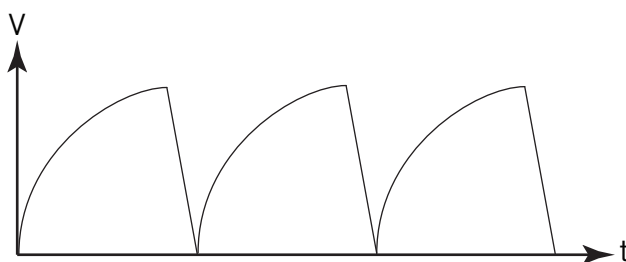
- Compare the gravitational and electrostatic forces between the bodies.
- What are the gravitational and electrical forces experienced by one of the bodies?
- Given the mass of the bodies and their distance apart, is this arrangement possible?



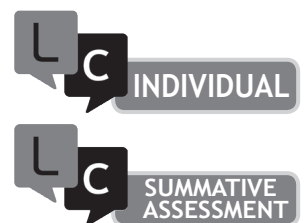
Activity 4

A **capacitor** is a device that stores charge on “plates” which could be parallel metal plates or even two layers of rolled up paper separated by an insulating layer. The amount of charge (Q) that can be stored is related to the potential difference (V) across the plates and the “capacitance” – a measure of the device’s charge storing ability.

All capacitors will have a maximum capacity so that when the potential difference across the plates exceeds a certain value, more charge will accumulate than the capacitor can hold and it will discharge automatically. This gives rise to the “sawtooth” variation in the voltage across a capacitor.



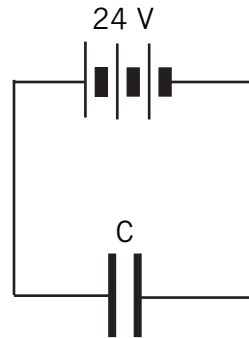
What is happening is that as charge builds up (due to the applied p.d.) the voltage between the plates also builds up. Then, at the point where charge has accumulated to the maximum that the capacitor can hold at that voltage the



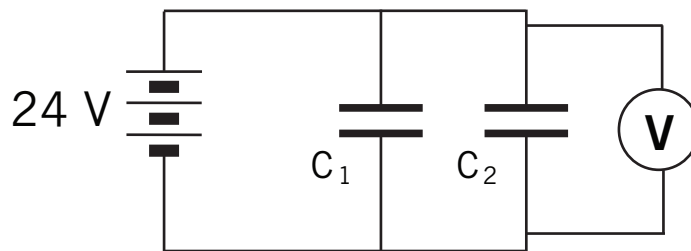
capacitor discharges and the p.d. between the plates drops to zero. Then the process starts again.

The rate of charge-and-discharge depends on the resistance and capacitance in the circuit. If these are known then the charge-discharge time can be determined very accurately and used in electronic measuring devices.

- a) What charge can be carried by a capacitor with a capacitance of 12 pF when it is connected to a 24 V battery?



- b) What will the effective capacitance be when two of these capacitors (i.e. with $C = 12 \text{ pF}$) are connected in parallel?
- c) How will several capacitors connected in parallel compare with resistors connected in parallel?



Understanding the problem

The thing to realise here is that each capacitor, C_1 and C_2 , has an applied potential difference across it of 24 V due to the battery. That means that we can work out the total charge collected on each capacitor. The charge on each capacitor depends on the capacitance of each capacitor.



ELECTROMAGNETISM, INDUCED CURRENT AND TRANSFORMERS

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Lessons

11–
12

Overview

The discovery of the relationship between electricity and magnetism is the story of how scientific ideas develop. This development – of our understanding of the relationship – is perhaps the most significant development in modern physics when seen from an industrial and economic perspective. The names of certain individuals stand out in the story. One, a Dane named **Hans Christian Oersted**, was responsible for the early research and for announcing the fact of the relationship to the world. The other, an Englishman named **Michael Faraday**, was responsible for giving us a clearer understanding of the nature of the relationship between electricity and magnetism.

Oersted developed his interest in science as a boy. He and his brother were first educated through self-study at home. Later, in 1793, he went to Copenhagen University. Oersted did well academically and by 1796 he had received his degree in physics. In 1801, he travelled to Germany to study further and there he became aware of a possible connection between electricity and magnetism. Oersted believed in the unity of nature and to him relationships between natural phenomena seemed obvious.

When Oersted became a professor of physics at the University of Copenhagen in 1806, he continued his research into electricity and electric currents. In 1820, Oersted did an experiment whose result surprised him. He saw that a compass needle was deflected when an electric current from the battery was switched on and off. This suggested to him that a magnetic field (he wouldn't have used the word "field") surrounds a wire carrying an electric current. This confirmed the relationship between electricity and magnetism.

Static electricity from rubbing amber with fur was known in ancient Greece.

There is a fascinating possibility, through the use of what is known as "the Baghdad battery", that the electroplating of small metal objects may have been carried out over 2 000 years ago in Mesopotamia – present-day Iraq. Much later, Benjamin Franklin – the famous American polymath – did research on electricity and his famous kite-and-lightning investigation led him to believe that there was a link between static electricity and the electricity seen in a lightning strike. Franklin's ideas stimulated the interest of scientists such as Galvani, Volta, Faraday, Ampère and Ohm. These names may seem familiar. We recognise them from the units and instruments named after them.

Magnetism has been known even longer than electricity, notably by the Chinese and the ancient Greeks. Both cultures knew of a material we now call "lodestone" which could attract iron metal. When a piece of lodestone was suspended from a string, it would always orient itself in the same direction: the so-called magnetic North. We now know that the magnetic force arises from the movement of electrical charge. When charged particles move, we can detect magnetic effects.



95

Oersted could not give a satisfactory explanation for the phenomenon but after more systematic investigations he showed conclusively that an electric current in a conductor produces a magnetic field around the conductor. When he published his findings, it caused a flurry of related activity in the physics world. (An Italian, Romagnosi, had actually discovered the effect nearly 20 years earlier and although he had also published his findings they were overlooked. Often discoveries can be “ahead of their time” in the sense that the scientific community is not yet able to see the significance of the discovery when it is first announced. More members of the community must advance their body of knowledge on a given topic before a greater number of scientists will appreciate and agree on the significance of a new idea.) Following closely on Oersted’s work, André-Marie Ampère, a French physicist, developed a mathematical relationship which described the magnetic forces between pairs of parallel, current-carrying conductors. The game was on!

Michael Faraday was the greatest of all the 18th and 19th century experimental scientists. (In those days, he would have been referred to as a “natural philosopher”.) His contribution to physics and chemistry (especially in the physics of electricity and in electrochemistry) was enormous. Once the relationship between electricity and magnetism had been discovered, Faraday demonstrated that the two phenomena could give rise to each other, that is, electricity could cause magnetic effects and magnetism could cause electrical effects. The most lasting of Faraday’s many inventions were his devices that were forerunners of modern electric motors.

There was very little in the physical sciences that did not interest him and attract his experimental skills. Faraday discovered the chemical substance called benzene (a ring-shaped molecule with the formula C_6H_6), invented an early form of the Bunsen burner, developed the system of oxidation numbers and first used electrical terms such as “cathode”, “anode” and “ion” in public writing.

During his lifetime, he received many honours and awards but his memory is best served by the naming of the SI unit of capacitance (the **farad**), the “**Faraday constant**” (the charge on one mole of electrons or 96 485 coulombs) and **Faraday’s Law of Electromagnetic Induction**, which is the subject of this lesson.

He was elected a member of the Royal Society in 1824, appointed director of the Royal Institution’s laboratory in 1825; and in 1833 he was appointed Fullerian professor of chemistry in the Institution for life, without the obligation to deliver lectures. Nevertheless, he became a famous public figure through the Royal Institution’s Christmas lectures, which he made famous. His lectures did much to popularise science in England at the time. But it is his work on the development of the young science of electricity for which he is best remembered. The other thing that provides access to his work and thoughts was his habit of letter-writing. He was passionate about scientific discovery and, being a humble and generous person, whenever he found something new and interesting he would immediately share this with others in the field.

In 1821, when Oersted discovered the phenomenon of electromagnetism, Faraday immediately began developing its practical applications. He built two devices that produced what he called “electromagnetic rotation”. The devices are the foundation of modern electromagnetic technology. Still, his greatest discovery was that of electromagnetic induction, the basis of the transformer and other electromagnetic devices. He showed that a changing magnetic field produces an electric field, a fact that is used in dynamos and electrical generators.

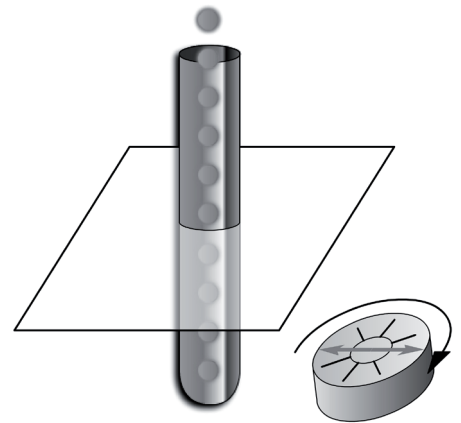
Faraday’s concept of flow or “flux” lines emanating from charged bodies and magnets provided a way to visualise electric and magnetic fields. (See the previous lesson.) His ability to convey his ideas in clear, simple language also contributed to the development of his ideas by other scientists of the time.



LESSON: Electromagnetism – an unfolding story

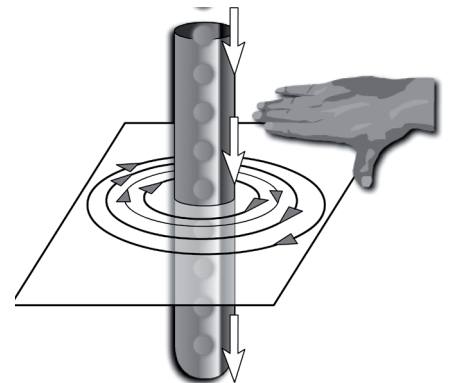
THE MAGNETIC FIELD NEAR A CURRENT-CARRYING CONDUCTOR

- Moving charge is an electrical current.
- Charge flowing in a conductor results in a magnetic field. (This was the effect discovered by Oersted in 1820. See the introduction.)
- By using a compass needle, the magnetic field can be shown to be circular.
- The field is stronger near the conductor and it weakens as one gets further away.



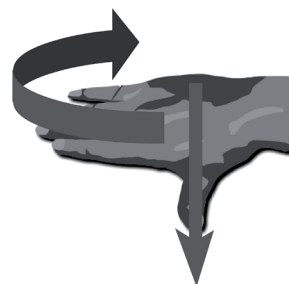
THE DIRECTION OF THE FIELD AROUND A CURRENT-CARRYING CONDUCTOR

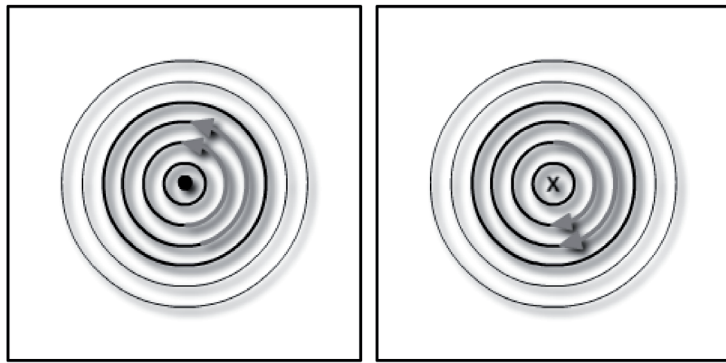
- We can use Faraday’s method of showing a magnetic field.
- Faraday spoke of “lines of magnetic flux” or “flux lines”.
- The word “flux” refers to “flow” – so Faraday was thinking of a magnetic field as flowing and of exerting some kind of moving influence on whatever could be affected by the magnetic field.
- The other important feature of Faraday’s method was that, the stronger the field, the closer the flux lines.
- As one can see from the effect of a magnet on a compass needle, the closer the compass to the source of magnetism, the stronger the effect on (i.e. the movement of) the compass needle.



THE RIGHT-HAND RULE AND THE DIRECTION OF AN ELECTRIC CURRENT

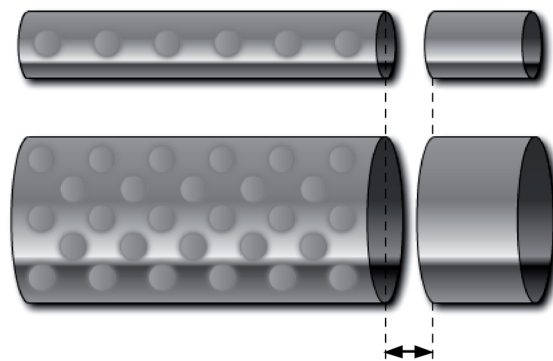
- The usefulness of the right-hand rule depends on knowing the direction of the electric current.
- Our convention for the direction of electric current is the direction of the flow of the POSITIVE electric charge.
- Point the thumb of the right hand in the direction of the flow of positive charge.
- The direction in which the fingers curl shows the direction of magnetic field.
- Another convention which is used is to show electric current as if it is coming towards the viewer and if it is going away from the viewer. (These symbols come from what you would see if you were looking at an arrow either coming towards or travelling away from you.)
- So the magnetic fields around current-carrying conductors coming out of or going into the page would look like this:





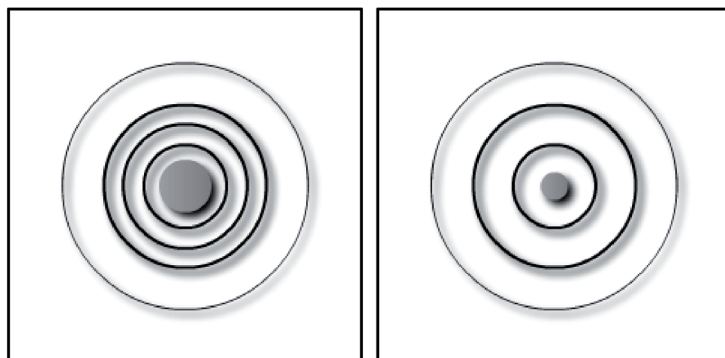
THE MAGNETIC FIELD STRENGTH AROUND AN ELECTRICAL CONDUCTOR

- As one might imagine, the strength of a magnetic field which is caused by a flow of charge depends on the strength of that flow – or current, as it is termed.
- Electric current (I) is defined as the rate of movement of charge (Q/t).
- Because charge will move in a specific kind of conductor (say copper wire) at a speed that is related to the way copper atoms are arranged, we can hypothesise that t (or the rate of flow) will remain approximately the same and that the size of the current will depend on the amount of charge (Q) that flows past a point in a fixed amount of time.
- The amount of charge flowing therefore depends on the electrical “force” (we call it “potential difference” – see Lesson 13) that causes the charge to flow and the cross-sectional area of the conductor.



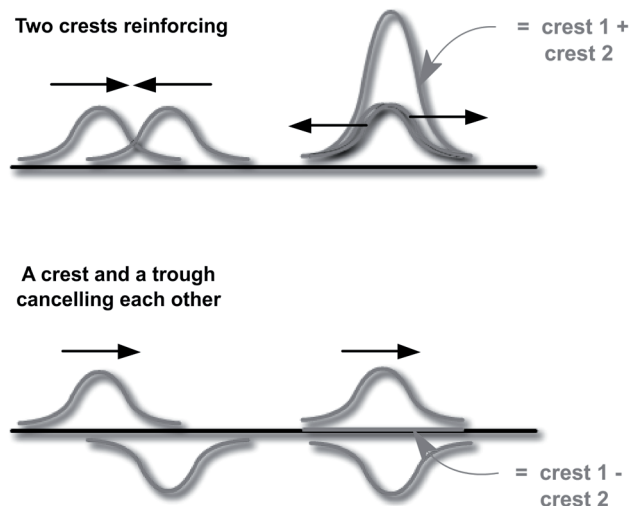
How many charged particles will spill out of the gaps in the two conductors in one second? *Obviously, more will spill from the thicker conductor!*

- So the more charge that flows past a point in one second the stronger the current.
- And the stronger the current the stronger the magnetic field that arises from the greater flow of charge.



THE PRINCIPLE OF SUPERPOSITION

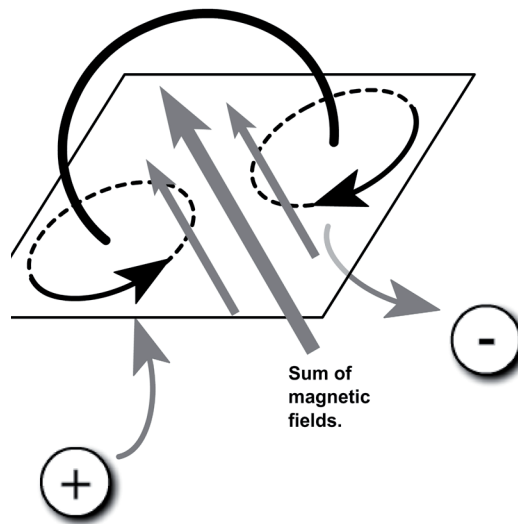
- The principle of superposition applies in many areas of physics where two influences either reinforce or reduce one another.
- When there are two light bulbs in a room, one light bulb on its own gives a certain amount of illumination (light). When both light bulbs are switched on, the room is brighter. That is because the illuminations from the two sources are superimposed and reinforce each other.
- When two water waves travel towards each other, they can either reinforce each other when two crests coincide or they can cancel each other out when a crest coincides with a trough. This is another example of superposition.



THE MAGNETIC FIELD AROUND A SINGLE COIL OF CONDUCTING WIRE

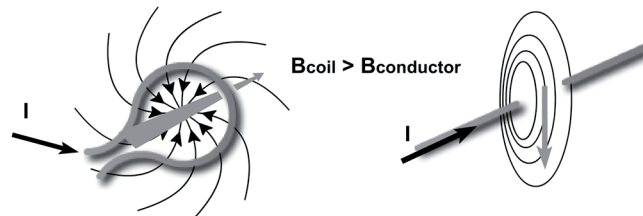
- The principle of superposition also applies to magnetic fields.
- The magnetic effect from two sources of magnetism can either cancel or reinforce, depending on the directions of the magnetic fields.
- Take a single coil of conducting wire. When charge flows through it, a magnetic field is established around every small piece on the circumference of that coil of wire.
- We can use the right-hand rule to determine the direction of the magnetic field resulting from every small piece around the circumference of the coil.
- Then we can see whether these "bits" of magnetic field cancel or reinforce each other around the coil. In the following diagram, we use the right-hand rule to show that the two elements from the two magnetic fields in the centre of the single coil are superimposed and therefore magnetic field strength there is increased.



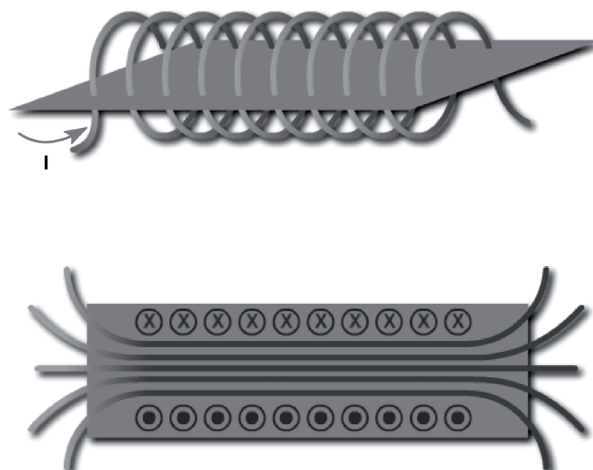


THE MAGNETIC FIELD IN A SOLENOID

- Now we have the following interesting possibility: when we take a single coil of a conductor, the magnetic field strength (this is a vector quantity – because it has a direction – and is given the symbol B) at the centre of the coil will be greater than the magnetic field strength at the same distance from the conductor when it is stretched out straight – PROVIDED that the current in both conductors is the same.
- Here again we see the principle of superposition in action because each small length of the coil has a magnetic field associated with it and all of those small contributions add up inside the coil to give a stronger field than we get at the same distance from the straight conductor.



- What will happen if we make many coils using a single piece of conducting wire?
- This arrangement is called a solenoid and, as one might expect, the magnetic field associated with it is many times greater than the field from a single turn. (How much greater? What will determine the strength of the magnetic field inside a solenoid?)



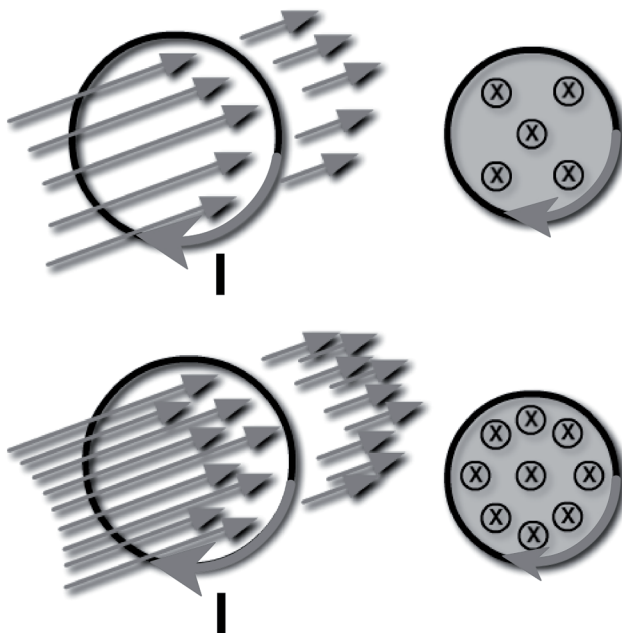
- The strength of the magnetic field inside the solenoid depends on the number of turns (or “loops” or “coils”) in the solenoid.
- The other important observation about the magnetic field caused by a current-carrying solenoid is that it looks very much like the field from a simple bar magnet!



- Using the right-hand rule, satisfy yourself that the magnetic field caused by the solenoid would be in the same direction as the bar magnet’s.

MAGNETIC FIELD STRENGTH AND MAGNETIC FLUX

- We can combine the idea of magnetic field strength (B) and Faraday’s method of illustrating magnetic fields using “magnetic flux lines”.
- First, imagine that a single line shows the presence of a magnetic field at a point. The line’s direction shows the direction of the field.
- The actual strength of the field can be shown by the number and distribution (or “density”) of the lines of magnetic force in a space or an area:



- We now define a new quantity called magnetic flux. It can be visualised as the number of lines of magnetic field in an enclosed area. If we take the strength of one line of magnetic force as B and the area enclosed by a loop of conductor (as in the above picture) as A, then the actual strength of the magnetic field inside the enclosed area is:

$$\text{Magnetic flux} \equiv \Phi = B \times A$$

- When we draw a picture of a magnetic field using Faraday’s method of “lines of flux”, how close together or how spread out the lines are tells us what the strength of the whole magnetic field in a space will be.



CHANGING MAGNETIC FIELDS AND INDUCED EMF

- Faraday's greatest contribution was in fact discovered almost simultaneously by Joseph Henry in the USA. The important physical law these two great scientist-inventors gave us is now known as ...

... Faraday's Law of Electromagnetic Induction ...

'the average emf induced in a closed loop is equal to the negative of the rate of change of magnetic flux inside the loop'

$\mathcal{E} = ???$ where $F = BA$ is the magnetic flux

$$\mathcal{E} = -N \frac{\Delta\Phi}{\Delta t} \text{ where } \Phi = BA \text{ is the}$$

[The unit B of is the tesla (T) and therefore the unit of magnetic flux (Φ) is Tm^2 .]

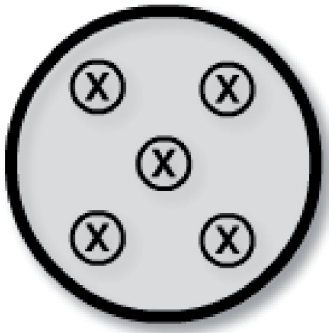
What is an "induced emf"?

- The term simply means that when the conditions are right, an emf can be caused or produced – or "induced", to use Faraday's word.
- An emf (\mathcal{E}) – or "electromotive force", which is its full name – is what causes a charged particle to experience an electrical force. An electrical force causes a charged particle to move.
- A device (such as a battery) causes an electric field within a conductor when its terminals are connected to the ends of that conductor. The maximum amount of energy a battery can deliver to a unit of charge is a measure of its \mathcal{E} .
- NOTE 1: A changing magnetic flux causes or "induces" an \mathcal{E} whether or not there are charged particles present.
- NOTE 2: If a charged particle is present in the electric field that results from the induced \mathcal{E} , then the \mathcal{E} causes it to move in a certain direction.
- NOTE 3: Induced \mathcal{E} can be regarded as a "voltage" or potential difference. If the potential difference is applied between two points and there is charge between those two points, an electrical current results.
- NOTE 4: A conductor is a material that contains charged particles which are free to move when an electrical force is applied to them.

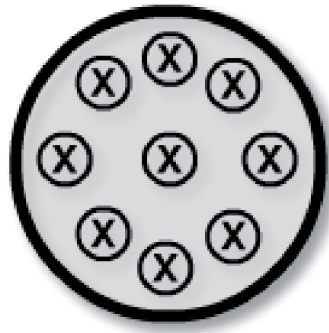
What is meant by "rate of change of magnetic flux"?

- In these two diagrams, we see that the magnetic flux (Φ) through the first loop is less than the magnetic flux in the second loop.
- NOTE 1: In this case, the magnetic field is not caused by a current in the loop as was the case above. Here the magnetic flux is caused by some other magnetic source such as a bar magnet.



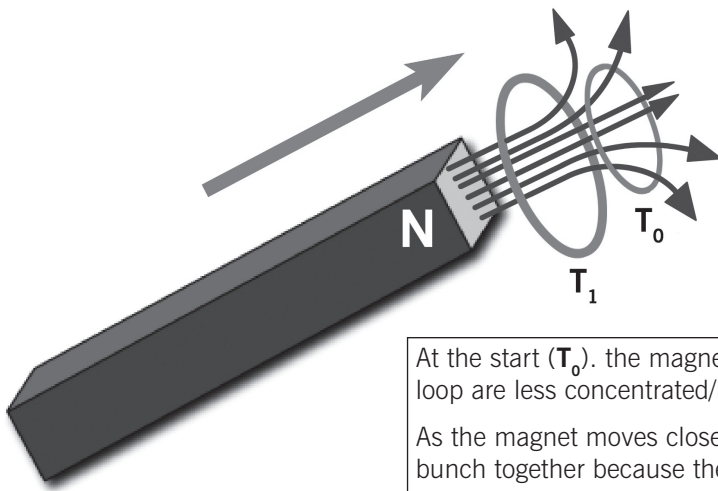


Initial time ($T_0 = 0$)



A later time ($T_1 = t$)

- NOTE 2: Here we see a loop with a certain magnetic flux through it at time T_0 and t seconds later ($T_1 - T_0 = t - 0 = \Delta t$) the magnetic field has increased. Here is how the magnetic flux might have changed:



At the start (T_0), the magnetic flux lines through the loop are less concentrated/bunched together.

As the magnet moves closer to the loop, the lines bunch together because the magnetic field is strongest nearer the magnet.

So by T_1 the magnetic flux has increased – in other words, there has been a change in magnetic flux ($\Delta\Phi$) in the time interval Δt .

- NOTE 3: The magnetic flux could be changed either by moving the magnet towards or away from the loop or by moving the loop towards or away from the magnet.
- NOTE 4: It is necessary to speak of the rate of change because the speed with which the magnetic field and loop move relative to one another affects the size of the \mathcal{E} . If they move fast, \mathcal{E} is greater. If they move slowly, \mathcal{E} is smaller.

What is the meaning of “N” in the formula for induced emf?

- N refers to the number of loops. For a single loop, $N = 1$. But for every loop that is added, \mathcal{E} increases by that multiple. So if $N = 10$, \mathcal{E} will be 10 times greater.

Why do we speak of the “negative” of the rate of change?

- Remember that earlier in this lesson we saw that when charge flows in a loop it induces (causes) a magnetic field.
- An induced \mathcal{E} in a loop will cause charge to flow in that loop.
- This current in the loop will therefore cause an induced magnetic field.



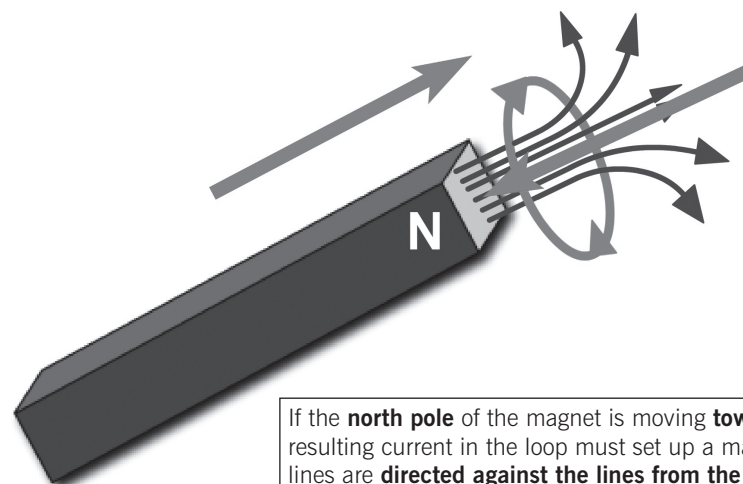
- If the current in the loop causes a magnetic field that further attracts the magnet that is causing the induced \mathcal{E} , we would be creating energy, i.e.
 - ... moving magnet induces \mathcal{E} , which causes current in loop, which induces a magnetic field (B), which attracts magnet, which moves faster, which induces larger \mathcal{E} , which causes bigger current, which induces bigger **B**, which ... **and so on ... AND SO ON.**
- And this is a BIG NONSENSE because energy cannot be created!!
- But how do we resolve this puzzle, this conundrum?

LENZ'S LAW AND THE CONSERVATION OF ENERGY

- The puzzle was solved by a law that was formulated by a German physicist, Heinrich Lenz, in 1834. He realised that:
 - the direction of the induced emf (\mathcal{E}) in a conducting loop
 - and the electric current that resulted from it
 - had to be in such a direction
 - that the (secondary) magnetic field resulting from the induced current
 - would oppose whatever influence had caused it.
- An induced \mathcal{E} always gives rise to a current whose magnetic field opposes the original change in flux.
- From this, he formulated his very simply stated law, Lenz's Law.

An induced \mathcal{E} always gives rise to a current whose magnetic field opposes the original change in flux.

- The part that says: "... gives rise to a current whose magnetic field opposes ..." tells us why Faraday's Law talks of the negative of the rate of change of magnetic flux.



If the **north pole** of the magnet is moving **towards** the loop, the resulting current in the loop must set up a magnetic field whose flux lines are **directed against the lines from the magnet**.

Using the **right-hand rule** (thumb in the direction of the current), we see that a current as shown will give a magnetic field inside the loop that is **directed towards the north pole of the bar magnet** (the direction of the curled fingers).

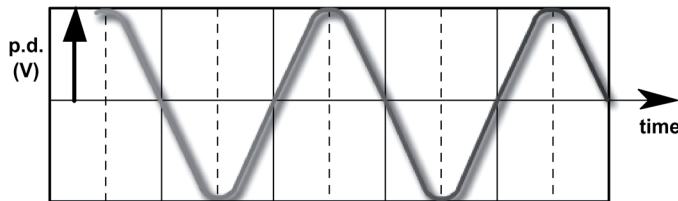
In other words, **the resulting current sets up a magnetic field that opposes the cause of the induced emf!**



TRANSFORMERS

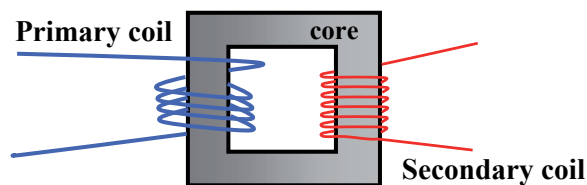
Alternating current

Transformers can only be used with alternating current (AC) electricity because in AC we have a potential difference that builds up and then falls off in one direction and builds up and falls off in the other direction. This is why the term “alternating” is used – because the current changes direction. Our household AC supply alternates at 50-60 Hz, i.e. the current changes direction between 50 and 60 cycles per second. It is the characteristic of building up and falling off that enables us to transform potential difference.



The construction of a transformer

First there is a soft iron (*iron is a magnetic material*) core that links the primary and the secondary coils.



Next there are the primary and secondary coils around the core.

The primary and secondary coils have a different number of turns (the ratio of the number of primary: secondary turns determine whether this is a “step-up” or a “step-down” transformer).

How a transformer functions

- An alternating potential is applied across the primary coil.
- As the pd builds up in the primary coil from 0 V to a higher potential difference (say 220 V, as in our household supply), a magnetic field builds up inside the soft iron core.
- The induced magnetic field builds up throughout the whole soft iron core. This means that the secondary coil has a magnetic field building up inside it.
- This means that the magnetic flux inside the secondary coil is changing.
- The rate of change of magnetic flux felt by the secondary coil, because it is confined to the same iron core, is the same as for the primary coil.
- The situation can be shown using the equation from Faraday’s Law of Electromagnetic Induction:

$$\mathcal{E}_{\text{PRIMARY}} = -N_{\text{PRIMARY}} \times \frac{\Delta\Phi}{\Delta t}$$

- A changing emf in the primary coil causes a changing magnetic flux ($\frac{\Delta\Phi}{\Delta t}$), which can be written as:

$$\frac{\Delta\Phi}{\Delta t} = \frac{\text{emf in the primary (V}_p\text{)}}{\text{number of turns in the primary (N}_p\text{)}}$$

- In the secondary coil, the situation is similar:

$$\frac{\Delta\Phi}{\Delta t} = \frac{\text{emf in the secondary (V}_s\text{)}}{\text{number of turns in the secondary (N}_s\text{)}}$$



- By equating the right-hand sides of these two equations, we get a third equation:

$$\frac{V_p}{N_p} = \frac{V_s}{N_s} \text{ or}$$
- What the second equation tells us is that the potential difference across the ends of the secondary coil (V_s) is the pd across the primary coil (V_p) multiplied by the turns ratio. If $N_s > N_p$ then we have a **step-up transformer**. This means that the input potential at the primary coil is increased in the secondary coil (by the ratio $\frac{N_s}{N_p}$). On the other hand, if $N_p > N_s$ then it is a **step-down transformer**.

Another look at the energy involved in transformers

The Law of Conservation of Energy provided the clue for solving the puzzle about the direction of the induced emf when the magnetic flux in a conducting coil changes. This is not entirely surprising because the conservation of energy is a fundamental principle of the universe!

The question might have occurred to you regarding step-up and step-down transformers: Is energy being created or destroyed here when the potential difference is stepped up or stepped down?

- To answer the question, we need to introduce the concept of electrical power.
- Power can be defined as the rate at which energy is converted from one form to another OR the rate at which energy is transferred.
- Power is therefore the amount of energy converted/transferred per second:

$$\text{Power} = \frac{\text{Energy transferred}}{\text{time taken}}$$

- From this we see that:

$$\text{Energy} = [\text{Power}] \times \text{time}$$

- In the case of electrical energy, $\text{Energy} = [V \times I] \times t$
- Now, starting from the Law of Conservation of Energy, we can say with confidence that the energy output at the secondary coil is equal to the energy input at the primary coil:

$$V_p I_p = V_s I_s$$

- If one studies this equation, we see that, as the potential difference in the secondary coil (V_s) increases, so the current (I_s) will decrease.
- $V_s \times I_s = [220 \text{ V} \times N_s / N_p] \times I_s$

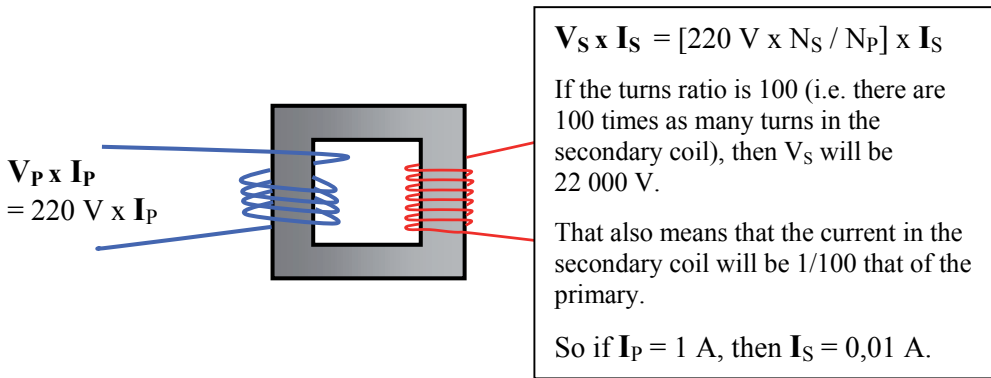
If the turns ratio is 100 (i.e. there are 100 times as many turns in the secondary coil), then V_s will be 22 000 V.

That also means that the current in the secondary coil will be 1/100 that of the primary.

So if $I_p = 1 \text{ A}$, then $I_s = 0,01 \text{ A}$.

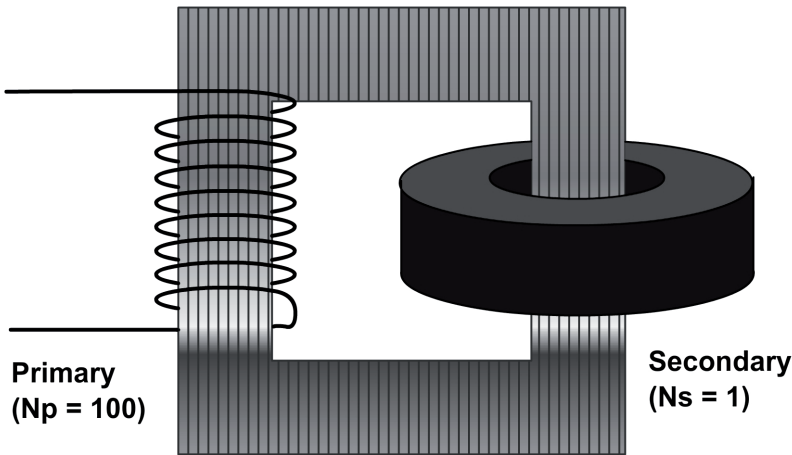
- The potential difference in high-voltage transmission lines that carry electrical energy around the country in the national grid can be very high. Because it is AC, meaning that the current changes direction at least 50 times per second, if the current was also high the conductors would heat up quickly and a great deal of precious energy would be lost as heat. But when voltage is increased in step-up transformers, current is decreased by the inverse of the turn ratio.





INDUCTION FURNACES

Imagine we have a transformer with 100 turns in the primary coil which is connected to a normal 220 V household supply. If the secondary circuit has only one coil then we can expect the current in the secondary coil to be $100 \times I_P$. This is the principle of the induction furnace.

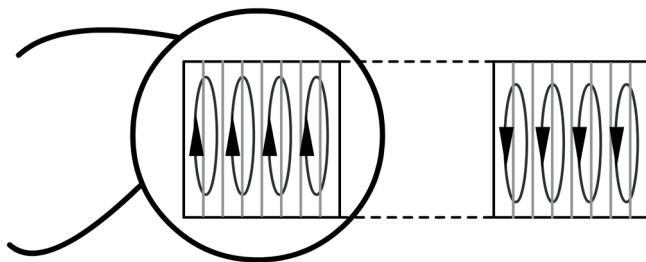


The ring can be filled with water or a solid. The single ring in the secondary coil makes this behave like a step-down transformer. If the primary coil is connected to a 220 V supply, the emf in the secondary coil will be 2,2 V but the current will be 100 times greater than the current in the primary coil.

Large currents tend to produce large amounts of heat in conductors. Induction furnaces can even be used to melt metals.

WHY IS THE IRON CORE IN A TRANSFORMER LAMINATED?

Look at a transformer core from the top. We know that the magnetic flux in the core changes, getting larger and smaller, larger and smaller as the pd in the primary varies.



Iron is a conductor of electrical current. So, as the magnetic flux varies within the soft iron core of the transformer, small “eddy currents” are set up in the iron core



at right angles to the direction of the changing magnetic flux. The energy used by the eddy currents makes the transformer less efficient, so some way must be found of reducing them. This is done by laminating the core with many platelets of iron arranged at right angles to the eddy currents so that they are interrupted.

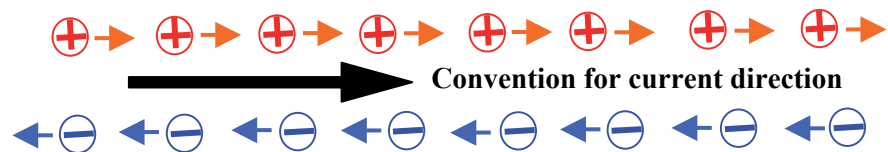
MOTORS AND TELEVISION SCREENS

Read this set of logically connected electrical and magnetic causes and effects.

- An electric current (I) in a circular conductor (a coil) will cause a magnetic field at right angles to the plane of the coil. (Oersted)
- When the magnetic flux (Φ) through a coil changes, charged particles in the coil will move, i.e. they experience a force from the induced emf (\mathcal{E}). (Faraday)
- The direction of the current caused by an induced emf will itself cause a magnetic field (B) that opposes the changing magnetic flux that induced the emf. (Lenz)

Another electromagnetic effect

- When a current of charged particles moves at right angles to a magnetic field, they experience a force which is at right angles to both the current and the magnetic field.
- NOTE 1: The convention for current direction is the direction that positively charged particles are moving or would move.
- NOTE 2: If negative particles move from right to left, this is equivalent to positive particles moving from left to right. Hence, according to the convention, current direction is still taken as moving from left to right.



The motor effect

In their investigations, both Michael Faraday and Joseph Henry discovered an amazing effect that has come to be known as “the motor effect”. This is the phenomenon in which either a current of moving charged particles in a magnetic field experience a force or a whole current-carrying conductor (e.g. a wire) in a magnetic field can be moved. Both men harnessed the effect to produce what were the forerunners of the electric motor. There is probably no single invention that has had as big an impact on the growth of the modern world and its industrial capacity.

The left-hand rule motor

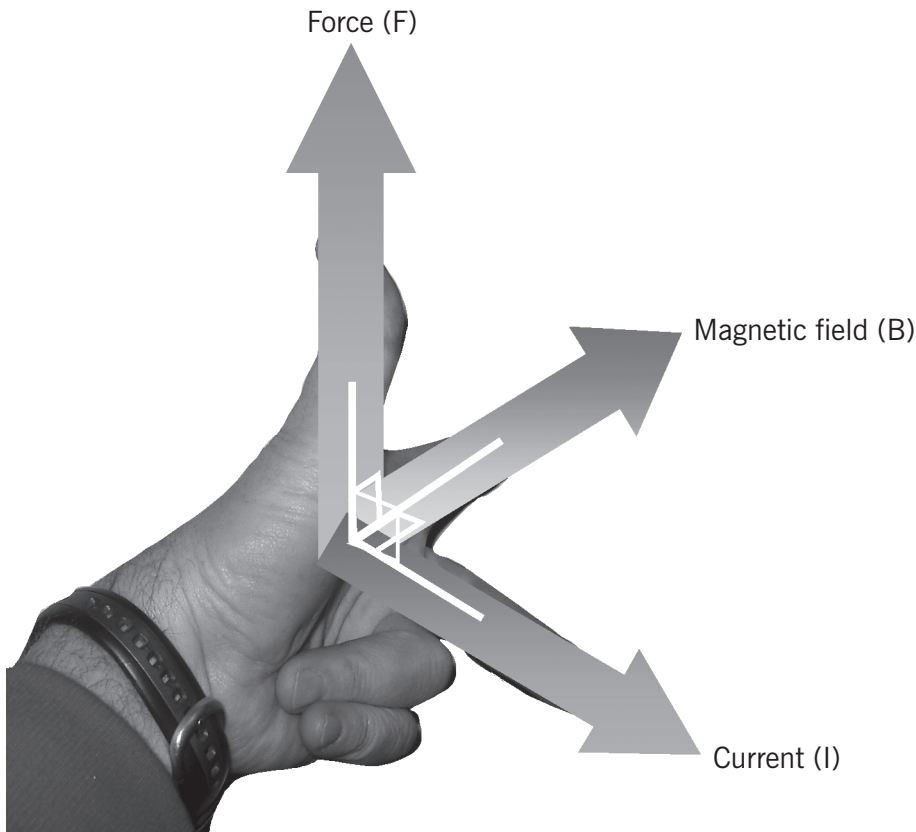
The force that is exerted on a moving charge in a magnetic field is given by the equation:

$$\mathbf{F} = q\mathbf{v}\mathbf{B}$$

- The three terms \mathbf{F} , \mathbf{v} and \mathbf{B} are written in bold to denote that they are all vector quantities.
- q is the size of the charge in coulombs (C).
- The three vectors (\mathbf{F} , \mathbf{v} and \mathbf{B}) are at all right angles to one another.
- Their directions can be shown using the left-hand rule where:
 - \mathbf{F} (force) is given by the **T**humb (**T**hrust);
 - \mathbf{B} (magnetic field) is given by the **F**orefinger (**F**ield); and



- \mathbf{v} (velocity of positive charge) is the direction of the charge and is shown by the middle (\mathbf{I} = current).



- Can you see why this is sometimes called the “FBI gun rule”?
- In the electric motor, the windings in the armature carry current. Whenever a part of the winding is at 90° to the permanent magnetic field of the motor’s magnet, the winding experiences a force. This force causes the motor to turn.
- In a television, an “electron gun” fires a beam of electrons between the poles of a magnet. Either by varying the velocity (v) of the electron beam or by varying the strength of the magnetic field (B), or both, the force on the electron beam can be varied so that its position moves to precise points on a fluorescent screen. In this way, the beam can be made to trace out pictures on the screen. By controlling the variations in electron velocity and magnetic field with tiny variations in voltage (called the TV “signal”), we are able to trace out patterns on the TV screen that will carry all the colour and shading information that translate into a clear picture. The variations are so fast that the eye is unable to detect any gaps in these signals.

Activity



TASK 1

In the National Senior Certificate Exemplar examination paper (2007) for Physics (Paper 1), there was a question about induced emf.

- The first part of the question asked for Faraday’s Law to be stated.
- The second part of the question was as follows:
One complete loop of wire has an area of $0,1 \text{ m}^2$ and a resistance of 10Ω . The magnetic field perpendicular to the plane of the loop initially has a magnitude of $0,2 \text{ T}$. The magnetic field strength is reduced to zero uniformly (see Teacher Tips) in a time of 10^{-4} s .
Calculate the induced emf and the resulting current.



TASK 2

Investigate the uniformity or constancy of the Earth's magnetic field. Consider the constancy in the present time compared with its constancy over geological time (aeons!). Learners should also research the evidence (e.g. geological) for their answers and the methods and instruments used for gathering the data. (See **Teacher Tips**)

TASK 3

In all the stories about the development of electrical supply during the 19th and 20th century, the name of Nikola Tesla crops up over and over again. Born in present-day Croatia, Tesla lived and worked for the majority of his adult years in the USA. Today he is recognised as a great scientist but a rather poor business man. His biggest business adversary of the time was Thomas Edison, one of the inventors of the electric light bulb. (Edison was good at self-promotion, so today we hardly know of the Englishman who invented the light bulb at the same time as Edison [who was he?] or of his competitor, Nikola Tesla.) Tesla was one of those geniuses whose true worth was only recognised after his death. The unit of magnetic induction, the tesla (T), was only named in his honour in 1960. And even though Marconi is still thought of as the inventor of the radio telegraph (he was awarded a share of the Nobel Prize in 1909 for his work), it is significant that in 1943 the Supreme Court of the USA credited Tesla with being the inventor of the radio. Today it is accepted that Tesla's patents and inventions are largely responsible for AC power systems.

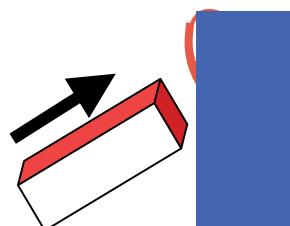
Find out as much as you can about Nikola Tesla and try to appreciate, through the story of his life, how much we benefit from the determination and perseverance of scientific pioneers like him.

TASK 4

Find out more about the operation of motors and television screens and relate their operation to the physics of moving charge and the interaction of electricity and magnetism (electromagnetic interactions) in this section.

TASK 5

- Look again at the section on Electromagnetic Induction.
- In the diagram, we see the north pole of a bar magnet being pushed into a single loop/coil of conducting wire.
- According to Faraday's Law, the current that arises in the ring (because of the emf induced by the changing magnetic flux through the ring) will itself set up a magnetic field that opposes the north pole moving into the ring.
- In other words, the current in the ring will set up a field that points down towards the approaching north pole. (The direction of a magnetic field is taken as being away from the north pole.)
- Satisfy yourself, by using the right-hand rule, that the current arising in the loop of wire will circulate like this:



Draw similar diagrams to show the circulation of the current in the loop under the following circumstances:

- 5.1** The south pole is moved away from the loop.
- 5.2** The north pole is moved away from the loop.
- 5.3** The south pole is moved towards the loop.
- 5.4** Is there any pattern or symmetry to these interactions?



TRANSFORMERS

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 1:

Conducting an investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

INTRODUCTION

What you must know in this section of the curriculum is:

- Electromagnetism and induced current
- Transformers
 - Magnetic field associated with a current induced by changing magnetic field
 - Transformers
 - Motion of a charged particle in a magnetic field

This lesson will focus on calculations using the basic knowledge in this section:

- Solving problems involving induced currents
- Solving problems involving transformers

Before tackling these problems be sure to have studied Lessons 11 & 12 carefully.

Activity 1

- Understand why and how the changing magnetic flux in the primary coil of a transformer affects the secondary coil.
- Understand why and how the changing magnetic flux in the secondary coil causes a potential difference in the secondary circuit.

Understanding the problem

Once you have understood these two points the operation of the transformer becomes quite clear. The two points are related through the equation:

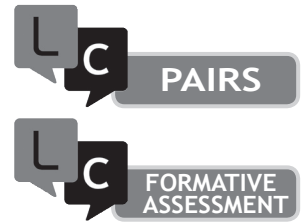
$\mathcal{E} =$ where $\Phi = \mathbf{BA}$ is the **magnetic flux**

Study the notes in Lessons 11 and 12 for a detailed explanation of what this equation means and the relationship between a loop or coil (i.e. many loops) of wire, a changing magnetic flux through the coil and a changing electrical potential (“voltage”).



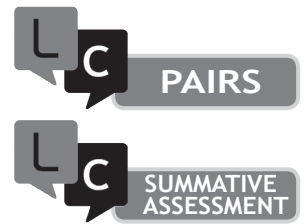
Activity 2

- Draw a diagram to illustrate how electricity is taken from the national grid and made available as the domestic electrical supply – the electricity we use in our homes.
- The power supply from Eskom comes into our towns and suburbs on 11 000 V power lines. This is then stepped down in transformers (sometimes called substations) before it is supplied to individual houses in a street. What is the turns ratio of the transformer used to provide homes with their domestic supply?
- If the primary coil of the transformer described here has 2 000 turns, how many turns will there be in the secondary coil?



Activity 3

If the current drawn by all the homes in an area served by the transmission lines and transformer described in the previous activity is limited to 50 A, what will be the maximum current in the primary circuit?



Activity 4

In the USA the domestic supply is 120 V. A small transformer can be used there to transform the 120 V domestic AC supply to 9 V AC for a portable radio. If the secondary coil contains 30 turns and the radio draws a 400 mA current, calculate:

- the number of turns in the primary coil;
- the current in the primary; and
- the power transformed.



Lessons

13–
14

ELECTRIC CIRCUITS: POTENTIAL DIFFERENCE, ELECTRIC CURRENT AND RESISTANCE TO THE FLOW OF CHARGE

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

An understanding of the principles and concepts of electricity dealt with in Lessons 9 to 12 can be applied in many ways to the analysis of electrical circuits. The notion of a circuit is simply that of a closed pathway in which charge can flow. Once the flow of charge (which is referred to as electrical current) has been started by some appropriate source of energy, it can be impeded (by resistors). To make charge move, it must be given energy. When the pathway that charge moves through also impedes its progress, the charge must do work and hence it loses energy. In other words, the analysis of what happens when charge passes through the parts of a circuit is all about a logical application of the basic principles of physics.

LESSON: PART 1

OHM'S LAW

The most important relationship in the analysis of circuits is that between current and the work done in moving charges in a conductor. It is stated in **Ohm's Law**.

The current (**I**) between any two points in a conductor is proportional to the potential difference between the two points (**$I \propto V$**) provided the temperature of the conductor remains constant (**$\Delta T = 0$**).

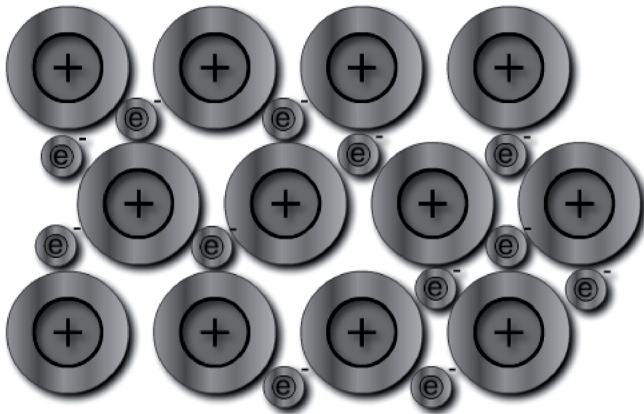
The Law can be stated mathematically as follows: $I = \frac{V}{R}$

although the more familiar way of writing the Law is: $V = I R$

Resistance is interesting. It refers to how much the conductor impedes the flow of charge. Perfect conductors don't impede the flow of charge at all. But it is physically very difficult to make a perfect conductor, which is why all conductors will become warm when there is a current in them. It means that there is actually some work being done in making the charge move through the conductor.

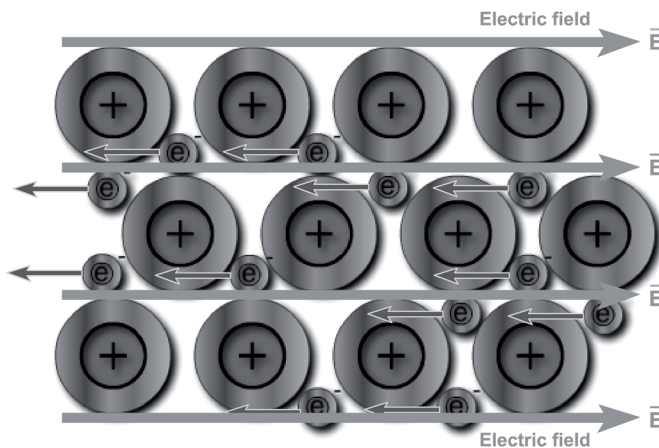


A MODEL OF METALS (WHICH ARE GOOD CONDUCTORS)



Metals are excellent conductors because of two important factors. Firstly, their atoms are arranged in neat patterns called “crystal lattices” which results in the existence of fairly clear pathways for electrons to move among them. So atoms in pure metals are in regular, ordered arrays. The second factor is that the outer electrons in metals (also known as the *valence electrons*) are rather weakly held by the positive nuclei. The valence electrons are relatively far from the nucleus and they are somewhat shielded from the attractive force of the nuclei by the electrons in the atom that lie between them and the nuclei. So the valence electrons move in the metal conductor if there is an electric field in the metal.

- When an electric field is set up inside a conductor, any free charges will move as a result of the field because they will experience a force. (Lessons 11 & 12)



- The direction of an electric field is defined as the direction in which a positive test charge would move. (Lesson 9)
- The convention for the direction of an electric current is the direction that positive charge will flow in the conductor, i.e. the electric field direction. (NOTE: Negative charge flowing in one direction is, in an electrical sense, the equivalent of positive charge flowing in the opposite direction. Therefore it is acceptable to adhere to a convention even though we know that the story it tells is not quite the correct one.)
- Impurities in the conductor, among other things, can impede the flow of charge. When this happens, we have a less-than-perfect conductor and we call any disruption of the smooth flow of charge, resistance.



RESISTANCE

- Any device that impedes the flow of charge in a circuit is called a resistor.
- Certain substances such as ceramics and carbon might conduct electricity without being very good conductors.
- Note that a resistor is still a conductor, i.e. it allows the flow of charge even though it is causing some resistance to the current.
- When the current in a resistor obeys Ohm's Law, we say that the resistor is ohmic. This means that if we measure the potential difference across the ends of the resistor (V) and the current in it (I) we will find that $I \propto V$.
- The reason Ohm's Law specifies that temperature must remain constant (i.e. $\Delta T = 0$ or zero change in temperature) is that as temperature rises the atoms in the conductor begin to vibrate more vigorously and this further impedes the flow of charge so that current is no longer proportional to the potential difference across the conductor.

Lesson: Part 2

RULES FOR ANALYSING ELECTRICAL CIRCUITS

The rules for analysing circuits and calculating resistance, current and potential difference follow directly from Ohm's Law and our understanding of the processes inside a conductor when charge flows in it.

Rule 1

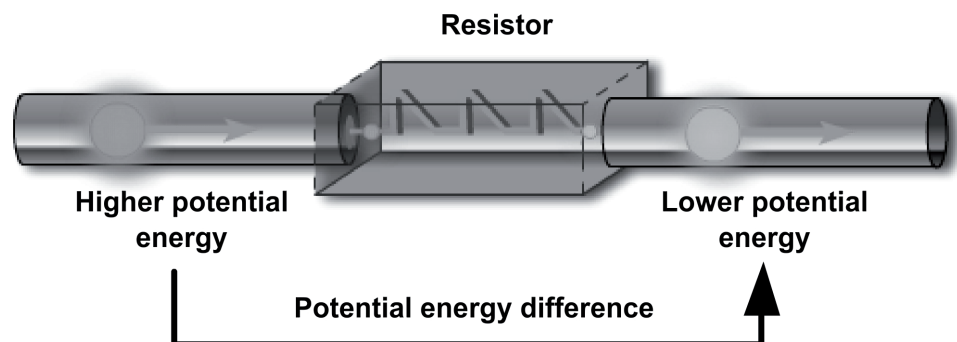
Current in the external circuit is from the positive to the negative terminal of the battery.

*The **convention** is that current is the flow of positive charge. Therefore, in the external circuit, current direction is from the positive terminal of the battery to the negative terminal.*

Rule 2

Resistors impede the flow of charge (i.e. current). This means that charge loses energy when moving through a resistor. And this means that there is a drop in potential difference (pd) across a resistor when there is a current in it.

If charge has to do work in moving from one point to another, then it loses electrical potential energy as it does the work. The loss of energy by the moving charge can be detected as an increase in the temperature of the resistor.



Rule 3

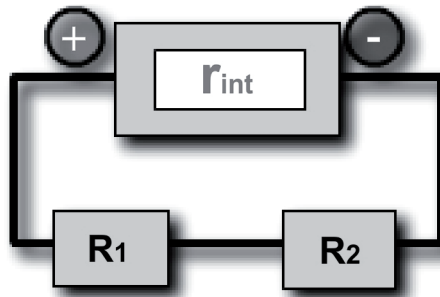
Assume that conductors offer no resistance to electrical current. This means that no energy is lost by charge flowing in that conductor. And this means that there is no pd across a connecting conductor in a circuit.

Although this may not be exactly the case in real circuits, it is a very good approximation.

Rule 4

Although we may sometimes ignore internal resistance in a cell/battery, when r_{int} is present we treat it as a single resistor in series with the battery.

The internal resistance in a cell/battery arises because, when charge is given electrical potential energy inside the cell/battery, the process is not as efficient as it should be. Some energy is lost by the charge as it is moved from the negative to the positive terminal inside the cell/battery. So it seems as though there is a resistance inside the battery impeding the flow of charge. When we analyse the circuit, we regard this as just another resistance in the circuit.



Rule 5

Resistors in series have a total resistance that is the sum of all the resistors.

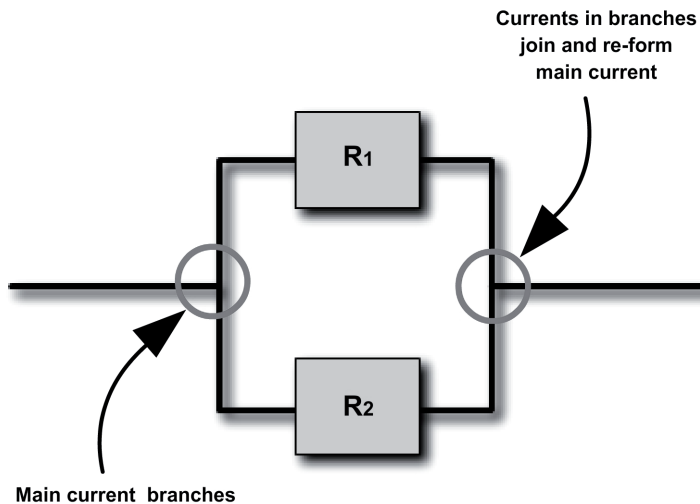
In the example shown in Rule 4, the total resistance for that circuit would be:

$$R_{total} = r_{int} + R_1 + R_2$$

For calculation purposes, the internal resistance in a cell/battery is regarded as an ordinary resistance in series.

Rule 6

When there is a branching point in a conductor, i.e. where the current splits, we have resistors in parallel. Whenever there is a branching point, we will find another point further along the conductor where the currents join again.



Rule 7

- a) The “effective” resistance for a set of resistors in parallel is calculated using the familiar “1 over R” formula.

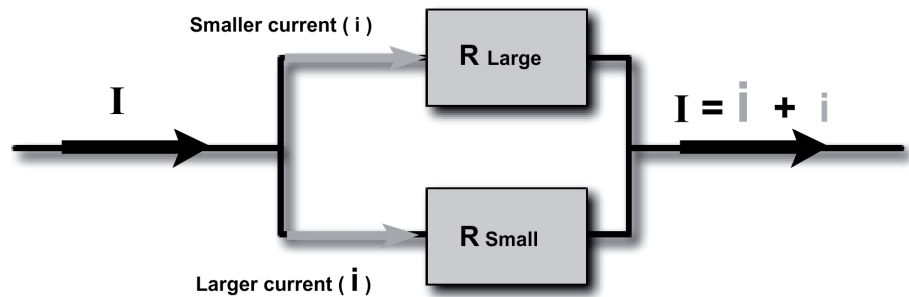
$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$

NOTE that the value of R_p will always be smaller than the smallest of the resistors in parallel, e.g.

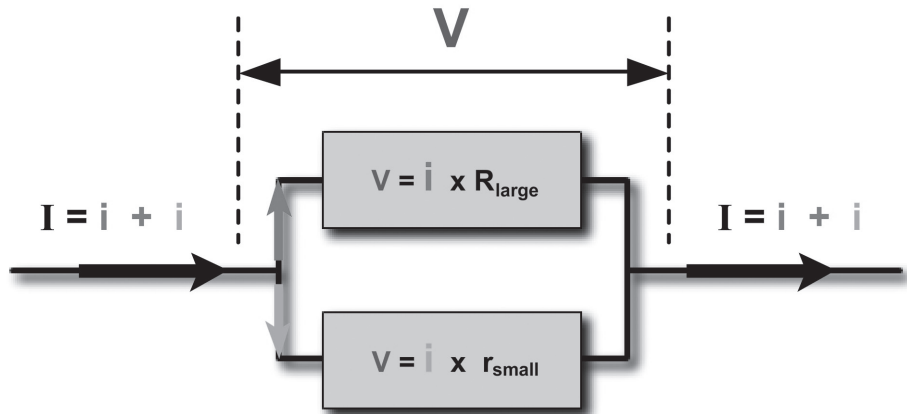
$$\frac{1}{R_p} = \frac{1}{2} + \frac{1}{5} = \frac{5+2}{10} \therefore R_p = \frac{10}{7} = 1,4 \text{ and } 1,4 \Omega < 2 \Omega$$

- b) When current splits at a branching point, we find a **lower** proportion of the overall current in the **larger** resistor and a **higher** proportion in the **smaller** resistor.

NOTE: We sometimes explain this by saying that flowing charge “chooses the path of least resistance”. So the larger portion of the total current will find its way to the lower resistance or the “easier path”.

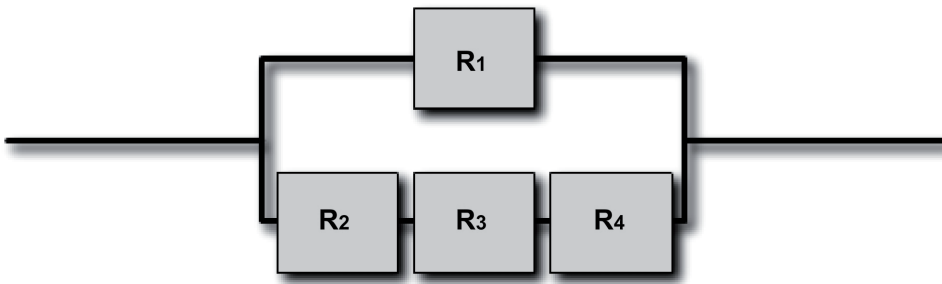


- c) The potential difference across every resistor in a parallel arrangement is the same (i.e. the pd measured between the branching point and the point where the split currents join again).



- d) It is possible to have a series of resistors in one branch of the parallel arrangement.





$$R_s = R_2 + R_3 + R_4$$

$$\frac{1}{R_s} = \frac{1}{R_p} + \frac{1}{R_1}$$

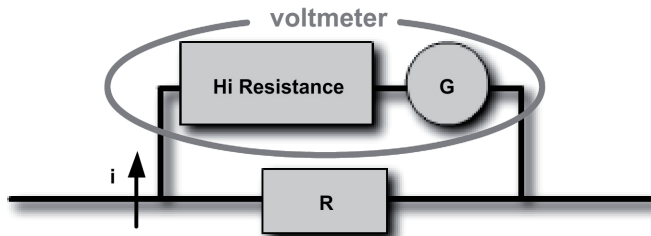
Rule 8

Ammeters have a very low resistance (we can ignore it) and are always connected in series in a circuit. This means that they do not affect the current in the circuit. It also means that there is a negligible potential difference across an ammeter, i.e. charge expends very little energy to flow through the ammeter.

NOTE that if you are given the actual resistance of the ammeter it is treated like any other resistance in series.

Rule 9

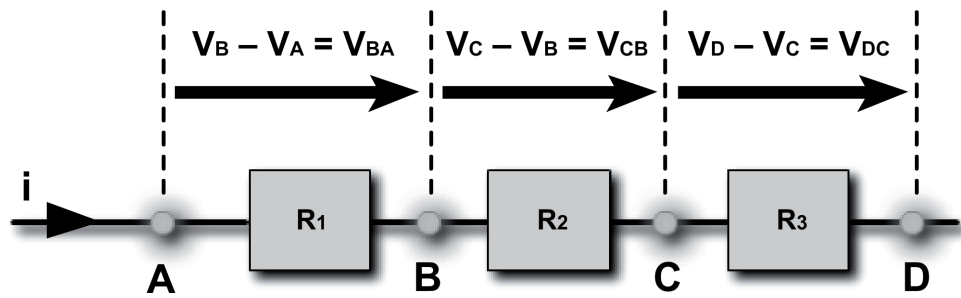
- a) Voltmeters have a very high resistance in series with a galvanometer. For this reason, they are always connected in parallel so that they draw a very small current and therefore have a minimal effect on the potential difference across the resistor.



NOTE that a voltmeter is a galvanometer with a scale that has been calibrated to show potential difference. The voltmeter's high resistance is in series with the galvanometer, which is a very sensitive instrument for detecting the presence of an electric current. The value of the high resistance is accurately known so the fraction of the total current (i) which is drawn off to the galvanometer is also accurately known. This enables the galvanometer to be accurately calibrated so that it gives the value of the potential difference across R .

- b) A voltmeter measures the potential difference across a resistance. This is sometimes referred to as the **potential drop**. The unit of pd is the "volt". (See Lesson 9).





When charge arrives at **A**, it has a certain amount of electrical potential energy. Once that charge has passed through resistor R_1 , it has lost some of its energy because of the work done in getting through the resistor. A voltmeter connected between **A** and **B** measures the potential difference or “potential drop” V_{BA} . The same is true for V_{CB} and V_{DC} . By the time the charge has reached point **D**, the charge that has passed through the resistors $R_1 + R_2 + R_3$ will have lost $V_{BA} + V_{CB} + V_{DC}$ volts or joules per coulomb of electrical potential energy.

- c) If the ends of a voltmeter are connected between two points which are at the same potential, the voltmeter reading will be zero.

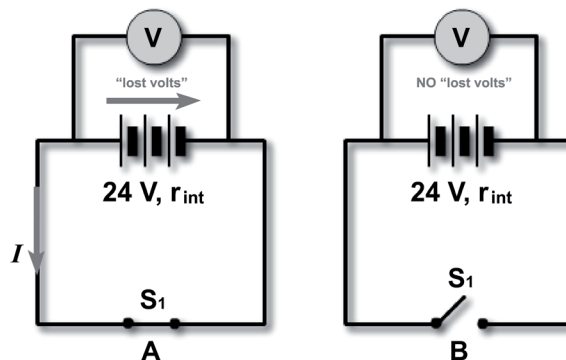
If the electrical potential energy of the charge at **A** is the same as the potential energy at **B** then no work will have been done between **A** and **B**. So $V_A = V_B$ and the potential difference or “potential drop” (V_{BA}) will be $V_B - V_A = 0$.

Rule 10

- a) The emf (\mathcal{E}) of a battery is the maximum amount of energy that it can give per coulomb of charge to the charge passing through it.

Inside the battery, chemical processes are happening through which charge is given the energy it needs to travel around the external circuit. During those processes in which the charge is gaining energy, it is also losing some energy (as it “bumps” into ions, for instance) and this will be seen as “internal resistance”. If the processes in the battery were perfectly efficient then the internal resistance would be zero. In most cases, a fresh battery has negligible internal resistance so we can ignore it. As batteries age, the process of transferring energy to charge becomes less efficient and this will be seen as increasing internal resistance.

- b) A voltmeter connected across a battery when there is a current in the circuit does not measure \mathcal{E} because of the voltage drop across the internal resistance in the battery (the so-called “lost volts”).



The voltmeter in **Diagram A** measures the potential difference across the “external circuit” which is less than the **emf** (\mathcal{E}) because the reading will



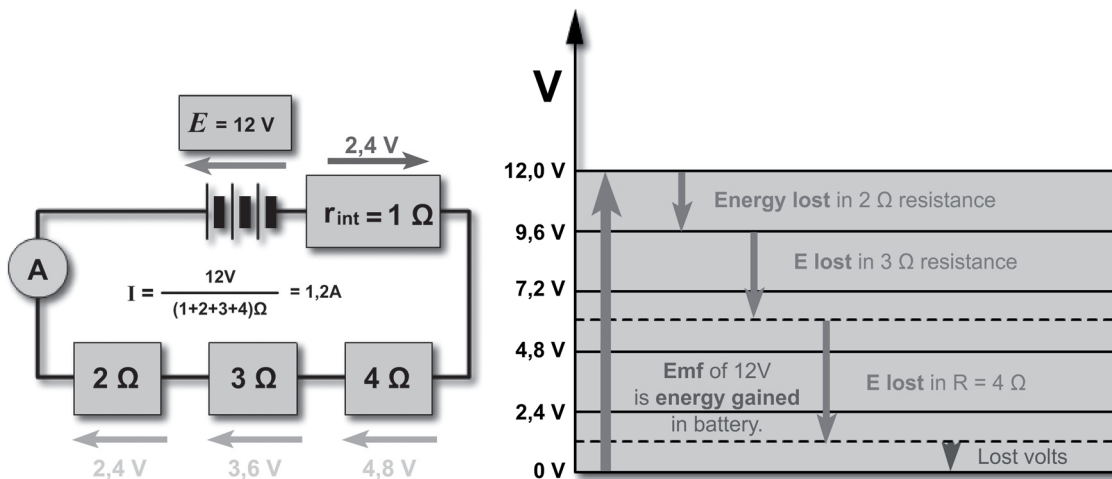
be (**emf** – “lost volts”). Because there is a current in the external circuit (the circuit between the terminals of the battery outside of the battery), when this current passes through the battery it causes a further potential drop $V_{int} = I \cdot r_{int}$.

V_{int} is what is referred to as the “lost volts”.

The voltmeter in the circuit shown in **Diagram B**, where switch S_1 is open and hence where $I = 0 \text{ A}$ reads 0 V because with no current in the external circuit there can be no “lost volts” inside the battery.

- c) \mathcal{E} is given by the sum of the potential difference across the external circuit and the “lost volts” (or V_{int}) i.e. $\mathcal{E} = V_{ext} + V_{int}$.

Another way of saying this is that the sum of the “potential drops” across all of the resistances in a circuit is equal to the **emf** (\mathcal{E}).



WORKED EXAMPLE

This is a typical circuit problem in a battery (you will either be told what the value of the internal resistance is **or** you will be told that r_{int} is negligible).

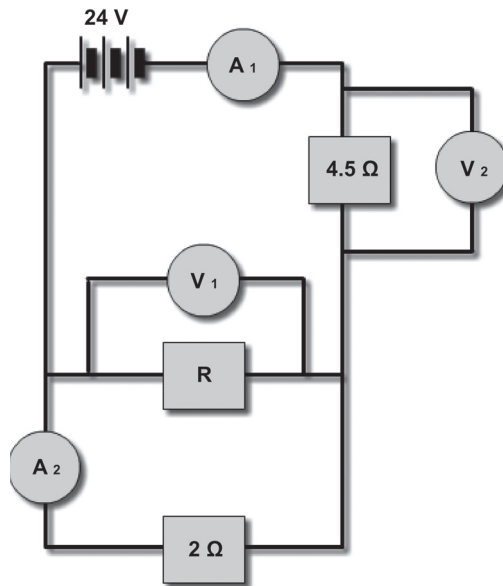
Identify immediately any resistances in parallel and remember that the potential drop across every resistor in the parallel arrangement is the same.

The first two questions will usually require you to calculate the total resistance in the circuit and hence the total current. (Where there are resistors in parallel, the current will divide according to the size of the resistors in the branches.)

This could be tricky as there is an unknown resistance in parallel with the 2Ω resistor. Satisfy yourself that it cannot be calculated unless you are told at least one of the readings on A_1 , A_2 , V_1 or V_2 . Depending on which you are told, you will employ a different strategy to calculate R .

In this case, assume that you have been told that $V_2 = 18 \text{ V}$.

What this tells us is that the potential drop ($V = IR$) across the 4.5Ω is 18 V . This will be the case when there is a current equal to $I = V/R = \frac{18}{4.5} = 4 \text{ A}$ in that resistor.



Therefore the total current (I_{tot}) in the circuit (and the reading on A_1) is **4 A**.

Therefore the total resistance (R_{tot}) in the circuit is $\mathcal{E}/I_{\text{tot}} = \frac{24}{4} = \mathbf{6 \Omega}$.

Now we also know that the total potential drops across the resistors in the circuit will be equal to the **emf** of the battery, i.e. **24 V**. So if the potential drop across the **4,5 Ω** is **18 V** then the drop across the remaining resistors must be $(24-18)V = \mathbf{6V}$.

Therefore $V_1 = \mathbf{6 V}$.

The only other resistance in the circuit is from the two resistors in parallel. If the total current is **4 A** and the potential drop across the parallel resistors is **6 V**, then $R_p = \frac{6}{4} = \mathbf{1,5 \Omega}$. Therefore we calculate **R** as follows:

$$\begin{aligned}\frac{1}{R_p} &= \frac{1}{R} + \frac{1}{2} \\ \frac{1}{R} &= \frac{1}{R_p} - \frac{1}{2} \\ &= \frac{1}{1,5} - \frac{1}{2} \\ &= \frac{2}{3} - \frac{1}{2} \\ &= \frac{4-3}{6} \\ &= \frac{1}{6}\end{aligned}$$

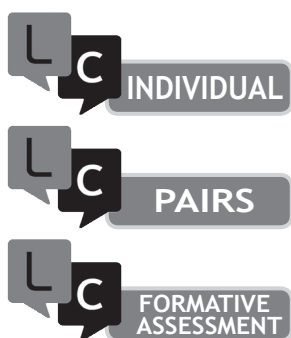
$$\therefore R = 6 \Omega$$

If $R = 6 \Omega$ then the current in the resistor can be determined from $\frac{V_1}{R} = \frac{6}{6} = \mathbf{1 A}$.

Now, if the current through the **6 Ω** resistor is 1 A, we can determine the reading in two ways.

First, if the total current in the circuit (the reading on A_1) is **4 A**, and the current in **R** ($= 6 \Omega$) is 1A, then the reading on A_2 is **3 A**.

The second method of calculating the reading on A_2 is by saying that, because the potential drops across both parallel resistors must be the same, and because we know that $V_1 = 6V$, the reading on A_2 is $I_2 = \frac{6V}{2\Omega} = \mathbf{3 A}$.



Activity

TASK 1

Some scientific laws named after people

Science and mathematics abound with important laws, principles, procedures and ideas that are named after the people who first formulated them. This is a way of honouring scientists and mathematicians who brought about important breakthroughs in the understanding of their particular subjects or disciplines.

Do your own research on the following list of physical laws. Find out more about the laws themselves and the lives of the people after whom they are named. Note when the individuals lived.

Ampère's Law

physics – electrical current

Archimedes' Principle

physics – floating and sinking bodies

Avogadro's Law

chemistry – basic theory of matter

Boyle's Law

physics – behaviour of gases

Charles's Law

physics – behaviour of gases

Coulomb's Law

physics – electrostatics

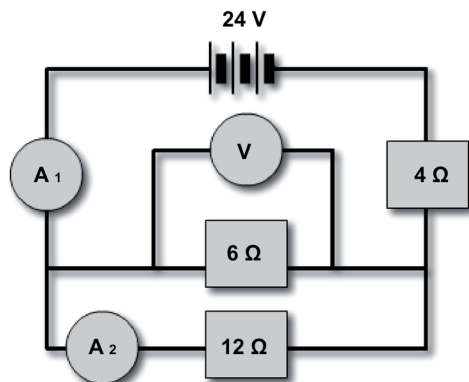
Dalton's Laws	chemistry – chemical bonding
Einstein's General Theory of Relativity	physics – theories of gravitation and light
Faraday's Law of Induction	physics – electromagnetism
Faraday's Law of Electrolysis	chemistry – effects of electrical current
Galileo's Law of Inertia	physics – motion of bodies
Hooke's Law	physics – elasticity of materials
Le Chatelier's Principle	chemistry – chemical equilibrium
Lenz's Law	physics – electromagnetism
Lewis Structures	chemistry – explaining bonding mechanisms
Newton's Law of Cooling	physics – energy: heating and cooling
Newton's Law of Gravitation	physics – universal gravitation
Newton's Laws of Motion	physics – mechanics
Ohm's Law	physics – electricity and electronics
Pascal's Triangle	mathematics – number theory
Pythagoras' Theorem	mathematics – geometry
Young's Modulus	physics – mechanical properties of matter

TASK 2

There are many other laws and principles, etc, in science and mathematics that are named after the people who are credited with their discovery.

Find some others and try to understand the principles they deal with.

TASK 3

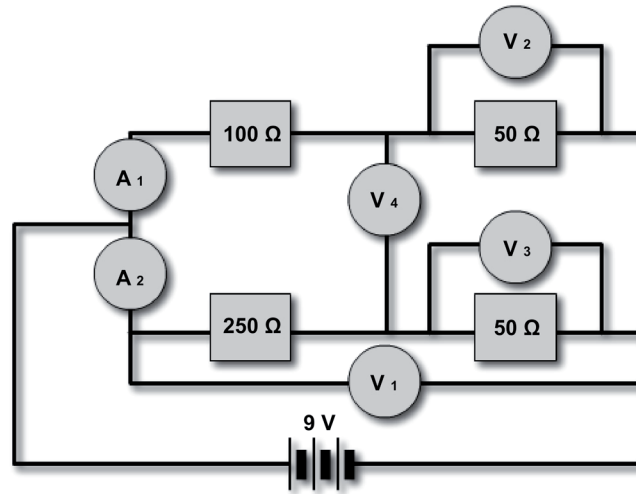


In the circuit, the ammeters have negligible resistance and the battery has no internal resistance. **Calculate:**

- The total resistance of the circuit.
- The reading on ammeter A_1 .
- The reading on the voltmeter.
- The current through the $12\ \Omega$ resistor (A_2).



TASK 4



The battery has negligible internal resistance. Analyse the electric circuit represented in this circuit diagram and answer the following questions:

- What is the effective value of the resistors as connected in the diagram?
- What is the reading on ammeters A_1 and A_2 ?
- What is the reading on the following voltmeters?

(i) V_1	(ii) V_2	(iii) V_3	(iv) V_4
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ELECTRIC CIRCUITS TO ANALYSE

LEARNING OUTCOMES AND ASSESSMENT STANDARDS:



Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 1:

Conducting an the investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

INTRODUCTION

What you must know in this section of the curriculum is:

Series circuits: calculations should include internal resistance

- Parallel circuits and equivalent resistance
- Combination circuits: series and parallel
- Relation between current, voltage and resistance (Ohm's Law)
 - Potential drop

This lesson will focus on calculations using the basic knowledge in this section:

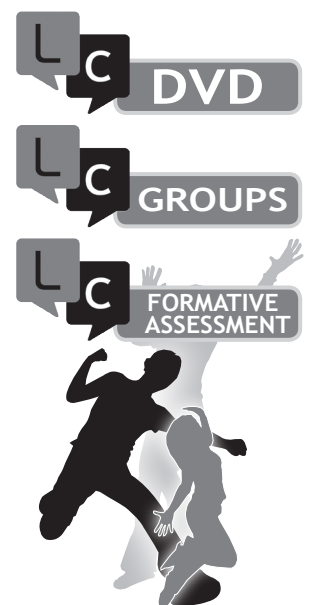
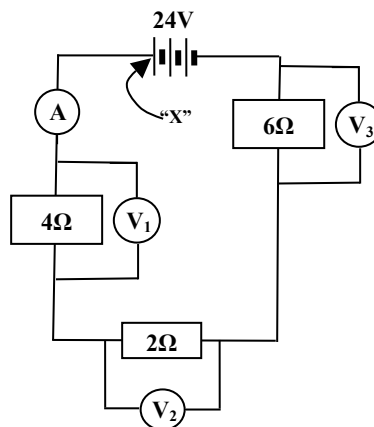
- Solving circuit problems
- Using “potential drop”
- The Wheatstone bridge

Lesson

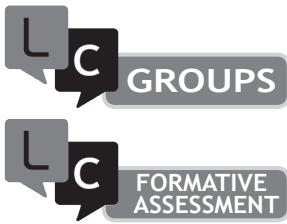
Activity 1

In this circuit there are three resistors connected in series with a 24 V battery.

- Calculate the total resistance in the circuit.
- Use Ohm's Law to calculate the reading on the ammeter, i.e. the current in the circuit.
- Calculate the readings on the three voltmeters.
- Imagine you are a charged particle, with a charge of 1 C, leaving the battery at point X.
 - How much energy have you got at point X?
 - How much energy do you lose at each of the three resistors?
 - How much energy have you lost by the time you get back to the battery?



e) Plot the energy losses on a graph for the whole journey around the circuit.



Activity 2

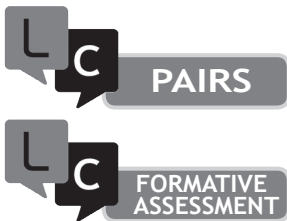
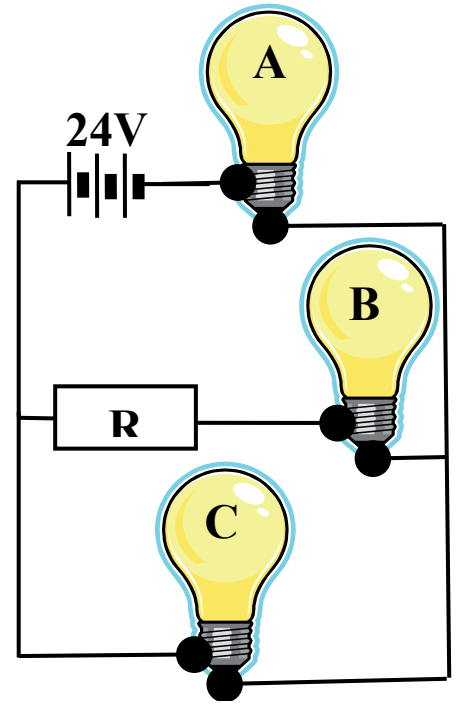
Three **identical** light bulbs are connected to a 24 V battery as shown.

Which of the bulbs will burn the most brightly?

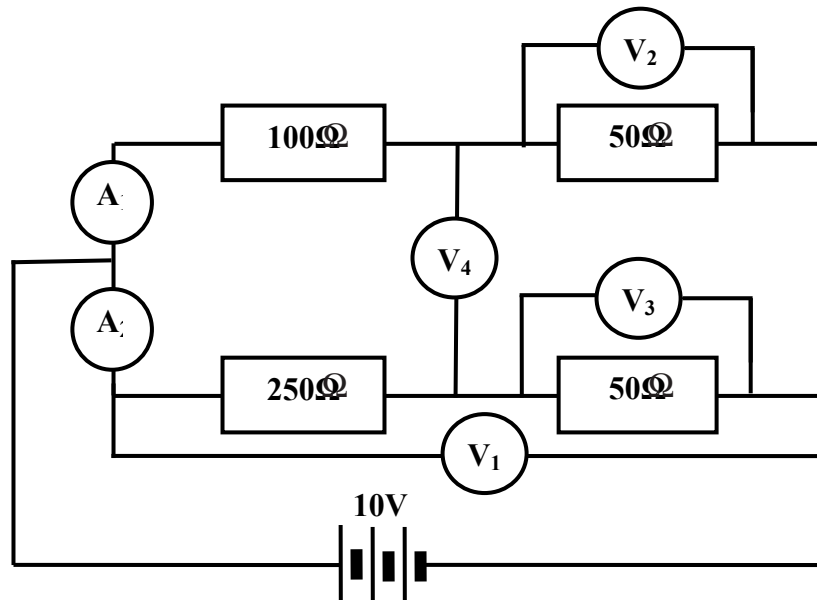
Understanding the problem

- Identify which bulbs are in series and which bulbs are in parallel with one another.
- Think about the size of the current in each bulb. A bulb's brightness is an indication of the size of the current in the bulb.

Discuss the problem and when you have agreement in the group, see whether your answer was correct or not.



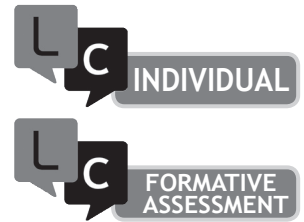
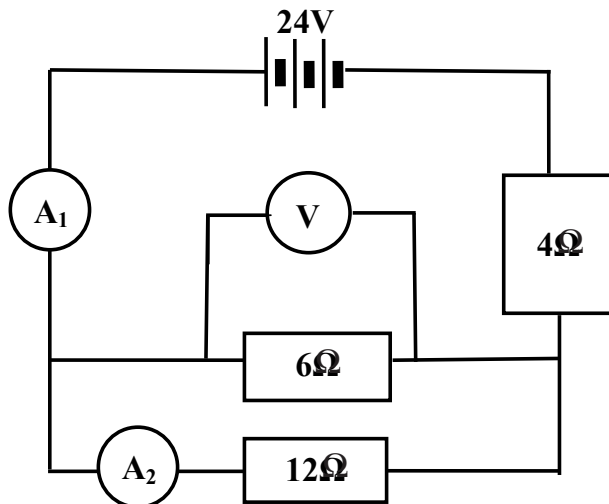
Activity 3



- Calculate the readings on the two ammeters and the four voltmeters.
- Why do voltmeters #2 and #3 have different readings even though they are both connected across 50 Ω resistors?
- If V_4 was replaced by a piece of conducting wire, would there be a current in it?

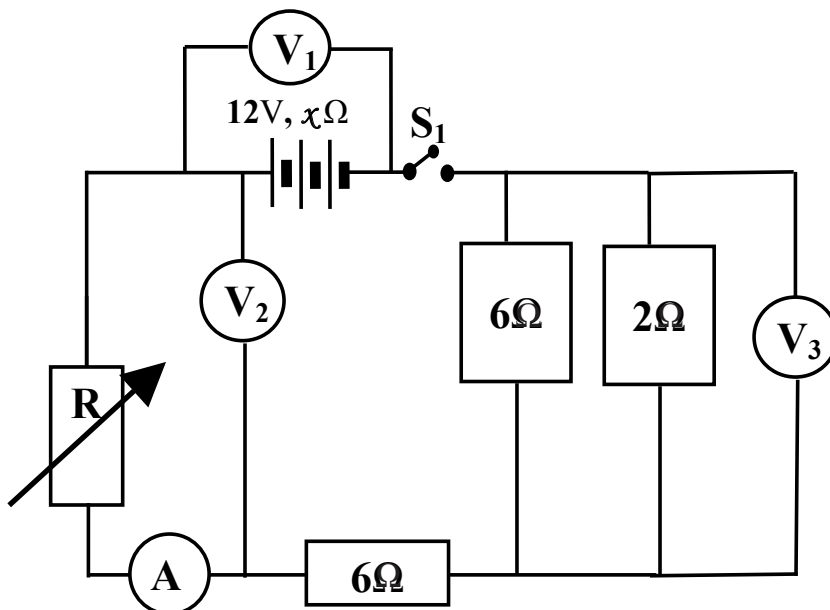


Activity 4



- Calculate the readings on the two ammeters and the voltmeter.

Activity 5



The circuit shown in this diagram contains a **12 V** battery (with an unknown **internal resistance**), a switch (S_1), an ammeter (**A**), three voltmeters (V_1 , V_2 , V_3), three fixed resistors of **6 Ω**, **6 Ω** and **2 Ω** and a variable resistor, **R**.

- Calculate the effective resistance of any parallel resistors.
- What is the reading on V_1 when S_1 is open? If R is set at 0 and S_1 is closed, the reading on A is 1,5 A.
- Predict whether there will be any change in the reading on V_1 when S_1 is closed.
- What will the reading on V_1 be when S_1 is closed?
- Calculate the value of the internal resistance of the battery. R is now adjusted so that the readings on V_2 and V_3 are the same.
- Calculate the new reading on the ammeter.



BASIC CHEMICAL CONCEPTS: THE NUCLEUS, ATOMS, BONDING AND MOLECULES

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

In this lesson we will deal with several basic concepts in chemistry and the physics of the atomic nucleus. **This work is basic to all the chemistry lessons that follow and should be referred to frequently.** Once you master the basic concepts in chemistry, the subject becomes both easy to understand and exciting because it applies to so many aspects of everyday life.

The most fundamental concept in chemistry is the **atom** which is defined as the smallest particle of matter that cannot be broken down by ordinary, physical or chemical means. It is also the smallest unit of a chemical element (the elements are set out in a very specific order in the periodic table) that can take part in a chemical reaction and therefore an atom must have the same chemical properties as a sample of the element. In some texts you may see the atoms of an element being described as being *identical to all other atoms in the element*. THIS IS WRONG, as you will realise when we discuss **isotopes**. But if the definition specifies that every atom in a sample of an element is *chemically* identical, then that is correct.

Something you should remember is that all chemical interactions obey the rules of physics. Chemistry is not mysterious. It's actually very logical and quite simple. Really!

Remember that when we study chemistry we are usually looking at the behaviour of electrons around and between atoms. Chemistry deals with the interactions of electrons and these are affected by (1) the size of the positive charge on the atomic nucleus, (2) the actual size of the atom and (3) the number of electrons in the outer energy levels of the atom. In this lesson we will also look more closely at the fascinating world of the atomic nucleus and so-called **nuclear reactions**.

Atoms bond with other atoms (from the same or different elements) to form **molecules**. A bond, as we mentioned in the section on electrostatics, is the overall (or net) force of attraction between two atoms that holds them together. **Work** must be done to separate atoms and therefore **energy** is used in this process. These are not new concepts – they are no different from those you have already met in physics and mechanics. Only the very small scale of the atom is different from the “macroscopic” processes we experience in our everyday lives. When bonds break, energy is released. Isn't it amazing to think that the tiny amounts of energy stored in the chemical bonds between single atoms can be the basis for all the chemical processes of life on Earth?

This lesson covers the following sections. Please use them **with** and **not instead of** a textbook!

- The periodic table
- The size of atoms



- The atomic nucleus and isotopes
 - Atomic number
 - Mass number
 - Symbols
 - Ions
 - Isotopes
- Atomic mass and relative atomic mass
- The mole, molar mass and molar volume of gases
- Radio-isotopes and radioactive decay of atomic nuclei
- The half-life of isotopes
- Radiocarbon dating
 - The origins of carbon-14 (^{14}C) in nature
 - The effect of fossil fuel burning on radiocarbon dating
- Nuclear fission
- An introduction to chemical bonding
 - Electronic configurations – how electrons are arranged in an atom
- Lewis structures
- Bonds
 - Ionic bonding
 - Covalent bonding
- Bond length and bond energy
- Electronegativity
- Partial ionic character (and partial covalent character)
- Polar covalent bonds

Lesson

THE PERIODIC TABLE

The periodic table is the chemist's map as it contains a great deal of the information required when determining how reactions will proceed. In most chemical interactions, not all of the electrons interact but rather the so-called "bonding electrons" which take part in the joining or separation of atoms in molecules. Nevertheless, the other electrons in an atom can play an important role in determining how much energy is required to start a reaction. "Non-bonding" electrons can also determine the structure of molecules and solids as well as the physical properties of substances, e.g. the high boiling point of liquid water. The periodic table is an important tool because from it one can determine the electronic configurations of atoms, i.e. how the electrons are arranged in an atom.

The chemical elements are the many different forms that matter can occur in. The elements can be arranged according to the number of protons in their nuclei, starting from the simplest atom, hydrogen.

Elements are arranged in increasing atomic number (given by the number of protons in the nucleus). The **periods** are families of elements in rows across the table. Many

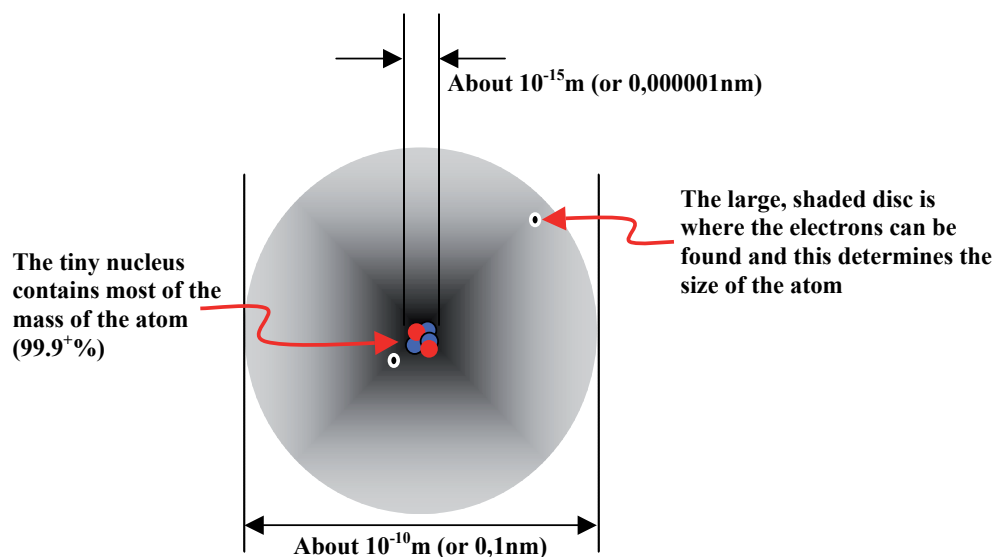


of the neighbours have similar physical and properties. Columns or **groups** have very similar properties although their degree of reactivity might vary up or down the table. The elements are also divided into metals and non-metals. The periodic table gives us additional information on whether elements occur as solids, liquids or gases in their natural state.

THE SIZE OF ATOMS

Atoms, even the largest of them, are very, very small. But the nucleus of the atom, where about 99,9% of the mass of the atom resides, is many, many times (about 100 000 times) smaller! It is incredibly difficult for the human mind to comprehend the vastness of the solar system, the galaxies and the universe. It is just as difficult to comprehend the incredible smallness of the atom.

Look at the diagram below that gives the approximate dimensions of an atom – **THOUGH NOT TO SCALE!** To give one some idea of what the numbers mean, imagine that the nucleus shown here is a collection of five green peas. If the atomic nucleus were about 2,0–2,5 cm in diameter, the diameter of the whole atom would be between 2–2,5 km, or nearly 20 soccer fields long!

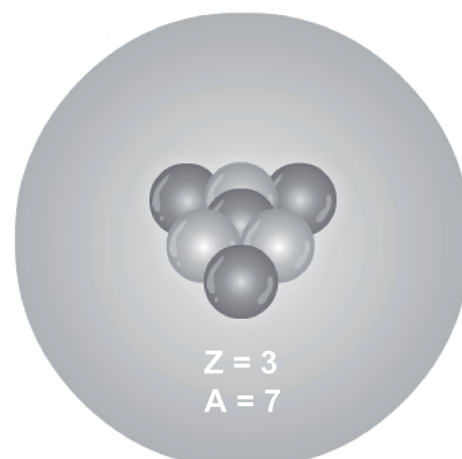


THE ATOMIC NUCLEUS AND ISOTOPES

The nucleus of the atom contains two kinds of particles: the **proton** and the **neutron**. The important information about these two nuclear particles is given in the table below. (The information on the electron is given for comparison but remember that electrons are not actually found in the nucleus with the heavier protons and neutrons.)

Atomic number (Z)

- The atomic number of an atom is the number of protons in its nucleus.
- The periodic table is arranged in order of atomic numbers.
- In neutral atoms, there are as many electrons surrounding the nuclei as there are protons in it.
- For every proton that is added to the nucleus, one electron is added to the electron energy levels outside of it in the neutral atom.



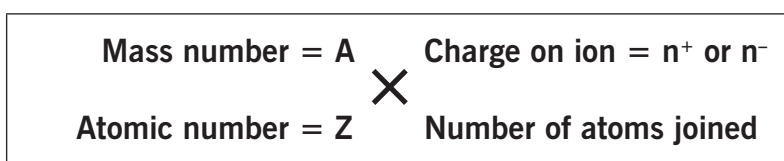
- Each time a proton is added to the nucleus and an electron to the shells around the nucleus, we get the next element on the periodic table.

Mass number (A)

- The mass number gives the total number of particles in the nucleus, i.e. (number of protons plus number of neutrons).
- To find the number of neutrons, calculate (A–Z).
- Because electrons have such an insignificant mass, we can say that the mass of an atom is given by the mass number A (in appropriate units).

Symbols

- Each element has its own symbol, e.g. H (hydrogen) or O (oxygen).
- The symbols are given on the periodic table.
- There is a specific format for writing an atom in symbolic form.



- Because the mass of the electron is so much less than that of protons and neutrons, it is often taken as zero. The three basic atomic particles are written:



Ions

- If a neutral atom gains or loses one or more electrons, the atom becomes electrically charged.
- Such atoms are called ions and they behave differently from neutral atoms.
- E.g. When a neutral atom of calcium (Ca; Z = 20; A = 40) loses two electrons, we write:

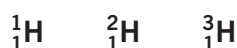


- An important fact to remember, especially when you deal with acids, is that a hydrogen ion (i.e. a hydrogen atom with its only electron removed) is actually just a proton. The hydrogen ion can be written:



Isotopes

- Every atom of a certain element has the same number of protons in its nucleus.
- But the number of neutrons in the nucleus can vary.
- Although an atom's isotopes are all chemically the same, each isotope has a different mass.
- Isotopes of a single element are chemically the same because they all have the same number of electrons.
- E.g. The three isotopes of hydrogen are known as hydrogen (Z = 1; A = 1), deuterium (Z = 1; A = 2) and tritium (Z = 1; A = 3) and can be written:



- It is not usual for different isotopes to be given unique symbols but in the case of the isotopes of hydrogen the following symbols are also used:



- Processes for separating isotopes have been developed. One, the ultracentrifuge, uses the fact of their difference in mass so that by spinning a sample of the element very fast the heavier and lighter isotopes are separated. This is one method of separating the two very famous isotopes of the element uranium:



- U-235 is the nucleus which can be split, releasing large amounts of energy either in bombs (thus “weapon-grade uranium” contains an unnaturally high proportion of U-235) or as a nuclear fuel in nuclear reactors. U-238 is the more stable isotope.
- In nature, the elements consist of a mixture of isotopes of that element. In the next section, we see that this is why the atomic masses given on the periodic table are never nice, round numbers.

	PROTONS	NEUTRONS	ELECTRONS
Number in neutral atom given by ...	<i>atomic number Z</i>		<i>atomic number Z</i>
To calculate number of neutrons ...		<i>Mass N^o – At N^o (A – Z)</i>	
Symbol for the particle	<i>p⁺</i>	<i>n⁰</i>	<i>e⁻</i>
Where found?	<i>in nucleus</i>	<i>in nucleus</i>	<i>outside nucleus</i>
Mass	<i>1,7 × 10⁻²⁷ kg</i>	<i>1,7 × 10⁻²⁷ kg</i>	<i>9,0 × 10⁻³¹ kg</i>
Charge	<i>+1,6 × 10⁻¹⁹ C</i>	<i>0</i>	<i>-1,6 × 10⁻¹⁹ C</i>
Varies for each isotope of element		<i>A and (A-Z)</i>	
Examples		<i>¹²C, ¹³C, ¹⁴C</i>	
Identical for every atom in an element	<i>Z protons</i>		<i>Z electrons</i>

ATOMIC MASS AND RELATIVE ATOMIC MASS

- There is no natural measure of mass. Length, for instance, is defined as the distance travelled by light in a vacuum in 1/299 792 458 of a second; and one second of time is currently defined as the time taken for 9, 192, 631, 770 oscillations of the caesium (¹³³Cs) atom (an atomic clock!). Despite the awkward numbers, the point is that there are natural processes that can be used to define time and distance but there is no such thing for mass. So we have to invent a standard of mass.
- The kilogram is defined by a lump of platinum-iridium metal kept in Paris but this is not really convenient for defining the mass of atoms.
- The standard for one atomic mass unit (1 u) is $\frac{1}{12}$ of the mass of the ¹²C isotope.
- In other words, the mass of one atom of the carbon-12 isotope is 12u.
- In nature we find three isotopes of carbon in the following proportions: ¹²C (98,9%), ¹³C (1,1%), ¹⁴C (10⁻¹² or one part per trillion). Carbon-14 can be ignored for the present purposes although it is a very important isotope, as we will see presently (radio-carbon dating).



- In any sample of carbon we will have ^{12}C and ^{13}C present in those proportions. So the average mass of the atoms in a sample of carbon is:
 $(0,989)(12) + (0,011)(13) = 11,868 + 0,143 = 12,011 \text{ u}$
- This is referred to as relative atomic mass because the mass is measured relative to a scale on which carbon-12 is taken as exactly 12 u.
- No other isotope in nature has a mass which can be expressed as an integer (a whole number).
- The atomic mass for carbon on many periodic tables will be 12,011 u. Our periodic table is rounded to the first decimal place, i.e. 12,0 u.

THE MOLE, MOLAR MASS AND MOLAR VOLUME OF GASES

The mole is a very large number with a special significance. Let's explain the significance by starting with a small pile of pure carbon.

If the pile contains ...

- only single atoms of carbon;
- only ^{12}C isotopes; and
- has a mass of exactly 12 g;

then there will be **exactly $6,023 \times 10^{23}$** atoms of carbon in the pile. This extremely large number is called a **mole**. In the same way that a dozen is 12, a score is 20 and a gross is 144, a mole is $6,023 \times 10^{23}$. It's as simple as that!

- One mole of atoms of the ^{12}C isotope has a mass of exactly 12 g.
- One mole of natural carbon, which contains both ^{12}C and ^{13}C isotopes in the proportions mentioned above, has a mass of 12,011 g.
- Oxygen has a relative atomic mass of 15,999 u. The oxygen we breathe is a diatomic molecule (two oxygen atoms, i.e. O_2). It has a relative atomic mass of 32,998 u. Thus one mole of oxygen molecules has a mass of 32,998 g.
- One mole of calcium carbonate (CaCO_3) molecules would have a mass of $(40 + 12 + 3[16]) \text{ g}$ or 100 g.
- If you have a container with 22 g of carbon dioxide gas in it (one mole of CO_2 has a mass of $12 + 2[16] = 44 \text{ g}$) that is $(0,5 \text{ mol or } \frac{1}{2} \times 6,023 \times 10^{23})$ molecules.
- We speak of molar mass. This is the mass of one mole of something and is expressed in units of $\text{g}\cdot\text{mol}^{-1}$.
- The molar mass of carbon is $12,011 \text{ g}\cdot\text{mol}^{-1}$; of oxygen gas is $15,998 \text{ g}\cdot\text{mol}^{-1}$; and of calcium carbonate is $100 \text{ g}\cdot\text{mol}^{-1}$.
- A most useful and important number is the volume that one mole of any gas occupies at STP – standard temperature and pressure – a pressure of 101,3 kPa and temperature of 273 K (0°C).
- **The molar volume of all gases at STP is $22,4 \text{ dm}^3$.**
- Water has a density of $1 \text{ g}\cdot\text{cm}^{-3}$. In other words, 1 cm^3 of water has a mass of 1 g.
- The molar mass of water (H_2O) is $[2(1) + 16] = 18 \text{ g}\cdot\text{mol}^{-1}$.
- Therefore 18 cm^3 of water – that is about $\frac{1}{14}$ of a cup – contains one mole of water molecules, i.e. $6 \times 10^{23} \text{ H}_2\text{O}$ molecules!!



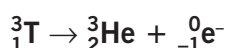
RADIO-ISOTOPES AND RADIOACTIVE DECAY OF ATOMIC NUCLEI

- The nuclei (plural of nucleus) of some isotopes are unstable. This means that they can spontaneously break into several pieces.
- The reason they split is because of an unfavourable neutron : proton ratio.
- Up to $Z = 20$ (calcium), a favourable ratio is 1:1, so ^{40}Ca is the most stable of the isotopes of calcium as are ^{12}C and ^{16}O for carbon and oxygen respectively.
- After Ca the ideal ratio for nuclear stability rises.
- After ^{83}Bi (bismuth) nuclei become unstable and break up very fast, i.e. from polonium (^{84}Po) through to uranium (^{92}U).
- Beyond uranium we have the so-called “trans-uranic elements” which are all so unstable that they are not found to occur naturally. These elements are man-made in very high-energy reactors. They live for very short times before decaying into more stable products.
- This breakdown of unstable nuclei is the phenomenon called “radioactive decay” or radioactivity. Here is an example: the decay of the nucleus of tritium, the very unstable isotope of hydrogen ($n^0 : p^+$ ratio of 2:1).
- Radioactivity or radioactive decay results in the emission of three kinds of radiation: alpha, beta and gamma radiation. But what are they?
- Alpha (α) radiation. This is the lowest energy form of radiation and is actually the nucleus of a helium atom: ^4He . Because it is only the nucleus, that means it must have had its two electrons stripped away and hence it is also an ion.
- Beta (β) radiation. This is a higher-energy form of radiation than alpha and is actually electrons that come from within the nucleus. Nuclear reactions are very complex. A fairly accurate picture of beta decay is that it is a neutron in the nucleus becoming a proton and an electron. The electron is radiated away from the decayed nucleus.
- Gamma (γ) radiation. This is the highest energy form of radiation found. Gamma radiation is “pure” energy and is not an actual particle with mass as the other forms of nuclear radiation are. Gamma radiation is very harmful to living cells and can cause a very rapid breakdown of cell functions.

	ALPHA	BETA	GAMMA
Symbol for the radiation	α	β	γ
What is it?	<i>A particle</i>	<i>A particle</i>	<i>A packet of energy</i>
	<i>Helium nucleus</i>	<i>An electron</i>	<i>A photon</i>
	$^4\text{He}^{2+}$	e^-	γ
Penetrating ability	<i>Very poor</i>	<i>Good</i>	<i>Very high</i>
Penetrates ...	<i>Very thin paper</i>	<i>3 mm aluminium</i>	<i>Walls, steel sheet</i>
... but is stopped by	<i>Thick paper; stomach walls</i>	<i>+3 mm aluminium</i>	<i>Thick lead shield 1 m concrete</i>
Energy of the radiation	<i>Low</i>	<i>High</i>	<i>Very high</i>
Mass	$6,8 \times 10^{-27}\text{kg}$	$9,0 \times 10^{-31}\text{kg}$	0
Charge	+2	-1	0

Examples of spontaneous radioactive decay

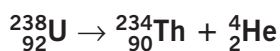
1. Radioactive decay of tritium



- In this nuclear decay reaction we see two important principles being illustrated. First, we see the conservation of mass number ($3 \rightarrow 3 + 0$).
 - Second, we see the conservation of charge ($1 \rightarrow 2 + [-1]$).
 - The half-life of tritium is 12,32 years. (See below). This tells us that when an atom of tritium decays we are left with an atom of helium and an electron.
 - TASK: read about beta radiation in the section immediately above. Would you say that tritium decays by beta radiation?
2. Radioactive decay of radium



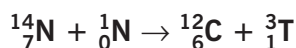
- Again we see the conservation of mass number and atomic number in the reaction.
3. Radioactive decay of uranium-238



- Again we see the conservation of mass number and atomic number in the reaction.

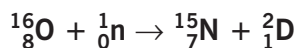
Examples of radioactive decays that are induced by neutron bombardment

1. Bombardment of an isotope of nitrogen by fast neutrons



- Again we see the conservation of mass number ($14 + 1 \rightarrow 12 + 3$).
- There are no ions in the reaction so charge is conserved: ($0 + 0 \rightarrow 0 + 0$).
- The number of positive charges on the nuclei (protons: $7 + 0 \rightarrow 6 + 1$) remain the same before and after the nuclear reaction.
- We see the formation of tritium taking place. Tritium is highly radioactive and will decay as in Example 1 in the previous section.
- This is different from the reaction that produces ${}^{14}\text{C}$ (see the section below on radiocarbon dating).

2. Bombardment of an isotope of oxygen by fast neutrons



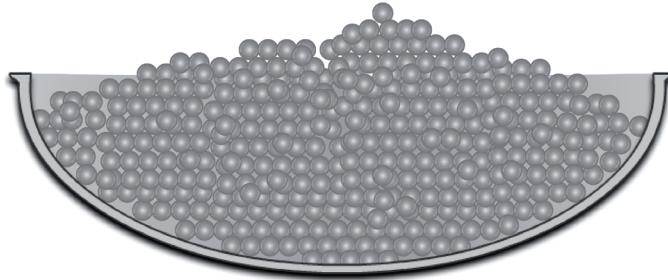
- Satisfy yourself about the conservation of mass number, charge and atomic number in this reaction.
- In Example 1 we see ${}^{14}\text{N}$ being bombarded by a neutron. In this example we see ${}^{15}\text{N}$ being produced. Both of these isotopes are more stable than ${}^{13}\text{N}$. Why?
- Note that deuterium – a stable isotope of hydrogen with a neutron in the nucleus – is produced.

THE HALF-LIFE OF ISOTOPES

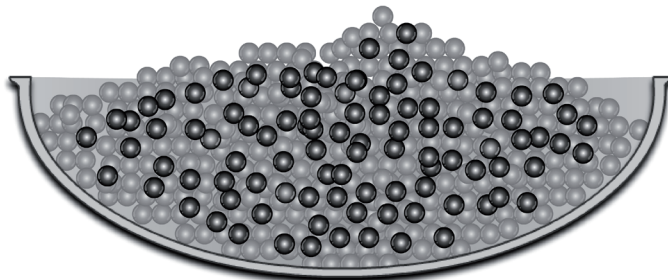
Many isotopes are stable. What this means is that they are unlikely to break down by radioactive decay as in the examples given above. Remember that for elements $Z=1$ to $Z=20$, the most stable isotopes have a proton : neutron ratio of very close to 1:1.



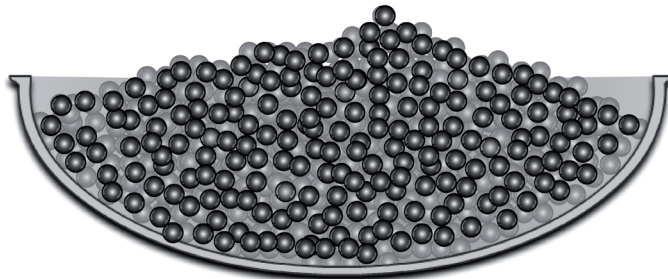
But there are also many isotopes which do break down, in the process producing “daughter” atoms and particles, as we see. The question arises, **what determines how fast isotopes will break down?** The answer to that question is actually another of the deep mysteries of the universe: *what determines the rate of nuclear breakdown*. But what we do know very accurately is how to measure the rate of breakdown. We call it the **half-life** of isotopes. Here is how it works.



600 atoms of a radioactive isotope are placed in a dish at T_0 .



After a certain time called the half-life of the isotope ($T_{\frac{1}{2}}$), one half of the original 600 atoms will have decayed into a different element. 300 of the original atoms will have survived.



After another half-life, half of the remaining 300 atoms of the original isotope, i.e. 150 atoms, will have decayed and the balance, 150 atoms, will have survived.

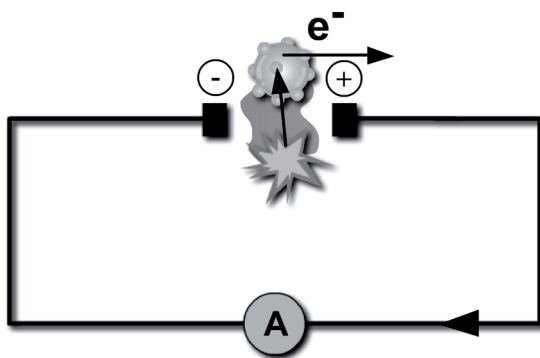


After a third half-life, 75 of the original 600 atoms will have survived and 525 ($300 + 150 + 75$) will have decayed. The process will continue for as many half-lives as it takes to reduce the original sample to almost zero.



Continue the calculation. Do you agree that after three more half-lives there will be fewer than 10 of the original atoms left in the pile?

- We can never predict which particular atom will decay next. All we can say is that after one half-life, half of the atoms that were there at the beginning of the half-life will have decayed. We cannot tell when an individual atom will decay.
- Tritium (^3H) has a half-life of 12,32 years. (Thus in 12,32 years, a sample of tritium will have decayed to half its original number of atoms.)
- One mole of tritium has a mass of 3 g. If we have 1 g of tritium that is $\frac{1}{3}$ mole – or about 2×10^{23} atoms.
- 12,32 years is $(12,32 \times 365,25 \times 24 \times 3\,600) = 3,89 \times 10^8$ seconds – or approximately 4×10^8 s.
- In the first half-life, the atoms in the 1 g of tritium ($\pm 2 \times 10^{23}$) will therefore reduce to half that number (i.e. 1×10^{23}) in 4×10^8 s.
- This is a rate of decay of $2,25 \times 10^{14}$ or 225 000 000 000 000 (2,25 trillion) decays per second.
- This fact gives us an insight into the huge numbers and the tiny sizes we are dealing with when we look at things on the atomic scale.
- When tritium decays it produces a helium-3 isotope and an electron. So the decay of tritium produces 225 trillion electrons per second. What size electric current would this number of electrons per second give us?



- Look at this simple circuit in which a sample of tritium is placed between two charged plates. As a tritium atom decays it releases an electron. The electron is attracted towards the positive plate. Electrons flow in the circuit, through an ammeter, and on towards the negative plate. What is the value of I , the current measured by the ammeter?
- $I = \text{number of } e^- \text{ per second} \times \text{charge on an electron}$
 $= 5 \times 10^{14} \text{s}^{-1} \times 1,6 \times 10^{-19} \text{C}$
 $= 8,0 \times 10^{-5} \text{C}\cdot\text{s}^{-1}$
 $= 80 \mu\text{A}$
- This circuit shows the principle that could be used to construct a device for measuring radioactive decay by α and β radiation, both of which consist of charged particles.

RADIOCARBON DATING

The half-life of radioactive isotopes can be determined very accurately because the half-life of a radioactive isotope never varies. If we know exactly how much of an isotope there was in a material when it was formed, then we can use this fact to find out how much time has passed since it was formed.

All green, living plants take in carbon dioxide, water and minerals from their environments. During the hours of sunlight, they use light energy from the Sun plus their own chlorophyll (which gives a plant its green colour) to turn the carbon

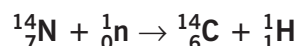


dioxide, etc, into plant carbohydrates. This process continues only as long as the plant is alive.

- When a living plant dies, e.g. when it is cut down to make some implement or to be used as food, the plant can no longer produce plant fibre and other carbohydrates.
- The isotopes of carbon occur in living materials in fixed proportions – about 98,9 % ^{12}C , 1,0999% ^{13}C and a very small amount, say about 0,0001% ^{14}C .
- What is important is that the proportion of $^{14}\text{C}/^{12}\text{C}$ in the atmosphere is constant (well almost; man has messed things up a bit – see below).
- Plants take in carbon through their leaves in the form of carbon dioxide that is found in the atmosphere. Whatever carbon dioxide is taken in by a living plant contains a fixed proportion of $^{14}\text{CO}_2/^{12}\text{CO}_2$ – in the same proportion as these isotopes of carbon occur in the atmosphere.
- From the moment of a plant's death the only carbon that can ever be present in its fibres (and which might be used to make a wooden handle or a plant-fibre cloth, e.g. linen or cotton) is what was there at the time of its death.
- In the living plant the carbon isotope ratio is constant. But when the plant dies no new carbon dioxide enters the plant so the ratio immediately starts changing because of the faster radioactive decay of ^{14}C than ^{12}C .
- We know the half-life of ^{14}C . It is 5 730 years. (The calculations above show how this fact can be translated into the level of radioactivity that can be measured using a suitable device.)
- We also know the ratio $^{14}\text{C}/^{12}\text{C}$ in a living plant and hence the expected radioactivity levels for a known mass of carbon.
- So if we take a sample of carbon (of known mass) from some material with plant origins (say a bow or an arrow from a cave in which some ancient people used to live), we can calculate the $^{14}\text{C}/^{12}\text{C}$ in its carbon. It might be less than expected and by knowing how much less, we can use the half-life of ^{14}C to determine how long it has been since the tree from which the bow/arrow was made was cut down.

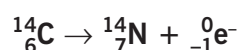
The origins of ^{14}C in nature

Carbon-14 is produced in the upper layers of the troposphere and in the stratosphere (see Lesson 29). The highest rate of production occurs at between 10–15 km above the Earth's surface. When cosmic radiation, mainly fast-moving particles from the huge nuclear fission reactions that take place in our nearest star, the Sun, collides with the constituents of the atmosphere, one of the products of these collisions is slow-moving neutrons. When **slow** (or “thermal”) **neutrons** are absorbed by the nuclei of nitrogen atoms they cause the following nuclear reaction:



Once the ^{14}C has been produced it reacts with oxygen to form carbon dioxide and in this way it is quickly and evenly distributed throughout the atmosphere. From there it is taken up by plants during photosynthesis. This is how a fixed proportion of ^{14}C finds its way into living materials.

Remember that while things are living, of all the carbon in their tissues a small percentage is ^{14}C . Once that living material dies the percentage of ^{14}C starts falling off as the carbon-14 isotope decays as follows:



Carbon-14 decays (into stable, non-radioactive, nitrogen-14) with a half-life of 5 730 years.

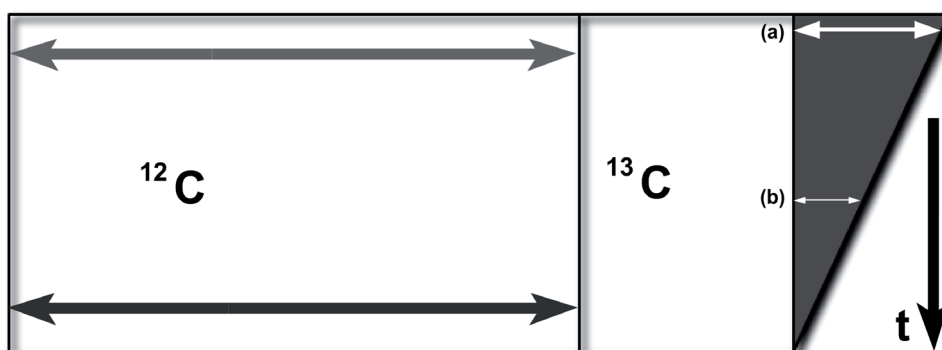
Summary

In living matter the proportions of carbon isotopes would be (not to scale):

98,9%	1,0999%	0,0001%
^{12}C (stable)	^{13}C (stable)	^{14}C

The $^{14}\text{C}/^{12}\text{C}$ ratio in the living plant is 0,0001/98,9 or 1/989 000. After the death of a plant, whereas the amount of the ^{12}C isotope remain unchanged, the amount of the radioactive ^{14}C decreases steadily (losing half its original mass every 5 730 years).

One mole of the ^{14}C isotope – i.e. 14 g – will reduce to 7 g after one half-life, decaying at a rate of about $1,7 \times 10^{12}$ atoms per second. So even after several half-lives, there will still be a measurable amount of decay occurring.



- Look at the example in the diagram. See how the ratio of the arrow lengths changes? If the small arrow (b) is $\frac{1}{4}$ the length of the arrow (a) then two half-lives have passed since last the material was growing. So the age of the material must be approximately $2 \times 5\,730$ years or 11 460 years old.

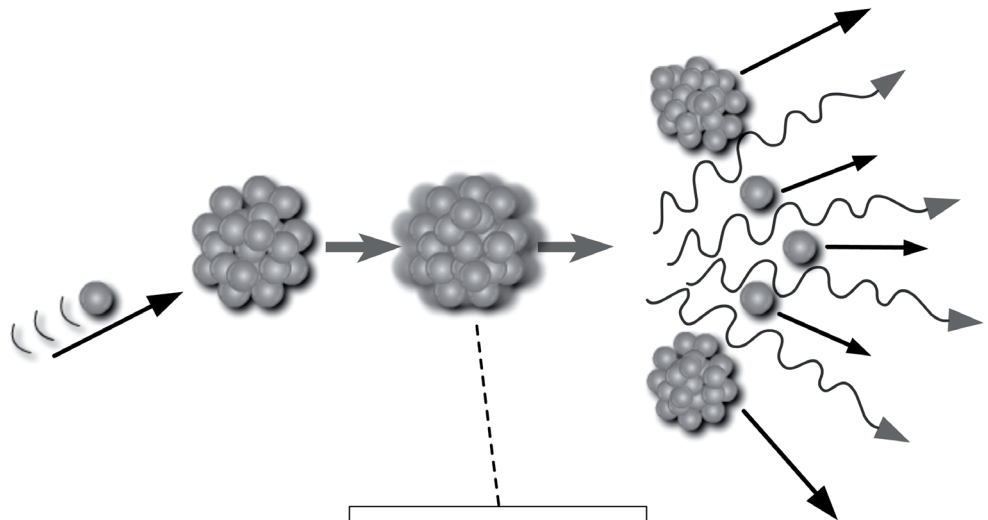
This is the basis of radiocarbon dating.

The effect of fossil fuel burning and thermonuclear explosions on radiocarbon dating

As we have seen, radiocarbon dating depends on having a constant $^{14}\text{C}/^{12}\text{C}$ ratio. Fossil fuels such as coal and oil are very old. This means that virtually all of the carbon-14 in fossil fuels will long since have decayed. So all the carbon released into the atmosphere when coal or petrol is burnt will contain little or no ^{14}C . This will change the ratio and make our radiocarbon dating less accurate. Similarly, the nuclear bomb testing that went on in the 1950s and 1960s (mainly by Russia and the USA) caused carbon-14 levels to increase unnaturally. Again this has made current radiocarbon dating less accurate.



NUCLEAR FISSION



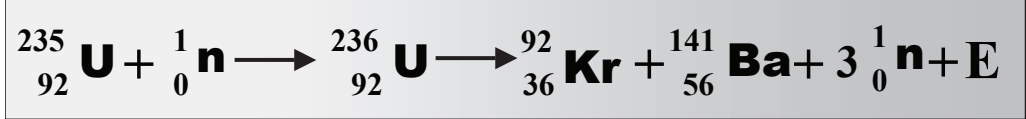
STAGE 2
The slow neutron joins the ^{235}U nucleus. A highly unstable uranium-236 is formed.

STAGE 1
A slow (thermal) neutron collides with the nucleus of the ^{235}U (uranium-235) atom.

STAGE 2
The slow neutron joins the ^{235}U nucleus. A highly unstable uranium-236 is formed.

STAGE 3
Unstable ^{236}U breaks up into several pieces in a process called “**nuclear fission**”.

- The process of nuclear fission is not the same as radioactive decay because it is caused by a separate particle – in the case of ^{235}U , it is a slow-moving neutron.
- In the process of nuclear fission a huge amount of energy (represented by the wavy arrows) is given off. This is the energy that held the nucleus together before it broke up. The energy that holds the nucleus together is called the nuclear binding energy.
- The fission of ^{235}U is the nuclear reaction that occurs during the explosion of an atomic bomb.
- The nuclear equation for the fission of the uranium-235 nucleus is:



- The three thermal neutrons that are emitted during the fission of uranium-235 can each cause the fission of another uranium atom. This is called a nuclear chain reaction and it happens almost instantaneously. The number of neutrons produced increases by a power of three in each step.
- If each step takes, say, 10^{-12}s , calculate the time taken for 10 steps and how many neutrons will have been released. This will give some idea of the scale of nuclear reactions. Also remember that a large amount of energy is released for every nucleus that breaks up. ($3^0, 3^1, 3^2, 3^3, 3^4, 3^5, 3^6, 3^7, 3^8, 3^9, 3^{10}, 3^{12}, 3^{13}, 3^{14}, 3^{15}$ [± 45 million] etc.)



AN INTRODUCTION TO CHEMICAL BONDING

We will leave nuclear reactions for a while and return to chemistry – where we deal with the interactions of electrons.

Electrons are arranged in the atom according to the pattern set by the periodic table.

HAVE A PERIODIC TABLE HANDY AS YOU STUDY THIS SECTION.

Electronic configurations 1: how electrons are arranged in an atom

Look at the table. As you study it, some rules will emerge for the filling of electrons in the energy levels of atoms.

- The number of electrons in a neutral atom is determined by its atomic number (Z), i.e. the number of protons in the nucleus.
- Each ROW (or PERIOD) on the periodic table represents one electron energy level.
- Each electron energy level contains one or more pairs of electrons.
- Electrons fill energy levels in pairs.
- The first ROW (or PERIOD) contains only two atoms: H and He, i.e. in the first energy level, there is only space for ONE PAIR of electrons.
- Therefore hydrogen, H, has an unfilled first electron energy level.
- Helium, He, a noble gas, has a filled first electron energy level. (All noble gases have filled energy levels.)
- Helium is a noble (or “inert”) gas because it has a filled, outer electron energy level.
- The noble gases (He, Ne, Ar ...) have filled energy levels. In a sense they are “satisfied” and don’t need any extra electrons.
- In 1916 Gilbert Lewis (a famous American chemist) suggested that when an atom reacts with one or more other atoms, it tries to fill its outer energy level with the maximum number of electrons needed to fill the energy level.
- Lewis also suggested that atoms could share electrons in order to fill the outer energy level. (This gives rise to what we call covalent bonds.)
- Today we still use the clever system of diagrams that Lewis invented to show how the electron levels of atoms fill and how atoms combine by sharing electrons.
- Lewis diagrams usually use dots (•) to represent the outer electrons in a single atom but crosses (x) can be useful to distinguish between electrons coming from different atoms in bonding situations. The electrons themselves are identical.
- The symbol for the element represents the nucleus and the electrons in the inner energy levels.
- From a chemical point of view, we are only interested in the outer electrons because only these electrons will take part in chemical reactions.

On the next page are the Lewis diagrams for the first twenty atoms.





LEWIS STRUCTURES

$\times \text{H}$	Li	$\times \text{Na}$	K	
$\times \times \text{Be}$	Mg	$\times \times \text{Ca}$		

$\times \text{H}$	$\cdot \text{B} \cdot$	$\times \text{C} \times$	$\cdot \text{N} \cdot$	$\times \times \text{O} \times$	$\cdot \text{F} \cdot$	$\times \times \text{Ne} \times \times$
$\times \times \text{He}$	$\times \times \text{Al} \times$	$\cdot \text{Si} \cdot$	$\times \times \text{P} \times$	$\cdot \text{S} \cdot$	$\times \times \text{Cl} \times$	$\cdot \text{Ar} \cdot$

Notice how the electrons fill the second and third electron energy levels (rows, across). For Li (lithium), Na (sodium) and K (potassium), there is one electron in the outer energy level. For Be, Mg and Ca their outer electrons are shown as a pair. These are all metals and they normally give up their one or two outer electrons in reactions and become ions, i.e. Li^+ , Na^+ , K^+ , Be^{2+} , Mg^{2+} , Ca^{2+} . From B to F (boron to fluorine) and again from Al to Cl (aluminium and chlorine), the outer electrons are shown as filling the eight available places first, singly up to carbon (C) and silicon (Si). Then from N to Ne (nitrogen and neon) and from P to Ar (phosphorus and argon) the electrons begin to form pairs. The noble (or "inert") gases all have the maximum number of electrons that the outer energy level can hold, i.e. two for helium, eight for neon and eight for argon. The outer electrons that can take part in bonding with other atoms are known as the **valence electrons**. Hydrogen is shown in two positions. It can behave as though it has one unshared electron in its outer energy level or as though it needs one electron to achieve the inert gas electron configuration.

Electronic configurations 2: how electrons are arranged in an atom

The periodic table tells us how the electrons are arranged in atoms. Make sure you know the table well so that you can read off it all the information you need.

The Lewis diagrams tell us how many valence electrons there are in the outer energy level. If we write out the total number of electrons for the first 20 elements, we get this picture:

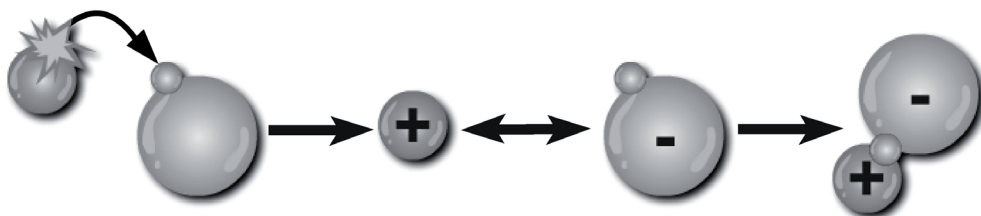
₁ H	1				₁₁ Na	2	8	1	
₂ He	2	[full energy level]			₁₂ Mg	2	8	2	
₃ Li	2	1			₁₃ Al	2	8	3	
₄ Be	2	2			₁₄ Si	2	8	4	
₅ B	2	3			₁₅ P	2	8	5	
₆ C	2	4			₁₆ S	2	8	6	
₇ N	2	5			₁₇ Cl	2	8	7	
₈ O	2	6			₁₈ Ar	2	8	8	[full energy level]
₉ F	2	7			₁₉ K	2	8	8	1
₁₀ Ne	2	8	[full energy level]		₂₀ Ca	2	8	8	2

BONDS

Bonding is the joining of two atoms through the transfer or sharing of electrons. When electrons are transferred from one atom to another, one becomes a positively charged ion and the other a negatively charged ion. This leads to simple, electrostatic attraction – or ionic bonding.

Ionic bonding

A simple picture of an **ionic bond** is two atoms coming close enough to one another for one of them (the non-metal) to gain one or more electrons from the other (usually a metal). Once the electronic exchange has taken place, we have two ions. One will be an **anion** (i.e. negative after gaining an electron or electrons) and the other a **cation** (positive). Because they are close together, they will exert a coulomb force of attraction on one another.

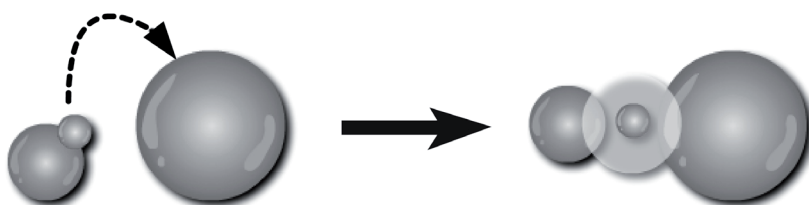


Covalent bonding

Two different atoms might not exert enough mutual force on one another for electrons to be removed from (lost) or added to (gained) atoms for ions to be formed. Lewis's great insight was that atoms might share electrons and form what he called **covalent bonds**. The word "covalent" tells us that the bonding involves the two atoms doing something *together*. Think of the words **co**-operate and **valent**. When talking **either** of outer electrons in an atom which can be passed to another atom **or** the number of places in the outer energy level which are empty and need to be filled (to attain a noble gas configuration) we use the word **valency** and we talk of **valence electrons**.

So covalent bonding can be understood as **a sharing of the valence electrons rather than a giving or taking**.





BOND LENGTH AND BOND ENERGY

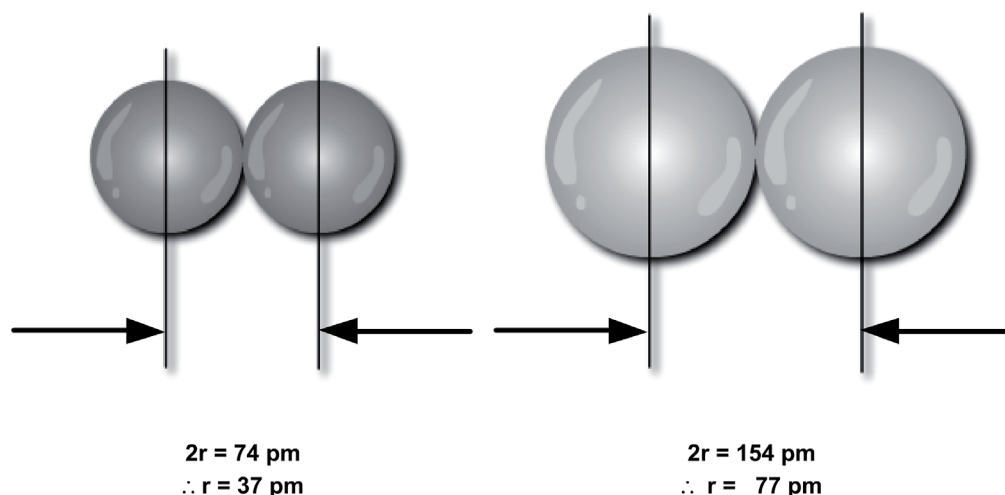
The distance between the centres of two bonded atoms is called the **bond length**. Bond lengths depend on many factors but in general they are very consistent.

Bond lengths can be determined using a variety of analytical instruments and methods, e.g. studying the light emitted or absorbed by molecules or by examining the patterns that X-rays make when they pass through crystalline solids.

The bond lengths range from the shortest of 74 pm for H-H bond to as large as 200 pm for large atoms. Half of the bond length of a single bond of two similar atoms (e.g. H-H) is called the **covalent radius** and this is used to calculate bond length. The sum of two covalent radii of two atoms is usually the single bond length.

Example

The covalent radii of H and C are 37 pm and 77 pm respectively.



Therefore the **C-H** bond length, calculated in this way, is $(37+77) = 114 \text{ pm}$.

The amount of energy required to break a bond is called **bond energy**. As bond lengths are consistent, bond energies of similar bonds are also consistent. Thus, tables of bond energies are also of common occurrence in handbooks. Some typical bond lengths in picometres ($1 \text{ pm} = 10^{-12} \text{ m}$) and bond energies in kJ/mol are given below.

The bond energy is essentially the average energy change when, in a gas reaction (the molecules are in a gaseous form), all the bonds of one type are broken. Bond energy also tells us how strong a chemical bond is: the greater the bond energy, the stronger the bond.



Bond length (pm) and bond energy (kJ/mol)					
Bond	Length	Energy	Bond	Length	Energy
H-H	74	436	H-C	109	413
C-C	154	348	H-N	101	391
N-N	145	170	H-O	96	366
O-O	148	145			
F-F	142	158			
Cl-Cl	199	243			
Br-Br	228	193			
I-I	267	151			
C-N	147	308	C=C	134	614
C-O	143	360	O=O	121	498
C-S	182	272	C=O	120	799
C-F	135	488	H-F	92	568
C-Cl	177	330	H-Cl	127	432
C-Br	194	288	H-Br	141	366
C-I	214	216	H-I	161	298

There appears to be something wrong! Look at the value for the C-H bond length. When we calculated the value from the covalent radii for H-H and C-C we found a C-H bond length of 114 pm. Yet the table shows a value of 109 pm.

Calculate the theoretical bond length for C-O and compare it with the measured value in the table. There is a difference: the measured value is smaller. What causes the difference?

ELECTRONEGATIVITY

The problem of bond length is that the measured value of many bond lengths is less than the calculation using covalent radii. But why should bond lengths contract in bonds between two different atoms? The answer lies in a tendency referred to as “electronegativity”.

- Electronegativity is a measure of the attraction an atom has for a pair of bonding electrons in a covalent bond with another atom.
- Electronegativity only applies in a bond. Therefore it is the electronegativity difference between two bonded atoms that gives us information about the bond.
- Highly electronegative atoms such as fluorine (electronegativity of 4,0) have a very strong attraction for bonding electrons.
- Low electronegativity atoms such as lithium (electronegativity of 1,0) have a weaker hold over the electrons in their bonds with other atoms.
- For obvious reasons (because they do not form bonds under normal circumstances) the inert gases do not have electronegativity values.



The electronegativity of the first 20 elements

H 2,1						
Li 1,0	Be 1,5	B 2,0	C 2,5	N 3,0	O 3,5	F 4,0
Na 0,9	Mg 1,2	Al 1,5	Si 1,8	P 2,1	S 2,5	Cl 3,0
K 0,8	Ca 1,0	Sc 1,3	Ge 1,8	As 2,0	Se 2,4	Br 2,8

Look at the trends in electronegativity values down the columns (also known as groups) and across the rows (or periods).

On this evidence, where would you position the hydrogen atom: in the group of atoms that lose an outer electron and become positive ions or above the halogens (F and Cl) which gain an electron in order to fill the outer level and thereby become negative ions?

PARTIAL IONIC CHARACTER (and partial covalent character)

As a rough rule of thumb, we say that when lithium (Li) ionises it becomes a cation (Li^+). When lithium and fluorine (F) bond their electronegativity difference of 3,0 (i.e. $4,0 - 1,0$) tells us that the valence electron in the bond will spend more of its time nearer to the fluoride side of the bond. The electronegativity difference suggests that this is an ionic bonded molecule. **But how can we say that?**

Linus Pauling, another American chemist, devised a scale to show whether a bond is partially ionic in character or partially covalent. In other words, are the electrons in the bond between two atoms really shared (a low “partial ionic character” value) or are the electrons pulled more strongly towards one or other of the atoms? Logically, if something has a “partial ionic character” of, say, 20% then the other part of its bond character will be a partial covalent character (of 80%). Here is Pauling’s scale of **partial ionic character**.

Difference in electronegativity	Percentage of ionic character	Difference in electronegativity	Percentage of ionic character
0,0	0 e.g. -PH , O_2	1,7	51
0,1	0,5 e.g. -BH	1,8	55
0,2	1	1,9	59
0,3	2 e.g. -SiH	2,0	63 e.g. -AlO
0,4	4	2,1	67
0,5	6 e.g. NO , -CN	2,2	70 e.g. -SiF
0,6	9	2,3	74
0,7	12	2,4	76
0,8	15	2,5	79 e.g. Li_2O , -BeF
0,9	19 e.g. -PN , HCl	2,6	82
1,0	22	2,7	84
1,1	26	2,8	86 e.g. -MgF
1,2	30	2,9	88
1,3	34	3,0	89 e.g. LiF , -CaF
1,4	39 e.g. -OH	3,1	91 e.g. NaF
1,5	43 e.g. -SF	3,2	92 e.g. KF
1,6	47		



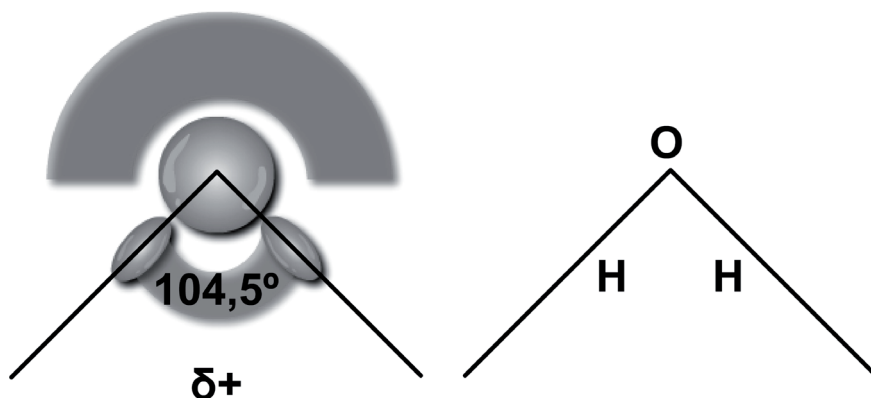
POLAR COVALENT BONDS

As we know, the bonds between the same type of atom are called **covalent bonds** as the electrons in the bond will be shared equally because there is no reason for electrons to favour one or other of the atoms. The table above shows that the bonds between atoms when their electronegativity differs only slightly (say less than 0,7) are predominantly covalent in character. (That is, their partial ionic character is only slight.) The following substances are predominantly covalent:

- Elements: H_2 , Li_2 , B_2 , C_2 , N_2 , O_2 , F_2 , Cl_2 , S_8 , P_4 , I_2 , diamond, graphite, silicon, etc.
- Covalent compounds: H_2O , NH_3 , CH_4 , H_3C-CH_3 , $H_2C=CH_2$, SiO_2 , CO_2 , N_2O_4 , NO_2 , SO_2 , SO_3 , etc.

Theoretically, even ionic bonds have some covalent character. This is why we speak of **polar covalent bonds**. The best-known example of these is water.

We know that certain molecules are polar, for instance the water molecule. **Polar** means that a molecule has a positive end and a negative end. Why does this happen? Let us take water as an example because it is the most important polar molecule in our lives. Oxygen ($Z=8$) has two single electrons in the outer shell as well as two paired electrons. Hydrogen ($Z=1$) has a single electron and it is available for bonding. So two hydrogen atoms (electronegativity 2,1) readily bond with an oxygen atom (electronegativity 3,5). The electronegativity difference between H and O is 1,4. This electronegativity difference is sufficient to cause the bonding electrons in the H to O bonds to spend more time nearer the oxygen end of the bond, making water a polar covalent molecule with a slightly negative end (δ^-) and a slightly positive end (δ^+).



When you study the shapes of molecules, you will find that the water molecule's shape is influenced by the two pairs of electrons in the outer shell of oxygen. These are referred to as **lone pairs**. (This will be discussed in much greater detail in the lesson on VSEPR.)



Activity

- Separate the first 20 elements into metals, non-metal solids and gases.
- If the relative at mass of oxygen is 15,999, what will be the order of abundance (top to bottom) of these three isotopes: ^{15}O , ^{16}O , ^{17}O ?
If necessary consult the list of isotope half-lives given below.
- Radium-226 decays into radon-222 and an alpha particle. Write the nuclear reaction for this decay.
- Strontium-90 ($Z=38$) was one of the radioactive isotopes released into the atmosphere during the meltdown of the Chernobyl nuclear power station in Russia in 1986. It undergoes β -decay and forms ytterbium-90 ($Z=39$).
 - Write down the equation for the decay.
 - If $1\mu\text{g}$ of ^{90}Sr falls on a surface, calculate the average number of atoms that will decay every second because of the strontium's decay during the first half-life.
- What are the five most stable and the five least stable isotopes on the list?
- By how much does the radioactivity of:
 - Radium-228 decrease in 12 years?
 - ^{32}Si decrease in 2 500 years?
- Why does the excessive burning of fossil fuels affect ^{14}C radiocarbon dating?
- Use Lewis diagrams to show the bonding in chlorine gas.
- Calculate the theoretical values for the C-O and C-N bond lengths.
- Explain why the theoretical values for the C-O and C-N bonds are larger than the measured bond lengths.
- Why is the H-I bond stronger than the C-I bond?
- Which two elements from $Z=1$ to $Z=20$ will yield the strongest and most strongly ionic bond?
- Which of the following molecules will have the strongest polarity: water or hydrogen sulphide (H_2S)?
- Carbon dioxide is not polar. Can you explain why?
- Write the symbols for the nuclei in the list.

ELEMENT

Bismuth-208
 Bismuth-210
 Cadmium-113m
 Calcium-42
 Carbon-14
 Cesium-134
 Cobalt-60
 Hydrogen-3 (tritium)
 Iodine-129
 Iron-55
 Lead-205

NUCLEUS

^3_1H

HALF-LIFE

4×10^5 years
 5 days
 14 years
 14 000 years
 5 730 years
 2 years
 5 years
 12 years
 $15,7 \times 10^6$ years
 3 years
 14,3 years



Lead-210		22 years
Molybdenum-93		3 500 years
Phosphorus-32		14,3 days
Potassium-40		1×10^9 years
Radium-224		37 years
Radium-225		14 years
Radium-226		1 622 years
Radium-228		6 years
Radon-222		3,82 days
Radon-223		11 days
Silicon-32		500 years
Strontium-90		28,78 years
Thorium-227		19 days
Thorium-228		2 years
Thorium-229		7 300 years
Thorium-230		$7,7 \times 10^4$ years
Thorium-231		1 day
Thorium-232		14×10^9 years
Thorium-234		24,1 days
Uranium-234		$2,48 \times 10^5$ years
Uranium-235		7×10^8 years
Uranium-236		$2,39 \times 10^7$ years
Uranium-238		$4,51 \times 10^9$ years



ELECTRON INTERACTIONS (1): MULTIPLE BONDS, OXIDATION STATE, MOLECULAR SHAPE AND CONDUCTION

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2: Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1: Recalling and stating specified concepts.

Assessment Standard 2: Indicating and explaining relationships.

Overview

In this lesson we will look at more electron interactions – including the behaviour of electrons in solids such as metals and an interesting and important category of materials that lies between metals and non-metals called semi-conductors.

All of the chemistry sections will draw on basic concepts covered in Lessons 15 and 16. And once again, please use these lessons – which are notes on key concepts as much as they are actual lessons – **with** and **not instead of** your textbook. If you are studying alone it is strongly recommended that you buy, from among the many good books available, a textbook that appeals to your personal learning style and which you find readable.

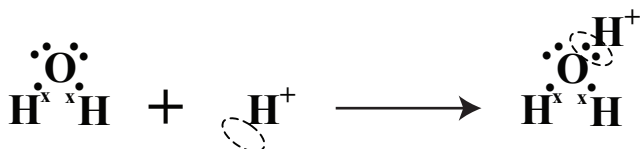
- Multiple bonds
- Oxidation state and oxidation number
 - Explaining the relative electron “richness” of bonded atoms
- Predicting molecular shape
 - Valence shell electron pair repulsion (VSEPR) theory
 - Is water a polar molecule?
- Ionic liquids
 - Conduction in ionic liquids
- Metals
 - Conduction bands: conduction in metals
- Insulators
 - The breakdown of insulators
- Semiconductors
 - Principles of the p-n junction and the junction diode
 - Conduction in semiconductors
 - Intrinsic properties and doping – properties by design
 - p-type (gallium doping)
 - n-type (arsenic doping)
 - Characteristic curve



Lesson

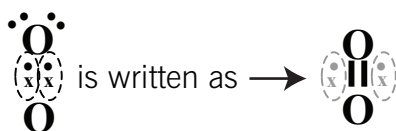
MULTIPLE BONDS

Using Lewis diagrams, we can see how two atoms can bond by sharing a pair of electrons. Normally the shared pair will be formed by each of the atoms providing an electron to the pair. Once the pair is formed one cannot tell which electron comes from which atom because electrons are identical. In what is known as a **dative covalent bond**, one atom can provide both electrons in a bonding pair. This happens when one atom has a **lone pair** of electrons and it is shared with an atom or ion that has an empty “orbital” in its outer electron shell.

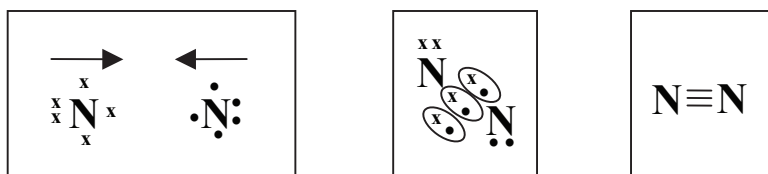


Another kind of bonding can take place when an atom with more than one unpaired electron (e.g. the oxygen atom) can form more than one covalent bond with another atom, even an atom of the same element. **Multiple bonds** can be either **double** or **triple** bonds. Here are some examples.

Two oxygen atoms bond in a **double covalent bond**:



When two nitrogen atoms bond, three unshared electrons from each nitrogen atom will pair up to give three separate covalent bonds, or a **triple covalent bond**:



Double and triple bond energies are greater than single bond energies, for the obvious reason that the atoms are held together more strongly. The stronger bonding of the multiple bonds also has an effect on the bond length. (See **ACTIVITIES** below.)

OXIDATION STATE AND OXIDATION NUMBER

When atoms bond to form a molecule (e.g. H_2O or SO_3) or a complex ion (e.g. NH_4^+ or MnO_4^- or $\text{Cr}_2\text{O}_7^{2-}$) we can count up all the electrons involved in the various bonds in the molecule and divide these up according to which atoms tend to **give** electrons when bonding takes place and which atoms tend to **take**. We can assign numbers to atoms in a bond that indicate the relative electron “richness” of a bonded atom. For example, in water or H_2O , the more electronegative oxygen atom may appear to have “gained” two electrons from the two hydrogen atoms. Hydrogen atoms, obviously, will appear to have “lost” two electrons (one each) in the process of bonding with the oxygen. Although the bonding process is not as simple as that, this picture does help to explain how atoms behave when they are in certain molecules or complex ions.



Explaining the relative electron “richness” of bonded atoms

The numbers we assign to atoms are either positive (e.g. +3) or negative (e.g. -2). An atom which appears more likely to have “given up” electrons will be positive, and vice versa. Fortunately, there are some atoms that are very consistent in their behaviour. For instance, hydrogen almost always “gives up” one electron and oxygen almost always “gains” two electrons, so we say that their **oxidation numbers** or the **oxidation state** of hydrogen and oxygen when they are bonded into molecules or ions will be **+1** or **-2**.

The oxidation state of an atom can be written in stock notation, which uses Roman numerals to indicate the oxidation state, e.g. copper(I) oxide (Cu_2O) or copper(II) oxide (CuO), known as cuprous oxide and cupric oxide respectively. When atoms can have more than one oxidation state – e.g. Cu(I) or Cu(II) – the *lower* state is called **–ous** and the *higher* oxidation state is called **–ic**.

The basic rules for determining oxidation numbers are as follows:

- The neutral atom of an element is ... 0
- Ion with a charge of $n+$ or $n-$ is ... $+N$ or $-N$
- Polyatomic ions with a charge of $n+$ or $n-$ is ... $+N$ or $-N$
- Hydrogen and oxygen are ... $+1$ and -2
- Group 1A is ... $+1$
- Group 2A is ... $+2$
- Group 3 is ... $+3$
- Group 5 is ... -3
- Group 7 is ... -1
- Molecules: the sum of the oxidation numbers is ... 0

Sulphur can have various oxidation states. For instance, in H_2S sulphur is -2 , i.e. it has an oxidation number like that of oxygen, but in SO_2 and SO_3 it has oxidation numbers of $[+4 + 2(-2) = 0]$ and $[+6 + 3(-2) = 0]$ respectively. In its natural state, sulphur forms rings of eight sulphur atoms, i.e. S_8 . In this arrangement, because it is a pure element, the oxidation number will be 0. The oxidation numbers of oxygen, nitrogen and chlorine in their natural states is also 0 even though we know that the gases occur as diatomic molecules, i.e. O_2 , N_2 and Cl_2 .

I	II		III	IV	V	VI	VII	VIII
H +1								He 0
Li +1	Be +2		B +3	C +4 (+2)	N +5 (-3)	O -2	F -1	Ne 0
Na +1	Mg +2		Al +3	Si +4	P +5	S *	Cl -1	Ar 0
K +1	Ca +2		Ga +3	Ge +4	As +5			



PREDICTING MOLECULAR SHAPE

We have been looking at the electronic constitution of atoms but so far we have concentrated only on the numbers of electrons. An important factor in explaining the behaviour of compounds is to know their shape. As we see in the case of water, a molecule's shape can be very influential in its chemical behaviour. A simple and effective method of working out molecular shape is called the ...

VALENCE SHELL ELECTRON PAIR REPULSION (VSEPR) THEORY

In effect, all VSEPR does is provide a method for determining the number of electron pairs that are distributed around the central atom in a molecule. When the number of pairs has been calculated, it is relatively simple to visualise how the pairs will be arranged around the central atom. Before we can use VSEPR, there are a few basics to be mastered.

To do VSEPR calculations, one must know how to ...

- determine the electron arrangement of the outer shells of atoms from the periodic table and hence ...
- find the number of valence electrons in an atom of an element;
- represent molecules using Lewis diagrams;
- deduce the bonding of different atoms from the sharing of unpaired valence electrons (atoms with incomplete complements of electrons in their valence shells can share);
- deduce the number of lone pairs on atoms that do not share these electrons to form bonds;
- deduce where a lone pair of electrons from another atom might form a dative covalent bond with an empty space (or orbital) in the valence shell of an atom as in NH_4^+ , H_3O^+ ; and
- deduce where atoms with more than one unpaired valence electron can share these electrons to form multiple bonds.

Armed with this knowledge one can ...

- draw Lewis diagrams, given the formula and using electron configurations, for simple molecules, e.g. F_2 , H_2O , NH_3 , HF , OF_2 , HOCl ;
- for molecules with multiple bonds, e.g. N_2 , O_2 and HCN ;
- for molecules where atoms can have variable valencies, e.g. H_2S , SO_2 , SO_3 ; and
- for atoms or molecules which donate a lone pair to another molecule or ion with vacant orbitals in the valence shell forming a dative covalent bond e.g. H_3NBF_3 .

Thus the underlying assumptions in the VSEPR method about the nature of bonding are ...

- atoms in a molecule are bound together by electron pairs called bonding pairs;
- more than one set of bonding pairs may result in multiple bonding;
- some atoms may also possess pairs of electrons not involved in bonding called lone pairs or non-bonded pairs;
- bonding pairs and lone pairs around an atom in a molecule adopt positions in which their repulsions are minimised, i.e. electron pairs are negatively charged and will force each other as far apart as possible; and



- lone pairs occupy more space than bonding electron pairs and influence bond angles and molecular shape.

GEOMETRIES

- Imagine that all molecules are based on only five geometrical shapes.
- The nucleus of the central atom in the molecule is at the centre of a sphere.
- The electron pairs are spread out over the surface of that sphere ... so that they are as far apart as possible.

The resulting geometries are quite simple. If there are ...

... 2 e ⁻ pairs		then the molecule will be linear
... 3 e ⁻ pairs	“ “ “ “	will be trigonal planar
... 4 e ⁻ pairs	“ “ “ “	will be tetrahedral
... 5 e ⁻ pairs	“ “ “ “	will be trigonal bipyramidal
... 6 e ⁻ pairs	“ “ “ “	will be octahedral .

- Once the simple picture is known, factors such as the influence of lone pairs of electrons can be considered.

USING THE VSEPR WORKSHEET (See next page or page 303)

- Write down the molecular formula, e.g. H₂O.
- Draw a Lewis structure based on the central atom.
This structure is also known as the structural formula.
(One can use lines or pairs of dots/crosses to show the bonding pairs.)
- Determine the number of valence electrons on the central atom.
- Identify singly, doubly or triply bonded atoms and any dative covalent bonds.
- Always regard groups such as =O and =S as being double bonded to the central atom and groups such as ≡N and ≡P as being triple bonded.
- The geometry of a molecule is determined by the bond framework regardless of whether the bonds are single or double.
 - Therefore the electrons from the central atom electrons that are involved in double bonds can be discounted, i.e. subtract one electron for each double bond involving the central atom.
- Any overall charge on the molecule is always assigned to the central atom.
 - Thus a negative charge constitutes an additional electron for the central atom, while a positive charge requires subtraction of one electron from the central atom electron count, and so on.
- Divide the total number of electrons associated with the central atom by two to give the number of electron pairs and determine the basic molecular geometry.

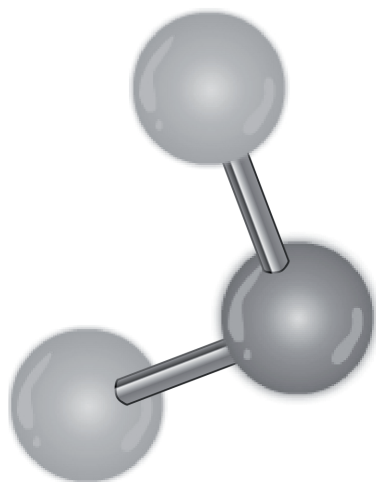


Is water a polar molecule?

As we all know, water is made up of three atoms, two of hydrogen and one of oxygen. An interesting bit of geometry arises here. If you look at the round black pots (“potjies”) that we use for cooking over an open fire, you will see that it has three legs. There is a good geometrical reason for this: a plane can be defined by three points.

What that means is that no matter how uneven the ground is, the three legs of a black pot will always stand firm, whereas a four-legged pot might rock because

one leg is at a different level to the other three. So when we see that water has three atoms in it we might be tempted to say that it is a planar molecule. That would be a fair deduction to make but if we do the VSEPR calculation for water we discover something unexpected.



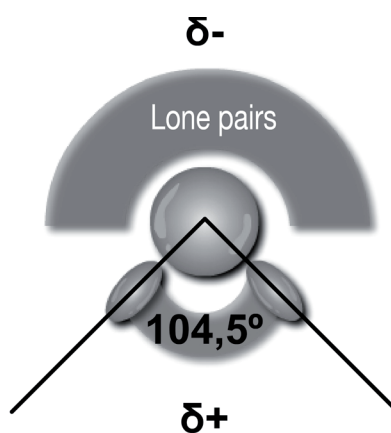
Is **water (H₂O)** a **planar** or a **tetrahedral** molecule?

The VSEPR worksheet is completed as follows:

Molecule (Molecular formula): H ₂ O	Lewis structure (Structural formula)	Electron arrangement on central atom (Valence electrons, i.e. outer shell) O: (inner) 2 + (outer) 2,4	
Atoms attached to the central atom		2 H atoms	
Valence electrons on central atom		6	Total number of electrons
Valence electrons from attached atoms		2 × 1	
Electrons in multiple bonds (Subtract one per multiple bond)		none	8
Electrons in dative covalent bonds (+ 2 e ⁻ per dative covalent.)		none	
Ionic charge (Subtract for positive charged ions)		none	
to find e⁻ pairs		4 pairs	
Therefore the molecular geometry is ...		tetrahedral	

The water molecule has four pairs of electrons on the central oxygen atom, making it a tetrahedral shape. Even though there aren't atoms along each of the four arms, **it is still tetrahedral!** But why?

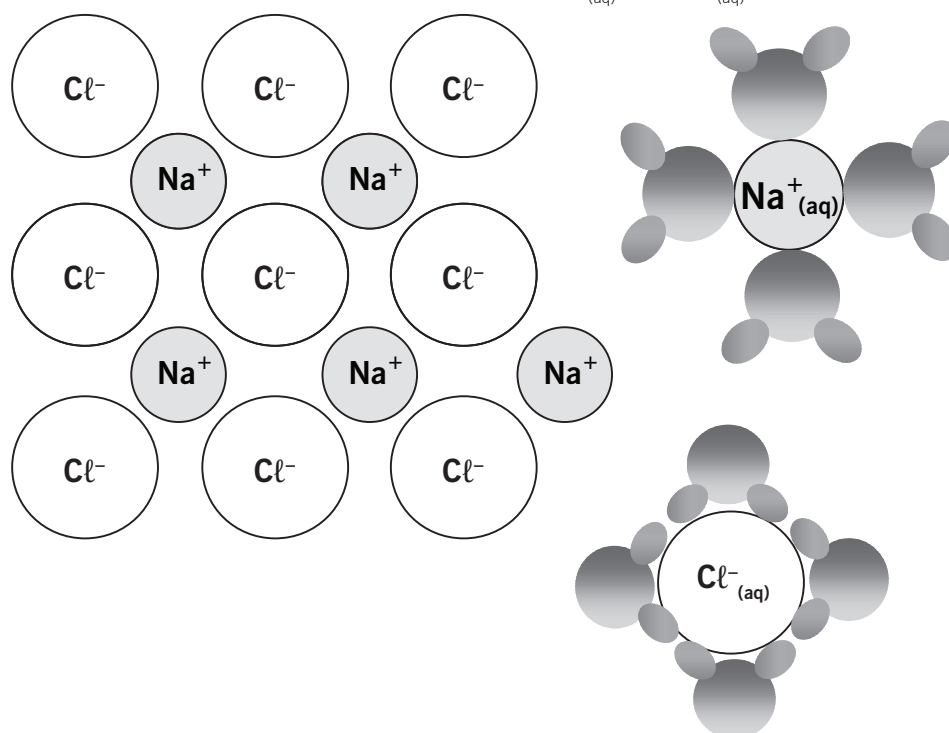
The answer lies in the **lone pairs of electrons**. Oxygen has two of them and its two unpaired electrons form covalent bonds with the hydrogen. (Look at the Lewis diagram again.) The effect of the lone pairs on the oxygen atom is as follows: their repulsive effect on the shared electrons in the O-H bonds causes the H-O-H bond to decrease in size. The expected angle between the arms of a regular tetrahedron is 109,7°. And yet when the H-O-H angle for water molecule is measured accurately the value comes out to be much less: 104,5°.



In addition to this, the electronegativity difference between O and H of 1,4 (3,5 – 2,1) causes the bonding electrons in the H to O bonds to spend more time nearer the oxygen end of the bond, making water a strongly polar covalent molecule.

IONIC LIQUIDS

Because water is a highly polar molecule, it will dissolve ionic solids. Take a crystalline solid like sodium chloride – NaCl. The crystal is actually made up of a regular pattern of Na⁺ ions and Cl⁻ ions. When the crystal is placed in water, the polar water molecules take the crystal ions into solution by first attracting them away from their oppositely charged neighbours. Once the Na⁺ and Cl⁻ ions are in solution, the water molecules form a “jacket” around the ions. Because of this jacket, when ions are in solution we say they are **aqueous ions** (from the Latin word *aqua* meaning “water”) which we write Na⁺_(aq) and Cl⁻_(aq).

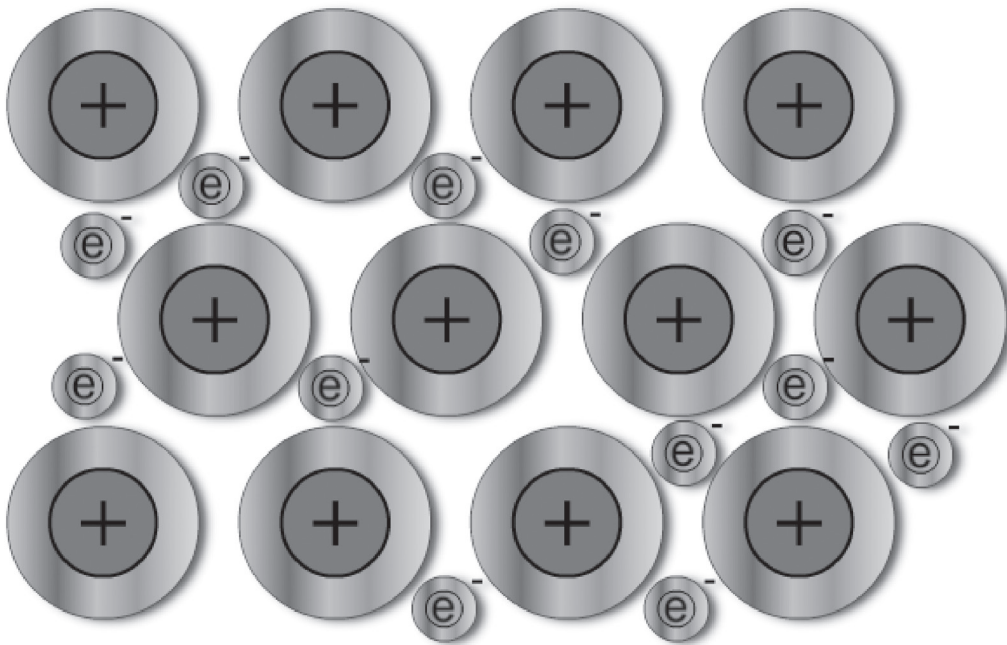


Ions in solution can conduct electricity. When two electrodes or electrical terminals that are connected to a battery are placed in an aqueous solution of ions, the ions will migrate to the oppositely charged electrode. This movement of charge is an electric current – hence we can say that the ionic liquid conducts electricity.

ELECTRONS IN METALS

Metals are usually crystals in that the metal atoms are arranged in neat, ordered arrangements – what we called crystal lattices. From the section on electrostatics, you will remember that the force of attraction between two oppositely charged bodies depends on the size of the two charges and their distance apart. Metals have valence electrons that are quite weakly held or attracted by the nucleus (they can be given up easily during chemical reactions) because they are relatively far from the nucleus and the nucleus has a relatively small positive charge. In pure metals we have a situation that looks like this:





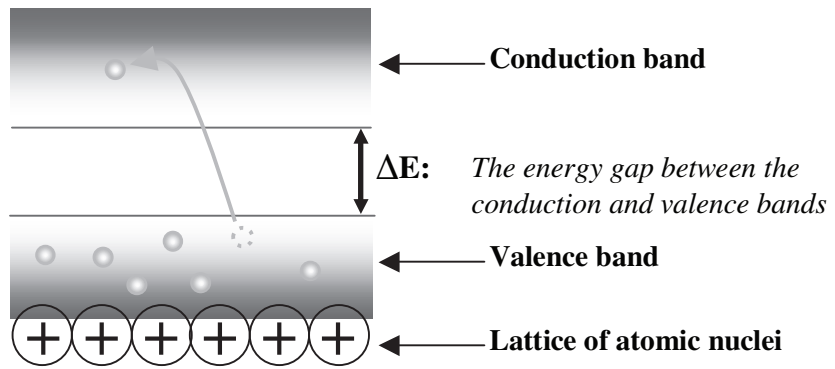
Because the electrons in metals are free to move, when there is an electric field in the metal (i.e. a potential difference across two points in a metal) the movable charges (i.e. the electrons) will move from negative to positive potentials.

BAND THEORY: CONDUCTION AND VALENCE BANDS

A theory used to explain how electrons move (or why they do not move) in solids is called the **band theory of solids**. Electrons in solids, where many atoms are side by side in neat arrangements, can be thought of as forming a “sea” or “gas” of electrons that is able to flow around the atoms quite freely. This is why metals are such good conductors of electricity.

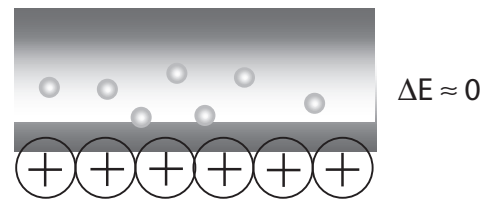
- In band theory we imagine two bands that electrons can occupy.
- These are called the valence and conduction bands.
- If the atoms in a solid have valence electrons (as happens in metals), these are found in the valence band.
- Having electrons in the valence band means that a solid could possibly conduct electricity, BUT IT DOES NOT NECESSARILY MEAN THAT THE SOLID WILL DO SO.
- To conduct electricity, a solid must have some of its electrons in the conduction band.
- The size of the energy gap (ΔE) is the amount of energy an electron needs to get from the valence band into the conduction band and therefore be able to conduct electricity.
- The size of the energy gap (ΔE) varies depending on the type of material we are dealing with.



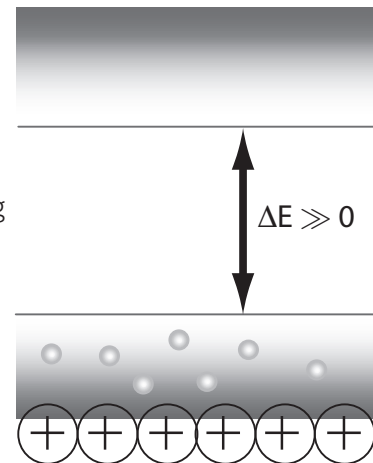


CONDUCTORS AND INSULATORS

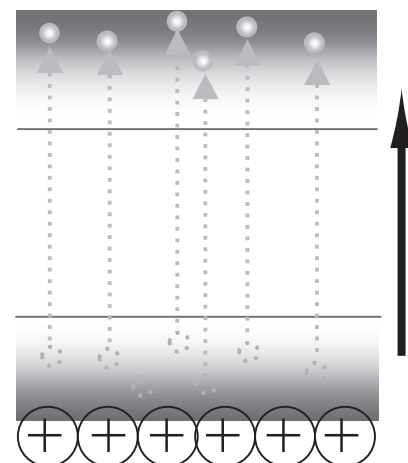
Conductors are materials where the **energy gap (ΔE)** is effectively zero. We picture this as being an overlapping of the valence and conduction bands, which means that all the valence electrons are free to conduct electricity.



Insulators are materials in which the energy gap is large, effectively preventing electrons from entering the conduction band.



The breakdown of insulators occurs when a large potential difference is applied to a material, thus giving the valence electrons enough energy to “jump” the large energy gap. The material can conduct electricity when breakdown occurs.



SEMICONDUCTORS

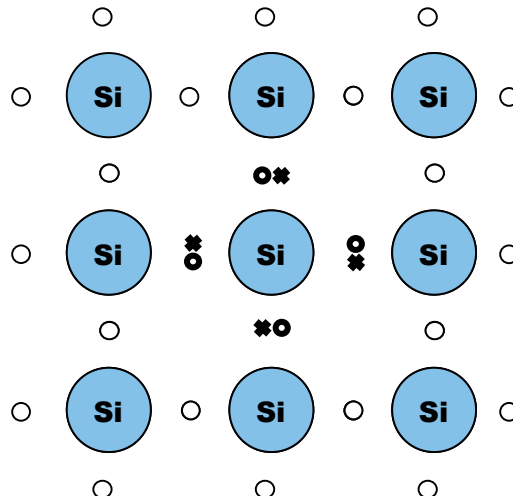
Two materials in particular, silicon (Si) and germanium (Ge), exhibit a property that makes them **semiconductors**. The valence and conduction bands in semiconductors do not overlap, but nor are they as far apart as in insulators. If a way could be found to help electrons move across the gap then semiconductors could be made to conduct. Fortunately there is a way of doing this.



Doping

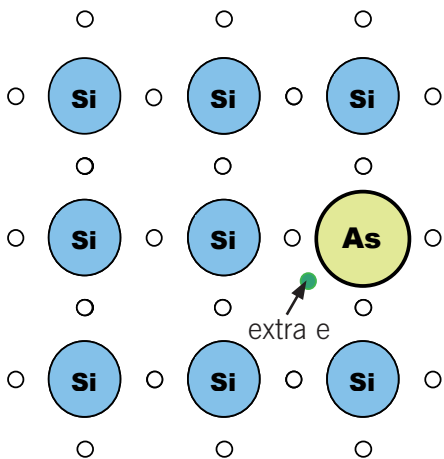
Silicon has an electron structure similar to carbon: four valence electrons which allow it to form strong bonds with other silicon atoms in its crystal lattice.

The method of doping involves taking an element that has either one valence electron more than silicon (e.g. arsenic [As]) or one valence electron less than silicon (e.g. gallium or aluminium [Ga or Al]).

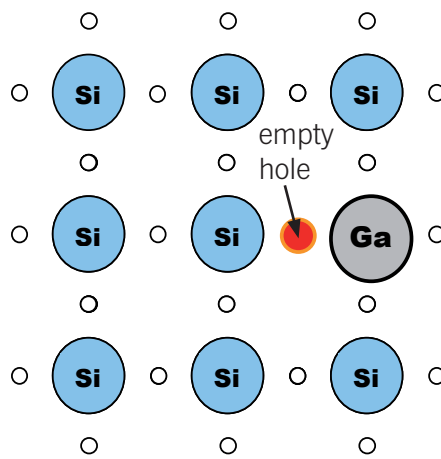


Look at your periodic table and see why both silicon (Si) and germanium (Ge) can be used as semiconductors and why aluminium (Al), gallium (Ga) and arsenic (As) are used as doping agents.

These two diagrams illustrate the effect of introducing extra electrons into silicon (**n-type**, using **arsenic as a doping agent**) or of introducing a “hole” or an empty space with an electron missing (**p-type**, using **gallium as a doping agent**)



Arsenic doped: n-type

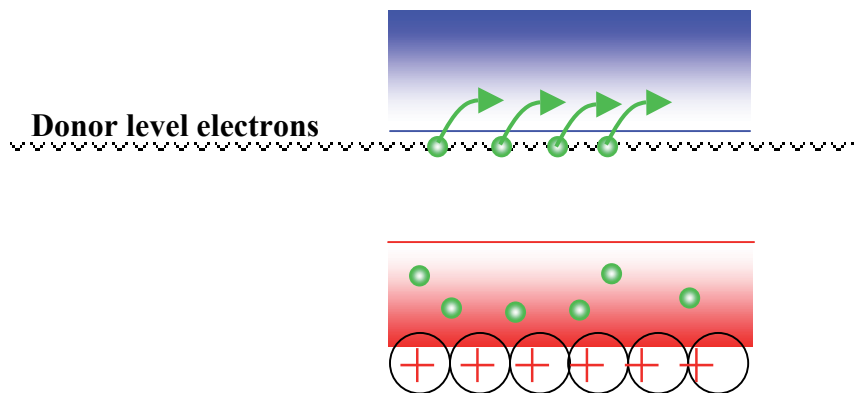


Gallium doped: p-type

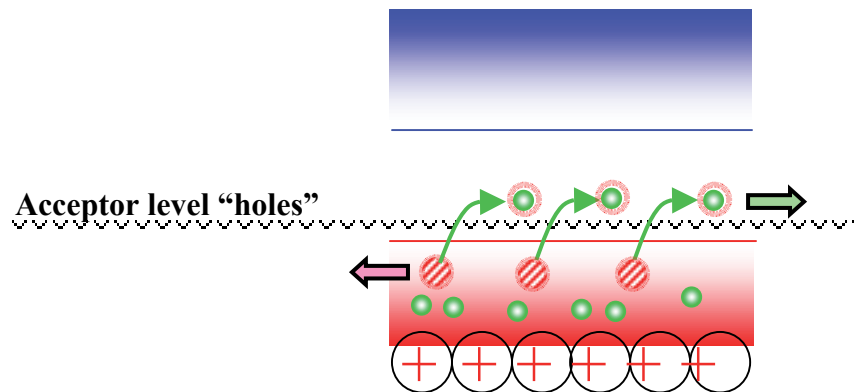
The band theory picture of these two doped semiconductors shows two different situations.

First there is a **donor level** in the gap between the valence and conduction bands for the **n-type**. The extra electrons from the arsenic-doped silicon fills the donor level and when these electrons make the move into the conduction band, the semiconductor starts conducting. Because **the donor levels are closer to the conduction band** in energy, it takes little energy to get the electrons in the donor level to make the move. This can happen at room temperature. The conducting ability of semiconductors depends on temperature. As temperature increases, conducting ability also increases. We say that ΔE is “temperature-dependent”.



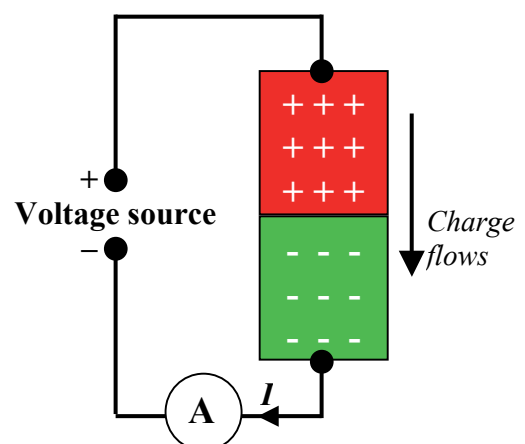
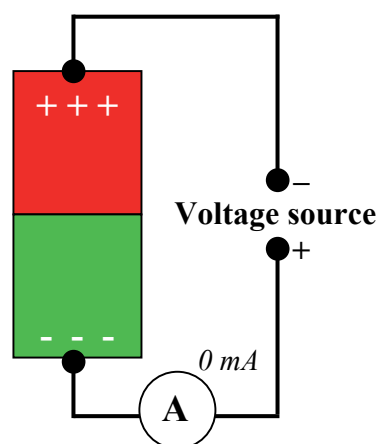


Then there is an **acceptor level** in the gap between the valence and conduction bands for the **p-type semiconductor**, but this is close to the valence band. The acceptor level **does not contain extra electrons** but empty spaces from the gallium doping. Electrons from the valence band can enter these empty spaces and as they do we get “holes” in the valence band moving in the opposite direction to the electrons in the acceptor level. This also represents a semiconductor that is conducting. The **acceptor levels are close to the valence band**, so once again it takes very little energy for the semiconductor to start conducting.



The principle of the p-n junction and the junction diode

If a piece of p-type semiconductor is joined to some n-type semiconductor and the two pieces are then joined, end-on, as shown, we get what is known as a “p-n junction diode” or just “a junction diode”. A diode is a device with two electrical poles, in other words it has a positive end and a negative end.



When the **negative terminal** from the voltage source is connected to the **p-type side of a p-n diode**, we refer to this as **reverse biased**. The holes in the p-type are



attracted to the negative terminal of the battery (voltage source) and the electrons in the n-type are attracted to the positive terminal. The current carriers (holes and electrons) do not meet at the p-n junction and no charge flows, i.e. $I = 0$ mA.

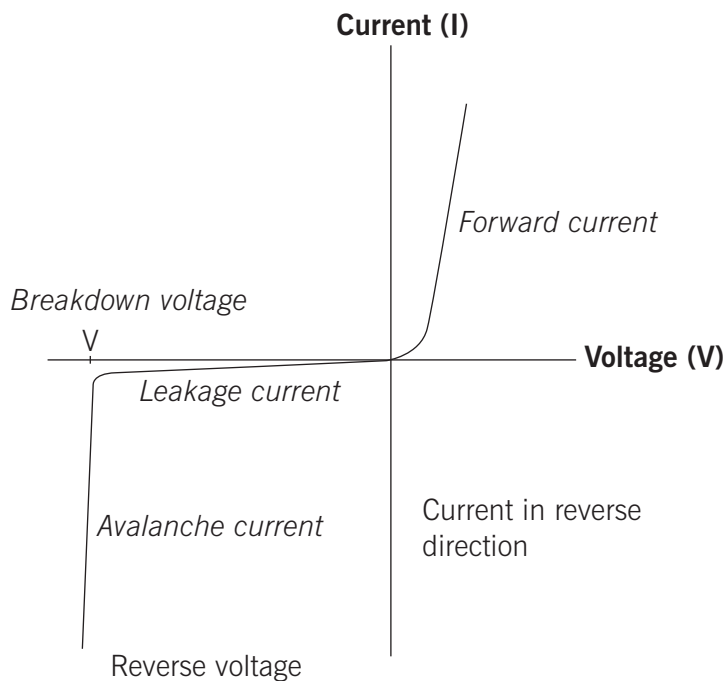
Note 1: If the voltage is very high, the p-n junction breaks down and we get very high currents. This is called “breakdown” and the current is called an “avalanche current”.

Note 2: Even when the reverse-biased voltage is quite low, some charge can “leak” across the p-n junction and we get a small current. This is called “leakage current”.

When the **negative terminal** from the voltage source is connected to the **n-type side of a p-n diode, and vice versa** we refer to this as **forward biased**. As soon as the potential difference is high enough, electrons from the n-type are repelled by the negative terminal (i.e. they are given sufficient energy) and cross the p-n junction to fill the holes in the p-type. The positive terminal continually pulls electrons off the end of the p-type and creates holes so the process continues. There is a high current beyond that voltage where charge has sufficient energy to move across the p-n junction freely.

Characteristic curve for the p-n junction diode

The plot of the current in the p-n junction diode against the applied potential (i.e. either reverse or forward bias) is known as the **characteristic curve**. Follow the explanation given and make sure you understand how this will give rise to the characteristic curve.





PAIRS



BASELINE ASSESSMENT

Activity 1

Examine this table and explain the trends in bond length and bond energies for the multiple bonding that can occur in oxygen, nitrogen and carbon.

Bond length (pm) and bond energy (kJ/mol)					
Bond	Length	Energy	Bond	Length	Energy
O---O	148	145	N-N	145	170
O=O	121	498	N=N	121	498
			N≡N	110	942
C-C	154	346			
C=C	134	602			
C≡C	120	835			



PAIRS



BASELINE ASSESSMENT

Activity 2

Give the following:

- oxidation state/number of the atoms in each molecule; and
- name the compound, showing the oxidation number of any atom given in bold print using stock notation, e.g. **magnesium (II)** chloride (for **MgCl₂**).
 - H₂O
 - SO₃
 - KMnO₄
 - (NH₄)₂SO₄
 - Li₂Cr₂O₇
 - FeCl₂
 - FeCl₃
 - NO₂
 - NO

Activity 3

Use VSEPR theory to determine the shapes of the following molecules:



PAIRS



FORMATIVE ASSESSMENT

Activity 3.1

<p>Ammonia (NH₃)</p> <p>Is the molecule a pyramid or a tetrahedron?</p> <p>(See page 299)</p>	
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Use the worksheet (see page 153 or page 303) and begin by identifying the central atom from the diagrams.

Additional task: Once you have determined the shape of ammonia, explain the bonding and shape of the ammonium ion: **NH₄⁺**. (See page 300.)



Activity 3.2

Boron trifluoride (BF_3)

Show that the molecule has a **trigonal planar** geometry.

(Draw a diagram of the molecule.)

(See page 301)

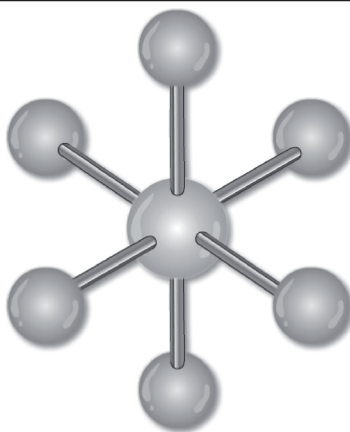


Activity 3.3

Sulphur hexafluoride (SF_6)

What is the **shape** of the SF_6 molecule?

(See page 301)

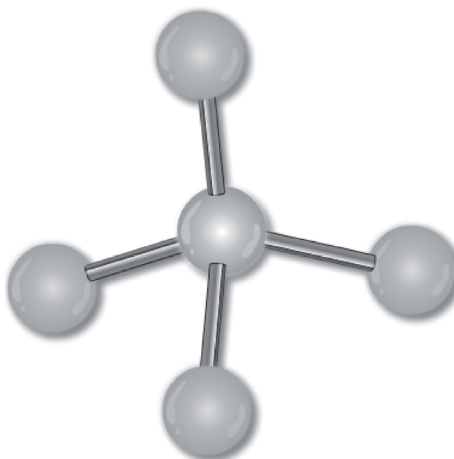


Activity 3.4

Methane (CH_4)

Tetrahedral molecule

(See page 298)



Note: A worksheet for VSEPR calculations can be found on page 303.



EXERCISES ON BASIC CHEMICAL CONCEPTS

Learning Outcomes and Assessment Standards:

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 1:

Conducting an investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

Lesson 17a



INTRODUCTION

What you must know in this section of the curriculum is:

- Atomic numbers, atomic mass and mass number
- Isotope and radio-isotopes
- Lewis theory
- Electronegativity
 - A chemical bond as the net electrostatic force between two atoms sharing electrons
 - Chemical bonds as explained by Lewis theory and represented using Lewis diagrams
 - Electronegativity of atoms to explain the polarity of bonds
- Bond energy and length
- Multiple bonds
- Molecular shape using VSEPR
- Applications of molecular shape and molecular geometry from VSEPR
 - Bond energy and length
 - Multiple bonds
 - Molecular shapes as predicted using the Valence Shell Electron Pair Repulsion (VSEPR) theory

This lesson will focus on calculations using the basic knowledge in this section:

- The periodic table
- Applications of the theory of bonding
- Oxidation number of atoms in molecules to explain their relative “richness” in electrons
- More VSEPR examples



Activity 1

Do the following problems and calculations in a group. Make sure that those who understand the concepts explain them to those who have not yet grasped them.

- What are the atomic numbers of carbon, hydrogen, nitrogen and sulphur?
- What is the atomic number of the uranium-235 isotope?
- How do the uranium-235 and the uranium-238 isotopes differ?
- If the relative atomic mass of carbon is 12,011 u, what is the most common isotope of carbon.
- When a ^{235}U isotope is bombarded with a neutron the latter can embed itself in the nucleus of the larger atom and produce the ^{236}U isotope. This isotope is unstable and breaks up into ^{92}Kr and ^{141}Ba and how many neutrons?
- Which of the following molecules will be polar covalent, ionic and non-polar covalent, and why? Na_2O , H_2S , Cl_2 and HBr .
- Calculate the oxidation number of the atoms in bold print in the following molecules: CH_3F ; $\text{K}_2\text{Cr}_2\text{O}_7$; H_2S ; NO_2 ; SiO_2 ; CuSO_4 .
- In a reaction the oxidation number of manganese (Mn) changes from +7 to +2. What does this signify?
- In the reaction of sulphur dioxide with oxygen, what is the change in oxidation number of the sulphur atom if we take oxygen as being -2?
- Water (H_2O) is well known as a polar solvent. We know this because it easily dissolves ionic salts. This suggests that the water molecule is bonded by polar covalent bonds. Could water be polar if the molecule was linear?



Lesson 17b

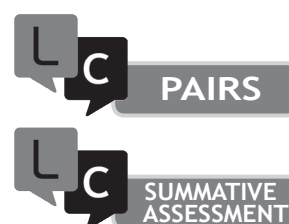
Activity 2

Without referring to the activities in the previous lesson or to the answers, use the VSEPR theory to determine the shape of the METHANE molecule.



Activity 3

Without referring to the activities in the previous lesson or to the answers, use the VSEPR theory to determine the shape of the AMMONIA molecule.





PAIRS



SUMMATIVE
ASSESSMENT



INDIVIDUAL



SUMMATIVE
ASSESSMENT

Activity 4

Without referring to the activities in the previous lesson or to the answers, use the VSEPR theory to determine the shape of the AMMONIUM ION.

Activity 5

Without referring to the activities in the previous lesson or to the answers, use the VSEPR theory to determine the shapes of the following molecules or ions:

PF_6^- ; and BF_3 ; $\text{H}_3\text{N}\cdot\text{BF}_3$; CO_2



NUCLEAR REACTIONS AND INTERACTIONS

Learning Outcomes and Assessment Standards

Lessons 19–20

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

In this lesson we extend some basic concepts and ideas that were introduced in Lessons 15 & 16.

- Nuclear structure and stability
- Ionising radiation
- Fission and fusion and their consequences
 - Nuclear technology
 - A-bombs and H-bombs
- Nucleosynthesis – the Sun and stars
- Age determination in geology and archaeology

O-YAY, O-YAY, O-YAY

In mediaeval Europe, when an important announcement was about to be made, the Town Crier would stand in the town square and call for everybody's attention by yelling "O-yay, o-yay, o-yay!". In modern South Africa, when an important person arrives at an important function, there is an mBongi – a praise-singer – to call attention to the important person's accomplishments.

In science we need such a person – a Town Crier or an mBongi – to draw everybody's attention

**to the fact that ... ENERGY,
or the ability to do work, IS CENTRAL TO
EVERY PROCESS IN THE NATURAL WORLD!**

And that is true of both living and inanimate systems. So we really cannot study meaningfully either the life sciences or the physical sciences until we appreciate that energy is the most important concept in the universe. So understanding natural systems starts with understanding these ...

... TEN IMPORTANT ENERGY FACTS

1. All processes in natural systems involve the input (giving to) or output (taking out or removing) of energy.
2. Energy is the ability to do work. (Simplest definition.)
3. Conversely, in order to do work, energy must be used.
4. Energy is not a physical substance but is very real, all the same.



5. Energy can be manifested in different ways. (We speak of different forms of energy.)
6. Energy cannot be created or destroyed.
7. In natural processes energy can be transferred or transformed.
8. In all processes where something is made or formed, there is an “energy cost”. (In other words, energy is used and probably transformed.)
9. In many processes, where heat is given off during the process, we speak of energy being “lost”. This does not mean that energy has been destroyed. It means that we are unable either to recover all of the heat energy given off or to make use of all of the heat energy to do some other useful work.
10. Much of the energy that is “lost” during processes on Earth is radiated out into the atmosphere and space as heat energy. Fortunately, the Earth is constantly receiving huge amounts of energy from our nearest star, the Sun.

O-yay, o-yay, o-yay!

Lesson

ENERGY

Whenever we find particles held together at a distance or attached to one another in some arrangement, we need to do work on the particles to move them away from those positions. This is true for any size of particle, from the Earth orbiting around the Sun, to our moon orbiting the Earth, to a rock lying on the ground, to a water molecule fixed into an ice crystal, to an electron moving in its shell (or energy level) around an atomic nucleus, to a proton bound to neutrons and other protons in the atomic nucleus.

In all of these cases we must use energy to disrupt or break the arrangement AND we get energy back when we remake the arrangement. Here are some diagrams showing what happens at the molecular, atomic and nuclear levels. In the molecular level we look at an ice crystal held together by intermolecular bonds. At the atomic level we look at electrons in the energy levels of the atom. And at the nuclear level we look at the forces that bind the neutrons and protons together in the nucleus.

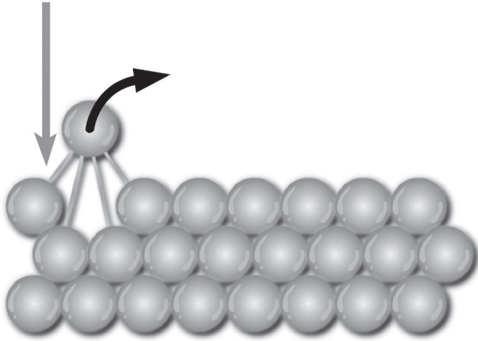
Although the amounts of energy involved in interactions at these three levels differ greatly, the principles involved are exactly the same.



ENERGY TAKEN FROM SURROUNDINGS

When a water molecule is removed from an ice crystal, work is done ON the crystal, i.e. in breaking intermolecular bonds.

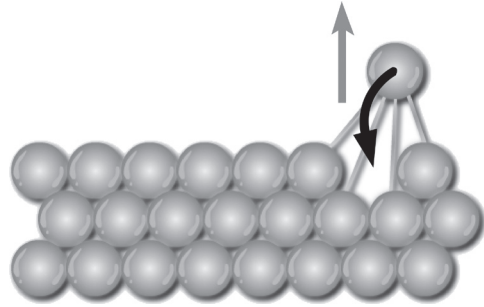
If the energy used to do this work comes from the environment, the environmental temperature drops.



ENERGY GOES INTO THE SURROUNDINGS

When water molecules join ice crystals, there is less energy in the crystal bonds than was possessed by the water vapour molecules.

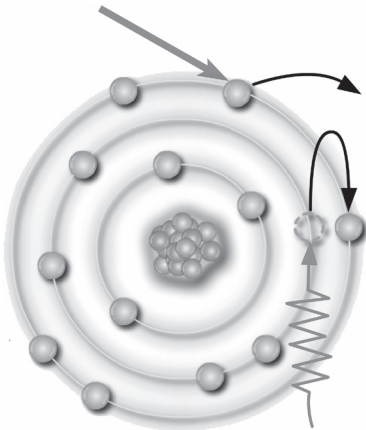
When intermolecular bonds are made, energy passes into the environment, therefore the temperature of the environment will rise.



WORK DONE ON ELECTRONS IN THE ATOM

Electrons can be removed from an atom by extreme heat energy or by other particles striking the outer electrons. When outer electrons are removed from an atom this is called “ionisation”.

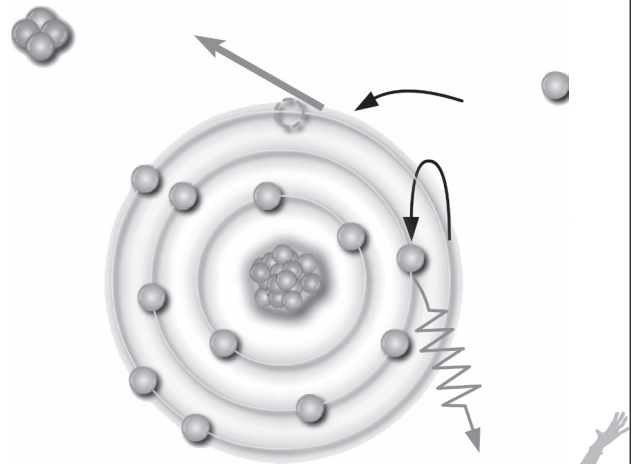
Electrons can be made to “jump” to a higher energy level in an atom by electromagnetic radiation such as light, microwaves or X-rays.



WORK DONE ON ELECTRONS IN THE ATOM

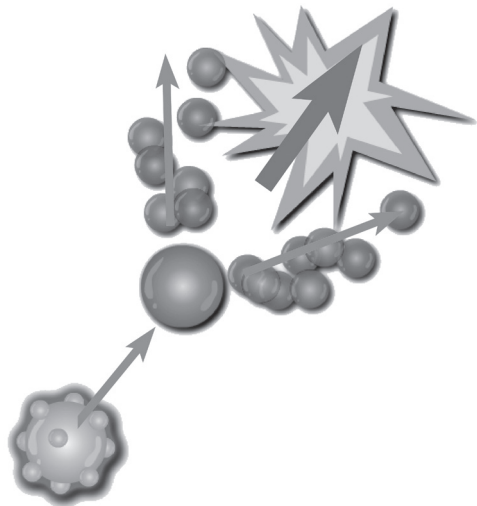
When an electron is replaced in an outer energy level that it was previously removed from, the same amount of energy is given back to the surroundings that was used to remove the electron in the first place.

Similarly, an electron that was knocked into a higher energy level by radiation will give back the same amount of energy (in the form of light) when it settles back into the original level.



ENERGY RELEASED BY NUCLEAR FISSION

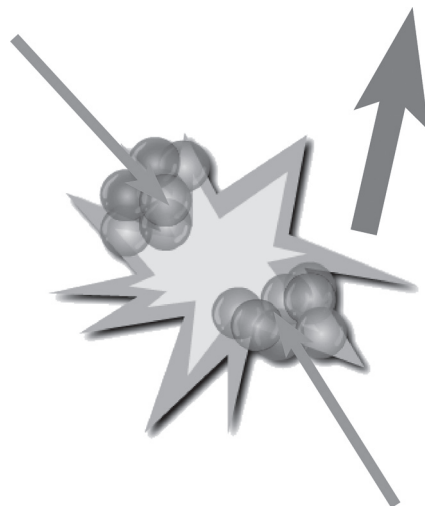
When a high-energy particle strikes a nucleus, it can cause “nuclear fission” – the splitting of the nucleus. The huge amounts of NUCLEAR BINDING ENERGY released indicate the HUGE forces needed to hold a nucleus together.



ENERGY RELEASED DURING NUCLEAR FUSION

It needs a HUGE amount of work (i.e. a HUGE input of energy) to force two nuclei together.

A nucleus formed in this way represents a more stable situation. In nature, when there is a gain in stability, energy is released into the environment.



NUCLEAR STRUCTURE AND STABILITY

All chemical reactions involve electrons and changes in the ways electrons are arranged in the electronic shells of the atoms. The nuclei of atoms remain unchanged during chemical reactions. But atomic nuclei can undergo changes of their own – in what are called nuclear reactions. The range of energies involved in nuclear reactions is from 1 000 (10^3) to 10^{10} kJ mol⁻¹ whereas in chemical reactions it is from about 1 to 10^3 kJ mol⁻¹. Nuclear reactions involve huge amounts of energy because the forces that hold the nucleus together are much larger than the coulomb forces holding the electrons in atoms.

The atomic nuclei of elements consist of protons (p^+) and neutrons (n^0). These are two of the so-called **fundamental particles**. The word **nucleons** refers to both protons and neutrons – in other words, the particles that make up the atomic nucleus. p^+ and n^0 have almost the same masses ($m_p = 1,00727$ u and $m_n = 1,00866$ u) but, while protons have an electrical charge of $+1e$, neutrons are electrically neutral. In an atom, the number of protons is given by the atomic number (Z) whereas the number of nucleons (p^+ and n^0) is given by the mass number (A). Therefore the number of neutrons can be calculated ($A-Z$). Atomic nuclei are written in this symbolic form: A_ZX

Atomic nuclei are stable or unstable depending on the number of neutrons they contain as long as the ratio of protons to neutrons is suitable. It is as though the neutrons are there to “dilute” the large forces that exist between positively charged protons situated so close to one another.

Another observation is that when the number of protons exceeds 83 (bismuth: $Z = 83$), the atomic nucleus becomes unstable and undergoes radioactive disintegration regardless of the number of neutrons. Thus, ${}^{209}_{83}\text{Bi}$ is the heaviest element of which at least one isotope is stable. After bismuth, the half-lives of all isotopes become relatively low in terms of the rate of radioactive decay. (See Lessons 15 and 16.)



Band of stability

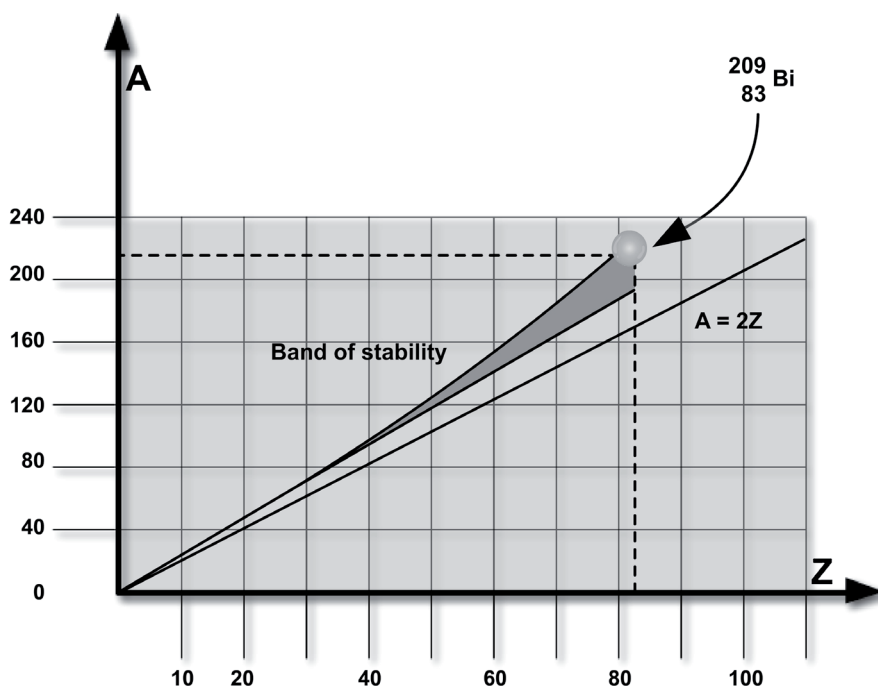
If we plot a graph of number of protons (Z) vs number of nucleons (A), the stable nuclei all fall in an area enclosed by two curved lines known as the *band of stability*. The band of stability also stops at element 83 because there are no known stable isotopes above it. Elements lying outside this band of stability are unstable. As the number of protons increases, the ratio of neutrons to protons $\left(\frac{A-Z}{Z}\right)$ increases. This is because more neutrons are needed to compensate for the increasing proton-proton repulsions. Isotopes occurring above and to the left of the band tend to emit β -radiation, i.e. electrons $({}_{-1}^0e)$ because they want to lose a neutron and gain a proton as follows:



Isotopes above element 83 tend to emit α -radiation, i.e. helium nuclei because they have too many nucleons. Their disintegration happens as follows:



The atomic nuclei whose A/Z ratio do not fall into the stability band undergo a radioactive disintegration.



The graph shows the stable nuclei in blue. Notice that:

- There are no stable nuclei with an $Z > 83$ or $(A-Z) > 126$.
- The more protons in the nuclei, the more neutrons are needed for stability. (The band of stability rises above the $A=2Z$ line).
- Unstable nuclei, or radioactive isotopes, undergo nuclear decay until they become stable. Because there are only a few types of nuclear decay, most isotopes will take a few periods of decay to become stable nuclei.

TWO RULES OF NUCLEAR STABILITY

The Odd-Even Rule

When the numbers of neutrons and protons in the nucleus are both even numbers, the isotopes tend to be far more stable than when they are both odd, **unless the isotope falls outside of the band of stability**. (Of the stable nuclei, 168 are even-even and only four are odd-odd.) Out of all the 264 stable isotopes,



only five have odd numbers of both neutrons and protons, whereas 157 have even numbers of both and the rest have a mixed number, i.e. an even number of neutrons and an odd number of protons, or vice versa. So, in general, when we find an isotope with both (A-Z) odd and Z odd, we expect the half-life to be very short, especially if the isotope is quite large.

The Magic Numbers

Another rule of nuclear stability is that isotopes with certain numbers of protons or neutrons tend to be more stable than the rest. These numbers are called the *magic numbers*. For reasons too complex to explain here, these magic numbers are 2, 8, 20, 50, 82 and 126. When a nucleus has a number of protons and neutrons that are the same magic number, it is very stable.

For example: ${}^4_2\text{He}$, ${}^{16}_8\text{O}$, and ${}^{40}_{20}\text{Ca}$. One stable isotope of lead, ${}^{208}_{82}\text{Pb}$, has 82 protons and 126 neutrons.

IONISING RADIATION

The black-on-yellow symbol is the familiar standard danger sign for radioactive material. The other symbol is newer and more explicit. In short, it says: *This emits ionising radiation. It is dangerous. Run for your life!*"



Ionising radiation is high-energy particles or high-energy waves that can ionise an atom or molecule by knocking out one or more electrons from the electron shells.

Note that for a particle (e.g. α or β or a neutron) or a wave (X-rays or gamma [γ] radiation) to be able to ionise an atom, the actual particle or wave itself must have enough energy to do the ionising. This means that, even if you bombard an atom with many, many particles, they will not ionise the atom because of their numbers alone – they must have enough energy as individual particles.



Ionisation caused by the particles or waves emitted during radioactive decay can be destructive to biological organisms, and can cause damage to DNA, i.e. **deoxyribonucleic acid**, the molecule that contains the genetic code for making the body's proteins. If the code is damaged, it can result in the wrong proteins being formed or damage cells. Cancers or genetic mutations can be caused in this way.

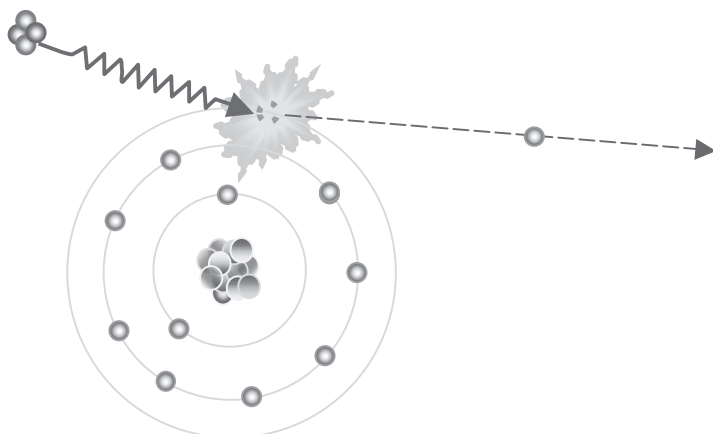
Alpha radiation consists of a helium nucleus and can be stopped by a sheet of paper.

Beta radiation consists of electrons and can be stopped by a thin aluminium plate.

Gamma radiation consists of high-energy waves and will eventually be absorbed as it penetrates a dense material like lead or concrete. High-energy

electromagnetic radiation can also be pictured as small “packets” of energy called **photons**.

The nuclear radiation called “radioactivity” that results in ionisation was discovered by chance in the late 19th century by the French scientist Henri Becquerel. He noticed that a photographic plate had darkened without being exposed to light when it was left in the presence of a mineral called uranium oxide. The first-ever Nobel Prize for physics was awarded to Wilhelm Röntgen in 1901 for his discovery of X-rays. Becquerel was awarded the 1903 Prize jointly with two other pioneers of nuclear physics: Pierre and Marie Curie. The New Zealand-born English physicist Ernest Rutherford identified the three types of nuclear radiation we call α , β , and γ **radiation**.



FISSION AND FUSION AND THEIR CONSEQUENCES

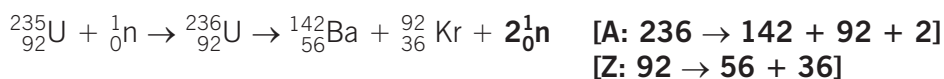
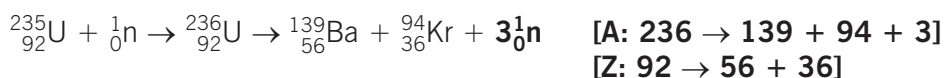
Nuclear fission

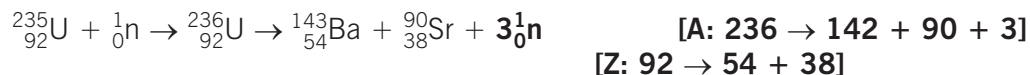
Sometimes, instead of emitting a particle, (e.g. a helium nucleus [α -] or an electron (β -), an unstable atomic nucleus can disintegrate (fall apart) into fragments. This is called nuclear fission and leads to fragments whose combined mass is the same as that of the original nucleus. As an example, let us take a artificially made element, americium. It can be produced in a particle accelerator. The $^{244}_{95}\text{Am}$ isotope of americium can decay spontaneously as follows:



The nuclear fission of an unstable nucleus will not always produce the same fragments but the atomic numbers and the mass numbers will always be balanced in a nuclear equation.

Nuclear fission can also be induced by bombarding a heavy nucleus with the right particles. Perhaps the best known induced nuclear fission is caused by the bombardment of a nucleus of uranium-235 with neutrons. The uranium absorbs a thermal neutron to give the highly unstable uranium-236 isotope. (See page 138.) This is described as an artificial isotope because it does not occur naturally. Uranium-236 then decays into fragments. The very interesting phenomenon we notice here is that the disintegration can happen in several ways:





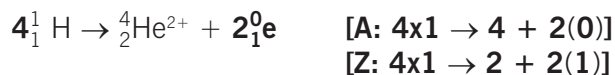
Nuclear fission is always accompanied by liberation of high energy. (See above)

This particular nuclear reaction, nuclear fission, caused by the neutron bombardment of the uranium-235 isotope, was discovered in 1938 by Otto Hahn, Lise Meitner and Fritz Strassmann. Atomic nuclei that are susceptible to nuclear fission are called **fissile**. The most important fissile nuclei are uranium-235 and plutonium-239. These atomic nuclei are used as nuclear fuels because of the large amounts of energy set free by nuclear fission. (See above)

Both the atom bomb and nuclear power stations make use of nuclear fission. The difference between them is that the rate of the reaction in nuclear power stations can be controlled whereas it is not in the atomic bomb. Nuclear power plants are safe as long as the radioactive by-products are contained and disposed of safely but that is clearly a part of the process that is full of potential for human error. In April 1986, one of the reactors in a nuclear power plant at **Chernobyl** near Kiev in Russia suffered a massive steam explosion and a “nuclear meltdown” with the release of radioactive materials (including strontium-90) that affected large parts of Russia, northern, eastern and western Europe, southern Scandinavia and western North America. *Find out more about the disaster at Chernobyl, its causes and effects.*

Nuclear fusion

The fission of an atomic nucleus produces much energy. But an even greater amount is produced during **nuclear fusion** in which a number of small particles are forced together. The forces required to make protons join, for instance, must overcome the coulombic forces of repulsion and must therefore be very large. Four protons may fuse to give a helium nucleus. If we do our check on mass number and atomic number, we find something unusual:



Apart from the helium nucleus, we find four **positive electrons** (or **positrons**) being produced. Positions are denoted ${}_1^0\text{e}$

Energy of about 27 MeV (mega-electron volts) is produced. This is equivalent to 10^8 kJ·mol⁻¹. In other words, for every mole of protons (6×10^{23} p⁺) the nuclear fusion reaction releases 10^8 kJ of energy. If we translate this into usable electricity, it means that if we use 4 g of protons in a fusion reaction we will get out approximately 30 000 kWh of electricity. The present charge for electricity in South Africa is approximately 30c per kWh and a household can use about 2 000 kWh in a month. This 4 g of hydrogen used in a nuclear fusion reaction could supply a household with about 15 months of electricity worth approximately R10 000 at present-day rates!



The nuclear-fusion reaction of hydrogen is the origin of the Sun's energy and that of all the other stars in the universe. Hydrogen is the most abundant element of the universe (about 90% of cosmic matter). Helium makes up about 5% of cosmic matter. Through further nuclear reactions, helium nuclei can fuse in hotter regions of the stars to form heavier atomic nuclei like iron. ${}_{26}^{56}\text{Fe}$ is the most stable isotope in the universe. The Earth's core, like the cores of stars such as red giants, consists of iron-nickel alloys. (*Do you think there is any connection? How might you explain this?*)

The stars are immense nuclear reactors in which the chemical elements are produced by nuclear fusion from the parent elements of hydrogen and helium.

The energy produced by these nuclear fusions is enormous, as we know, and the temperature in the stars is in the order of millions of degrees Celsius.

Perhaps the most thought-about future technology is the harnessing of nuclear fusion in the laboratory. If this can be achieved it will certainly resolve the problems of energy supply on Earth. Yet it is worth considering what other problems it might cause because “there is no such thing as a free lunch”. The key engineering problem in harnessing the nuclear fusion reaction lies in overcoming the strong electrostatic repulsions of the protons before they can be fused. A very embarrassing scientific error may have been committed by researchers in Utah in the USA in March 1989 when they published a paper claiming to have produced an excess of energy in a so-called “cold fusion” experiment. So far there has been no finality in the matter and research on “cold fusion” continues in laboratories around the world. Find out more about attempts to produce fusion energy in the laboratory and what the advantages of cold fusion would be if it could be achieved.

NUCLEOSYNTHESIS

Nucleosynthesis of the transuranium elements

When uranium-238 is bombarded with intense beams of particles that have been accelerated in particle accelerators (also nicknamed “atom smashers”), the nuclear reactions caused can produce nuclei of artificial or “man-made” elements such as neptunium-93, plutonium-94 and californium-98.



To date, the periodic table of the elements has been extended to element 111. So our knowledge of elements now extends 19 places beyond uranium, which is why we speak of these artificial elements as being **transuranic**. Nucleosynthesis of the heaviest elements produced thus far has been performed in Darmstadt (Germany). Sometimes the amount produced is just a few atoms at a time, which is why one must marvel at the accuracy of the instruments used to detect the atoms when they are produced. Transuranic elements are very unstable (they have very short half-lives) and they cannot be studied chemically as this takes too long.

Nucleosynthesis in the universe, the Sun and other stars

BBN (big bang nucleosynthesis or primordial nucleosynthesis) refers to the production of nuclei other than those of hydrogen-1 (the normal, light isotope of hydrogen with nuclei consisting of a single proton each) during the first few minutes of our universe’s life. It is believed to be responsible for the formation of deuterium (hydrogen-2) as well as other light isotopes such as helium-3 and helium-4, lithium-6 and lithium 7. In addition, some unstable, radioactive isotopes such as tritium (hydrogen-3), beryllium-7 and beryllium-8 were produced. Some of the unstable isotopes decayed and others fused with the lighter isotopes to make heavier but stable isotopes. The stable isotopes formed in this way became the “stardust” (as the famous cosmologist Carl Sagan called it) from which all the stars and planets in the billions of galaxies in the universe were formed.

Stellar nucleosynthesis



This occurs in stars during the process of their evolution and is responsible for generating the known natural elements from carbon ($Z=6$) up to calcium ($Z=20$) by nuclear fusion. Carbon and other elements formed by this process are also fundamental to life.

Carbon is particularly important. It is formed from He and is the main element that produces free neutrons within the stars. These neutrons are slowly taken in (absorbed) by the lighter nuclei so that the nuclei grow until they form stable heavy elements like iron and nickel (^{56}Fe and ^{62}Ni). The products of stellar nucleosynthesis are slowly distributed throughout the universe by solar winds (from jets of particles that erupt from the centre of stars) and on the arms of the spiral nebulae as they sweep through space.

The first direct evidence of stellar nucleosynthesis was the detection of the element technetium in the atmosphere of a red giant star by astronomers in the early 1950s. Technetium is radioactive with a half-life much less than the age of a star so its abundance means that it must have been created within the star during its lifetime.

AGE DETERMINATION IN GEOLOGY AND ARCHAEOLOGY

To understand the process of “radiometric dating”, see the section on radiocarbon dating in Lessons 15 and 16. The principle of finding the age of an object by measuring its amount of radioactivity is exactly the same as for radiocarbon dating, i.e. by measuring the amount of radioactive decay of a radioactive isotope with a known half-life, we can determine the age of a material. There are various radioactive isotopes that can be used for this purpose.

Radiocarbon dating involves the decay of carbon-14 (half-life 5 730 years) and can be used to date things younger than 50 000 years. After about nine to ten half-lives the amount of carbon-14 will have reduced to almost nothing and the measurement of the quantity of the isotope in a sample will therefore be unreliable.

Some of the radioactive decays that are used for dating different geological periods are:

- Uranium to lead: This technique measures the ratio of two lead isotopes (Pb-206 to Pb-207) to the amount of uranium in a mineral or rock. Uranium-lead dating is applied to samples older than about one million years.
- Potassium-argon and argon-argon dating is based on the decay of potassium-40 to argon-40 and is used to date geological events such as the cooling of igneous rocks after volcanic eruptions. The method can be used to measure eruptions as recent as about 2 000 years ago, as has been shown by the dating of rocks produced when Mount Vesuvius destroyed the Roman city of Pompei.
- Uranium to lead is used to date carbonates such as in those fossil corals and bones as old as about 700 000 years.



Prediction Activity



Make a table of the following isotopes. For each one:

- Write down the symbol showing both A and Z.
 - Calculate the A/Z ratio.
 - Predict whether the isotope will be stable (long half-life) or unstable (short half-life).*
- * When predicting the stability of an isotope, use the notes in the lesson on
- (a) the band of stability (if $A=2Z$ then $A/Z = 2$);
 - (b) odd-odd values for protons (Z) and neutrons (A-Z); and
 - (c) the magic numbers for proton and neutron numbers and nuclear stability.

Bismuth-210

Cadmium-113

Calcium-40

Calcium-42

Cesium-134

Cobalt-60

Helium-4

Hydrogen-3 (tritium)

Iodine-129

Lead-208

Lead-210

Oxygen-16

Phosphorus-32

Potassium-40

Radium-228

Radon-222

Strontium-90

Thorium-232

Uranium-238



KINETIC THEORY, IDEAL GASES AND GAS LAWS

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

In this lesson we apply some basic concepts to a study of matter in general and ideal gases in particular.

- Physical processes and changes in state
- The kinetic theory of matter
- Ideal gases
- Ideal gas law
- Motion of particles
- Kinetic theory of gases
- Temperature and heating (ideal gases)
- Pressure (ideal gases)
 - Deviations from ideal behaviour
 - Calculations using the ideal gas law

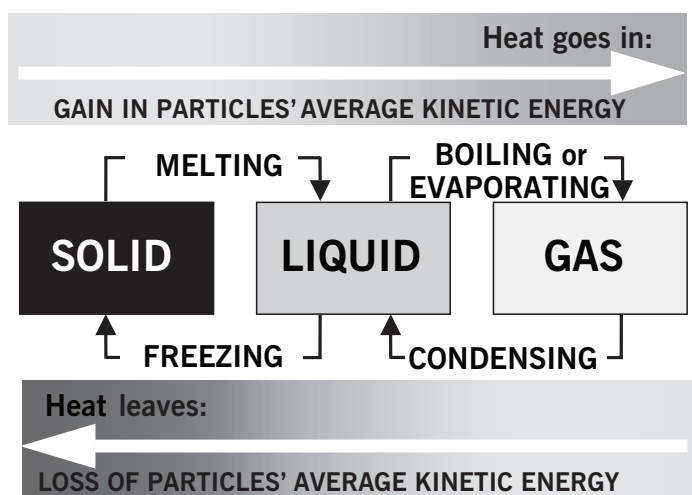


Lesson

Physical processes and phase changes

There are three phases, or **states**, in which matter can be found: solids, liquids and gases. Normally matter passes from one phase to another, e.g. from solid to liquid to gas. But there is one process, **sublimation**, by which a solid may pass directly to the gaseous state without first liquefying. In the extreme case of very sudden cooling to well below the freezing point, it might be possible for a vapour to go directly to the solid phase but this is difficult to prove. So apart from sublimation we will consider all other cases as obeying a “one-step rule”. The rule is represented in this diagram:



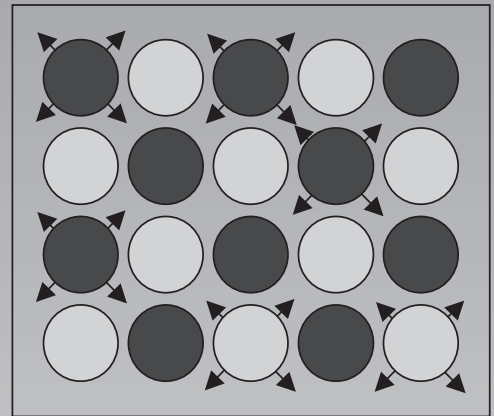


The kinetic theory of matter

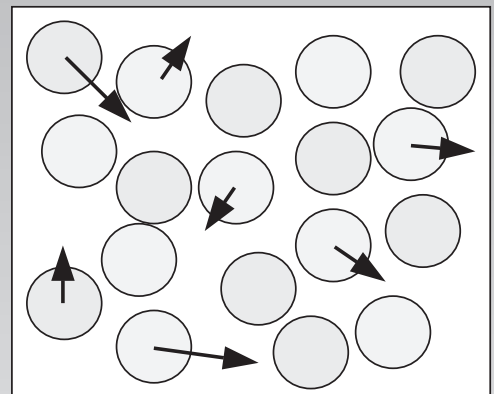
If we regard matter as being composed of tiny particles that are in constant motion (except when they have had all the energy removed from them) we can develop a simple physical picture, or model, that can be used to explain the behaviour of matter in its various states or phases. When we speak of “behaviour” we refer to the way matter responds when the external conditions are changed, e.g. when temperature or pressure are changed. The key features of **the kinetic theory of matter** are:

- Matter is made up of **very small particles** in constant motion in **straight lines**.
- The particles of matter are usually referred to as **molecules**.
- The straight-line motion of molecules can be interrupted when they strike other molecules.
- When particles collide with each other or with the walls of their container, we assume that no energy is lost. (We say that the **collisions are elastic**.)
- **Forces of cohesion** exist between all particles.
- The strength of the cohesive force varies with distance.
- Solids form a definite shape.
- Molecules in a liquid are approximately the same average distance apart as in solids. Hence, liquids are difficult to compress.
- Liquids have no definite shape and form a surface. Apart from their surface, they take the shape of their container.
- Cohesive forces in liquids are less important than in solids.
- In liquids, forces of adhesion (forces between liquid molecules and the molecules of the container) are important.
- Gases have no definite shape and take the shape of their container.
- Liquids and gases are referred to as “fluids” because they will flow in order to fill a space evenly.

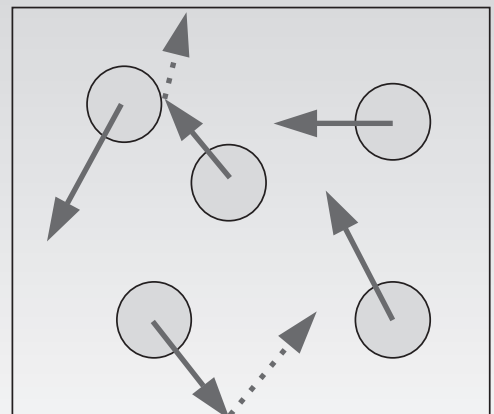
- Molecules in a **solid** are in fixed positions relative to their neighbours.
- The molecules move – or vibrate – about these fixed positions.
- In crystals the arrangement of the molecules on an array of fixed points is known as a **crystal lattice**.



- **Liquids** are a form of condensed matter.
- The average intermolecular distance in liquids is approximately the same as in solids.
- **Molecules move constantly and bump into one another.**
- The kinetic energy of the molecules of liquids is **sufficient to overcome intermolecular forces of attraction**.



- In **gases** particles are very far apart.
- **Particles move about freely** and take the shape of their container.
- Gas volume is the amount of space taken up by its constantly moving particles.
- **Gas particles collide with each other frequently.**
- Gas molecules' **collisions are elastic** (no energy losses).
- The cohesive forces between gas particles are unimportant, **except at low temperatures and high pressures**.
- Particles of matter are very small; ignore the volume of the actual gas molecules themselves **except at high pressures and low temperatures**.
- Particles are widely spaced and therefore **gases are easy to compress**.
- At low temperature and high pressure, real gases liquefy.



Heating and the effect of temperature on molecules of matter

- **Heating a substance increases the energy of its particles**, making them move about more violently.
- When a substance is heated the violent **motion of its particles is likely to overcome the cohesive forces between the particles**.
- Temperature is a measure of the average kinetic energy of the particles in an amount of matter.

- **The pressure exerted by a gas depends on how often and with what force the particles collide with the walls of a container.**
- **Gas pressure depends on temperature** – or the average kinetic energy of the gas particles.

Kinetic theory applied to ideal gases

- Models often deal with things as they **should be** and not as they **actually are**.
- “Ideal gas behaviour” means the way gases would behave if they were ideal.
- Models are regarded as good approximations to reality.
- Scientists use simplified models to understand how things behave in general; once they do they adapt and modify their models by adding in factors that bring the ideal model closer to reality.

Real gas molecules ...	Ideal gas molecules ...
have odd shapes that can affect their properties , e.g. the shape of the water molecule in water vapour	are identical, perfect spheres
occupy volume : the molecular volume becomes noticeable at low temperatures when molecules slow down	are so small that they occupy no volume
do exert forces on each other , especially at low temperatures and high pressures	exert no force whatsoever on one another , even at low temperatures and high pressures when intermolecular distances decrease
lose energy during collisions with other molecules and the walls of their container	collide elastically (with each other and the walls of containers) i.e. no energy lost in collisions.

Temperature and the effect of heating on an ideal gas

Temperature and pressure

Look at the model of an ideal gas and the diagram of molecules in a container and consider the following sequence of changes to gas behaviour. Remember that the temperature of a quantity of gas is a measure of the average kinetic energy of the gas molecules.

- As a gas is heated and its molecules move about more and more, they bump into the sides of their container more often.
- When gas molecules move faster, the force they exert on the sides of a container is also greater.
- This means that as the temperature of a **fixed mass of gas** increases, so the pressure exerted by the gas also increases **as long as the volume** (and hence inside area of the wall of the container) **remains constant**.
- The first important relationship in describing gas behaviour can be stated mathematically as:

The pressure exerted by a fixed mass of ideal gas is directly proportional to its absolute temperature:

$$P \propto T \quad \dots \quad \text{as long as } V \text{ remains constant}$$

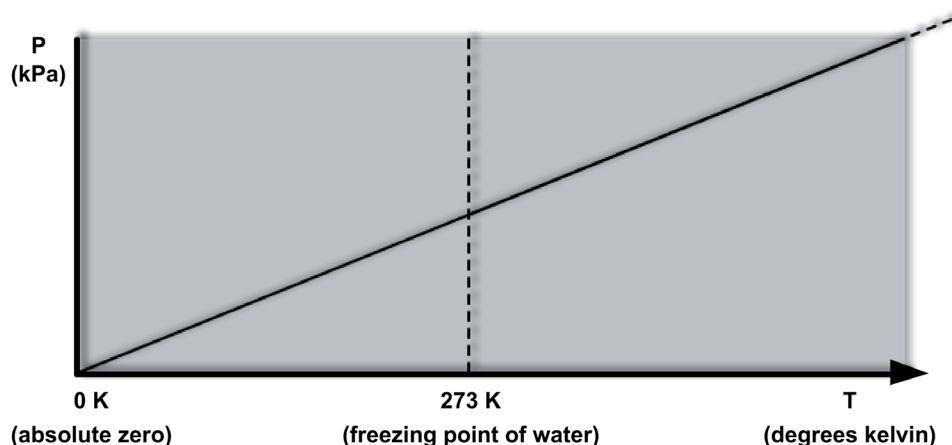


Absolute temperature

This is measured on the **kelvin scale** and a temperature measured in “kelvin” is referred to as “degrees Kelvin” but is denoted “200 K” (with no degree° symbol).

The reason we use the absolute scale of temperature is that on this scale “zero degrees” is the temperature at which molecules of matter cease to move altogether. This temperature is known as **absolute zero**.

IF we wish to write the above relationship, i.e. that the pressure of a gas is **directly proportional** to temperature, and IF **temperature is** a measure of the **average energy of movement** (kinetic) of molecules, THEN we must use a temperature scale on which pressure is zero when temperature is zero. In terms of a graph of P vs T we say that it will be a straight line graph that passes through the origin.



From this graph we see that:

- When the temperature of an ideal gas reaches absolute zero, it exerts no pressure.
- P and T are in (direct) proportion to one another. In other words, for every increase in the gas temperature by a certain factor the increase in pressure is also by a fixed factor.
- Temperature is the independent variable (X-axis) because pressure follows (depends on) temperature; as the temperature is raised molecules move faster and exert a greater pressure, and not vice versa.
- If the melting/freezing point of water is 0°C , then to convert from one scale to the other we use this formula: **degrees K = $(^{\circ}\text{C} + 273)$** .

Temperature and volume

Look at a fixed mass of ideal gas in a sealed container with a movable piston:



- As the temperature of the gas increases, the molecules of the gas exert a greater and greater pressure on the wall of the container and the piston.
- The atmospheric pressure outside the container exerts a force on the piston.
- As the gas pressure increases, the piston will move until the inside and outside pressures on it are equal. (Equilibrium)
- As the piston moves outwards, the volume of the gas increases.
- The pressure of a gas is proportional to its absolute temperature and the volume of the gas increases with temperature while the gas pressure remains constant.

We now have a second relationship for ideal gases:



The volume of a fixed mass of ideal gas is directly proportional to its absolute temperature:

$$V \propto T \dots \text{as long as } P \text{ remains constant}$$

Pressure and the effect of compressing an ideal gas

The relationship between the pressure exerted by an ideal gas and its volume is known as **Boyle's Law** which can be stated: **For a fixed amount of gas kept at a fixed temperature, P and V are inversely proportional.**



- As the piston is moved to the left, the gas is compressed into a smaller volume.
- If the temperature of the fixed mass of gas is kept constant, the gas molecules maintain the same rate of movement.
- But, because the gas molecules are colliding with the inside of the container as often as before, the collisions (and hence total forces exerted) are now concentrated over a smaller area because the volume has decreased.
- Hence, as the volume decreases, the pressure exerted by the gas increases.
- The exact relationship must be determined experimentally because, although we can see that the relationship is inverse in nature, we cannot simply guess what it is.

Yet, as you see, we are in luck and we now have a third, **simple** relationship for ideal gases:

The pressure exerted by a fixed mass of ideal gas is inversely proportional to its volume:

$$P \propto \frac{1}{V} \dots \text{as long as } T \text{ remains constant}$$

IDEAL GAS LAW

A general law for ideal gases can be derived from these three experimentally derived relationships. The three proportionalities can be written as equations by introducing proportionality constants. We can also see how, when two variables are plotted on a graph while the third variable is kept constant, we can find straight-line relationships. (In the case of Boyle's Law, the second variable for a straight line must be $\frac{1}{V}$ and not V .)

The three relationships are:

Pressure and temperature	Volume and temperature	Pressure and volume
Gay-Lussac's Law	Charles' Law	Boyle's Law
P vs T	V vs T	P vs V
Fixed mass of gas, i.e. a fixed number of molecules	Fixed mass of gas	Fixed mass of gas
Volume kept constant	Pressure kept constant	Temperature kept constant
If $P \propto T$, then ... $P = k_1 T$ or $\frac{P}{T} = k_1$	If $V \propto T$, then ... $V = k_2 T$ or $\frac{V}{T} = k_2$	If $P \propto \frac{1}{V}$, then ... $P = k_3 \cdot \frac{1}{V}$ or $PV = k_3$



and $\frac{P_1}{T_1} = \frac{P_2}{T_2}$	and $\frac{V_1}{T_1} = \frac{V_2}{T_2}$	and $\frac{P_1}{V_1} = \frac{P_2}{V_2}$
---	---	---

The three relationships for a fixed mass of ideal gas can be combined into one relationship called **the ideal gas law** or the **combined gas law**:

$$\frac{PV}{T} = \text{constant} \text{ and hence we can write } \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

In this relationship, if we keep pressure constant, we get $V = \text{const} \times T$ and so on, which is the form of the original equations.

The constant includes a term telling us how much (what fixed mass of) ideal gas is present. We choose **n**, which is the number of moles of gas. This number tells us how many molecules of gas are present. The other part of the constant is called **the universal gas constant**, R. R is the amount of energy that will raise the temperature of 1 mole of ideal gas by 1 K.

$$R = 8,314 \text{ J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$$

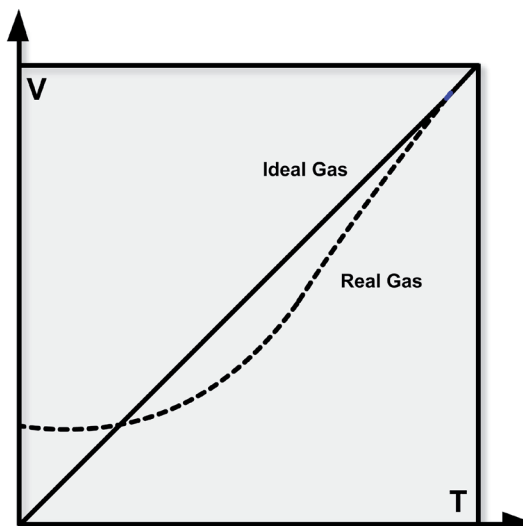
DEVIATIONS FROM IDEAL BEHAVIOUR

Real gases may behave much like an ideal gas under normal circumstances. But when conditions become extreme, e.g. very high pressures or very low temperatures, we find that the assumptions made in the ideal gas model, e.g. that the molecules are so small that they have no volume, no longer hold true. The three assumptions that do not hold under extreme conditions are:

- **Gas molecules have no volume.**
- **There are no intermolecular forces.**

The following graphs show the behaviour of real gases compared with our expectations of ideal gases based on the assumptions we have made in the ideal gas model and the kinetic theory of matter.

The first graph shows how the volume of a real gas decreases as temperature falls to absolute zero.

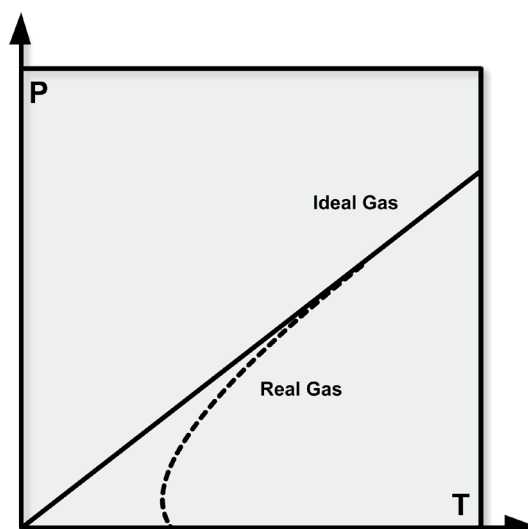


- At absolute zero, the molecules of a gas have no kinetic energy, i.e. they are not moving.
- When the molecules of an ideal gas stop moving, they occupy no volume.
- What the graph shows is that real gases, although they have no energy at absolute zero, DO still occupy some volume.
- This volume (dotted line) is that of the liquid or frozen solid that the real gas has become.

- The deviation below the red line shows that, as the molecules move more slowly and come closer together, the intermolecular forces come into play and pull the molecules closer together, thus reducing the gas volume.

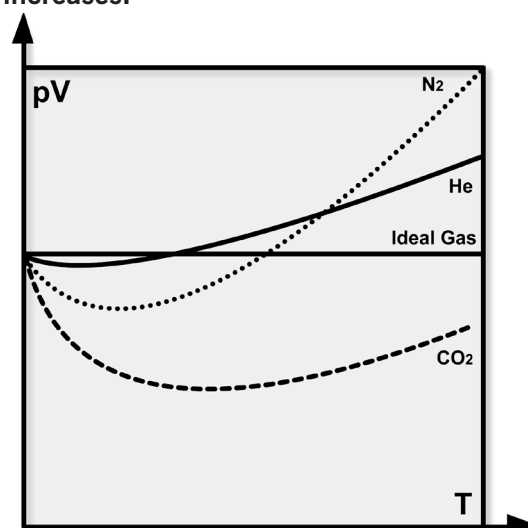
The second graph shows how pressure in a real gas decreases as temperature falls to absolute zero.

- At absolute zero, the molecules of a gas have no kinetic energy.
- Because they stop moving at absolute zero, the molecules of an ideal gas stop exerting a pressure only at absolute zero.
- Real gases do exert cohesive forces (of attraction) on one another.
- As the average velocity of gas molecules decreases at low temperatures, molecules come very close together.
- Once they are close enough for intermolecular forces to be exerted, molecular movement drops off sharply.
- Pressure also drops off sharply at this point, which is above absolute zero.



The third graph shows how PV for real gases varies as pressure increases.

- From Boyle's law we know that PV should remain constant for a fixed mass of ideal gas at a constant temperature.
- As pressure increases, the volume of an ideal gas decreases proportionally so that PV remains constant, i.e. a horizontal line on the graph of PV vs T(K).
- In **real gases**, as pressure increases, molecules are forced closer together and intermolecular forces of attraction are exerted.
- As attractive, intermolecular forces start acting, the graph for a real gas drops below that for an ideal gas because **volume is less than expected**.
- When the graph for a real gas rises towards or above the ideal gas graph, it means that **the volume is now becoming greater than expected**.
- **A higher than expected volume is the result of the effect of repulsive forces.** When pressures are high, molecules are forced much closer together. Repulsive intermolecular forces act over shorter distances than the attractive forces, which is why they become significant at higher pressures.
- Intermolecular forces are stronger when the molecules are larger and have a higher number of electrons. Hence CO₂ has a much greater deviation from ideal behaviour and the helium atom's behaviour is almost ideal, especially at low pressures.
- Comparing the graphs for CO₂ and N₂, the difference between them as the pressure begins to rise (CO₂ falls off sharply; N₂ not as sharply) is because of their respective sizes: (M[CO₂] = 44 g·mol⁻¹) and (M[N₂] = 28 g·mol⁻¹).
-



Calculations using the ideal gas law

Activity 1

A sample of nitrogen gas is collected in a 500 cm³ flask.

The pressure of the nitrogen is 133 kPa at a temperature of 15°C.

- What is the mass of nitrogen in the flask?
- What volume will the nitrogen occupy at **STP**?

STP: This stands for **S**tandard **T**emperature and **P**ressure. To compare gas behaviours the gases being compared must be under the same conditions. We therefore choose a standard temperature of 0°C (273 K) and standard pressure (1 atm or 101,3 kPa).

Activity 2

A 20 dm³ gas bottle holds a quantity of helium gas at 7°C and 1,4 MPa. (*mega (M) = 10⁶*)

- What is the capacity of the gas bottle compared to a 2-litre plastic milk bottle?
- What is the mass of helium gas in the gas bottle? (*Correct to one decimal place.*)
- The outside temperature at a remote weather station is 27°C and the pressure is normal atmospheric pressure (101,3 kPa). How many 250 dm³ weather balloons can be filled from the helium gas bottle under these conditions?
- If the gas bottle is filled to the same pressure as before with carbon dioxide gas (CO₂) at 3°C, what will the mass of the gas bottle be now?



INTERPRETING GRAPHS: HOW GRAPHS REPRESENT THEORY; BOYLE'S LAW

Learning Outcomes and Assessment Standards

Lesson

21a

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

What you must know in this section of the curriculum is:

- Physical processes and changes in state
- The kinetic theory of matter
- Ideal gases
- Ideal gas law
- Motion of particles
- Kinetic theory of gases
- Temperature and heating (ideal gases)
- Pressure (ideal gases)
 - Deviations from ideal behaviour
 - Calculations using the ideal gas law.

This lesson will focus on calculations using the basic knowledge in this section:

- Ideal gases
- The ideal gas law
 - Boyle's Law – a practical determination
 - Boyle's Law calculations

Activities

THE LAWS OF PHYSICS: THEORETICAL AND EXPERIMENTALLY DETERMINED

When Newton formulated his Law of Universal Gravitation – the law that tells us how two “massive” bodies (i.e. bodies with mass) attract one another – he did so from theory. The story of an apple falling on Newton's head while he was sitting under an apple tree in the yard of his family home in Woollesthorne in Lincolnshire, England, is probably untrue. But what he probably realised was that the forces that kept the Moon in orbit around the Earth and the force that attracted the Earth and the apple to one another were of the same kind. Newton then developed his theory of gravitation as a theoretical exercise although he undoubtedly found clues in the astronomical measurements, observations and theories of the likes of Galileo Galilei, Tycho Braahe and Johannes Kepler, as well as his own. But once he had his formula – the mathematical expression of his theory – the way was open for Newton himself and others to test that theory against actual measurements and observations.



Not all laws of science are developed from theoretical considerations. There is another class of laws that are “experimentally determined”. Ohm’s Law, for instance, arose because Georg Simon Ohm noticed a relationship between the size of an electrical energy source and the electrical current in a circuit. Thus Ohm’s Law ($V = IR$) is experimentally determined. Johannes Kepler, mentioned above, spent many, many years studying huge collections of astronomical measurements for the movements of planets and comets around the Sun. He was seeking order and patterns in the data and, in the end, he discovered “inductively” (going from the general to particular relationships) a set of laws about the orbits of planets. Undoubtedly Kepler’s work influenced Newton’s thinking as he puzzled out the “music of the heavens”.

A similar situation arose when the 17th-century “gentleman” scientist, Robert Boyle, was studying the relationship between the volumes of gases and the pressures they exerted. He perfected a pressure gauge and a pump which allowed him to measure the pressure exerted by gases under a variety of conditions. Here is an example of what Boyle found. It led to what we is known today as Boyle’s Law.

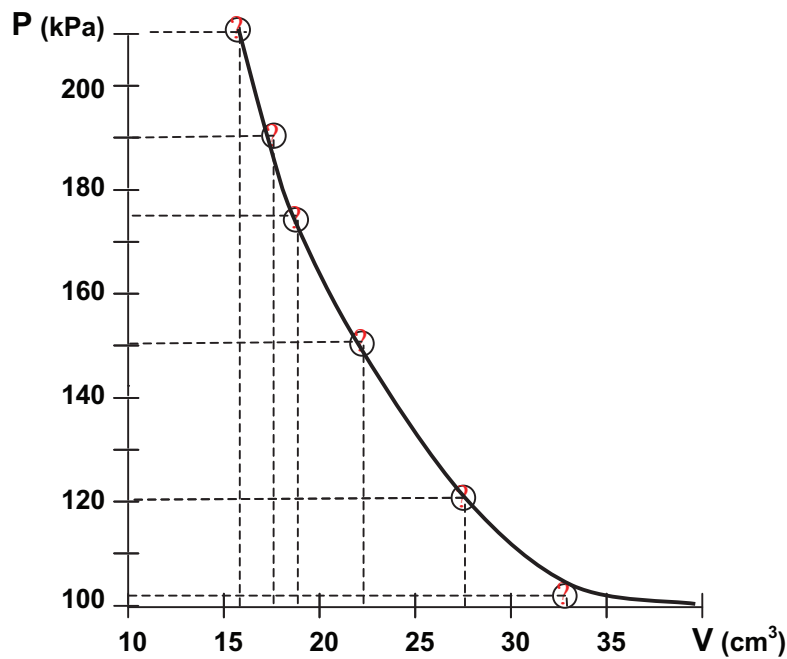
Table of readings

The first thing to do is set up an experiment with suitable apparatus to measure the **gas pressure** exerted by **different volumes** of **a fixed mass of gas** at **constant temperature**. The reason for the last two conditions is that we must always keep to two variables. If the temperature were to vary or the actual mass of gas be changed during the experiment, one would never know precisely what was causing changes in gas pressure. *Robert Boyle did not make his measurements using the same units as in our table but the units are unimportant. All that is of interest is HOW the variables vary.*

Volume (V) cm ³	Pressure (P) kPa
32,8	101,0
27,6	120
22,3	150
18,8	175
17,5	190
15,8	210
Range: 20	120

To start with, it is quite simple to plot **P vs V** for the readings obtained.





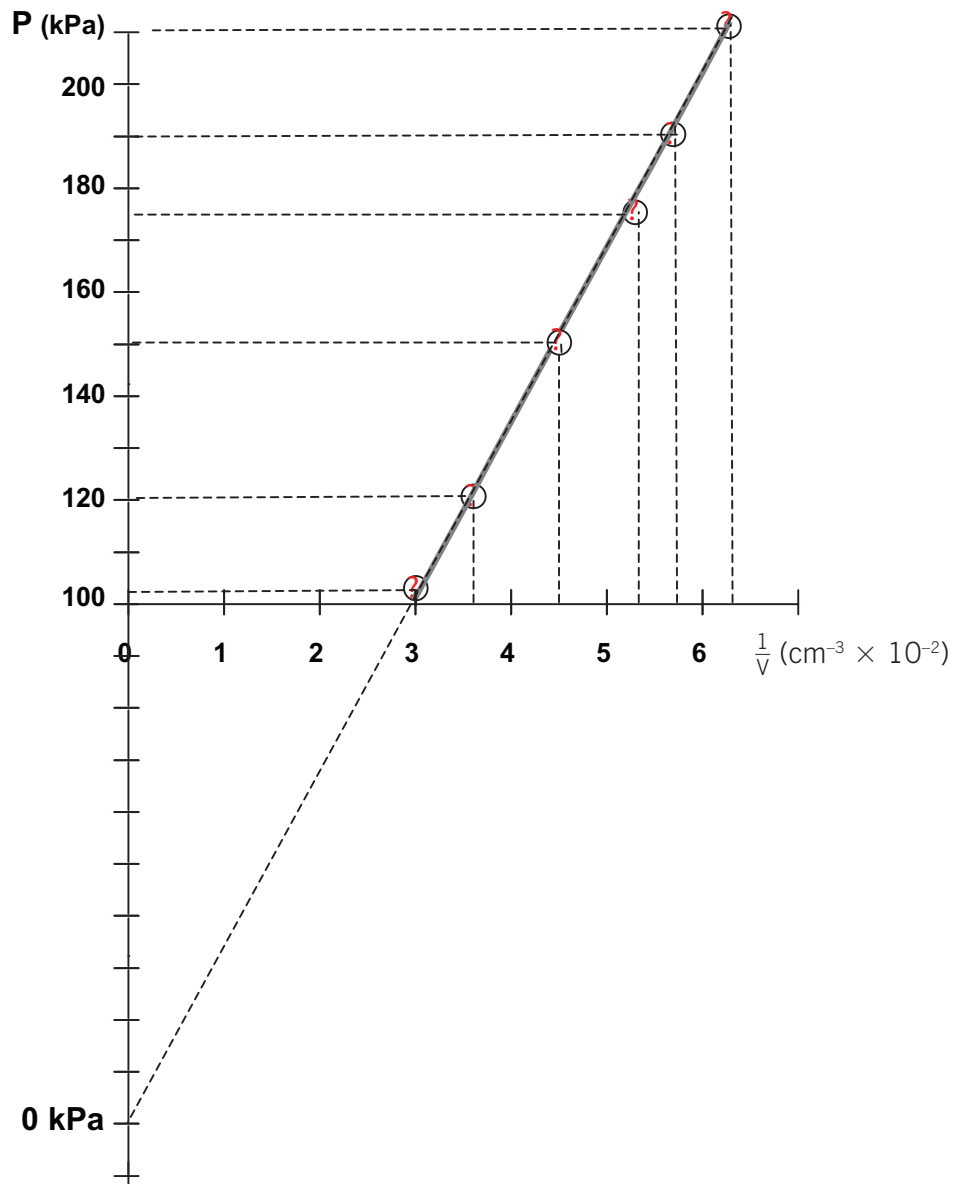
Having plotted the graph of **P** vs **V** we might be slightly disappointed. There is no obvious straight-line relationship – which is what we are looking for. A straight line indicates a linear relationship of the type $y = mx + c$.

So we start by looking at the PV curve and making intelligent guesses about what sort relationship exists between P and V. What we do notice is that as V gets larger, P gets smaller. This suggests an “inverse relationship” – something like

$P = \frac{1}{V}$. Having made our educated guess, we must try it out. First we must compute the values of $\frac{1}{V}$.

Volume (V) cm ³	Pressure (P) kPa	$\frac{1}{V} \text{cm}^{-3} \times 10^{-2}$
32,8	101,0	3,0
27,6	120	3,6
22,3	150	4,5
18,8	175	5,3
17,5	190	5,7
15,8	210	6,3
Range: 20	120	3,3





This choice of variables, i.e. P and $\frac{1}{V}$, seems to fit the bill as a graph plotted on these axes give a straight line. If we extrapolate the graph back to the y-axis, we get a point where both P and $\frac{1}{V}$ are zero. We can't be altogether certain what happens to the graph for these conditions because we have not actually done the measurements. But the situation does seem consistent with our theory of gases, namely that as V gets smaller (the gas is more compressed), P increases. As V increases (the gas is compressed less and less) so $\frac{1}{V}$, and hence P , decrease. What this says is that if you place a fixed mass of gas in a very large volume, the gas doesn't exert much pressure. It is too spread out! We cannot be sure that actual measurements of the gas pressure at infinite volume would be close to zero but the extrapolated graph and the theory are consistent.



Activity 1



Volume (V) cm ³	Pressure (P) kPa
40,8	117
37,3	128
29,8	160
24,9	192
23,0	208
21,2	225

Show that the values for gas pressure and volume in this table, taken from an experiment in which the pressure exerted by a fixed mass of gas is measured in relation to the volume of the gas, obey Boyle's Law. Six readings of volume and pressure were taken and the units used are shown.

- Draw a graph for P vs V.
(On a normal piece of centimetre graph paper, use a scale of 1 cm \equiv 2 cm³ and plot values from 20 to 42 cm³ on the x-axis; and a scale of 1 cm \equiv 10 kPa and plot values from 100 to 240 kPa on the y-axis.)
- State why pressure is plotted on the y-axis of the graph.
- Draw a second graph in which the x-axis has been adjusted in order to find a straight-line relationship for the mass of gas.
- Explain why the second graph confirms the conclusion reached by Robert Boyle in the 17th century.

Activity 2



Use the graphs you have drawn in Activity 1 and your knowledge of gas behaviour, answer the following questions:

- What would the volume of the gas be when the pressure it exerted was measured at
 - 142 kPa
 - 176 kPa
 - 240 kPa?
- If we realise that the gas being used in the experiment is real and not ideal, would you expect the volume of the gas to be greater or less than about 16 cm³ when the pressure exerted reached about 300 kPa?
- If, in the experiment in Activity 1, the gas temperature was held constant at 320 K (47°C), how would you expect the values of pressure and volume to change if the experiment was conducted at:
 - 27°C and
 - 67°C?



IDEAL GASES, DEVIATIONS FROM IDEAL GAS BEHAVIOUR AND IDEAL GAS CALCULATIONS

Learning Outcomes and Assessment Standards

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Assessment Standard 2:

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Learning Outcome 2: Constructing and applying scientific knowledge.

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What you must know in this section of the curriculum is:

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- Pressure (ideal gases)
 - Deviations from ideal behaviour
 - Calculations using the ideal gas law

This lesson will focus on calculations using the basic knowledge in this section:

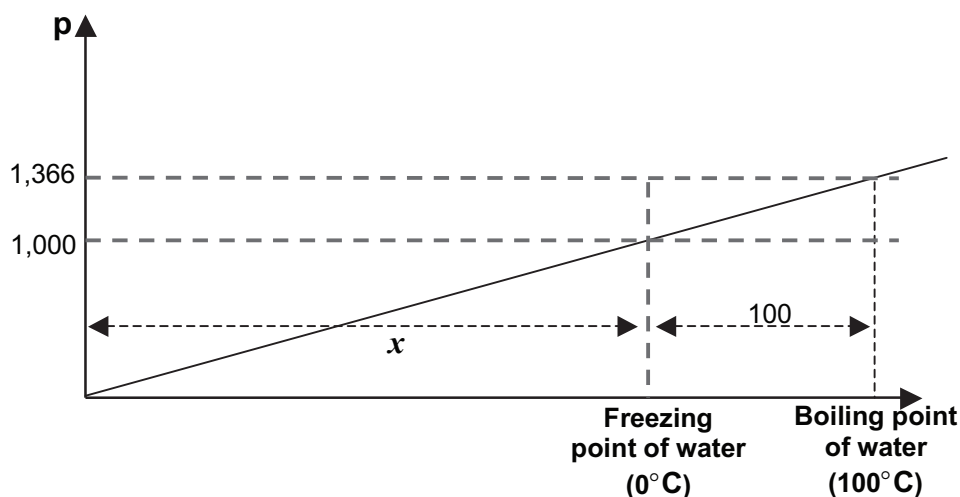
- Ideal gas law
 - Deviations of real gases from ideal gas behaviour
 - Calculations using the ideal gas law

Activities

GAS PRESSURE AND TEMPERATURE FOR A CONSTANT VOLUME OF GAS

A fixed mass of gas is kept at a constant volume. As the temperature is varied (i.e. the gas is either heated or cooled) the corresponding gas pressures are measured.





- We find that if the pressure of a fixed volume of gas is plotted against temperature in degrees centigrade (Celsius), the graph is a straight line.
- The pressure exerted by the gas at the steam point or boiling point (BP) of water is 1,366 times greater than the pressure exerted by the same volume of the same gas at the freezing point or ice point (FP) of water, regardless of what units we use to measure the gas pressure.

Using similar triangles (this is simple geometry) we can show that:

$$x = \frac{100}{(1,366 - 1,000)} = \frac{100}{0,366} = 273,15$$

THE KELVIN TEMPERATURE SCALE

- The relationship between pressure and temperature for an ideal gas is $P \propto T$. This can be used to define **Absolute Zero as $-273,15$ K** (the value of x from the graph). If we start our temperature scale at absolute zero (i.e. at 0 K), we find that the freezing point of water is 273,15 K and the boiling point is at 373,15 K.
- Note that we do not use the degree sign ($^{\circ}$) for the Kelvin temperature scale although we do speak of degrees Kelvin.*
- To convert from $^{\circ}\text{C}$ to K one simply adds 273, e.g. $92^{\circ}\text{C} = 365$ K.*
- We can state that **the pressure exerted by a fixed mass of gas kept at constant volume is directly proportional to its Kelvin (K) temperature.**
 - This can be stated mathematically as $P \propto T$
 - or $\frac{P}{T} = \text{constant}$, i.e. $P_1 T_2 = P_2 T_1$ for two different sets of conditions.

THE GAS EQUATION

- We now have two relationships that can be applied to the behaviour of a fixed mass of gas.
- The first is Boyle's Law which tells us that $PV = \text{constant}$ when T is constant.
- The second is that $\frac{P}{T} = \text{constant}$ when V is constant.
- When using a fixed mass of gas (i.e. an unvarying number of moles of the gas) we can combine the two relationships to get: $\frac{PV}{T} = \text{constant}$ or $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$.
- This can be generalised into the general gas equation $PV = nRT$.



USING THE GENERAL GAS EQUATION

- a) **P** Pressure is expressed in kilopascals (kPa). 1 pascal = $1 \text{ N}\cdot\text{m}^{-2}$. Standard pressure (atmospheric pressure at sea level) is taken as 101,3 kPa. (*kPa must be converted to Pa by multiplying by 10^3 .*)
- b) **V** Volume is expressed in m^3 . (*cm^3 must be converted to m^3 by multiplying by 10^{-6} .*)
- c) **n** This gives the number of moles and is just a **number** without actual units. (*Even though molar mass is given in $\text{g}\cdot\text{mol}^{-1}$ and $m [n = m/M]$ is in grams [g] it does not matter that these values are not SI units.*)
(*1 mol of gas at standard temperature and pressure (STP) occupies $22,4 \text{ dm}^3$.*)
- d) **R** The *Universal Gas Constant* with a value of $8,31 \text{ J}\cdot\text{K}^{-1}$.
- e) **T** Temperature in Kelvin. Standard temperature is 273 K (0°C).
($^\circ\text{C} + 273 = \text{temperature in Kelvin [K]}$.)

COMPARING IDEAL GASES AND REAL GASES

If we want to understand why real gases do not always behave like ideal gases we need to look at the assumptions we made when we defined an “ideal gas” in the first place. There is no such thing as an ideal gas. But there are gases that behave almost like an ideal gas under certain circumstances. When conditions become extreme, e.g. when pressure gets very high and temperature get very low, gases which might behave like ideal gases in the normal range of pressure and temperature (around STP: 0°C and one atmosphere of pressure) start deviating from ideal behaviour. Think about it: what similar thing happens to gas molecules when either pressure is increased or temperature is decreased? When temperature is low molecular movement slows down and molecules come closer together. When pressure increases molecules are forced closer together.

The fact is that all deviations from ideal behaviour occur when molecules get close to one another. So what comes into play when molecules get closer together, i.e. what assumptions about ideal gas molecules no longer apply when molecules get too close?

Here follows a summary of the ideal gas assumptions and a more sober assessment of real gases!

IDEAL GAS MOLECULES ...	REAL GAS MOLECULES ...
are identical, perfect spheres	have odd shapes that can affect properties, e.g. water
occupy no volume	occupy volume molecular volume noticeable at low T when molecules slow down
exert no force on one another even at low T and high P when intermolecular distances decrease	do exert forces on each other especially at low T and high P
collide with each other and the walls of a container perfectly elastically	lose energy during collisions with other molecules and the walls of their container

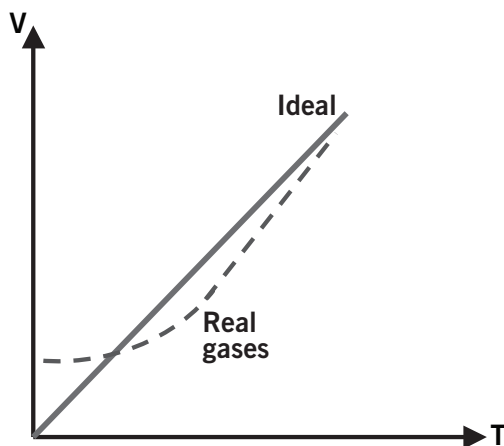


Think about the ideal gas assumptions and decide which of them are unrealistic under extreme conditions.

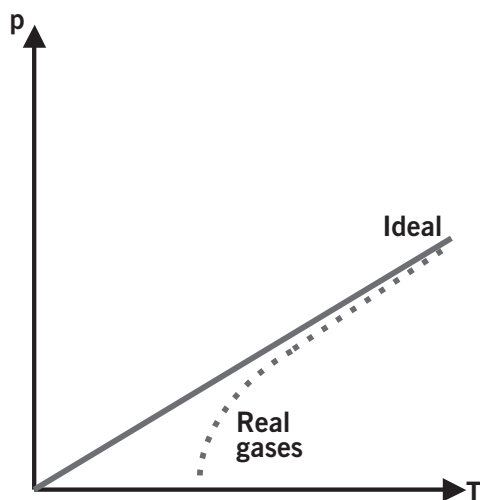
Look at the graphs in Activities 1 and 2. Use the information in the above table and explain the deviations from ideal gas behaviour.

In each case think of the effect the real situation would have, e.g. if gas molecules DO have volume, will this cause the graph to deviate at low temperatures (slow movement and hence low volumes) or at higher temperatures?

Activity 1



Activity 2



Activity 3

A sample of nitrogen gas is collected in a 500 cm³ flask. The pressure of the gas is 133 kPa at a temperature of 15°C.

- What is the mass of nitrogen in the flask?
- What volume would it occupy at STP? (Do this calculation using **two different methods**. **Firstly**, use the ideal gas law equation for the two sets of conditions. **Secondly**, see if you can think of a much shorter method.)



ELECTRON INTERACTIONS (2): AN OVERVIEW OF CHEMICAL REACTIONS

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

In this lesson we will study chemical reactions. We will apply many of the basic concepts covered in Lessons 15 & 16, Lessons 19 & 20 (specifically energy relations) and Lessons 21 & 22 (kinetic theory of matter) to a study of when and how atoms and molecules react.

- Molecular and formula mass
- Composition of substances
- Concentration
- Ions and radicals
- Stoichiometric calculations
- Energy changes in reactions related to bond energy changes
 - Exothermic and endothermic reactions
 - Activation energy
 - Energy changes in reactions related to bond energy changes
- Acid-base reactions
- Oxidation and reduction: redox reactions
- Substitution, addition and elimination reactions

Lesson

Molecular and formula mass

If you analyse a substance in the laboratory and find that it contained 1,5 parts of iron to two parts of oxygen, what would that tell you? Or if you analysed a sample of an organic substance (one containing mainly carbon) and found that it contained three parts carbon to six parts hydrogen to one part oxygen, what would you know with certainty?

Let's take the iron oxide. We know we cannot have fractions of an atom (see Dalton's Laws under Stoichiometric Calculations below), so the minimum it could be is Fe_3O_4 , which is still in the ratio 1,5:2 but raised to integers. But what if a molecule of this iron oxide was actually Fe_6O_8 ? And what if the organic compound was actually $\text{C}_6\text{H}_{12}\text{O}_2$? Both of these are quite possible. The fact is that this first analysis doesn't give a complete answer.

The simplest formula, with the simplest whole-number proportions, is known as the **empirical formula** because it gives the formula that we would calculate from an empirical laboratory analysis in which we determine the simple proportions of



the elements in a substance. We must use other methods as well as the empirical analysis to find the correct **molecular mass**. In the case of our examples above, we would get Fe_3O_4 . As a matter of interest, in the case of this iron oxide the story does not stop there. A still more detailed analysis will show that Fe_3O_4 is actually a combination of two different oxides of iron: FeO and Fe_2O_3 in a 1:1 ratio! If one calculates the oxidation number of iron in the two oxides, we find that FeO is iron (II) oxide – or **ferrous** oxide – and Fe_2O_3 is iron (III) oxide – or **ferric** oxide. (Remember that the higher oxidation number is named **-ic** and the lower **-ous**.)

Molecular mass (also called molecular weight)

We also speak of the **relative molecular mass (or weight)** of a compound because it is the mass of a molecule of the compound relative to a scale on which the mass of an atom of the ^{12}C isotope taken as exactly 12 u (or **atomic mass units**).

Formula mass (also called formula weight)

This term is used when we want to be strictly correct because the term “molecule”, according to the strict definition, only applies to groups of bonded atoms that can exist on their own. A crystal of sodium chloride (see Lessons 17 & 18) is actually composed of many, many Na^+ and Cl^- ions in a 1:1 ratio. When we use the formula “ NaCl ” it is on the understanding that there is actually no such independent entity as a sodium chloride molecule as such. Therefore we speak of NaCl as the formula and 58,442 u (= 22,989 u + 35,453 u) as being its **relative formula mass**. But in truth, these days the terms “molecular mass”, “molecular weight”, “formula mass” and “formula weight” are used interchangeably.

We will use the term **molecular mass** here even though we realise that not all formulae represent molecules in the strictest sense of the word.

CALCULATING MOLECULAR MASS (mm) AND THUS MOLAR MASS (M)

Carbon monoxide (CO)

- CO is composed of one atom of carbon and one atom of oxygen.
- Atomic mass one carbon atom = 12,01 (from the Periodic Table)
Atomic mass of one oxygen atom = 16,00 (from the Periodic Table)
- Molecular mass for C = Atomic mass carbon + atomic mass oxygen

$$\begin{aligned}\text{mm}[\text{CO}] &= 12,01 \text{ u} + 16,00 \text{ u} \\ &= 28,01 \text{ u}\end{aligned}$$

- If the relative molecular mass of one molecule is 28,01 u then ...
- ... one mole of CO molecules has a mass of 28,01 g.
- \therefore Molar mass of CO is ... $M[\text{CO}] = 28,01 \text{ g}\cdot\text{mol}^{-1}$

Carbon dioxide, CO_2

- $\text{mm}[\text{CO}_2] = 12,01 + (2 \times 16,00) = 12,01 + 32,00 = 44,01 \text{ u}$
- $\therefore M[\text{CO}_2] = 44,01 \text{ g}\cdot\text{mol}^{-1}$



Water, H₂O

- $mm[\text{H}_2\text{O}] = (2 \times 1,008) + 16,00 = 2,016 + 16,00 = 18,016 \text{ u}$
- $\therefore M[\text{H}_2\text{O}] = 18,016 \text{ g}\cdot\text{mol}^{-1}$

Calcium hydroxide, [Ca(OH)₂]

- $mm[\text{Ca(OH)}_2] = 40,08 + (2 \times 16,00) + (2 \times 1,008)$
 $= 40,08 + 32,00 + 2,016 = 74,096 \text{ u}$
- $\therefore M[\text{Ca(OH)}_2] = 74,096 \text{ g}\cdot\text{mol}^{-1}$

Ammonium sulphate, (NH₄)₂SO₄

- $mm[(\text{NH}_4)_2\text{SO}_4] = (2 \times 14,01) + (8 \times 1,008) + 32,06 + (4 \times 16,00)$
 $= 28,02 + 8,064 + 32,06 + 64,00$
 $= 132,144 \text{ g}\cdot\text{mol}^{-1}$
- $\therefore M[(\text{NH}_4)_2\text{SO}_4] = 132,144 \text{ g}\cdot\text{mol}^{-1}$

COMPOSITION OF SUBSTANCES

After testing a substance, if we get an empirical formula of C₃H₆O₂ we need to perform other tests to see whether that is, indeed, the molecular formula as well. Let us assume that it is not. After further tests, we find that each molecule of the substance is actually C₆H₁₂O₄. Now the chemist's task is to find out the exact shape of the molecule and what atoms are joined where. For instance, is it the molecule C₅H₁₁COOH (hexanoic acid) or some other substance with the same ratio of C:H:O?

CONCENTRATION

When making up a solution, one dissolves:

- a known amount of a substance (the **solute**)
- in a known amount of **solvent** (e.g. water or alcohol).

It is important to know exactly how much of each we have. For example, in **solution A** we have 5,286 g of (NH₄)₂SO₄ in 250 cm³ of water; while in **solution B** there is 1,321 g of (NH₄)₂SO₄ in 500 cm³.

If we take exactly 100 cm³ of each solution and evaporate the solvent (water) we will be left with two different amounts of the solute, i.e. ammonium sulphate. What is important to know in each case is the ratio of the mass of solute to the volume of solvent. That ratio is what we call the **concentration**.

The standard unit of concentration is "**moles per dm³**". If we know the molar mass of the **solute** (e.g. 132,144 g·mol⁻¹ for ammonium sulphate) and the volume of **solvent** it was dissolved in, we can calculate the concentration using the formula:

$$\text{concentration} = \frac{\text{moles}}{\text{volume}}$$

or $c = \frac{n}{V}$

The number of moles of solute, $n = \frac{\text{mass}}{\text{molar mass}} = \frac{m}{M}$
 $\therefore c = \frac{m}{M \times V}$

Calculations

- Concentration of solution A (5,286 g of (NH₄)₂SO₄ in 250 cm³ of water):

$$c = \frac{5,286}{132,144 \times 0,25} \text{ mol}\cdot\text{dm}^3$$

- Concentration of Solution B (1,321 g of (NH₄)₂SO₄ in 500 cm³ of water):

$$c = \frac{1,321}{132,144 \times 0,50} \text{ mol}\cdot\text{dm}^3$$



If we take 100 cm^3 of each solution (or $0,1 \text{ dm}^3$) and evaporate the solvent we will be left with $0,016 \text{ mol}$ of $(\text{NH}_4)_2\text{SO}_4$ from solution A – or $2,11 \text{ g}$; and $0,020 \text{ mol}$ of $(\text{NH}_4)_2\text{SO}_4$ from solution B – or $2,64 \text{ g}$.

STOICHIOMETRIC CALCULATIONS

In the early 1800s an English schoolteacher, John Dalton, put forward five laws of chemical combination that laid the basis for accurate chemical research. He was the first modern advocate of atomic theory, namely that all matter consisted of tiny particles (called atoms) and that every different element of matter was made up of identical atoms which were different from the atoms of every other element. Dalton's Laws are:

- All elements are composed of small particles called “atoms”.
- All atoms of the same element are identical.
- The atoms of a given element are different from those of any other element.
- Atoms cannot be created, divided into smaller particles nor destroyed. (Today we would add the words: “in the chemical process”.)
A chemical reaction simply changes the way atoms are grouped together.
- Atoms combine in simple ratios to form “compound atoms”. (Today we call these “molecules.”)

The most important conclusion from Dalton's Laws is that, in chemical reactions, substances will react in whole-number proportions. This gives us the basis of **stoichiometry** and what we know as **the laws of chemical combination**. (*Two of Dalton's “laws” are now known to be false, but at the time he formulated them there was no way of knowing this. We now know that not all atoms of an element are identical because a variable number of neutrons in the nucleus yields different isotopes. But the different isotopes of an element do not change the way atoms react chemically. The second law we now know to be false is the one about atoms being created or destroyed. Lessons 19 & 20 go into detail about nuclear fusion and fission. Dalton can hardly be blamed for not foreseeing developments in nuclear physics that only began 100 years later!*)

BONDING AND VALENCY; RADICAL IONS

As we know, in chemical reactions atoms react according to how many electrons they lose, gain or share. For example, if we describe an atom as having a **valency of one**, the atom might **either gain an electron** (as in the reaction between F or Cl with H, which loses an electron) **or lose an electron** (as in the reaction between Na or K reacting with F to produce NaF or KF). **The word valency applies to the number of electrons commonly lost or gained by single atoms.**

By knowing where the atom lies on the periodic table, we will know whether it is more likely to gain an electron and become a negative ion (atoms on the right-hand side of the table) or lose an electron and become a positive ion (atoms on the left-hand side of the table). Atoms can also share electrons and carbon, which lies in the middle of the periodic table, is the best example of a “sharer”. But we also get sharing when two atoms of the same kind form a molecule, e.g. F_2 , Cl_2 , O_2 or N_2 .

In many reactions, a group of atoms with a charge (because of too many or too few electrons in the group) might take part in the reaction without undergoing any change. Examples of these are the acid radicals that we get when an acid dissolves in water. Sulphuric acid, H_2SO_4 , and nitric acid, HNO_3 , yield $2\text{H}^+ + \text{SO}_4^{2-}$ and $\text{H}^+ + \text{NO}_3^-$ respectively. SO_4^{2-} and NO_3^- are the sulphate radical and the nitrate radical respectively.



(The table in Teacher Tips on page 342 gives some common valencies and the charge on various common radicals. It also gives instructions on the naming of some classes of compounds.)

ENERGY CHANGES IN REACTIONS RELATED TO BOND ENERGY CHANGES

The energy involved in chemical reactions is because bonds are being broken (where energy is given out) and new bonds are being made (where energy is taken in). The energy of a reaction is the overall amount of energy that is either given out during a reaction (a so-called **exothermic reaction**) or taken in during the reaction (a so-called **endothermic reaction**).

To find out more about the energy relationships in reactions, see the diagrams in Lessons 19 & 20 and the explanation of bond energies in Lessons 15 & 16.

Activation energy

It takes a certain amount of energy to get a reaction started. The energy that is put into a system to start the reaction is called the activation energy and we get this energy back once the reaction has started. In the diagrams below, the activation energy is represented by the shaded arrows. The activation energy is the energy required to get over the “energy hill”.

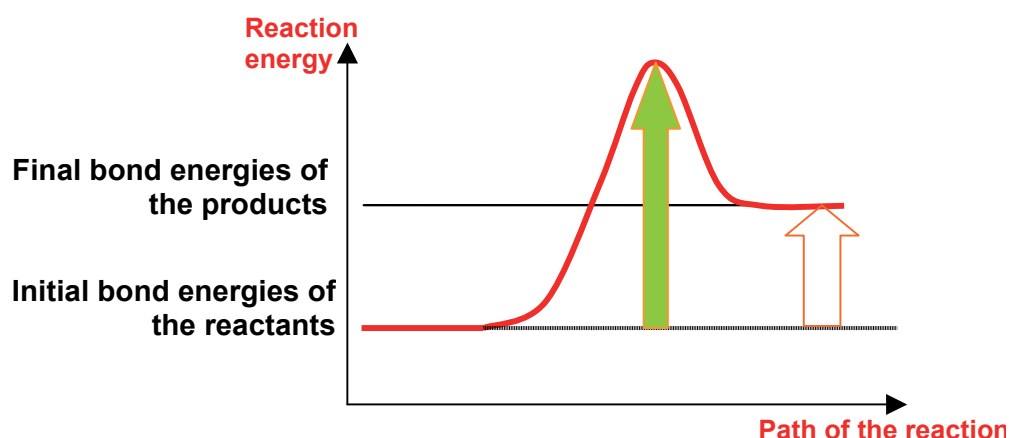
Endothermic reactions

When the total bond energies of the products are greater than the total for the reactants, it means that some energy had to be taken in from the environment. This energy is now locked up in the bonds of the products and can only be released when those bonds are broken again. When an endothermic reaction takes place in a container, it gets cooler because energy is being drawn into the container from the outside environment. The symbol used for energy of reactions is **H** (or “heat of reaction”).

For **endothermic** reactions, $\Delta H_{\text{reaction}} = H_{\text{final}} - H_{\text{initial}}$

Since $H_{\text{final}} > H_{\text{initial}}$

$\therefore \Delta H_{\text{reaction}} > 0$ (i.e. positive)



Exothermic reactions

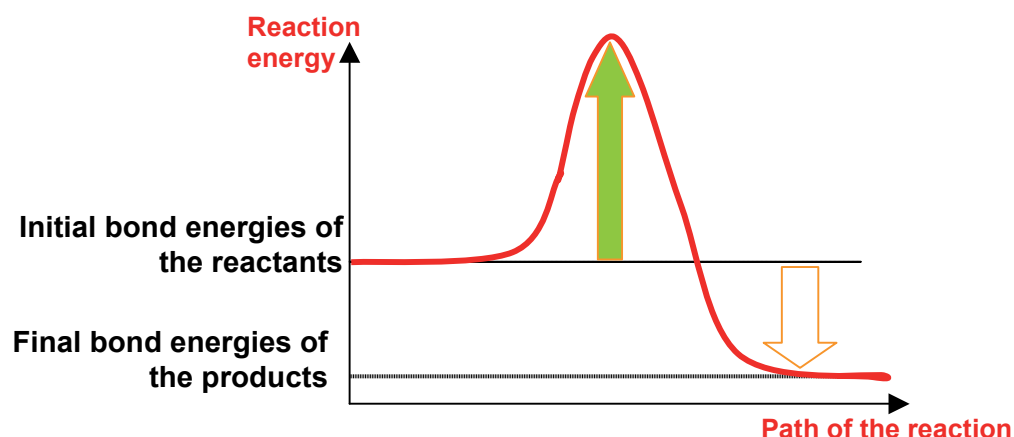
When the total bond energies of the reactants are greater than the total for the products, energy is passed into the environment. When exothermic reactions take place in a container, they heat up.



For **exothermic** reactions, $\Delta H_{\text{reaction}} = H_{\text{final}} - H_{\text{initial}}$

Since $H_{\text{final}} < H_{\text{initial}}$

$\therefore \Delta H_{\text{reaction}} < 0$ (i.e. negative)



ACID-BASE REACTIONS

What is an acid?

The early definitions of acids and bases revolved around the sour taste of acids (as in acidic fruits and vegetables), their effect on natural vegetable colourings (like litmus or beetroot juice), the soapy feel of alkalis (they actually turn the oils in the skin into soap!) and their detergent qualities and their ability to break down oils and fats. In 1923, TM Lowry and JN Brønsted proposed that **acids** be regarded as substances that can **donate a proton** to another substance and **bases** are substances that **accept protons** (from other substances like acids!).



This is not the actual reaction because acid-base reactions occur in solution and the H^+ ion (a proton) cannot exist in that form in solution. The diameter of a hydrogen ion (i.e. a proton) is about 10^{-15} m. Other positive ions in solution are much bigger (about 10^{-10} m). Because the electric field around the much smaller proton is so intense (and positive), it attracts any molecule with unshared electrons, such as water. So for a proton in solution we get this reaction:



When **hydrogen chloride gas** dissolves in water we get this reaction taking place:



In this reaction the hydrogen chloride is the acid because it is donating a proton to the water molecule. Because we have an equilibrium, there are more hydronium ions (H_3O^+) than would normally be found in pure water. In acid reactions in solution with water, the hydronium ion is the proton donor. When a molecule like **HCl** separates into its ions we call the process **dissociation**.

When **ammonia gas** dissolves in water:



the water acts as a proton donor and the base, the ammonia gas, is the proton acceptor. By donating a proton, the water molecule produces an hydroxyl ion (OH^-) which is the powerful proton acceptor in acid-base reactions in solution.



Water dissociates into the hydrogen and hydroxyl ions and the ammonia molecule and hydrogen ions associate to form an ammonium ion.

Acids and bases: strong and weak, dilute and concentrated

What makes an acid strong?

- For something to act as an acid, it must donate protons.
- The more protons a substance can donate, the stronger its acidity.
- In solutions, acids dissociate (or ionise) into their component ions.
- If one of those ions is a proton (H^+), the hydronium ion (H_3O^+) is formed.
- The more hydronium ions formed, the stronger the acid.
- So strong acids are substances that dissociate almost completely.

What makes an acid weak?

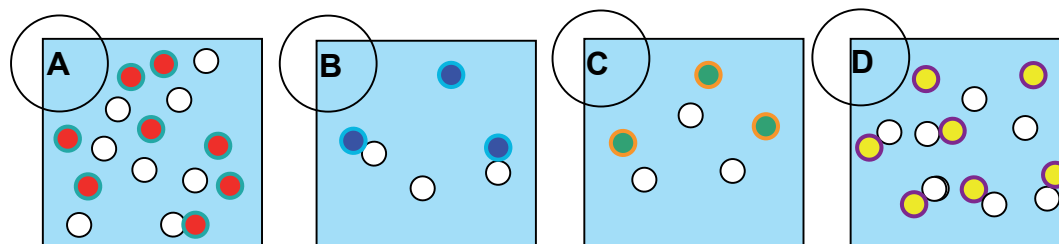
- And weak acids are substances whose molecules dissociate only slightly.
- Weak acids produce very few hydronium ions.

What makes bases strong or weak? (Use the same logic as for acids but change some of the terms!)

- ... base ... accepts protons.
- ... hydroxyl ions (OH^-).
- ... greater dissociation ... more hydroxyl ions ... stronger base.
- ... strong bases dissociate almost completely.

And now, what makes a solution (of acid or base) concentrated or dilute?

- Concentrated means a large number of molecules per unit volume.
- In solutions this means a lot of solute for not so much solvent.
- Dilute means a relatively small number of molecules per unit volume.
- In gases this means a few gas molecules relative to the volume of the container.



In the four diagrams representing four acids the white circles represent the hydrogen ion, H^+ , and the coloured circles represent acid radicals. Some of the acids in the diagrams have dissociated into ions.

Identify which of the diagrams **A-D** depict:

1. A **dilute, strong** acid?
2. A **concentrated, weak** acid?
3. A **dilute, weak** acid?
4. A **concentrated, strong** acid?

(The answers are at the end of this section on acids and bases.)

Types of acid: strong, medium and weak



The strength of an acid depends on what proportion of the acid molecules will dissociate when the acid is dissolved in water. We can define a number, K_a , for acids which is called the **dissociation constant**. If an acid is HA then $K_a = [H_3O^+][A^-]$ which is the product of the concentrations of the hydronium ions formed and the acid radical. For strong acids K_a is large and for weak acids K_a has a low value.

STRONG	<i>Sulphuric acid</i>	<i>Nitric acid</i>	<i>Hydrochloric acid</i>
	H_2SO_4	HNO_3	HCl
	$K_a \text{ approx } 10^3$	$K_a \text{ approx } 10^3$	$K_a \text{ approx } 10^3$
MEDIUM	<i>Phosphoric acid</i>	<i>Oxalic acid</i>	<i>Sulphurous acid</i>
	H_3PO_4	$(COOH)_2$	H_2SO_3
	$K_a = 7 \times 10^3$	$K_a = 5,4 \times 10^{-2}$	$K_a = 1,7 \times 10^{-2}$
WEAK	<i>Carbonic acid</i>	<i>Hydrogen sulphide</i>	<i>Ammonium ion</i>
	H_2CO_3	H_2S	NH_4^+
	$K_a = 4,4 \times 10^{-7}$	$K_a = 1,3 \times 10^{-2}$	$K_a = 5,6 \times 10^{-10}$

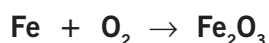
Look at the K_a value for the ammonium ion. $5,6 \times 10^{-10}$ is a very, very small number. What this indicates is that the chances of an ammonium ion dissociating into ammonia (NH_3) and a proton or hydrogen ion (H^+) are highly unlikely.

(ANSWERS TO DIAGRAMS: 1C, 2D, 3B, 4A)

OXIDATION AND REDUCTION: REDOX REACTIONS

What is oxidation?

Early chemists were aware of an important class of chemical reactions in which metals reacted with oxygen from the air. These were called “oxidation” reactions. The product of these reactions was an oxide, for instance “rust”:



The idea of oxidation numbers (see Lessons 17 & 18) was introduced to indicate the changes an atom would undergo in oxidation reactions.

During a chemical reaction ...

if the **oxidation number increases** an element is said to be **oxidised**.

If the **oxidation number decreases** the element is said to be **reduced**.

In the reaction above, iron (**Fe**) goes from **0** to **+3** i.e. the iron is **oxidised**;
oxygen (**O**) goes from **0** to **-2** i.e. it is **reduced**.

Although the word “**oxidation**” has remained with us, we now define the chemical process in terms of the movement of electrons rather than the presence of oxygen as a reactant.

OXIDATION is the ...

LOSS of electrons

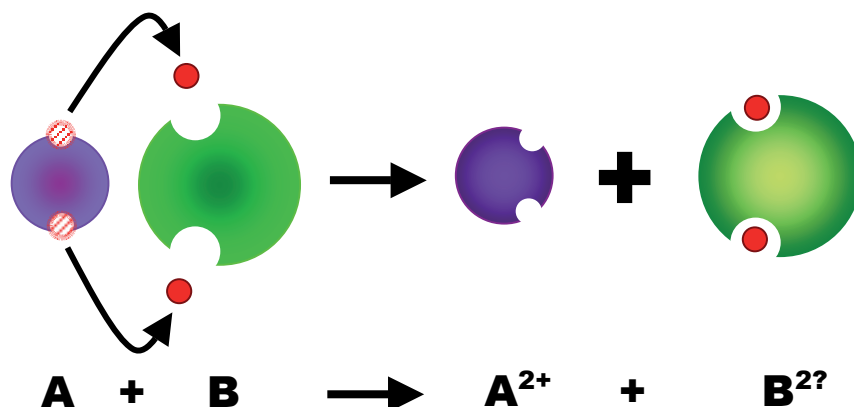
If we use this definition of oxidation we see that it includes many other reactions besides those which involve oxygen. Another point to realise is that in a chemical reaction where electrons are LOST, something else must GAIN those electrons because we cannot have free electrons just “moving around”. So we define the other part of the process as:



REDUCTION is the ...

GAIN in the number of electrons

Oxidation and reduction reactions go hand-in-hand. If one substance **LOSES** electrons in a reaction (becomes **OXIDISED**) then something else must **GAIN** electrons (become **REDUCED**).



Reactions in which one substance is oxidised and another is reduced are known as oxidation – reduction reactions or **REDOX REACTIONS**.

In the picture we see that A loses two electrons and becomes A²⁺. In the same reaction B gains the two electrons lost by A and becomes B²⁻.

What is a half reaction?

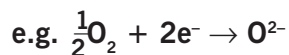
As we have seen, a redox reaction involves a loss of electrons by one substance and the gain of electrons by another. Even though these two processes must go together it is convenient to separate them out and look at the two halves of the reaction separately. We show the electrons in the half-reactions:



OXIDATION HALF-REACTION



REDUCTION HALF-REACTION



Balancing REDOX reactions

When one atom gives electrons and another takes them, we must ensure that **the number of electrons given is the same as the number of electrons taken**.

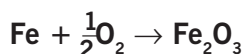
Making sure that the number of electrons is balanced is an excellent way of balancing the whole equation. Balancing the equation of a chemical reaction means that we make sure that:

- there is as much matter after the reaction has been completed as there was initially; and,
- if charged particles are involved, there is as much charge after as there was before.

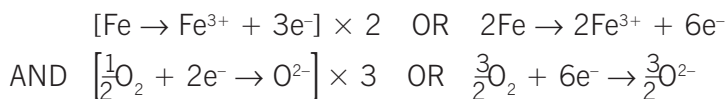
Using the iron (Fe) and oxygen (O) example again, we can see that $Fe + O \rightarrow Fe_2O_3$ is not balanced.



For a start, oxygen occurs naturally as a diatomic molecule so we denote one atom of oxygen like this:



But the number of atoms on both sides of a chemical equation must be equal so this is still unbalanced. By using the half reactions and balancing the electrons we get:



By adding the two equations we get **six electrons** on each side. By “cancelling the electrons” we understand that what is lost by the iron is gained by the oxygen. Because there is no such thing as “one and a half” oxygen molecules, we multiply through by two again to get:



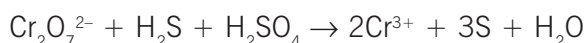
... we get a final equation which is: $4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3$

Examples

Look at the positions of nitrogen and sulphur on the periodic table. They are both in groups whose elements readily GAIN electrons. This makes them strong oxidising agents – i.e. they cause other atoms, ions and molecules to be oxidised (or lose electrons). Other well-known oxidising agents are the permanganate ion and the dichromate ion. Here are some examples of their redox reactions:



The nitrate ion is said to **oxidise** iodine to the iodate (IO_3^-) so the **NO_3^- ion** is the **oxidising agent**. The nitrate ion is reduced to nitric oxide, or **NO_2** . Check the change in oxidation numbers to verify this.



The dichromate ion **oxidises** the sulphide to pure sulphur. The **$\text{Cr}_2\text{O}_7^{2-}$ ion** is the **oxidising agent** and is itself reduced to **Cr^{3+}** .

In order to balance a redox reaction we need at least FIVE facts:

- How likely is a reactant to gain or lose electrons?
- Which reactant will gain and which will lose electrons?
- How many electrons are gained or lost by a particular reactant?
- Are hydrogen ions involved (i.e. does the reaction take place in an acidic medium)?
- Is water involved in the reaction?

To balance equations for redox reactions we can use **tables of half-cell reactions** which give us the number of electrons gained and lost, the presence of H^+ ions and the involvement of water in the reaction. When water is used as a solvent to form solutions of aqueous ions it is not regarded as being *involved* in a reaction and is therefore not shown in the balanced equation.

ORGANIC CHEMISTRY

This is the branch of chemistry that deals with the chemical properties of one element: **carbon**. The fact that carbon atoms have four valence electrons and are much more likely to share electrons with other atoms than “give” or “take,” as in ionic reactions, is highly significant. For one thing it enables carbon to form long chains of carbon atoms. Other atoms can attach to the carbon on the chains and give the almost infinite number of possible carbon compounds many different



properties. Carbon chemistry is often called the “chemistry of life” because carbon, or organic, molecules form the basis of all processes in living organisms.

The four outer electrons of carbon arrange themselves in a **tetrahedral** shape (see VSEPR in Lessons 17 & 18) so the long chains of carbon actually follow a zigzag shape based on the angles of bonds around a tetrahedron.

If you can't picture a tetrahedron, take a small ball of plasticine or Prestik. Take four matches and stick them into the ball so that the angles between every pair of matches is the same.

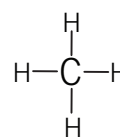
The shape you are holding is a tetrahedron!

Covalent bonding of carbon

Four carbon electrons can be shared with many other atoms that have single electrons to share. The carbon itself has four unshared electrons.

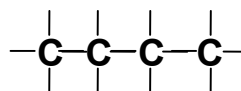


A carbon atom drawn like this shows four electrons available for bonding – but with nothing actually bonded yet.



And here we have a carbon atom whose four unshared electrons, have each formed a bond with the unshared electron from a hydrogen atom.

When carbons share electrons with each other they can form long chains.



Homologous series

Groups of organic molecules of the same type but which increase in size by one unit at a time are called **homologous series**. The simplest of these are the **hydrocarbons** whose molecules contain only carbon and hydrogen. And the simplest of the hydrocarbons are the **alkanes** in which we get only single bonds. The first four alkanes (methane, ethane, propane and butane) have unsystematic names, but thereafter they take their names from Greek numbers e.g. pentane (“penta” is Greek for “five”), hexane, heptane, octane, nonane, decane, etc.

Double bonds

It is possible for two atoms that each have more than one unshared electron to make more than one bond. In other words, if two electrons from carbon shares with two electrons from another atom, e.g. oxygen, we get a **double bond**.

Chemical reactions are basically interactions involving electrons; double bonds are electron rich; and electrons in the double bond are quite exposed.

This makes double bonds highly reactive, i.e. **double bonds provide a ready site for chemical reaction.**

Functional groups

It is possible to form molecules that are based on carbon chains by replacing one or more hydrogen atoms atoms or groups of atoms that are called **functional groups**. Instead of homologous series of alkanes, for instance, we can now have series of substances like **alcohols, aldehydes, ketones, ethers, carboxylic acids,**



esters and **halo-alkanes** in which halogens use their single, unshared electrons to form single covalent bonds with carbon atoms. Another type of functional group is derived from the alkanes. When methane loses one hydrogen it becomes a **methyl radical** ($-\text{CH}_3$). The alkyl radicals also form an homologous series, i.e. **methyl-**, **ethyl-**, **propyl-** and **butyl-** groups, etc.

Functional group	Suffix	Functional group	Suffix
alcohol	-ol	aldehyde	-al
carboxylic acid	-oic acid	ketone	-one
ether	+ ether	ester	+ ester

Molecular and structural formulae

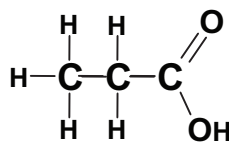
When we write formulae for organic molecules we can do so in three different ways. We can write the **molecular formula** in which we give the number of atoms of each different element in the molecule.

Example: $\text{C}_3\text{H}_6\text{O}_2$ [$mm = 3(12) + 6(1) + 2(16) = 74 u$]

This formula is useful if we want to calculate the molecular mass but it gives no clue about the shape of the molecule. For this we need to know where the atoms are situated in the molecule. We also need to know what functional groups are present. The two kinds of structural formula give us this information:

Examples: $\text{CH}_3\text{CH}_2\text{COOH}$

Partial structural formula



Structural formula

SUBSTITUTION, ELIMINATION AND ADDITION REACTIONS

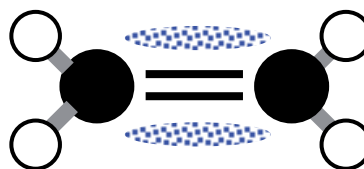
Reactions of organic compounds

Now that we know what organic molecules look like and where the electrons are to be found in the bonds we are in a better position to appreciate how they react.

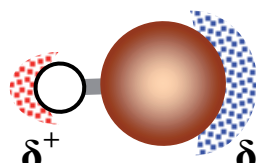
Addition reactions

This is a very important group of reactions that involves the double bond. Because of the greater number of electrons in the double bond and the fact that the bonding electrons do not all lie precisely between the double-bonded atoms, they are very easily involved in certain reactions.

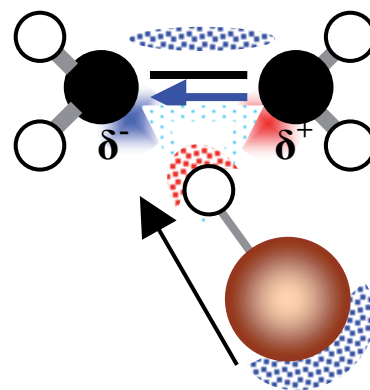
Here is an example of a typical addition reaction between a molecule with two, double-bonded carbon atoms (the molecule is called "ethene" and it is a gas) and a molecule of hydrogen bromide.



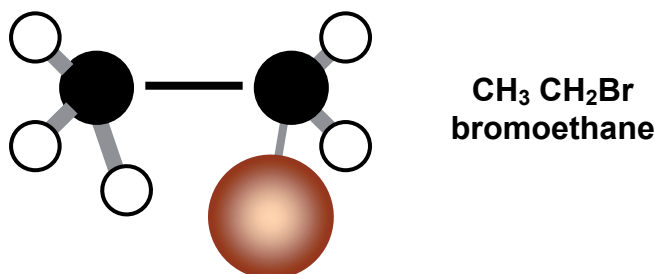
Because of the electronegativity difference (see Lessons 15 & 16) we know that HBr will be a polar covalent molecule. This means that the shared pair of electrons in the H-Br bond will separate leaving the bromine end more negative and the hydrogen end more positive.



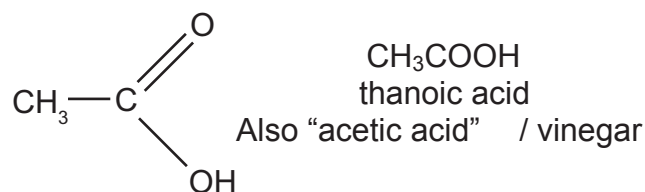
The positive end of the HBr molecule will “seek” the exposed electrons in the ethane double bond. (For this reason the HBr is called an “**electrophile**” because it is an “electron lover”.) When the positive end of the HBr approaches the double bond its electrons are pulled out of shape. This leaves one of the carbons slightly negative and the other one slightly positive. The positive and negative ends of the HBr will take advantage of the fact. The double bond is now broken and two new single bonds (one a C–H and the other a C–Br) are formed.



Once the approaching HBr has disturbed the distribution of electrons in the ethene the positive end (H⁺) can bond with the left-hand carbon and the Br⁻ part of the HBr will bond with the right-hand carbon. The double bond is broken but each carbon still have four bonds



The example of HBr being added across the double bond was an example of electrophilic addition because the positive/electron-seeking part of the HBr molecule was active in breaking the double bond. It is also possible to get a different addition mechanism: nucleophilic attack. If a part of a molecule is exposed because of the electrons being drawn away, it is possible for a positive-seeking molecule to become attached to that point.

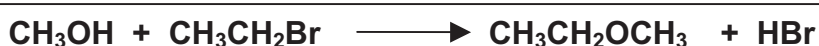
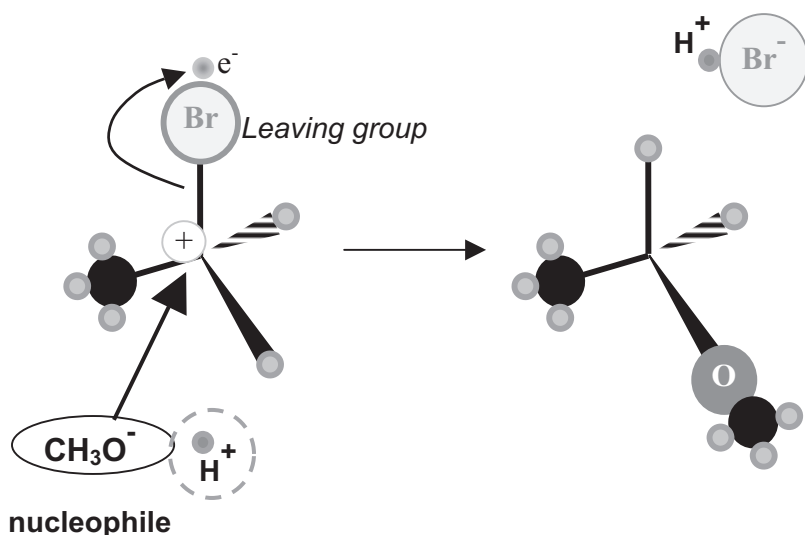


The highly electronegative oxygens will draw electrons in the bonds away from the central carbon and leave it exposed and slightly positive. A molecule like water, with two unpaired electrons, can react with the ethanoic acid at this point.

Substitution reactions

In a **substitution reaction**, a functional group in a chemical compound is replaced by another group. Because of the high electronegativity of halogens compared to carbon, a carbo-halogen bond in a molecule will be **polarised** i.e. the electrons in the bond will spend more time closer to the halogen (e.g. the fluorine, chlorine or bromine atom) The partially positive carbon that results from the polarisation is therefore **electrophilic** and can be attacked by **nucleophiles**. When a suitable nucleophile attacks the carbo-halide bond, it can displace the halogen in a **substitution reaction** to release the halide anion and form a new bond to the carbon, as shown below.





Elimination reactions

An **elimination reaction** is a type of organic reaction in which two substituents are removed from a molecule in either a one- or two-step mechanism. The atoms or groups being removed can be replaced through either substitution or addition reactions.

Activity 1

Name the following compounds (where necessary use the stock notation to indicate the oxidation state of atoms) and calculate their formula masses:

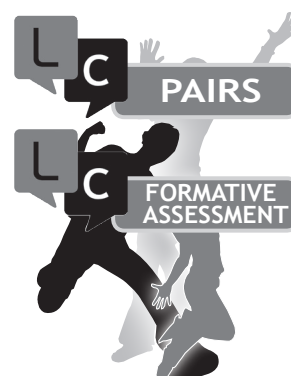
- | | |
|-------------------------------|--------------------------------------|
| a) Fe_2O_3 | b) $\text{Ca}(\text{HCO}_3)_2$ |
| c) SO_3 | d) $\text{K}_2\text{Cr}_2\text{O}_7$ |
| e) LiClO_3 | f) $\text{Mg}(\text{NO}_3)_2$ |
| g) $(\text{NH}_4)\text{SO}_4$ | h) HgO |
| i) AgNO_3 | j) CoBr_2 |
| k) HNO_3 | l) NH_3 |
| m) H_2O_2 | |

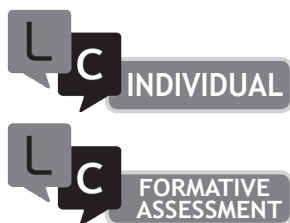


Activity 2

Write the formulae for the following compounds:

- | | |
|---------------------------|------------------------|
| a) sulphur (IV) oxide | b) potassium carbonate |
| c) iron (III)nitrate | d) ammonium sulphate |
| e) potassium permanganate | f) aluminium sulphate |
| g) magnesium phosphate | h) carbon (II) oxide |
| i) calcium hydroxide | j) beryllium sulphite |
| k) copper (II) sulphate | l) Ammonium phosphate |





Activity 3

Balance the following equations and name the products:

- Which reactions probably represent decomposition by heating?
- State which reactions represent acid-base reactions or redox reactions.
- In the case of redox reactions, state what is being reduced and what is being oxidised.

	Reactants	Product(s)
a)	$K + O_2$	K_2O
b)	H_2O_2	$H_2O + O_2$
c)	$Cl_2 + NaBr$	$NaCl + Br_2$
d)	$SO_2 + O_2$	SO_3
e)	$KClO_3$	$KCl + O_2$
f)	$Cu(NO_3)_2 + C$	$CuO + NO_2 + CO_2$
g)	$Fe + HCl$	$FeCl_2 + H_2$
h)	$Mg + N_2$	Mg_3N_2
i)	$MnO_2 + HCl$	$MnCl_2 + H_2O + Cl_2$
j)	$C_{12}H_{22}O_{11} + O_2$	$CO_2 + H_2O$
k)	$AgNO_3 + BaCl_2$	$AgCl + Ba(NO_3)_2$
l)	$N_2 + H_2$	NH_3 (<i>the Haber process</i>)
m)	$NaOH + H_2SO_4$	$Na_2SO_4 + H_2O$
n)	$Al + O_2$	Al_2O_3
o)	KNO_3	$KNO_2 + O_2$



Activity 4

Write balanced chemical equations for the following reactions:

	Reactants	Product(s)
a)	magnesium + oxygen	magnesium oxide
b)	copper(II)oxide + carbon	copper + carbon(IV) oxide
c)	iron + hydrogen chloride	iron(III) chloride + hydrogen
d)	sodium + water	sodium hydroxide + hydrogen
e)	copper(II) carbonate	copper(II) oxide + carbon dioxide
f)	chlorine + potassium bromide	potassium chloride + bromine
g)	aluminium + iodine	aluminium iodide
h)	calcium carbonate + an acid	calcium chloride + water + carbon dioxide
i)	sodium hydroxide + an acid	sodium sulphate + water
j)	ammonia + hydrogen chloride	ammonium chloride



BASIC STOICHIOMETRIC CALCULATIONS

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

What you must know in this section of the curriculum is:

- Atomic weights
- Molecular and formula weights
 - Atomic weights
 - Molecular and formula weights
 - Determining the composition of substances
- Composition of substances
- Amount of substance (mole)
 - Molar volume of gases
 - Concentration
- Stoichiometric calculations
 - Amount of substance (mole), molar volume of gases, concentration
 - Basic chemical calculations
 - Stoichiometric calculations

This lesson will focus on calculations using the basic knowledge in this section:

- Stoichiometric calculations
 - Amount of substance (mole), molar volume of gases, concentration
 - Basic chemical calculations
 - Stoichiometric calculations

Activities

Before doing the activities we will collect all the information we are likely to need.

Atomic masses (rounded):

Hydrogen (H)	*	1
Carbon (C)		12
Nitrogen (N)	*	14
Oxygen (O)	*	16
Magnesium (Mg)		24
Sulphur (S)		32



Chlorine (Cl)	35,5
Calcium (Ca)	40
Copper (Cu)	64

* All **diatomic molecules** in their natural state, i.e. H₂, N₂, O₂, Cl₂

Facts and formulae:

1 mole of gas at STP occupies 22,4dm³

$$\text{number of moles} = \frac{\text{mass of sample (g)}}{\text{molar mass (g}\cdot\text{mol}^{-1})} \left[n = \frac{m}{M} \right]$$

$$\text{concentration} = \frac{\text{number of moles (mol)}}{\text{volume (dm}^3\text{)}} \left[c = \frac{n}{V} \right]$$



Activity 1

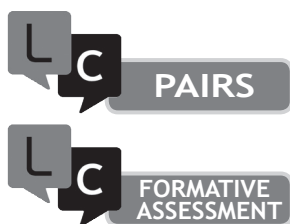
What is the product when 20 g of pure magnesium ribbon is burnt in air and how much of the product is formed?

Understanding the problem:

When something like magnesium burns in air it is combining chemically with the oxygen in the air.

Because there is an excess of oxygen available we can assume that all the magnesium will react.

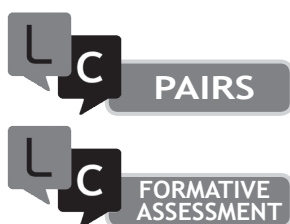
Always start with a balanced equation for the reaction.



Activity 2

When acids react with carbonates, two of the products are carbon dioxide and water.

If 250 g of calcium carbonate is reacted with an excess of acid, what mass and hence what volume of carbon dioxide gas will be formed at STP?



Activity 3

Blue crystals of copper sulphate actually contain water molecules that are part of the crystal structure. When copper sulphate crystals are heated the product is white anhydrous copper sulphate.

What percentage of the mass of hydrated copper sulphate (CuSO₄·5H₂O) is water?

What mass and volume of water can be produced when 37,5 g of copper sulphate crystals are heated?

Understanding the problem:

Water of crystallisation means that a certain number of water molecules are bound into the crystal structure, so the water is an integral part of the hydrated copper sulphate. When the water is driven off during heating the hydrated crystal structure breaks down and a new crystal structure (for white anhydrous copper sulphate) is formed.



Activity 4

A balloon full of methane gas has a volume of 11,2 dm³ at STP. This gas is burnt in air. What mass of water will be formed and what volume of carbon dioxide gas, also at STP, is evolved during the reaction?

Understanding the problem:

Again, there is an excess of oxygen so we can assume that the methane will burn completely.



Activity 5

When carbon dioxide gas is bubbled through lime water (calcium hydroxide) the lime water turns milky. This is the standard test for carbon dioxide gas.

If the milkiness is caused by a carbonate being formed and the only other product is water,

- balance the equation of the reaction; and
- calculate the mass of carbonate formed when an excess of CO₂ is bubbled through a solution made by dissolving 21,6 g of calcium hydroxide in water.
- What is the concentration of the calcium hydroxide solution if the 21,6 g of calcium hydroxide was dissolved in 1,5 litres of water?



ENERGY IN CHEMICAL AND PHYSICAL REACTIONS

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 1:

Conducting an investigation.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

INTRODUCTION

What you must know in this section of the curriculum is:

- Energy changes in reactions related to bond energy changes
- Exothermic and endothermic reactions
- Activation energy
 - Energy changes in reactions related to bond energy changes
 - Exothermic and endothermic reactions
 - Activation energy
- More on energy in physical processes and chemical reactions.
- Cell energy.

This lesson will focus on the energy involved in certain physical processes and chemical reactions.

Specific references to Lesson notes are as follows:

Lessons 19 & 20, page 165 – see the diagrams illustrating “energy IN” and “energy OUT” of systems.

Lessons 23 to 27, page 194 – see the diagrams explaining exothermic and endothermic reactions.

Additional notes: Energy in living cells

Life needs energy to transport liquids and energy-giving substances (!) around bodies and organisms; to operate muscles; to remove waste matter; to repair cells and build new ones to replace those that have been damaged; and even to transmit electrical signals down neural pathways (nerves and neurons). None of the essential processes occurring in our bodies, in animals’ bodies or in the structures of every member of the plant kingdom can take place unless energy is supplied. Every life process requires energy.

Where does that energy come from? It is possible in many cases to trace the energy used on Earth back to the Sun whose light somehow finds its way into every energy pathway. For instance, in the sea there are trillions and trillions of tiny, green plant-like organisms that use photosynthesis to build their cells. As a base level in the marine food chain these wonderful algae and so on trap energy from the Sun and pass it into the great food webs of the Earth’s oceans.



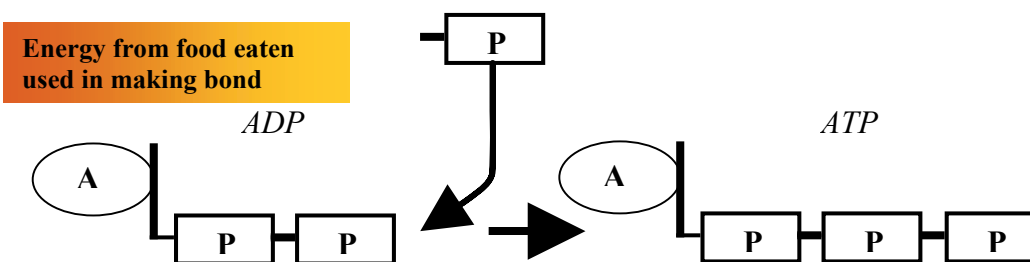
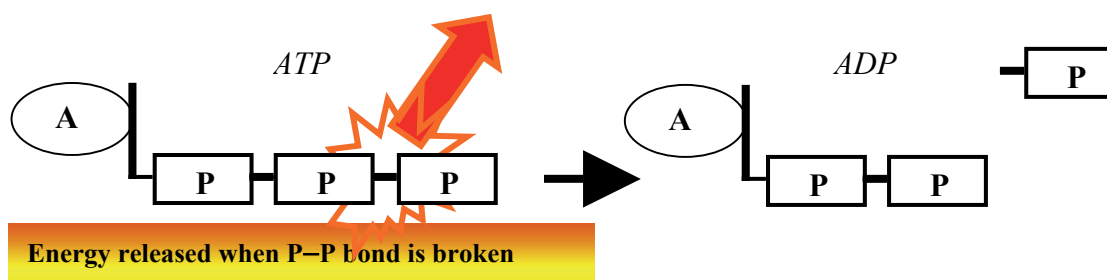
Every cell function in every living thing needs energy to live. And where is the energy stored? **In the chemical bond energy that is stored in the bonds between the atoms that make up the molecules which support life.** In order for energy to be released in order to do useful work in cells, inter-atomic bonds must be broken and the energy released that used to hold those atoms together.

ATP: the universal energy carrier

The principal source of cell energy is one, remarkable molecule. It has the ability to release energy in the breaking of one specific bond. But what is truly remarkable is that as soon as there is sufficient energy available in the cell the broken bond is remade and the energy used to remake the bond is thus stored again. This molecule that seems to recharge itself over and over again after every occasion that it supplies some energy is called **ATP: adenosine triphosphate.**

ATP is a unit of **adenosine** with a “tail” of three phosphate units. The phosphate units are bonded by high-energy chemical bonds. The last (or end) phosphate unit can break away and the bond energy is released for use in cell functions. When this one phosphate unit is released it leaves behind **ADP: adenosine diphosphate.** When a phosphate unit (there are phosphates circulating inside the cell) rejoins the ADP we have another ATP. Whenever a cell process is about to take place one or more ATP molecules must supply the energy by being converted to ADP again.

Remaking ATP from ADP requires energy and this comes from the food that is taken in by the organism or body. ATP itself is produced in tiny bodies called **mitochondria.** During the process of energy release in the mitochondria, oxygen plays a key part.



Photosynthesis

Photosynthesis is the process by which plants make high energy molecules that can take energy to the plant’s mitochondria. This is the only major difference between the energy processes in plants and animals: plants make their own fuel molecules whereas animals must either eat plants or something that has in order to get fuel to the mitochondria. The process of photosynthesis takes its energy from the light (photo-) from the Sun. The chlorophyll molecules in green plants (chlorophyll gives plants their green colour) absorbs light energy and transfer

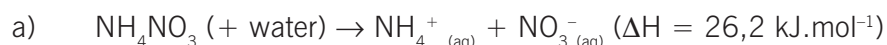


this energy electrons. In effect the process of photosynthesis involves absorbing carbon dioxide from the atmosphere and then using sunlight to produce oxygen and glucose sugar.



Activity 1

Cold packs used for immediate treatment of sports injuries contain water and a sealed container of some substance that causes cooling when it dissolves in a solvent like water. When the sealed container is broken the physical process of dissolution takes place. The dissolution of ammonium nitrate in water is an endothermic reaction which absorbs 26,2 kilojoules of heat per mole ($\text{kJ}\cdot\text{mol}^{-1}$) of reactant.



The processes that take place when NH_4NO_3 dissolves are: the salt separates (dissociates) into two ions and the ions become aqueous ions – which means that the polar water molecules form jackets (associate) around the positive NH_4^+ and negative NO_3^- ions.

**Which of these processes take in energy and which give out energy?
Which of the processes involves more energy, dissociation or association?**

- The molar mass of NH_4NO_3 is $80,0 \text{ g}\cdot\text{mol}^{-1}$.
- The solubilities of ammonium nitrate at different temperatures are given in the table below as “grams per 100 ml”. For example, at 40°C , 286 grams of NH_4NO_3 will dissolve in 100 ml of water. The equivalent solubility in a different system of units is $35,75 \text{ mol}\cdot\text{dm}^{-3}$.
- A **saturated solution** is one in which no more solute will dissolve. So if we have 100 ml of water at 40°C , a maximum of 286 g of NH_4NO_3 will dissolve in it. That will give a saturated solution. Thus to make 1 dm^3 of saturated solution we must dissolve 35,75 mol or $(35,75 \times 80) \text{ g}$.
- The energy absorbed when we make 1 dm^3 of saturated solution at 40°C can be calculated since it has been determined experimentally that for every mole of NH_4NO_3 that dissolves, 26,2 kJ of energy is absorbed from the environment (surroundings). Thus when making 1 dm^3 of saturated solution at 40°C (solubility $35,75 \text{ mol}\cdot\text{dm}^{-3}$), 936,7 kJ will be absorbed.

b) **Complete the table by calculating the missing solubilities and completing the energy column.**

Solubility (g/100ml)	Temperature ($^\circ\text{C}$)	Solubility ($\text{mol}\cdot\text{dm}^{-3}$)	Energy (kJ) absorbed when 1 dm^3 of saturated solution is prepared.
119	0		
190	20		
286	40	35.75	936,7
421	60		
630	80		
1024	100		

c) **Draw a graph of solubility vs temperature.** Label the axes.



Activity 2

The reaction shown for magnesium and water is very energetic once it has been initiated. The bright white light is characteristic of magnesium reactions and for this reason, magnesium is used in the manufacture of emergency flares. The bright white light also contains wavelengths of ultraviolet light, which is why one should not stare too long at burning magnesium.

Normally the word “burning” is used when things react with oxygen to form various oxides. Should we consider a magnesium-aluminium pencil sharpener as “burning” when it reacts with steam (very hot water vapour)? Probably not. Instead we will use the term “reacts (violently) with”.

Thermite reactions use a finely ground metal and an oxide of another metal. Once the reaction has been initiated, the pure metal in the mixture is oxidised and the metal in the oxide is reduced to pure metal. As the name suggests, thermite reactions produce enormous amounts of energy. The reaction of iron oxide and aluminium can be used to weld steel e.g. railway lines. The thermite reaction is carried out in a metal container placed over the position where the weld is to be made. When the iron metal is formed it is molten. It is allowed to pour from the container and solidify at the weld point.

The complete formula for the thermite reaction using iron (III) oxide is as follows:



The formula for the reaction using iron (II,III) oxide:



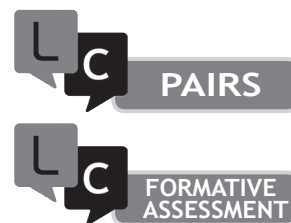
Molar masses: Fe: 55,8 g·mol⁻¹; O: 16,0 g·mol⁻¹; Al: 27,0 g·mol⁻¹.

- When thermite is made using iron (III) oxide, for maximum efficiency it should contain, by mass 25.3 % aluminium and 74.7 % iron oxide. Show by calculation how these percentages arise.
- When thermite is made using iron (II and III) oxide (or “magnetite” - see Lessons 23 to 27, page 194), for maximum efficiency it should contain, by mass, 23.7% aluminium and 76.3% iron oxide. Show by calculation how these percentages arise.
- While the reaction using Fe₃O₄ produces a substantially larger amount of energy per mole, the reaction using Fe₂O₃, produces more energy pr. gram of thermite mixture. Show by calculation that this is true.
- Balance the thermite reaction that uses Fe₃O₄ instead of Fe₂O₃ i.e. determine the values of x and y.
- Does the pencil sharpener reaction have a high or a low activation energy? (Watch the video of the reaction being performed and you will get a clue to help you answer this.)

Activity 3

This activity is about the reaction between hydrogen gas and oxygen gas.

The following information is from a KSC (Kennedy Space Center) fact sheet. Read it carefully and see why it is a relatively convenient propellant to us in rockets. (Note the difference between what NASA calls a **fuel** and an **oxidiser**.) More facts on rocket fuels and propellants can be found at <http://www-pao.ksc.nasa.gov/nasafact/count2.htm>.



CRYOGENIC PROPELLANTS

Cryogenic propellants are liquid oxygen (LOX), which as an oxidiser, and liquid hydrogen (LH₂), which is a fuel. The word cryogenic is a derivative of the Greek kyros, meaning "ice cold." LOX remains in a liquid state at temperatures of -298 °F (-183 °C).

LH₂ remains liquid at temperatures of -423 °F (-253 °C). In gaseous form, oxygen and hydrogen have such low densities that extremely large tanks would be required to store them aboard a rocket. But cooling and compressing them into liquids vastly increases their density, making it possible to store them in large quantities in smaller tanks.

The distressing tendency of cryogenics to return to gaseous form unless kept super cool makes them difficult to store over long periods of time, and hence less satisfactory as propellants for military rockets, which must be kept launch-ready for months at a time.

But the high efficiency of the liquid hydrogen/liquid oxygen combination makes the low-temperature problem worth coping with when reaction time and storability are not too critical. Hydrogen has about 40 % more "bounce to the ounce" than other rocket fuels, and is very light, weighing about 0.06 kilogram per litre. Oxygen is much heavier, weighing about 1.2 kilograms per litre.

The high efficiency engines aboard the Space Shuttle orbiter use liquid hydrogen and oxygen. The fuel cells in an orbiter use these two liquids to produce electrical power through a process best described as electrolysis in reverse. Liquid hydrogen and oxygen burn clean, leaving a by-product of water vapour.

The rewards for mastering LH₂ are substantial. The ability to use hydrogen means that a given mission can be accomplished with a smaller quantity of propellants (and a smaller vehicle), or alternately, that the mission can be accomplished with a larger payload than is possible with the same mass of conventional propellants. In short, hydrogen yields more power per litre.



Before doing the next activity, read the following facts. When you have done so, tackle the Activity and then watch the video.

Bond strengths:	H–H	436 kJ·mol ⁻¹
	O = O	498 kJ·mol ⁻¹
	H–H	366 kJ·mol ⁻¹

When hydrogen and oxygen react to form water, the following processes take place:

- The hydrogen molecules must be separated into two hydrogen atoms.
- The oxygen molecules must be separated into two oxygen atoms.
- The breaking of the product bonds requires that energy be put into the system.
- Two hydrogen – oxygen bonds are formed per water molecule.

- When an H – O bond is formed it represents a more stable (i.e. less energetic) situation than having two free, separate atoms of oxygen and hydrogen.
 - Hence when the H – O are formed energy released since bonded atoms represent lower energy than individual atoms.
- a) Give a balanced equation for the reaction when hydrogen gas reacts with oxygen gas.
 - b) Calculate the amount of energy taken in or given out when 2 moles of hydrogen gas reacts with one mole of oxygen gas.
 - c) State whether the reaction is endothermic or exothermic.
 - d) Does the reaction have a high activation energy or not?



ACID-BASE REACTIONS

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.



Overview

What you must know in this section of the curriculum is:

- Acid-base reactions

This lesson will focus on calculations using the basic knowledge in this section:

- More acid-base reactions.
- Titrations and calculations

Activities

The most common mineral acids are hydrochloric, nitric and sulphuric acids. They are the least complicated acids to deal with because, being strong acids, they dissociate completely. That means that 1 mole of HNO_3 will give one mole of H^+ ions (protons) and 1 mole of NO_3^- ions in solution with water.

When a proton or H^+ ion is formed in water, water molecules are immediately attracted to the hydrogen ion which is a positive charge with a high electric field intensity since it is a small particle. Polar molecules of water immediately react with the proton to form an hydronium ion:



The hydronium ion (H_3O^+) is also positive and will attract more polar water molecules. In this case, however, they do not actually react with other water molecules. Instead water molecules form a “jacket” around the hydronium ion to form an aqueous hydronium ion. To be perfectly correct one should write this $\text{H}_3\text{O}^+_{\text{aq}}$, but this is often shortened to H^+_{aq} .

When an acid and a soluble hydroxide – called an alkali – react they are said to neutralise one another. The neutralisation reaction is exothermic and the products are salt and water.

WHAT IS A TITRATION?

Titrations depend on the neutralisation reaction between an acid (**HA**) and an alkali (a base - **BOH**) to give a salt (**A⁺B⁻**) plus water (**H₂O**):



In a titration we take a known volume of a base with a known concentration and add to it an accurate amount of acid whose concentration we do not know; OR *vice versa*.

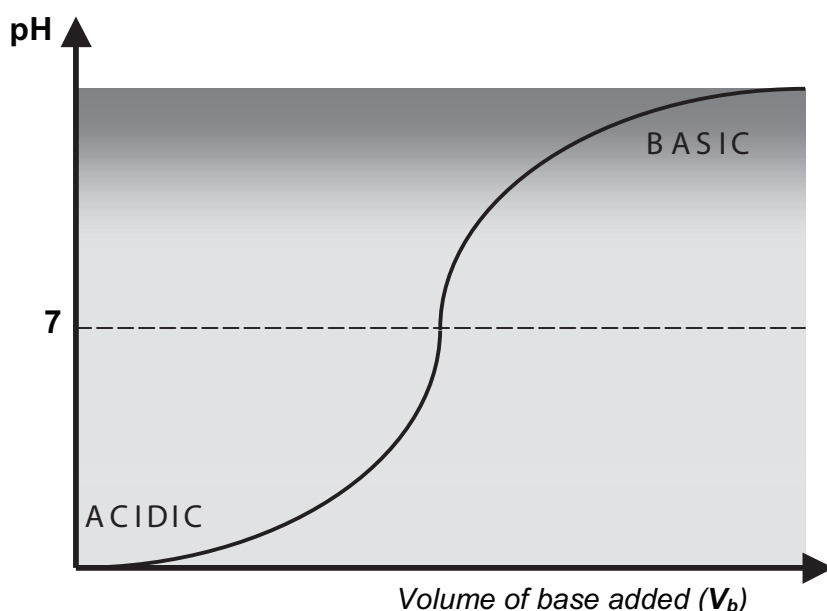


$n = \frac{m}{M_r}$	If m is the mass of a substance (in g) and M_r is the molar mass (in g·mol⁻¹), then n gives the number of moles.
If m grams of a substance is dissolved in a known volume (dm⁻³) of solvent, we can determine the concentration of the solution.	The concentration of a solution is: $\frac{\text{moles (n)}}{\text{volume (V)}}$ Concentration is given in mol·dm⁻³
If $c = \frac{n}{V}$ then ... $n = c \times V$	The number of moles of a substance in solution can be calculated by multiplying concentration by volume.

INDICATORS AND THE ENDPOINT

In neutralisation reactions we use indicators to show when the **endpoint** has been reached. The endpoint is the point where there are as many hydronium ions as hydroxyl ions i.e. their concentrations are equal: $[\text{H}_3\text{O}^+] = [\text{OH}^-]$. An **indicator** is a substance which has a different colour in acid and base. The **indicator** we use in a titration is important because we want the colour change to occur at the exact point where the acid neutralizes the base.

Titration between a **STRONG ACID** and a **STRONG BASE**



For reactions between strong acids and strong bases (i.e. where the dissociation into ions is almost complete), **neutralisation occurs at pH 7**. The indicator we choose is **bromothymol blue** because it changes colour at exactly pH 7. (The colour change is indicated by the colours on the graph i.e. yellow in acid to blue in base.) The endpoint is reached at higher or lower values of pH when we titrate either **strong acids with weak bases** or **weak acids with strong bases**.





GROUPS

Activity 1

When an acid (e.g. sulphuric acid) and an alkali react together the reaction is called a “neutralisation reaction” and the products are a salt and water e.g. Na_2SO_4 (sodium sulphate) + $2\text{H}_2\text{O}$.

Write balanced reactions for the neutralisation reactions between hydrochloric acid, nitric acid and sulphuric acid and the alkalis sodium hydroxide and calcium hydroxide.



BASELINE ASSESSMENT



PAIRS

Activity 2

A solution of sulphuric acid has a concentration of $0,5 \text{ mol}\cdot\text{dm}^{-3}$.

If 1 dm^3 of sulphuric acid neutralises 2 dm^3 of solution of sodium hydroxide, what is the concentration of the alkali solution?



FORMATIVE ASSESSMENT



INDIVIDUAL

Activity 3

What volume of a $0.1 \text{ mol}\cdot\text{dm}^{-3}$ solution of hydrochloric acid will be required to neutralise 50 ml of a $0.2 \text{ mol}\cdot\text{dm}^{-3}$ potassium hydroxide solution?



FORMATIVE ASSESSMENT



INDIVIDUAL

Activity 4

A $0.5 \text{ mol}\cdot\text{dm}^{-3}$ solution of sulphuric acid is used to break down 250 g of calcium carbonate completely.

- What volume of acid will be required?
- What volume of gas will be produced at STP?



SUMMATIVE ASSESSMENT

Note: Discuss what is meant by a “reaction” or “chemical reaction”. What are the key features of (what **must** happen in) the process known as a chemical reaction? Base your discussion on what you know so far.



REDOX REACTIONS

Lesson

27d

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

What you must know in this section of the curriculum is:

- Oxidation-reduction reactions
- Substitution, addition and elimination reactions

This lesson will cover:

- more information on oxidation reactions.

Activities

BALANCING REDOX REACTIONS

- When we compute the oxidation numbers for reactants and products in a chemical reaction, these numbers allow us to determine the number of electrons that pass from one reactant to another during the reaction.
- Obviously the number of electrons that are lost by whatever is being oxidized must be the same as the number of electrons being received by whatever is being reduced.
- By making sure that as many electrons are lost by one reactant as are gained by another reactant, we can easily determine the mole ratio (see Lesson 27c on Acid and Base calculations to refresh your memory on the meaning of “mole ratio”).
- Once you have determined the ratio of reactants it is easy to balance the equation.

Remember that ...

- several common or laboratory gases occur as diatomic molecules;
- reactants and products take part in reactions in whole number proportions ...
- ... because the different elements of matter occur in an assortment of unique atoms whose sizes never vary (from a chemical point of view);
- therefore, for instance, when a reaction occurs between oxygen and hydrogen molecules, that reaction involves the same amount of energy and matter, and in the same proportions, as in every other reaction between oxygen and hydrogen that has ever taken place!



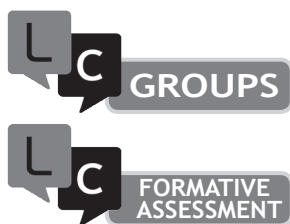
223

- WHAT IS BEING “BALANCED” IN THE EQUATION FOR A CHEMICAL REACTION?
- The answer is: matter **and** charge (not energy as that is either taken in or given out – but not “lost” in the sense of being “destroyed” as energy is conserved).



Activity 1

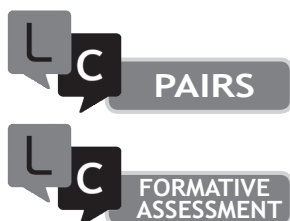
- 1.1 Balance the equation of the reaction that takes place when a mixture of hydrogen and oxygen is heated.
- 1.2 Water can be considered an oxide of hydrogen. There are many other gases produced when non-metals react with oxygen. Write balanced equations for the production of the following gases:
 - a) N_2O , NO and NO_2 ;
 - b) SO_2 and SO_3 .
 - c) P_2O_3 and P_2O_5 .
- 1.3 Calculate the oxidation number for the non-metal (N, S and P) in each of the oxides.



Activity 2

Iron plus oxygen: iron shavings are heated and immersed in oxygen.

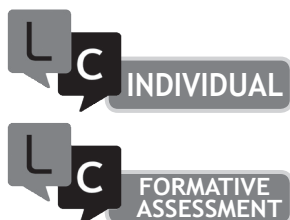
Balance the equations for the formation of the Fe(II) and Fe(III) oxides i.e. ferrous oxide and ferric oxide.



Activity 3

Chlorine is bubbled through a solution of potassium iodide.

What is likely to happen? (Look at the periodic table for a clue.)
Balance the equation for the reaction.



Activity 4

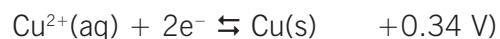
Hydrogen sulphide and sulphur dioxide gases are bubbled through water.

What do you know about the two reactants?
Oxidants and reductants

Activity 5

The problem:

In a branch of chemistry, closely related to redox reactions, called electrochemistry, many so-called “half reactions” are assigned a “potential” in volts. For example:



There are several pieces of information we can draw from these two equations.

Use the following information to answer the questions 1,1 and 1,2 on the following page.

- When a metal (e.g. Zn) is placed in a solution of its ions (e.g. Zn^{2+}) an equilibrium is set up as shown.
- When things are in chemical equilibrium (e.g. $\text{A} \rightleftharpoons \text{B}$) it means that whatever is written on left changes into what is written on the right at the same rate as whatever is written on right changes into what is written on the left.
- In the second of the two examples given above, for instance, two electrons would be joining a Cu (II) ion to create a copper atom at the same rate as copper atoms are giving up electrons to form Cu^{2+} ions.
- Metal ions in solution with water form aqueous ions (e.g. $\text{Cu}^{2+}(\text{aq})$ or Cu^{2+}aq).
- The half reactions are written as reductions i.e. electrons are added to a reactant to form a product – in this case to a metal ion to form a metal atom.
- The reverse reaction (right to left) is an oxidation reaction i.e. electrons are lost in going from Zn metal to $\text{Zn}^{2+}(\text{aq}) + 2\text{e}^{-}$.
- The voltages given for half reactions such as the two examples above – called standard reduction potentials – tell us which half reactions have the greater tendency to go to the right or to the left.
- The more negative the standard reduction potential is, the greater the tendency of the half reaction to go from right to left i.e. to be oxidised (and lose electrons).
- When two half reactions are joined we can find that both reactions proceed.
- When joining the two half reactions the metal rods, as shown, are joined with a piece of conducting wire. This is the “external circuit”.

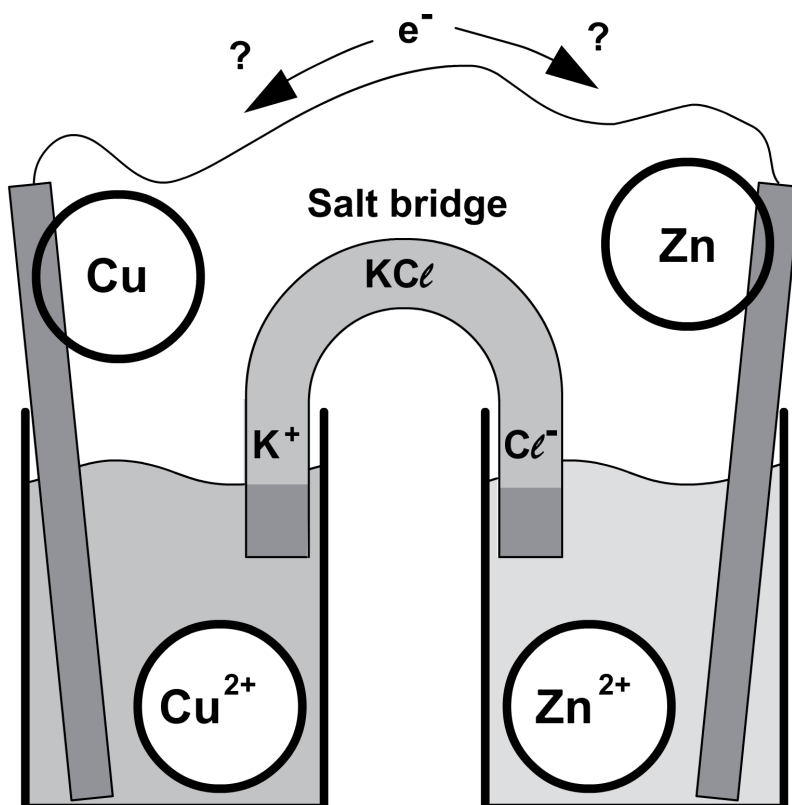


- To avoid a charge build-up in the two containers another electrical connection must be made. The device used is called a “salt bridge” which is a “U” tube (not “YouTube”!!) filled with a concentrated solution of a salt (like potassium chloride) that forms aqueous ions. The aqueous ions can conduct electricity and therefore they complete the circuit.

This is the basic information you will require in a study of electrochemistry. The top will be covered in greater detail in the Grade 12 course Lessons 25–27.

- 1.1** Look at the diagram of the electrochemical cell below. It consists of two half cells joined by conducting wire and a salt bridge.

Use the information in the box to determine whether electrons will flow towards the left or the right in the external circuit. Explain your answer.



- 1.2** The table below gives a list of standard reduction potentials.

STANDARD REDUCTION POTENTIALS

Half-reaction	E° (V)
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mg}(\text{s})$	-2.38
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}(\text{s})$	-0.13
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\text{Hg}_2^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons 2\text{Hg}(\text{l})$	+0.80
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80



In which direction will the electrons flow in the external circuit if the following electrochemical cells are constructed as shown above?

	Left hand half-cell	Right hand half-cell
a)	$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Mg}(\text{s})$	$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Cu}(\text{s})$
b)	$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Cu}(\text{s})$	$\text{Ag}^{+}(\text{aq}) + \text{e}^{-} \rightleftharpoons \text{Ag}(\text{s})$
c)	$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Pb}(\text{s})$	$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Zn}(\text{s})$
d)	$\text{Hg}_2^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons 2\text{Hg}(\ell)$	$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons \text{Mg}(\text{s})$
e)	$\text{Ag}^{+}(\text{aq}) + \text{e}^{-} \rightleftharpoons \text{Ag}(\text{s})$	$\text{Hg}_2^{2+}(\text{aq}) + 2\text{e}^{-} \rightleftharpoons 2\text{Hg}(\ell)$

Note: Think back to your discussion on the meanings of “chemical reaction” at the end of Lesson 27c. Have you learnt anything new in Lesson 27d that has made you alter your view?



Lessons

28–
30

LO3 ISSUES IN SCIENCE, TECHNOLOGY AND SOCIETY

- *Exploiting the lithosphere*
- *Atmospheric chemistry*
- *Drugs in sport*

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Assessment Standard 4:

Communicating and presenting information and scientific arguments.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 3:

Applying scientific knowledge.

Learning Outcome 3: The nature of science and its relationship to technology, society and the environment.

Assessment Standard 1:

Evaluating knowledge claims and science's inability to stand in isolation from other fields.

Assessment Standard 2:

Evaluating the impact of science on human development.

Assessment Standard 3:

Evaluating science's impact on the environment and sustainable development.



Overview

INTRODUCTION TO STS

The important attitude to maintain during debates on science, technology and society (STS) issues is an insistence that any facts used in arguments must be scientifically determined and scientifically verifiable. By “scientific facts” we mean the products of respectable scientific enquiry using appropriate methods and tools WITH the proviso that such facts be treated with the appropriate amount of scientific skepticism and reserve until their authenticity and accuracy are both publicly demonstrated and accepted by the majority of the scientific community.

Good science sets itself high standards and good scientists regard an improvement upon their own theories as desirable progress – no matter how bitter the pill of being proved wrong may be to swallow! But scientists are human and they live in human society. This means that, like any normal people, they will be protective (sometimes over-protective) of their theories. Unfortunately, it follows that when scientists' ideas are attacked and they are forced to defend their ideas vigorously, they may sometimes descend into personal attacks on their opponents. This and other unpleasant forms of defence can tarnish the image of science as a whole. Scientists have even been guilty of outright fraud and when this is uncovered the scientific community tends to react quite harshly. The reason being that fraud and fraudulent claims damage the image of science and open the noble enterprise to irrational disbelief.

Ideally, LO3 should deal with the STS issues and debate based on scientific fact, but the material that can be introduced here is a good deal richer because it helps us to recognise how the issues can mask a complex mix of individual interests, personal and professional credibility, reputations, economic well-being and a good deal of emotional investment. Under these circumstances, scientific



228

issues becomes as much a story about people, their histories and their social and economic behaviour as about the actual science itself.

The term “economic well-being” was used in the previous paragraph. Very often (probably even “most often”) one sees economics lying at the heart of STS issues. The exploitation of the lithosphere is the obvious example. In the modern world, we need minerals to make our artefacts, buildings and machines. The pollution of the atmosphere is also “caused by economics” because it comes largely as a result of our rampant use of fossil fuels to supply energy to our economies. And, finally, even the use of drugs in sport has an economic motive: success is often counted in financial terms.

SOME BASIC ECONOMICS

According to Alfred Marshall, economics is a study of mankind in the ordinary business of life. According to other definitions, the central problem in the study of economies arises because resources are limited but “wants” are unlimited. When we look at sports cheats, how do their actions relate to economics? You could think of the rewards available to professional athletes (money and glory) as the resources. Not only are the resources limited, so is the time that athletes have at their disposal to acquire a share of those resources. So although athletes have an unlimited desire (“want”) to achieve (or acquire resources) the resources they compete for are limited. Bear these ideas in mind and reflect on them as you encounter the STS issues in these lessons. Remember that we can study the economics of small communities (the economics of professional cycling), cities (the New York economy), whole nations (the South African economy) and even the “world economy”. You will also be able to apply a simple definition of economics to the exploitation of the lithosphere and to the effects of our economic activity on the air, land and seas.



STUDYING STS ISSUES

These three lessons provide a certain amount of fact and plenty of open-ended questions. There are few clear-cut answers to STS questions. In fact, most questions lead to tentative answers and these often lead to still more questions. Because answers are often little more than untested opinions unless they are backed up by hard, reliable fact, the scientific method and its products are important in the resolution of STS issues. But be warned: what makes STS issues really complicated is that the debates are interwoven with people’s beliefs (including religious beliefs), ethics (ideas of right and wrong) and emotion. Science is unable to clarify these things. But whatever else may be brought into STS debates, they are utterly futile when facts are unreliable and invalid because of poor measurement and data gathering. This is when scientists become important, because they can also help us to avoid the irresponsible use of partial truths.

As a learner, you need to gather as many accurate facts as possible. You also need to understand the questions. In these lessons there is a good deal of fact and also some questions for you to consider. Factual material can be gathered from magazines, newspapers, TV reports and documentaries and talks on the radio. Once you have an STS topic, there is almost no limit to the amount of available data. What is important is that you verify that what passes as fact is indeed accurate and that you maintain an open mind in the quest for useful answers.



Lesson

PART 1

In this section, “exploiting the lithosphere”, you are required to know something about:

- Mining, mineral resources and mineral processing in South Africa and their impact on society
- In particular, the processing of gold, iron and phosphates
- The environmental impact of South African mining activities
- Energy resources and their use

Much of the information required can be found in sources such as textbooks. What is presented here is a picture of mineral exploration. First of all, we must understand the term “lithosphere” and gain some idea of the processes of mineralisation and periods of time over which the mineral wealth which we now try to exploit came to be in the lithosphere.

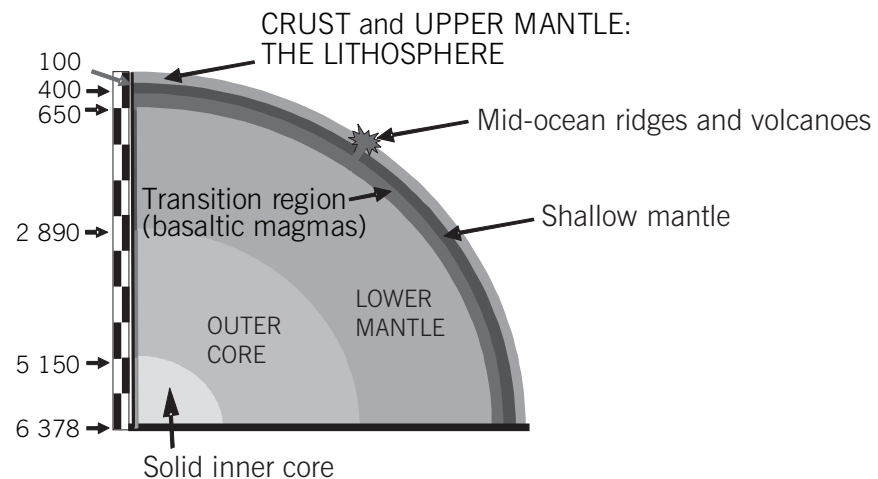


Figure 1: A cross-section of the Earth

The Earth’s CRUST is a layer that ranges between five and 70km thick. The UPPER MANTLE is about 30km thick and the SHALLOW MANTLE is about 300km thick. The TRANSITION REGION between the shallow and lower mantle, which contains basaltic magmas (molten rock), is the layer from which volcanic eruptions occur. Its composition is important because valuable minerals can be taken to the Earth’s surface and deposited there during volcanic activity. The LOWER MANTLE is viscous (thick but flows like syrup) and there are currents circulating in it. The tectonic plates (plates of higher density rock on which we find the continents) float on the lower mantle and the currents move the plates around in what we call “continental drift”. The OUTER and INNER CORE consist mainly of iron and nickel (as do meteorites – could there be some connection? See pages 173 and 174). The INNER CORE is solid and is at a temperature of about 6 000°C. The Fe/Ni core gives rise to Earth’s magnetic field. The Earth’s radius is about 6 400 km.



Tasks

- Calculate the volume of the Earth.
- If the mass of the Earth is approximately $6,4 \times 10^{24}$ kg, what is the average density of the Earth?
- Research the density of different elements (use a good periodic table), minerals and rocks, and compare the Earth's average density with these.
- Find out which chemical elements are most abundant in the Earth.
- What are the main constituents of the shallow and lower mantles?

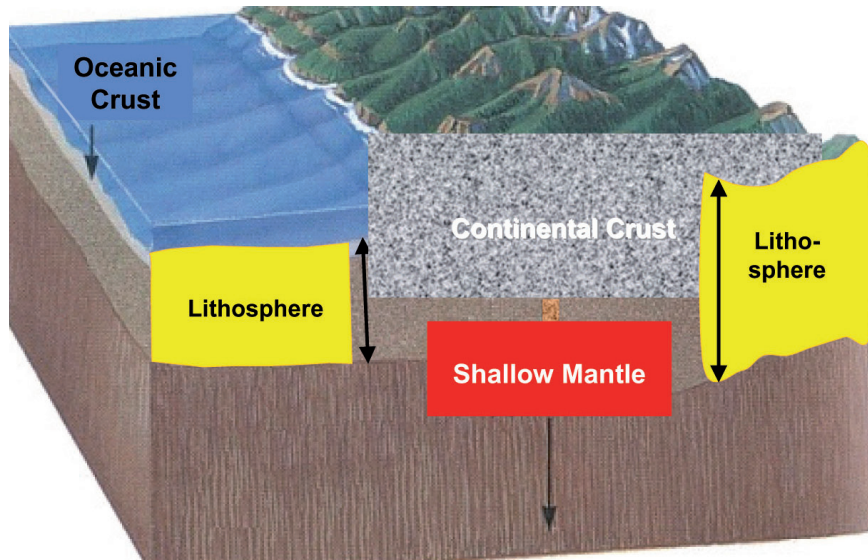


Figure 2: The lithosphere

The Earth's crust varies in thickness. The crust and the layer of rocks between it and the shallow mantle form the **lithosphere**. The lithosphere consists of rocks made of various inorganic solids called minerals. Minerals are composed of combinations of elements but some elements such as gold, silver and copper can be found in their pure form. The upper part of the lithosphere, the crust, also contains fossils and what are known as "fossil fuels" – natural gas, oil and coals. Because of the useful materials that are found in the lithosphere, it is not surprising that people have mined and extracted mineral wealth for thousands of years.

Tasks

- What minerals do you think the ancient peoples of the Earth would have gathered or mined?
- What uses would these materials have had?
- Find out when people started collecting and using the Earth's fossil fuel reserves.

In the remainder of this part of the lesson we will do a **case study** of a mining exploration in a remote part of South Africa. We will look at some of the processes used to find minerals and their **relative abundance** and factors that determine **economic viability** (find out the meaning of these terms).



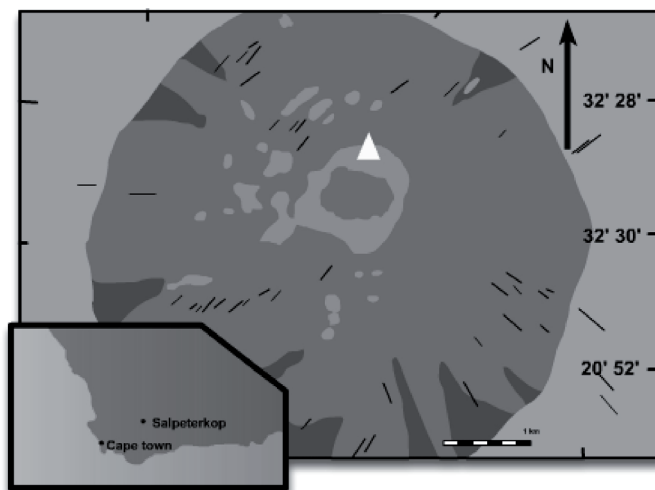


Figure 3: Salpeterkop, near Sutherland in the Northern Cape

Look at this geological map of Salpeterkop. This rocky outcrop just north of Sutherland in the Northern Cape, the home of South Africa's most important astronomical observatories, was a volcano in the Late Cretaceous period, about 66 million years (M yr) ago. The volcano is now extinct (that is, inactive). Its crater was about 1 km in diameter with an upward (convex) domed ring about 5,5 km in diameter around the crater. On the northern rim of the crater is a topographical survey beacon (what is its function?), shown here as a triangle.

In the 1960s, with the rise in the use of nuclear power and therefore the increasing world demand for uranium to use as a nuclear fuel, mining companies in South Africa started exploring (prospecting) for the metal. (See Lesson 20 for an explanation of how energy can be released in nuclear reactions involving uranium.)

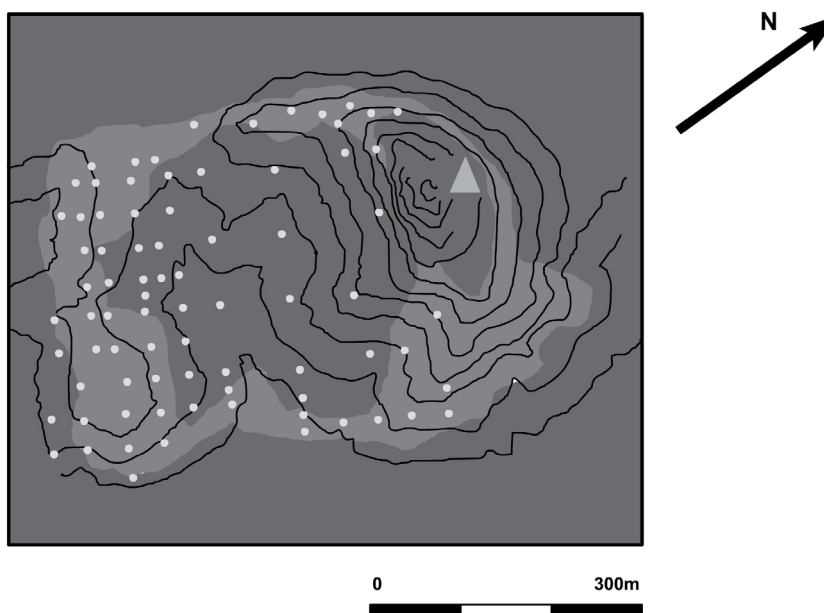


Figure 4: Salpeterkop: exploration borehole pattern

Prospecting geologists are constantly combing the land for signs that there might be valuable mineral deposits in an area. When they see hopeful surface signs they may then take rock samples for analysis. If the analyses look promising a big mining company may buy the land and/or the rights to mine it.

Tasks



- Why would Salpeterkop be regarded as an interesting prospect for mining? In other words, why would a mining company be prepared to spend large sums of money on doing a detailed mineral exploration of the site?
- What might the environmental impact of mining in this area be? Try to find out more about the Sutherland area and the Tanqua Karroo. What activities take place in the region?
- Are there any activities in the Sutherland area that might be adversely affected by a full-scale mining operation at Salpeterkop, with blasting, crushing plants, mineral extraction (what does this process entail?), heavy vehicles using the roads and the possibility of dust and smoke pollution in the air?

A method used by mining companies when prospecting seriously for minerals is to drill a series of boreholes. The core samples that are extracted can be analysed for their mineral content. The geologists take the shape of the ground into account and site the boreholes accordingly. For instance, in the case of Salpeterkop they might look at the ancient volcanic crater and see which parts have been eroded. Water and wind can erode surface structures over millions of years. This was the case at Salpeterkop even though it is now in a very dry area.

Tasks

- Using the map, consider which direction the water would have come from. Do you agree that the gentler slopes on the south of Salpeterkop would be where sediments might have come to rest when the crater rim eroded because of wind and water? (Find out more about contour lines on a map. When the lines are close together, it indicates a steep slope. When they are further apart, the slope is gentle.)
- Where would the minerals have originated? (See Fig. 1 and Fig. 2.)
- Which part of the volcano would have contained the most interesting minerals?
- Examine the pattern of the borehole positions in Fig 4. Discuss what factors the geologists might have taken into account when deciding where to drill.
- Make a sand model of the area using the contours on the map as a guide. Now look again at how the crater was eroded and where minerals might be found.

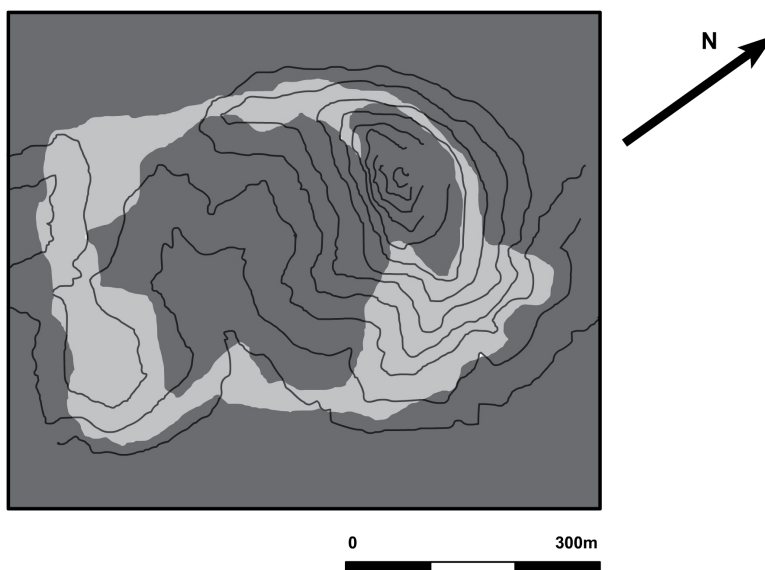


Figure 5: The mineralisation of Salpeterkop – core sample analysis results

Once the borehole core samples have been analysed, the mineralised zone can be plotted. The dark zone on the contour map is where any minerals of any potential value were found.

The map gives one a view from the top but it does not tell us how deep any body of minerals might be. So geologists and mining engineers need three-dimensional (3-D) information. Today, with computers, miners have beautiful 3-D models available to them when they plan the exploitation of an ore body. The following diagrams give you an idea of how the data from the core samples taken from the boreholes is pieced together into usable information.

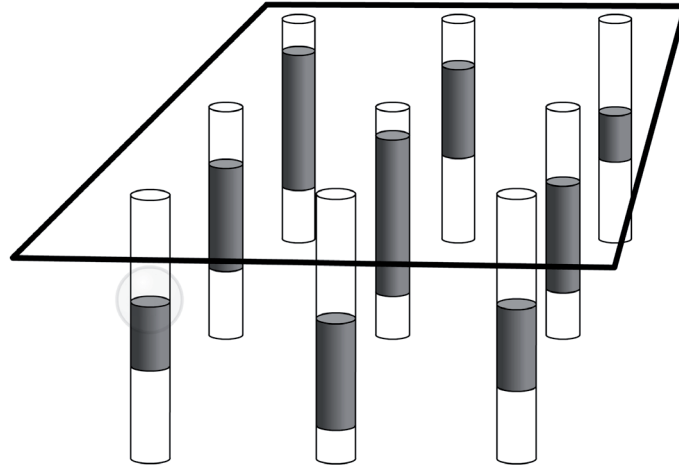


Figure 6A: Core samples showing sections rich in a certain mineral

In Fig. 6A we have an array of core samples showing the sections on each core that are rich in a certain mineral or element. A new analysis must be done on each section of the core down its length and for each different mineral. (Actually, modern instruments can now test a section and give a computer printout of the accurate amounts of every element that the operator tells the instrument to look for!) Once the borehole core samples have been analysed, the mineralised zone can be plotted in 3-D for each element or mineral of interest to the mining company.

The diagrams in Figs. 6B and 6C show how the 3-D picture is built up.

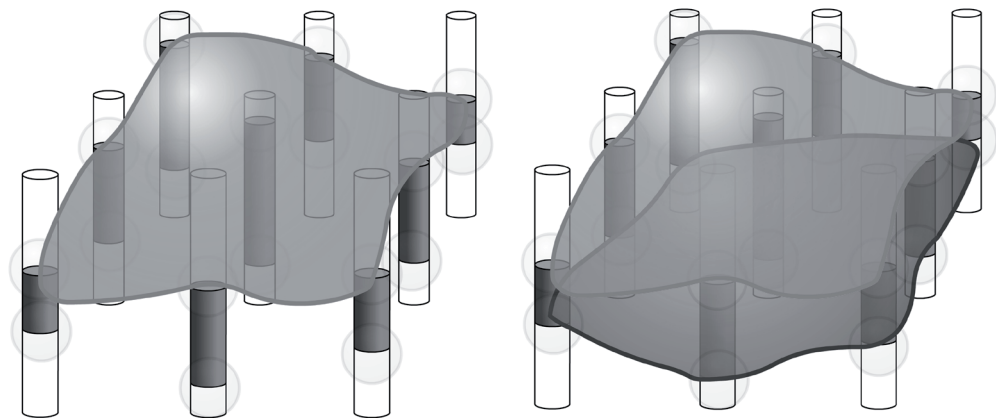


Figure 6B: The shape emerges

Figure 6C: The mineral body

Analyses will show the relative abundance of a mineral in the body.

Tasks

- Consider how the question of whether or not to mine an area now becomes mainly an economic one. Discuss how the following factors will come into the decision:
 - Cost of starting up the mining operations. (Start-up costs.)
 - The abundance of the mineral/element to be mined.
 - Whether more than one mineral/element occurs in the same mineral body.



- The cost of concentrating the mineral to the point where extraction of the desired element can take place.
- The availability of water: mining operations use large quantities of water so, if boreholes are sunk, what might this do to local farming?
- So far we have only spoken of the economic decisions. In the new laws governing the exploitation of the lithosphere in South Africa, due consideration must be given to environmental factors as well.

What environmental factors would have to be considered before the exploitation of the Salpeterkop complex could take place?

What minerals are available?

Once the core samples have been analysed, a general map of the mineralisation of the area can be drawn.

Fig 5

Then the detailed analyses can also be plotted to show exactly what minerals are present, where they are and in what concentrations. A series of contour maps will be drawn showing where mineable quantities of each important minerals lie.

The following maps for niobium (Nb), zirconium (Zr), thorium (Th) and YHerbium (Y) can be orientated relative to the Salpeterkop Topographical Survey Beacon.

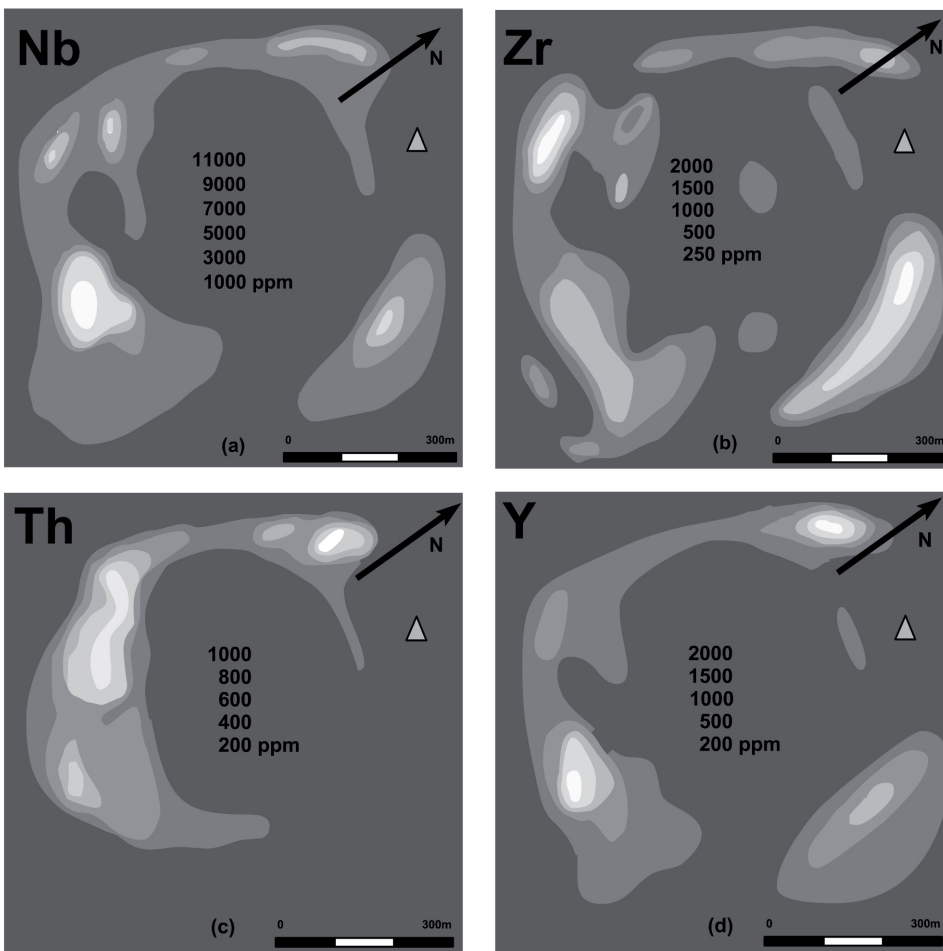


Fig 7: Relative abundance of Nb, Zr, Th and Y

For the purposes of this case study, we will look more closely at one element, the metal called **molybdenum** (chemical symbol **Mo**). The molybdenum at



Salpeterkop was found in a quartz-fluorite vein ($\text{SiO}_2 - \text{CaF}_2$) in the mineralised zone. Its actual mineral form was molybdenite or MoS_2 , a molybdenum sulphide. As it turned out, molybdenum was present in only quite small amounts, the concentrations in the dark zones (A – G) being of the order of 200 ppm or “parts per million”. That means that every 1 kg of molybdenite/quartz-fluorite mined from these zones will yield 200 millionths of a kilogram of molybdenum or 0,0002 kg (or 0,2 g).

This is clearly a very low concentration but does this fact alone mean that Mo cannot be mined profitably?

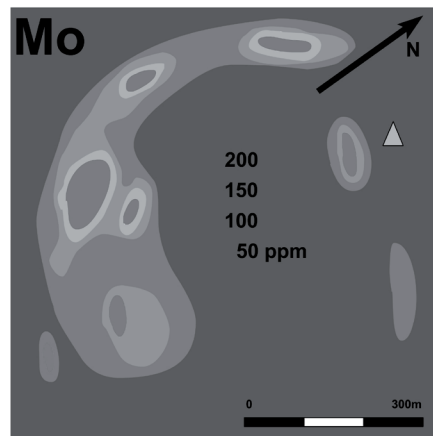


Fig 8: A profile showing molybdenite concentrations

Before we know whether it could be economical to mine for Mo we need to know more about the metal’s uses.

Uses of molybdenum

- Essential for animal life BUT ... toxic in excessive doses
- Found in about 20 enzymes (including nitrogenase) in humans, animals, terrestrial plants and algae
- Used in cast iron and high-quality “moly steel”
 - Strong up to 2 000 °C
 - Low thermal expansion (lowest of all engineering metals)
 - Good electrical and thermal conductivity
 - High corrosion resistance
 - Good resistance to wear
- Coating aircraft and rocket engine parts, tools, e.g. drill bits, saw blades, gear cutters
- Lubricants
- In armour plating for military vehicles e.g. tanks



The value of a commodity depends on the **demand** for it.

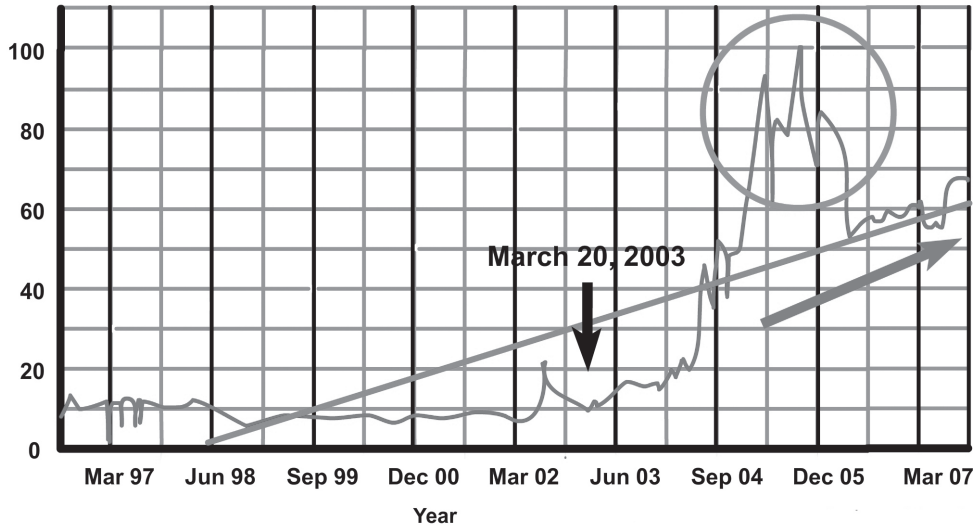
When **demand is high**, there are many buyers in the market.

If a material is abundant, i.e. supply is relatively plentiful, the price will remain low despite a high demand.

But when **supply is low** and **demand is high**, commodity prices rise.

Bear in mind that the most important use of molybdenum is as a low concentration additive in high-quality steel for the armaments industry. If we look at a graph of the price of **molybdenum metal** over the past 15 years, we see a “spike” between mid-2003 and mid-2005. (The unit “MT” stands for metric tonne or 1 000 kg).

**Molybdenum prices (\$US/MT)
1992 - 2007**



From the mid-1990s until 2003, the price was stable but then the price started rising sharply in mid-March, 2003. **Why?**

Tasks

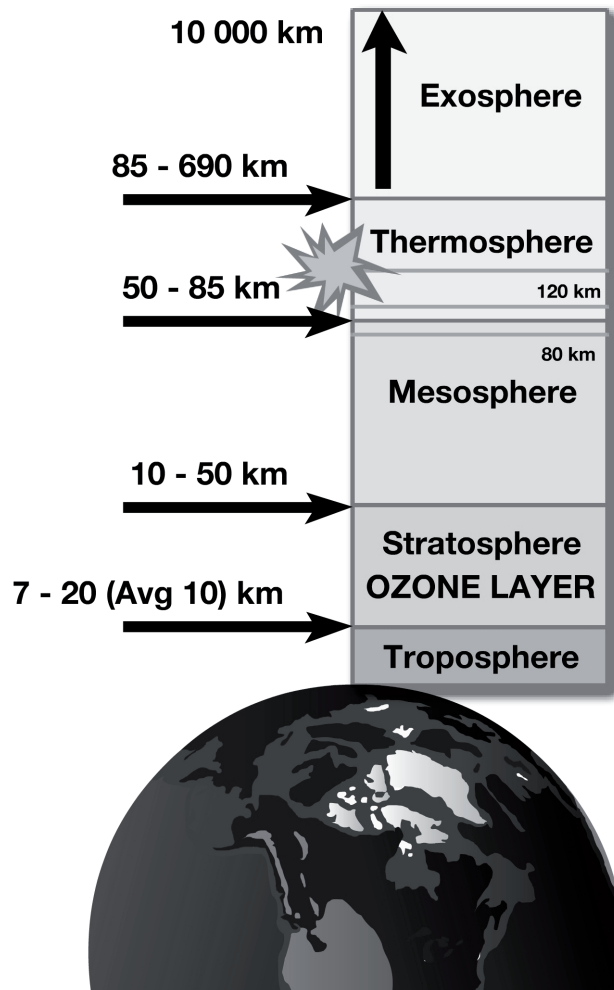
- What was happening in the world that might have made the price of molybdenum rise so steeply? (The date 20 March 2003 is a clue.)
 - Compare the molybdenum price graph with world events.
 - Consider the possible effect of the rapid growth of the two giant Asian economies, China and India.
- Make a list with as many of the:
 - economic factors; and
 - environmental factors ...
 ... that you think must be taken into account before a mining project is started.
- Make a list of the people or organisations who are:
 - likely to want a mining project to go ahead in a certain area;
 - likely NOT to want a mining project to go ahead.
- Imagine you are a member of the local government and part of the decision-making process. What would you require the mining company to do (or promise to do) before you would grant permission for mining operations to proceed? Make a list of your points.
 - Compare your list with the lists of some of your friends. (Remember, if you want the mining company to boost the local economy, you must not “kill the goose that lays the golden egg”!)

This section was a case study – one specific example to illustrate the underlying principles at work. These principles are important when discussing STS issues.



Lesson

PART 2



INTRODUCTION

In this section we will deal with the atmosphere and, specifically, the chemistry of the atmosphere. In order to discuss certain STS issues, we need to be in command of a body of fact. Natural chemical processes in the atmosphere are responsible for maintaining balance – in fact, some very delicate balances. It therefore stands to reason that because the chemical balances in the atmosphere are delicate, they can be easily disturbed. That is what is happening to the Earth's atmosphere as humanity stamps its influence on the atmosphere through the release of gases and other pollutants.

THE BOUNDARY BETWEEN Earth AND SPACE

There is no clear boundary between the Earth's atmosphere and space because the density of the atmosphere gradually decreases as the altitude increases. Nevertheless, the internationally accepted norm of an altitude of 100 km has been established as the boundary between **aeronautics** (airplanes) and **astronautics** (rockets). But the United States designates people who travel above an altitude of 80 km as astronauts. During the re-entry of space vehicles such as the shuttle, atmospheric drag becomes noticeable at an altitude of about 120 km.

THE LAYERS IN THE ATMOSPHERE

The atmosphere is a chaotic system, i.e. small changes to one part of the system can have large effects on the system as a whole. This idea is sometimes called the



butterfly effect, from the rather humorous idea that systems are so sensitive that air currents caused by the flapping wings of a butterfly could eventually produce marked changes in the state of the atmosphere! Because of this sensitivity to small changes it is never possible to make perfect weather forecasts.

Troposphere

This is the lowest layer of the atmosphere which begins at the surface and extends to between 7 km at the poles and 17 km at the equator. The variation is caused by weather factors. The troposphere has a great deal of vertical mixing (currents starting at the surface and circulating up and down) because of the heating of the surface by the Sun. This heating warms air masses which makes them less dense, so they rise. When an air mass rises the pressure upon it decreases so it expands, doing work against the opposing pressure of the surrounding air. To do work is to expend energy, so the temperature of the air mass decreases. As the temperature decreases, water vapour in the air mass may condense or solidify into rain and snow. Almost all of what we perceive as “weather” occurs in the troposphere. Some weather phenomena do occur in the stratosphere and these can affect weather in the troposphere.

Stratosphere

The stratosphere extends from the troposphere (7–17 km) to about 50 km. Temperature increases with height. The stratosphere includes the ozone layer (15–35 km) which contains relatively high concentrations of ozone – a few parts per million – compared to the lower atmosphere. The thickness of the ozone layer varies seasonally.

Mesosphere

From about 50 km to between 80–85 km. The temperature **decreases** with height in this layer.

Thermosphere

From between 80–85 km and about 690 km. The temperature **increases** with height.

Ionosphere

The part of the atmosphere that is ionised by solar radiation. It influences medium and shortwave radio transmissions on Earth as the radio waves bounce (reflect) between the ionosphere and the ground. The ionosphere is located in the thermosphere and, as the name implies, it contains a high concentration of ions caused by the impact of high-energy particles from the Sun (solar radiation) on molecules of the gases in the ionosphere.

Exosphere

From 500–1 000 km (300–600 miles) up to 10 000 km (6 000 miles), free-moving particles that may migrate into and out of the magnetosphere because of the solar wind. (10 000 km is about one and a half Earth radii from the Earth’s surface.)



Average composition of dry atmosphere (by volume)		
Nitrogen	78,084 %	78,084
Oxygen	20,946 %	99,030
Argon	0,934 %	99,964
Minor constituents	0,036 %	100,0
Carbon dioxide*	383,0 ppm (v)	
Neon	18,2 ppm	
Helium	5,2 ppm	
Methane*	1,7 ppm	
Krypton	1,1 ppm	
Hydrogen	0,6 ppm	
Water vapour content (variable)	typically about 1%	
Average molar mass of air	28,97 g/mol.	
*Concentrations of CO ₂ and CH ₄	vary by season & location	

THE COMPOSITION OF THE ATMOSPHERE

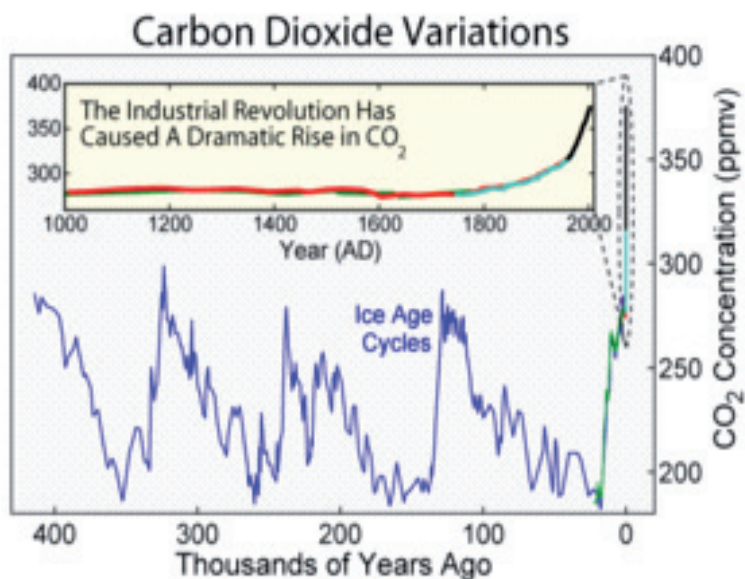
The atmosphere consists mainly of nitrogen (about four-fifths) and oxygen (about one-fifth). Nitrogen is rather unreactive but it is still an important constituent of molecules such as proteins which are essential to life. Animals and plants cannot use atmospheric N₂ directly. It has to be converted into a usable form first. This process is called “fixing”. Rain contains small amounts of nitrogen compounds such as ammonium or nitrates. They are probably formed during lightning strikes which provide the energy for nitrogen to react. The soil contains bacteria that produce enzymes which further “fix” the atmospheric nitrogen compounds by converting them into chemicals that can be used in the chemical processes of plants (i.e. in plant metabolism).

Tasks

- Explain what is meant by “the concentration of atmospheric carbon dioxide is about 400 ppm by volume”.
- Calculate the volume in dm³ that 400 ppm of carbon dioxide would occupy at STP. (Answer: 0,0004 dm³)
- At STP (i.e. standard temperature and pressure is a temperature of 0°C [273 K] and one atmosphere [101,3 kPa] of pressure) one mole of gas occupies 22,4 dm³ of volume. How many moles of CO₂ are there in a litre (1 dm³) of air at STP? ($1,8 \times 10^{-2}$ mol.)
- Explain why carbon dioxide (CO₂) and methane (CH₄) concentrations can vary seasonally.



CARBON DIOXIDE



Carbon dioxide has always been present in the atmosphere, mainly because, in darkness, plants respire, i.e. they take in oxygen and give out CO_2 . This also applies to marine plants such as algae and planktons. CO_2 is also a by-product of the combustion of carbon-based fuels such as wood, peat, natural gas, oil and coal. So there are plenty of natural sources of CO_2 . In the last 200 years, however, since the start of what is known as the Industrial Revolution, CO_2 emissions have increased by a factor of approximately two (we could also say: “doubling” or “an increase of 100%”).

CO_2 is very soluble in water

It has a solubility in water of $1,45 \text{ kg}\cdot\text{m}^{-3}$ at 25°C .

CO_2 exhibits the interesting feature of becoming MORE soluble as the temperature of the solvent drops.

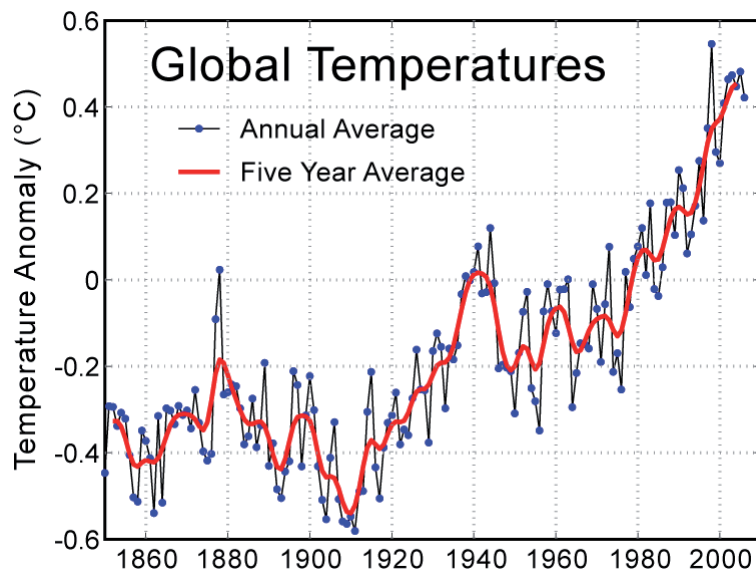
In water at 0°C the solubility of CO_2 is $3,35 \text{ kg}\cdot\text{m}^{-3}$

- Show that the figure of $1,45 \text{ kg}\cdot\text{m}^{-3}$ can be written as $33 \text{ mol}\cdot\text{m}^{-3}$, i.e. 33 moles of CO_2 ($M(\text{CO}_2) = 44 \text{ g}\cdot\text{mol}^{-1}$) dissolves in a cubic metre of water (i.e. 1 000 litre or 1 000 dm^3) at 25°C .
- Even though 1 m^3 is a large volume – measure it out in the corner of the room and see for yourself – 33 mol is still a large amount of CO_2 .
- What approximate mass of CO_2 will dissolve in 1 m^3 of water at the polar ice caps?

Tasks

- Taking your calculation on CO_2 solubility into account, discuss why the warming of the sea in the polar regions would be a bad thing for the Earth.
- Examine the graphs of CO_2 concentration in the atmosphere over the past 400 000 years and past 1 000 years. Explain the variation in terms of the great ice ages. Would the atmospheric concentration of CO_2 have increased or decreased as the seas froze? Discuss this and give a reason for your answer.
- Why has CO_2 in the atmosphere increased so dramatically since 1800?
- Is this evidence of humankind’s influence on the atmosphere or could it be part of a new ice age?





- The graph of global temperatures since 1860 shows a steady upward trend. Have you heard of the greenhouse effect and greenhouse gases? Before you read the next section, try to work out for yourself what it means and how these gases could cause the steady rise we see in the graph.

THE GREENHOUSE EFFECT AND GREENHOUSE GASES

*[Please note the spelling of the word “gases”. It is **not** spelt “gasses”!]*

The Earth receives energy from the Sun in the form of solar radiation and reflects about 30% of it directly back into space. The remaining 70% is absorbed by the Earth where it warms the oceans, the land and the atmosphere. Now we say that the Earth is in a **steady state** because on average the energy stored in the atmosphere and the oceans does not change with time. (If we were to measure the stored energy in every part of the globe at several different times we would find the sum of all of that energy remained the same, even if the temperatures changed at certain points.)

Energy equal to the absorbed solar radiation must be radiated back into to space in order to maintain the steady state. And anything that disturbs this balance will cause the Earth either to **cool down** (i.e. more energy going back into space than is received from the Sun) or to **warm up** (i.e. less energy going back into space than is received from the Sun).

This picture of energy absorption and radiation is what we would call a **scientific model**. A model is a set of ideas that uses well-known scientific principles that then allow us to explain some phenomenon – such as global warming. **Note:** the model presented above is a very simple model. But if we start with a simple model we can add more and more accurate information and gradually build up the sophistication of the model, e.g.

- there are many different wavelengths of radiation from the Sun and each wavelength is absorbed and reflected to different degrees;
- the different layers of the atmosphere (see above) absorb and reflect different wavelengths to different degrees as well; and
- within the troposphere in particular we have convection currents in the air so that energy is continuously being distributed to different parts.

So this all makes the whole picture a lot more complicated. But the good news is that even the simplest models do give a good indication of the processes that are occurring!



The energy that is radiated from the Earth back towards space is mainly infrared radiation (with wavelengths around 1–3 cm, slightly longer than visible red light).

In the Earth’s atmosphere, the main infrared-absorbing gases are water vapour (H₂O), carbon dioxide (CO₂) and ozone (O₃). But there are others that have a significant effect such as methane (CH₄), nitric oxide (NO) and chlorofluorocarbons or CFCs (e.g. C₂H₂F₂Cl₂). CFCs are now banned but they were once used as refrigerant gases and to make the light, “exploded” polystyrene that is used for heat-insulating containers.

The greenhouse effect (GE) can now be defined as the *difference between the infrared radiation that the surface would radiate to space if there were no atmosphere and the actual infrared radiation escaping to space*. In other words, the GE is the trapping of energy in the gas jacket around the Earth (the Earth’s atmosphere) that one would otherwise expect to be radiated out into space.

Computational models have been developed to show the GE of specific gases. What the models do is to calculate by how much the GE is reduced when a particular gas is removed. That figure tells us how important that gas is in keeping heat energy in the atmosphere – hence the name “greenhouse gas”. The figures given here were computed using a very simple model but the results of much more complex models are quite similar.

The atmospheric gas to be removed	Percentage reduction in GE when the gas is removed
Water vapour H ₂ O	36%
Carbon dioxide CO ₂	12%
Ozone O ₃	3%

(Source:http://en.wikipedia.org/wiki/Greenhouse_effect and Ramanathan and Coakley, Rev. Geophys and Space Phys, 16 465 (1978))

From these figures we see that water vapour can be regarded as providing a three times greater greenhouse effect than carbon dioxide. If both water vapour and carbon dioxide are removed, the effect of removing both of these constituents would be considerable. In other words, if these two constituents were removed altogether, the atmosphere’s ability to hold heat energy would be diminished by half. That shows that there must be a delicate balance in the atmosphere. If we were to **remove** all the CO₂ we would lose too much heat and the Earth would descend into an ice age. Yet if we **add** too much CO₂ (and we don’t know exactly what “too much” is but the models suggest that CO₂ levels are getting dangerously high) we keep too much heat in the atmosphere and the Earth warms up.

Methane is an even more effective greenhouse gas than carbon dioxide. If global warming causes large-scale melting of the Arctic tundra, the vegetation in the tundra could start rotting. The greatly increased concentration of methane in the atmosphere (about **70 000 million tonnes** is being estimated) could result in a runaway GE with the Earth getting much warmer very fast.

Atmospheric concentrations of CO₂ and CH₄ have increased by 31% and 149% respectively compare to the pre-industrial levels from 1750. These CO₂ and CH₄ levels are considerably higher than at any time during the past 650 000 years, the period for which reliable data has been extracted from ice cores. (**Task:** find out how we can tell what the levels were 250 years ago by taking very accurate measurements from ice cores.)

From other scientific evidence we find that CO₂ levels were last this high around 20 million years ago. Furthermore, about 75% of the man-made emissions of CO₂ into the atmosphere over the past 20 years have been caused by burning fossil fuels. The IPCC *Special Report on Emissions Scenarios* predicts future CO₂ levels ranging between about 500 and 1 000 ppm by the year 2100. Fossil fuel



reserves are sufficient for us to reach these levels and higher, so the predictions are not impossible.

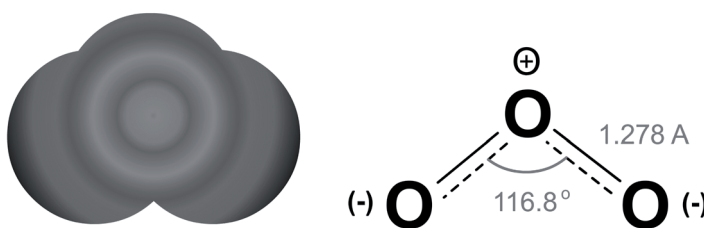
OZONE

Ozone is a bluish gas. Ground-level ozone is an air pollutant with harmful effects on the respiratory systems of animals. On the other hand, ozone in the upper atmosphere protects living organisms by preventing damaging ultraviolet (UV) light from reaching the Earth's surface. It is present in low concentrations throughout the atmosphere. Ozone in the ozone layer filters out the shorter wavelengths of UV light which includes wavelengths from 270 to 400 nm. UV light comes to us from the Sun and harmful to most forms of life in large doses. Yet UV light is also biologically important as those same wavelengths are responsible for the production of Vitamin D in the skin, which is essential for human health. The highest levels of ozone in the atmosphere are in the stratosphere, in the ozone layer, between 10 km and 50 km above the surface of the Earth.

Ozone's chemical name is trioxygen (O_3) and its molar mass is $47,998 \text{ g}\cdot\text{mol}^{-1}$.

Structure

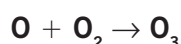
The bonding is a single bond on one side and a double bond on the other side. But the two bonds constantly switch between single and double in a process called **resonance**. So in effect we have a 1,5 bond on each side!



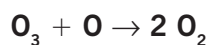
Basic reaction



This is called the **photo-dissociation** of oxygen gas. Photo-dissociation only takes place in the upper stratosphere where UV light and oxygen are plentiful. After the dissociation, a single oxygen atom bonds with an oxygen molecule:

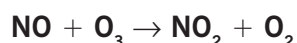


Ozone is destroyed when it reacts with another single atom of oxygen:



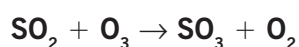
Ozone and nitric oxide

Nitric oxide is produced in the exhaust gases of jet airliners which fly in the high troposphere and low stratosphere.



NO_2 (nitrogen dioxide) is a gas which is harmful to humans. It is also very reactive and will therefore react with other constituents of the atmosphere. These are unnatural and unwanted reactions.

Ozone and oxides of sulphur; acid rain



When sulphur trioxide (SO_3) dissolves in water, sulphuric acid is produced. There is more than one reaction by which sulphuric acid is produced from ozone, either starting from elemental sulphur or from sulphur dioxide. Both can be released into the atmosphere in volcanic eruptions. More significantly, sulphur dioxide from



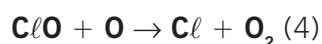
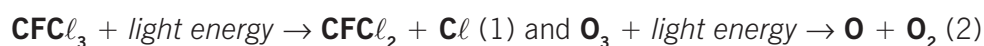
the burning of high-sulphur content coal in heavily industrialised regions causes serious environmental damage.



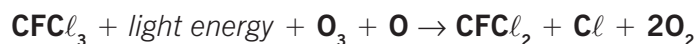
When this sulphuric acid dissolves in rain, it lowers the pH of the soil and affects plant growth. Places such as the Black Forest in Germany and the forests in the north-eastern states of the USA and south-eastern Canada are only now recovering from the damage caused to them by rampant industrialisation in the 19th century.

Depletion of the ozone layer

Over the past 40-50 years, the amount of ozone in the stratosphere has been declining, mostly because of emissions of CFCs and similar organic molecules containing chlorine and bromine atoms. CFCs react with ozone and remove it from the ozone layer, causing the depletion of the ozone layer we hear so much about.



The net reaction is:



The net effect of these reactions is to increase the rate of recombination of ozone to form oxygen molecules ($\text{O}_3 + \text{O} \rightarrow 2 \text{O}_2$), leading to an overall decrease in the amount of ozone.

For this particular mechanism to operate there must be a source of O atoms, which is primarily the photo-dissociation of O_3 (reaction 2). This mechanism is only important in the upper stratosphere where the required atoms and molecules are abundant and where there is light of sufficiently high energy to cause photo-dissociation of ozone.

A single chlorine atom (first as a product from reaction 1 and then from reaction 4) can remain in the atmosphere and keep on destroying ozone for up to two years. This is the time scale for the transport of these chlorines back down to the troposphere where they can bond more permanently.

Task

A scientist, who does not agree with what he calls “the prophets of doom”, refuses to accept that global warming (the increase in greenhouse gases in the atmosphere and hence the increase in the greenhouse effect) is because of the effect of people on the environment. He also argues that there is no sure evidence that the steady depletion of the ozone layer is caused by humans.

Compose a speech that you intend making at an environmental event which the doubting scientist will also be attending. In your speech, you intend showing this scientist why his views are irresponsible.

Make your speech as unemotional and factual as you can.



Lesson

PART 3

Kids doping on the up

The Star, June 20, 2007

France – More than one in 100 French 11-year-olds use banned drugs to boost their performance in sports, according to a study published online on Monday.

Researchers in eastern France questioned 3 500 11-year-olds about their use of drugs banned by the World Anti-Doping Agency (WADA) and followed the youngsters up every six months for the next four years.

At the start, 1,2 percent said they had used one or more drugs, but by the time they were 15, the proportion had risen to three percent.

The most commonly used performance booster was salbutamol, a stimulant that is also prescribed for asthma, which was taken by 45 percent of users. This was followed by corticosteroids (10 percent) and cannabis (six percent), while other stimulants and anabolic agents made up 38 percent. – *Sapa-AFP*

INTRODUCTION

Each year the media is full of stories about drug cheats in sport. Even cricket, the “gentlemen’s game”, is starting to formalise drug testing now that two Pakistani fast bowlers were found guilty of doping (and then exonerated by the PCB – the Pakistani Cricket Board). Drug taking in sport used to be associated with the events that required strength and short bursts of speed such as shot put, hammer throwing and discus in athletics (track and field) or rugby or American football. But even marathon runners are suspected of taking drugs that allow them to recover more quickly from training so that they can log up longer distances in training and clock super times in competitions.

STS issues abound in this area: **ethical questions** (should competitors be allowed to gain an unfair advantage over their opponents by taking performance-enhancing substances?); **moral questions** (see the newspaper article above: what about the influence that the habits and behaviour of sporting heroes can have on impressionable young people?); **health issues** (steroids can cause permanent liver damage); and even **social issues**. In a survey done some years ago, a sample of young sportsmen and women was asked whether, if they could take a wonder drug that would guarantee them an Olympic gold medal but which would also kill them before they turned 40, would they be prepared to take the drug? Over 90% of those asked the question said they would do so. That is a chilling statistic and one which ought to give political, social and religious leaders pause for thought.

In this section you will be introduced to the World Anti-Doping Agency’s code of conduct and the drugs and chemical substances that they proscribe (ban or prohibit the use of by athletes.)

Issues are highlighted and some key points are made in text boxes spread throughout the section. You are encouraged to discuss these and others in your own time.

DRUGS IN SPORT

This is a lesson about cheating and ethics in sport. It is also a story about how the legal scientific community must expend enormous amounts of money and effort to stay ahead of those who might use science and scientific methods to cheat in sporting competitions.



But it is not just the competitive will to win that drives athletes. Many athletes have economic, psychological and socio-political needs to win and it is these more than pure competitive spirit that probably drives athletes to cheat.

The World Anti-Doping Code
THE 2007 PROHIBITED LIST
INTERNATIONAL STANDARD
 Valid 1 January 2007
The use of any drug should be limited to medically justified indications

The World Anti-Doping Agency (WADA) is an organisation of international sports bodies that are committed to eradicating drug usage in sport. Many countries have their own anti-drug organisations and these are affiliated to WADA. WADA and national anti-drug bodies have to maintain or make use of expensive laboratories for the testing of athletes' samples so it is a costly operation. Furthermore, the tests themselves must be continuously updated, developed and refined because the drug cheats and their medical "advisors" are continually looking for ways of subverting the tests. In other words, the cheats are trying to cheat the tests, not only the sport!

WADA's member organisations are bound by a code of conduct that stipulates which drugs are prohibited.

This lesson has more questions than answers. Questions are included in the text and are intended for your own discussion and debate. You should link your discussions to the sections on health in the Life Orientation curriculum.

SUBSTANCES AND METHODS PROHIBITED AT ALL TIMES (IN- AND OUT-OF-COMPETITION)

S1. ANABOLIC AGENTS: Anabolic agents are prohibited.
1. Anabolic Androgenic Steroids (AAS)
a. EXOgenous* AAS, including:

1-androstendiol	(5 α -androst-1-ene-3 β ,17 β -diol);
1-androstendione	(5 α -androst-1-ene-3,17-dione);
danazol	(17 α -ethynyl-17 β -hydroxyandrost-4-eno[2,3-d]isoxazole);
4-hydroxytestosterone	(4,17 β -dihydroxyandrost-4-en-3-one);
methyl-1-testosterone	(17 β -hydroxy-17 α -methyl-5 α -androst-1-en-3-one);
methylnortestosterone	(17 β -hydroxy-17 α -methylestr-4-en-3-one);
methyltrienolone	(17 β -hydroxy-17 α -methylestra-4,9,11-trien-3-one);
1-testosterone	(17 β -hydroxy-5 α -androst-1-en-3-one)

testosterone **17 β -hydroxy-4-androsten-3-one**

"exogenous" refers to a substance which is not ordinarily capable of being produced by the body naturally.

The word ANABOLIC comes from "anabolism" meaning "growth". Growth hormones include testosterone – the male growth hormone whose chemical name is given in the box above – and the banned substances listed above are all derivatives of testosterone. Testosterone is among a class of biochemicals known as "anabolic steroids". The early anabolic steroids used by human athletes were actually veterinary products designed to build muscle mass in race horses (for speed and power) and cattle (for more meat). The steroids act by increasing protein synthesis in muscles; in other words, they build muscle mass. And the bigger the muscles, the stronger they are!

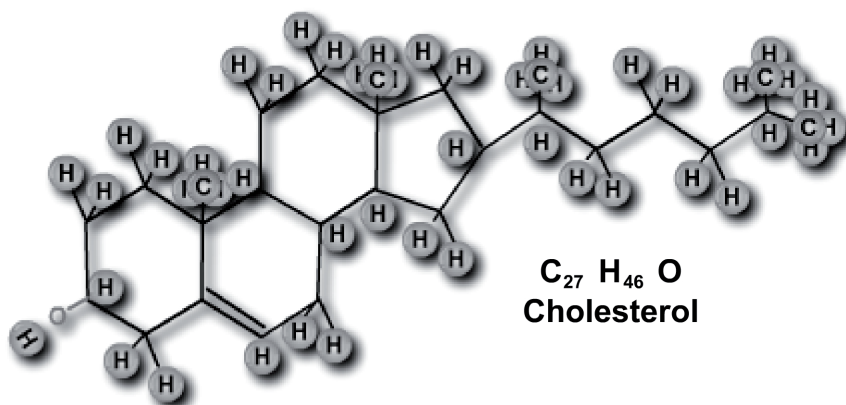
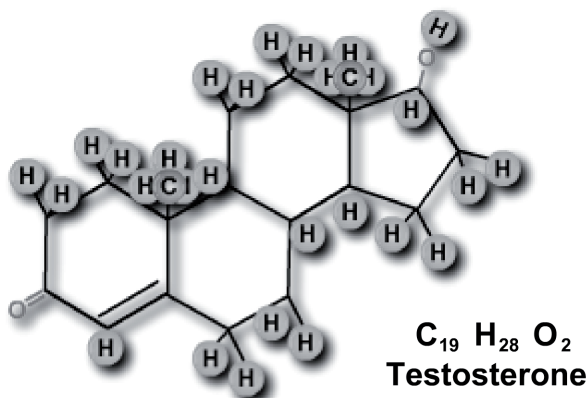


Compare the common name and chemical name of “testosterone”, a natural product produced in the testes, with the names and chemical names of the derivatives used illegally by athletes.

The adjective ANDROGENIC is often used when talking about female drug cheats. Female athletes who take testosterone-derivative anabolics often developed masculine characteristics (e.g. facial hair, deeper voices, etc). The Russians and East Germans (before 1989, Germany was divided into West and East Germany, the latter being in the “Russian/communist sphere of political influence” while the former was part of the so-called “capitalist West”).

In the West, drug cheats tended to be individuals whose coaches either gave them the drugs or secretly pointed them to where they could be obtained without becoming directly (and legally) involved themselves. In countries in the Eastern Bloc, and East Germany was the most notable of these, there were state-sponsored programmes of systematic drug-taking by athletes. Why would a national government encourage the use of drugs by its top sportsmen and women?

STEROIDS contain a chemical structure known as a “terpenoid lipid ring structure” or the 6, 6, 6, 5 ring structure seen in the two structural formulae below.



Both testosterone (17β-hydroxy-4-androsten-3-one) and cholesterol, which goes by the chemical name 10,13-dimethyl-17- (6-methylheptan-2-yl)-2,3,4,7,8,9,11,12,14,15,16,17-dodecahydro -1H- cyclopentaphenanthren-3-ol, contain the terpenoid lipid ring structures, as one can see. That structure survives when derivatives are prepared by adding or removing branches or “side chains”. Derivatives are sufficiently like the original natural substances to function as they do but who knows what side effects the molecular tampering could cause?



The naming convention for organic chemicals (carbon-containing, natural chemical substances and their derivatives) is called the IUPAC convention.

Find out what the acronym IUPAC stands for.

Look at the testosterone molecule. Each vertex in the rings is a carbon atom and each carbon has four bonds. Start with the double-bonded oxygen (lower left side) and count carbons until you get to the –OH or “hydroxyl” group. Can you see how the “17 β ” might come about?

The other structural clues in the names of organic substances are word elements such as the suffixes “-one” (contains an =O or ketone group) and “-ene” (denoting a double bond e.g. C=C).

The first list of banned substances in the WADA code contains both exogenous (substances that cannot ordinarily be produced in the body) and endogenous substances (capable of being produced in the body although this is not ordinarily the case.)

Discuss with your English teacher why the WADA code of conduct uses the word “ordinarily” where one might expect the word “normally” to be used. Does the word perhaps cover a legal loophole?

WHEN DOPING BECOMES ILLEGAL

- Where an anabolic androgenic steroid
- is capable of being produced endogenously,
- a sample will be deemed to contain such prohibited substance
- where the concentration of such prohibited substance or its metabolites or markers
- and/or any other relevant ratio(s) in the athlete’s sample
- so deviates from the range of values normally found in humans
- that it is unlikely to be consistent with normal endogenous production.

Analyse the wording in the WADA code above.

When are endogenous substances illegal?

Explain the term “range”.

At the time of writing, the winner of the 2006 Tour de France, Floyd Landis of the USA, was still under investigation for taking drugs. As a result he is not taking part in the 2007 race. He and his legal team claim that the increased levels of testosterone found in his body after one amazing day’s ride in 2006 in which he destroyed his rivals’ hopes can be accounted for by natural variations in testosterone levels. Could he be telling the truth?

Professional cycling has been plagued by drug scandals and if the stories are true then drugs have been a part of the sport for many years. *Discuss why this might be so. (Consider factors such as popularity, money and esteem, etc.)*



S2. HORMONES AND RELATED SUBSTANCES

The following substances, including other substances with a similar chemical structure or similar biological effect(s), and their releasing factors, are prohibited:

- Erythropoietin (EPO)
- Growth hormone (hGH), insulin-like growth factors (e.g. IGF-1)
- Gonadotrophins (LH, hCG), prohibited in males only
- Insulin
- Corticotrophins

The 1972 Olympic Games in Munich is now remembered mainly for the attack on the Olympic Village by Palestinians in which several Israeli athletes were murdered. But there was also a case of possible blood doping in which a long-distance athlete was suspected of a practice that, although not illegal at the time, was considered by some to be cheating.

What is supposed to have happened is this: several weeks before an event, an athlete donates a quantity of blood. The blood is then centrifuged and the fraction containing red blood corpuscles is frozen and stored. Shortly before the big race at the Olympics the red blood cells are transfused back into the athlete's body. He now has an abnormally high concentration of red cells which are responsible for transporting oxygen to the cells where it is used to release energy. (See page 213.)

What advantage does this form of blood doping give an athlete?

Because an athlete is using his own blood, is this unfair? Would you ban the practice and on what grounds?

EPO AND BLOOD DOPING

(Find out what the terms in bold lettering mean.)

- Erythropoietin or EPO is a hormone that is a red blood cell precursor in the bone marrow; in other words, it is a natural substance that is involved in the process of building red blood cells in the body.
- EPO is produced by the kidneys.
- EPO regulates red blood cell production.
- EPO is available as a therapeutic agent produced by recombinant DNA technology in a mammalian cell culture.
- EPO is used in treating anaemia resulting from chronic renal failure or from cancer chemotherapy.
- The use of EPO is believed to be common as a blood doping agent in endurance sports such as bicycle racing, triathlons and marathon running.

EPO is especially dangerous to athletes who exercise over prolonged periods. A well-conditioned endurance athlete is more **dehydration resistant** than a **sedentary** individual. During demanding exercise, as fluid losses mount, water is shifted out of the blood stream. The medical term for this is that the "**hematocrit rises**". (A low hematocrit means dilute or "thin" blood and a high hematocrit means concentrated or "thick" blood.) If one is already starting with an artificially elevated hematocrit then you can begin to see the problem when artificial amounts of EPO are producing even more red cells than normal. The blood could become too **viscous** ("thick") and one gets dangerously close to the critical "sludge



zone” at which an individual runs the risk of developing blockages in the blood vessels. If this happens in the brain, it results in a stroke and, in the heart, a heart attack. Several top athletes who have used EPO have died in this way.

WADA prohibits three methods involving blood tampering, including the blood doping that may or may not have happened in Munich in 1972. (See M1 below).

PROHIBITED METHODS

M1. ENHANCEMENT OF OXYGEN TRANSFER

- Blood doping, including the use of autologous, homologous or heterologous blood or red blood cell products of any origin.
- Artificially enhancing the uptake, transport or delivery of oxygen, including but not limited to ... modified haemoglobin products (e.g. haemoglobin-based blood substitutes, microencapsulated haemoglobin products).

M2. CHEMICAL AND PHYSICAL MANIPULATION

- Tampering, or attempting to tamper, in order to alter the integrity and validity of samples collected during doping controls is prohibited. These include but are not limited to catheterisation, urine substitution.

M3. GENE DOPING

- The non-therapeutic use of cells, genes, genetic elements or of the modulation of gene expression, having the capacity to enhance athletic performance, is prohibited.

The prohibited methods described use the body’s own mechanisms but corrupt them slightly. The drugs are used to fool the body into doing things that the body would not normally (ordinarily?) do.

Discuss the concept of “gene doping”. Is gene doping a scientific possibility or is it just science fiction? And if it is beyond our current scientific ability to manipulate genes in a way that enhances performance, why would WADA want to add this stipulation to its code of conduct?

If and when gene doping becomes scientifically possible, would you regard it as cheating in the same way that blood doping or taking a performance-enhancing drug is cheating? Why?

Before a doctor can treat a patient’s illness, he must diagnose the ailment, i.e. use all the observable symptoms and possibly the patient’s history to make an educated guess (a hypothesis) about what the problem is. The treatment, one hopes, then fits the ailment. This is a part of medicine that closely resembles the “scientific process”.

In a similar way, when testing for drugs in an athlete’s blood or urine sample, the tester must test for something specific. If a drug test is positive it means that (a) the banned substance being tested for is present, and (b) the substance is present in sufficiently high concentrations for the testing agency to be sure that the substance could not have been produced by natural processes in the athlete’s body. Apart from designing ever more effective performance enhancing drugs, the chemists and doctors who make them have also been busy developing ever more sophisticated ways of avoiding detection.

Why would drug cheats use diuretics* and masking agents**?

Alcohol is the most widely used depressant drug. As such, competitors might feel that taking a little alcohol will calm their nerves in intense competition situations. The other problem with alcohol is one of perception: when people drink they *feel* sharp and alert. But the facts are different, because alcohol *is* a depressant and

* A diuretic is a substance that removes water from the body (and causes one to urinate more.)

** A masking agent will get in the way of a test, i.e. it will hide or “mask” whatever it is that the test is designed to expose.



actually slows a drinker's reactions down, causing unsteadiness and loss of co-ordination. For all of these reasons alcohol is banned by most sporting codes. In some such as motor sports, archery, rifle shooting and others, for obvious reasons the consumption of alcohol by competitors is taken very seriously indeed.

SUBSTANCES PROHIBITED IN PARTICULAR SPORTS

ALCOHOL

Alcohol (ethanol) is prohibited *in-competition* only, in the following sports.

Detection will be conducted by analysis of breath and/or blood.

- Aeronautic (0.20 g/L)
- Archery (0.10 g/L)
- Automobile (0.10 g/L), motorcycling (0.10 g/L), powerboating (0.30 g/L)
- Karate (0.10 g/L)
- Modern pentathlon (0.10 g/L) for disciplines involving shooting

BETA-BLOCKERS

- Aeronautic, automobile, motorcycling, sailing for match race helms only
- Archery (also prohibited out-of-competition)
- Billiards, bobsleigh and bridge
- Gymnastics
- Modern pentathlon for disciplines involving shooting
- Shooting (also prohibited out-of-competition)
- Wrestling (FILA)

β -blockers are a class of drugs used particularly for the management of cardiac arrhythmias (irregular heart beats) and cardio-protection after myocardial infarction or heart attack: heart (*cardio*), muscle (*myo-*) infarction (*tissue death resulting from obstruction of the blood supply*).

Although once the first-line treatment for hypertension, their role was downgraded in June 2006 in the United Kingdom to fourth-line as they do not perform as well as other drugs, particularly in the elderly. There is increasing evidence that the most frequently used beta-blockers at usual doses also carry an unacceptable risk of provoking type-2 diabetes. (Type-1 diabetes is the condition that requires sufferers to be injected with insulin because the pancreas no longer produces it naturally. Type-2 diabetes is also called adult-onset diabetes or non-insulin-dependent diabetes – a major cause of which is obesity.)

In particular beta-blockers block the action of endogenous epinephrine (adrenaline). Epinephrine acts on the part of the sympathetic nervous system which mediates the “fight or flight” response, hence the sudden surge of strength one can have when suffering a sudden shock. For this reason, it is also banned in sports.

There are other classes of drugs that are banned – for obvious reasons, including narcotics (which include many varieties of street drugs) and, of course dagga or marijuana – *Cannabis sativa*. The active chemical agents in cannabis, known as cannabinoids, are very poisonous.



PROHIBITED SUBSTANCES

S6. STIMULANTS include:

- adrenaline (when associated with local anaesthetics or by local administration, e.g. nasal, ophthalmologic, is not prohibited)
- amphetamine and methamphetamine
- cocaine
- ephedrine (prohibited when concentration in urine $> 10 \mu\text{g}$ per ml)

S7. NARCOTICS

- diamorphine (heroin)
- methadone
- morphine
- pethidine

S8. CANNABINOIDS

- cannabinoids (e.g. hashish, marijuana) are prohibited

The South African constitution affords citizens many rights but it has been criticised in some quarters for saying too little about citizens' duties and responsibilities.

From a radical human rights point of view, one might say that any athlete who wants to enhance his or her performance should be allowed to do so and for any sporting body to deny him or her that right is to deny freedoms which are enshrined in the constitution. What arguments can you offer for and against this view?

Does the athlete have any duties and responsibilities when using his or her natural talents? Could it be argued that an athlete's responsibilities exclude the right to take performance-enhancing drugs? (To whom might the athlete be responsible?)

If there were a state health system and an athlete became ill as a result of the abuse of performance-enhancing drugs (which are prohibited by law), is the state obliged to treat the athlete for what amounts to a self-inflicted injury?

Does the state have an obligation to protect free citizens against their own bad decisions?

These arguments go to the heart of how you view your democratic rights and responsibilities under a democratic constitution. One might make the argument that prohibitions on substances with short-term benefits (e.g. faster times) but with only potentially (i.e. not proven) harmful, long-term effects is nothing more than the behaviour of a "nanny" state which is, in effect, limiting freedoms. What do you say?

NOTE

Some of the issues raised in the lesson on drugs in sport are emotive – that is, they might bring out emotion in a discussion because people hold to some of the ideas at a very emotional level, e.g. freedom and democracy. When debating the issues, try to avoid letting discussions get to the point where they produce more heat than light. Try to maintain a rational, scientific perspective. And when people do get emotional, try to understand why the issue should become so for some people.



Activities

The activities for this section consist of your own research and reading and the discussions and debates that arise from the issues raised in the text. As such, there is no formal assessment and hence no actual answers. The learning to be achieved here (see LO3 of the Physical Sciences curriculum) lies firstly in your awareness of STS issues and where they might arise and secondly in your ability to tackle the issues in a responsible, scientific way.

Many of these issues are closely related to the Life Orientation curriculum and the sections of the Life sciences curriculum where STS issues are discussed.



CHEMICAL REACTIONS IN THE ATMOSPHERE AND MINERAL PROCESSING

Lesson

30a

Learning Outcomes and Assessment Standards

Learning Outcome 1: Practical scientific inquiry and problem-solving skills.

Assessment Standard 2:

Interpreting data to draw conclusions.

Learning Outcome 2: Constructing and applying scientific knowledge.

Assessment Standard 1:

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Overview

Lesson

What you must know in this section of the curriculum is: **Processing of gold, iron, phosphate**

- Mining and mineral processing – gold, iron, phosphate
- South Africa's strengths environmental impact of these activities
- Energy resources and their use.
- Global warming and environmental impact of population growth
 - Acid rain and corrosion of metals
 - Establish relative strength of acids by measuring conductivity

This lesson will cover:

- More on the chemical processes used in mining.
- More on the chemistry of the atmosphere.

Activities

Mining for the noble metals

At some point very early in humankind's economic development, certain things were given value by virtue of their rarity or their symbolic value to the tribe or community. Such things included stones, tusks and shells amongst other things. But chief amongst materials of great value were metals, mainly because at first the technology by which metals could be purified was beyond most people. Amongst metals, the rarest and most sought after were those that were difficult to come by and difficult purify and supreme amongst these were the so-called "noble metals".

Noble metals, by their strict, physics definition, include only copper, silver and gold. However the general, less exacting definition, is that noble metals are those that are resistant to corrosion or oxidation, unlike most "base metals". The noble metals tend to be precious metals and examples include gold, silver, tantalum, platinum, palladium and rhodium. So like the "noble gases", which early chemists knew were unwilling to mix with "common", elements, noble metals are very unreactive. One of the few liquids known to the old alchemists that could dissolve gold was called "aqua regia" – the king's water! In the social hierarchy of the day



255

only something royal could overcome something that was “merely noble”! **Aqua regia** is prepared by mixing concentrated nitric acid and concentrated hydrochloric acid, usually in the ratio of one volume of nitric to three volumes of hydrochloric. It dissolves both gold and platinum.

When Germany invaded Denmark during World War II, a Hungarian chemist named de Hevesy dissolved the gold, Nobel Prize winners’ medals awarded to Max von Laue and James Franck, in **aqua regia** to prevent the Nazis from stealing them. Frank and von Laue had fled the country to escape Nazi persecution. de Hevesy placed the gold-bearing solution in a bottle on a shelf in his laboratory at the Niels Bohr Institute, a famous scientific institute in Copenhagen. After the war, de Hevesy returned to Copenhagen and found the solution undisturbed. He precipitated the gold from the acid and the Nobel Society in Sweden recast the two medals using the original gold!

Gold is by far South Africa’s most important product both in terms of its value and the number of people employed in the gold mining industry. Here are some fascinating “golden facts” taken from the Chamber of Mines website, <http://www.bullion.org.za/>. It also contains information on the geological origins of the gold we mine.

- Africa’s gold deposits were formed some 3,4 billion years ago.
- On average, gold in South African mines is found in only 5.1 parts per million from rock extracted at depths of up to 3.5 km below surface.
- An estimated 10 billion tons of gold is suspended in the seas of the world.
- The exact origins of a piece of ‘virgin gold’ (unblended with gold from any other source) can be ascertained since all gold has a chemical “fingerprint” of trace impurities that pinpoint where it came from.
- The deepest mine in the world is Western Deep Levels gold mine on the Far West Rand, now approaching a depth of 4 km.
- The total volume cut from rock each year in South African gold mines would make a 3500 km railway tunnel long stretching between London and Leningrad.
- For every ton of rock mined, nearly 15 tons of ventilation air is pumped underground.
- The volume of water pumped daily from South African mines would fill 3 million domestic bath tubs to the brim.
- Cooling plants on South African gold mines have a capacity equal to nearly 3.5 million domestic refrigerators.
- Virgin rock temperatures > 52°C have been recorded in South African gold mines.
- The South African gold mining industry consumes enough electricity (> 23 million MWh) to provide energy to a city with 3 million inhabitants.
- The largest South African gold nugget weighed 7.8 kg and was found at Pilgrim’s Rest near the Kruger National Park between 1875 and 1881.
- The largest nugget ever discovered weighed 70.92 kg and was found in Victoria, Australia.
- All the gold ever mined in the world would fit into a store room measuring 17 m long, 17 m high and 17 m wide (approximately 5 000 m³).



- More steel is poured in one hour than gold has been poured since the beginning of time.
- The American Federal Reserve on Wall Street, New York, is the biggest repository of gold in the world. About 13 000 tonnes of gold are kept behind 90 ton steel doors in vaults blasted out of solid granite.
- Of the estimated 127 000 tonnes of refined gold in the world - bullion, jewellery, coin – no less than 42 000 tonnes (or 33 %) has been mined in South Africa since 1886.
- Gold has been used as a currency for over 5 000 years.
- The oldest gold jewellery was crafted in Africa (3 200 BC).
- India uses by far the biggest amount of gold annually: 508 tonnes in 1996 - enough to make about 175 million plain, 18 carat wedding rings.
- It is estimated that the portion of mineworkers' earnings sent to Lesotho account for about 60 % of the country's Gross Domestic Product.
- Gold can be beaten wafer thin - technically that's 0.00001mm thick.
- 30 g of gold can be beaten into 16 m² of gold leaf.
- 30 g can be drawn into 8 km of gold wire.
- The gold used in the electronics industry each year accounts for over 10 billion tiny electrical contacts.
- Nearly 40 tons of gold were used in the construction of space shuttle 'Columbia' in preparation for its maiden flight in April 1981.
- The world's dentists use over 60 tons of gold every year.
- Gold has medicinal and healing properties - it can be used in treating rheumatoid arthritis, chronic ulcers and tuberculosis.
- Gold can be eaten - it is indeed eaten in many Asian cultures.
- Gold is found in minute proportions in the human body, whether you have eaten it or not.

Activity 1

Gold- and silver cyanide are among the very few soluble forms of these two metals. Therefore cyanides are used in mining in the so-called **cyanide process**. There are two methods used. In the first, finely ground, high-grade ore is mixed with a cyanide compound to form gold-cyanide ions. In this process sodium cyanide (NaCN) is mixed with the gold ore to a concentration of about 2 kg NaCN per tonne of the ground, ore-bearing rock.

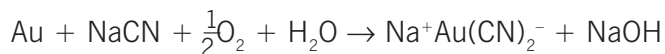
1.1 Explain why it is important for the mines to dig out and process only the rock containing the seams of gold.

Low-grade ores can be stacked into heaps and sprayed with a dilute cyanide solution. The concentration of cyanide used in this so-called “heap leaching process” is about 1 kg of NaCN per tonne of ore. As the cyanide solution trickles through the crushed gold ore it dissolves the gold. The solution is then collected and the dissolved gold recovered.

1.2 Diagram showing how the heap leaching process works.

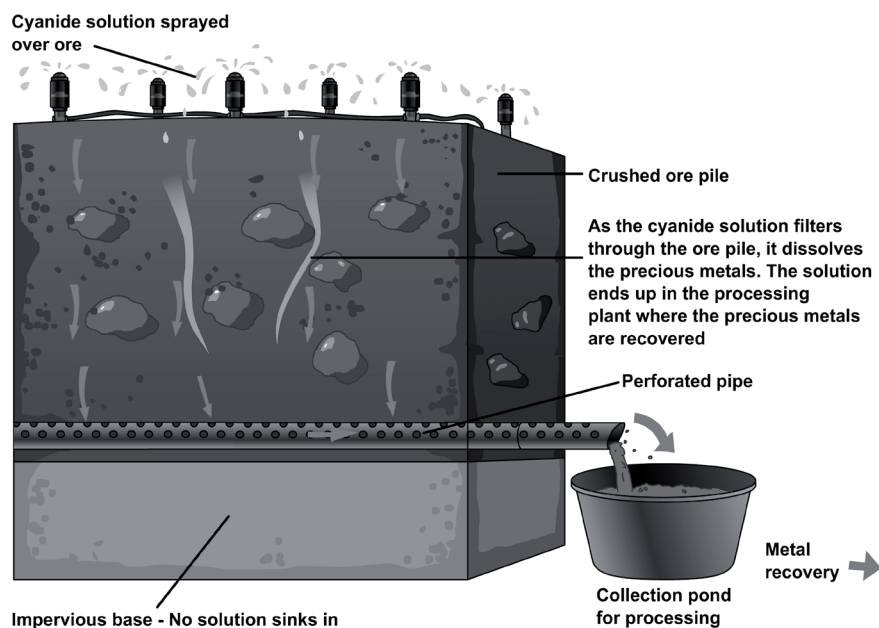
The chemical process by which gold and silver can be recovered from finely crushed rock – in which they are present as pure metals but in very small pieces – is described in the **Elsner Equation**:





The precious-metal ions (Au^{n+}) and the cyanide ions (CN^-) join to form bigger, soluble ions i.e. $[\text{Au}(\text{CN})_2]^-$ or $[\text{Ag}(\text{CN})_2]^-$. The precious metals are now in solution.

HEAP LEACHING



- 1.3 a) Balance the Elsner equation for the recovery of gold using an NaCN solution.
- b) Write the process equation when potassium cyanide (KCN) is used.
- c) Use oxidation numbers to show that in this part of the process, gold is oxidized.
- d) Identify the oxidising agent in the Elsner Equation.

Silver is less “noble” than gold i.e. it is more reactive than gold, and it occurs not as pure silver but as a silver compound – usually as the sulphide. In this case the reaction with the cyanide solution is not a redox reaction but simply an ion exchange reaction in which the $[\text{Ag}(\text{CN})_2]^-$ ion is formed. The silver ion is Ag^+ and oxygen ($\frac{1}{2}\text{O}_2$) and water (H_2O) do not take part in the reaction.

- 1.4 a) Write the equation for the first part of the recovery of silver from silver sulphide-containing ores.
- b) Use oxidation numbers to show that in this part of the recovery process, silver is not oxidised but simply replaced by a similar ion.

The “pregnant liquor” – the solution containing the gold/silver ions - is then separated from any remaining solids which are discarded to a “tailing pond” or “spent heap”, the recoverable gold or silver having been removed. The metal can be recovered from the pregnant solution by reduction with zinc dust. This process can result in environmental and health problems.

- 1.5 a) Write the equation for the recovery of gold from the cyanide solution.
- b) Suggest what part(s) of the reaction might result in environmental damage.



Activity 2

Australia was the world's largest producer and exporter of ilmenite ore in 2005-2006, with 1.1 million tonnes, followed by South Africa (952 000 t), Canada (809 000 t), China (about 400 000 t) and Norway (380 000 t). Most of South Africa's ilmenite was recovered from sand dunes in the Richard's Bay area.

Read the following account of the mining operations in Richard's Bay.

"In the sand dunes on the coast of Northern KwaZulu Natal, near Lake St Lucia, Richard's Bay Minerals (RBM) mine three minerals: rutile, zircon and ilmenite. (1) First the minerals are sucked up as a slurry from the bottom of artificial dams built in the coastal sand dunes. Because the minerals are heavier than the normal sands (SiO_2), they are easily separated by being shaken and spun rapidly in a concentrator. (2) The wet mixture of the three heavy minerals, or slurry, is then partially separated using powerful magnets because ilmenite is magnetic. (3) The other two are then dried and separated using an electrostatic process. The three minerals are then processed differently to produce different products. (4) The first to be processed is ilmenite. It is heated in high temperature furnaces with a very hard coal called anthracite. From this we get pig iron, a brittle mixture of iron and carbon that is used in steel making*. The left over portion from this process is called "titania slag" – a glass-like substance. (5) Rutile is mixed with the crushed, milled and screened titania slag to produce titanium dioxide, a brilliant white material that is used to whiten toothpaste, white paint, plastic and paper. It is even used to brighten the coloured coatings of the popular sweets called Smarties. (6) Zircon is a sand with a very high melting point – around 2 000°C. Its high M.P. makes it a suitable material for manufacturing moulds and crucibles for molten materials in the glass and metal industry. Titanium metal, which can be made by reducing rutile is very light and very, very strong. It is known as a 'space age metal' and one of its major uses is in the manufacture of artificial limbs, bones and joints; heart pacemakers; and light, strong spectacle frames. It is also used to make titanium steel, an alloy that is lighter and stronger than normal carbon steel and which is used in military and passenger jet aircraft and spacecraft."

*The amount of carbon in pig iron is greater than required for good quality steel. Pig iron is processed in a Bessemer Converter where the molten iron is blasted with jets of air. The carbon in the iron and the oxygen from the air combine to form carbon dioxide produced. When CO_2 is driven off it leaves a higher quality (lower carbon content) steel behind.

- Ilmenite is a weakly magnetic titanium-iron oxide mineral which is iron-black or steel-gray. It is a crystalline iron titanium oxide (FeTiO_3).
- Rutile is a mineral composed primarily of titanium dioxide, TiO_2 .
- Zircon is a mineral belonging to the group of nesosilicates. Its chemical name is zirconium silicate and its chemical formula is ZrSiO_4 .

2.1 Draw a flow diagram of the process described in the box above.

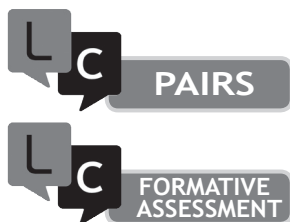
2.2 a) Balance the equation for the process (4) in the description above: the heating of ilmenite in a furnace with anthracite:



- b) Use oxidation numbers to show which reactant(s) act as oxidizing agents in this reaction.



CLUE. In order to determine accurately what oxidation and reduction has taken place one needs to know what are the oxidation states of Fe and Ti in the ilmenite mineral. We are told that ilmenite is magnetic. Its magnetism is due to the iron (Fe) whose oxidation state makes it magnetic. Of the two iron oxides FeO and Fe₂O₃, only the latter is magnetic. So the oxidation state of Fe in Fe₂O₃ is the same as the oxidation number of Fe in ilmenite (FeTiO₂).

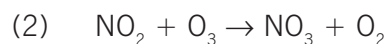


Activity 3

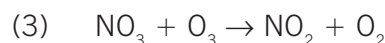
Ozone in the ozone layer is destroyed when it reacts with nitrogen oxides emitted by jet aircraft flying in or near the ozone layer. The cycle starts when nitric oxide (NO) reacts with ozone:



The NO₂ can then be oxidized further by ozone which is a strong oxidizing agent:

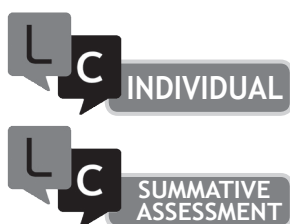


The nitrogen in NO₃ is in a high oxidation state and could be oxidized by another ozone molecule:



In each of these three possible reactions we see an ozone molecule being destroyed and a nitrogen oxide being produced which, in its turn, can break down yet another ozone molecule. Note that the process was started in reaction (1) by a single molecule of nitric oxide. Reactions (2) and (3) form a loop which will keep a number of nitrogen atom reacting with ozone. It has been suggested that single atoms of chlorine and possibly nitrogen atoms too can maintain these ozone-destroying reaction loops for 1 – 2 years.

Balance the three chemical equations for the nitrogen oxide – ozone cycle.



Activity 5

Acid Rain

In the presence of water, sulphur trioxide gas (SO₃) is converted rapidly to sulphuric acid.

- Write the chemical reaction by which sulphuric acid can be formed in the atmosphere.
- Show how in two separate steps, one sulphuric acid molecule can release two hydrogen ions.
- Show how a hydrogen ion reacts with a water molecule to form an hydronium ion, the ion that is responsible for most “acidic” behaviour.
It has been shown that a nitrogen dioxide molecule can react with a free hydroxyl ion to produce an acid molecule.
- Write a chemical equation and name the acid.

A SCIENCE, TECHNOLOGY AND SOCIETY (STS) ISSUE

The effect of mine dumps; mine dump management

Lesson

30b

Learning Outcomes and Assessment Standards:

Learning Outcome 1: Practical Scientific Inquiry and Problem-solving Skills**Assessment Standard 2:**

Interpreting data to draw conclusions.

Assessment Standard 4:

Communicating and presenting information and scientific arguments.

Learning Outcome 2: Constructing and Applying Scientific Knowledge**Assessment Standard 1:**

Recalling and stating specified concepts.

Assessment Standard 2:

Indicating and explaining relationships.

Assessment Standard 3:

Applying scientific knowledge.

Learning Outcome 3: The Nature of Science and its Relationship to Technology, Society and the Environment**Assessment Standard 1:**

Evaluating knowledge claims and science's inability to stand in isolation from other fields.

Assessment Standard 2:

Evaluating the impact of science on human development.

Assessment Standard 3:

Evaluating science's impact on the environment and sustainable development.

Lesson



Requirements for this section of the curriculum

- Mining and mineral processing – gold, iron, phosphate; South Africa's strengths.
 - Environmental impact of these activities.
 - Give a brief history of humankind across the ages.
 - Linking their technology and the materials they have used to their tools and their weapons.
 - Referring to evidence of these activities in South Africa.
- Describe the recovery of gold referring to
 - Why it is worth mining?
 - The location of the major mining activity in South Africa?
- Describe the recovery of iron.
 - Why it is worth mining?
 - Why does South Africa export iron ore?
 - The location of the major mining activity in South Africa?
- Describe the recovery of phosphates.
 - Why it is worth mining?
 - The location of the major mining activity in South Africa?
- The environmental impact of:
 - Mining operations.



261

- Mineral recovery plants.
- Energy resources and their use.
 - Describe the recovery/processing of coal (and crude oil)
 - Why do humans recover oil and coal (fossil fuels)?
 - The original source of oil and coal their non-renewable nature
 - The location of the major coal mining activity in South Africa?
 - The source of South Africa's crude oil (imported from the Middle East and Africa - Nigeria).
- Describe the consequences of the current large scale burning of fossil fuels; many scientists and climatologists are predicting global warming as a result.

Introduction

Modern, commercial gold mining in South Africa began in the 19th century in the Witwatersrand. One view might be that as the need for mine dumps emerged (places to deposit the processed rock from the mining operations), they were strategically placed in and around the black townships. Another view might be that black townships were created in the areas where mining operations – and hence mine dumps – were situated. This view would hold that labour was placed close to the industry where it was needed. The situating of mine dumps raises many questions and issues that can be dealt with under the heading of Science-Technology-Society (STS): why were mine dumps and the places where black miners settled so close to one another? Were mining companies aware of health risks associated with mine dumps and their contents? What health implications do mine dumps hold for people living close to them and who is responsible for remedying adverse conditions? The answers to these and any other socially and politically sensitive questions require thorough research on the economic and socio/political conditions that prevailed at the time; and wise decisions on what to do and how to do it.

The advantages of gold mining

- Improved the economy of South Africa
- Provided many employment opportunities

The disadvantages

- Mine dumps pose health hazards.
- Uranium minerals are often found together with gold-bearing rocks.
- Uranium is poisonous and radioactive. Radium, which has more or less similar properties, and uranium are both byproducts of gold mining

Case Study 1: The uranium-contaminated Wonderfontein Spruit.

- Wonderfontein in the Randfontein area is home to some of the largest gold mining companies in the world such as AngloGold, Goldfields, DRD and Harmony.
- Over 40 000 jobs created.
- The Coetzee family stopped farming mealies as their mealie plants were damaged when irrigated using water from the Wonderfontein Spruit.
- Animals in the Krugersdorp Nature Reserve died from drinking water suspected of being uranium-contaminated.
- Some animals began to show signs of infertility.



- People lost their jobs in the nearby farms and nature reserves.
- People have died from radiation and pollution related diseases.

Case Study 2: Social responsibility: mine dumps around Soweto

- One requirement for a disused mine dump is that there must be pipelines positioned for the purpose of irrigating the grass grown on them to contain the dust in windy and stormy conditions.
- Cases have been reported of people stealing the irrigation pipes.
- Dust is now uncontrollable around the mine dumps resulting in the increase of respiratory related illnesses in and around Soweto.

Case Study 3: Asbestos mining

- Asbestos mine dumps are also a threat to people's health.
- The Kgalagadi District in the Northern Cape gives us at least one example of the ill effects of asbestos mining as there is an epidemic of asbestos-related diseases in this area.
- A young researcher recently died from the disease.
- The asbestos situation arises because when it was first used for domestic (roofing materials and use in insulating panels next to stoves and geysers) and industrial (lagging or the insulation of pipes) purposes, people did not know how harmful asbestos was to human health.
- Take someone who spent her high school years in a rural school in, say, Giyani in Limpopo Province. If the classrooms had no ceilings, this learner would have been indirectly exposed to the asbestos roof during her time in this school's classroom. Do fibres of asbestos actually wear off the asbestos roof sheeting? If so, how much? And if asbestos fibres were inhaled by this learner, how much asbestos might she have inhaled over a five-year period? Is the body able to get rid of small amounts of asbestos in the lungs or does it remain permanently in or on the lung tissues? If it remains in the lungs, and if it does have adverse consequences in the expected amounts in this situation, what effects might this learner experience? How long might it take for the effects to be felt? And if the five years our learner spent in school is unlikely to have had harmful effects on her health, what can one say of a teacher who spent 10 or 15 or 20 years at the school?
- STS issues are often subtle. They therefore require the input of good, reliable data and information. Hasty conclusions on the basis of poor factual information is not only scientifically irresponsible, it is dishonest. Often there are people who wish, for whatever reasons of their own, to make a political, social or personal point. In order to make the point they may twist or leave out facts in a way that strengthens the argument they are trying to make. This is what a scientifically responsible approach to STS issues tries to avoid.

Social action

- There is no purpose in studying problems without some commitment to seeking solutions to the problems.
- Only when communities are informed does their activism become meaningful.
- Mariette Liefferink, the South African Erin Brockovitch, took action against the Wonderfontein Spruit mining companies for showing no care to human life and the environment whilst engaging in their mining activities.



- Strongman Mpangana, a union official, learnt the facts about the negative impacts of mining on human health and the environment at large and then committed himself to doing something about the problem.

Lesson



Activity 1

- 1.1 In groups of four, discuss both the advantages and disadvantages of mining.
- 1.2 In which ways are mining activities contributing to the destruction of the natural environment?
- 1.3 List ways on how you could help the government to regulate the mining industry.



Activity 2

- 2.1 One of the by-products of gold mining is uranium. Uranium is a highly radioactive substance. Do some research on uranium. Focus on the following headings:
 - Physical properties
 - Effects on the environment
 - Effects on human health
 - How the radioactive decay of uranium atoms occurs (make use of equations to show this)
- 2.2 What is asbestosis? Explain in full.
- 2.3 The Diepkloof mine dump is only about 800 m to 1 km away from the community that lives in the area. The dust that comes from the dump during windy days is harmful to human health. Over the years people have stolen the dump piping which irrigates the grass that is grown to prevent dust from being blown to peoples' houses. People who are involved in such theft do so without knowing or caring about the ill effects the mine dump dust has on people's health.

You are a learner at Masombuka High School in Diepkloof and the Physical Sciences teacher has made you aware about the effects of mine dump dust on human health. Prepare an A3 Poster that you could use to inform the community about the dangers of inhaling mine dump dust. Your poster information will be assessed based on the following:

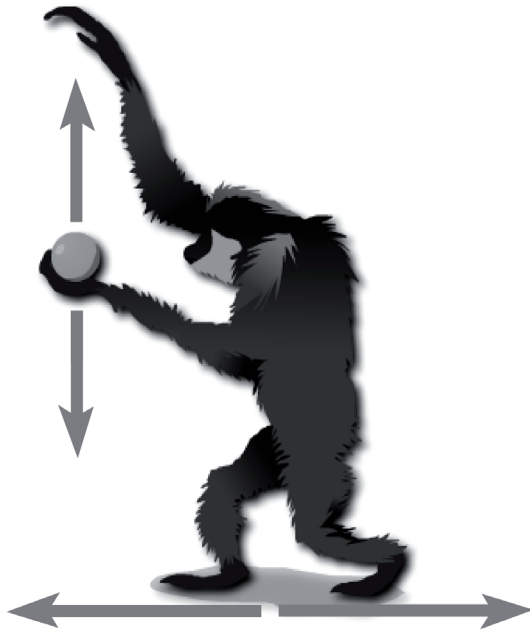
 - Usefulness
 - Accessibility of the language used to the community
 - Correctness of the scientific knowledge used
 - Visibility and legibility of the wording on poster
 - Attractiveness



ANSWERS AND ASSESSMENT

Lesson 1

Activity 1.1



The four forces shown result from:

- Gravity
- The force of the hand on the ball
- The force of the foot pushing on the ground
- The ground pushing on the foot

Can you identify which force is which?

Activity 1.2

Examples of very small forces exerted in nature:

A butterfly flaps its wing

A puff of air moves a flower

A ripple of water makes a floating leaf move

A drop of water hits the ground

A fly lands on the table

Activity 1.3

Examples of very large forces exerted in nature:

A tsunami (sea wave from a disturbance below the sea)

An earthquake

A hurricane wind

A shockwave in the air caused by a lightning strike

An avalanche



Activity 2

Some clues for your diagrams:

1. A cricket bat hits a ball: BAT HITS BALL AND BALL HITS BAT!
2. An axe strikes a piece of wood: THE BLADE IS WEDGE-SHAPED.
3. A car remains stationary on the road: THE WEIGHT OF THE CAR.
4. A nail in the road pierces a car tyre: RUBBER STRETCHES FIRST.
5. A worker stands on a ladder: THE RUNG SUPPORTS HIS WEIGHT.

Activity 3

Use the fewest possible forces, i.e. the smallest possible force to:

1. Get crate moving to the right: apply to the right F_3
2. Get crate moving to the left and keep it sliding to the left: apply F_3 and then reduce to F_2
3. Lift the crate off the ground: apply upwards F_6
4. Keep the crate rising off the ground at a steady speed: apply upwards F_5
5. The largest possible force to the right: $F_6 - F_f = F_6 - F_2$
6. Apply the smallest possible force that will reduce the frictional force between the crate and the floor: F_1 applied upwards

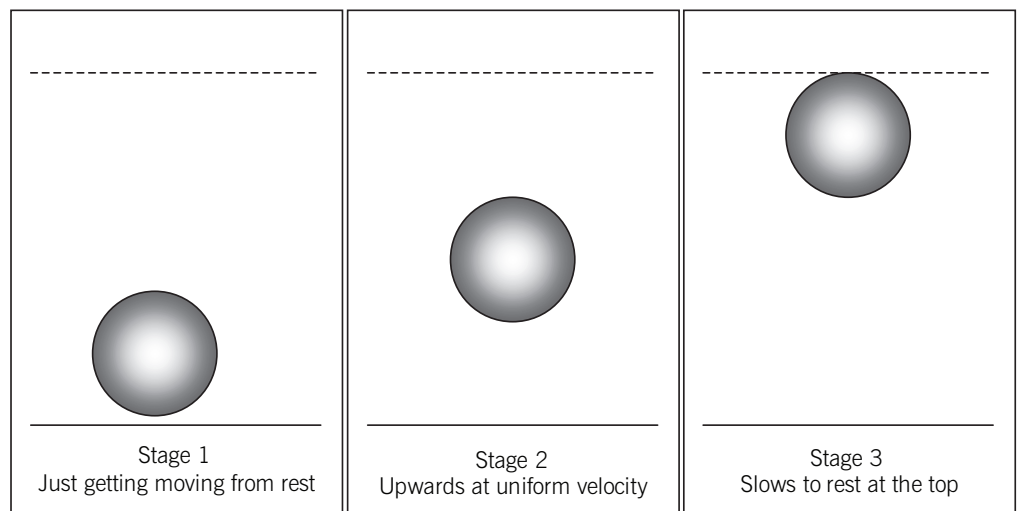


Assessment Task

An Assessment Task is a summary task for you to do when you have completed the lesson. It is intended to help you assess yourself so that you can find out where you need to do more work.

IDENTIFY THE FORCES INVOLVED WHEN A BALL IS LIFTED

Here are three questions about the lifting of a ball. Show the forces being exerted in each of the three stages in the movement of the ball by representing the forces with a neat arrow. Make sure that larger forces are represented by larger arrows and vice versa.



Stage 1 Ball moves upwards, from rest to a certain velocity, v .

Stage 2 Ball continues to move upwards at constant (uniform) velocity, v .



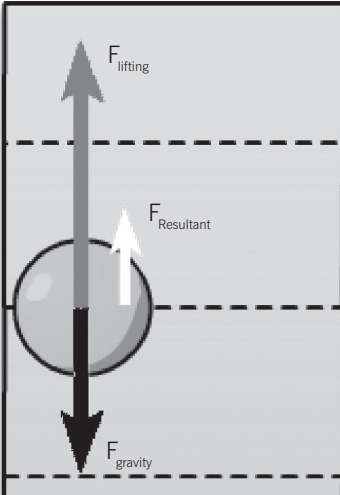
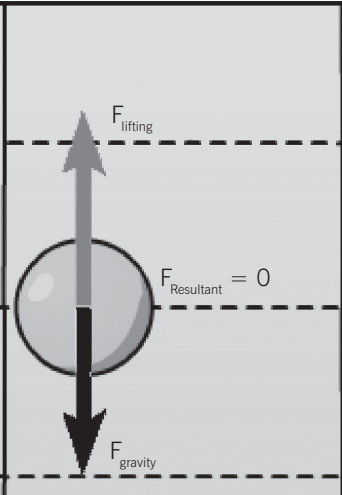
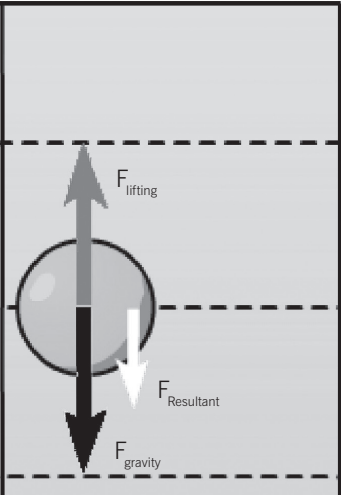
Stage 3 Ball comes to rest at the top of its lift, i.e. slows from v to $0 \text{ m}\cdot\text{s}^{-1}$.

1. Draw the three diagrams, one for each stage.
2. Use arrows to show what forces are acting at each stage.
3. State, with reasons, which of Newton's laws best explains the motion at each stage.
4. **Complete this summary:**

The resultant force on the ball is at Stage 1 is **zero / not zero**

The resultant force on the ball is at Stage 2 is **zero / not zero**

The resultant force on the ball is at Stage 3 is **zero / not zero**

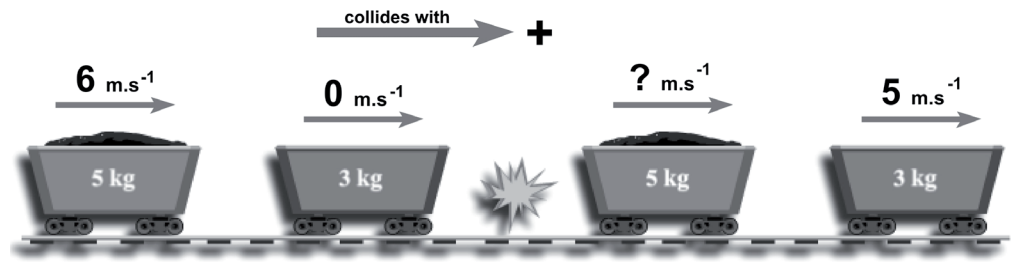
		
<p>Stage 1</p> <p>The lifting force is greater than the weight of the ball (i.e. the force of gravity) so the result is more than zero and upwards. Therefore the ball accelerates upwards from rest. Newton's Second Law explains this situation.</p>	<p>Stage 2</p> <p>The lifting force is equal in size to the weight of the ball (i.e. the force of gravity) so the result is zero. Therefore the ball continues to move upwards at constant velocity. Newton's First Law (Law of Inertia) explains this situation.</p>	<p>Stage 1</p> <p>The force of gravity (i.e. the weight of the ball) is greater than the lifting force so the result is more than zero but downwards. Therefore the ball accelerates negatively (slows down) to rest. Newton's Second Law explains this situation.</p>

Lesson 1a

Activity 1

Understanding the problem

The law of conservation of linear momentum will apply to this system because it is closed, i.e. no external forces (such as friction) are acting.

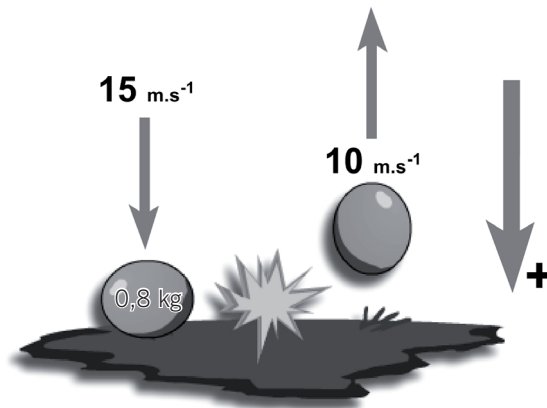


Total linear momentum before collision = Total linear momentum after collision

$$\begin{aligned}
 m_A u_A + m_B u_B &= m_A v_A + m_B v_B \\
 5(+6) + 3(0) &= 5(v_A) + 3(+5) \\
 \therefore -5v_A &= 15 - 30 \\
 v_A &= +3 \text{ m}\cdot\text{s}^{-1}
 \end{aligned}$$

Activity 2

Understanding the problem



The law of conservation of linear momentum will not apply to this system as there is an external force acting (apart from air resistance, which we are usually told to ignore), namely the force by the ground on the ball that deforms the ball as it collides with the ground. We could use the law of conservation of linear momentum if we were able to take the change in momentum of the ground into account! As it is, the information we are given only allows us to determine the change in momentum of the ball.

$$\begin{aligned}
 \text{Momentum of ball BEFORE} &= p_B \\
 &= mu \\
 &= (0,8)(+15) \\
 &= 12,0 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 \text{Momentum of ball AFTER} &= p_A \\
 &= mv \\
 &= (0,8)(-10) \\
 &= -8,0 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 \Delta p &= p_A - p_B \\
 &= -8,0 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} - (12,0 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1})
 \end{aligned}$$



$$\begin{aligned}
 &= -20 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \\
 \mathbf{F}\Delta\mathbf{t} &= \Delta\mathbf{p} \\
 \therefore \mathbf{F}_{\text{AV}} &= -20 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} / 0.16 \\
 &= -125 \text{ N}
 \end{aligned}$$

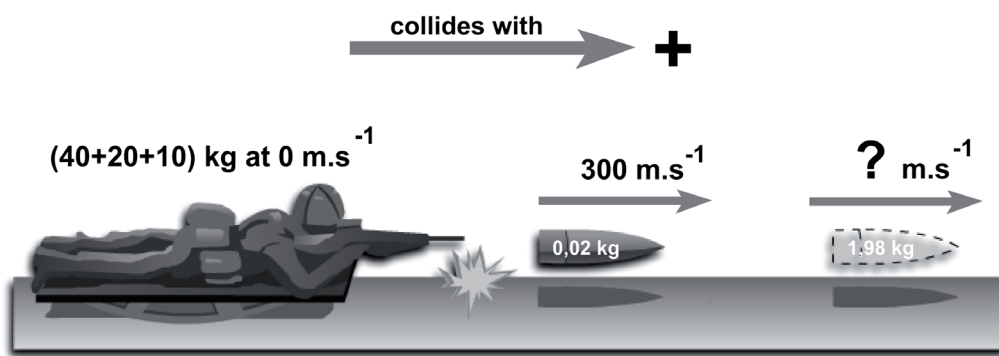
Observation

The calculation shows that the average force is a negative number. You will remember that our direction convention was “downwards positive”. So the average force is in an upwards direction. And, of course, this should be obvious! We were asked to calculate the average force of the ground on the ball. We did this by calculating the change in momentum of the ball and that value was also negative. It must be obvious by now that the force which CAUSES the ball’s momentum to change is the upwards force BY THE GROUND on the ball.

Activity 3

Understanding the problem

The law of conservation of linear momentum will apply to this system because it is closed. We can assume that there is no friction action between the rails of the sled and the ice surface.



a) speed with which the boy and the sled begin to move:

Total linear momentum before collision = Total linear momentum before collision

$$\begin{aligned}
 M_T u_T &= m_{B+S} v_{B+S} + m_{\text{bullet}} v_{\text{bullet}} \\
 (40+20+10)(0) &= (70 - 0,02)(v_{B+S}) + 0,02 (+300) \\
 \therefore -69,98 v_{B+S} &= +6 \\
 v_{B+S} &= -0,09 \text{ m}\cdot\text{s}^{-1} \text{ (i.e. backwards)}
 \end{aligned}$$

b) speed with which the block of wood moves when the bullet enters it:

Total linear momentum before collision = Total linear momentum before collision

$$\begin{aligned}
 m_{\text{bullet}} u_{\text{bullet}} + m_{\text{Block}} u_{\text{Block}} &= M_{b+B} v_{b+B} \\
 0,02 (+300) + 1,98 (0) &= (0,02 + 1,98)(v_{b+B}) \\
 \therefore -2 v_{b+B} &= -6 \\
 v_{b+B} &= +3 \text{ m}\cdot\text{s}^{-1} \text{ (i.e. in a positive direction)}
 \end{aligned}$$



If someone were to ask you why a rocket moves forwards when hot gas is fired backwards out of the jets, will you be able to explain it to him/her? If you are still

not sure, look again at Newton's Third Law of Motion: "To every action there is an equal and opposite reaction." Bear this in mind and return to the problem after you have worked through Lessons 2a and 3a.



Activity 4

Supplementary problem

Discuss the application of the concept of impulse to traffic safety measures including airbags and seatbelts in cars and the arrestor beds that one finds alongside steep descents and passes, e.g. below the Du Toit's Kloof Pass and on the N3 highway between Pietermaritzburg and Durban.

Lesson 2

Activity 1

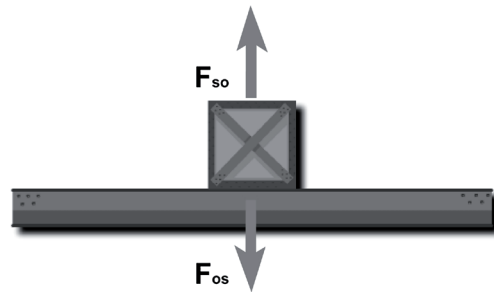
$$F \cdot \Delta t = (mv - mu)$$

$$(F \text{ N}) \cdot (0,4 \text{ s}) = (0,5 \text{ kg}) \cdot [-30 \text{ m} \cdot \text{s}^{-1} - (+30 \text{ m} \cdot \text{s}^{-1})]$$

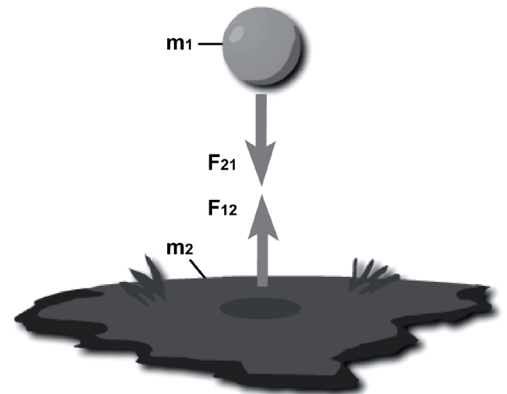
$$F = (0,5) \cdot (-60 \text{ m} \cdot \text{s}^{-1}) / 0,4$$

$$= -75 \text{ N (i.e. opposite to the direction of the incoming ball)}$$

Activity 2



When an object (**O**) rests on a surface (**S**), it applies a downward force (F_{os}) on the surface. The reaction of the surface to this force is a force on the object ($-F_{so}$), equal in size but in the opposite direction to F_{os} .



When two masses (m_1 and m_2) exert a gravitational force on each other, the force (F_{12}) with which the first mass (m_1) attracts the second mass (m_2) is the same size but in the opposite direction to the force with which the second mass attracts the first mass, i.e. $-F_{21}$.



Lesson 3

Activity 1

- a) The weight of the steel sheet is $W = mg = 250 \times 10 = 2\,500\text{ N}$
- b) $F_f = \mu \cdot N$ and $\mu = 0,7$ for steel/steel.
 $= 0,7 \times 2\,500 = 1\,750\text{ N}$

Activity 2

- a) $\tan \Theta = \tan 30^\circ = 0,577$
- b) Probably not. Various woods differ greatly in their hardness and texture (how fine or close together the grain of the wood is). This also makes a difference in how well and smoothly the surface can be sanded and polished. So, unless one knows more about the wood and its preparation, one could not state the coefficient of friction with any confidence.

Activity 3

- c) $N = W \cos \Theta = 10 \times 10 \cos 45^\circ = 100 \times 0,707 = 70,7\text{ N}$
- d) Glass on glass (0,9) and rubber on concrete (1,0) would NOT slide at 45° . One would need more accurate measurements of steel on steel and copper on steel (both 0,7) to be sure what those materials might do. Anything from 0,65 to 0,74 would be 0,7 if the figures were rounded off to one decimal place.

Allowing learners to do the practical for determining coefficients of friction and then discussing their experimental procedure and results will allow a teacher to assess how well they understand the concept of sliding friction.

Lessons 3a and 3b

Activity 1

Study the graphic on the DVD until you understand what it is saying and how the lengths of the arrows accurately represent the physical reality of the situation. Throw a ball into the air as in the graphic and observe it closely. Also throw two different sized balls and observe these. Finally, drop two different sized balls (try to find balls with different masses) and satisfy yourself of the physics explanation of why they fall at the same rate.

Activity 2

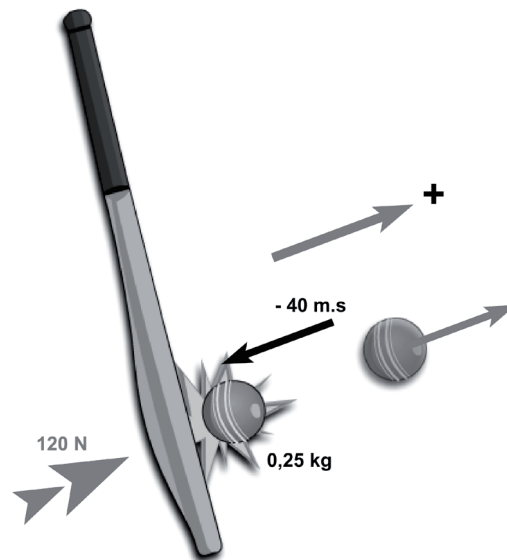
Once you understand how the forces in this system work, you will have a good understanding of Newton's Third and Second Laws. You may not grasp it immediately but with persistence you will! Keep at it until you understand it. You will know that you do when you can explain the concept to a friend so that he/she does too!!

Activity 3

Understanding the problem

The force that the BAT exerts ON THE BALL will cause the ball's change in momentum (and vice versa.). By calculating the change in momentum, we have also determined the size of the impulse that the bat is applying on the ball.





$$\begin{aligned}
 \text{Momentum of ball BEFORE} &= p_B \\
 &= mu \\
 &= (0,25)(-40) \\
 &= -10,0 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}
 \end{aligned}$$

$$\begin{aligned}
 \text{Momentum of ball AFTER} &= p_A \\
 &= mv \\
 &= 0,25 \times v
 \end{aligned}$$

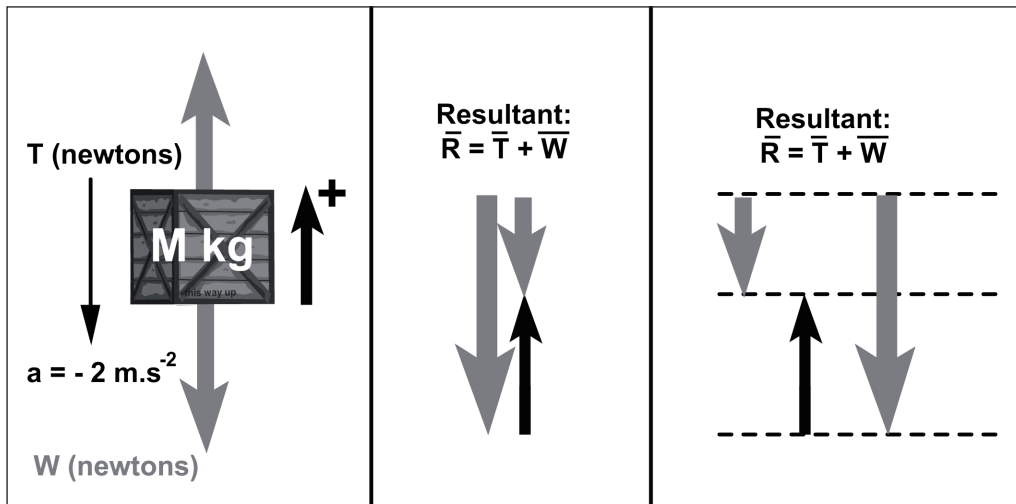
$$\begin{aligned}
 F\Delta t &= \Delta p \\
 120 \text{ N} \times 0,1 \text{ s} &= (0,25 \times v) - (-10,0 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}) \\
 \therefore -0,25 v &= -12 \text{ N}\cdot\text{s} + 10,0 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1} \text{ [note } \text{Ns} \equiv \text{kg}\cdot\text{m}\cdot\text{s}^{-1}] \\
 &= 2 \text{ kg}\cdot\text{m}\cdot\text{s}^{-1}
 \end{aligned}$$

Observation: Because the ball arrived at the bat at a higher speed than it left, this is what cricketers would call “playing the ball with soft hands” – in other words by allowing the bat to move with the incoming ball and effectively hitting the ball back softly. Let’s say you knew that the bat had a mass of 5 kg and was moving at 2 m·s⁻¹ when the batsman hit the ball “with soft hands”, could you use the law of conservation of linear momentum to determine the speed with which the bat moves backwards after hitting the ball? The answer is “NO” and the reason is that this was NOT a closed system. Can you identify any external forces?

Activity 4

Understanding the problem

When dealing with an accelerating lift, the first thing to realise is that when a body accelerates it MUST have a resultant force acting on it. The resultant force is the sum of all the other forces acting on the lift – namely the WEIGHT of the lift and passengers and the TENSION in the cable. If acceleration is upwards, the tension > weight, and vice versa. In the problem, the lift is moving UP but SLOWING DOWN. So the acceleration is DOWNWARDS! “Up” has been chosen as positive so the acceleration and thus the resultant force are both negative (downwards).



Resultant: $\bar{R} = \bar{T} + \bar{W}$ Resultant: $\bar{R} = \bar{T} + \bar{W}$

Resultant force = $M \times a$
 = 500×-2
 = $-1\,000\text{ N}$

Tension (T) = $R - W$
 = $-1\,000 - (-500 \times 10\text{ m}\cdot\text{s}^{-2})$
 = $(-1\,000 + 5\,000)\text{ N}$
 = $4\,000\text{ N}$

Observation

The upward tension in the cable is less than the downward weight of the lift. So the net force is downwards (-). That means that the acceleration is downwards. And because the lift is moving upwards, it must be slowing down (accelerating negatively).

Activity 5

Understanding the problem

When the rock hits the ground, the ground exerts an upwards force on it. The other force acting on the rock is the downwards force of gravity. The resultant must be upwards because the rock slows down to zero while moving downwards. Knowing what the rock’s speed was as it hit the ground and its final speed ($0\text{ m}\cdot\text{s}^{-1}$) and the time taken to slow down to zero allows us to calculate the acceleration. The 18 cm is interesting but irrelevant! (All it does is give us some idea of the hardness of the ground.)

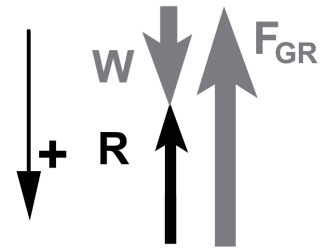


$$\begin{aligned} \text{Acceleration} &= \frac{\Delta v}{\Delta t} \\ &= \frac{(0 - 30)}{0,012} \\ &= -2\,500 \text{ m}\cdot\text{s}^{-2} \end{aligned}$$

$$\begin{aligned} \text{Resultant force} &= Ma \\ &= (4 \text{ kg})(-2\,500 \text{ m}\cdot\text{s}^{-2}) \\ &= -10\,000 \text{ N} \end{aligned}$$

$$\text{Resultant: } \bar{R} = \bar{F}_{GR} + \bar{W}$$

$$\begin{aligned} F_{GR} &= R - W \\ &= (-10\,000) - (+40) \\ &= -10\,040 \text{ N} \end{aligned}$$

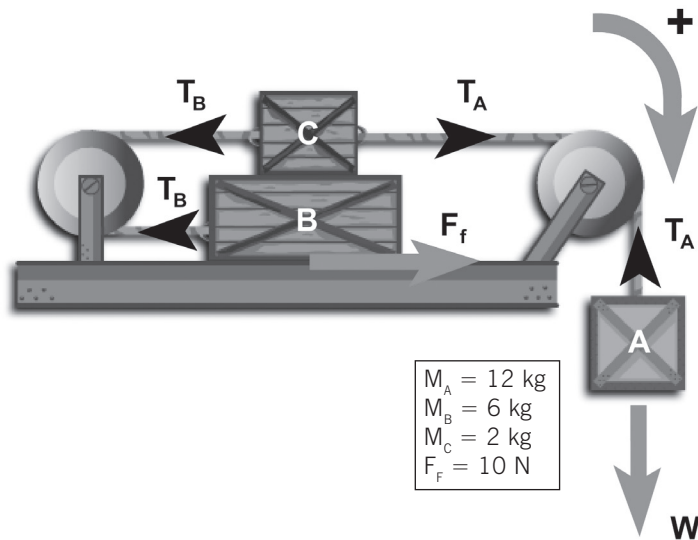


Observation

The upward force of the ground on the rock must overcome the weight of the rock and also supply enough force to achieve the resultant force that slows the rock down in a very short time.

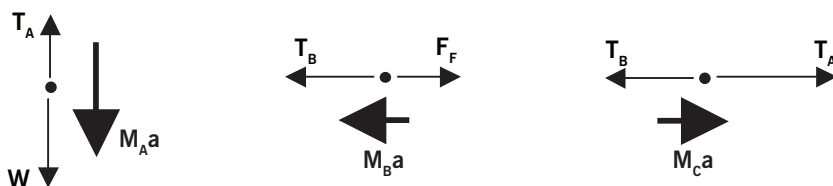
Activity 6

Understanding the problem



With a complex system like this (as with the horse and cart problem) we can look at it in parts. What we know is that all parts of the system will have the same acceleration even if the pulleys change the direction of movement in places. The other thing to notice is that all tensions in a piece of string will add up to zero because there is no resultant force in an inextensible string.

Free body diagrams (similar to vector force diagrams except that we reduce the body to a single point for simplicity's sake) can be drawn for each individual body. We show the resultant force on free body diagrams if possible.



$$\text{Eq 1: } W - T_A = M_A a \quad \text{Eq 2: } T_B - F_F = M_B a \quad \text{Eq 3: } T_A - T_B = M_C a$$

$$W = M_A g$$

$$= 12 \text{ kg} \times 10 \text{ m}\cdot\text{s}^{-2}$$

$$= 120 \text{ N}$$

Add Eq 1 and Eq 3:

$$W - T_A + T_A - T_B = M_A a + M_C a$$

$$W - T_B = (M_A + M_C) a \dots \quad \text{Eq 4}$$

Add Eq 4 and Eq 2:

$$W - T_B + T_B - F_F = (M_A + M_C) a + M_B a$$

$$W - F_F = (M_A + M_B + M_C) a$$

$$(120 - 10) \text{ N} = (12 + 6 + 2) a$$

$$\therefore 110 \text{ N} = 20 a$$

$$\therefore a = 5,5 \text{ m}\cdot\text{s}^{-2} \text{ in the direction shown}$$

Substituting the value for “a” into each equation, we get values for the tensions in the strings.

From Eq 1:

$$T_A = 120 - (12 \times 5,5)$$

$$= 54 \text{ N}$$

From Eq 2:

$$T_B = 10 + (6 \times 5,5)$$

$$= 43 \text{ N}$$

Observation

The free body diagrams show us how to write the equations. Once the equations have been written down correctly, the rest is algebra. The physics lies in understanding the diagrams and writing down the forces with the correct signs to show the directions of the forces.

Lesson 4

Activity 1

When the astronaut is one Earth radius from the surface of the Earth, he is two Earth radii from the Earth’s centre. So the distance between the centres of the Earth and the astronaut will have doubled. Therefore $1/r^2$ will have gone from $1/R^2$ to $1/(2R)^2$ or $1/4R^2$. So his weight will have quartered to $800/4 = 200 \text{ N}$.

Activity 2

- $5 \times 10^{-7} \text{ N}$
- If the distance between their centres is halved, the force will increase by a factor of 4 to $2 \times 10^{-6} \text{ N}$ or 2 micronewtons.
- If one of the masses is doubled, the force will double ($F \propto m_1$) i.e. 10^{-6} N .

Activity 3

- Both masses doubled so this increases the force by a factor of (2×2) . The distance between them is halved so the force increases by another factor of $(\frac{1}{2})^{-2}$. So the overall increase is $[4 \times 4]$ times, or 16 times, i.e. to 1 600 N.



- b) Both masses are halved so this decreases the force by a factor of $(\frac{1}{2} \times \frac{1}{2})$. The distance between them is doubled so the force decreases by another factor of $\frac{1}{4}$ (i.e. $\frac{1}{2} \times \frac{1}{2}$). So the overall decrease is 16 times or by $(\frac{1}{4} \times \frac{1}{4})$, i.e. to $\frac{100}{16} = 6,25$ N.

Assessment

1. In order to test your understanding of gravitational forces, explain the following without referring back to the notes:

- Why all bodies near the surface of the Earth will fall with an acceleration of about $9,81 \text{ m}\cdot\text{s}^{-2}$, regardless of their mass.
- Why the force on a body at the surface of the Earth will drop to one quarter of that value when the body is taken to a height of about 6 364 km above the Earth's surface.
- Why there is a point somewhere between Earth and the Moon where the gravitational force on a body (the space shuttle, for example) is zero.
- Why the point in space referred to in the previous question is closer to the Moon than Earth.

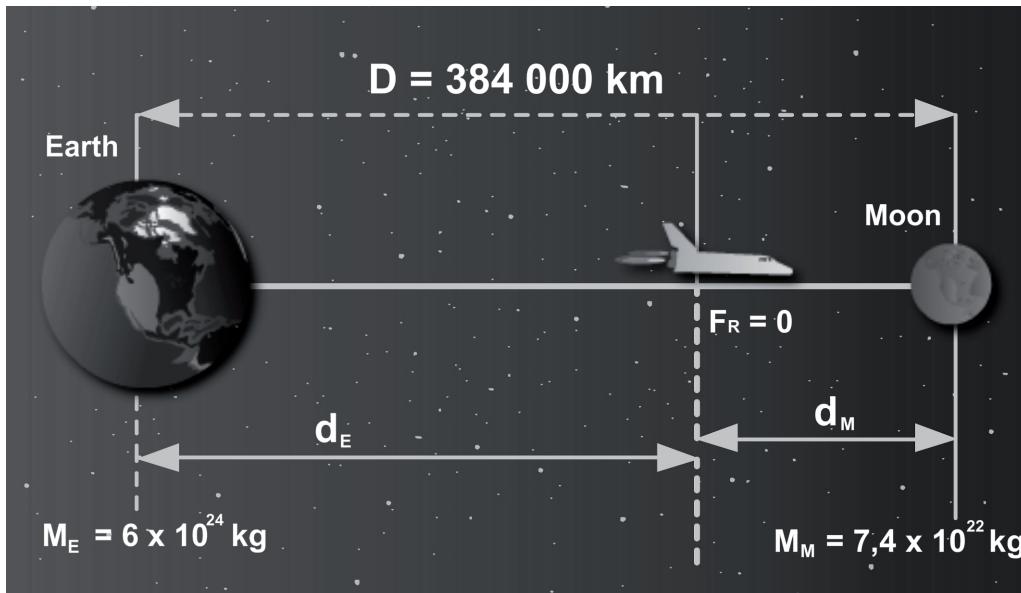
2. THIS IS AN ADVANCED PROBLEM WITH SOME MATHEMATICS INVOLVED. It is intended for students who understand the work well and who want to test their ability to apply mathematics to a physical problem.

When a space rocket travels from the Earth to the Moon, the first thing it must do is overcome the very strong gravitational attraction of the Earth. The rockets that do this carry an enormous load of fuel which is burnt up very fast in order to give the rocket the velocity needed to escape the Earth's attraction. This is known as the "escape velocity." Once the rocket has escaped the Earth and is speeding away from it, it still feels the Earth's pull. But as the rocket travels towards the Moon, it gradually comes under the influence of the Moon's gravitational. Now, if you have both the Earth and the Moon pulling on the spacecraft, at some point their forces on the spacecraft will be equal and opposite. In other words, for a very brief time, the two forces will be in equilibrium and the force exerted on the spacecraft will be zero, i.e.

$$F_R = 0$$

If you know the masses of the Earth and the Moon (M_E and M_M) and their distance apart (D), you can calculate accurately the point at which the gravitational attractions are in equilibrium (or "balanced"). Use this diagram to set up your equations.





Hint: Think about the problem first. Which should be bigger, d_E or d_M ? Guess how much bigger!

Hint: One method of solving this problem involves a quadratic equation whose roots you can find using the values given.

This calculation will be done for you in Activity 4, Lesson 4a.

Lesson 4a

Activity 1

When we place the right kind of matter in a field, it experiences a force. For instance, when we place *charge* in an *electrical field*, it experiences a force equal to $q\mathbf{E}$, or the product of the size of the charge and the strength of the field. Similarly, when we place a mass in the gravitational field of another mass, the force it experiences is equal to the product of the size of the mass and the strength of the field, i.e. $m\mathbf{g}$. In other words, gravitational field strength is \mathbf{g} .

Activity 2

Understanding the problem

To solve this problem, we must imagine taking the same mass, m , and finding its weight at both the surface of the Earth and the surface of the Moon. Weight is the force of gravitational attraction on a mass, e.g. “the weight of mass m at the surface of the Earth is $m\mathbf{g}$.” But we can also determine the weight using Newton’s Law of Universal Gravitation which gives the force between any two masses a certain distance apart. If one of those masses is either the Earth or the Moon then the force on the “test mass”, m , is what we call the weight of m .



Earth	Moon
Weight on Earth = F_E = $G \times \frac{M_{\text{Earth}} \times m}{R_{\text{Earth}}^2}$	Weight on Moon = F_M = $G \times \frac{M_{\text{Moon}} \times m}{R_{\text{Moon}}^2}$
$G = 6,67 \times 10^{-11}$	$G = 6,67 \times 10^{-11}$
Mass of Earth = 6×10^{24} kg	Mass of Moon = $7,4 \times 10^{22}$ kg
$M_E = 81 M_M$	
Radius of Earth = 6 380 km	Radius of Moon = 1 740 km
$R_E \approx 4R_M$	

Answer: Because the Earth's mass is much greater (approximately 80 times greater) whereas the Earth's radius is only four times greater (approximately), even when we take the inverse square of the radius ($\frac{1}{16}$), the weight of a mass on Earth will still be >5 times greater than on the Moon.

Use the figures given in the table above to calculate the difference accurately.

Activity 3

If the distance between them is doubled then the force is reduced by a quarter because

$$F_g \propto \frac{1}{(2r)^2} = \frac{1}{4r^2} = \frac{1}{4} \times \frac{1}{r^2}$$

But if one of the masses is halved then the force is also reduced by a further half because:

$$F_g \propto m_1 \times \frac{1}{2} m_2 = \frac{1}{2} m_1 \cdot m_2$$

So the overall decrease in the force is by $\frac{1}{4} \times \frac{1}{2} = \frac{1}{8}$

Activity 4

Understanding the problem

At some point between the Earth and the Moon, the resultant force on the astronaut's capsule will be zero because the Earth and the Moon will be pulling on it with equal forces in opposite directions. At this point, the capsule will be travelling at a constant velocity, i.e. it is not accelerating. We know this from Newton's First Law, the Law of Inertia, which tells us how bodies behave when the resultant force on them is zero.



$$F_R = 0 : \frac{GM_E m}{d_E^2} = \frac{GM_M m}{d_M^2}$$

$$\therefore \frac{d_E^2}{d_M^2} = \frac{M_E}{M_M}$$

$$\therefore \frac{(D - d_M)^2}{d_M^2} = \frac{M_E}{M_M}$$

$$\therefore \frac{D^2}{d_M^2} - \frac{2D \cdot d_M}{d_M^2} + \frac{D_M^2}{d_M^2} = \frac{M_E}{M_M} = c$$

$$\frac{D}{d_M} = x$$

$$\therefore x^2 - 2x + 1 = c$$

$$\therefore x^2 - 2x + (1 - c) = 0$$

$$\therefore x = \frac{2 \pm \sqrt{4(1 - c)}}{2}$$

$$= 1 \pm \sqrt{c}$$

$$= 1 \pm \sqrt{\frac{6 \times 10^{24}}{7,4 \times 10^{22}}}$$

$$= +10 \text{ (or } -8)$$

$$\therefore \frac{D}{d_M} = 10$$

$$D = d_E + d_M = 10 d_M$$

$$d_E = 9 d_M$$

ratio : $9 d_M : d_M$

$$= 9 : 1$$

$$\therefore d_E = 0,9 \times 384 \times 10^3$$

$$= 3,456 \times 10^5 \text{ km}$$

\therefore 90% of the distance from Earth to the Moon

Lesson 5

Activity 1

	Anticlockwise moments (Nm)	Clockwise moments (Nm)	Will the beam turn?	If so, in which direction?
Beam 1	8,0	8,0	No	~
Beam 2	10,0	10,0	No	~
Beam 3	10,5	11,10	Yes (difference 0,6 Nm)	Clockwise
Beam 4	24,0	24,0	No	~
Beam 5	42,5	40,0	Yes (difference 2,5 Nm)	Anticlockwise



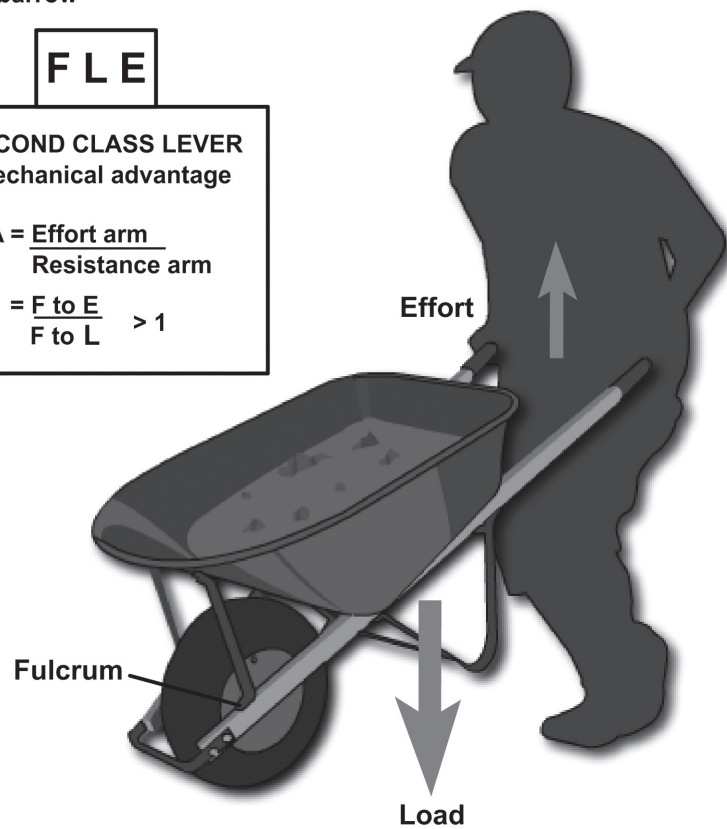
Activity 2

(a) Wheelbarrow

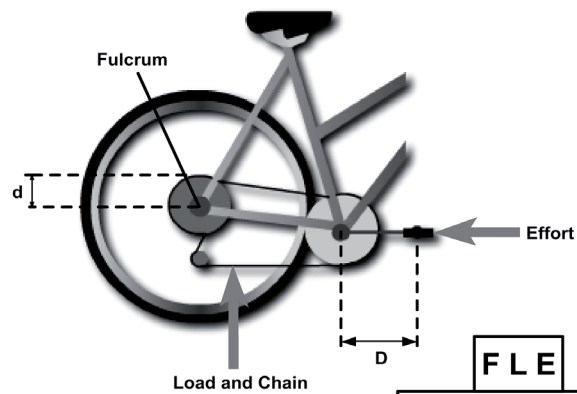
F L E

SECOND CLASS LEVER
Mechanical advantage

$$MA = \frac{\text{Effort arm}}{\text{Resistance arm}}$$

$$= \frac{F \text{ to } E}{F \text{ to } L} > 1$$


(b) Bicycle



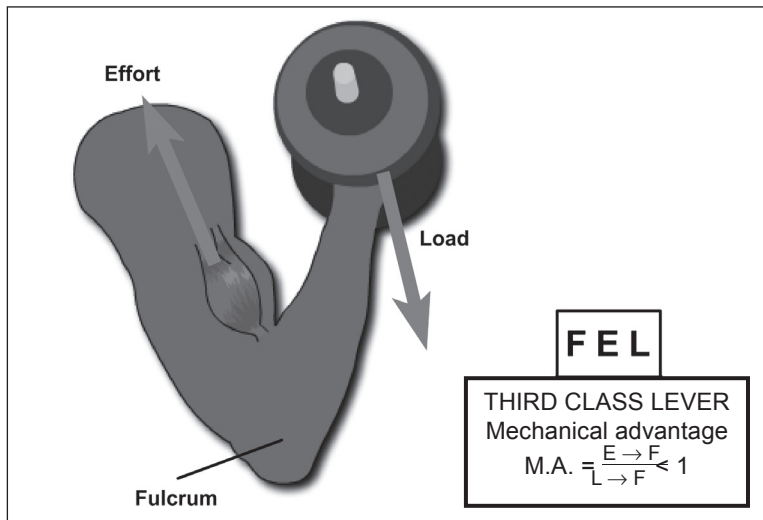
F L E

FIRST CLASS LEVER
Mechanical advantage

$$MA = \frac{D}{d} > 1$$

In the case of a bicycle,
the mechanical
advantage is > 1





ASSESSMENT

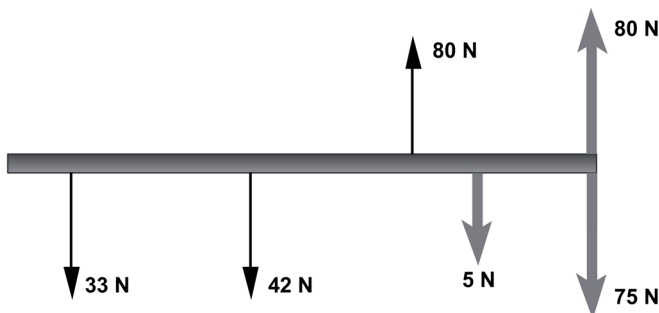
It is important to be able to discuss simple, everyday machines such as can openers and bicycles, etc, in terms of the type of levers they are and the mechanical advantage they give. Or do the simple machines give a “moment advantage” as in third-class levers where the effort is greater than the load but for a small moment of the effort (arm) we get a much larger moment of the load (arm)?

See the table in the Teacher Tips to assess the learners’ drawings for Activity 2.1.

The example of why chimpanzees are so strong is an excellent application of the theory of levers. Learners who can appreciate that discussion have a good, basic grasp of machines and mechanical advantage. (See Teacher Tips)

Lesson 5a

Activity 1



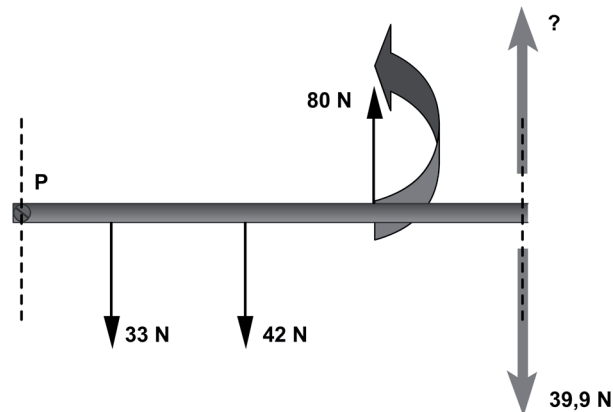
Observation

This beam has no pivots and it is light so, even though the forces are not symmetrically placed, the beam will move under the combined effect of the upward and downward forces.

When the forces on a body are in equilibrium, $\sum_{x=1}^n F_x = 0$, in other words, the resultant of (or vector sum of) all the forces acting must be zero. If the total upward forces are 80 N and the downward forces are 75 N, we must **add a 5 N downward force to bring the forces into equilibrium.**



Activity 2



Understanding the problem

- By stipulating that the “metre rule is light” means that we can ignore the effect of its weight and the turning effect of that force.
- We must now look at the torques (or moments or turning effects) of the forces acting on the beam.
- When a beam is in equilibrium (with respect to rotation) it means that the combined torque of all of the forces is zero.
- This means that when a body is in equilibrium, the sum of the anticlockwise torques or moments (positive) is equal to the sum of the clockwise torques or moments (negative). This is called the Law of Moments.

Solution

$$\text{Anticlockwise moments} = 80 \text{ N} \times 0,75 \text{ m} = 60 \text{ Nm}$$

$$\begin{aligned} \text{Clockwise moments} &= (33 \text{ N} \times 0,10 \text{ m}) + (42 \times 0,40) = 3,3 + 16,8 \\ &= 20,1 \text{ Nm} \end{aligned}$$

Because the anticlockwise moment is greater than the sum of the clockwise moments (60 Nm against 20,1 Nm) the body will turn until a suitable force is applied that brings the body into equilibrium.

The force must be applied at the 100 cm or 1 m mark.

$$\text{Additional torque required} = (60 - 20,1) \text{ Nm}$$

$$= \mathbf{39,1 \text{ Nm of clockwise torque required.}}$$

$$\therefore \text{ add force as shown} \quad \mathbf{F = (39,9 \text{ Nm})} \div 1 \text{ m}$$

$$= \mathbf{39,9 \text{ N acting at 1 m in a downwards direction}}$$

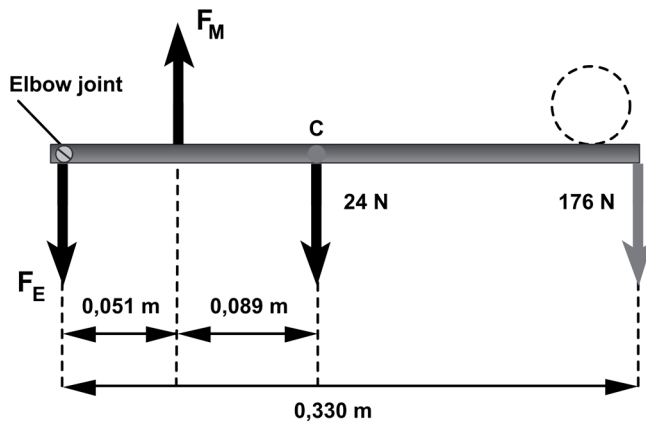
Activity 3 (National Department exemplar examination, June 2007)

Part 6.1

A torque is the turning effect of a force.



Part 6.2



Observation

- One might think that the weight of the forearm (24 N) should be acting halfway along the arm – at about 0,165 m from the elbow. But you must remember that the mass of the forearm is not evenly distributed. The arm muscle is thicker towards the elbow and the bone mass is also greater at that end.
- The force downwards at the elbow may come as a surprise. But try to imagine what the force in the bone of the upper arm is doing. It must be applying a downwards force to give the arm stability.
- If we look at the moments or torques around the elbow, the downward force F_E will not provide any turning effect because the line of action of the force is through the elbow joint. Hence the perpendicular distance to the pivot/fulcrum (i.e. the elbow joint) is 0 m.
- The attachment of the biceps muscle (the word “biceps” is the singular) to the radius bone of the forearm provides the effort when lifting masses in the hand. The effort is between the elbow (fulcrum) and the hand (load), making the forearm a third-class lever.
- A third-class lever is the least efficient sort because it has a mechanical advantage that is always less than one. (See the next activity.)

A project activity

Try to design a more efficient arm by taking into account the type of lever and where the effort and load are on the forearm.

Part 6.3

The forearm is held stationary so the forces are in equilibrium. The force equation is written assuming that **upwards is positive**:

$$\begin{aligned}
 \text{Resultant force} &= \mathbf{F_R = 0\ N\ (because\ in\ \equiv\ ium)} \\
 &= \Sigma F \\
 &= F_E + 24\ \text{N} + 176\ \text{N} - F_M = 0 \\
 \therefore F_E &= F_M - 200\ \text{N}
 \end{aligned}$$

$$\text{Anticlockwise moments} = \text{Clockwise moments}$$

$$\begin{aligned}
 F_M \times (0,051) &= [24\ \text{N} \times (0,051 + 0,089)] + [176\ \text{N} \times (0,330)] \\
 &= 3,36 + 58,08 \\
 &= 61,44\ \text{Nm}
 \end{aligned}$$



$$\therefore F_M = 1204,7 \text{ N (upwards)}$$

$$\therefore F_E = 1004,7 \text{ N (downwards)}$$

Part 6.4

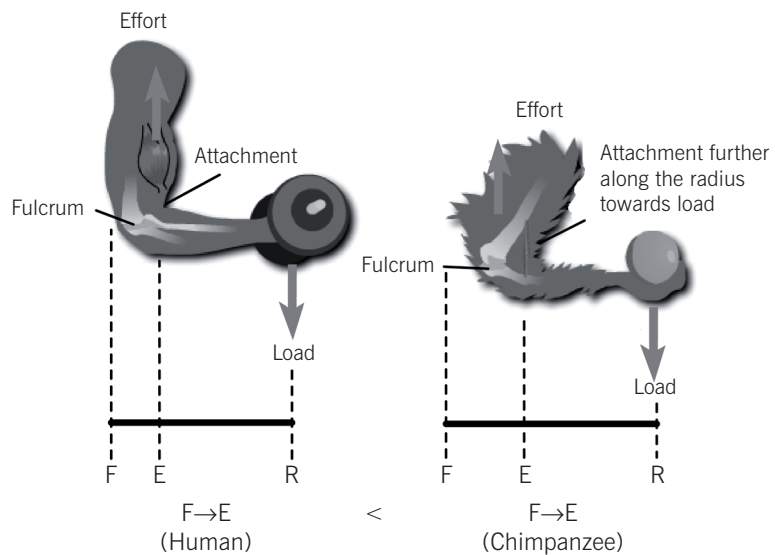
The forearm does not rotate so the clockwise and anticlockwise torques are equal in size and are in equilibrium. Consider the torques around point **C**, the centre of gravity of the forearm. F_M and the force of the mass on the hand both produce a clockwise torques or turning effects. The only way that the forearm can remain in rotational equilibrium is if the force at the elbow produces an anticlockwise torque. Therefore the force at the elbow must be downwards.

Activity 4

Understanding the problem

Notice the difference in the position of the biceps attachment to the radius.

It is assumed that the forearms of human and chimp have equal mass and length.



$$\text{Resultant force} = F_R = 0 \text{ N (because in } \equiv \text{ ium)}$$

$$= \Sigma F$$

$$= F_E + 24 \text{ N} + 176 \text{ N} - F_M = 0$$

$$\therefore F_E = F_M - 200 \text{ N}$$

$$\text{Anticlockwise moments} = \text{Clockwise moments}$$

$$F_M \times (0,089) = [24 \text{ N} \times (0,089 + 0,051)] + [176 \text{ N} \times (0,330)]$$

$$= 3,36 + 58,08$$

$$= 61,44 \text{ Nm}$$

$$\therefore F_M = 690,3 \text{ N (upwards)}$$

$$\therefore F_E = 490,3 \text{ N (downwards)}$$

Because of the superior mechanical advantage in the chimpanzee's arm, a far smaller force needs to be exerted by its biceps muscle.



Observation

	Human	Chimpanzee
Effort arm	0,051	0,089
Load arm	0,330	0,330
Mechanical advantage (MA)	0,15	0,27

With a biceps that contains about one third of the muscle mass of a human's, a chimpanzee can exert almost double the force. This is because of the better positioning of the biceptal attachment in the chimpanzee's forearm.

Lessons 6 and 7

Activity 1

ANSWER 1.1

Term	Symbol	Description	Definition	Measure in units of
Displacement	x, y	The distance a particle in the medium moves away from the equilibrium position	See description	metres (m)
Amplitude	A	The distance from its equilibrium position to the furthest point a particle in the medium can reach when a wave passes through it	The maximum disturbance in the medium during one wave cycle	metres (m)
Crest	-	The maximum height of a transverse wave	-	-
Trough	-	The maximum depth of a transverse wave	-	-
Equilibrium	-	The rest position of a particle in a medium when there is no disturbance in it	The position of zero displacement	-
Period	T	The time taken to complete one cycle	See description	seconds (s)
Frequency	f	The number of cycles completed in one second	See description	Hertz (Hz) (s^{-1})
Wavelength	l	The distance a wave has travelled when a particle in the medium returns to the position it was at when the wave disturbance began	The length a wave travels in one cycle	metres (m)

ANSWER 1.2

- a) If it takes two seconds to complete one cycle then in one second only one half of a cycle is completed.

Similarly, if it takes three seconds to complete one full wave/cycle then one-third of a cycle is completed in one second.

And if one cycle takes half a second, clearly two cycles are completed in one second.



In these examples, we see that there is a reciprocal relationship between period (T) and frequency (f).

b)

$T_A = 1 \text{ s}$	$T_B = 2 \text{ s}$	$T_C = 4 \text{ s}$
$f_A = 1 \text{ Hz or } 1 \text{ s}^{-1}$	$f_B = 0,5 \text{ Hz or } 0,5 \text{ s}^{-1}$	$f_C = 0,25 \text{ Hz or } 0,25 \text{ s}^{-1}$

Activity 2

ANSWER 2.1

Assume $c = 338,5 \text{ m}\cdot\text{s}^{-1}$ (two-fifths of the interval between c for 10 and 15°C.)

$$l = 0,3385 \text{ m}$$

ANSWER 2.2

$$l = 0,567 \text{ m}$$

ANSWER 2.3

$$v = l \times f$$

Does this mean, therefore, that $v \propto f$? Looking at the equation, one might agree that it is so and that doubling frequency will double the speed of sound. But remember that for a given set of conditions the speed of sound is constant and l and f are the variables. So the statement is not true.

ANSWER 2.4

$$l = 1,34 \text{ m}$$

Find a piano, hit Middle C and try to identify the string that has been struck to make this sound. Compare the length of the string in the piano with the wavelength of Middle C. Now the question arises: if the wavelength is related to the length of the string – which is fixed – then must the piano be retuned to give the same note of Middle C when the temperature rises?

ANSWER 2.5

$$l = 1,665 \text{ cm (0,01665 m)}$$

ANSWER 2.6

$$\text{Elephants: } l = 34,5 \text{ m}$$

$$\text{Dogs: } l = 7,67 \text{ mm}$$

$$\text{Cats: } l = 5,75 \text{ mm}$$

The wavelength of the low sounds that elephants can hear must have something to do with the size of their ears and especially the length of the canals in their inner ears. On the other hand, dogs and cats must have very tiny mechanisms in their ears to detect such high-frequency (and low-wavelength) sounds. One needs to discuss this hearing ability from the point of view of evolution too. Speak to your Life Sciences teacher (again)!

ANSWER 2.7

- b) Remember that the speed of sound in nitrogen will be constant and the wavelength of a sound does not affect the speed.

Assessment

In common with most concepts in physics, a learner's understanding can be tested by holding a conversation about the concept. If a learner can explain, with confidence, the difference between transverse and longitudinal waves, where they



can occur, the passage of sound through the air and how sound can be detected by the ear (and the physical reasons for its detection), then the chances are that the learner understands the concepts.

But, as the old Aesop's fable goes, who will bell the cat? Where is the time to hold probing discussions with large classes of learners? The answer – or part of it – may lie in organising colleagues to mind a class while doing some practical work and then holding small group discussions for assessment purposes. The system of sampling, i.e. taking a few learners per topic, is also useful but the method is obviously better for teacher assessment (testing one's own teaching to investigate general levels of understanding) than learner assessment.

Pen and paper tests and other conventional and routine forms of assessment can provide a certain amount of useful information. In physical science, however, where good understanding of a concept correlates to an ability to discuss it and its applications, holding a simple conversation to probe understanding is a technique worth trying.

Lesson 8

Position of object	Orientation of object	Position of image	Compared to object	Orientation of image	Magnification (<1; =1; or >1)
<i>Beyond 2F</i>	<i>Upright</i>	<i>Between F' and 2F'</i>	<i>On opposite side of lens</i>	<i>Inverted</i>	<i><1</i>
<i>At 2F</i>	<i>Upright</i>	<i>At 2F'</i>	<i>On opposite side of lens</i>	<i>inverted</i>	<i>=1</i>
<i>Between 2F and F</i>	<i>Upright</i>	<i>Beyond 2F'</i>	<i>On opposite side of lens</i>	<i>inverted</i>	<i>>1</i>
<i>At F</i>	<i>Upright</i>	<i>No image</i>	<i>On opposite side of lens</i>	<i>inverted</i>	<i>–</i>
<i>Between F and lens</i>	<i>Upright</i>	<i>Between F and 2F</i>	<i>On same side of lens</i>	<i>upright</i>	<i>>1</i>

ANSWER 1

- When the rays of light intersect (cross one another) on the far side of the lens, it means that all the rays from one point on the object are converging at one point on the other side of the lens.
- If we place a screen at that point on the far side of the lens, an image of the object is projected there.
- This is how images are formed and there must be a source of light energy at some point for a real image to be projected beyond the lens.
- Also, all the light energy being reflected off a point on the image and then passing through the lens must be focused on a single point to get a clear image.
- If the light rays DO NOT meet (or focus or intersect) at a point, there is no image.

ANSWER 2

To answer this question you need to compare the triangles formed by the two rays from the tip of the object both before they enter and after they leave the lens. Also look at the line through the middle of the lens, starting from the optical centre. Work with congruent triangles which have the following aspects in common and



equal: three sides [s,s,s]; two angles and one side [a,a,s]; two sides and the included angle [s,a,s]; and a right angle, one side and the hypotenuse [r,h,s].

ANSWER 3

In this case, we have what is called a **virtual image** because the image is where the light appears to come from. This means that there is no light actually coming from where the image appears to be, hence its being called a virtual image. A virtual image cannot be projected on to a screen, only real images can be.

ASSESSMENT

Look at the answer to Question 1 again and work out a method to find where the focal point of a simple thin lens will be (and hence the value of the focal length).

A clue is to look at an object through the lens and to move the lens until the values of u and v are such that we have the conditions that apply in Question 2.

Lesson 8a

Activity 1

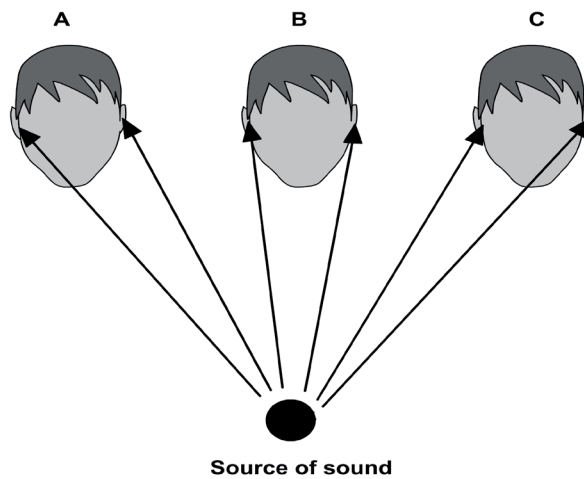
LONGITUDINAL	TRANSVERSE
Sound waves	Light waves and ocean waves
Shockwaves in the ground or water due to earthquakes or explosions as in seismic exploration	At the Earth's surface the ground will carry surface waves. On the ocean's surface we get transverse waves which might be very large tidal waves or tsunamis.
A centipedes legs (songololo)	
The foot of a snail seen from beneath	

Activity 2

Why we have two ears?

Not only do two ears allow us to hear the sounds, they also give important spatial information about the direction of the sounds, like a well set up stereo system. Whereas B in the diagram hears the sound with both ears at the same time, A's left ear will hear the sound slightly before his right ear and **vice versa** for C. This slight difference in the time taken for the sound to reach the two ears of A and C can be translated by the brain into a sense of where (the direction from which) the sound emanated.





What examples do we have from the animal kingdom?

Many animals that rely on their ears for protection or the detection of prey have large pinnae (the outer part of the ear that picks up sound). The ears of many animals such as antelope, dogs and rhinoceros – can move independently in order to detect the direction of a source of sound very accurately.

Activity 3

The answers to the questions posed (e.g. “where we find a lever operating?” “where are longitudinal waves in the air are transformed into vibrations in a solid body” etc.) can be found in the notes given.

Activity 4

Condition A is hyperopia.

Condition B is myopia

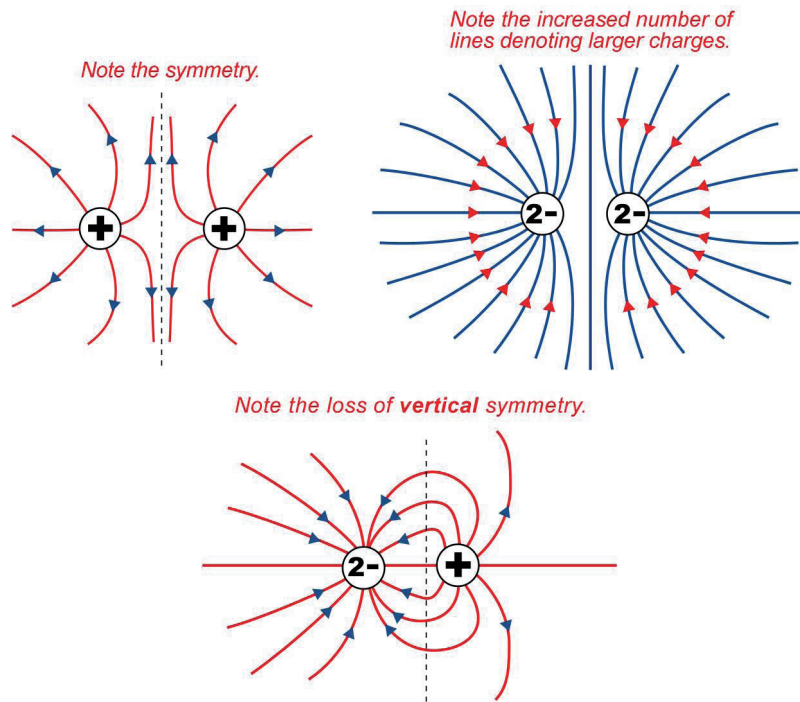
Activity 5

Normally any light passing close to the sun would be obscured by the Sun’s corona – or flaming outer surfaces. The light of a star is not noticeable against the Sun’s brightness. During an eclipse the Sun’s corona is blocked by the moon which is positioned between Earth and the Sun. Any light passing near to the Sun is now visible. The star whose light might be expected to travel in a straight line past the Sun is actually bent so that it curves around the Sun very close to it because of the Sun’s very strong gravitational field.



Lessons 9–10

Refer to task on electric fields on page 75.



- | | | | | | |
|-----------|--|-----------|---|-----------|---|
| 1 | b | 2 | c | 3 | a |
| 4 | b | 5 | a | 6 | c |
| 7 | d | 8 | d | 9 | d |
| 10 | c | 11 | a | 12 | a |
| 13 | horizontal 0 N
vertical 0,0125 N | | | | |
| 14 | a) $3 \times 10^5 \text{ Vm}^{-1}$ (or $\text{N}\cdot\text{C}^{-1}$) towards the $-4 \mu\text{C}$ charge
b) 1,2 N | | | | |
| 15 | a) 10^4 Vm^{-1}
b) $1,2 \times 10^7 \text{ m}\cdot\text{s}^{-1}$ | | | | |
| 16 | a) 40 A
b) $6,67 \times 10^3 \text{ Vm}^{-1}$
c) $2 \times 10^7 \text{ J}$ | | | | |
| 17 | a) $7,2 \times 10^{-6} \text{ N}$ towards X
b) i) $900 \text{ N}\cdot\text{C}^{-1}$ towards Y
b) ii) Charge at Y | | | | |
| 18 | 6,67 pF | | | | |
| 19 | a) $3,0 \times 10^{-3} \text{ C}$
b) $2,5 \times 10^2 \text{ V}$ | | | | |



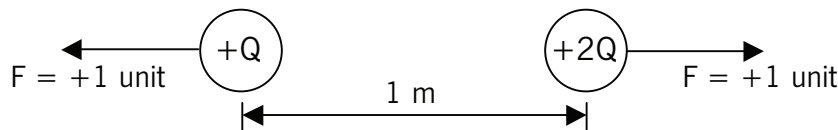
Lesson 10a

Activity 1

Coulomb's Law of electrostatic attraction and Newton's Law of universal gravitation are both inverse square laws. Mathematically they are similar as the two equations are of the same form.

The two laws differ mainly because of the size of the constants G ($6,67 \times 10^{-11}$) and k (9×10^9). The vastly different size of the constants suggests that the electrostatic force ($\dots \times 10^9$) is much stronger than the gravitational force ($\dots \times 10^{-11}$), a fact that is borne out by the table that shows the relative strength of the four, known forces of nature.

Activity 2



Observation

The "+1" refers to the fact that the forces are repulsive because like charges repel. This is why we get the positive value ($+1 \times +1 = +1$; and $-1 \times -1 = +1$). Normally the equation for Coulomb's Law is written $F_e = -k \dots$ so that repulsive forces come out as negative, which seems to be more appropriate (i.e. $-F$ is repulsive and $+F$ is attractive). In the above example where we are told that $F = +1$ unit, this provides us with a point of reference related to the direction of the force on each charge taken separately. **Be careful not to associate the "+" sign as indicating an overall direction convention!**

The new force between A and B in each of the following:

- 1 unit.
- $+\frac{1}{4}$ unit
- Charges now $\frac{3}{2}Q$ each. $F = +2,25$ units
- Charges now $\frac{1}{2}Q$ each $Q_1 \cdot Q_2 = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$
Separated to 0,5 m apart $\frac{1}{r^2} = \frac{1}{(\frac{1}{2})^2} = 4$.
Force remains the same ($+\frac{1}{4} \times 4 = +1$)

Activity 3

- $\frac{F_g}{F_e} = \frac{GM^2}{kQ^2} = \frac{5}{108} \times 10^{-2}$
- $F_R = F_g = F_e$
 $0,5760 - 0,0003 = 0,5757$ N repulsion
- Assuming that the two bodies are spheres, if the centres of the two bodies are 500 cm apart it means that each of the spheres can have a radius of maximum 250 cm. (Measure this and picture a sphere of this size.) For a sphere of this size to have a mass of 1 tonne (or 1 000 kg), the material would have to be very dense indeed. In fact if the spheres just made contact the density of the material would be $16\,000 \text{ kg}\cdot\text{m}^{-3}$.

Would there be a problem with the electrostatics part of the experiment if the two spheres were in contact?



There are several materials that are denser than $16\,000\text{ kg}\cdot\text{m}^{-3}$ and from which one could make spheres with a mass of 1 tonne but with a diameter of less than 500 cm. They would be rather expensive, however.

Gold (Au) has a density of $19\,300\text{ kg}\cdot\text{m}^{-3}$

Platinum (Pt) $21\,400$

Uranium (U) $18\,700$

To find out just how expensive, why don't you look for the reigning metal prices in the newspaper or on the internet and calculate the cost of 2 tonnes of the metal?(Are there any non-metals with a high enough density? Can you think of a reason for your answer?)

Interestingly enough, some of the metals that we might expect to be dense enough, like mercury (Hg, $13\,600\text{ kg}\cdot\text{m}^{-3}$) and lead (Pb, $11\,300\text{ kg}\cdot\text{m}^{-3}$), would not be suitable.

What other metals would be dense enough for the experiment?

Activity 4

a) $C = \frac{Q}{V}$

$$Q = C \times V$$

$$Q = 12 \times 10^{-12} \times 24$$

$$Q = 2,88 \times 10^{-10} \text{ coulombs}$$

b) The charge on **each** capacitor is $Q = 2,88 \times 10^{-10} \text{ C}$.

So the combined charge on the two capacitors connected in parallel is $2Q$.

$$\begin{aligned} \text{Total capacitance } C_{\text{Total}} &= 2 \times \frac{Q}{V} \quad (V \text{ is the p.d. across } C_1 \text{ and } C_2) \\ &= \frac{Q}{V} + \frac{Q}{V} \\ &= \frac{Q_1}{V} + \frac{Q_2}{V} \\ &= C_1 + C_2 \end{aligned}$$

c) When capacitors are connected in parallel as in the problem we find their total capacitance by adding their capacitances, like resistors in series:

$$R_{\text{Series}} = R_1 + R_2$$

Can you show that when capacitors are connected in series the total capacitance is calculated similarly to resistors in parallel? In other words ...

$$\frac{1}{R_{\text{Total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$

Lessons 11–12

TASK 1

See Faraday's Law in the text of the lesson.

Induced emf

$$\begin{aligned} \Delta\Phi &= \Delta BA \\ &= (0 - 0,2)(0,1) \\ &= -0,02 \text{ T}\cdot\text{m}^2 \end{aligned}$$

$$\begin{aligned} \mathcal{E} &= -N \frac{\Delta\Phi}{\Delta t} \\ &= -(1)(-0,02)/10^{-4} \\ &= 200 \text{ V} \end{aligned}$$



Current in the loop (See Lessons 13 & 14)

$$\begin{aligned} I &= \frac{V}{R} \\ &= 200/10 \\ &= 20 \text{ A} \end{aligned}$$

TASKS 2–4

These are research topics. A good place to start on any research topics these days is Wikipedia, a free online encyclopedia. Once on Wikipedia (<http://en.wikipedia.org/wiki/>), one then does a search for specific topics by typing the topic into the search box, e.g. “Nikola Tesla”, “Earth’s magnetic field”, “electric motor” or “television”. These topics can also be used for Google searches (Google is the best search engine around) but the first site Google suggests is usually Wikipedia!

TASKS 5

- 5.1 The south pole is moved away from the loop.
- 5.2 The north pole is moved away from the loop.
- 5.3 The south pole is moved towards the loop.
- 5.4 Is there any pattern or symmetry to these interactions?

YES: One opposite (i.e. a change from **N to S** or from **towards to away**) changes the current direction.

Two opposites (i.e. a change from **N to S and** from **towards to away**) keeps the current direction the same.

Lesson 12a

Activity 1

As the electric field builds up (gets stronger) ...
... the potential difference in the loop of conducting wire increases ...
... so the current (flow of charged particles) builds up ...
... and as the flow of charge builds up in the loops of wire ...
... so a magnetic field builds up inside the loop of wire ...
... which magnetises the soft iron core around the loops of wire are wound ...
... and the magnetic field builds up all through the soft iron core ...
... including inside another coil of wire (the secondary coil) ...
... on the opposite side of the soft iron core ...
... the strengthening magnetic field inside the coil ...
... induces a potential difference across its ends ...
... and this results in an electrical current in the secondary coil.

The following relationships are important:

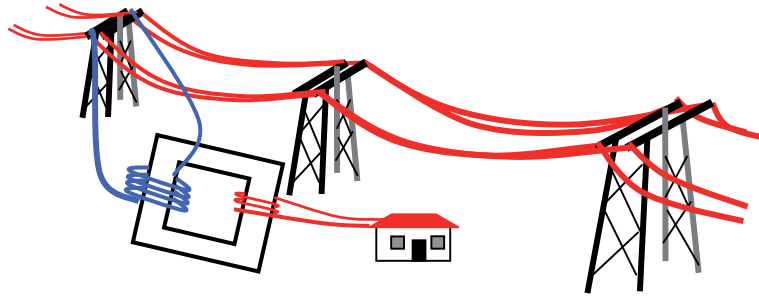
- 1) $V_s = \frac{N_s}{N_p} V_p$ where $\frac{N_s}{N_p}$ is called the **turns ratio** of the transformer.
- 2) In a **perfectly efficient transformer**
ALL the energy IN at the primary side in one second will be converted into the SAME AMOUNT of energy OUT in one second on the secondary side.



3) Electrical power (**P**) = potential difference \times current = **V \times I**

Activity 2

a)



$$b) \frac{V_s}{V_p} = \frac{N_s}{N_p} \therefore \frac{N_p}{N_s} = \frac{11\,000}{220} = 50:1$$

$$c) \frac{N_s}{N_p} = \frac{N_s}{2\,000} = \frac{1}{50}$$

$$\therefore N_s = \frac{2\,000}{50} = 40 \text{ turns (a step-down transformer)}$$

Activity 3

Understanding the problem

The houses in a suburb represent the secondary circuit so a current of 50 A drawn by the houses is I_s . We need to calculate I_p or the current in the primary circuit.

$$V_p I_p = V_s I_s$$

$$I_p = \frac{V_s}{V_p} \times I_s = \frac{220 \times 50}{11\,000} = 1 \text{ A}$$

Activity 4

In the USA the domestic supply is 120 V. A small transformer can be used there to transform the 120 V domestic AC supply to 9V AC for a portable radio. If the secondary coil contains 30 turns and the radio draws a 400 mA current, calculate:

$$a) \frac{N_p}{N_s} = \frac{V_p}{V_s}$$

$$\therefore N_p = \frac{N_s V_p}{V_s} = \frac{30 \times 120}{9} = 400 \text{ turns}$$

$$b) V_p I_p = V_s I_s$$

$$I_p = \frac{V_s}{V_p} \times I_s = \frac{9 \times 400 \times 10^{-3}}{120} = 0,03 \text{ A}$$

$$c) P_s = V_s I_s = 9 \text{ V} \times 0,4 \text{ A}$$

$$= 3,6 \text{ W}$$

Observation

This will be the answer IF the transformer is 100% efficient, i.e. if all of the energy that is present in the primary circuit appears in the secondary circuit without any energy being lost as heat energy. In actual fact, this never happens. But transformer technology is so advanced that transformers are now being built that have >99% efficiency. For our purposes this can be considered “totally efficient”.



Lessons 13–14

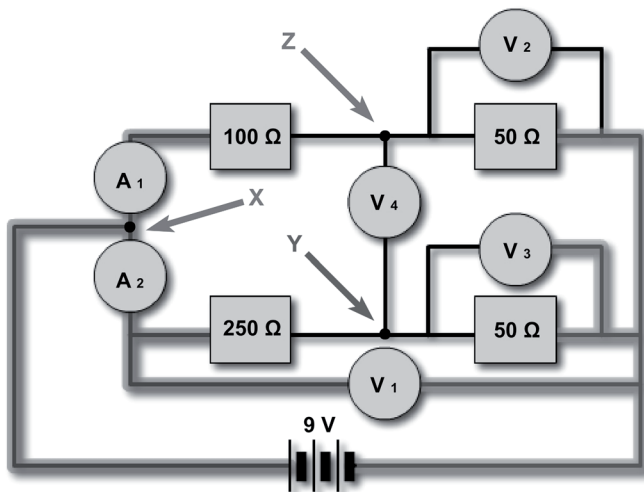
TASKS 1 & 2

Research task. Use <http://en.wikipedia.org/wiki/>.

TASK 3

- a) 8Ω
- b) 3 A
- c) 12 V
- d) 1 A

TASK 4



- a) **The effective value of the resistors**
 Start at the positive terminal of the battery and find the branch point between the two ammeters. Ignore the connection to the voltmeter V_4 . Look for the junction point. You will see that there are two resistors in series ($100 \Omega + 50 \Omega$). These two (total 150Ω) are in parallel with the other two resistors in series with one another ($250 \Omega + 50 \Omega$). Therefore the effective resistance of the circuit can be calculated for a 150Ω resistor in parallel with a 300Ω resistor, i.e. **100Ω** .
- b) **Readings on A_1 and A_2**
 To find the ammeter readings, one must first calculate the total current in the circuit. The emf of the battery (no internal resistance) is 9V and the total resistance is 100Ω . Therefore the total current is **$I = 0,09 \text{ A}$** .
 The current in A_1 (i.e. in the 150Ω arm of the parallel arrangement) will be double that in A_2 , i.e. in the 300Ω arm. Because the potential drop across the 150Ω arm will be the same as across the 300Ω arm, the reading on A_1 will be twice that on A_2 , i.e. **$0,06 \text{ A}$** and **$0,03 \text{ A}$** respectively.
 NOTE that the readings on A_1 and A_2 add up to $0,9 \text{ A}$.
- c) **Readings on ...**
- (i) **V_1**
*The terminals of the battery are connected across the parallel arrangement and because we assume that there are no potential drops in the conductors (they are assumed to be perfect conductors) we can trace all the points of similar potential from the positive terminal to one of the voltmeter connections. We can say that all the points shaded in red on the diagram are at **$+9$***



V potential. Similarly all the points at the same potential as the negative terminal of the battery are at 0 V potential.
It is clear that voltmeter V_1 will read $(9-0)\text{V} = 9\text{ V}$.

(ii) $V_2 = 0,06\text{ A} \times 50\ \Omega = 3\text{ V}$

[Confirm this result by making sure that the potential drop across the $100\ \Omega$ plus the pd across the $50\ \Omega$ add up to 9 V , because the terminals of the battery are connected across the parallel arrangement.]

(iii) $V_3 = 0,03\text{ A} \times 50\ \Omega = 1,5\text{ V}$

(iv) V_4

The potential at point Z will be (potential at point X – potential drop across $100\ \Omega$) or $[9\text{ V} - (0,06 \times 100)] = 9\text{ V} - 6\text{ V} = 3\text{ V}$.

We can write that $V_z = 3\text{ V}$.

Similarly, the potential at point Y is:

$[9\text{ V} - (0,03 \times 250)] = 9\text{ V} - 7,5\text{ V} = 1,5\text{ V}$.

We can write that $V_y = 1,5\text{ V}$.

The potential difference $V_{zy} = V_z - V_y = (3 - 1,5)\text{ V} = 1,5\text{ V}$.

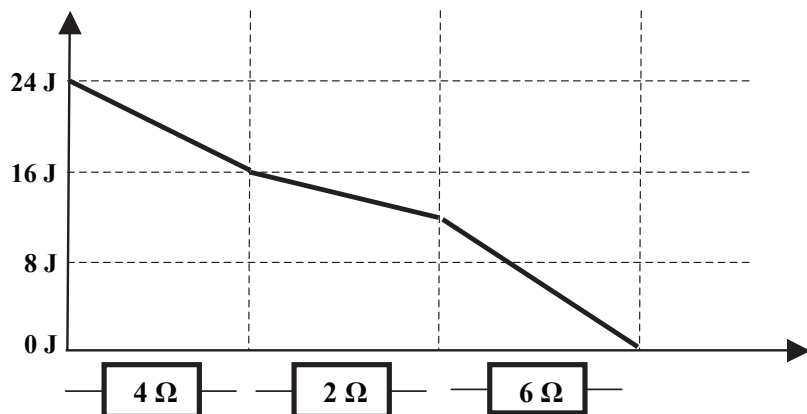
Therefore the reading on V_4 , which is connected from Z to Y, is $V_4 = 1,5\text{ V}$.

Lessons 14a and 14b

Activity 1

- a) $12\ \Omega$
 b) 2 A
 c) $8\text{ V}, 4\text{ V}, 12\text{ V}$
 d) i. 24 J
 ii. $8\text{ J}, 4\text{ J}, 12\text{ J}$
 iii. 24 J

e)



Activity 2

Bulb A

Activity 3

- a) $A_1 = 0,067\text{ A}$
 $A_2 = 0,033\text{ A}$



$$\begin{aligned} V_1 &= 10 \text{ V} \\ V_2 &= 3,33 \text{ V} \\ V_3 &= 1,67 \text{ V} \\ V_4 &= 1,67 \text{ V} \end{aligned}$$

- b) Different currents in the two 50Ω resistors.
 c) Yes, because there is a $1,67 \text{ V}$ pd between the two points.

Activity 4

$$\begin{aligned} A_1 &= 3 \text{ A} \\ A_2 &= 1 \text{ A} \\ V &= 12 \text{ V} \end{aligned}$$

Activity 5

Resistance of parallel resistors (6Ω and 2Ω): **$1,5 \Omega$**

Reading on V_1 when S_1 is open: **12 V**

Change in the reading on V_1 when S_1 is closed: **reading will be less than 12 V**

Reading on V_1 be when S_1 is closed: **$11,25 \text{ V}$**

Value of the internal resistance of the battery: **$0,5 \Omega$**

Reading on ammeter when $R(?)$ adjusted: **$1,2 \text{ A}$**

Lessons 15 and 16

- Metals:** Li, Be, Na, Mg, Al, K, Ca; **non-metal solids:** B, C, Si, P, S; **gases:** H, He, N, O, F, Ne, Cl, Ar.
- ^{16}O , ^{15}O , ^{17}O .
- ^{226}Ra ($Z=88$) \rightarrow ^{222}Rn ($Z=86$) + ^4He ($Z=2$).
- 4.1. ^{90}Sr ($Z=38$) \rightarrow ^{90}Y ($Z=39$) + $^0_{-1}\text{e}$ ($Z=-1$).
 4.2. $3,3 \times 10^8$ decays per second.
-

ELEMENT	HALF-LIFE
Thorium-232	14×10^9 years
Uranium-238	$4,51 \times 10^9$ years
Potassium-40	1×10^9 years
Uranium-235	7×10^8 years
Uranium-236	$2,39 \times 10^7$ years
Iodine-129	$15,7 \times 10^6$ years
Thorium-234	24,1 days
Thorium-227	19 days
Radon-223	11 days
Bismuth-210	5 days
Radon-222	3,82 days
Thorium-231	1 day

- 6.1. $\frac{3}{4}$



$$6.2. \frac{1}{32}$$

7. It changes the $^{14}\text{C}/^{12}\text{C}$ ratio in the atmosphere.



9. 151 pm and 150 pm.

10. Measured bond lengths are 143 pm and 147 pm respectively. The contraction is caused by the electronegativity difference of 1,0 for C–O and 0,5 for C–N.

11. In H–I bond the hydrogen is small but highly positive for its size. Hence a stronger attraction to the iodine than the carbon atom.

12. K·F.

13. H_2O : the H–O electronegativity difference is 1,4 whereas for H–S it is 0,4.

14. The molecule is linear and there is as much pull on electrons towards the one oxygen atom as to the other. Hence no net separation of charge: $\text{O}=\text{C}=\text{O}$.

Lessons 17 and 18

Activity 1

As the number of bonding pairs increases so the bond length decreases (atoms are held together more tightly and hence closer together). Similarly, as the number of bonds increases, so does the bond energy. The energy of a bond indicates how much energy will be required (or how much work must be done) to break the bond.

Activity 2

- H_2 (a) H: +1 O: –2
(b) water (or hydrogen oxide)
- SO_3 (a) S: +6 O: –2
(b) sulphur (VI) oxide (or sulphur trioxide)
- KMnO_4 (a) K: +1 Mn: +7 O: –2
(b) potassium permanganate
- $(\text{NH}_4)_2\text{SO}_4$ (a) N: –3 H: +1 S: +6 O: –2
(b) ammonium sulphate
- $\text{Li}_2\text{Cr}_2\text{O}_7$ (a) Li: +1 Cr: +6 O: –2
(b) lithium dichromate
- FeCl_2 (a) Fe: +2 Cl: –1
(b) iron (II) chloride or ferrous chloride
NOTE: the lower oxidation state is -ous
- FeCl_3 (a) Fe: +3 Cl: –1
(b) iron (III) chloride or ferric chloride
NOTE: the higher oxidation state is -ic
- NO_2 (a) N: +4 O: –2
(b) nitrogen (IV) oxide or nitric oxide
NOTE: the higher oxidation state is -ic



- NO (a) N: +2 O: -2
(b) nitrogen (II) oxide or nitrous oxide
NOTE: the lower oxidation state is -ous

Activity 3

- 3.1 Ammonia is a tetrahedral molecule with three N-H bonds and a lone pair of electrons on the fourth arm of the tetrahedron. A hydrogen ion (no electrons) can form a dative covalent bond with the lone pair hence the ammonium ion is also tetrahedral.
- 3.2 Boron has three valence electrons and shares with each of three fluorine atoms. There are three pairs and hence the molecule is planar, i.e. trigonal planar.
- 3.3 Six pairs of electrons, hence octahedral.
- 3.4 Methane is a simple tetrahedron – a perfectly symmetrical molecule. When carbon atoms join in long chains, each carbon atom will have bonds arranged around it in a tetrahedral shape, provided they are all single bonds.

Lesson 17a

Activity 1

- a) *What are the atomic numbers of carbon, hydrogen, nitrogen and sulphur?*

12, 1, 7 and 16

- b) *What is the atomic number of the uranium-235 isotope?*

92

- c) *How do the uranium-235 and the uranium-238 isotopes differ?*

The first isotope has 143 neutrons in the nucleus (235 – 92) and the other has 146 (238 – 92).

- d) *If the relative atomic mass of carbon is 12,011 u, what is the most common isotope of carbon?*

¹²C

- e) *When a ²³⁵U isotope is bombarded with a neutron, the latter can embed itself in the nucleus of the larger atom and produce the ²³⁶U isotope. This isotope is unstable and breaks up into ⁹²Kr and ¹⁴¹Ba and how many neutrons?*

3 neutrons

A: $235 + 1 = 236$; $236 = 92 + 141 + 3$ neutrons

- f) Which of the following molecules will be polar covalent, ionic and non-polar covalent, and why? Na₂O, H₂S, Cl₂ and HBr.

We can use the following rule of thumb:

electronegativity differences ($\geq 1,7$) are usually considered to be ionic;

values between 1,7 and 0,4 are considered polar covalent;

values $< 0,4$ are considered non-polar covalent;

a difference of 0 indicates a completely non-polar covalent bond.

Na₂O (3,5 – 0,9 = 2,6) ionic

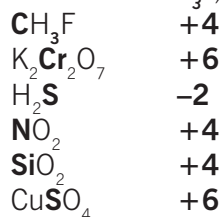
H₂S (2,5 – 2,1 = 0,4) non-polar (or, at most, VERY weakly polar)

Cl₂ (3,0 – 3,0 = 0,0) completely non-polar

HBr (2,8 – 2,1 = 0,7) polar



g) Calculate the oxidation number of each atom in bold print in the following molecules: CH_3F ; $\text{K}_2\text{Cr}_2\text{O}_7$; H_2S ; NO_2 ; SiO_2 ; CuSO_4 .

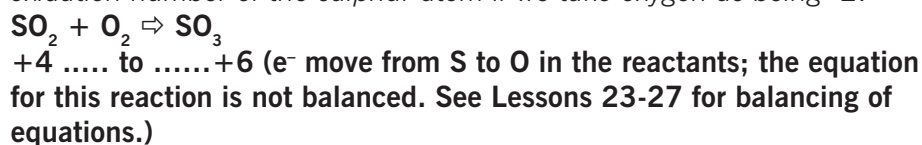


h) In a reaction the oxidation number of manganese (Mn) changes from +7 to +2. What does this signify?



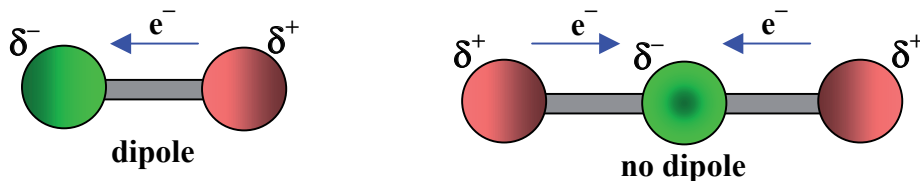
Signifies a loss of 5 electrons by the manganese in the permanganate ion to become an Mn^{2+} ion.

i) In the reaction of sulphur dioxide with oxygen, what is the change in oxidation number of the sulphur atom if we take oxygen as being -2?



j) Water (H_2O) is well known as a polar solvent. We know this because it easily dissolves ionic salts. This suggests that the water molecule is bonded by polar covalent bonds. Could water be polar if the molecule was linear?

If the molecule was linear, i.e. $\text{H} - \text{O} - \text{H}$, then even if some electrons moved from the hydrogen atoms to the oxygen (due to electronegativity difference) the ends would both be positive. This would not make the molecule polar because for true polarity we need a "dipole" i.e. the separation of positive and negative charge to opposite points in the molecule.



Summary of VSEPR rules

Valence electrons on the central atom	+
Single bonded electrons from attached atoms	+
Electrons from the central atom involved in multiple bonds	-
Electrons donated by central atom to dative covalent bonds	(+)
Charge on molecule – negative ions bring electrons, i.e. +	+/-
Total	=



Activity 2

Molecule (Molecular formula)	Lewis structure	Electron arrangement on central atom (Valence electrons i.e. outer shell)
CH ₄	$ \begin{array}{c} \text{H} \\ \times \\ \cdot \\ \text{H} \times \text{C} \times \text{H} \\ \times \\ \cdot \\ \text{H} \end{array} $	₆ C: 2, <u>4</u>
Atoms attached to the central atom		4 × H
Valence electrons on central atom		4
Valence electrons from attached atoms		4 × 1
Electrons in multiple bonds (Subtract 1 per multiple bond per atom)		0
Electrons in dative covalent bonds (2 e ⁻ per dative covalent bond; donated by central atom.)		0
Ionic charge (Subtract for positive charged ions)		0
<u>TOTAL ELECTRONS</u> 2 to find no. of e ⁻ prs		$\frac{8}{2} = 4$
Therefore the molecular geometry is ...		TETRAHEDRAL

Activity 3

Molecule (Molecular formula)	Lewis structure	Electron arrangement on central atom (Valence electrons i.e. outer shell)
NH ₃	$ \begin{array}{c} \text{H} \\ \times \\ \cdot \\ \text{H} \times \text{N} \times \\ \times \\ \cdot \\ \text{H} \end{array} $	₇ N: 2, <u>5</u>
Atoms attached to the central atom		3 × H
Valence electrons on central atom		5
Valence electrons from attached atoms		3 × 1
Electrons in multiple bonds (Subtract 1 per multiple bond per atom)		0
Electrons in dative covalent bonds (2 e ⁻ per dative covalent bond; donated by central atom.)		0
Ionic charge (Subtract for positive charged ions)		0
<u>TOTAL ELECTRONS</u> 2 to find no. of e ⁻ prs		$\frac{8}{2} = 4$
Therefore the molecular geometry is ...		TETRAHEDRAL

Observation

Although there are only three hydrogen atoms bonded to the nitrogen the remaining pair of electrons – a *lone pair* – is significant and plays a part in the ammonia molecule's geometry. The lone pair will repel the three bonding pairs in the N–H bonds. We know this because the H–N–H angles are less than expected.

Activity 4

Molecule (Molecular formula)	Lewis structure	Electron arrangement on central atom (Valence electrons i.e. outer shell)		
NH_4^+		${}_{7}\text{N}: 2, \underline{5}$		
Atoms attached to the central atom		$4 \times \text{H}$		
Valence electrons on central atom		5	Total number of electrons	
Valence electrons from attached atoms		4×1		
Electrons in multiple bonds (Subtract 1 per multiple bond per atom)		0		8
Electrons in dative covalent bonds (2 e^- per dative covalent bond; donated by central atom.)		2		
Ionic charge (Subtract for positive charged ions)		-1		
TOTAL ELECTRONS to find no. of e^- prs		$\frac{8}{2} = 4$		
Therefore the molecular geometry is ...		TETRAHEDRAL		

Observation

The five valence electrons from the central nitrogen are accounted for by saying “three valence electrons” plus “a lone pair involved in a dative covalent bond.” Even though we know that one of the hydrogen atoms is in fact a hydrogen ion (and therefore brings no electrons to the party at all), this deficiency is accounted for by subtracting one from the total of valence electrons because there is a positive charge on the ammonium ion (hence one electron missing so we add -1 when calculating the total number of electrons).

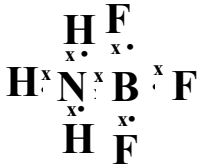
We note that both electrons in a dative covalent bond are provided by the central atom.



Activity 5


Molecule (Molecular formula) $[\text{PF}_6]^-$	Lewis structure $\begin{array}{c} \text{F} \quad \text{F} \\ \times \cdot \quad \times \cdot \\ \text{F} \times \text{P} \times \text{F}^- \\ \times \cdot \quad \times \cdot \\ \text{F} \quad \text{F} \end{array}$	Electron arrangement on central atom (Valence electrons i.e. outer shell) $_{15}\text{P}: 2, \underline{5}$
Atoms attached to the central atom	$6 \times \text{F}$	
Valence electrons on central atom	5	Total number of electrons
Valence electrons from attached atoms	6×1	
Electrons in multiple bonds (Subtract 1 per multiple bond per atom)	0	
Electrons in dative covalent bonds (2 e ⁻ per dative covalent bond; donated by central atom.)	0	
Ionic charge (Subtract for positive charged ions)	+1	
TOTAL ELECTRONS to find no. of e ⁻ prs $\frac{12}{2}$	$\frac{12}{2} = 6$	
Therefore the molecular geometry is ...	OCTAHEDRAL	

Molecule (Molecular formula) BF_3	Lewis structure $\begin{array}{c} \text{F} \\ \times \cdot \\ \text{F} \times \text{B} \\ \times \cdot \\ \text{F} \end{array}$	Electron arrangement on central atom (Valence electrons i.e. outer shell) $_{5}\text{B}: 2, \underline{3}$
Atoms attached to the central atom	$3 \times \text{F}$	
Valence electrons on central atom	3	Total number of electrons
Valence electrons from attached atoms	3×1	
Electrons in multiple bonds (Subtract 1 per multiple bond per atom)	0	
Electrons in dative covalent bonds (2 e ⁻ per dative covalent bond; donated by central atom.)	0	
Ionic charge (Subtract for positive charged ions)	0	
TOTAL ELECTRONS to find no. of e ⁻ prs $\frac{6}{2}$	$\frac{6}{2} = 3$	
Therefore the molecular geometry is ...	TRIGONAL PLANAR	

Molecule (Molecular formula) $\text{H}_3\text{N}-\text{BF}_3$	Lewis structure 	Electron arrangement on central atom (Valence electrons i.e. outer shell) ${}_{7}\text{N}: 2, \underline{5}$
Atoms attached to the central atom	$3 \times \text{H}$ and $1 \times \text{B}$ (none to dative)	
Valence electrons on central atom	5	Total number of electrons
Valence electrons from attached atoms	$(3 \times 1) + 0$	
Electrons in multiple bonds (Subtract 1 per multiple bond per atom)	0	
Electrons in dative covalent bonds (2 e^- per dative covalent bond; donated by central atom.)	2	
Ionic charge (Subtract for positive charged ions)	0	
TOTAL ELECTRONS 2 to find no. of e^- prs	$\frac{8}{2} = 4$	
Therefore the molecular geometry is ...	TETRAHEDRAL (around N)	

Observation

Theoretically we can use either the nitrogen atom or the boron atom as the central atom. But as a rule of thumb, where there is a dative bond involved (this can be seen when we draw the Lewis structure) we will always regard the central atom as being that atom which donates electrons to the dative covalent bond. In this case we take nitrogen as the central atom.

Molecule (Molecular formula) CO_2	Lewis structure 	Electron arrangement on central atom (Valence electrons i.e. outer shell) ${}_{6}\text{C}: 2, \underline{4}$
Atoms attached to the central atom	$2 \times \text{O}$	
Valence electrons on central atom	4 (+4)	Total number of electrons
Valence electrons from attached atoms	$2 \times 2 (+4)$	
Electrons in multiple bonds (Subtract 1 per multiple bond per atom)	$1 \times 2 \times 2 (-4)$	
Electrons in dative covalent bonds (2 e^- per dative covalent bond; donated by central atom.)	0	
Ionic charge (Subtract for positive charged ions)	0	
TOTAL ELECTRONS 2 to find no. of e^- prs	$\frac{4}{2} = 2$	
Therefore the molecular geometry is ...	LINEAR	

Observation

A double bond is made up of two pairs of bonding electrons. One pair gives the bond its direction (this is called the *sigma pair*) and the other pair forms a cloud above and below the *sigma bond*. This second pair makes up what is known as the *pi bond*. Triple bonds have a sigma bond which gives the bond its direction and two pi bonds which give a sausage-like cloud around the sigma bond.

WORKSHEET FOR VSEPR CALCULATIONS

Molecule (Molecular formula)	Lewis structure (Structural formula)	Electron arrangement on central atom (Valence electrons i.e. outer shell)	
Atoms attached to the central atom			
Valence electrons on central atom			Total number of electrons
Valence electrons from attached atoms			
Electrons in multiple bonds (Subtract 1 per multiple bond per atom)			
Electrons in dative covalent bonds (2 e ⁻ per dative covalent bond donated by the central atom.)			
Ionic charge (Subtract for positive charged ions)			
TOTAL ELECTRONS to find number of electron pairs $\frac{\quad}{2}$			
Therefore the molecular geometry* is ...			

*VSEPR geometries: 2 pairs (**LINEAR**);
 3 pairs (**TRIGONAL PLANAR**);
 4 pairs (**TETRAHEDRAL**);
 5 pairs (**TRIGONAL BIPYRAMIDAL**);
 6 pairs (**OCTAHEDRAL**)

Lessons 19 and 20

ISOTOPE	SYMBOL	NEUTRONS [= (A - Z)]	A/Z RATIO	HALF-LIFE
Bismuth-210	$^{210}_{83}\text{Bi}$	127	2,53	5 days
Cadmium-113	$^{113}_{48}\text{Cd}$	65	2,35	14 years
Calcium-40	$^{40}_{20}\text{Ca}$	20	2,00	Very stable
Calcium-42	$^{42}_{20}\text{Ca}$	22	2,05	14 000 years
Cesium-134	$^{134}_{55}\text{Cs}$	89	2,43	2 years
Cobalt-60	$^{60}_{27}\text{Co}$	33	2,22	5 years
Helium-4	^4_2He	2	2,00	Very stable
Hydrogen-3 (tritium)	^3_1H	2	3,00	12,3 years
Iodine-129	$^{129}_{53}\text{I}$	76	2,43	$15,7 \times 10^6$ years



ISOTOPE	SYMBOL	NEUTRONS [= (A - Z)]	A/Z RATIO	HALF-LIFE
Lead-205	$^{205}_{82}\text{Pb}$	123	2,50	$14,3 \times 10^6$ years
Lead-210	$^{210}_{82}\text{Pb}$	128	2,56	22,3 years
Oxygen-16	$^{16}_8\text{O}$	8	2,00	Very stable
Phosphorus-32	$^{32}_{15}\text{P}$	17	2,13	14,3 days
Potassium-40	$^{40}_{19}\text{K}$	21	2,11	1×10^9 years
Radium-228	$^{228}_{88}\text{Ra}$	140	2,59	6 years
Radon-222	$^{222}_{86}\text{Rn}$	136	2,58	3,82 days
Strontium-90	$^{90}_{38}\text{Sr}$	52	2,37	28,78 years
Thorium-232	$^{232}_{90}\text{Th}$	142	2,58	14×10^9 years
Uranium-238	$^{238}_{92}\text{U}$	146	2,59	$4,51 \times 10^9$ years

Lessons 21 and 22

Activity 1

Hint: start by organising the data and identifying what must be calculated.

$$p = 133 \text{ kPa} = 133 \times 10^3 \text{ N}\cdot\text{m}^{-2} \quad [\text{Convert to SI units}]$$

$$V = 500 \text{ cm}^3 = 500 \times 10^{-6} \text{ m}^3 \quad [\text{Convert to SI unit.}]$$

$$n = ? \quad [\text{Unknown}]$$

$$R = 8,314 \text{ J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$$

$$T = 15^\circ\text{C} = 288 \text{ K}$$

$$M = 28 \text{ g}\cdot\text{mol}^{-1} \text{ (molar mass of } \text{N}_2\text{)}$$

a) What is the mass of nitrogen in the flask?

$$PV = nRT$$

$$n = \frac{PV}{RT} = \frac{(133 \times 10^3)(500 \times 10^{-6})}{(8,314)(288)}$$

$$n = 2,8 \times 10^{-2}$$

$$= 0,028 \text{ mol } \text{N}_2$$

$$m = M[\text{N}_2] \cdot n = 28 \text{ g}\cdot\text{mol}^{-1} \times 0,028 \text{ mol}$$

$$= \mathbf{0,78 \text{ g}}$$

b) What volume will the nitrogen occupy at STP?

STP is 0°C (**273 K**) and atmospheric pressure (101,3 kPa or **$1,013 \times 10^5 \text{ Pa}$**).

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$V_2 = \frac{P_1}{P_2} \times \frac{T_2}{T_1} \times V_1$$

$$= \frac{(133 \times 10^3) \times (273) \times (5 \times 10^{-4})}{(1,013 \times 10^5)(288)}$$

$$= 622 \times 10^{-6} \text{ m}^3$$

$$V_2 = \mathbf{622 \text{ cm}^3}$$



Activity 2

$$P_1 = 1,4 \text{ MPa} = 1,4 \times 10^6 \text{ N}\cdot\text{m}^{-2} \text{ [Convert to SI units]}$$

$$V_1 = 20 \text{ dm}^3 = 2 \times 10^{-2} \text{ m}^3 \text{ [Convert to SI units]}$$

$$T_1 = 7^\circ\text{C} = 280 \text{ K}$$

$$R = 8,314 \text{ J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$$

$$n = ? \quad \text{[Unknown]}$$

$$M = 4 \text{ g}\cdot\text{mol}^{-1} \text{ (molar mass of He)}$$

$$P_2 = 101,3 \text{ kPa} = 1,013 \times 10^5 \text{ N}\cdot\text{m}^{-2} \text{ [Convert to SI units]}$$

$$V_2 = 250 \text{ dm}^3 = 0,25 \text{ m}^3 \text{ [Convert to SI units]}$$

$$T_2 = 27^\circ\text{C} = 300 \text{ K}$$

$$M = 44 \text{ g}\cdot\text{mol}^{-1} \text{ (molar mass of carbon dioxide)}$$

a) 1 litre = 1 dm³; therefore the gas bottle's capacity is equivalent to 10 milk bottles.

b) The mass of helium in the gas bottle.

$$PV = nRT$$

$$n = \frac{PV}{RT} = \frac{(1,4 \times 10^6)(2 \times 10^{-2})}{(8,314)(280)}$$

$$n = 12,0 \text{ mol He}$$

$$m = M[\text{He}] \cdot n = 4,0 \text{ g}\cdot\text{mol}^{-1} \times 12,0 \text{ mol}$$

$$= 48,0 \text{ g}$$

c) How many weather balloons can be filled from the gas bottle? In other words, how many moles of helium are required to fill the balloon under the given conditions?

$$n = \frac{PV}{RT} = \frac{(1,013 \times 10^5)(0,25)}{(8,314)(300)}$$

$$n = 10,2 \text{ mol He}$$

The gas bottle could be used to inflate **one weather balloon** (1,8 mol or 7,2 g of helium gas will remain.)

d) The mass of carbon dioxide in the gas bottle.

$$n = \frac{PV}{RT} = \frac{(1,013 \times 10^5)(2 \times 10^{-2})}{(8,314)(276)}$$

$$n = 0,88 \text{ mol CO}_2$$

$$m = M[\text{CO}_2] \cdot n = 44,0 \text{ g}\cdot\text{mol}^{-1} \times 0,88 \text{ mol}$$

$$= 38,8 \text{ g}$$

Lesson 21a

Activity 1

a) Your graph should look similar to the one drawn for the other set of measurements. Make sure your line is drawn closest to most of the points on the graph paper.

b) State why pressure is plotted on the y-axis of the graph. Because in the experiment the volume of the gas is varied and hence V is the



independent variable. Pressure changes result from the varying volume hence it is the **dependent** variable (Y-axis).

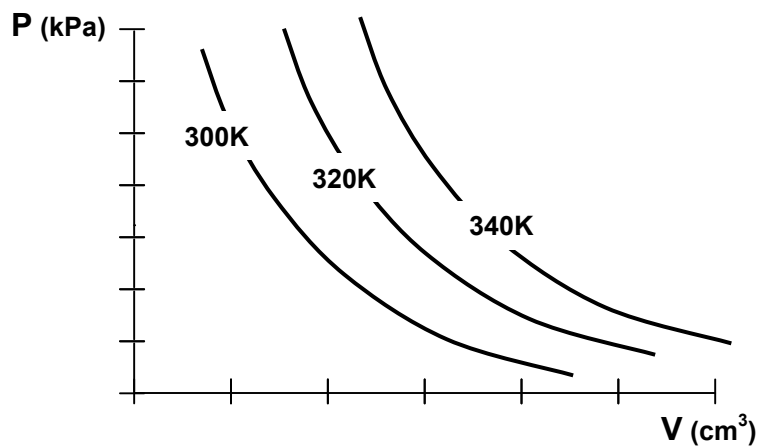
c)

Volume (V) m ³	Pressure (P) kPa	$\frac{1}{V} \text{cm}^{-3} \times 10^{-2}$
40,8	117	2,45
37,3	128	2,68
29,8	160	3,36
24,9	192	4,02
23,0	208	4,35
21,2	225	4,72
Range: 19	110	2,3

- d) Explain why the second graph confirms the conclusion reached by Robert Boyle in the 17th century.
Because the straight line tells us that as the volume of a gas is decreased so the pressure of that gas increases proportionally.

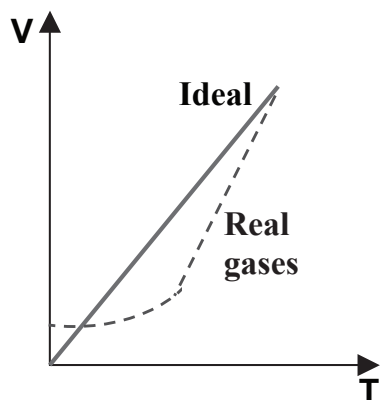
Activity 2

- a) i) $33,7 \text{ cm}^3 \pm 0,2 \text{ cm}^3$
 ii) $27,2 \text{ cm}^3 \pm 0,2 \text{ cm}^3$
 iii) $20,1 \text{ cm}^3 \pm 0,2 \text{ cm}^3$
- b) *At very high pressures, when molecules are being pushed close together, the volume of the gas molecules themselves starts to become important. As a result the theoretical volume for the gas would be lower than the actual measured volume of the real gas, i.e. the real gas volume is greater than expected for an ideal gas.*
- c) i) *When the temperature drops the gas molecules collide with the walls of the container less vigorously and therefore the pressure will be lower than at 320 K. The volume of the gas will also be less than expected.*
 ii) *If the experiment were conducted at 340 K the various readings of pressure and volume would be higher than for 320 K.*



Lesson 22a

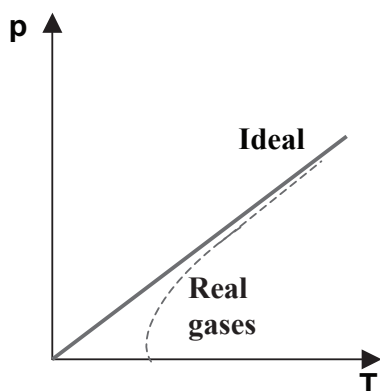
Activity 1



At high temperatures molecules move vigorously and occupy larger volume when pressure is kept constant. Intermolecular interactions are at a minimum because molecules are far apart.

At large gas volumes, therefore, the actual volume of molecules themselves is insignificant. As the temperature drops, and hence as the kinetic energy of the molecules decreases, on average the molecules get closer together. Intermolecular forces start acting and molecules are held together. In addition, now the volume of actual molecules becomes significant. **Hence the volume of real gases at low temperatures is higher than expected.**

Activity 2



The higher the temperature the more vigorously gas molecules move and hence the larger the volume they will occupy if allowed to do so. But if volume is kept constant gas molecules collide with the walls of the container more often in fixed intervals of time. The greater the rate of collisions the greater the average force on the container and therefore the greater the pressure – as predicted for ideal gases. Intermolecular interactions are at a minimum because molecules are far apart.

As the temperature drops intermolecular forces start acting and molecules are held together. This means that the rate of collisions with the container walls drops off faster than expected. **Hence gas pressure at low temperatures falls off faster than expected.**

Activity 3

Understanding the problem

The gas equation allows one to calculate the number of moles of a gas (n) under the given conditions. But to calculate the **mass** of a gas (m) we must convert moles to mass using the molar mass (M).

Once you know the pressure, temperature and volume of a gas under one set of values you can calculate those values under a new set of conditions provided that there is only one unknown.

A sample of nitrogen gas is collected in a 500 cm^3 flask.
The pressure of the gas is 133 kPa at a temperature of 15°C .

- What is the mass of nitrogen in the flask?
- What volume would it occupy at STP?

Start by collecting all the data and identifying what needs to be calculated.



- $p = 133 \text{ kPa} = 133 \times 10^3 \text{ N}\cdot\text{m}^{-2}$ $V = 500 \text{ cm}^3 = 500 \times 10^{-6} \text{ m}^3$
- $n = \text{[unknown]}$ $R = 8,31 \text{ J}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$
- $T = 15^\circ\text{C} = 288\text{K}$ $M = 28 \text{ g}\cdot\text{mol}^{-1}$ (molar mass of N_2)
- STP: 0°C (273 K); and one atmosphere (1 atm) 101,3 kPa or $1,013 \times 10^5 \text{ Pa}$
- Molar volume of a gas: at STP, one mole of a gas will occupy 22,4 dm³

$$\begin{aligned} \text{a) } n &= \frac{pV}{RT} = \frac{(133 \times 10^3) \cdot (500 \times 10^{-6})}{(8,31 \times 288)} \\ &= 27,8 \times 10^{-3} \\ &= 0,0278 \text{ mol} \end{aligned}$$

$$\begin{aligned} n &= \frac{m}{M} \quad \therefore m = 0,0278 \text{ mol} \times 28 \text{ g}\cdot\text{mol}^{-1} \\ &= 0,778 \text{ g.} \end{aligned}$$

b) **First method**

$$\begin{aligned} \frac{P_1 V_1}{T_1} &= \frac{P_2 V_2}{T_2} \\ V_2 &= \frac{P_1}{P_2} \times \frac{T_2}{T_1} \times V_1 \quad (V_2 \text{ is the volume at STP}) \end{aligned}$$

Now substitute the values given in the original problem.

$$\begin{aligned} &= \frac{(133 \times 10^3) \times (273) \times (5 \times 10^{-4})}{(1,013 \times 10^5) \times (288)} \\ &= 622 \times 10^{-6} \text{ m}^3 \end{aligned}$$

$$V_2 = 622 \text{ cm}^3$$

Observation

When using this formula we can use any units of pressure and volume, provided that we use the units consistently. If we are calculating pressure of volume then the answer will be in the units that we have chosen for the other value of pressure of volume. But we cannot do the same thing for temperature. Temperature **must** be given in degrees Kelvin (K). This is because when we convert from $^\circ\text{C}$ to K we add a number to convert – we don't multiply by a factor.

$$\frac{1 \times A}{2 \times A} = \frac{1}{2} \quad \text{but} \quad \frac{1 + A}{2 + A} \neq \frac{1}{2}$$

Second method

Using the fact that one mole of gas occupies 22,4 dm³ at STP, any multiple or fraction of one mole will occupy that multiple/fraction of 22,4 dm³.

$$\begin{aligned} \text{Hence: } V &= 0,0278 \times 22,4 \\ &= 622 \text{ cm}^3 \end{aligned}$$



Lessons 23 to 27

Activity 1

- | | | |
|----|----------------------------|-----------|
| a) | iron (III) oxide | [159,70*] |
| b) | calcium hydrogen carbonate | [162,12] |
| c) | sulphur trioxide | [80,07] |
| d) | potassium dichromate | [294,22] |

- e) lithium chlorate [90,42]
 f) magnesium nitrate [148,34]
 g) ammonium sulphate [132,17]
 h) mercury (II) oxide [216,61]
 i) silver (I) nitrate [169,89]
 j) cobalt bromide [218,78]
 k) nitric acid [63,02]
 l) ammonia [17,04]
 m) hydrogen peroxide [34,02]

*** all formula masses in units of "u"**

Activity 2

- | | |
|---|--|
| a) Fe | b) SO ₂ |
| c) K ₂ CO ₃ | d) Fe(NO ₃) ₃ |
| e) (NH ₄ ⁺) ₂ SO ₄ | f) KMnO ₄ |
| g) Al ₂ (SO ₄) ₃ | h) Mg ₃ (PO ₄) ₂ |
| i) C | j) Ca(OH) ₂ |
| k) BeSO ₄ | l) CuSO ₄ |
| m) (NH ₄ ⁺) ₃ PO ₄ | |

Activity 3

- a) $4\text{K} + \text{O}_2 \rightarrow 2\text{K}_2\text{O}$ (redox reaction: **K**: 0 to +1; **O**: 0 to -2)
 b) $2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2$ (redox reaction: **O**: -1 to 0 and **O**: -1 to -2; could be decomposition by heating)
 c) $\text{Cl}_2 + 2\text{NaBr} \rightarrow 2\text{NaCl} + \text{Br}_2$ (redox reaction: **Cl**: 0 to -1 and **Br**: -1 to 0)
 d) $2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3$ (redox reaction: **S**: +4 to +6 and **O**: 0 to -2)
 e) $2\text{KClO}_3 + \text{heat} \rightarrow 2\text{KCl} + 3\text{O}_2$ (decomposition by heating; redox reaction: **Cl**: +5 to -1 and **O**: -2 to 0)
 f) $2\text{Cu}(\text{NO}_3)_2 + \text{C} \rightarrow 2\text{CuO} + 4\text{NO}_2 + \text{CO}_2$ (redox reaction: **N**: +5 to +4 and **C**: 0 to +4)
 g) $\text{Fe} + 2\text{HCl} \rightarrow \text{FeCl}_2 + \text{H}_2$ (redox reaction: **Fe**: 0 to +2 and **H**: +1 to 0)
 h) $3\text{Mg} + \text{N}_2 \rightarrow \text{Mg}_3\text{N}_2$ (redox reaction: **Mg**: 0 to +2 and **N**: 0 to -3)
 i) $\text{MnO}_2 + 4\text{HCl} \rightarrow \text{MnCl}_2 + 2\text{H}_2\text{O} + \text{Cl}_2$ (redox reaction: **Mn**: +4 to +2 and **Cl**: -1 to 0)
 j) $\text{C}_{12}\text{H}_{22}\text{O}_{11} + 12\text{O}_2 \rightarrow 12\text{CO}_2 + 11\text{H}_2\text{O}$ (combustion)
 k) $2\text{AgNO}_3 + \text{BaCl}_2 \rightarrow 2\text{AgCl} + \text{Ba}(\text{NO}_3)_2$ (double decomposition – straight exchange of ions)
 l) $\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$ (redox reaction: **N**: 0 to -3 and **H**: 0 to +1)
 m) $2\text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$ (acid-base neutralisation reaction)
 n) $4\text{Al} + 3\text{O}_2 \rightarrow 2\text{Al}_2\text{O}_3$ (redox reaction: **Al**: 0 to +3 and **O**: 0 to -2)
 o) $2\text{KNO}_3 + \text{heat} \rightarrow 2\text{KNO}_2 + \text{O}_2$ (decomposition by heating; also redox reaction: **N**: +5 to +3 and **O**: -2 to 0)



Activity 3

Hydrated copper sulphate (blue crystals) → copper sulphate + water



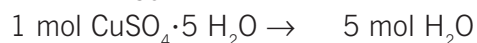
[37,5 g]

$$\begin{aligned} M\text{CuSO}_4 \cdot 5\text{H}_2\text{O} &= [64 + 32 + 4(16) + 5(1 + 1 + 16)] \\ &= 250 \text{ g} \cdot \text{mol}^{-1} \end{aligned}$$

$$\begin{aligned} M\text{H}_2\text{O} &= [1 + 1 + 16] \\ &= 18 \text{ g} \cdot \text{mol}^{-1} \end{aligned}$$

$$\% \text{ water of crystallisation} = \frac{M_{5\text{H}_2\text{O}}}{M\text{CuSO}_4 \cdot 5\text{H}_2\text{O}} = \frac{5 \times 18}{250} = 36\% \rightarrow$$

$$n\text{CuSO}_4 \cdot 5\text{H}_2\text{O} = \frac{m}{M} = \frac{37,5}{250} = 0,15 \text{ mol}$$



$$\therefore 0,15 \text{ mol} \rightarrow 0,75 \text{ mol}$$

$$\begin{aligned} \therefore m_{\text{H}_2\text{O}} &= n \times M \\ &= 0,75 \times 18 \\ &= \mathbf{13,5 \text{ g water}} \end{aligned}$$

The density (**d**) of water at room temperature is $1,0 \text{ g} \cdot \text{cm}^{-3}$. In other words, 1 g of water will occupy a volume of 1 cm^3 (or 1 millilitre). $\therefore V \text{ CO}_2 = m \div d_{\text{water}}$

$$\begin{aligned} &= 13,5 \div 1,0 \\ &= \mathbf{13,5 \text{ cm}^3 \text{ water}} \end{aligned}$$

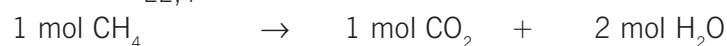
Activity 4

Methane + oxygen gas → carbon dioxide + water



[11,2 dm³]

$$\equiv 0,5 \text{ mol } \left(\frac{11,2}{22,4} \right)$$



$$\begin{aligned} \therefore \text{Volume}_{\text{CO}_2} &= 0,5 \times 22,4 \\ &= 11,2 \text{ dm}^3 \end{aligned}$$

$$\begin{aligned} m\text{H}_2\text{O} &= n \times M \\ &= 1,0 \times 18 \\ &= 18 \text{ g (or } 18 \text{ cm}^3 \text{) water} \end{aligned}$$

Activity 5

Calcium hydroxide + carbon dioxide → calcium carbonate + water

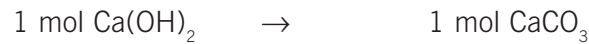


[21,6g]

$$\begin{aligned} M\text{Ca(OH)}_2 &= [40 + 2(16 + 1)] & M\text{CaCO}_3 &= [40 + 12 + 3(16)] \\ &= 74 \text{ g} \cdot \text{mol}^{-1} & &= 100 \text{ g} \cdot \text{mol}^{-1} \end{aligned}$$



$$n\text{Ca(OH)}_2 = \frac{m}{M} = \frac{21,674}{74} = 0,29 \text{ mol}$$



$$\therefore 0,29 \text{ mol} \rightarrow 0,29 \text{ mol}$$

$$\therefore m \text{ CaCO}_3 = 0,29 \times 100 \text{ g}\cdot\text{mol}^{-1}$$

1

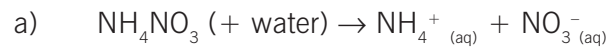
$$= 29 \text{ g carbon dioxide} \rightarrow$$

$$\therefore c \text{ CaCO}_3 = \frac{0,29 \text{ mol}}{1,5 \text{ dm}^3}$$

$$= 0,19 \text{ mol}\cdot\text{dm}^{-3} \rightarrow$$

Lesson 27b

Activity 1



Which of these processes take in energy and which give out energy?

When ions associate with water molecules i.e. when the aqueous ions are formed, energy is taken in. Energy is given out when the ionic ammonium nitrate dissociates in water.

Which of the processes involves more energy, dissociation or association?

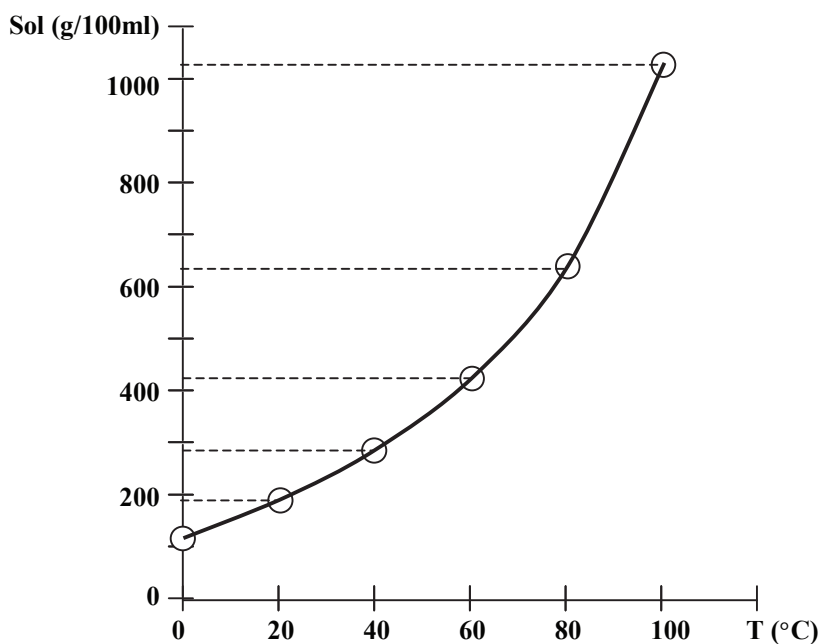
Clearly the formation of aqueous ions takes in more energy than is given out when the ammonium nitrate dissociates hence the nett energy “flow” is from the surroundings and therefore this is an endothermic process.

- b) Complete the table by calculating the missing solubilities and completing the energy column.

Solubility (g/100 ml)	Temperature (°C)	Solubility (mol·dm ⁻³)	Energy absorbed per 100 ml of saturated solution prepared. (kJ)
119	0	14,88	389,9
190	20	23,75	622,3
286	40	35,75	936,7
421	60	52,63	1378,9 (1,379 MJ)
630	80	78,75	2063,3 (2,063 MJ)
1024	100	128,00	3353,6 (3,354 MJ)

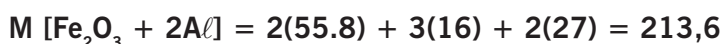
- c) **Draw a graph of Solubility vs Temperature.** Label the axes.





Activity 2

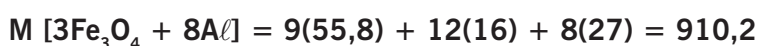
- a) When thermite is made using iron (III) oxide, for maximum efficiency it should contain, by mass 25,3 % aluminium and 74,7 % iron oxide. Show by calculation how these percentages arise.



$$\therefore \% \text{Fe}_2\text{O}_3 = \frac{159,6 \times 100}{213,6} = 74,7$$

$$\therefore \% \text{Al} = \frac{54 \times 100}{213,6} = 25,3$$

- b) When thermite is made using iron (II and III) oxide (or "magnetite" - see Lessons 23 to 27, page 194), for maximum efficiency it should contain, by mass, 23,7% aluminium and 76,3% iron oxide. Show by calculation how these percentages arise.



$$\therefore \% \text{Fe}_3\text{O}_4 = \frac{694,2 \times 100}{910,2} = 76,3$$

$$\therefore \% \text{Al} = \frac{216 \times 100}{910,2} = 23,7$$

- c) While the reaction using Fe_3O_4 produces a substantially larger amount of energy per mole, the reaction using Fe_2O_3 , produces more energy per gram of thermite mixture. Show by calculation that this is true.

For 1 mol Fe_2O_3 the energy yield (exothermic reaction) is 851,5 kJ.

The total mass of reactants ($\text{Fe}_2\text{O}_3 + 2\text{Al}$) is 213,6 g

\therefore energy per gram = $3,99 \text{ kJ} \cdot \text{g}^{-1}$ of iron oxide (Fe_2O_3).

For 1 mol Fe_3O_4 the energy yield (exothermic reaction) is 3347,6 kJ.

The total mass of reactants ($3\text{Fe}_3\text{O}_4 + 8\text{Al}$) is 910,2 g

\therefore energy per gram = $3,68 \text{ kJ} \cdot \text{g}^{-1}$ of iron oxide (Fe_3O_4).

- d) Balance the thermite reaction that uses Fe_3O_4 instead of Fe_2O_3 i.e. determine the values of x and y.

$$x = 4; y = 9$$



- e) Did the pencil sharpener reaction have a high or a low activation energy? (Watch the video of the reaction being performed and you will get a clue to help you answer this.)

Very high activation energy. A great deal of energy must be put into the system (the sharpener is heated to glowing hot and the water is boiled to produce steam) before the reaction takes place. Once the reaction starts it is exothermic so the released energy can be used to maintain the reaction.

Activity 3 (Individual problem)

- a) Give a balanced equation for the reaction when hydrogen gas reacts with oxygen gas.
- $$2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$$
- b) Calculate the amount of energy used / taken in or given out when 2 moles of hydrogen gas reacts with one mole of oxygen gas.

The initial energy used (ENERGY IN) to break the bonds of the reactants:

$$2(436) + (498) = 1\,370 \text{ kJ}\cdot\text{mol}^{-1}$$

The energy that is released into the surroundings (ENERGY OUT) when product bonds are formed is:

$$4(366) = 1\,464 \text{ kJ}\cdot\text{mol}^{-1}$$

$$\text{Nett energy GIVEN OUT in the reaction} = 1\,464 - 1\,370 = 94 \text{ kJ}$$

- c) State whether the reaction is endothermic or exothermic.

Exothermic (nett energy is given OUT).

- d) Does the reaction have a high activation energy or not?

Not particularly high activation energy.

Takes relatively little heat to initiate the reaction.

Lesson 27c

Activity 1

Alkali → Acid ↓	Sodium hydroxide (caustic soda) $\text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^-$	Calcium hydroxide (lime water) $\text{Ca(OH)}_2 \rightarrow \text{Ca}^{2+} + 2\text{OH}^-$
Hydrochloric acid $\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$	$\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$	$2\text{HCl} + \text{Ca(OH)}_2 \rightarrow \text{CaCl}_2 + 2\text{H}_2\text{O}$
Nitric acid $\text{HNO}_3 \rightarrow \text{H}^+ + \text{NO}_3^-$	$\text{HNO}_3 + \text{NaOH} \rightarrow \text{NaNO}_3 + \text{H}_2\text{O}$	$2\text{HNO}_3 + \text{Ca(OH)}_2 \rightarrow \text{Ca(NO}_3)_2 + 2\text{H}_2\text{O}$
Sulphuric acid $\text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-}$	$\text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$	$\text{H}_2\text{SO}_4 + \text{Ca(OH)}_2 \rightarrow \text{CaSO}_4 + 2\text{H}_2\text{O}$

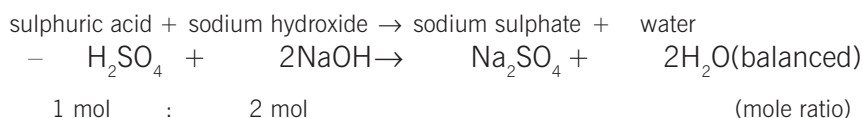
Activity 2

Understanding the problem:

Always start by writing a balanced equation for the neutralisation. This will give you the **mole ratio** for the acid-base reaction. In the case of sulphuric acid (a **diprotic acid** because it has two protons that can produce two hydronium



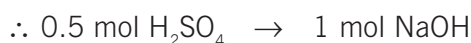
ions when the strong acid dissociates) and sodium hydroxide (which gives one hydroxyl group when it dissociates) the mole ratio is **1 : 2**.



$$\text{concentration} = \frac{\text{number of moles (mol)}}{\text{volume (dm}^3\text{)}} \quad [\text{mol}\cdot\text{dm}^{-3}]$$

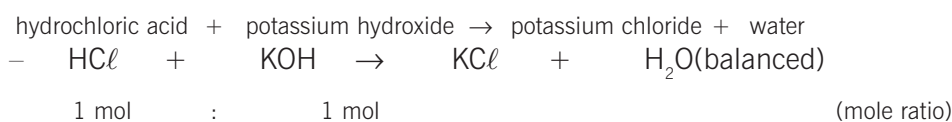
$$\begin{aligned} n_{\text{H}_2\text{SO}_4} &= c_{\text{H}_2\text{SO}_4} \times V_{\text{H}_2\text{SO}_4} \\ &= 0,5 \times 1 \\ &= 0,5 \text{ mol} \end{aligned}$$

The mole ratio for the neutralisation tells us that 1 mole of acid will react with 2 moles of hydroxide.



$$\therefore \text{conc}(\text{NaOH}) = \frac{1 \text{ mol}}{2 \text{ dm}^3} = 0,5 \text{ mol}\cdot\text{dm}^{-3} \rightarrow$$

Activity 3



$$[\text{Convert: } 50 \text{ ml} = 50 \text{ cm}^3 = 50 \times 10^{-3} \text{ dm}^3]$$

$$\begin{aligned} n_{\text{KOH}} &= c_{\text{KOH}} \times V_{\text{KOH}} \\ &= 0,2 \times 50 \times 10^{-3} \\ &= 1 \times 10^{-2} \text{ mol (or } 0,01 \text{ mol)} \end{aligned}$$

The mole ratio for the neutralisation tells us that 1 mole of hydroxide will react with 1 mole of acid.

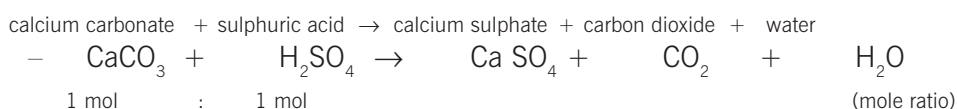


$$\therefore \text{if conc} = \frac{n \text{ (mol)}}{\text{vol (dm}^3\text{)}}$$

$$\text{then vol of acid (dm}^3\text{)} = \frac{\text{number of moles (mol)}}{\text{conc acid (mol}\cdot\text{dm}^{-3}\text{)}}$$

$$\text{vol of acid (dm}^3\text{)} = \frac{0,01}{0,1} = 0,1 \text{ dm}^3 \rightarrow$$

Activity 4



$$\begin{aligned} M_{\text{CaCO}_3} &= [40 + 12 + 3(12)] \text{ g}\cdot\text{mol}^{-1} \\ &= 100 \text{ g}\cdot\text{mol}^{-1} \end{aligned}$$

$$\therefore n_{\text{CaCO}_3} = \frac{m}{M} = \frac{250}{100} = 2,5 \text{ mol}$$

\therefore 2,5 mol acid is required to break down 2,5 mol calcium carbonate

$$\therefore \text{vol of acid (dm}^3\text{)} = 2,5 \text{ mol} / 0,5 \text{ mol}\cdot\text{dm}^{-3}$$

$$\text{(a)} \quad = 5 \text{ dm}^3 \rightarrow$$

1,0 mole carbonate yields 1 mole of carbon dioxide

\therefore 2,5 mol yields 2,5 mol

$$\therefore \text{vol of acid (dm}^3\text{)} = 2,5 \text{ mol} / 0,5 \text{ mol}\cdot\text{dm}^{-3}$$



$$V \text{ CO}_2 = n \times 22,4 \text{ dm}^3 \text{ per mole of gas}$$

$$= 2,5 \times 22,4$$

(b) $= 56 \text{ dm}^3 \text{ carbon dioxide}$

Lesson 27d

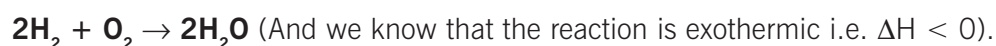
Activity 1

1.1 hydrogen + oxygen \rightarrow water

Observation:

This is a simple reaction which can be balanced “by inspection” i.e. just by looking at it and applying a little logic and reasoning. For example, we know that water is H_2O – so in the water molecule hydrogen and oxygen are in a **2:1 ratio**. Remember Dalton’s rules? Substances react in simple, whole number ratios.

Both gases are diatomic molecules. So it follows that:



Balancing equations by using oxidation numbers:

	Goes from ...	to ...	Oxidation number change
Molecule \rightarrow	H₂	H₂O	
Oxidation number	0	2(+1)	goes from 0 to +1
Molecule \rightarrow	O₂	H₂O	
Oxidation number	0	(-2)	goes from 0 to -2

... meaning

Oxidation number of a hydrogen atom in the reaction goes from **0** (*the O.N. of elements in their pure, natural form*) to **+1** (*in the water molecule where it has been bonded to an oxygen atom by way of losing an electron and becoming H⁺*).

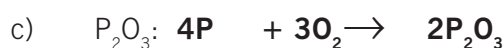
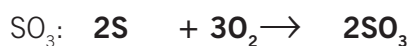
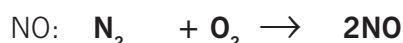
Hydrogen **loses 1 electron** and is **oxidised**.

Oxidation number of an oxygen atom in the reaction goes from **0** (*the O.N. of elements in their pure, natural form*) to **-2** (*in the water molecule where it has been bonded to two hydrogen atoms by way of gaining two electrons and becoming O²⁻*).

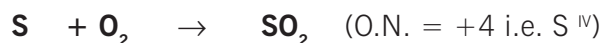
Oxygen **gains 2 electrons** and is **reduced**.

Now balance “electrons lost” with “electrons gained”:

2 **hydrogen** atoms **lose 2 \times 1** electrons and 1 **oxygen** atom **gains 2** electrons
 \therefore **mole ratio: 2 to 1**



1.3 Calculate the oxidation number for the non-metal (N, S and P) in each of the oxides.



NAMING OXIDES OF NITROGEN

The oxide with nitrogen in its lowest oxidation state, N_2O , is **nitrous oxide**.*

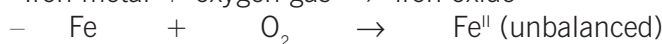
The oxide with nitrogen in its next highest oxidation state, NO , is **nitric oxide**.*

The oxide with nitrogen in its highest oxidation state, NO_2 , is **nitrogen dioxide**.*

* Please note that the names given here are correct. If nitrogen oxides are referred to by their incorrect names elsewhere in these notes or in the video lessons, we apologise for the error.

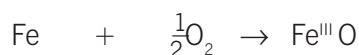
Activity 2

Iron metal + oxygen gas \rightarrow iron oxide

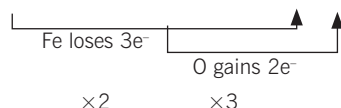


FeO is **ferrous** oxide because iron is in its lowest oxidation state (II).

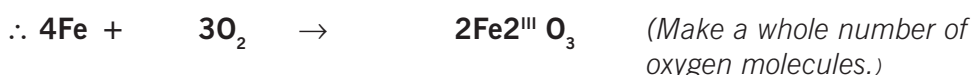
However iron can form an oxide when in its higher oxidation state, **Fe^{III}**, or the **ferric** ion. The oxide produced is **ferric** oxide. We can balance this more complex equation using oxidation numbers,



(Shows one atom as a half diatomic molecule.)



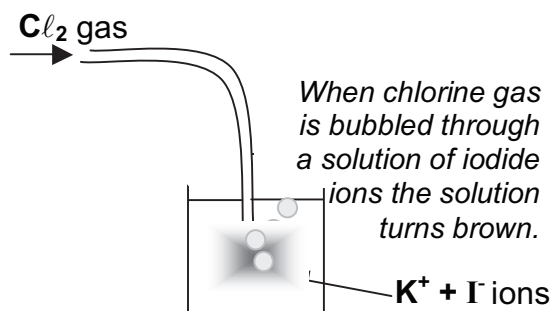
(Cross-multiply to balance e⁻ lost with e⁻ gained.)



The compound Fe_3O_4 is the mineral **magnetite**. It is the most magnetic of all naturally occurring, magnetic minerals. Its accepted name is ferrous-ferric oxide. The two oxides of iron, FeO and Fe_2O_3 , are chemically combined – not merely a simple physical mixture – in a 1:1 ratio. Both oxides are integrally involved in the magnetite crystal structure.



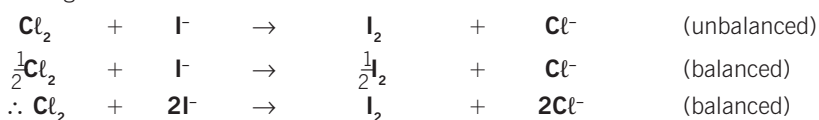
Activity 3



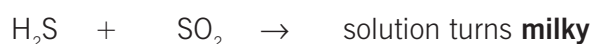
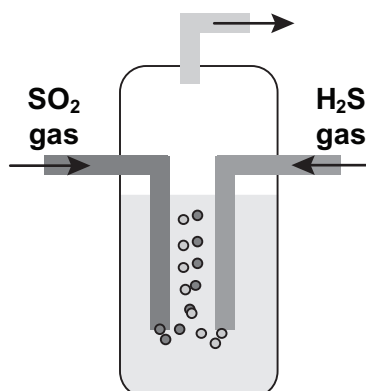
Understanding the problem:

You will notice on your periodic table that chlorine is above iodine in Group 7. This means that if there is a competition for an electron between atoms of chlorine and iodine, the chlorine will win. The chlorine atom will also take an electron away from a bromide or an iodide ion. That is what is happening in this reaction:

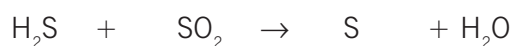
Chlorine gas + iodide ions \rightarrow iodine in solution + chloride ions



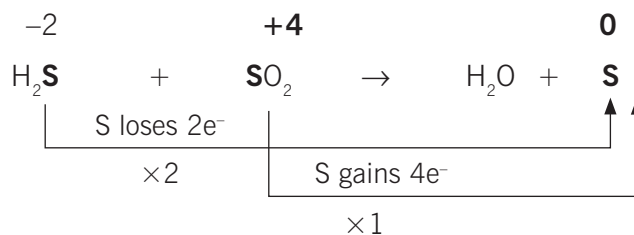
Activity 4



When sulphur compounds react in solution and the solution turns milky it means that **insoluble sulphur is being produced**. Just looking at the reactants one can guess that the other product will be water.



The sulphur from H_2S will react differently to the sulphur from the SO_2 .



- SO_2 – sulphur dioxide – is a pungent gas. It is a strong oxidising agent (it causes other reactants to lose electrons) and is used as a preservative in foods and as a bleaching agent in the production of sultana raisins.



- H_2S – hydrogen sulphide – is the gas that is given off by rotten eggs. It is a strong reducing agent (it causes other reactants to gain electrons). Because it produces sulphides in reactions with metals it can be used to test for certain metals since some sulphides have distinct colours.

Activity 5

- 1.1** In the zinc-copper cell shown the **electrons will flow from right to left** in the external circuit.

The half-cell potential for zinc ($-0,76\text{ V}$) is more negative than that of the copper half-cell ($+0,34\text{ V}$). Therefore when these two half-cells are connected the zinc metal will oxidise to Zn^{2+} more readily than copper metal will to Cu^{2+} i.e. the zinc metal will lose electrons and the Cu^{2+} ions will gain electrons. (The other consequence is that copper metal atoms will be deposited on the copper rod and the zinc metal rod will be eroded as Zn^{2+} ions go into solution.)

- 1.2**
- Electrons will flow from the left hand half-cell (Mg/Mg^{2+}) to the right hand half-cell (Cu/Cu^{2+}).
 - Electrons will flow from the left hand half-cell (Cu/Cu^{2+}) to the right hand half-cell (Ag/Ag^+). Although the half-cell potential for the copper side is $+0,34\text{ V}$ it is less positive (i.e. more negative) than for the silver half-cell ($+0,80\text{ V}$).
[To understand this better plot the half-cell potentials on a number line; values that are more negative or closer to the negative part of the number line will lose electrons more readily.]
 - From the right hand half-cell towards the left.
 - From the right hand half-cell towards the left.
 - Since the half-cell potentials are identical ($+0,80\text{ V}$) neither half-cell will lose electrons to the other and there will be no current in the external circuit.

Lesson 30a

Activity 1

- 1.1** When unnecessary rock is excavated it still has to be crushed and treated. By processing “dead” ore (which contains no precious metal) the cost of recovery increases and the mine’s efficiency (and hence economic value) will decrease. At worst the mining company might make a loss on its operations.
- 1.3**
- $$\text{Au} + \text{NaCN} + \frac{1}{2}\text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Na}^+\text{Au}(\text{CN})_2^- + \text{NaOH}$$

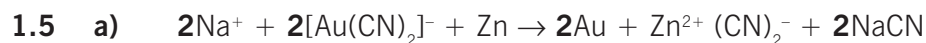
$$2\text{Au} + 4\text{NaCN} + \frac{1}{2}\text{O}_2 + \text{H}_2\text{O} \rightarrow 2\text{NaAu}(\text{CN})_2 + 2\text{NaOH}$$

$$4\text{Au} + 8\text{NaCN} + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{NaAu}(\text{CN})_2 + 4\text{NaOH}$$
 - $$4\text{Au} + 8\text{KCN} + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{K}[\text{Au}(\text{CN})_2] + 4\text{KOH}$$

$$(4\text{Ag} + 8\text{KCN} + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{K}[\text{Ag}(\text{CN})_2] + 4\text{KOH})$$
 - The oxidation number for gold is 0 as the pure metal. In the metal cyanide ion it is +1 \therefore during the reaction Au loses electrons i.e. it is oxidised.
 - $\frac{1}{2}\text{O}_2$
- 1.4**
- $\text{Ag}_2\text{S} + 4\text{KCN} \rightarrow 2\text{K}[\text{Ag}(\text{CN})_2] + \text{K}_2\text{S}$



- b) Ag_2S : $2(+1) + (-2) = 0$; $\text{K}[\text{Ag}(\text{CN})_2]$: $(+1) + (+1) + 2(-1) = 0$;
 Ag – no change in O.N.



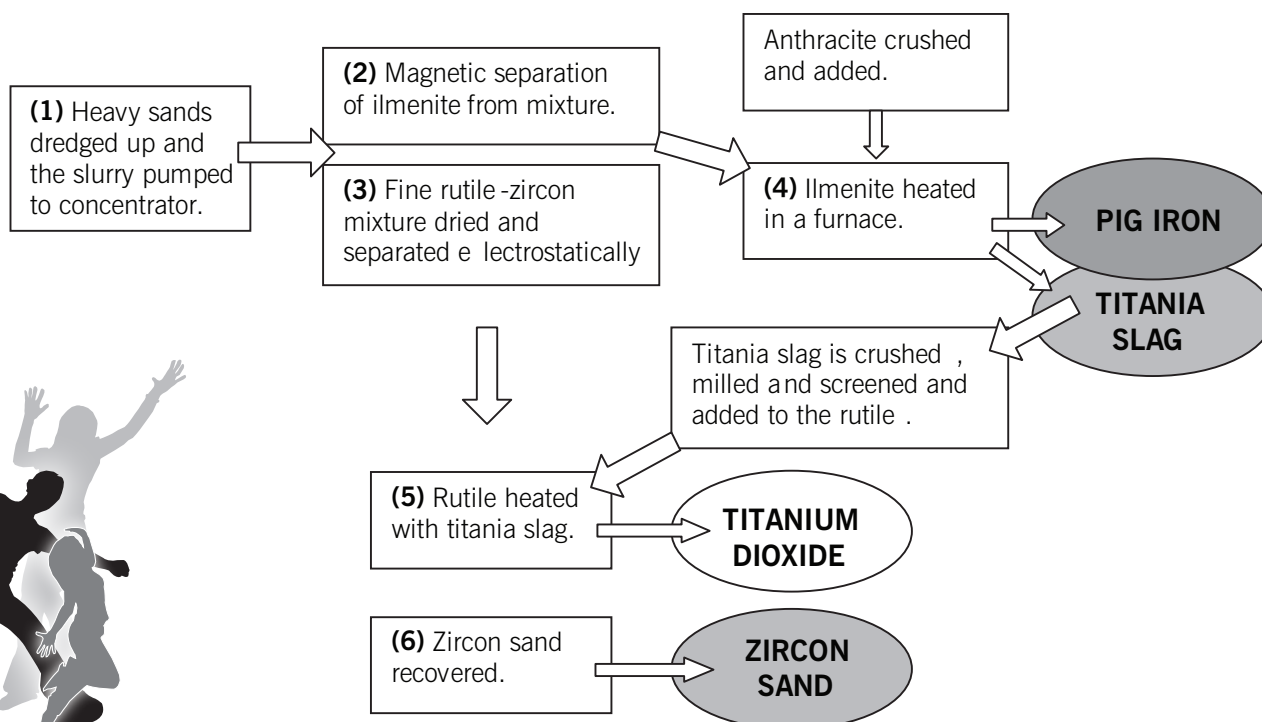
Au^+ ions are reduced to Au metal atoms and the zinc (the reducing agent) is oxidised.

- b) Both the highly toxic CN^- ions which are still in the tailings after the process and the zinc ions (which will be in higher concentrations than are normally found in the environment) could cause environmental damage.

Activity 2

2.1 Draw a flow diagram of the process described in the box above.

In the first stage of the ilmenite mining process an artificial lake (or “pond”) is created in the sand dunes. The dunes on the far side are sprayed with high pressure hoses and the titanium-bearing sands are washed into the pond. The dredger in the foreground sucks up a slurry of sand and feeds it to the floating factory in the background where the first stage of recovery takes place. The sand tailings are sprayed back onto the dunes which are then replanted with the original, indigenous flora.



- 2.2 a) $2\text{FeTiO}_3 + \text{C} \rightarrow 2\text{Fe} + 2\text{TiO}_2 + \text{CO}_2$
 b) In FeTiO_3 : Fe is (+3) because ilmenite is magnetic; \therefore Ti is (+3) because O is (-2);

∴ Fe changes from (+3) to (0) i.e. it is reduced (gains 3 electrons);
 Ti changes from (+3) to (+4) i.e. it is oxidised (loses 1 electron).
 C (0) changes to (+4) in CO₂ i.e. it is also oxidised (loses 4 electrons).

∴ **Fe^{III}, which gains electrons (and hence causes Ti and C to lose some of their electrons) is termed the oxidising agent.**

Observation:

One sees how to balance the equation from this information:

2 Fe will gain $2 \times 3 = 6 e^-$

1 C and **2 Ti** will lose $(4 + 2 \times 1) = 6 e^-$ ∴ **2FeTiO₃ + C → 2Fe + 2TiO₂ + 1CO₂**

Activity 3

- (1) NO + O₃ → NO₂ + O₂
- (2) NO₂ + O₃ → NO₃ + O₂
- (3) NO₃ + O₃ → NO₂ + **2O₂**

Activity 4

- a) SO₃(g) + H₂O(l) → H₂SO₄(l).
- b) H₂SO₄ ⇌ H⁺ + HSO₃⁻
 HSO₃⁻ ⇌ H⁺ + SO₃²⁻
- c) H⁺ + H₂O ⇌ H₃O⁺
- d) NO₂ + OH ⇌ HNO₃

Lesson 30b

Activity 1

1.1

Advantages	Disadvantages
<ul style="list-style-type: none"> ● Create more jobs ● Improves the economy of the country ● Contribute to the development of communities as cities and towns are formed; etc 	<ul style="list-style-type: none"> ● People lose their lives whilst working underground ● Radioactive substances produced as by-products in mining are harmful to human life ● Mine dumps expose people to dust and radioactive substances resulting in ill health such as respiratory problems; etc

1.2 Learners are expected to discuss issues around ...

- Air pollution
- Acid rain
- Effects of radiation of the growth of plants; etc

1.3 Learners are expected to discuss issues around ...



Regulation of fume emissions from mines

Control of radioactive substance dumping

Ensuring that mines have environmental policies governing how they dispose harmful materials

How mines should contribute to the development of communities around them and how to use safe mining techniques to ensure that the health of the communities around them is protected.

Activity 2

- 2.1 For these activities, teachers are advised to model the answers and
and 2.2 to also draw a rubric on how the learners will be assessed using the subheadings as outlined in the question.
- 2.2 Asbestosis is a disease caused by inhaling air that contains asbestos. The disease is associated with respiratory problems that includes shortness of breath, wheezing and pains in the chest etc. It is a deadly disease.



TEACHER TIPS

Lesson 1

INTRODUCTION

Our Learning Channel webnotes will deal with key concepts in the new Grade 11 Physical Sciences curriculum. Ideally, the notes should be used AFTER watching the short TV programme on the topic but this is not essential. As far as possible, the webnotes have been written as a stand-alone resource but it is advised that they be used together with a good, readable textbook of the learner's choice.

HOW THE PHYSICAL SCIENCES CURRICULUM IS STRUCTURED

The new curriculum is structured around learning outcomes (LOs) and assessment standards (ASs) that tell you what skills and knowledge you must gain in the course. But the Physical Sciences assessment standards do not, *on their own*, give teachers enough guidance on what *content* should be covered to achieve the assessment standards.

Therefore notes have been prepared by the National Department of Education to support teachers of the Physical Sciences. The notes spell out in great detail the content requirements of the curriculum. *Every teacher of the Physical Sciences should have these notes and study them carefully when preparing lessons.* The required content from the official document has been reproduced in each lesson under "Overview".

Here are some examples to show how the notes would extend and clarify the meaning of an assessment standard when applied to a specific content area.

EXAMPLES OF THE CONTENT DESCRIPTION IN MECHANICS SECTION

Learning Outcomes and Assessment Standards	EXAMPLES FROM MECHANICS SECTION
LO1 AS Interpreting data	Extracting information from a table of data or understanding the significance of the answer to a numerical problem.
AS Conducting investigation	Proving Newton's Second Law, within the limits of experimental accuracy.
AS Solving problems	Ordering the data given, identifying what needs to be calculated, selecting an appropriate formula and finding the unknowns.
AS Communicating information and scientific arguments	Understanding and then explaining the significance of Galileo Galilei's thought experiment that is the foundation of Newton's First Law.
LO2 AS Recalling and stating concepts	Stating Newton's three laws of motion or defining momentum.
AS Indicating and explaining relationships	The relationship between an impulse and the change in momentum of an object which is at rest or in motion.
AS Applying scientific knowledge	Applying Newton's three laws of motion to the analysis of forces from a picture or diagram.
LO3 AS Evaluating knowledge claims	Your friend says that a Formula 1 racing car's acceleration when it brakes at the end of a straight is like driving a car into a brick wall at 300 km.h ⁻¹ . Can you do a calculation to see if this is a reasonable statement? Do you feel that it is important for you to go to the effort of testing his claim?



AS Evaluating impact of science on human development	What has been the influence of the internal combustion engine and the development of the motor car industry on our development as human beings?
AS Evaluating impact of science on environment and sustainable development	What are some of the effects of the development of the motor car industry on the environment and on our economic development? Debate the issue of whether the industry contributes to our development as human beings?

CURRICULUM CONTENT IN THE FIVE LESSONS IN THE MECHANICS SECTION: AN EXEMPLAR FOR TEACHER PLANNING

Here is a preview of what appears in the first Lessons of the Grade 11 course. The lessons deal with key concepts to be covered in the Grade 11 course.

LESSON 1

Identifying forces acting in specific situations in answer to the question: “Where are the forces?” A qualitative understanding that, although forces can be very large, they can also be very small. Using arrows is a common and useful way of representing forces. Newton’s First Law of Motion is also called the Law of Inertia as it defines this quantity. (Also reviewed in Lesson 2.) The quantity called momentum. A resultant force causes an object’s momentum to change. This is the correct way of defining Newton’s Second Law of Motion. The alternative form of Newton’s Second Law is also stated. There is a brief discussion on acceleration as the “rate of change of velocity” as done in Grade 10.

LESSON 2

Develop concepts from Lesson 1: force, impulse, momentum, acceleration and the effects of forces. A net force causes an object’s momentum to change (Newton’s Second Law). The net (or resultant) force acting on an object is equal to the rate of change of momentum. Explain the relationship between net force and change in momentum for a variety of motions. Draw vector diagrams to illustrate the relationship between the initial momentum, the final momentum and the change in momentum in specific cases. Calculate the change in momentum when a resultant force acts on an object. Pairs of interacting objects exert equal forces on each other: you can’t touch without being touched; you can’t pull without being pulled. State Newton’s Third Law (N3). Revisit forces; types of forces; differentiate between contact and non-contact forces (lays the foundation for treatment of “forces at a distance” in gravity and electrostatics). Apply Newton’s Third Law (N3) to contact forces; analyse more physical situations in pictures.

LESSON 3

The equivalence of impulse and the change of momentum. Conservation of momentum. Apply the conservation of momentum to collisions of two objects moving along a straight line. Calculations on quantities related to forces. Forces experienced when objects are in contact, including distortion. Objects in contact exert forces on each other (e.g. normal force, frictional force). The effect of contact forces: impulse, momentum change, acceleration (Newton’s Second Law). Objects in contact exert forces on each other. Identify a variety of contact forces (e.g. pushes, pulls, tension, normal and friction forces). Surfaces exert two types of contact force: a normal force perpendicular to the surface and a force of friction parallel to the surface. Distinguish between static and dynamic friction forces and explain why there is difference. Calculate the value of the static friction force for an object at rest and of the dynamic friction force for a moving object.



Components of forces. Solve problems for objects on a horizontal surface and on an incline.

LESSON 4

Masses can exert forces on each other (gravitational attraction) without being in contact. Fields. Force between two masses. Newton's Law of Universal Gravitation. Use the equation for universal gravitation to calculate the mutual force between two masses. Understand that objects can interact with a field, which is how masses can exert forces on each other without touching. Gravitational field strength 'g' is the force per unit mass, $g = F/m$, with an approximate value of $9.8\text{m}\times\text{s}^{-2}$ on or near the surface of the Earth. The weight of an object is the force the Earth exerts on the object on or near the surface of the Earth. Introduce the idea of a gravitational lens.

LESSON 5

Moment of force. Mechanical advantage (MA). An object fixed or supported at one point and a force acting on it a distance away from the support tend to make the object turn. The moment of a force, or torque, is the product of the distance from the support and the component of the force perpendicular to the object. Calculate the moment of the force, or torque, resulting from each force when several forces act on the same object. For an object to be in equilibrium, both the sum of the forces acting on the object and the sum of the moments of the forces must be zero. Solve problems involving objects in equilibrium. The terms "load" and "effort" for a lever. Define "mechanical advantage" as the ratio of "load/effort" and calculate the mechanical advantage for simple levers. Apply the concept of mechanical advantage to everyday situations.

Lesson 2

CALCULATION ACTIVITY 2.1

Note that the units of impulse (N.s) are equivalent to the units of momentum (or change of momentum), i.e. $\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$.

$$\begin{aligned} F \cdot \Delta t &= (200 \text{ N}) \cdot (0,01 \text{ s}) \\ &= 2 \text{ Ns} \end{aligned}$$

When a ball hits a wall, the ball will deform slightly. Then it will reform into its original shape as it leaves the wall. Deforming a body requires a force and one can see that this force will gradually increase to a maximum as the ball "squashes" and then decrease to zero as the ball moves away from the wall again. But, as it is too complex to try and calculate this varying force, we speak rather of an average force acting for a time and we assume that the force remains constant at this "average" value for the whole duration of its action, i.e. for Δt seconds (in this case 0,01 s).

YOU CAN'T TOUCH WITHOUT BEING TOUCHED!

Newton's Third Law is quite tricky because forces of reaction are not intuitively recognisable. We can understand the idea of a force because we feel the effects of an push or a pull. But we don't think in terms of a wall pushing us when we lean against it!

When we think about it carefully, we can see that the wall must be pushing us when we lean on it. If it did not, the wall would collapse. That brings us to the idea that the strength of a structure such as a wall determines how much force




it can exert on something pushing against it. If a car hits a concrete barrier and only crumples, it is because the barrier is strong enough (by virtue of its structural design and the kind of material it is made of) to withstand the force exerted by the crashing car. On the other hand, the car crumples too because it is not able to withstand the force of the barrier on it. These days cars are designed with “crumple zones” because that allows the car to decelerate (lose its momentum) over a slightly longer time, which reduces the size of the force (the rate of change of momentum) on the driver and passengers. (Crumple zones also make sure that the parts of the car that crumple aren’t those parts close to the people in the car, e.g. the cavity around the legs.)

As far as the idea of simultaneity goes, drum in the idea of “you can’t touch without being touched” and “you can’t pull without being pulled.” It is impossible for you to touch someone without AT THE SAME TIME being touched by that person. Similarly, it is impossible for a force of ACTION to be present without a simultaneous force of REACTION being present.

This leads to the not-so-obvious conclusion that all forces occur in pairs!

REVISIT THE ASSESSMENT TASK FROM LESSON 1

Start with this problem of identifying the forces involved in lifting a ball. The first analysis is in terms of Newton’s First and Second Laws. After that, we can ask why the ball doesn’t fall through the lifter’s hand! And that will take us on to the discussion of Newton’s Third Law because, clearly, the hand is opposing the downward force of the ball on it. Draw a hand under the ball in each of the three stages in the movement of the ball and show the action-reaction pair that results.

		
Stage 1 Just getting moving from rest	Stage 2 Upwards at uniform velocity	Stage 3 At rest again at the top



PORTFOLIO SECTION

Learners have to maintain a portfolio for all their subjects. Here are some supplementary tasks that could be assigned for portfolio purposes.

• Tasks

- 1.1. Collect pictures of physical situations on which you draw in the forces acting. Use crayons and rulers, so the arrows are neat, straight and colourful.
- 1.2. Try to find a picture of Sir Isaac Newton. (Visit a library or the internet if it is available to you.)
- 1.3. Read about Newton.
- 1.4. Read about Galileo Galilei. Which of Newton’s Laws were taken from the work of Galileo?
- 1.5. On what day of the year was Sir Isaac Newton’s birthday? In which year was Sir Isaac born?

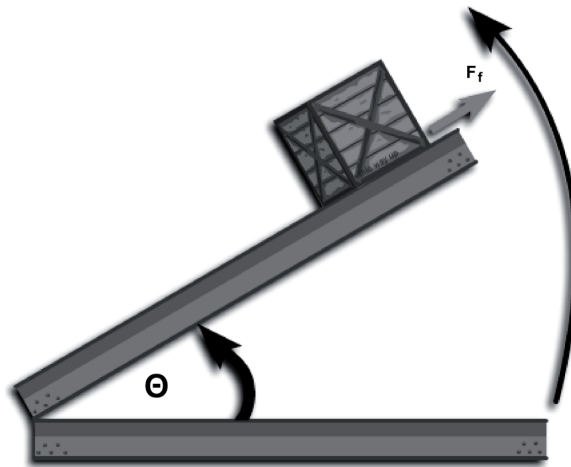
1.6. In which year did Galileo Galilei die?

Lesson 3

WHY STATIC AND KINETIC COEFFICIENTS OF FRICTION ARE DIFFERENT

To demonstrate the difference between the coefficients, find a piece of smooth plank or board. Place any object on it (e.g. a brick or a small box which has been weighted) and incline the plank at an increasing slope. Draw this diagram on the board so that learners can relate the theoretical to the actual while the real thing is happening.

What we find is that, when a certain (angle of) slope/inclination is reached, the body starts moving down the slope.



What we also find is that, as soon as the body starts moving, the angle of inclination can be decreased slightly so that the body moves down the slope with a constant velocity. From Newton's First Law, we know that under these conditions the force exerted on the block must be zero. That in turn means that the force exerted by gravity down the slope is equal to the frictional force in the other direction. And that means that, when we decreased the incline slightly to achieve this condition, **the force of kinetic friction** (i.e. the frictional force acting when two surfaces move relative to one another) **is less than the force of static friction** (i.e. the frictional force acting when two surfaces are stationary relative to one another).

It is quite easy to measure the coefficient of friction using the method described above, i.e. that μ is equal to the tangent of the angle of inclination of a sloping surface. Learners can see that, once a body is sliding, the angle can be reduced without making the body stop. This shows that the coefficient of kinetic (or dynamic or "sliding") friction is less than that of static friction. The latter can also be measured by giving the body on the slope a gentle nudge until it slides down the slope at a constant velocity.

WHY DOESN'T THE FRICTIONAL FORCE DEPEND ON THE CONTACT AREA?

A frequently asked question – and, in fact, a common misconception about friction – is that the frictional force depends on the size of the surface area. In fact, if you look at the diagrams in which the surfaces are greatly magnified, only a very small proportion of the total area of two surfaces are **actually in contact**. So "contact" area, as measured by the dimensions of the surface of a body that rests on a surface, is not a factor when determining the frictional force.

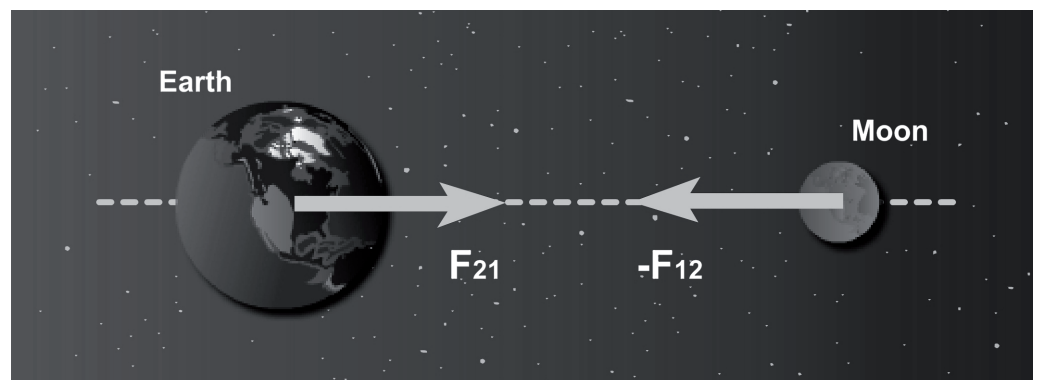
This is a surprising result but quite a logical one. It can be tested practically. In fact, we can say that any relationships to do with the force of friction are empirical because they are discovered by doing practical measurements.

To read more about this fascinating subject, consult Wikipedia, the website that tells you something about everything, although not necessarily everything about everything! Wikipedia gives an excellent start to any quest for knowledge and understanding. The explanation of friction is at <http://en.wikipedia.org/wiki/Friction>.



Lesson 4

- The force of gravity between two objects is a **MUTUAL** force of attraction because there is no force at all unless there are two bodies. Newton's Third Law explains the meaning of an "action-reaction pair" of forces. So two gravitational forces:
 - **have the same magnitude** (both F_{21} and F_{12} are given by the same formula);
 - **act in opposite directions** (F_{12} and $-F_{21}$ are opposed);
 - **act on different objects** (F_{12} is "1" acting on "2"; and F_{21} is "2" acting on "1");
 - **act simultaneously** (F_{12} and F_{21} act at the same time because each force exists only because the other force exists); and
 - **are the same kind of force** (they are both gravitational forces of attraction).



- Points to bear in mind for bodies falling under the effect of gravity near the Earth:
 - When a body falls, it accelerates towards the Earth (we say "downwards") **in a straight line**.
 - The distance of fall is **h**, the time of fall is **t**, and the velocity it attains after **t** is **v m·s⁻¹**.
 - Bodies accelerate "downwards" because they experience the "**downward**" force that we call "the force of gravity".
 - To a good degree of accuracy, the **acceleration caused by gravity (g)** can be taken as **a constant, approximately equal to 10 m·s⁻²**.
 - This means that a falling body increases its downward velocity at a rate of 10 m·s⁻¹ (or 9,8 m·s⁻¹) for each second it falls.
 - When a body is **dropped** (i.e. when it **falls from rest**), it has an initial downwards velocity of **u = 0 m·s⁻¹**.
 - If a body is **thrown downwards**, both the downward acceleration **and** its initial velocity must be taken into account.

In the case of motion under the effect of the Earth's gravitational field near the Earth, the three equations for motion in a straight line with a constant acceleration apply. They can be rewritten as:

$$v = u + gt \quad [1] \quad (v = gt \text{ if } u = 0 \text{ m}\cdot\text{s}^{-1})$$

$$h = ut + \frac{1}{2}gt^2 \quad [2] \quad (h = \frac{1}{2}gt^2 \text{ and } t = \sqrt{2gh} \text{ if } u = 0 \text{ m}\cdot\text{s}^{-1})$$

$$v^2 = u^2 + 2gh \quad [3] \quad (v^2 = 2gh \text{ if } u = 0 \text{ m}\cdot\text{s}^{-1})$$

$$(u = v_i; V = v_f; h = y; t = \Delta t.)$$



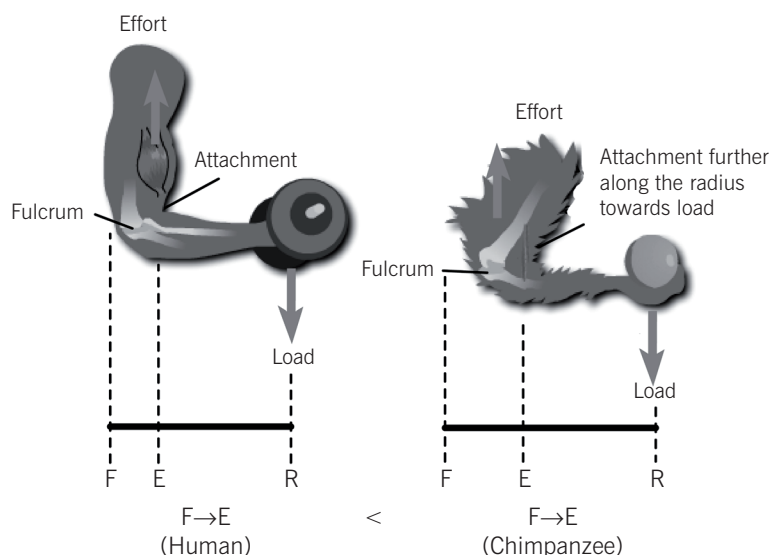
Lesson 5

- Use this table to check on the type of lever and the mechanical advantages.

		Middle		Mechanical advantage
First-class lever	E	F	R	$>1, =1$ or $<1 \dots$ depending on where the fulcrum is positioned
Second-class lever	E	R	F	Always >1
Third-class lever	F	E	R	Always <1

- The bicep muscle in the arm is an important example of third-class levers and this example, in particular, should be studied well. Chimpanzees' arms are much stronger than their human counterparts because the attachment of the biceptal tendon is further down the forearm than in the human arm. (In fact, a full-grown chimpanzee's biceptal muscle mass is only about one-third that of a human, adult male.)

A comparison of relative strengths purely on the basis of muscle mass would tell us that humans are, on average, three times as strong as chimpanzees. The fact that they are not tells us about the importance of the relative lengths of effort arms and resistance arms when calculating the relative effectiveness of levers.



Lessons 6 and 7

Bear in mind, when dealing with ideal gases later in the year, that the speed of sound c depends on temperature only, and **not on the pressure or density** (as these change in lockstep with a given temperature and cancel out). Air is almost an ideal gas. The temperature of the air varies with altitude, giving the following variations in the speed of sound if we assume standard atmospheric conditions.

The notes below are taken from the NCS-FET content document. Lessons 6 & 7 have dealt with the nature of wave phenomena and the development of the wave equation. What follows here are extensions and applications of the basic concepts. A solid understanding of waves and wave nature will assist learners in their efforts to understand these applications.

Longitudinal waves

- Explain the relationship between wave speed and the properties of the medium in which the wave travels (gas, liquid or solid). Learners should understand



that sounds waves are pressure waves. For this reason, the more closely spaced the molecules of the medium, the faster the wave travels. That is why sound travels faster in water than in air and faster in steel than in water.

This statement on Longitudinal waves is disputed on the website Wikipedia. An abridged extract from Wikipedia follows and sets out some of the finer details of the physics behind the speed of sound in dense material mediums which the NCS statement obfuscates.

At worst, the NCS statement is quite wrong. At best, it is guilty of well-intentioned over-statement, i.e. repeating “common knowledge” that is often peddled in textbooks because it gives a plausible explanation and approximately correct answers and is therefore deemed “good enough for school purposes”. But, in doing this, the statement is guilty of ignoring a scientific verity – one which should not be omitted from high-school textbooks. The verity is that if we want to be “scientific” we should never state with too much conviction a presumed “scientific truth” when, in all likelihood, the situation is more subtle than we are saying, even if we don’t know it yet. For sure, it is impossible to go into all the detail and subtlety of every theory at high school or even undergraduate level. But the fact that we can use good approximations of theories and get credible results from the approximations is no excuse for not acknowledging that they are just that: approximations.

To pass an approximation off as being definitive obscures that important feature of science as an enterprise of the human intellect that proceeds by “conjecture and refutation”, as Karl Popper puts it. The very power of scientific theory lies in our acknowledgement of its fragility and fallibility. This procedural habit aims to keep science on its toes and thus ever open to more powerful theories about the workings of nature. So, while it is absurd to add too much subtle detail into high school science, we should never hide the real nature of science when presented with opportunities to do so.

ABRIDGED WIKIPEDIA EXTRACT:

The transmission of sound can be explained using a **toy model**. *(In physics, a toy model is a simplified set of ... equations ... that can nevertheless be used to understand a mechanism that is also useful in the full, non-simplified theory. In “toy” mathematical models, this is usually done by reducing the number of dimensions or reducing the number of ... variables ... In “toy” physical descriptions, an everyday example of an analogous mechanism is often used to illustrate an effect in order to make the phenomenon easier to visualise. An example of “toy models” in physics might be describing orbital mechanics by assuming that the Earth is attached to the Sun by a large elastic band.)*

A **“Tinker-toy model”** is sometimes used (to explain the speed of sound in solids) ... Tinker-toys consist of an array of balls interconnected by springs. (For a real material, the balls represent atoms or molecules and the springs represent the bonds between them.) Sound passes through the model by compressing and expanding the springs, transmitting energy to neighbouring balls, which [then] transmit energy to *their* springs, and so on. The speed of sound through the model depends on the stiffness of the springs. **Stiffer springs transmit energy more quickly.**

For a real material, the **stiffness of the springs** (bonds) is called the **elastic modulus** and the **mass** corresponds to the **density**. **All other things being equal, sound will travel more slowly in denser materials, and faster in stiffer ones.** (NOTE: compare this statement with the one underlined in the NCS statement above.)

For instance, sound will travel faster in aluminium than uranium, and faster in hydrogen than nitrogen, **because of the lower density of the first material of**

each set. At the same time, sound will travel faster in aluminium than hydrogen, because the internal bonds in a solid such as aluminium are much stronger (stiffer) than the gaseous bonds between hydrogen molecules. In general, solids will have a higher speed of sound than liquids, and liquids will have a higher speed of sound than gases. (NOTE: the conclusion is the same as stated in the NCS document but the statement clearly ignores the subtleties outlined in the Wikipedia article.)

Some textbooks mistakenly state [or imply] **that the speed of sound increases with increasing density. This is usually illustrated by presenting data for three materials, such as air, water and steel. With only these three examples, it indeed appears that speed is correlated to density, yet including only a few more examples would show this assumption to be incorrect.**

In general, the speed of sound c is given as: $c = \sqrt{\frac{C}{r}}$

where C is a **coefficient of stiffness** and r is the **density**.

Thus, noting that c is proportional to $C^{1/2}$ and inversely proportional to $r^{1/2}$, we see that the speed of sound **increases with the stiffness of the material**, and **decreases with the density**.

CONCLUDING NOTE: It is generally held to be true that the speed of sound in solids is greater than the speed of sound in liquids or in gases. But, as we have seen, it is clearly wrong to use the statement $c_{\text{STEEL}} > c_{\text{WATER}} > c_{\text{AIR}}$ to prove that speed of sound is dependent on density. The implication of the proposition that **“the more closely spaced the molecules of the medium, the faster the wave travels”**, as used in the NCS statement, is that density is responsible for increasing speed of sound and not the stiffness of intermolecular bonds. Along with the increasing density of air to water to steel comes the increasing stiffness of the bonds between atoms/molecules and it is this and not density that is behind the increase. As the Wikipedia extract implies, the relationship between speed of sound and density must be tested within one type of material.

Interestingly, what we have here is the error committed when we assume that correlation implies cause and effect. In the materials selected, we see a positive correlation between speed of sound and density. **But this is not a fair scientific test.**

WHAT IS NOT COVERED IN THE WORKBOOK FOR THIS SECTION OF THE CURRICULUM:

Pitch, loudness and quality (tone) of sound

- Relate the pitch of a sound to the frequency of a sound wave.
- Relate the loudness of a sound to both the amplitude of a sound wave and the sensitivity of the human ear.
- Relate the quality of a sound to the harmonics that are superposed in a given sound wave. The human ear is more sensitive to some frequencies than to others. Loudness thus depends on both the amplitude of a sound wave and its frequency (whether it lies in a region where the ear is more or less sensitive).
- Make a link between the quality of the sound and the standing waves produced in different musical instruments. The quality of the sound produced by a particular instrument depends on which harmonics are superposed and in which proportions.



Physics of the ear and hearing

- Identify the important features in a simple diagram of the human ear showing the outer ear, eardrum, ear canal, ossicles, inner ear and auditory nerve.
- Refer to the features listed above to explain how sound is transmitted from the outer ear to the auditory nerve, from where a signal is sent to the brain.
- State that the intensity of sound is measured in decibels (dB).
- Indicate the relative intensities of a variety of sounds
- Explain the dangers of exposure to very loud sounds and what can be done to reduce these dangers.
- Learners should get a table of intensities for a variety of different sounds. They should understand that permanent damage can be caused by exposure to very loud sounds. This is an opportunity to discuss the importance of safety equipment such as ear protectors for workers in loud environments, e.g. those who use jackhammers or direct airplanes to their parking bays.

Ultrasound

- Describe sound with frequencies higher than 2kHz as ultrasound, up to about 100 kHz.
- Explain how an image can be created using ultrasound based on the fact that when a wave encounters a boundary between two mediums, part of the wave is reflected and part is transmitted.
- Describe some of the medical benefits and uses of ultrasound, e.g. safety, diagnosis, treatment, pregnancy.
- Make a link to Grade 10 reflection and transmission at a boundary. When an ultrasound wave travels inside an object comprising different materials such as the human body, each time it encounters a boundary, e.g. between bone and muscle, or muscle and fat, part of the wave is reflected and part of it is transmitted. The reflected rays are detected and used to construct an image of the object.

Physics of music

- Standing waves in different kinds of instruments.
- Describe how sounds are produced in string and wind instruments in terms of standing waves.
- Draw pictures to show the fundamental and higher frequency harmonics for standing waves on a string fixed at both ends and in pipes either open at one end or open at both ends.
- Calculate the frequency and wavelength for various harmonics for different wind and string instruments.
- Make a link to Grade 10 standing waves with different boundary conditions. The boundary conditions for a string fixed at both ends are that there must be nodes at both ends. For a pipe open at one end and closed at the other, there must be an antinode at one end and a node at the other. For a pipe open at both ends, there must be antinodes at both ends.



Lesson 8

- The ray diagrams will make more sense when learners have had the opportunity to play with lenses and see how images can be formed.
- Remember that the image is what we actually see through a lens. In the case of a virtual image, we can see it but it cannot be projected.
- The old trick of setting a piece of paper alight using a lens demonstrates the focal length of the lens in a most dramatic way. But there is a slight hitch. The electromagnetic radiation that causes the paper to char and burn is not the light, as such, but the infrared radiation whose wavelength is longer than that of red light. So, when the paper begins to char, the dot of light looks slightly blurred because we are focusing rays that can't be seen even though their effect can!
- Geometry is now an optional topic in NCS Mathematics so it might not be possible to take as strong a geometrical approach to this topic if the learners are not familiar with basic geometry.

Lessons 9–10

Formulae for electrostatics

$F = \frac{kQ_1Q_2}{r^2}$	$(k = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2})$	$V = \frac{W}{Q}$
$E = \frac{F}{q}$		$W = QEs$
$E = \frac{kQ}{r^2}$	$(k = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2})$	$E = \frac{V}{d}$
$C = \frac{Q}{V}$		$Q = It$

Make sure that learners understand the meaning and context in which the equations are used. In general, learners will benefit from knowing how equations are derived even though they are not required to do those derivations.

Lessons 11–12

“Constant” and “uniform”

Is there any difference between these two terms that appear to be used interchangeably?

Although the dictionary definitions look rather similar, this author defines the terms in a scientific context as follows: **“constant”** refers to a quantity that does not vary with time. In other words, as time passes, the quantity stays the same. On the other hand, **“uniform”** refers to a quantity that is evenly distributed or of an equal size everywhere in a space (volume), on a plane (area) or along a line.

Using these definitions of the terms, we might speak of a “uniform magnetic field” inside a loop because it has the same strength at every point inside that loop. If it does not change with the passing of time, then it is also constant. The field around a straight piece of conducting wire is not uniform because **B** is greater closer to the wire. If the current in the wire varies then the field will not be constant either.

Is the Earth’s gravitational field constant? Well, we make the assumption that it is but this only holds in relatively small volumes (regions). As a spacecraft travels to



the Moon, it experiences a changing gravitational field so it is not really uniform. But the field strength at a fixed point does not change, so the field is constant.

In the exemplar exam question, the word “uniformly” is used in another sense: that of “steadily” or “evenly” or “at a fixed rate”. The idea here is that if the magnetic field changes “*to zero uniformly in a time of 10^{-4} s*” then it is changing at a steady rate.

Using this section

Thinking of three-dimensional space and then interactions in that space is not easy. The task is made more difficult when all we have is verbal descriptions and formulae. In this lesson, there is a fair amount of description. But the developing story of electromagnetism has been set out in easy-to-follow, logical steps. A learner who reads through the sequence of steps and follows the explanations (and formulae, where applicable) should gain an understanding of basic electromagnetic interactions. Most of this material lays a foundation for Grade 12 work.

Superposition

The section on superposition applies to many areas of physics. It is applicable to light and becomes very important in Grade 12 when learners must come to grips with the concept of interference and interference patterns in light and other wave phenomena.

Lessons 13–14

There are many circuit problems to be found in textbooks and study guides. The best way to become proficient at circuit problems is to do many of them. This lesson has concentrated on understanding the basic principles and processes. Circuit problems can be done quite mechanically and procedurally, most of the time. But, every once in a while, examiners come up with a really innovative problem which can only be solved with a real understanding of the processes. This is where we aim to take our learners.

An inclusion in the content prescription is the Wheatstone bridge. It is a rather old instrument and there are probably very few still in use. Yet the principle underlying the Wheatstone bridge is still used. Understanding the principle behind its operation requires an understanding of potential difference, why charge flows and how the magnitudes of currents in the arms of a parallel arrangement of resistors can be determined.

Show learners how the bridge is constructed and tell them its purpose. Then let them study the instrument singly or in small groups. Once they have explained its operation satisfactorily, one can be sure that they have a fair grasp of things electrical!

THE WHEATSTONE BRIDGE

Function

To make precise measurements of resistance.

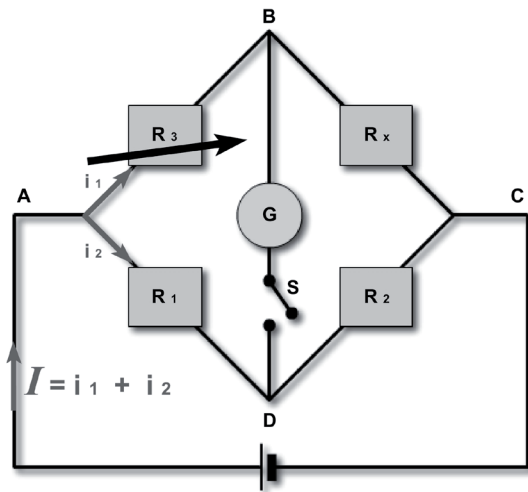
Construction

- Four resistances arranged in parallel.
- A galvanometer (G) – which is an instrument used to detect very small electrical currents – is connected across the parallel arrangement and can be seen to be functioning as “the bridge”.
- Two fixed resistances (R_1 and R_2), whose values are very accurately known.



- A variable resistor (R_3), whose value can be accurately determined.
- An unknown resistor (R_x), whose value is to be determined.
- A battery.

Diagram



Operation

- An unknown resistance, R_x , is connected as shown.
- When the switch, S, is closed, the galvanometer, G, will register a current in the arm BD. (Depending on which direction the galvanometer needle deflects, one can tell whether the flow of charge is from B to D or from D to B.)
- The variable resistor, R_3 , is adjusted until the galvanometer deflection is zero.
- When this happens we know there is no potential difference between the points B and D, i.e. $V_{BD} = 0$ V (and hence there is no current between B and D).

Explanation

- We know that the potential drop across each arm of resistances in parallel will be equal

$$\text{So: } i_1 (R_3 + R_x) = i_2 (R_1 + R_2)$$

- When there is no galvanometer deflection (i.e. $I_{BD} = 0$ A) then the potential difference is $V_{BD} = 0$ V. We can also say that the potentials at points B and D are equal, i.e.

$$V_B = V_D$$

$$V_A - i_1 \cdot R_3 = V_A - i_2 \cdot R_1$$

$$i_1 \cdot R_3 = i_2 \cdot R_1$$

$$i_1 = i_2 \cdot (R_1/R_3) \quad \dots \text{Eq 1}$$

- Because point C is common to both arms (they join there), we can say that:

$$V_B - i_1 \cdot R_x = V_C$$

$$\text{and } V_D - i_2 \cdot R_2 = V_C$$

So by subtracting we get:

$$V_B - V_D - i_1 \cdot R_x + i_2 \cdot R_2 = 0$$

$$-i_1 \cdot R_x = -i_2 \cdot R_2$$

$$i_1 = i_2 \cdot (R_2/R_x) \quad \dots \text{Eq 2}$$

If we equate Eq 1 and Eq 2, we get:

$$i_2 \cdot (R_1/R_3) = i_2 \cdot (R_2/R_x)$$



$$R_1/R_3 = R_2/R_x \text{ and}$$

$$R_x = R_3 \times (R_2/R_1)$$

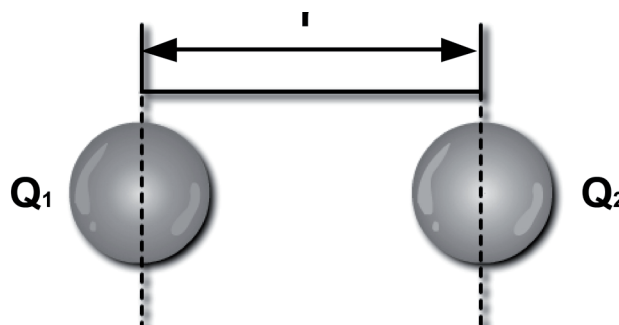
- This relationship tells us that the unknown resistance can be calculated by knowing the accurate values of R_3 , R_2 and R_1 .

Lessons 15 and 16

Wherever possible try to relate chemical concepts to the basic physics concepts the learners have studied. A good example of this arises in the section on bonding.

BONDS

Refresh your memory on the electrostatic force in Lesson 9:



We write Coulomb's Law as $F = \frac{k \cdot Q_1 \cdot Q_2}{r^2}$

The value of the proportionality constant, **k**, reminds us how strong the electrostatic force is. The strength of materials (wood and plastic, for instance) is the result of the strength of the bonds between atoms and molecules.

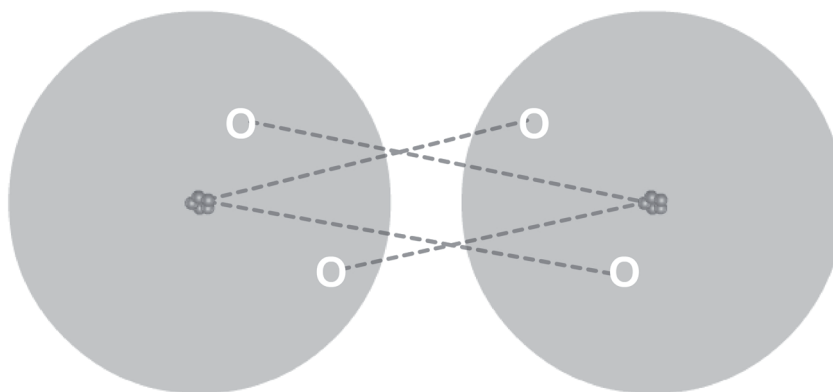
The origin of the strength of an atomic bond can now be seen:

The dotted lines represent forces of attraction between the electrons from one atom and the nucleus of another atom.

The electrons are moving constantly but they position themselves between the nuclei so that the average force between the two atoms is attractive.

The repulsive forces between nuclei and among the electrons have not been shown as they will be weaker than the attractive forces.

The more electron pairs that are involved in the bond between two atoms, the stronger the bond.



MECHANICAL (CONTACT) FORCES

When you sit on a chair, why don't you fall through it? After all, Earth's gravity attracts you towards its centre so you exert a downward force on the chair seat.



The answer is that the chair exerts an equal and opposite reaction to the action that you exert on it. And the reason that the chair can exert a force is that it has the strength to do so. What we refer to as the strength of the chair comes down to the strength of the bonds between molecules in the wood or the plastic of the chair seat.

Lessons 17 and 18

Background notes on Van der Waals forces, the forces on electrons in molecules, bonds and the shapes of molecules and ions.

These teacher notes have been adapted from Wikipedia, the free, open-source, web-based encyclopedia. For more detailed information, do a search of Wikipedia starting from en.wikipedia.org/wiki/Main_Page. For great graphics that illustrate what happens when molecules interact through the London forces between them, see antoine.frostburg.edu/chem/senese/101/liquids/faq/h-bonding-vs-london-forces.shtml. Underlined words can be used in searches on the Wikipedia site.

In early 20th-century [chemistry](#), the term **Van der Waals force** (no apostrophe) referred to all forms of [intermolecular forces](#). But in modern usage it tends to refer to inter-molecular forces caused by the polarisation of molecules. On a more advanced level, all forces that deal with dipoles and shifts in electron cloud distribution ([London forces](#)) are named after the Dutch chemist [Johannes Diderik van der Waals](#) who first documented these interactions.

Intermolecular forces = *Van der Waals + intermolecular covalent + intermolecular ionic (the later two are rare) and*

Van der Waals forces = *London (induced dipole-induced dipole) force + dipole-dipole force + dipole-induced dipole.*

Van der Waals interactions are even observed in [noble gases](#), which are very stable and tend not to interact. This is why it is difficult to [condense](#) them into [liquids](#). But the larger the [atom](#) of the noble gas (the more electrons it has), the easier it is to condense the gas into a liquid. This happens because when the [electron cloud](#) surrounding the gas atom gets large, it does not form a perfect sphere around the [nucleus](#). Rather, it's only spherical if averaged over longer times and generally forms an [oval](#), which has a slight negative charge on one side and a slight positive charge on the other. Thus the atoms become temporary dipoles. When one temporary dipole like this induces the same shift in the electron clouds of neighboring atoms, the effect can spread from one atom to the next. Unlike charges attract and the induced dipoles are held together by this Van der Waals (or dispersion) force, also known as London forces.

The Van der Waals force is the force to which the [gecko](#)'s climbing ability is attributed. A gecko can hang on a glass surface using only one toe. Efforts continue to create a synthetic "gecko tape" that exploits this knowledge. So far research has produced some promising results, including an [adhesive tape](#) product which claims to provide an adhesive force 200 times the adhesive force of natural materials.

London forces, named after the German physicist [Fritz London](#), are weak [intermolecular forces](#) that arise from the attractive force between temporary [dipoles](#) in [molecules](#) that do not have permanent polarity. London forces are also called **dispersion forces** and, as shown above, are included among the **Van der Waals forces**. London forces can be exhibited by non-polar molecules because of the way the electron density about a molecule is able to shift and change shape.



There is always a good chance that the electron density will not be evenly distributed throughout (or around) a non-polar molecule. When an uneven distribution occurs (for instance, when the electron cloud is knocked out of shape by another molecule that approaches it closely) a temporary polar molecule can be created. This dipole may interact with other nearby dipoles.

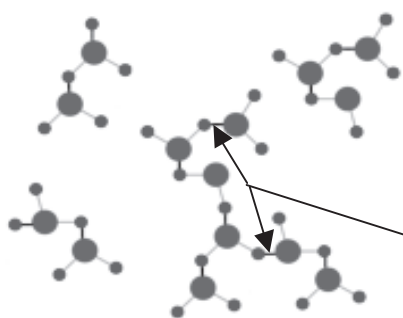
When a one molecule approaches another whose [electron](#) cloud has already been redistributed (knocked or forced out of shape to produce a polar molecule), electrons will gather on the side of a molecule that faces the positive charge on the polar molecule or retreat from the negatively charged side. Hence, a transient (“temporary” or “fleeting” or “fleetingly temporary”) polar molecule can be produced by a nearby polar molecule or even another transient dipole in another non-polar molecule.

London forces are weaker than other [intermolecular forces](#) such as ionic interactions, [hydrogen bonding](#) or permanent dipole-dipole interactions. This phenomenon is the only attractive intermolecular force at large distances present between neutral atoms (e.g. [helium](#)), and is the major attractive force between non-polar molecules such as [nitrogen](#) or [methane](#). Without London forces, there would be no attractive force between [noble gas](#) atoms and they could not then be obtained in a liquid form. Helium, the smallest of the noble gases, is the last to go into the liquid phase and only within a fraction of a Kelvin away from absolute zero.

London forces become stronger as the atom (or molecule) in question becomes larger. As explained above, this is because of the increased polarisability of molecules with larger electron clouds. This trend is also seen in the [halogens](#) (from smallest, F_2 through Cl_2 and Br_2 to the largest that we encounter naturally: I_2). [Fluorine](#) and [chlorine](#) are [gases](#) at room temperature, [bromine](#) is a liquid and [iodine](#) is a solid.

More electrons in a molecule or atom means potentially larger electron imbalances and so stronger London forces. This nicely explains the periodic trend in boiling points for the noble gases: Ne boils at a much lower temperature than Xe because, having fewer electrons, its London forces are more easily overcome by thermal motion. It also explains why high-molecular weight, non-polar compounds tend to be solids or liquids while light non-polar compounds tend to be gases. A high molecular weight generally means more electrons that can be knocked, pushed or pulled out of shape and hence the stronger the London attractions possible.

Hydrogen bonding



Hydrogen bonds between water molecules are represented by the lines indicated by the arrows. The lighter lines are covalent bonds that hold oxygen (larger circles) and hydrogen (smaller circles) atoms together in the water molecules.

H–O hydrogen bonds like these are responsible for the well-known hexagonal crystals found in ice.

In [chemistry](#), a **hydrogen bond** is a type of attractive [intermolecular force](#) that exists between two [partial electric charges](#) of opposite polarity. Although stronger than most other intermolecular forces, **the typical hydrogen bond is much weaker than either the [ionic bond](#) or the [covalent bond](#)**. Within [macromolecules](#)

such as [proteins](#) and [nucleic acids](#), it can exist between two parts of the same molecule and has important effects on such molecules' overall shape.

As the name “hydrogen bond” implies, one part of the bond involves a [hydrogen atom](#). The hydrogen must be attached to a strongly [electronegative](#) atom (obviously of another element such as [oxygen](#), [nitrogen](#) or [fluorine](#)). The electronegative element attracts the electron cloud from around the hydrogen nucleus and, by distorting the cloud, leaves the atom with a partial positive charge. Because of the small size of hydrogen relative to other atoms and molecules, the resulting charge, though only partial, nevertheless represents a large charge density. A hydrogen bond results when this strong positive charge density around the hydrogen then, in turn, attracts a [lone pair](#) of electrons from another atom.

Yet **hydrogen bonds are not like simple attractions between point charges**. The hydrogen bond can be shown to have some of the characteristics of a covalent bond, i.e. there is a certain degree of “sharing” (of the lone pair of electrons) between the hydrogen atom that has had its electron cloud pulled away by the highly electronegative atom it is attached to and the atom that provides the lone pair of electrons. The best example, and the easiest to understand, is water.

Hydrogen bonds can vary in strength from very weak ($1\text{--}2\text{ kJ mol}^{-1}$) to so strong (40 kJ mol^{-1}) that it is indistinguishable from a covalent bond, e.g. as in the ion HF_2^- . This is literally the amount of energy needed (or the work that must be done) in order to break the bonds. Because we are dealing with very tiny particles and tiny (though relatively strong) forces, it is convenient to measure the total energies required for a mole ($6,023 \times 10^{23}$) of bonds. Typical values include:

- $\text{O-H}\cdots\text{N}$ ($7\text{ kcal}\cdot\text{mol}^{-1}$) ($1\text{ kJ} = \text{kcal}$)
- $\text{O-H}\cdots\text{O}$ ($5\text{ kcal}\cdot\text{mol}^{-1}$)
- $\text{N-H}\cdots\text{N}$ ($3\text{ kcal}\cdot\text{mol}^{-1}$)
- $\text{N-H}\cdots\text{O}$ ($2\text{ kcal}\cdot\text{mol}^{-1}$)

Hydrogen bonds in water

The most common example of a hydrogen bond is found between [water](#) molecules which have two hydrogen atoms and one oxygen atom. Two molecules of water can form a hydrogen bond between them. The oxygen of one water molecule has two lone pairs of electrons, each of which can form a hydrogen bond with hydrogens on two other water molecules. This repeats so that every water molecule is H-bonded with four other molecules (two through its two lone pairs, and two through its two hydrogen atoms).

[Liquid](#) water's high [boiling point](#) (100°C) is caused by this high number of hydrogen bonds each molecule can have relative to its low [molecular mass](#). Water is unique in that its oxygen atom, with its two lone pairs, and its two hydrogen atoms can form four hydrogen bonds per molecule. Hydrogen bromide, for example, has two lone pairs on the Br atom but only one H atom and therefore can have a total of only two bonds. (Verify this using Lewis diagrams)

In pure water at [standard temperature and pressure](#), very low numbers of water molecules form two [polyatomic ions](#) of opposite charge, specifically a [hydroxide](#) ion and an [hydronium](#) H-O^- and H_3O^+ . On average about one in every 5.5×10^8 molecules gives up a proton to another water molecule, thus forming OH^- and H_3O^+ .

Hydrogen bond in proteins

Hydrogen bonding also plays an important role in determining the three-dimensional structures adopted by proteins and nucleic acids. In these macro-



molecules, bonding between parts of the same macro-molecule cause it to fold into a specific shape, which helps determine the molecule's physiological or biochemical role. The double helical structure of [DNA](#), for example, is largely because of hydrogen bonding between the [base pairs](#), which link one complementary strand to the other and enable [replication](#).

A further note on electronegativity

Electronegativity (**e'neg**) is a measure of the ability of an atom or molecule to attract electrons that participate in a chemical bond. The type of bond formed between two atoms is largely determined by the e'neg difference between them. Atoms with similar e'neg values constantly "steal" an electron from each other (misleadingly referred to as "sharing") and form [covalent bonds](#). If the difference is large enough, the electron is permanently transferred from one atom to another atom and an ionic bond will form. Furthermore, if one atom pulls slightly harder than the other on the electrons involved in a covalent bond, a [polar covalent bond](#) forms. Bonds between atoms with a large e'neg difference (≥ 1.7) are usually considered to be [ionic](#). Values **between 1.7 and 0.4** are considered **polar covalent**. Values < 0.4 are considered **non-polar covalent**, and an e'neg diff of 0 (e.g. H – H) indicates a completely non-polar covalent bond.

Electronegativity trends

In general, the degree of electronegativity decreases down the groups and increases across the periods, as shown below. Down a group, the nuclear charge has less effect on the outermost shells. Therefore, the most electronegative atoms can be found in the upper right-hand side of the periodic table, and the least electronegative elements can be found at the bottom left. [As atomic radius decreases](#) → **electronegativity increases**.

Group	[1]	[2]										[3]	[4]	[5]	[6]	[7]	[8]	
Period																		
1	H 2.20																He	
2	Li 0.98	Be 1.57										B 2.04	C 2.55	N 3.04	O 3.44	F 3.98	Ne	
3	Na 0.93	Mg 1.31										Al 1.61	Si 1.90	P 2.19	S 2.58	Cl 3.16	Ar	
4	K 0.82	Ca 1.00	Sc 1.36	Ti 1.54	V 1.63	Cr 1.66	Mn 1.55	Fe 1.83	Co 1.88	Ni 1.91	Cu 1.90	Zn 1.65	Ga 1.81	Ge 2.01	As 2.18	Se 2.55	Br 2.96	Kr 3.00
5	Rb 0.82	Sr 0.95	Y 1.22	Zr 1.33	Nb 1.6	Mo 2.16	Tc 1.9	Ru 2.2	Rh 2.28	Pd 2.20	Ag 1.93	Cd 1.69	In 1.78	Sn 1.96	Sb 2.05	Te 2.1	I 2.66	Xe 2.6
6	Cs 0.79	Ba 0.89	Lu 1.27	Hf 1.3	Ta 1.5	W 2.36	Re 1.9	Os 2.2	Ir 2.20	Pt 2.28	Au 2.54	Hg 2.00	Tl 1.62	Pb 2.33	Bi 2.02	Po 2.0	At 2.2	Rn
7	Fr 0.7	Ra 0.9	Lr	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo

NOTE:

By knowing how to use the information in this periodic table, the basic characteristics of almost any bond between two atoms can be determined.

Note: The elements from 112(Uub) to 118(Uuo) have not been officially discovered yet. Nor have they been officially named. For the time being, therefore, they have been given the names: "Un Uu bium" (meaning one one two-ium", "one one three-ium" ... and "one one eight-ium" i.e. bi-, tri- ... and oct."

Lessons 19 and 20

Investigating nuclear reactions is fun and relatively simple because the calculations involve little more than basic arithmetic. There are many websites that provide useful teaching materials and tables of data. Below are three such websites. Also search for topics in nuclear physics on Wikipedia and Google, where a wealth of exciting material can be found.

www.lon-capa.org/~mmp/kap30/Nuclear/nuc.htm

<http://ithacasciencezone.com/chemzone/lessons/11nuclear/nuclear.htm>

www.unit5.org/christjs/Half-Life/Table.htm

Lessons 21 and 22

An important gas law which is seldom taught together with the other gas laws is known either by **Avogadro's law** or **hypothesis** or **principle**. It is a gas law as much as Boyle's or Charles' laws. In 1811 Amedeo Avogadro wrote that *equal volumes of gases, at the same temperature and pressure, contain the same number of particles, or molecules*.

Avogadro's law is very important because it provides the missing piece in the process of combining the other three gas laws into one ideal gas law. An implication of Avogadro's law is that his relationship holds for a specific number of gas molecules in a specific volume of gas and that the actual size or mass of the gas molecules is irrelevant. Hence equal volumes of carbon dioxide (molecular mass of 44u) and hydrogen (molecular mass 2u) will contain exactly the same number of gas molecules, as long as they are at the same temperature and pressure.

Similarly to the way the other laws were written mathematically, we can say that:

$$\mathbf{V = n \times k_4}$$

and ... $\frac{V}{n} = k_4$

i.e. $\frac{V_1}{n_1} = \frac{V_2}{n_2}$

If the kind of gas is kept the same and the number of gas molecules is increased by a certain factor, then the volume of the gas will increase by the same factor provided that the pressure and temperature are kept constant.

Avogadro's law leads to the concept of "molar gas volume" – see Lessons 15 and 16 – namely that *for all gases at STP, one mole of a gas will occupy a volume of exactly 22,4 dm³*.

STP is 0°C (**273 K**) and atmospheric pressure (101,3kPa or **1,013 × 10⁵ Pa**).

Atmospheric pressure is also referred to as 1 bar (the unit still used in some petrol stations) or 1 atm.



Lessons 23 to 27

This table gives:

- the valencies of familiar elements and
- the charges on their common ions.

It also gives:

- the charges on various common radicals and, where metals are found in more than one oxidation state, the table gives:
- the name given to the metal ion from the metal.

Forms one bond		Forms two bonds		Forms three bonds		Forms four bonds	
Valency	1 (+)	Valency	2 (+)	Valency	3 (+)	Valency	4 (+)
Ionic charge	+1	Ionic charge	+2	Ionic charge	+3	Ionic charge	+4
H	hydrogen	Be	beryllium	Al	aluminium	C	carbon
Li	lithium	Mg	magnesium	Cr	chromium	Si	silicon
Na	sodium	Ca	calcium				(Note: C and Si will normally share electrons, i.e. not give up or accept e ⁻ in ionic-type bonds.)
Ag	silver	Ba	barium				
		Zn	zinc				
Cu	copper (I)	Mn	manganese (II)	Fe	iron (III)		
Hg	mercury (I)	Fe	iron (II)				
		Cu	copper (II)				
		Hg	mercury (II)				
		Pb	lead (II)				
Cu ⁺	cuprous -	Mn ²⁺	manganous -	Fe ³⁺	ferric -	Mn ⁴⁺	manganic -
Hg ⁺	mercurous -	Fe ²⁺	ferrous -			Pb ⁴⁺	plumbic -
		Cu ²⁺	cupric -				
		Hg ²⁺	mercuric -				
		Pb ²⁺	plumbous -				
NH ₄ ⁺	ammonium						
Valency	1 (-)	Valency	2 (-)	Valency	3 (-)	Valency	4 (-)
Ionic charge	-1	Ionic charge	-2	Ionic charge	-3	Ionic charge	-4
F	fluorine	oxygen		N	nitrogen		
Cl	chlorine	S	sulphur	P	phosphorus		
Br	bromine						
I	iodine						
H ⁻	hydride	O ²⁻	oxide	N ³⁻	nitride		
F ⁻	fluoride	S ²⁻	sulphide	P ³⁻	phosphide		
Cl ⁻	chloride						
Br ⁻	bromide						
I ⁻	iodide						
MnO ₄ ⁻	permanganate			PO ₄ ³⁻	phosphate		
NO ₂ ⁻	nitrite						
NO ₃ ⁻	nitrate						
HSO ₃ ⁻	hydrogen sulphite	SO ₃ ²⁻	sulphite				
HSO ₄ ⁻	hydrogen sulphate	SO ₄ ²⁻	sulphate				
		CO ₃ ²⁻	carbonate				
		CrO ₄ ²⁻	chromate				
		Cr ₂ O ₇ ²⁻	dichromate				
HCO ₃ ⁻	hydrogen carbonate						
OH ⁻	hydroxide						
BrO ₃ ⁻	bromate						
ClO ₃ ⁻	chlorate						
IO ₃ ⁻	iodate						
CH ₃ COO ⁻	acetate						
(COO) ₂ ²⁻	oxalate						



When naming compounds we usually give

- the name of the positive part of the compound first,

- followed by the negative part, e.g. ammonium nitrate (NH_4NO_3) or hydrogen sulphide (H_2S).

When hydrogen ions (H^+) are joined by a negative radical (e.g. SO_4^{2-}) we get an acid, e.g. H_2SO_4 , or sulphuric acid. The “-ic” suffix tells us that sulphur is in the higher oxidation state (i.e. +6), whereas in sulphurous acid (H_2SO_3) it is in the lower oxidation state (i.e. +4).

(This rule does not apply to H^+ and OH^- which give water when joined.)

The strong acids HBrO_3 (perbromic acid), HClO_3 (perchloric acid) and HIO_3 (periodic acid) all take the prefix “per-“ to show that they have oxygen in the radical and to distinguish them from the more familiar HCl , hydrochloric acid, etc.

Lessons 28 to 30

LO3 in the Physical Sciences curriculum, together with the same learning outcome in the Life Sciences, deals exclusively with science, technology and society (STS) issues. Although STS issues arise throughout the physical and life sciences curricula, it is appropriate to place the section near the end.

Unfortunately, when complex STS issues are debated publicly it usually becomes clear that many people voice opinions – and worse, they build arguments – that are based on a meagre knowledge of the science and technology that underpin these complex issues.

Although the science knowledge of Grade 11 pupils is still at a low level, by the end of Grade 11 they should have sufficient knowledge (and “feel” for scientific argument) to start appreciating the potentially devastating effects of our careless use of the products of scientific and technological advancement. An important attitude to maintain during debates on STS issues, which, typically, generate more “heat” and emotion than the light of reason, is to insist that the facts brought to bear on STS arguments should be both scientifically determined and scientifically verifiable. By this we mean that “scientific facts” are the products of respectable scientific enquiry using appropriate methods and tools AND that they be treated with an appropriate amount of scientific skepticism and reserve until their authenticity and accuracy are publicly demonstrated.

When collecting data, we speak of **reliable** and **valid** measurements or data.

Reliable measurements are those that will give the same results every time, no matter how often one does the particular measurement. Results are **valid** when the measurements taken actually measure what the scientist sets out to measure. **An example of reliability** is using a thermometer to measure the outside temperature. Whenever the temperature is $18,5^\circ\text{C}$, the thermometer will show $18,5^\circ\text{C}$. It is thus a reliable instrument for measuring temperature (at least in that temperature range). Reliability of measurement is the extent to which repeated measurements of some parameter are consistent over time when the conditions remain identical. **An example of validity** could be measuring the outside temperature at 6 o'clock each morning but taking the readings near the outlet of an air conditioner. The outlet will either be pumping out warm or cold air. Either way, the temperature reading will be influenced by the outlet air and cannot therefore be taken as a valid measurement of the outside temperature.

In science “fact” can only mean “confirmed to such a degree that it would be perverse to withhold provisional assent”. I suppose that apples might start to rise tomorrow, but the possibility does not merit equal time in physics classrooms. (Steven J Gould).

The most famous modern philosopher of science, Sir Karl Popper, speaks of “conjecture and refutation” in the progress of scientific study. We build theories



by making conjectures (i.e. by forming hypotheses) and then attempting, through well-designed experiments (the “fair test”), to refute them. The more that a theory can stand up to clever experiments that attempt to knock it down, the more respectable the theory becomes. In fact, to be a really respectable theory in the first place, it should be clear from the very statement of the theory how best to go about disproving it.

Good science sets itself high standards but there have been many celebrated cases of bad and bogus science over the years. Some of these were cases of out-and-out fraud and some of them set back progress in certain branches of science for many years. Of course, when the frauds were uncovered, the knowledge of these also tarnished public perceptions of science.

Your learners can research the following cases:

- Piltdown Man
- Lysenko and Russian genetics
- Cold fusion

Then attempt to answer the question: **Why do scientists commit scientific forgery?**

PORTFOLIO TASK ON DRUGS IN SPORT

Collect newspaper and magazine articles and research past stories on sportspersons who have been in trouble for taking performance-enhancing drugs. Get the learners to keep records of the sports involved and what drugs were taken.

Many of the issues covered in LO3 of the physical and life sciences curriculum overlap with the content of the Life Orientation curriculum. **Scan the web material on Grade 11 Life Orientation. Lessons 28 & 29 deal with ethics in sport (Life Orientation LO3, AS3) and FIFA’s Code of Ethics is investigated.** Obviously, the issue of drugs in sport, which clearly touches all sports and particularly at the professional levels of the game, comes to the fore every year nowadays with the staging of the Tour de France. Events like this which attract huge media attention are useful to teachers as focal points. The question of sports personalities as role models for the young cannot be underestimated. What do the learners of today think of superstars who are exposed for taking performance-enhancing drugs? Does the practice attract derision and anger or is the attitude more *laissez faire*?

This article can be analysed for the issues it raises and used as a starting point.

(Some terms have been highlighted. Learners must understand the meanings of these words.)

Growth in drug cheats lessened by new test

The Star, June 20, 2007

Experts believe a new test to detect human growth hormone may bring sports authorities a step closer to catching doping athletes.

The **blood test** was recently developed by Dr Ken Ho of Sydney’s Garvan Institute of Medical Research with support from the World Anti-Doping Agency (Wada).

“This new test is more sensitive to **human growth hormone** than what we’ve had in the past,” Ho said. “My message to athletes would be to train harder instead of cheating.”

It has been notoriously difficult to identify athletes illegally using human growth hormone. Not only is the hormone naturally produced in the body – making



it harder to detect **synthetic** versions – but the concentrations of it normally circulating in the body vary enormously and can disappear within minutes.

Human growth hormone (HGH) is produced by the **pituitary gland** and helps cells regenerate. Synthetic versions of the **hormone** are routinely prescribed to children with growth problems, or tuberculosis and Aids patients who need to maintain their body weight.

It is also widely taken among some anti-aging advocates since it can improve **skin elasticity**. But improper use of the hormone can lead to problems including the nerve disorder acute **carpal tunnel syndrome**, diabetes and unnatural growth of the bones.

The new test works by finding proteins triggered by the hormone. “We’ve been able to identify **markers** that show abuse by measuring when other hormones and proteins released by human growth hormone reach certain levels,” said Dr Olivier Rabin, Wada’s science director. Rabin said that these biological markers are not affected by any other differences between athletes, such as **ethnicity, gender, or physiology**.

Wada has already introduced another test which identifies the synthetic version of human growth hormone in the body on a limited scale. That test was in place at the Athens and Turin Olympic Games. The agency hopes to use both tests together to maximise their chances of detection. But finding cheating athletes on a large scale will be difficult since the hormone can be detected only in blood – only **trace amounts** are present in urine. And blood tests are not used as regularly as **urine tests**.

While designing the new test, Ho and his colleagues also made another interesting discovery: human growth hormone doesn’t work on its own. In their research, they looked at the effects produced by human growth hormone on its own and in combination with testosterone in nearly 100 **recreational athletes**.

In the study, 64 men were given either a **placebo**, human growth hormone, testosterone, or a combination of the latter two for eight weeks. In the other half of the study, 33 women were given a placebo or the growth hormone for eight weeks. Their physical performances were then tested in various categories.

“We found that growth hormone does not increase **muscle mass** or improve performance,” Ho said.

“Only when you combine growth hormone with testosterone does it have an effect,” he said. When taken together, the two substances have a synergistic effect, lowering the **body’s fluid and fat levels** while building muscle. – **Sapa-AP**



