Interesting Science fact #9

When Helium is cooled to almost absolute zero [-460°F or -273°C], the lowest temperature possible, it becomes a liquid with surprising properties: it flows against gravity and will start running up and over the lip of a glass container!

PHYSICAL SCIENCES

Content Booklet:
Targeted Support

GRADE 12 TERM 2

A MESSAGE FROM THE NECT

National Education Collaboration trust (NECT)

Dear Teachers,

This learning programme and training is provided by the National Education Collaboration Trust (NECT) on behalf of the Department of Basic Education (DBE)! We hope that this programme provides you with additional skills, methodologies and content knowledge that you can use to teach your learners more effectively.

What is NECT?

In 2012 our government launched the National Development Plan (NDP) as a way to eliminate poverty and reduce inequality by the year 2030. Improving education is an important goal in the NDP which states that 90% of learners will pass Maths, Science and languages with at least 50% by 2030. This is a very ambitious goal for the DBE to achieve on its own, so the NECT was established in 2015 to assist in improving education.

The NECT has successfully brought together groups of people interested in education so that we can work collaboratively to improve education. These groups include the teacher unions, businesses, religious groups, trusts, foundations and NGOs.

What are the learning programmes?

One of the programmes that the NECT implements on behalf of the DBE is the 'District Development Programme'. This programme works directly with district officials, principals, teachers, parents and learners; you are all part of this programme!

The programme began in 2015 with a small group of schools called the Fresh Start Schools (FSS). Curriculum learning programmes were developed for Maths, Science and Language teachers in FSS who received training and support on their implementation. The FSS teachers remain part of the programme, and we encourage them to mentor and share their experience with other teachers.

The FSS helped the DBE trial the NECT learning programmes so that they could be improved and used by many more teachers. NECT has already begun this scale-up process in its Universalisation Programme and in its Provincialisation Programme.

Everyone using the learning programmes comes from one of these groups; but you are now brought together in the spirit of collaboration that defines the manner in which the NECT works. Teachers with more experience using the learning programmes will deepen their knowledge and understanding, while some teachers will be experiencing the learning programmes for the first time.

LET'S WORK TOGETHER CONSTRUCTIVELY IN THE SPIRIT OF
COLLABORATION SO THAT WE CAN HELP SOUTH AFRICA ELIMINATE
POVERTY AND IMPROVE EDUCATION!

www.nect.org.za

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PROGRAMME ORIENTATION

Welcome to the NECT Physical Sciences learning programme! This CAPS compliant programme consists of:

- A Content Booklet: Targeted Support
- A Worksheet Booklet
- A Planner & Tracker to help you plan lessons and monitor curriculum coverage
- A Practical Booklet and Videos
- A Set of Posters
- A Formal Assessment Support Booklet

OVERVIEW AND APPROACH OF PROGRAMME

The FET Physical Sciences curriculum is long and complex. There are many quality textbooks and teachers' guides available for use. This programme does not aim to replace these resources, but rather, to supplement them in a manner that will assist teachers to deliver high quality Physical Sciences lessons.

Essentially, this programme aims to provide targeted support to teachers by doing the following:

1. Clarifying and explaining key concepts.
2. Clarifying and explaining possible misconceptions.
3. Providing worked examples of questions at an introductory level.
4. Providing worked examples of questions at a challenge level.
5. Providing the key teaching points to help learners deal with questions at challenge level.
6. Providing worksheet examples and corresponding memoranda for each topic.
7. Providing a Planner & Tracker that helps teachers to plan their lessons for a topic, and track their progress, pacing and curriculum coverage.
8. Providing videos of formal assessment practicals, together with worksheets and memoranda.
9. Providing guidance on how to structure formal assessment tasks.
10. Providing a 'bank' of questions and memoranda that may be used to structure formal assessment tasks.
11. Providing a set of posters with key information to display in the classroom.

CONTENT BOOKLET: TARGETED SUPPORT

1. The booklet starts with a ***contents page*** that lists all the topics for the term.

2. Every topic begins with a ***general introduction*** to the topic that states how long the topic runs for and the value of the topic in the final exam. It also gives a general idea of what is covered in the topic, and why this is important for our everyday lives.

3. This is followed by a ***list of requirements*** for the teacher and the learner. Try to ensure that you have all requirements on hand for the topic, and that your learners always have their requirements ready for each lesson. This is a simple classroom management practise that can improve your time-on-task and curriculum coverage significantly!

4. Next, you will see a ***sequential table*** that shows the prior knowledge required for this topic, the current knowledge and skills that will be covered, and how this topic will be built on in future years. Use this table to give learners an informal quiz to test their prior knowledge. If learners are clearly lacking in the knowledge and skills required, you may need to take a lesson to cover some of the essential content and skills. It is also useful to see what you are preparing learners for in the years to follow, by closely examining the 'looking forward' column.

5. This is followed by a ***glossary of terms***, together with an explanation of each term. It is a good idea to display these words and their definitions somewhere in the classroom, for the duration of the topic. It is also a good idea to allow learners some time to copy down these definitions into their books. You must explicitly teach the words and their meanings as and when you encounter these words in the topic.

   Once you have taught a new word or phrase, try to use it frequently in statements and questions. It takes the average person 20 – 25 authentic encounters with a new word to fully adopt it and make it their own.

6. Next, there are some very brief notes about the ***assessment*** of this topic. This just informs you of when the topic will be assessed, and of the kinds of questions that are usually asked. Assessment is dealt with in detail in the Assessment Booklet.

7. The next item is very useful and important. It is a table showing the ***breakdown of the topic and the targeted support offered***.

   This table lists the ***sub topic***, the classroom ***time allocation*** for the sub topic, and the ***CAPS page reference***.

The table also clearly states the ***targeted support*** that is offered in this booklet. You will see that there are three main kinds of support offered:

a. Key concepts are clarified and explained.
b. Possible misconceptions are clarified and explained.
c. Questions are odelled and practised at different levels (introductory level and challenge level).

8. After this introduction, the ***targeted support for each sub topic*** commences. This generally follows the same routine:
   a. A key concept or key ***concepts are clarified and explained***. It may be useful for you to work through this carefully with learners, and do any demonstrations that are included.
   b. ***Questions*** related to the key concepts are worked and explained.
      - These questions may be done at introductory level, at challenge level, or both.
      - It is important to expose learners to ***challenge level questions***, as this is often how questions are presented in exams.
      - These questions also challenge learners to apply what they have learnt about key concepts. Learners are, essentially, challenged to think at a critical and analytical level when solving these problems.
      - Please note that when calculations are done at challenge level, the key teaching points are identified.
      - Make sure that you effectively share these key teaching points with learners, as this can make all the difference as to whether learners cope with challenge level questions or not.
   c. At key points in the topic, ***checkpoints*** are introduced.
      - These checkpoints involve asking learners questions to check that they understand everything to that point.
      - The checkpoints also refer to a worksheet activity that is included in the Worksheet Booklet.
      - Use checkpoints to ascertain whether more consolidation must be done, or if your learners are ready to move to the next key concept.

9. Every topic ends with a ***consolidation exercise*** in the Worksheet Booklet. This exercise is not scaffolded as a test, it is just a consolidation of everything covered in this programme for that topic.

10. Finally, a section on ***additional reading / viewing*** rounds off every topic. This is a series of web links related to the topic. Please visit these links to learn more about the topic, and to discover interesting video clips, tutorials and other items that you may want to share with your learners.

PROGRAMME ORIENTATION

THE WORKSHEET BOOKLET

1. The Worksheet Booklet has different worksheets and corresponding memoranda for each topic.

2. First, there is a ***practice worksheet***, with questions that learners must complete during the topic. These are referred to in the checkpoints.

3. Once learners have completed these calculations, it is important to mark their work, using the ***memorandum*** supplied. Either do this together as a whole class, or display copies of the memorandum around the classroom, in spaces where learners can go and mark their work for themselves.

4. It is important that learners see how marks are allocated in the memorandum, so that they fully understand how to answer questions in tests and exams.

5. At the end of each topic, there is a ***consolidation worksheet*** and memorandum. This worksheet is a consolidation exercise of all the calculations covered in the topic. The consolidation worksheet is NOT scaffolded and it not designed to be used as a formal test. The level of the worksheet will be too high to be used as a test.

6. Again, it is important for learners to mark their work, and to understand how marks are allocated for each question.

7. Please remember that these worksheets do not replace textbook activities. Rather, they supplement and extend the activities that are offered in the textbook.

THE PLANNER & TRACKER

1. The Planner & Tracker is a useful tool that will help you to effectively plan your teaching programme to ensure that it is CAPS compliant.

2. The Planner & Tracker has a section for every approved textbook, so that regardless of the textbook that you use, you will be able to use this tool.

3. It also has space for you to record all lessons completed, which effectively allows you to monitor your curriculum coverage and pacing.

4. In addition, there is space for you to reflect on your progress and challenges at the end of each week.

5. At the end of the Planner & Tracker, you will find a series of resources that may be useful to you when teaching.

6. You will also find a sample formal assessment and memorandum.

PROGRAMME ORIENTATION

THE PRACTICALS BOOKLET AND VIDEOS

1. The following practicals must be completed as part of the formal assessment programme:
    a. Grade 10 Term 1: Heating and cooling curve of water
    b. Grade 10 Term 2: Electric circuits with resistors in series and parallel - measuring potential difference and current
    c. Grade 10 Term 3: Acceleration
    d. Grade 11 Term 1: Relationship between force and acceleration
    e. Grade 11 Term 2: The effects of intermolecular forces on: BP, MP, surface tension, solubility, capillarity
    f. Grade 12 Term 1: Preparation of esters
    g. Grade 12 Term 2: 1) Titration of oxalic acid against sodium hydroxide
        i. 2) Conservation of linear momentum
    h. Grade 12 Term 3: a) Determine the internal resistance of a battery
        b) Set up a series-parallel network with known resistor. Determine the equivalent resistance using an ammeter and a voltmeter and compare with the theoretical value.

2. Videos of all the listed practicals are supplied as part of this programme.

3. These videos should ideally be used as a teacher's guide. After watching the video, set up and complete the practical with your learners. However, if this is not possible, then try to show the video to your learners and allow them to record and analyse results on their own.

4. The videos should be used in conjunction with the practical worksheets. Learners should complete the worksheet whilst watching the video

PROGRAMME ORIENTATION

THE POSTERS

1. Every FET Physical Sciences teacher will be given the following set of five posters to display in the classroom:
    a. Periodic Table
    b. Chemistry Data Sheet
    c. Physics Data Sheet Part 1
    d. Physics Data Sheet Part 2
    e. Chemistry Half Reactions

2. <u>Please note that you will only be given these videos and posters once</u>.
    a. Make sure you store the videos safely.
    b. It is also important for you to make these posters as durable as possible. Do this by:
        - Writing your name on all posters
        - Laminating posters, or covering them in contact paper

3. Have a dedicated wall or notice board in your classroom for Physical Sciences, per grade:
    - Use this space to display the posters
    - Display definitions and laws
    - Display any additional relevant or interesting articles or illustrations
    - Try to make this an attractive and interesting space

THE ASSESSMENT BOOKLET

1. A separate Assessment Booklet is provided for Grade 10, Grade 11 and Grade 12.

2. These booklets first show you how to structure the formal assessment tasks for each term, according to CAPS requirements.

3. Next, the booklets provide you with a ‘bank’ of sample assessment questions for each topic.

4. This is followed by the memoranda for all the different questions that details the allocation of marks.

5. This booklet gives you all the support required to structure and design different tests and exams correctly.

PHYSICAL SCIENCES PLANNING AND PREPARATION

1. Get into the habit of planning every topic by using the following documents together
    a. The Physical Sciences Planner & Tracker
    b. The Content Booklet: Targeted Support
    c. The Worksheet Booklet
    d. The Practicals Booklet and Videos
    e. Your Textbook

2. Planning should always be done well in advance. This gives you the opportunity to not only feel well prepared but also to ask a colleague for help if any problems arise.

3. Follow these steps as you plan to teach a topic:
    a. Turn to the relevant section in the **Planner & Tracker** for your textbook.
        - Look through the breakdown of lessons for the topic.
        - In pencil, fill in the dates that you plan to teach each lesson. This will help with your sequencing.
    b. Next, look at the topic in the Content Booklet: **Targeted Support.**
        - Read through all the introduction points, including the table that shows the breakdown of lessons, and the targeted support offered.
        - Take note of the targeted support that is offered for each section.
        - Read through the whole topic in the Content Booklet: Targeted Support.
        - Complete all the examples in the Worksheet Booklet for the topic, including the Consolidation Worksheet.
        - Check your solutions against the memorandum.
        - Make notes in your Planner & Tacker to show where you will include the targeted support teaching and activities.
    c. Now, turn to the relevant section in your **Textbook**.
        - Read through each key concept in the Textbook.
        - Complete as many examples as possible. This will also help in your teaching – you will remember more points to share with the learners if you have done all of the work yourself.
        - Make careful notes in your Planner and Tracker of which sections and activities you will teach from the Textbook, and which you will teach from the Content Booklet: Targeted Support.
        - It will strengthen your teaching to use a combination of the two resources, but be careful not to leave anything out!
    d. If the Topic includes one of the Practicals for formal assessment, then consult the **Practical Booklet and Video**.
        - Complete the worksheet for the practical, whilst watching the video.
        - Try by all means to set up the practical and to conduct it with your learners. However, if this is not possible, ensure that learners see the video and complete the worksheet.

e. Document your **lesson plans** in the way that you feel most comfortable.
   - You may like to write notes about your lesson plans in a notebook.
   - You may like to use a standardised template for lesson planning. (A template is provided at the end of this section).
   - Remember to make notes about where you will use the textbook activities, and where you will use the targeted support activities.

f. Ideally, **Lesson Planning** for a topic should include:
   - Time to introduce the topic to learners
   - Time to establish the learners' prior knowledge
   - If required, time to address critical gaps in learners' prior knowledge
   - Introduction of terminology (glossary words)
   - Time to introduce and teach each key concept
   - Time for learners to complete practise exercises for each key concept
   - Time to correct and remediate each key concept
   - Time for a consolidation worksheet
   - Time to complete the required practicals

Note: Avoid giving learners an exercise to do that you haven't already completed yourself. This is useful for when the learners ask questions or get stuck on a question. You will be ready to assist them immediately instead of wasting time reading the question and working it out then.

PREPARATION AND ORGANISATION

1. Once you have completed your planning for a topic, you must make sure that you are properly prepared and organised to teach it.

2. Do this by completing all the steps listed in the planning section, including completing all the textbook and worksheet examples.

3. Have your lesson plans or teaching notes ready to work from.

4. Next, make sure that you have all resources required for the lesson.

5. Prepare your notice board for the topic, to give learners something visual to anchor their learning on, and to generate interest around the topic.

6. Print copies of the worksheets for all learners.

SAMPLE TEMPLATE FOR LESSON PLANNING

PHYSICAL SCIENCES LESSON PLAN

School	
Teacher's name	
Grade	
Term	
Topic	
Date	
Lesson Duration	

1. CONCEPTS AND SKILLS TO BE ACHIEVED:
   By the end of the lesson learners should know and be able to:

2. RESOURCES REQUIRED:

3. HOMEWORK REVIEW / REFLECTION:

Exercises to be reviewed and notes:

4. LESSON CONTENT / CONCEPT DEVELOPMENT

Explanation and examples to be done:

5. CLASSWORK ACTIVITY

Resource 1	
Page	
Exercise	
Resource 2	
Page	
Exercise	

Notes:

6. HOMEWORK ALLOCATION

Resource 1	
Page	
Exercise	
Resource 2	
Page	
Exercise	

7. LESSON REFLECTION:

What went well:

What could have gone better:

TERM 2 EXAM PREPARATION

Note: It is important to start preparing learners for their **exam from the beginning of the term**.

1. Make sure that your learners know exactly when their Physical Sciences exams will be written.
2. Ask learners to take out their exercise books, and to mark off what must be studied.
    a. Go through all their written work and textbook activities, and get them to tick off the work that they must study and practise.
    b. If learners are missing notes, they must copy the missing work from another learner.
    c. As you complete more work during the term that will be in the exam, tell learners to tick it off and to add it to their study plans.
3. If necessary, help learners to work out a study schedule.
    a. a. Estimate how long learners will need to study all the content required for the exam. This will differ from grade to grade, and from learner to learner.
    b. Be aware that some learners, even in the FET stage, have not yet developed these planning skills.
    c. Tell learners the number of hours that you think they need to study before the exam.
    d. Break this down into the number of hours they should study each week.
    e. Tell learners to think about their own lives and habits, and to work out when they have time to study, and when they study best.
    f. They must then use all of this information to work out their study and revision plan.

USEFUL REVISION RESOURCES

Note: It is important to start preparing learners for their **exam from the beginning of the term**.

1. **Assessment Booklets**
   a. THE Assessment Booklets that form part of this series may be used as a very useful exam preparation tool.
   b. These booklets include a 'bank' of questions for each topic at the different conceptual levels.
   c. If your province or district provides standardised tests and exams, use the questions in this booklet at revision and exam preparation for learners.
   d. Remember to carefully explain the question structure and meaning, together with the mark allocation.

2. **DBE Grade 12 'Mind the Gap' Study Guides**
   a. Grade 12 learners can access the 'Mind the Gap' Study Guides on the DBE website: https://www.education.gov.za/Curriculum/LearningandTeachingSupportMaterials(LTSM)/MindtheGapStudyGuides.aspx
   b. This series includes Grade 12 study guides for:
      - Physical Science: Physics
      - Physical Science: Chemistry
   c. These guides include an overview of the Grade 12 exam structures, useful study techniques, a guide to questions types, a comprehensive list of question words / terms, as well as a summary of key content and skills.
   d. Consider downloading a copy of these guides, and making copies for Grade 12 learners if possible.
   e. Alternately, tell learners how to access this useful resource.

3. **Vodacom e-school**
   a. a. If learners have a Vodacom number, they are eligible to use the Vodacom e-school as a free service, i.e. no data costs: http://www.vodacom.co.za/vodacom/test-templates/eschool-two
   b. This e-school includes Physical Science lessons as part of its curriculum.
   c. Tell learners how to access this useful resource.

TOPIC 5: Work, energy and power

A INTRODUCTION

- This topic runs for 10 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Work, energy and powerforms part of the content area Mechanics (Physics).
- Mechanics counts as 42% in the final exam.
- Work, energy and power counts approximately 10% of the final examination.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.
2. Chalk.
3. Grade 12 Physics Examination Data Sheet.
4. Flight of stairs, stopwatch, measuring tape (5m) or meter stick.

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. A4, 3 Quire exercise book, for notes and exercises.
2. Scientific calculator – Sharp or Casio calculators are highly recommended.
3. Pen, pencil, ruler.
4. Grade 12 Physics Examination Data Sheet.

B SEQUENTIAL TABLE

PRIOR KNOWLEDGE	PRIOR KNOWLEDGE	CURRENT
Grade 10	**Grade 11**	**Grade 12**
• Introduction to vectors & scalars. • Reference frame, position, displacement and distance. • Velocity and acceleration • Description of motion in words, diagrams, graphs and equations. • Gravitational potential Energy • Kinetic energy • Mechanical energy • Conservation of mechanical energy (in the absence of dissipative forces).	• Resolution of a vector into its horizontal and vertical components • Different kinds of forces: weight, normal force, frictional force, applied (push, pull), tension (strings or cables) • Force diagrams, free body diagrams • Newton's first, second and third laws.	• Definition of Work • Work–Energy Theorem • Conservation of energy with non-conservative forces present. • Power • Different kinds of forces: weight, normal force, frictional force, applied (push, pull), tension (strings or cables)

C

GLOSSARY OF TERMS

Please note: The highlighted definitions and laws are ones that learners must be able to state and are given in the CAPS document. For examination purposes, learners must know these definitions and laws by heart, and must write them exactly as they appear here.

TERM	DEFINITION
Work done on an object by a force	If a constant force F acts on a body while it undergoes a displacement (Δx), then the work done (W) by this force is defined as: $W = F\Delta x \cos 0$
Work-Energy Theorem	The net work done on an object is equal to the change in the object's kinetic energy: $W_{net} = E_{kf} - E_{ki}$
The law of conservation of energy	Energy cannot be created or destroyed, but is merely changed from one form into another.
The principle of conservation of mechanical energy	The total amount of mechanical energy, in a closed system in the absence of dissipative forces (e.g. friction, air resistance), remains constant.
Gravitational potential energy	The energy an object has due to its position in a gravitational field relative to some reference point.
Kinetic energy	The energy an object has due to its motion.
Mechanical energy	The sum of the gravitational potential energy and the kinetic energy of a system.
Conservative force	A force is a conservative force if the net work done by the force is zero, while moving an object around a closed path, starting and ending at the same point.
Non-conservative force	A non-conservative force is one for which work done on the object depends on the path taken by the object.
Power	The rate at which work is done.

D ASSESSMENT OF THIS TOPIC

- This topic is assessed by class/control tests as well as in the midyear and end of year examinations.
- There must be multiple-choice type questions, problems to solve (where the learners are expected to show their method), questions that require explanation and questions that ask for definitions.
- Recommended practical investigation for informal assessment: Perform simple experiments to determine the work done in walking up (or running up a flight of stairs). By timing the run and walk (same flight of stairs) one can enrich the concept of power.

BREAKDOWN OF TOPIC AND TARGETED SUPPORT OFFERED

- *Please note: that this booklet does not address the full topic – only targeted support related to common challenges is offered.*
- *For further guidance on full lesson planning, please consult CAPS, the NECT Planner & Tracker and the textbook.*

TIME ALLOCATION	SUB TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
2 hours	Definition of Work	117-118	**a. Explanation and calculation of the work done on an object by a force.** **b. The meaning of positive and negative work.** **c. Explanation and calculation of the net work done on an object.** **d. The meaning of positive and negative nett work.** **e. Numerous practice questions.**
2 hours	Work–Energy Theorem	118	a. Explanation of positive and negative net work done. b. Applying the work-energy theorem to horizontal and inclined planes. c. Numerous practice questions.
3 hours	Conservation of energy with non-conservative forces present.	119	a. Explanation of conservative and non-conservative forces. b. Applying the law of conservation of energy when non-conservative forces are present. c. Numerous practice questions.
3 hours	Power	120	a. Explanation of the concept of power. b. Explanation of the average power required to keep an object moving at constant speed on horizontal and inclined planes. c. Calculating the minimum power of an electric motor.

F

TARGETED SUPPORT PER SUB TOPIC

1. WORK

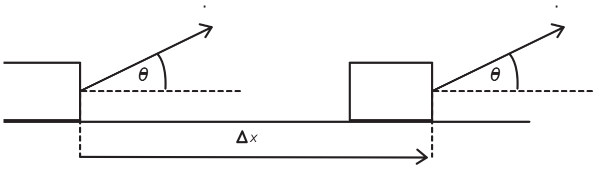
INTRODUCTION

When work is done then energy is being transferred. When work is done on an object by a force, mechanical energy is either added or removed from an object. It is important that your learners know how to calculate the work done on an object by a force and the meaning of positive and negative work. When net work is done on an object then the kinetic energy of that object will change.

CONCEPT EXPLANATION AND CLARIFICATION:

1.1 WORK DONE BY A FORCE ON AN OBJECT

Draw the following diagram on the board:



A **force** F acts on an object. The object is **displaced** (Δx) along a surface WHILE the FORCE F acts on it. The force F acts at an angle θ to the displacement of the object.

The direction of the displacement is VERY IMPORTANT. It determines the angle *θ*.

Write the definition of **THE WORK DONE BY A FORCE ON AN OBJECT** on the board:

If a constant force F acts on a body while it undergoes a displacement Δx, then the work done (W) by this force is defined as: $W = F\Delta x \cos\theta$

F is the magnitude of the force acting on the object. Force is measured in Newtons (N).

Δx is the magnitude of the displacement of the object, measured in metres (m).

W is the work done by the force F on the object is measured in joules (J). Work is a **SCALAR QUANTITY**, and therefore has magnitude, but no direction.

θ is the angle between the force F and the displacement of the object Δx.

Explain to your learners what they are actually calculating.

TOPIC 5: Work, energy and power

Whenever work is done on an object by a force, energy is being transferred from one object to another object. This is how energy transfers take place within a system.

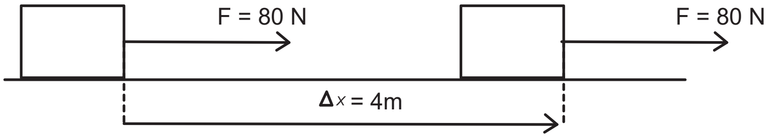
VERY IMPORTANT:

The **AMOUNT OF WORK DONE** by a force on an object **IS EQUAL TO** the **ENERGY BEING TRANSFERRED**.

WORK DONE = ENERGY TRANSFERRED

Work through the following calculation with your learners:

A force of 80 N acts on an object while the object is displaced 4 m along a horizontal frictionless surface.



The force F act in the SAME direction as the displacement.

The angle between the force F and the displacement Δx is 0°.

The work done by the 80 N force is:

$$W = F\Delta x \cos\theta = (80)(4)\cos 0^{\circ}$$

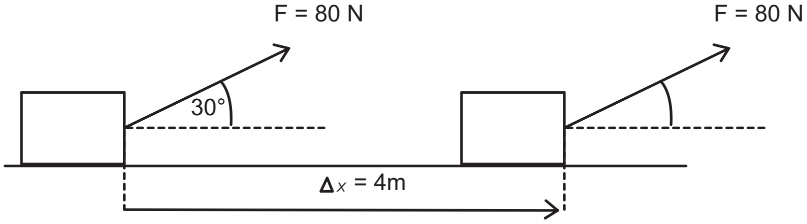
$$W = F\Delta x \cos\theta = (80)(4)(+1) \qquad (\cos 0^{\circ} = +1)$$

$$W = F\Delta x \cos\theta = +320\,J$$

POSITIVE WORK has been done on the object by the 80 N force.

320 J of mechanical energy (kinetic energy) will be **ADDED** to the system.

A force of 80 N acts on an object at an angle of 30° to the horizontal while the object is displaced 4 m along a horizontal frictionless surface.

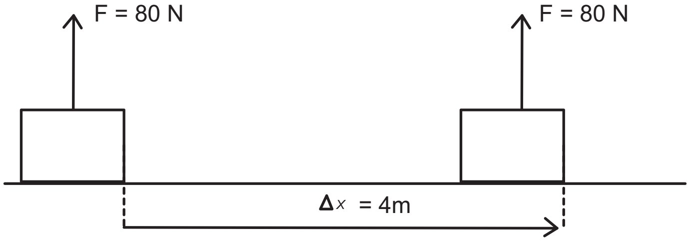


The work done by the 80 N force is: $W = F\Delta x \cos\theta = (80).(4)\cos 30^{\circ} = 277,13J$

POSITIVE WORK has been done on the object by the 80 N force.

277,13 J of mechanical energy (kinetic energy) will be **ADDED** to the system.

If the force F acts at 90° to the displacement, then **ZERO WORK** is done by this force.

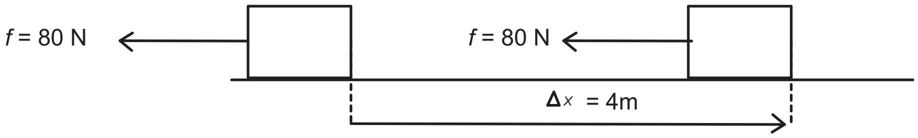


$$W = F\Delta x\cos\theta = (80).(4)\cos 90^\circ = 0J \qquad (\cos 90^\circ = 0)$$

When an object is displaced along a HORIZONTAL surface, then the weight W and the normal force N do **ZERO WORK** on the object.

If a force F acts in the OPPOSITE direction to the displacement, then NEGATIVE WORK is done on the object:

Friction f acts at 180° to the displacement of an object.



$$W_{friction} = f\Delta x\cos\theta$$

$$W_{friction} = (80)(4)\cos 180^\circ$$

$$W_{friction} = (80)(4)(-1) \qquad (\cos 180^\circ = -1)$$

$$W_{friction} = -320\,J$$

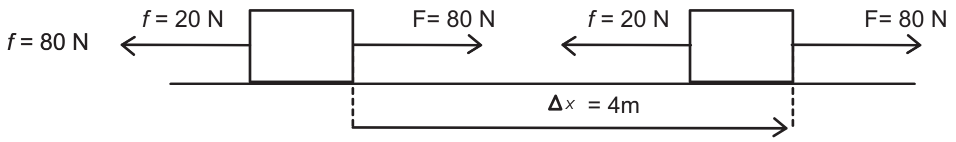
NEGATIVE WORK has been done on the object by the 80 N force.
320 J of mechanical energy (kinetic energy) will be **REMOVED** from the system. This energy will be dissipated to the surroundings as heat and sound energy.

1.2 THE NET WORK DONE ON AN OBJECT

Consider **two forces** acting on an object while it is displaced 4 m to the right.

A force of 80 N is applied in the same direction as the displacement.

A frictional force of 20 N acts in the opposite direction to the displacement.



To calculate the **NET WORK DONE ON AN OBJECT** (W_{net}), calculate the work done by **EACH FORCE** acting on the object while it is being displaced, and then **ADD UP** each contribution.

$$W_{net} = W_{applied\ force} + W_{friction}$$

$$W_{applied\ force} = F\Delta x\,cos\,\theta = (80)(4).cos\,0^{o} = +320\,J$$

The 80 N applied force does 320 J of positive work.

$$W_{friction} = f\Delta x\cos\theta = (20)(4)\cos 180^{o} = -80\,J$$

The 20 N frictional force does 80 J of negative work.

The NET WORK DONE on the object is:

$$W_{net} = W_{applied\ force} + W_{friction}$$

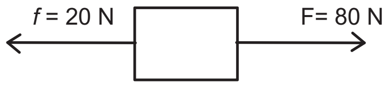
$$W_{net} = +320 - 80 = +240J$$

POSITIVE NET WORK will increase the kinetic energy of the system.

The KINETIC ENERGY of this block will INCREASE by 240 J.

ALTERNATIVE METHOD of calculating the **NET WORK DONE** on the object:

1. Draw a **force diagram** showing only forces **that act along the plane**. Ignore perpendicular forces (they do ZERO work on the object).



2. Calculate the **resultant force** (along the plane).

   Choose forward as positive:

$$F_{net} = F - f = 80 - 20 = +60 = 60\,N \qquad \textit{to the right}$$

3. Calculate the net work done on an object by taking the **product** of the **resultant force** (along the plane) acting on the object and its **displacement** along the plane.

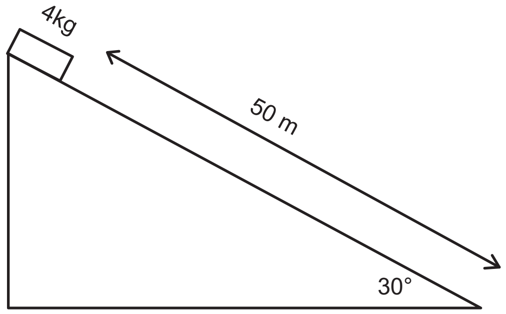
Reminder: It is important to identify the angle θ between the net force and the displacement.

In this example, the net force is in the same dire ction as the displacement, therefore θ=0°

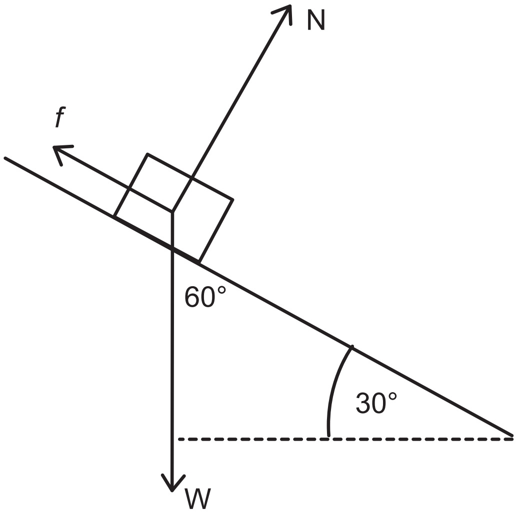
$$W_{net} = F_{net}\Delta x\cos\theta$$

$$W_{net} = (60)(4)\cos 0^{\circ} = +240\ J$$

Consider a 4 kg block which slides 50 m down a rough slope inclined at 30° to the horizontal. The block experiences a frictional force of 15 N.



You must identify the **forces** that **act on the block** while it slides down the slope.



The weight W acts at **60°** to the displacement.

The weight W does **positive work** on the block:

$$W_W = W\Delta x\cos\theta = (mg)\Delta x\cos 60^{\circ} = (4).(9,8).(50).\cos 60^{\circ} = +980J$$

The frictional force f acts at **180°** to the displacement.

The frictional force f will do **negative work** on the block:

$$W_f = f\Delta x\cos\theta = (15).(50).\cos 180 = -750J$$

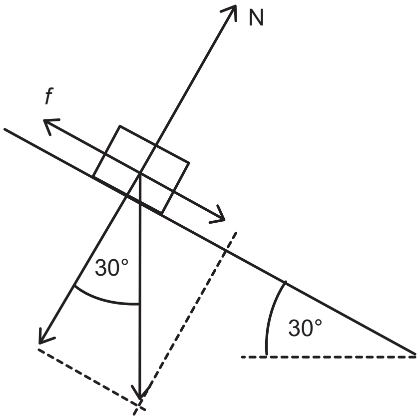
The **net work done** on the block as it slides 50 m down the slope is:

$$W_{net} = W_W + W_f = +980 - 750 = +230\,J$$

Positive net work is done on the block. The kinetic energy of the block will increase by 230 J.

Alternative method:

1. Draw a **force diagram** showing only forces that **act along the slope**. Ignore perpendicular forces (they do ZERO work on the object).



The component of the weight $\mathbf{W_x}$ acts parallel to the slope. Friction f also acts parallel to the slope.

The normal force N and the component of weight perpendicular to the slope W_y will do ZERO work on the block.

2. Calculate the **resultant force** (along the slope).

Choose down the slope as positive:

$$F_{net} = W_x - f$$

$$F_{net} = W sin\,30^{\circ} - f$$

$$F_{net} = (4)(9{,}8)\,sin\,30^{\circ} - 15$$

$$F_{net} = 19{,}6 - 15 = 4{,}6\,N\ down\ the\ slope$$

3. Calculate the net work done on an object by taking the **product** of the **resultant force** (along the plane) acting on the object and its **displacement** along the plane.

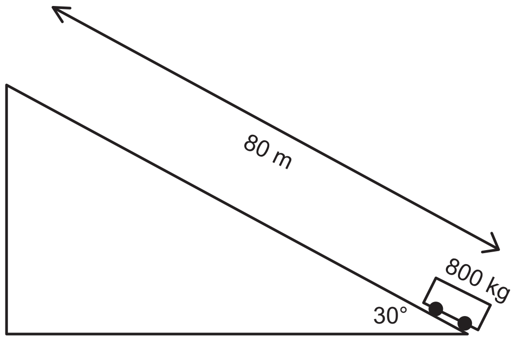
Reminder: The net force and the displacement are in the same direction, therefore $\theta = 0^{\circ}$

$$W_{net} = F_{net}\,\Delta x\,cos\theta$$

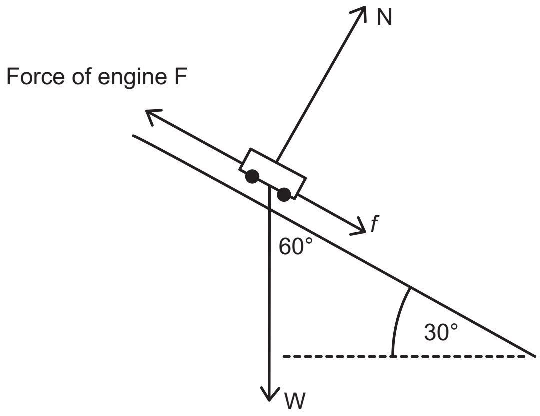
$$W_{net} = (4{,}6)(50)\,cos\,0^{\circ} = +230\,J$$

Consider a car of mass 800 kg which drives 80 m up a rough slope inclined at 30° to the horizontal. The car engine applies a forward force of 8000 N and the car experiences a frictional force off 2500 N.

Calculate the net work done on the car.



You must identify the **forces** that **act on the car** while it drives up the slope.



In this example, the direction of the displacement is UP the slope.

The weight W then acts at 120° to the displacement.

The weight W does negative work on the car:

$$W_W = W\Delta x\cos\theta = (mg)\Delta x\cos 120^{\circ} = (800)(9,8)(80)\cos 120^{\circ} = -313\,600\ J$$

The frictional force f acts at 180° to the displacement.

The frictional force f will do negative work on the car:

$$W_f = f\Delta x\cos\theta = (2500)(80)\cos 180^{\circ} = -200\,000\ J$$

The force of the engine F acts at 0° to the displacement.

The force of the engine F will do positive work on the car:

$$W_F = F\Delta x \cos\theta = (8000)(80)\cos 0^\circ = +640\,000\ J$$

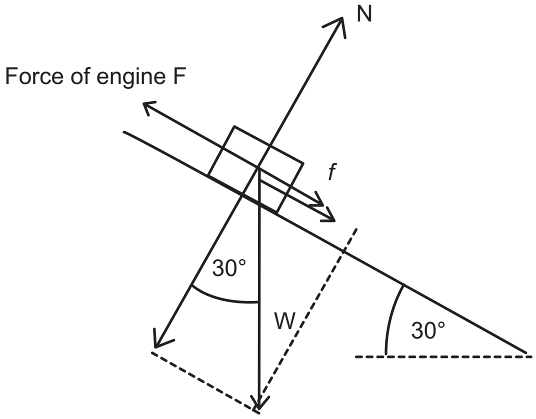
The net work done on the car as it drives 80 m up the slope is:

$$W_{net} = W_F + W_W + W_f = +640\,000 - 313\,600 - 200\,000 = +126\,400\ J$$

Positive net work is done on the car. The kinetic energy of the car will increase by 126 400 J.

Alternative method:

1. Draw a **force diagram**.



The component of the weight $\mathbf{W_x}$ acts parallel to the slope. Friction f also acts parallel to the slope.

2. Calculate the **resultant force** (along the slope).

   Choose down the slope as positive:

$$F_{net} = F - W_x - f$$

$$F_{net} = F - W \sin 30^\circ - f$$

$$F_{net} = 8000 - (800).(9,8).\sin 30^\circ - 2500$$

$$F_{net} = 8000 - 3920 - 2500 = 1580\ N\ up\ the\ slope$$

3. Calculate the net work done on an object by taking the **product** of the **resultant force** (along the plane) acting on the object and its **displacement** along the plane.

Reminder: The net force and the displacement are in the same direction, therefore θ=0°

$$W_{net} = F_{net}\Delta x \cos\theta$$

$$W_{net} = (1580)(80)\cos 0^\circ = +126\,400\ J$$

TOPIC 5: Work, energy and power

INTRODUCTORY LEVEL QUESTIONS

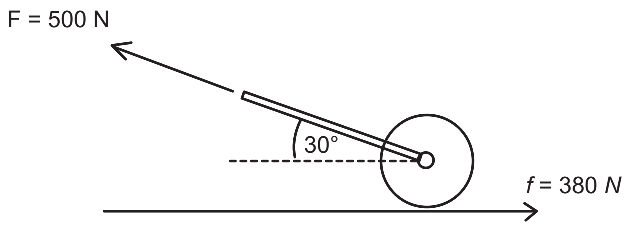
a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the calculation of work done by a force and the net work done on an object.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. A grounds man pulls a 100 kg roller across a cricket pitch with a force of 500 N at an angle of 30° to the horizontal as shown in the diagram. The roller experiences a frictional force of 250 N as it is moved 25 m along the pitch.



1.1 Calculate the work done by on the roller by the applied force.

1.2 Calculate the work done on the roller by friction.

1.3 How much work is done by the gravitational force on the roller? Explain your answer.

1.4 Calculate the net work done on the roller.

Solution:

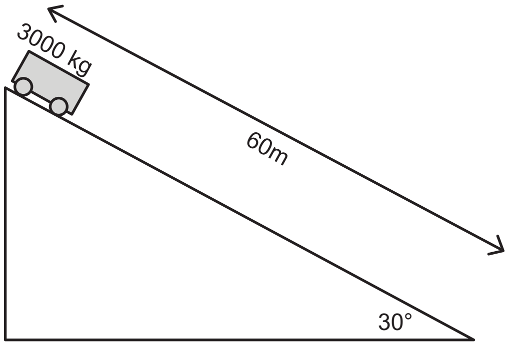
1.1 $W_F = F\Delta x \cos\theta = (500).(25).\cos 0^o = +12\,500\ J$

1.2 $W_f = f\Delta x \cos\theta = (380).(25).\cos 180^o = -9\,500\ J$

1.3 Zero work is done. The weight acts at 90° to the displacement.

1.4 $W_{net} = W_F + W_f = +12\,500 - 9\,500 = +3\,000\ J$

2. A truck of mass 3 000 kg, free wheels down a 60 m long inclined plane as shown in the diagram. The plane is inclined at 30° to the horizontal. The truck experiences a constant frictional force of 6 000 N as it free wheels down the inclined plane.

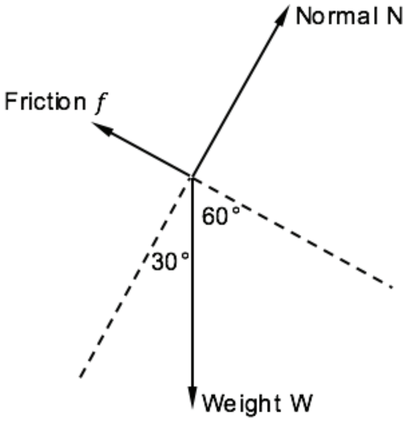


   2.1 Draw a fully labelled free-body diagram of the forces acting on the truck. Include any relevant angles.

   2.2 Calculate the net work done on the truck.

Solution:

2.1



2.2 $W_{net} = W_W + W_f$

$W_{net} = W\Delta x\cos 60^\circ + f\Delta x\cos 180^\circ$

$W_{net} = (3\,000)(9,8)(60)\cos 60^\circ + (6\,000)(60)\cos 180^\circ$

$W_{net} = +882\,000 + 360\,000$

$W_{net} = +522\,000\ J$

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic calculations, they are ready to deal with more challenging questions.

b. These questions require learners to apply their understanding of the work done by a force and the net work done on an object.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

Key Teaching:

a. Identify the forces acting of the object that will do work on the object.

b. Identify the direction of the displacement.

c. Forces that act at 90° to the displacement do ZERO work on the object.

d. Identify the angle between each force and the displacement of the object.

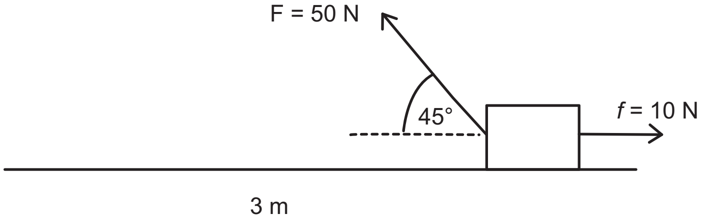
e. Calculate the work done on the object by each force.

f. Add the work done by each force to find the net work done on the object.

g. If positive net work is done then the kinetic energy of the object will increase.

h. If negative net work is done then the kinetic energy of the object will decrease.

3. The 50 N force is applied to a wooden block at an angle of 45° to the horizontal. The block experiences a 10 N frictional force as it moves 3 m along a rough horizontal surface.



3.1 Calculate the net work done on the block.

3.2 What is the net work done on the block if the block was moved at constant velocity? Explain your answer.

Solution:

3.1 The displacement is to the left.

$$W_{net} = W_F + W_f$$

$$W_{net} = F\Delta x \cos\theta + f\Delta x \cos\theta$$

$$W_{net} = (50)(3)\cos 45^{\circ} + (10)(3)\cos 180^{\circ}$$

$$W_{net} = +106{,}07 - 30$$

$$W_{net} = +76{,}07 J$$

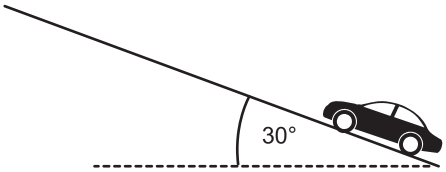
3.2 If the block moves at constant velocity, then the net force acting on the block is zero.

$$W_{net} = F_{net}\Delta x \cos\theta$$

$$W_{net} = (0)(3)\cos 0^{\circ} = 0$$

The net work done on the block is zero.

4. A car of mass 700 kg is driven up an inclined plane at constant velocity.



4.1 Name the three forces that act on the car as it drives up the inclined plane. State the direction of each force.

4.2 Which of the forces will do positive work on the car?

4.3 Which of the forces will do negative work on the car?

4.4 What is the net work done on the car? Explain your answer.

Suppose the car now accelerates 60 m up the inclined plane. The car engine exerts a forward force of 6 000 N and the coefficient of kinetic friction between the tyres and the plane is 0,43.

4.5 Draw a free-body diagram of the forces acting on the car. Label any relevant angles.

4.6 Calculate the net work done on the car.

4.7 Will the kinetic energy of the car increase, decrease or remain the same? Explain your answer.

Solution:

4.1 Force of engine up the slope.

Friction down the slope.

Weight vertically downwards.

The normal force acts perpendicular to the slope.

4.2 Forward force of car engine.

4.3 Friction down the slope will do negative work $(\theta = 0)(cos\,0^o = +1)$

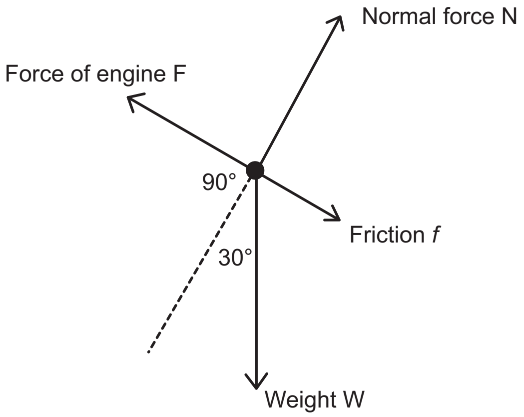
Weight will do negative work. The angle between the displacement and the weight is 120^o $(\theta = 120^o)(cos\,120^o = -0,5)$.

4.4 The car travels at constant velocity, therefore the net force acting on the car is zero.

$$F_{net} = 0$$

$$W_{net} = F_{net} \Delta x \cos\theta = 0$$

4.5



4.6 $W_y = W\,cos\,30^{\circ} = (700)\,.\,(9{,}8)\,.\cos 30^{\circ} = 5\,940{,}93\ N$

$N = 5\,940{,}93\ N$

$f_k = \mu_k N = (0{,}43)\,.\,(5\,940{,}93) = 2\,554{,}60\ N$

$W_{net} = W_F + W_f + W_W$

$W_{net} = F\Delta x\,cos\,\theta + f\Delta x\,cos\,\theta + W\Delta x\,cos\,\theta$

$W_{net} = (6\,000)\,(60)\,cos\,0^{\circ} + (2\,554{,}60)\,(60)\,cos\,180^{\circ} + (6\,860)\,(60)\,cos\,120^{\circ}$

$W_{net} = +360\,000 - 153\,276 - 205\,800$

$W_{net} = +924\ J$

4.7 Kinetic energy will increase because positive net work is done on the car.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. Calculating the work done on an object by a force.
2. Calculating the net work done on an object.
3. The meaning of positive and negative net work done on an object.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Work, energy and power Worksheet: Questions 1-2

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

2. WORK-ENERGY THEOREM

INTRODUCTION

The work-energy theorem relates the net work done on an object to the change in kinetic energy of the object. It is important that your learners are able to identify all the forces that will do positive and negative work on an object.

CONCEPT EXPLANATION AND CLARIFICATION:

Remind your learners that when a **net force** acts on an object, that object will **ACCELERATE** in the direction of the net force. When an object accelerates, the velocity of the object will change. If the velocity is changing then the kinetic energy of the object is also changing.

When **POSITIVE NET WORK** is done on an object, the **KINETIC ENERGY** of that object will **INCREASE**.

When **NEGATIVE NET WORK** is done on an object, the **KINETIC ENERGY** of that object will **DECREASE**.

Write the **WORK-ENERGY THEOREM** on the board:

The net work done on an object is equal to the change in the object's kinetic energy.

$$W_{net} = \Delta E_k$$

$$W_{net} = E_{kf} - E_{ki}$$ **Final kinetic energy – Initial kinetic energy**

$$W_{net} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

W_{net} is the net work done on the object (measured in J)

m is the mass of the object (measured in kilograms kg)

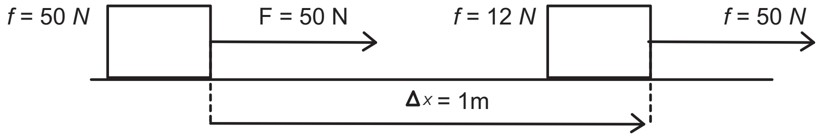
v_i is the initial velocity of the object (measured in $m.s^{-1}$)

v_f is the final velocity of the object (measured in $m.s^{-1}$)

TOPIC 5: Work, energy and power

Show your learners how to apply the Work-Energy Theorem to the following problem:

A 5 kg block is at rest on a horizontal surface. A forward force of 50 N is applied to the block and the block experiences a frictional force of 12 N as it travels 10 m along the horizontal surface.



Calculate the net work done on the block:

$$W_{net} = W_{applied\ force} + W_{friction}$$

$$W_{net} = F\Delta x\cos\theta + f\Delta x\cos\theta$$

$$W_{net} = (50)(10)\cos 0^{\circ} + (12)(10)\cos 180^{\circ}$$

$$W_{net} = +500 - 120 = +380\,J$$

The kinetic energy of the block will increase by 380 J.

Apply the Work-Energy Theorem:

$$W_{net} = \Delta E_k$$

$$W_{net} = E_{kf} - E_{ki}$$

$$W_{net} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$+380 = \frac{1}{2}(5)v_f^2 - \frac{1}{2}(5)(0)^2$$

The initial velocity of the block is zero: $v_i = 0$

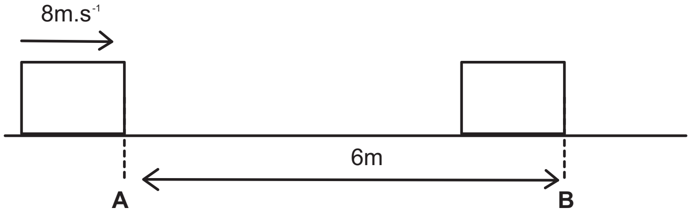
$$+380 = 2{,}5v_f^2$$

$$v_f^2 = 152$$

$$v_f = 12{,}33\,m.s^{-1}\,to\ the\ right$$

Show your learners how to apply the Work-Energy Theorem to the following problem:

A 3 kg block is sliding to the right at $8\,m.s^{-1}$ at point A on a rough horizontal surface. The block comes to rest at point B.



Use the Work-Energy Theorem to calculate the work done on the block by the frictional force.

$$W_{net} = \Delta E_k$$

$$W_{net} = E_{kf} - E_{ki}$$

The only horizontal force acting on the block is the frictional force. The work done on the block by friction **IS** the **NET WORK DONE** on the block.

$$W_f = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$W_f = 0 - \frac{1}{2}mv_i^2$ **The final velocity of the block is zero:** $v_f = 0$

$$W_f = -\frac{1}{2}(3).(8)^2$$

$$W_f = -96\,J$$

The kinetic energy of the block decreases by 96 J.

96 J of kinetic energy is removed from the block and dissipated to the surroundings as heat and sound energy.

Calculate the magnitude of the frictional force acting on the block.

$$W_f = -96\,J$$

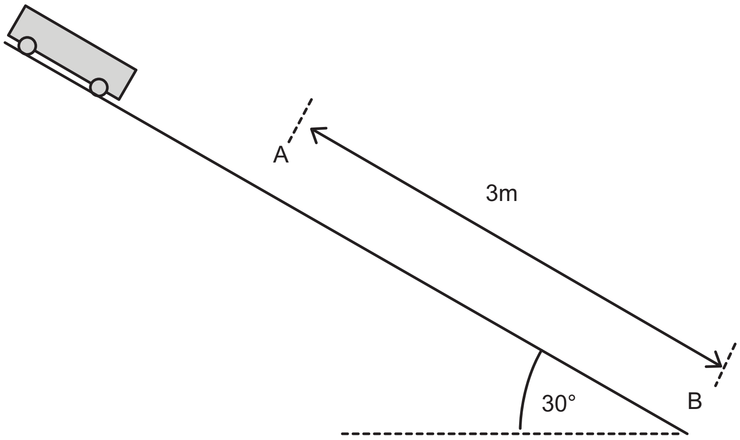
$$f\Delta x \cos\theta = -96$$

$$f(6)\cos 180^{\circ} = -96$$

$$f = 16N$$

Show your learners how to apply the work-energy theorem to the following problem:

A trolley of mass 1 kg is at held at the top of an inclined plane. The trolley is released and rolls down the inclined plane while experiencing a constant frictional force of 3,4 N. The speed of the trolley at point A is $1,5 m.s^{-1}$.



Use the Work-Energy Theorem to calculate the speed of the trolley at point B when it has rolled 3 m down the inclined plane.

$$W_{net} = \Delta E_k$$

$$W_{net} = E_{kf} - E_{ki}$$

$$W_W + W_f = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$mg\Delta x\cos\theta + f\Delta x\cos\theta = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$(1)(9,8)(3)\cos 60^{\circ} + (3,4)(3)\cos 180^{\circ} = \frac{1}{2}(1)v_f^2 - \frac{1}{2}(1)(1,5)^2$$

$$+14,7 - 10,2 = 0,5v_f^2 - 1,125$$

$$5,625 = 0,5v_f^2$$

$$v_f^2 = 11,25$$

$$v_f = 3,35 m.s^{-1}$$

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the work-energy theorem.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

TOPIC 5: Work, energy and power

1. A racing car of mass 500 kg, travelling at $20\,\text{m.s}^{-1}$ on a straight horizontal track, accelerates until it reaches a speed of $55\,\text{m.s}^{-1}$. The race car experiences an average frictional force of 2 000 N. Use the work-energy theorem to determine the work done by the car's engine after it has travelled 160 m.

   Solution:

   $$W_{net} = \Delta E_k$$

   $$W_{net} = E_{kf} - E_{ki}$$

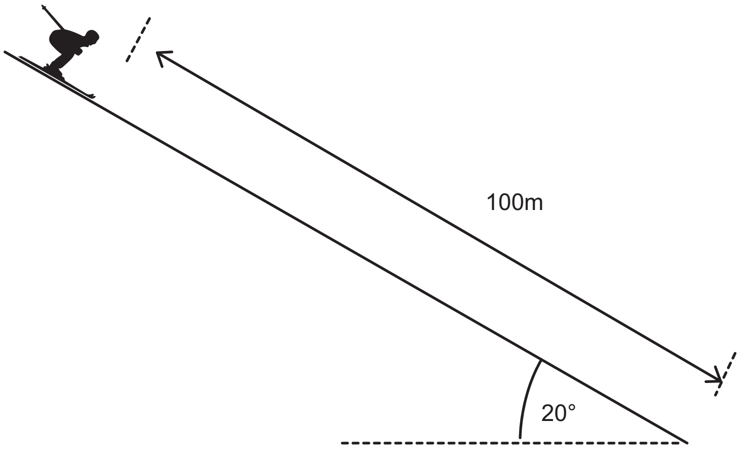
   $$W_{engine} + W_f = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

   $$W_{engine} + (2\,000)(160)\cos 180^\circ = \frac{1}{2}(500)(55)^2 - \frac{1}{2}(500)(20)^2$$

   $$W_{engine} - 320\,000 = 756\,250 - 100\,000$$

   $$W_{engine} = +976\,250\,J$$

2. A person skis down a 100 m long snow slope which makes an angle of 20° with the horizontal. The total mass of the skier and skis is 80 kg. There is a constant frictional force of 180 N opposing the skier's motion. The speed of the skier at the top of the slope is $2\,\text{m.s}^{-1}$.



   Use the Work-energy Theorem to calculate the maximum speed of the skier at the bottom of the 100 m slope.

   Solution:

   $$W_{net} = \Delta E_k$$

   $$W_{net} = E_{kf} - E_{ki}$$

   $$W_W + W_f = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$mg\Delta x\cos\theta + f\Delta x\cos\theta = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$(80)(9,8)(100)\cos 70^\circ + (180)(100)\cos 180^\circ = \frac{1}{2}(80)v_f^2 - \frac{1}{2}(80)(2)^2$$

$$26\,814,38 - 18\,000 = 40v_f^2 - 160$$

$$26\,814,38 - 18\,000 = 40v_f^2 - 160$$

$$8\,974,38 = 40v_f^2$$

$$v_f^2 = 224,36$$

$$v_f = 14,98 m.s^{-1}$$

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic calculations, they are ready to deal with more challenging questions.

b. These questions require learners to apply the work-energy theorem.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

Key Teaching:

a. Identify the forces acting on the object.

b. Identify the direction of the displacement.

c. Determine the angle θ of each force in relation to the displacement.

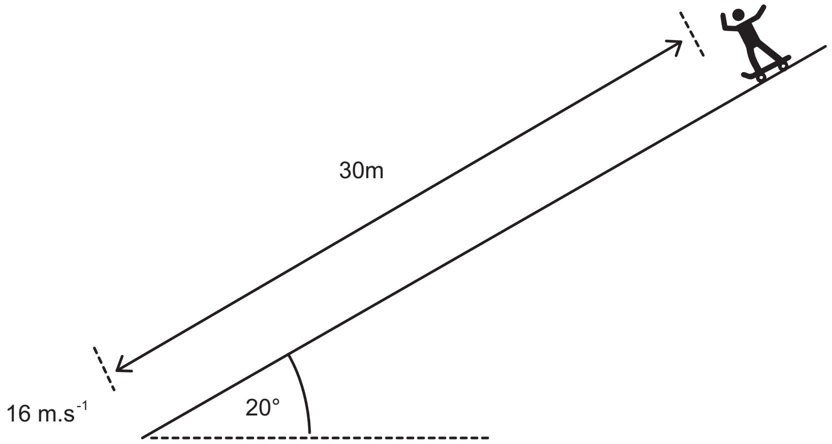
d. Calculate the net work done by adding up the work done by each force.

e. Identify the initial and final velocities of the object.

f. If negative net work is done on an object, then the kinetic energy of that object will decrease.

g. If positive net work is done on an object, then the kinetic energy of that object will increase.

3. A skateboarder with a mass of 60 kg who skates down a slope experiences a frictional force of 80 N. The slope forms an angle of 20° with the horizontal. The skateboarder covers a distance of 30 m before reaching the end of the slope at a speed of 16m.s^{-1}.



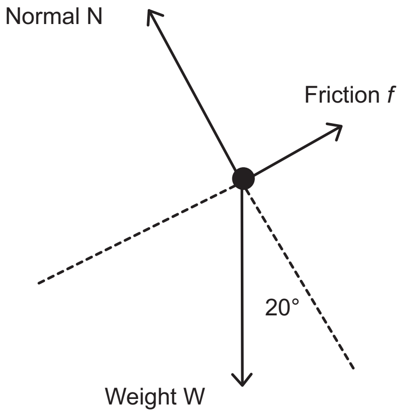
3.1 Draw a fully labelled free-body diagram of all the forces acting on the skateboarder as he moves down the slope.

3.2 Calculate the magnitude and direction of the net force acting on the skateboarder.

3.3 Use your answer to question 3.2 and the work-energy theorem to calculate the speed of the skateboarder at the top of the slope.

Solution:

3.1



3.2 $F_{net} = W_x - f$

$F_{net} = mg\,sin\,20^o - 80$

$F_{net} = (60)(9,8)\,sin\,20^o - 80$

$F_{net} = 201,11 - 80$

$F_{net} = 121,11\,N\ down\ the\ slope$

3.3 $W_{net} = \Delta E_k$

$W_{net} = E_{kf} - E_{ki}$

$F_{net}\Delta x\,cos\,\theta = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$

$(121,11)(30)\,cos\,0^o = \frac{1}{2}(60)(16)^2 - \frac{1}{2}(60)v_i^2$

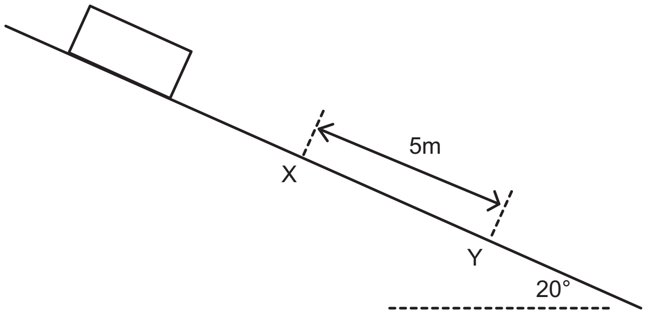
$3\,633,3 = 7\,680 - 30v_i^2$

$-4\,046,7 = -30v_i^2$

$v_i^2 = 134,89$

$v_i = 11,61 m.s^{-1}$

4. A crate of mass 20 kg slides down a rough incline that makes an angle of 30^o with the horizontal, as shown in the diagram below. The crate experiences a constant frictional force of magnitude 120 N during its motion down the slope.



The crate passes point X at a speed of $4,5 m.s^{-1}$ and moves a distance of 10 m before reaching point B lower down on the incline. Use the work-energy theorem to calculate the speed of the crate at point B.

Solution:

$$W_{net} = \Delta E_k$$

$$W_{net} = E_{kf} - E_{ki}$$

$$W_W + W_f = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$mg\Delta x\cos\theta + f\Delta x\cos\theta = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$$(20)(9,8)(5)\cos 60^\circ + (120)(5)\cos 180^\circ = \frac{1}{2}(20)v_f^2 - \frac{1}{2}(20)(4,5)^2$$

$$490 - 600 = 10v_f^2 - 202,5$$

$$92,5 = 10v_f^2$$

$$v_f^2 = 9,25$$

$$v_f = 3,04 m.s^{-1}$$

CHECKPOINT

At this point in the topic, learners should have mastered:

1. Drawing labelled free-body diagrams.
2. Determining the angle θ between each force and the displacement.
3. The calculation of positive and negative work done by a force on an object.
4. The calculation of the net work done on an object.
5. Calculation of the change in kinetic energy of an object.
6. Applying the work-energy theorem.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Work, energy and power Worksheet: Questions 3-4

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

3. CONSERVATION OF ENERGY WITH NON-CONSERVATIVE FORCES PRESENT.

Introduction

Conservative forces do not change the mechanical energy of an object. When non-conservative forces act on an object, the mechanical energy of that object is not conserved.

CONCEPT EXPLANATION AND CLARIFICATION:

3.1 CONSERVATIVE AND NON-CONSERVATIVE FORCES

Write the law of conservation of energy on the board:

The law of conservation of energy states that energy cannot be created or destroyed, but is merely changed from one form into another.

Remind your learners that the **MECHANICAL ENERGY** (E_m) of an object at a point is the **SUM** of the **GRAVITATIONAL POTENTIAL ENERGY** (E_p) and the **KINETIC ENERGY** (E_k) of an object.

$$E_m = E_p + E_k$$

$$E_m = mgh + \frac{1}{2}mv^2$$

Write the definition of a conservative force on the board:

> **A force is a conservative force if the net work done by the force is zero, while moving an object around a closed path, starting and ending at the same point.**

The GRAVITATIONAL FORCE W (weight) is an example of a CONSERVATIVE FORCE.

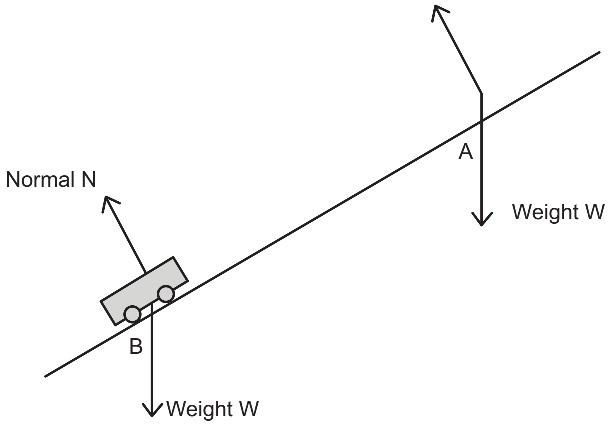
Whenever work is done by the gravitational force W, one form of mechanical energy (e.g. E_k) is transferred into another form of mechanical energy (e.g. E_p).

In other words, when the GRAVITATIONAL FORCE W acts on an object during its motion, the **TOTAL MECHANICAL ENERGY** of the object **IS CONSERVED**. The total mechanical energy of the object **DOES NOT CHANGE** during its motion. This means that the object neither gains nor loses mechanical energy during its motion.

Examples of conservative force are: Gravitational force W and the normal force N.

The **TOTAL MECHANICAL ENERGY** of an object **IS CONSERVED**, only when **CONSERVATIVE FORCES** are present.

Suppose a trolley moves down a FRICTIONLESS incline plane as show below (ignore air friction):



ONLY CONSERVATIVE FORCES are acting on the trolley (weight and normal force).

The TOTAL MECHANICAL ENERGY of the trolley will **REMAIN CONSTANT** throughout its motion along the slope. The mechanical energy of the trolley at A **IS EQUAL TO** the mechanical energy of the trolley at B.

$E_{m\ at\ A} = E_{m\ at\ B}$

Write the definition of a non-conservative force on the board:

A non-conservative force is one for which work done on the object depends on the path taken by the object.

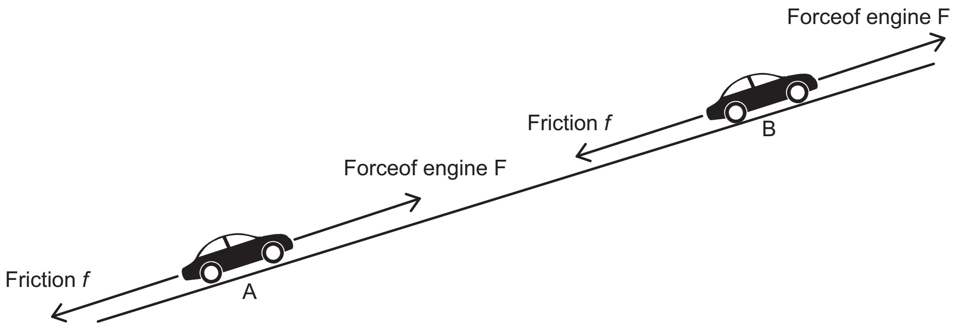
NON-CONSERVATIVE FORCES **CHANGE** THE TOTAL MECHANICAL ENERGY OF AN OBJECT.

Examples of non-conservative forces are:

Friction

An **applied external force** (e.g. the driving force of an engine, the tension in a rope or cable, an object is pushed or pulled)

Suppose a car is **DRIVING** up an inclined plane:



The forward force of the engine F is a non-conservative force. Friction is a non-conservative force.

If non-conservative force does POSITIVE WORK on an object, then energy is **ADDED** to the object. Total mechanical energy is NOT CONSERVED.

If non-conservative force does NEGATIVE WORK on an object, then energy is **REMOVED** from the object. Total mechanical energy is NOT CONSERVED.

Write the following summary on the board:

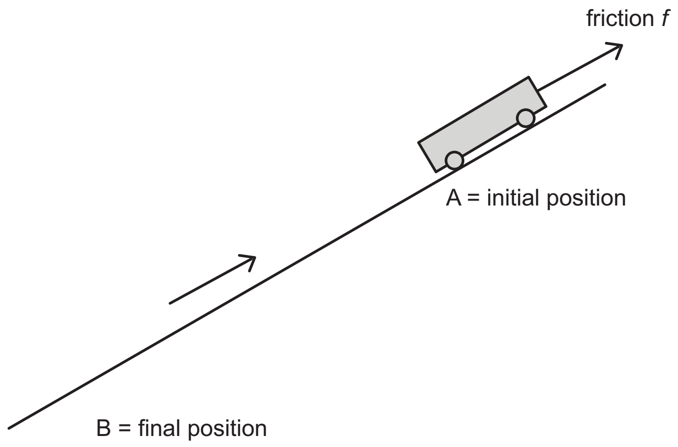
1. If a conservative force is the only force acting on an object during its motion, then the mechanical energy of the object is conserved (remains constant).
2. The gravitational force is a conservative force.
3. If non-conservative forces act on an object, then the mechanical energy of that object will not be conserved.
4. Friction will transfer some of the mechanical energy of the object into heat (thermal) energy.

Remind your learners that ENERGY is NEVER DESTROYED.

3.2 CONSERVATION OF ENERGY WITH NON-CONSERVATIVE FORCES

Work through the following derivation with your learners:

Suppose a trolley moves down a **rough** slope from point A to point B as shown below:



There is a non-conservative force (friction) acting on the trolley. The mechanical energy of the trolley at A is **NOT EQUAL** to the mechanical energy of the trolley at B.

$$E_{m\ at\ A} \neq E_{m\ at\ B}$$

Negative work is done on the trolley by friction, therefore some of the mechanical energy of the trolley will be **dissipated to the surroundings** as heat and sound.

When friction acts on the trolley, the initial mechanical energy of the trolley at A $(E_{m\,at\,A})$ is **GREATER THAN** the final mechanical energy of the trolley at B $(E_{m\,at\,A})$:

$$E_{m\,at\,A} > E_{m\,at\,B}$$

$$E_{pi} + E_{ki} > E_{pf} + E_{kf}$$

Let the work done by all non-conservative forces be W_{nc}

The negative work done by the non-conservative force (W_{nc}) is equal to the energy dissipated to the surroundings.

Remember that ENERGY IS ALWAYS CONSERVED.

We need to include the work done by the non-conservative force (W_{nc}) friction:

$$E_{pi} + E_{ki} + W_{nc} = E_{pf} + E_{kf} \qquad (1)$$

Equation (1) represents the **CONSERVATION OF THE TOTAL ENERGY** within this system.

If we solve for the work done by all non-conservative forces (W_{nc}) we get:

$$W_{nc} = E_{pf} + E_{kf} - E_{pi} - E_{ki}$$

$$W_{nc} = (E_{pf} - E_{pi}) + (E_{kf} - E_{ki})$$

$$W_{nc} = \Delta E_p + \Delta E_k \qquad (2)$$

The **left hand side** of this equation is the **WORK DONE** on the object by **ALL NON-CONSERVATIVE FORCES**.

The right hand side of this equation represents the **SUM** of the CHANGE IN THE GRAVITATIONAL POTENTIAL ENERGY ΔE_p of the object and the CHANGE IN THE KINETIC ENERGY ΔE_k of the object.

$$W_{nc} = \Delta E_p + \Delta E_k$$

In words we can state this equation as:

The work done by all non-conservative forces is equal to the change in the total mechanical energy of the system.

This is another form of the **WORK-ENERGY THEOREM**.

In summary:

1. The mechanical energy of a system is conserved when **only** conservative forces are present in the system (e.g. the gravitational force):

   $E_{pi} + E_{ki} = E_{pf} + E_{kf}$

2. The mechanical energy of a system is **not conserved** when non-conservative forces are present in the system (e.g. friction, air resistance, applied forces and tension). The work done by these non-conservative forces (W_{nc}) is equal to the change in the total mechanical energy of the system:

   $W_{nc} = \Delta E_p + \Delta E_k$

Work through each of the following introductory level calculations to develop your learners understanding of how to use $W_{nc} = \Delta E_p + \Delta E_k$

INTRODUCTORY LEVEL QUESTIONS

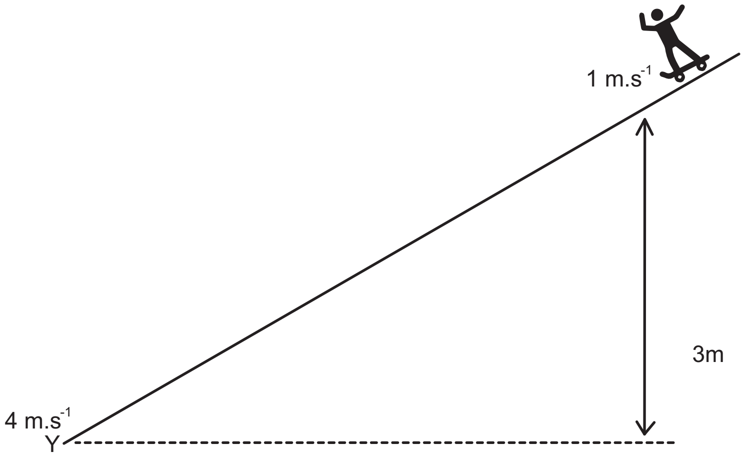
a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the conservation of energy when non-conservative forces are present. $W_{nc} = \Delta E_p + \Delta E_k$

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. A skateboarder with a mass of 65 kg skates down a slope from point X to Y while experiencing a frictional force of 150 N. Point X is 3 m above ground level. The speed of the skateboarder at point X is $1 m.s^{-1}$ and his speed at the bottom of the slope Y is $4 m.s^{-1}$.



1.1 Use energy principles to calculate the work done on the skateboarder by friction.

1.2 Calculate the distance between X and Y.

Solution:

1.1 $W_{nc} = \Delta E_p + \Delta E_k$

$W_{nc} = (E_{pf} - E_{pi}) + (E_{kf} - E_{ki})$

$W_f = [0 - (65)(9,8)(3)] + [\frac{1}{2}(65)(4)^2 - \frac{1}{2}(65)(1)^2]$

$W_f = [0 - 1\,911] + [520 - 32,5]$

$W_f = -1\,911 + 487,5$

$W_f = -1\,423,5\,J$

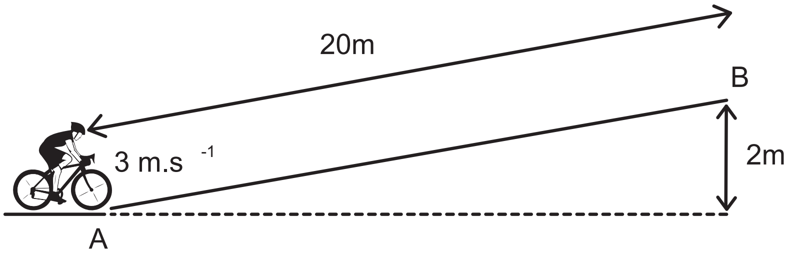
1.2 $W_f = f\Delta x\cos\theta$

$-1\,423,5 = (150)\Delta x\cos 180°$

$-1\,423,5 = -150\Delta x$

$\Delta x = 9,49\,m$

2. A cyclist pedals up a 20 m slope. The cyclist applies a pedalling force of 250 N and experiences a frictional force of 80 N as he cycles up the slope. The speed of the cyclist is $3\,m.s^{-1}$ at the bottom of the slope, point A. Point B is at a height of 2 m above the ground level. The total mass of the cyclist and cycle is 80 kg.



2.1 Calculate the increase in the gravitational potential energy of the cyclist.

2.2 Calculate the net work done on the cyclist by all the non-conservative forces.

2.3 Use energy principles to calculate the speed of the cyclist at point B.

Solution:

2.1 $\Delta E_p = E_{pf} - E_{pi}$

$\Delta E_p = (80)(9,8)(2) - 0$

$\Delta E_p = 1\,568\,J$

2.2 $W_{nc} = W_F + W_f$

$W_{nc} = F\Delta x\cos\theta + f\Delta x\cos\theta$

$W_{nc} = (250)(20)\cos 0^{\circ} + (80)(20)\cos 180^{\circ}\,{}^{\circ}$

$W_{nc} = 5\,000 - 1\,600$

$W_{nc} = +3\,400\,J$

2.3 $W_{nc} = \Delta E_p + \Delta E_k$

$+3\,400 = 1\,568 + (E_{kf} - E_{ki})$

$3\,400 = 1\,568 + [\frac{1}{2}(80)v_f^2 - \frac{1}{2}(80)(3)^2]$

$1\,472 = 40v_f^2$

$v_f^2 = 36,8$

$v_f = 6,07\,m.s^{-1}$

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic calculations, they are ready to deal with more challenging questions.

b. These questions require learners to apply the law of conservation of energy when non-conservative forces are present. $W_{nc} = \Delta E_p + \Delta E_k$

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

Key Teaching:

a. Identify the non-conservative forces present.

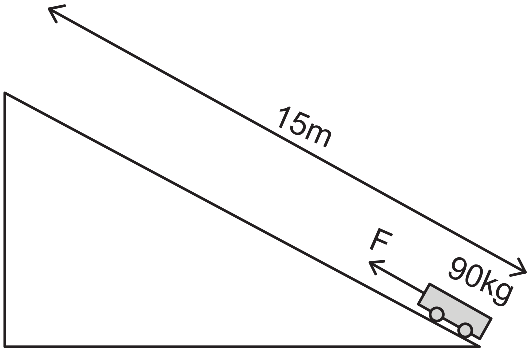
b. Calculate the work done by all non-conservative forces.

c. Calculate the initial and final kinetic energies and change in kinetic energy of an object.

d. Calculate the initial and final gravitational potential energies and change in gravitational potential energy of an object.

e. Apply the equation $W_{nc} = \Delta E_p + \Delta E_k$ to problems.

3. A force F is applied to a trolley to move it up a ramp of length 15 m and a vertical height of 1,2 m, as shown in the diagram below. The mass of the loaded trolley is 90 kg. The frictional force between the wheels and the surface of the ramp is 60 N. The trolley is moved up the ramp at constant velocity.



3.1 What is the magnitude of the net force acting on the trolley as it moves up the ramp? Give a reason for your answer.

3.2 Calculate the increase in the gravitational potential energy of the trolley when it reaches the top of the ramp.

3.3 Use energy principles to calculate the magnitude of force F.

Solution:

3.1 The net force is zero (the trolley is moving at constant velocity).

3.2 $\Delta E_p = E_{pf} - E_{pi}$

$\Delta E_p = (90)(9,8)(15) - 0$

$\Delta E_p = 13\,230\ J$

3.3 $W_{nc} = \Delta E_p + \Delta E_k$

$W_F + W_f = (E_{pf} - E_{pi}) + (E_{kf} - E_{ki})$

$F\Delta x \cos\theta + f\Delta x \cos\theta = (E_{pf} - E_{pi}) + 0$

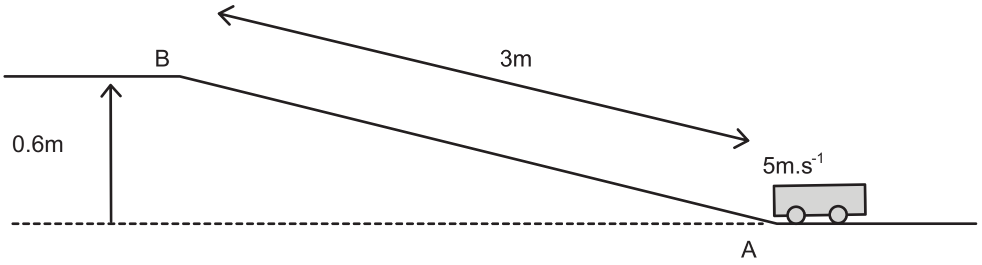
$F(15)\cos 0^{\circ} + (60)(15)\cos 180^{\circ} = (90)(9,8)(1,2) - 0$

$15F - 900 = 1\,058,4$

$15F = 1\,958,4$

$F = 130,56\ N$

4. A trolley of mass 2 kg moving at $4\,m.s^{-1}$, rolls from point A to B along a frictionless slope. The length of the runway is 3 m. The vertical height between points A and B is 0,6 m.



4.1 Is the mechanical energy of the trolley conserved as it moves from A to B? Explain your answer.

4.2 Calculate the speed of the trolley at point B.

Now suppose the surface AB is rough and the trolley experiences a constant frictional force of 4 N as it moves from X to Y.

4.3 Will the trolley reach point B? Justify your answer by means of a calculation.

Solution:

4.1 Yes. Only conservative forces act on the trolley.

4.2
$$E_{m\,at\,A} = E_{m\,at\,B}$$
$$E_{pA} + E_{kA} = E_{pB} + E_{kB}$$
$$0 + \frac{1}{2}(2)(5)^2 = (2)(9{,}8)(0{,}6) + \frac{1}{2}(2)v_B^2$$
$$25 = 11{,}76 + v_B^2$$
$$13{,}24 = v_B^2$$
$$v_B = 3{,}64\,m.s^{-1}$$

4.3
$$E_{m\,at\,A} = E_{k\,at\,A} = \frac{1}{2}(2)(5)^2 = 25\,J$$
$$E_{p\,at\,B} = (2)(9{,}8)(0{,}6) = 11{,}76\,J$$
$$W_f = f\Delta x\cos\theta = (4)(3)\cos 180^{\circ} = -12\,J$$
$$E_{m\,at\,A} - W_f = E_{m\,at\,B}$$
$$25 - 12 = E_{m\,at\,B}$$
$$E_{m\,at\,B} = 13\,J$$
$$E_{p\,at\,B} = 11{,}76\,J$$
$$E_{k\,at\,B} = 13 - 11{,}76 = 1{,}24\,J$$

The trolley will reach point B.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. The calculation of gravitational potential energy and change in gravitational potential energy.
2. The calculation of kinetic energy and change in kinetic energy.
3. Identifying non-conservative forces.
4. The calculation of the net work done by all non-conservative forces.
5. Applying the law of conservation of energy when non-conservative forces are present.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Work, energy and power Worksheet: Questions 5-6

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

4. POWER

INTRODUCTION

In this part of the topic you will develop an understanding of the rate at which work is done.

CONCEPT EXPLANATION AND CLARIFICATION:

4.1 POWER

Write the definition of power on the board:

Power is the rate at which work is done.

$$P = \frac{W}{t}$$

Where W is the work done. Work is measured in joules (J).

t is the time taken to do the work. Time is measured in seconds (s).

P is power and is measured in watts (W). Power is a scalar quantity.

$$1W = \frac{1J}{1s} = 1J.s^{-1}$$

$$1kW = 1\,000W$$

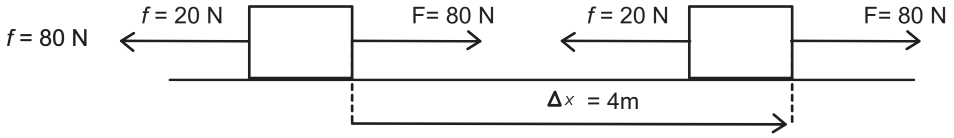
Remind your learners that when work is done energy is transferred.

Work done = Energy transferred

Power could also be stated as **the rate at which energy is transferred.**

Work through the following examples with your learners to develop their understanding of power:

Suppose a boy pushes a 25 kg crate with a horizontal force of 200 N along a horizontal floor for 10 m in 4 s. The force of friction between the box and the floor is 80 N.



The work done by the applied force on the box is:

$$W_F = F\Delta x \cos\theta = (200)(10)\cos 0° = 2\,000\,J$$

The power of the boy is:

$$P = \frac{W_F}{t} = \frac{2\,000}{4} = 500\,W$$

The boy transfers 500 J of energy to the box **per second**.

The work done by the frictional force on the box is:

$$W_f = f\Delta x \cos\theta = (80)(10)\cos 180° = -800\,J$$

The rate at which energy is dissipated is:

$$P = \frac{W_F}{t} = \frac{800}{4} = 200\,W$$

Energy is dissipated to the surroundings at a rate of **200 J per second**.

Suppose a 65 kg learner, starting from rest, ran up a flight of stairs, 5 m high in 8 s. The speed of the learner at the top of the stairs is $3\,m.s^{-1}$.

As the learner runs up the stairs, her gravitational potential energy is increasing.

As the learner runs up the stairs, her kinetic energy is also increasing.

The **WORK DONE BY THE LEARNER** is equal to her **CHANGE IN MECHANICAL ENERGY**:

$$W_{nc} = \Delta E_p + \Delta E_k$$

$$W_{nc} = (E_{pf} - E_{pi}) + (E_{kf} - E_{ki})$$

$$W_{nc} = [(65)(9,8)(5) - 0] + [\frac{1}{2}(65)(3)^2 - 0]$$

$$W_{nc} = 3\,185 + 292,5$$

$$W_{nc} = 3\,477,5\,J$$

The power of the learner is:

$$P = \frac{W_{nc}}{t} = \frac{3\,477,5}{8} = 434,69\,W$$

4.2 Average power needed to keep an object moving at constant speed

Suppose a car is moving at **constant speed** along a straight road. The car's engine exerts a forward force (F) on the car. The car also experiences a frictional force (f) in the opposite direction as shown in the diagram below.

Car moving at constant speed

If the car is driven at a constant speed, the magnitude of the forward force (F) is equal to the magnitude of the frictional force (f).

The **AVERAGE POWER** of the car's engine (to keep the car moving at **constant speed**) is:

$$P_{av} = \frac{W}{t} = \frac{F\Delta x \cos 0^{\circ}}{t} = \frac{F\Delta x}{t}$$

But $average\ speed = v_{av} = \frac{\Delta x}{t}$

Therefore: $P_{av} = Fv_{av}$

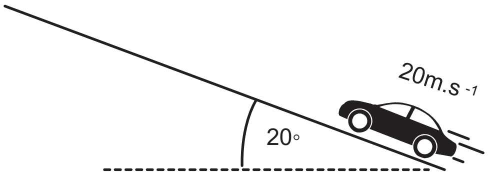
A truck of mass 5 000 kg is travelling at a constant speed of $25\,m.s^{-1}$ **. The truck experiences a frictional force of 9 800 N.**

Calculate the average power of the trucks engine.

The forward force of the engine is equal in magnitude to the frictional force.

$$P_{av} = Fv_{av}$$

$$P_{av} = (9\,800)(25) = 245\,000\,W$$



Suppose a car of mass 800 kg is driving up a **rough inclined plane** at a **constant speed** of 20 m.s^{-1}. The plane is inclined at 20° to the horizontal. The car experiences a frictional force of 1 500 N.

Calculate the average power of the car's engine.

There are **two forces** acting down the slope.

The frictional force acts down the slope.

The horizontal component Wx of the weight W of the car also acts down the slope.

$$W_x = W\sin 20^{\circ} = (800)(9{,}8)\sin 20^{\circ} = 2\,681{,}44\,N\ \textit{down the slope}$$

$$F_{downtheslope} = W_x + f = 2\,681{,}44 + 1\,500 = 4\,181{,}44\,N$$

If the car is driven at constant speed then the force of the engine up the slope must be equal in magnitude to the force down the slope.

The average power of the car's engine is:

$$P_{av} = Fv_{av}$$

$$P_{av} = (4\,181{,}44)(20) = 83\,628{,}8\,W$$

4.3 Power of an electric motor

An electric motor can be used to pump water up to the ground level. The water will be pumped at a particular rate through a vertical height h.

The rate at which water is pumped is often expressed in litres per minute $(L.\min^{-1})$ or $kg.\min^{-1}$.

For example, an electric motor is able to pump water at 120 kg per minute. This means that 120 kg of water is pumped to the ground level every minute.

Work through the following example with your learners to develop their understanding of the power of an electric motor.

Calculate the minimum power required of an electric motor to pump water at a rate of 80 kg per minute from a depth of 10 m.

Firstly we need to calculate the work done by the pump in raising 80 kg of water through a vertical height of 10 m:

The upward force exerted by the pump is a non-conservative force. The work done by the non-conservative force is equal to the change in mechanical energy of the water:

$$W_{nc} = \Delta E_p + \Delta E_k$$

The electric motor pumps water at a constant rate, therefore the water will move through the pipe at a **constant speed**. If there is no change in the speed of the water then its **change in kinetic energy is zero** $(\Delta E_k = 0)$

This means that the work done by the electric motor is equal to the change in gravitational potential energy of the water only:

$$W_{nc} = \Delta E_p \qquad (\Delta E_k = 0)$$

$$W_{nc} = E_{pf} - E_{pi}$$

If we take the level of the pump as the reference point, then

$$W_{nc} = mgh - 0$$

$$W_{nc} = mgh$$

$$W_{nc} = (80).(9{,}8).(10) = 7\,840\,J$$

7 840 J of work is done every minute to raise 80 kg of water through a height of 10 m.

The minimum power of the electric motor is:

$$P = \frac{W_{nc}}{t} = \frac{\Delta E_p}{t} = \frac{7\,840}{60} = 130{,}67\,W$$

The minimum power of the electric motor can be calculated in a different way:

The water is being pumped at an average speed of:

$$v_{av} = \frac{\Delta x}{t} = \frac{10m}{60s} = 0{,}1667\,m.s^{-1}$$

The water is pumped at constant speed, therefore the **upward force F of the pump** is equal in magnitude to the **weight of the water**:

$$F = W = mg = (80)(9{,}8) = 784\,N\ upwards$$

The average power required to keep an object moving at constant velocity is:

$$P_{av} = Fv_{av} = (784)(0{,}1667) = 130{,}69\,W$$

TOPIC 5: Work, energy and power

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with methods to calculate power, average power and the minimum power of an electric motor.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. A builder of mass 80 kg is carrying 10 kg of bricks up a flight of stairs 10 m high. He climbs the stairs in 20 s. Calculate the power output of the builder during his climb at constant speed.

   Solution:

   $W_{nc} = \Delta E_p + \Delta E_k$

   $\Delta E_k = 0$

   $W_{nc} = \Delta E_p = E_{pf} - E_{pi} = mgh - 0 = (90).(9,8).(10) = 8\,820\,J$

   $P = \frac{\Delta E_p}{t} = \frac{8\,820}{20} = 441\,W$

2. An 80 kg sprinter running on a horizontal track can accelerate from a standing start to a speed of $8\,m.s^{-1}$ in 2,5 s. Determine the average power of the athlete.

   Solution:

   $W_{nc} = \Delta E_p + \Delta E_k$

   $\Delta E_p = 0$

   $W_{nc} = \Delta E_k = E_{kf} - E_{ki} = \frac{1}{2}(80)(8)^2 - 0 = 2\,560\,J$

   $P = \frac{\Delta E_k}{t} = \frac{2\,560}{2,5} = 1\,024\,W$

3. A car of mass 750 kg is travelling at a constant speed of 80 km.h^{-1} on a rough horizontal road. The average power output of the engine is 90 kW.

   3.1 Calculate the magnitude of the average forward force of the car's engine.

   3.2 What is the magnitude of the frictional force acting on the car?

   The car then drives up a long hill inclined at 10° to the horizontal.

   3.3 Calculate the power output of the car's engine if it experiences the same frictional force and maintains the same constant speed up the hill.

   Solution:

   3.1 $v_{av} = \frac{80\,km.h^{-1}}{3,6} = 22,22\,m.s^{-1}$

   $P_{av} = Fv_{av}$

   $F = \frac{P_{av}}{v_{av}} = \frac{90\,000}{22,22} = 4\,050,41\,N$

   3.2 $f = 4\,050,41\,N$

   3.3 $W_x = W\,sin\,10^{\circ} = (750)(9,8).sin\,10^{\circ} = 1\,276,31\,N\ down\ the\ hill$

   $F_{down\ the\ slope} = W_x + f = 1\,276,31 + 4\,050,41 = 5\,326,72\,N\ down\ the\ hill$

   $P_{av} = Fv_{av} = (5\,326,72)(22,22) = 118\,359,72\,W$

4. An electric motor drives a water pump which is submerged at the bottom of a borehole that is 5 m deep.

   4.1 Calculate the minimum power of the electric motor if it pumps 20 kg of water at a constant rate up to the ground level in 10 s.

   4.2 Explain why an electric motor with a higher power rating would need to be used to perform this function?

   Solution:

   4.1 $v_{av} = \frac{\Delta x}{t} = \frac{5m}{10s} = 0,5\,m.s^{-1}$

   The water moves at constant speed, therefore the upward force of the pump on the water is equal to the weight of the water:

   $F = W = mg = (20)(9,8) = 196\,N\ upwards$

The average power required to keep an object moving at constant velocity is:

$$P_{av} = Fv_{av} = (196)(0,5) = 98\,W$$

OR

$$P = \frac{W_{nc}}{t} = \frac{\Delta E_p}{t} = \frac{mgh}{t} = \frac{(20)(9,8)(5)}{10} = 98\,W$$

4.2 Some of the electrical energy supplied to the electric motor will be transferred to heat and sound when work is done by friction. The electric motor will need to do more work per second (higher power).

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic calculations, they are ready to deal with more challenging questions.

b. These questions require learners to calculate power.

c. These questions require learners to calculate the average power required to keep an object moving at constant speed.

d. These questions require learners to calculate the minimum power of an electric motor.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

TOPIC 5: Work, energy and power

Key Teaching:

a. Power is the rate at which work is done.

b. When an object moves at constant speed then the change in kinetic energy is zero.

c. When an object moves up or down an inclined plane, there will be a change in gravitational potential energy.

d. Use $W_{nc} = \Delta E_p + \Delta E_k$ to calculate the change in mechanical energy of an object.

e. Calculate the average power required to keep an object moving at constant speed using $P_{av} = Fv_{av}$

f. Calculate the minimum power required by an electric motor to pump water from a depth at a constant rate using $P = \frac{\Delta E_p}{t}$

5. A car of mass 800 kg has a maximum power output of 200 kW.

   5.1 What maximum constant speed could the car maintain if it experienced a frictional force of 4 000 N along a straight level road?

   5.2 The car now travels up a slope inclined at 15° to the horizontal. Assume that the frictional force acting on the car is now 3 500 N. Determine the maximum constant speed that the car can maintain.

   Solution:

   5.1 $P_{av} = Fv_{av}$

   $200\,000 = (4\,000).v_{av}$

   $v_{av} = 50\ m.s^{-1}$

   5.2 $W_x = W\,sin\,15^\circ = (800)(9,8)\,sin\,15^\circ = 2\,029,14\ N\ down\ the\ hill$

   $F_{down\ the\ slope} = W_x + f = 2\,029,14 + 3\,500 = 5\,529,14\ N\ down\ the\ hill$

   $P_{av} = Fv_{av}$

   $200\,000 = (5\,529,14).v_{av}$

   $v_{av} = 36,17\ m.s^{-1}$

6. A water pump rated at 150 W is claimed to pump water from a borehole 30 m deep at a constant rate of 40 kg per minute. Is this possible?

   Solution:

   $P = \frac{\Delta E_p}{t} = \frac{mgh}{t} = \frac{(40).(9,8).(30)}{60} = \frac{11\,760}{60} = 196\,W$ Not possible.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. The calculation of power.
2. Calculate the average power required to keep an object moving at constant speed using $P_{av} = Fv_{av}$ along a rough horizontal surface and an inclined plane.
3. Calculate the minimum power required by an electric motor to pump water from a depth at a constant rate using $P = \frac{\Delta E_p}{t}$

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Work, energy and power Worksheet: Questions 7-8

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

CONSOLIDATION

- Learners can consolidate their learning by completing; **Worksheet Pack: Work, energy and power Consolidation Exercise**.
- Photocopy the exercise sheet for the learners. If that is not possible, learners will need to copy the questions from the board before attempting to answer them.
- The consolidation worksheet should be marked by the teacher so that she/he is aware of each learner's progress in this topic.
- Please remember that further consolidation should also be done by completing the examples available in the textbook.
- **It is important to note that this consolidation exercise is NOT scaffolded.**
- **It should not be administered as a test, as the level of the work may be too high to in its entirety.**

ADDITIONAL VIEWING / READING

In addition, further viewing or reading on this topic is available through the following web links:

1. https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/v/work-and-the-work-energy-principle
   Work done = energy transferred
2. https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/v/conservative-forces
   Conservative and non-conservative forces
3. https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/v/power
   Power

TOPIC 6: Doppler Effect

A INTRODUCTION

- This topic runs for 6 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Doppler Effect forms part of the content area Mechanics (Physics).
- Mechanics counts as 42% in the final exam.
- Doppler Effect counts approximately 6% to 7% of the final examination.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.
2. Chalk.
3. Grade 12 Physics Examination Data Sheet.
4. Tuning fork (or small sound source), string.

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. A4, 3 Quire exercise book, for notes and exercises.
2. Scientific calculator – Sharp or Casio calculators are highly recommended.
3. Pen.
4. Grade 12 Physics Examination Data Sheet.

TOPIC 6: Doppler Effect

B SEQUENTIAL TABLE

PRIOR KNOWLEDGE	LOOKING FORWARD
Grade 10	**Grade 12**
• Wavelength, frequency, wave speed. • Sound waves • Pitch • Ultrasound • EM spectrum	• Doppler Effect with sound and ultrasound. • The Doppler Effect with light (red shifts in the Universe)

C GLOSSARY OF TERMS

Please note: The highlighted definitions and laws are ones that learners must be able to state and are given in the CAPS document. For examination purposes, learners must know these definitions and laws by heart, and must write them exactly as they appear here.

TERM	DEFINITION
Frequency	The number of waves that pass a point per second.
Wavelength	The distance between two consecutive points that are in phase.
Speed	The rate of change of distance.
Velocity	The rate of change of displacement.
Doppler Effect	The apparent change in frequency of a source when there is relative motion between the source and the observer.
Redshift	Spectral lines are shifted towards the red end of the visible spectrum. The wavelengths of the spectral lines are longer than expected.
Blueshift	Spectral lines are shifted towards the blue end of the visible spectrum. The wavelengths of the spectral lines are shorter than expected.

D

ASSESSMENT OF THIS TOPIC

- This topic is assessed by class/control tests as well as in the midyear and end of year examinations.
- There must be multiple-choice type questions, problems to solve (where the learners are expected to show their method), questions that require explanation and questions that ask for definitions.

E BREAKDOWN OF TOPIC AND TARGETED SUPPORT OFFERED

- *Please note that this booklet does not address the full topic – only targeted support related to common challenges is offered.*
- *For further guidance on full lesson planning, please consult CAPS, the NECT Planner & Tracker and the textbook.*

TIME ALLOCATION	SUB TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
4 hours	With sound and ultrasound	121	a. Explanation of the Doppler Effect with clear diagrams. b. Numerous worked examples. c. Numerous practice questions.
2 hours	With light - red shifts in the universe (evidence for the expanding universe).	122	a. Explanations for red shifted and blue shifted spectral lines emitted by distant galaxies. b. Explanation of how redshift provides evidence for an expanding Universe. c. Numerous practice questions.

TOPIC 6: Doppler Effect

F TARGETED SUPPORT PER SUB TOPIC

1. DOPPLER EFFECT WITH SOUND AND ULTRASOUND

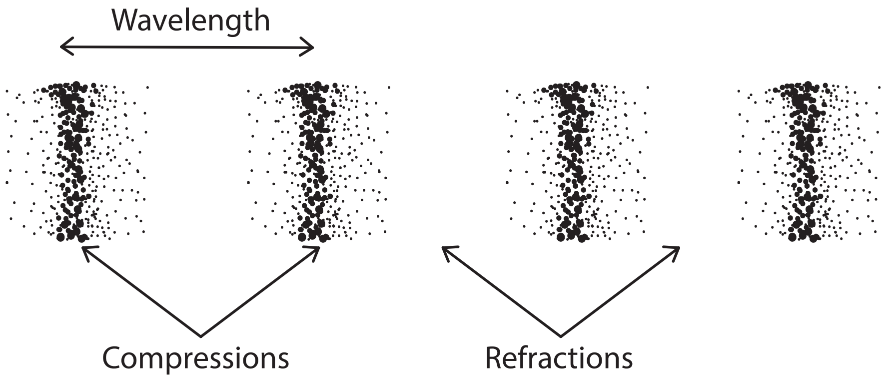
INTRODUCTION

A common example of the Doppler Effect occurs when an ambulance is travelling towards you and then passes, you can hear a change in the pitch of the sound coming from the siren. As the siren approaches you, the sound heard has a higher pitch than when the siren is moving away from you. This phenomenon is known as the Doppler Effect.

CONCEPT EXPLANATION AND CLARIFICATION:

Remind your learners of the following terms that they learnt in grade 10:

Sound is an example of a longitudinal wave. A longitudinal wave is made up compressions and rarefactions. Compressions occur where the particles of the medium are pushed closer together. Rarefactions occur where the particles of the medium are pulled further apart from each other.



Frequency (f) is the number of waves that pass a point per second.

Frequency is measured in hertz (Hz). For example, most sirens produce sound with a frequency of 2 000 Hz. This means 2 000 waves pass a listener per second.

When referring to sound waves, frequency can be referred to as **PITCH**. For example, a sound wave with a **higher pitch** means the sound wave has a **higher frequency**. A piece of chalk, screeching on the board is an example of a high pitched sound. A rumble of an earthquake is a low pitched sound.

TOPIC 6: Doppler Effect

Wavelength (λ) is the distance between two consecutive points which are in phase.

Wavelength is measured in metres (m). For example, the wavelength of the sound waves produced by a siren is approximately 0,17 m. This means there is 0,17 m between two consecutive compressions in this sound wave.

The speed (v) of a wave is calculated using the wave equation: $v = f\lambda$

The speed of a wave measured in $m.s^{-1}$.

VERY IMPORTANT:

At constant speed, the **frequency (f)** of a wave is **INVERSELY PROPORTIONAL** to the **wavelength (λ)** of the wave.

$$f = \frac{v}{\lambda}$$

In other words, if the **wavelength** of a sound wave is **increased**, then the **frequency** the new sound wave will **decrease** (fewer waves pass a point per second).

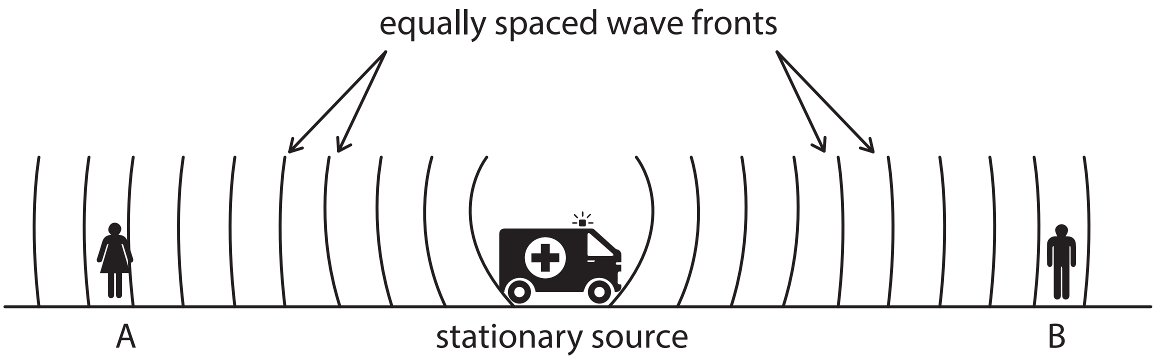
If the **wavelength** of a sound wave is **decreased**, then the **frequency** of the new sound wave will **increase** (more waves will pass a point per second).

1. Both the SOURCE and LISTENER are STATIONARY:

Consider a **STATIONARY** ambulance. The siren of the ambulance is **ON**. The siren is the **SOURCE** (S) of the sound. The frequency of the source (f_s) (the siren) is 1 000 Hz.

$$f_s = 1\,000 Hz$$

The sound waves produced by the **STATIONARY** siren are shown moving away from the source:



There are **STATIONARY LISTENERS** (observers) at A and B.

The frequency of the sound heard by the STATIONARY LISTENERS (f_L) is the **SAME** as the frequency of the STATIONARY SOURCE (f_s).

Take the **speed of sound in air** (v) to be $340\,m.s^{-1}$: $v = 340\,m.s^{-1}$

The frequency observed by the LISTENER (f_L) is calculated using:

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

In this case, the **SPEED** of the **LISTENER** is zero: $v_L = 0$

The **SPEED** of the sound **SOURCE** is zero: $v_s = 0$

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v}{v} f_s \qquad v_L = 0 \qquad v_s = 0$$

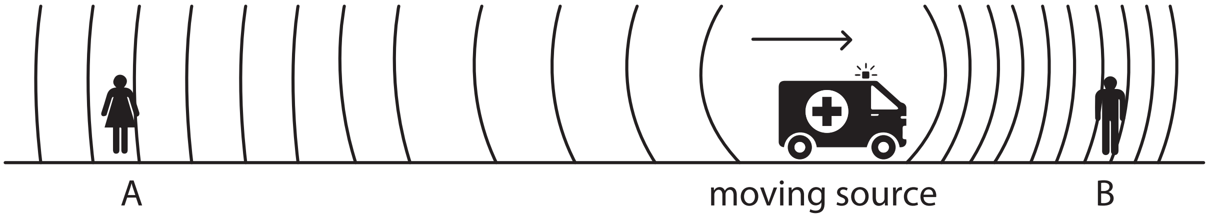
$$f_L = \frac{340}{340} f_s \qquad v = speed\ of\ sound\ in\ air = 340\,m.s^{-1}$$

$$f_L = f_s = 1\,000\,Hz$$

When the SOURCE and the LISTENER are **STATIONARY**, then the frequency observed by the LISTENER is the **SAME** as the frequency of the SOURCE.

2. The SOURCE is MOVING TOWARDS a STATIONARY LISTENER:

The source of the sound waves is moving **TOWARDS THE LISTENER** at point B.



The wavefronts IN FRONT of the source are CLOSER TOGETHER.

The **WAVELENGTH** of the sound waves in front of the source has **DECREASED**.

If the wavelength (λ) of the sound waves has DECREASED then the frequency (f) of the sound waves must **INCREASE**. (At constant speed, frequency is inversely proportional to wavelength.)

The source has a frequency of 1 000 Hz, **BUT** the frequency observed by listener B must be HIGHER than 1 000 Hz.

The sound observed by the listener at B will have a **HIGHER PITCH**.

There are more waves passing listener B per second.

This apparent change in frequency of a sound wave is known as the **DOPPLER EFFECT**.

Write the Doppler Effect on the board:

The Doppler Effect:

The apparent change in frequency of a source when there is relative motion between the source and the observer.

Suppose the speed of the ambulance is $40\,m.s^{-1}$ TOWARDS B.

The frequency observed by the listener (f_L) at B is calculated using:

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v}{v - v_s} f_s \qquad v_L = 0$$

$$f_L = \frac{340}{340 - 40}(1\,000) \qquad v = 340\,m.s^{-1} \qquad v_s = 40\,m.s^{-1} \qquad f_s = 1\,000\,Hz$$

$$f_L = \frac{340}{300}(1\,000)$$

$$f_L = (1,1333)(1\,000)$$

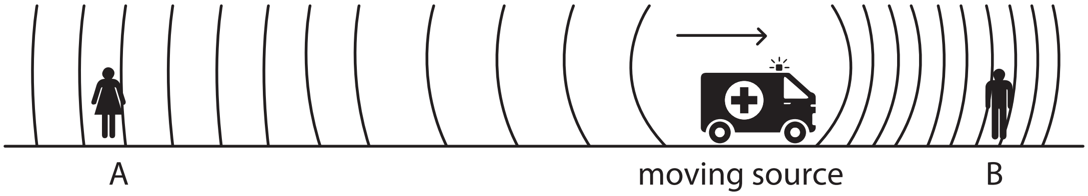
$f_L = 1133,33Hz$ (GREATER than 1 000 Hz)

When the SOURCE is **MOVING TOWARDS** a STATIONARY LISTENER, then the **FREQUENCY** observed by the LISTENER is **HIGHER THAN** the FREQUENCY of the SOURCE.

$f_L = \frac{v}{v - v_s} f_s$ $\quad(\frac{v}{v - v_s})$ is a number GREATER THAN 1

3. The SOURCE is MOVING AWAY from a STATIONARY LISTENER:

The source of the sound waves is moving **AWAY from THE LISTENER** at point A.



The wavefronts BEHIND of the source are FURTHER APART.

The **WAVELENGTH** of the sound waves behind the source has **INCREASED**.

If the wavelength (λ) of the sound waves has INCREASED then the frequency (f) of the sound waves must **DECREASE**. (At constant speed, frequency is inversely proportional to wavelength.)

The source has a frequency of 1 000 Hz, **BUT** the frequency observed by listener **A** must be **LESS than 1 000 Hz**.

The sound observed by the listener at **A** will have a **LOWER PITCH**.

There are fewer waves passing listener **A** per second.

The speed of the ambulance is $40\,\text{m.s}^{-1}$ **AWAY from A.**

The frequency observed by the listener (f_L) at A is calculated using:

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v}{v + v_s} f_s \qquad v_L = 0$$

$$f_L = \frac{340}{340 + 40}(1\,000) \qquad v = 340\, m.s^{-1} \qquad v_s = 40\, m.s^{-1} \qquad f_s = 1\,000\, Hz$$

$$f_L = \frac{340}{380}(1\,000)$$

$$f_L = (0{,}8947)(1\,000)$$

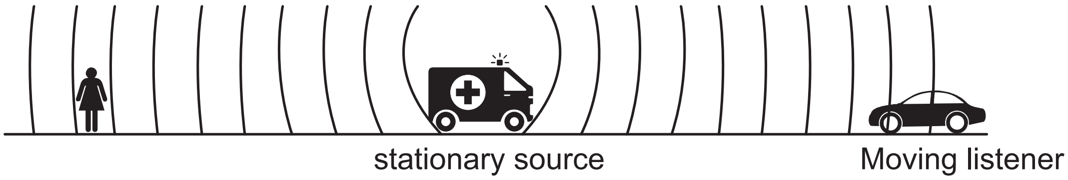
$f_L = 894{,}74\, Hz$ (LESS than 1 000 Hz)

When the SOURCE is **MOVING AWAY** from STATIONARY LISTENER, then the **FREQUENCY** observed by the LISTENER is **LESS THAN** the FREQUENCY of the SOURCE.

$f_L = \frac{v}{v + v_s} f_s$ $\qquad$ $(\frac{v}{v + v_s})$ **is a number LESS THAN 1**

4. The LISTENER is MOVING TOWARDS a STATIONARY SOURCE:

The **LISTENER** is **MOVING TOWARDS** a STATIONARY SOURCE.



If the frequency of the source is 1 000 Hz then 1 000 waves pass a **fixed point** per second. The listener is moving towards the source, therefore the listener is **moving through more wavefronts per second**. The frequency observed by the listener must be **HIGHER THAN**

1 000 Hz.

The moving listener will observe a **HIGHER PITCHED SOUND** than that of the source.

The **WAVELENGTH** of the observed sound waves has **DECREASED**.

Suppose the listener (B) is moving at $40\,m.s^{-1}$ **TOWARDS the stationary source.**

The frequency observed by the listener (f_L) at B is calculated using:

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v + v_L}{v} f_s \qquad v_s = 0$$

$$f_L = \frac{340+40}{340}(1\,000) \qquad v = 340\,m.s^{-1} \qquad v_L = 40\,m.s^{-1} \qquad f_s = 1\,000\,Hz$$

$$f_L = \frac{380}{340}(1\,000)$$

$$f_L = (1{,}1177)(1\,000)$$

$$f_L = 1117{,}65\,Hz$$ (GREATER than 1 000 Hz)

When the LISTENER is **MOVING TOWARDS** a STATIONARY SOURCE, then the **FREQUENCY** observed by the LISTENER is **HIGHER THAN** the FREQUENCY of the SOURCE.

$f_L = \frac{v + v_L}{v} f_s$ $\left(\frac{v + v_L}{v}\right)$ **is a number GREATER THAN 1**

If the frequency of the source is 1 000 Hz then 1 000 waves pass a f**ixed point** per second. The listener is moving away from the source, therefore the listener is **moving through fewer wavefronts per second**. The frequency observed by the listener must be **LOWER THAN** 1 000 Hz.

The moving listener will observe a **LOWER PITCHED SOUND** than that of the source.

The **WAVELENGTH** of the observed sound waves has **INCREASED**.

Suppose the listener (B) is moving at $40\,\text{m.s}^{-1}$ **AWAY FROM the stationary source.**

The frequency observed by the listener (f_L) at B is calculated using:

$$f_L = \frac{v \pm v_L}{v \pm v_s} f_s$$

$$f_L = \frac{v}{v - v_s} f_s \qquad v_s = 0$$

$$f_L = \frac{340 - 40}{340}(1\,000) \qquad v = 340\,m.s^{-1} \qquad v_L = 40\,m.s^{-1} \qquad f_s = 1\,000\,Hz$$

$$f_L = \frac{300}{340}(1\,000)$$

$$f_L = (0{,}8824)(1\,000)$$

$f_L = 882{,}35\,Hz$ (LESS than 1 000 Hz)

When the LISTENER is **MOVING AWAY FROM** a STATIONARY SOURCE, then the **FREQUENCY** observed by the LISTENER is **LESS THAN** the FREQUENCY of the SOURCE.

$f_L = \frac{v - v_L}{v} f_s$ $\quad$ $(\frac{v - v_L}{v})$ **is a number LESS THAN 1**

Write the following summary on the board:

Summary of the Doppler Effect with sound:

1. **Source and Listener are STATIONARY.**

   The frequency observed by the listener is **EQUAL TO** the frequency produced by the source.

   $f_L = f_s$

2. **SOURCE is moving towards a STATIONARY LISTENER.**

   The frequency observed by the listener is **HIGHER THAN** the frequency produced by the source.

   A higher pitched sound is observed. Wavelength is shorter.

   $f_L = \frac{v}{v - v_s} f_s$ $\quad$ $v = speed\ of\ sound\ in\ air$ $\quad$ $v_L = 0$

   $v_s = speed\ of\ source$ $\quad$ $(\frac{v}{v - v_s}) > 1$

3. **SOURCE is moving away from a STATIONARY LISTENER.**

   The frequency observed by the listener is **LESS THAN** the frequency produced by the source.

   A lower pitched sound is observed. Wavelength is longer.

   $f_L = \frac{v}{v + v_s} f_s$ $\quad$ $v = speed\ of\ sound\ in\ air$ $\quad$ $v_L = 0$

   $v_s = speed\ of\ source$ $\quad$ $(\frac{v}{v + v_s}) < 1$

4. **Listener is moving towards a STATIONARY SOURCE.**

The frequency observed by the listener is **HIGHER THAN** the frequency produced by the source.

A higher pitched sound is observed. Wavelength is shorter.

$f_L = \frac{v + v_L}{v} f_s$ $v = speed\ of\ sound\ in\ air$ $v_s = 0$

$v_L = speed\ of\ listener$ $(\frac{v + v_L}{v}) > 1$

5. **Listener is moving away from a STATIONARY SOURCE.**

The frequency observed by the listener is **LESS THAN** the frequency produced by the source.

A lower pitched sound is observed. Wavelength is longer.

$f_L = \frac{v - v_L}{v} f_s$ $v = speed\ of\ sound\ in\ air$ $v_s = 0$

$v_L = speed\ of\ listener$ $(\frac{v - v_L}{v}) < 1$

Applications of the Doppler Effect

1. The Doppler flow meter emits and receives continuous ultrasound waves and then measures the change in the frequency and wavelength. It is used to measure how fast or slow blood is moving through arteries and veins, which can indicate a circulatory problem.
2. A foetal heart Doppler is used to measure the heartbeat of a foetus in the womb.

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic questions that learners will be required to perform at this stage in the topic.

b. Their purpose is to test their understanding of the changes in wavelength and frequency of sound associated with the Doppler Effect.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

TOPIC 6: Doppler Effect

1. A police car approaches a crime scene at constant velocity. The siren of the police car emits sound waves at a frequency of 900 Hz. An observer at the scene measures the frequency of the emitted sound waves as 1 000 Hz.

    1.1. Define the term frequency.

    1.2. Explain why the measured frequency is higher than the frequency of the source.

    1.3. The principle of the Doppler Effect is applied in the Doppler flow meter. State ONE positive impact of the use of the Doppler flow meter on humans.

    Solution:

    1.1. The number of waves passing a point per second.

    1.2. Waves in front of the moving source are compressed. The observed wavelength decreases. For the same speed of sound, a higher frequency will be observed.

    1.3. Determine whether arteries are clogged / narrowed so that precautions can be taken in advance to prevent heart attack or stroke. Determine heartbeat of foetus to assure that child is alive / does not have a heart defect.

2. The whistle of a train emits sound waves of frequency 1 800 Hz. A stationary listener measures the frequency of these emitted sound waves as 1 700 Hz.

    2.1. Name the phenomenon responsible for the observed change in frequency.

    2.2. Is the train moving AWAY FROM or TOWARDS the stationary listener?

    2.3. Will the frequency observed by a passenger, sitting in the train, be GREATER THAN, EQUAL TO or SMALLER THAN 1 800 Hz? Explain the answer.

    Solution:

    2.1. The Doppler Effect.

    2.2. Away from.

    2.3. Equal to. The listener is moving at the same speed as the source.

CHALLENGE LEVEL QUESTIONS

a. Now that learners have had opportunities to test their understanding of the Doppler Effect, they are ready to deal with more challenging questions.

b. These questions require learners to apply the equation for the Doppler Effect when either the source or the listener are moving.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

Key Teaching:

a. For a constant speed, the frequency of a wave is inversely proportional to its wavelength.

b. When the source of sound is moving towards a stationary listener, the wavelength of the observed sound will decrease and the frequency (pitch) will increase: $f_L = \frac{v}{v - v_s} f_s$

c. When the source of sound is moving away from a stationary listener, the wavelength of the observed sound will increase and the frequency (pitch) will decrease: $f_L = \frac{v}{v + v_s} f_s$

d. When the listener is moving towards a stationary source of sound, the wavelength of the observed sound will decrease and the frequency (pitch) will increase: $f_L = \frac{v + v_L}{v} f_s$

e. When the listener is moving away from a stationary source of sound, the wavelength of the observed sound will increase and the frequency (pitch) will decrease: $f_L = \frac{v - v_L}{v} f_s$

f. Applications of the Doppler Effect with ultrasound waves in medicine, are to measure the rate of blood flow or the heartbeat of a foetus in the womb.

3. A fire engine, with its siren on, is moving at $25\,m.s^{-1}$ towards a burning house. A person standing next to the road, measures the frequency of the sound emitted by the siren to be 480 Hz. The measured frequency is higher than the frequency of the sound emitted by the siren.

   3.1. Is the fire engine moving toward or away from the person?

   3.2. Explain why the observed frequency is higher than that of the source.

   3.3. Calculate the frequency of the siren if the speed of sound in air is $340\,m.s^{-1}$.

   Solution:

   3.1. Towards.

   3.2. The waves in front of the truck are compressed. Wavelength decreases therefore frequency increases.

   3.3. $f_L = \frac{v \pm v_L}{v \pm v_s} f_s$

   $$f_L = \frac{v}{v - v_s} f_s$$

   $$480 = \frac{340}{340 - 25} f_s$$

   $$340 f_s = 480(340 - 25)$$

   $$340 f_s = 480(315)$$

   $$f_s = 444{,}71\,Hz$$

4. A train approaches a station at a constant speed of $30\,m.s^{-1}$ with its whistle blowing at a frequency of 470 Hz. An observer, standing on the platform, hears a change in pitch as the train approaches him, passes him and moves away from him.

   4.1. Name the phenomenon that explains the change in pitch heard by the observer.

   4.2. Calculate the frequency of the sound that the observer hears while the train is moving away from him. Use the speed of sound in air as $340\,m.s^{-1}$.

   4.3. How will the frequency observed by the train driver compare to that of the sound waves emitted by the whistle? Write down only GREATER THAN, EQUAL TO or LESS THAN. Give a reason for the answer.

Solution:

4.1. The Doppler Effect

4.2. $f_L = \frac{v \pm v_L}{v \pm v_s} f_s$

$$f_L = \frac{v}{v + v_s} f_s$$

$$f_L = \frac{340}{340 + 30} . (470)$$

$$f_L = 431,89\ Hz$$

4.3. Equal to. The listener is travelling at the same speed as the source.

5. The siren of a burglar alarm system has a frequency of 980 Hz. During a patrol, a police officer, travelling in his car, hears the siren of the alarm of a house and approaches the house at constant velocity. A detector in his car registers the frequency of the sound as 1 020 Hz

5.1. Name the phenomenon that explains the change in the observed frequency.

5.2. Calculate the speed at which the patrol car approaches the house. Use the speed of sound in air as $340\,\text{m.s}^{-1}$.

5.3. If the patrol car had approached the house at a higher speed, how would the detected frequency have compared to the first observed frequency of 1 020 Hz? Write down only HIGHER THAN, LOWER THAN or EQUAL TO.

Solution:

5.1. The Doppler Effect.

5.2. $f_L = \frac{v \pm v_L}{v \pm v_s} f_s$

$$f_L = \frac{v + v_L}{v} f_s$$

$$1\,020 = \frac{340 + v_L}{340}(980)$$

$$(1\,020)(340) = (980)(340 + v_L)$$

$$346\,800 = 333\,200 + 980.v_L$$

$$13\,600 = 980 v_L$$

$$v_L = 13,88\ m.s^{-1}$$

5.3. Higher than.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. At constant speed, the frequency of a wave is inversely proportional to its wavelength.
2. Explaining the change in wavelength and frequency (pitch) of the observed sound when there is relative motion between source and listener.
3. Applying the equation for the Doppler Effect.
4. Knowing that the applications of the Doppler Effect with ultrasound waves in medicine, are to measure the rate of blood flow or the heartbeat of a foetus in the womb.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: The Atom: building block of all matter: Questions 1-4

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

2. DOPPLER EFFECT WITH LIGHT

INTRODUCTION

Just like sound, LIGHT is also a wave. Therefore the observed light coming from a moving source (a distant galaxy) can have a longer or a shorter wavelength than expected. We can use the Doppler Effect to provide evidence that the universe is expanding.

CONCEPT EXPLANATION AND CLARIFICATION:

1. REDSHIFT

Consider the line absorption spectrum which comes from our **SUN** (Diagram 1) shown below. Then consider the line absorption spectrum coming from a **DISTANT GALAXY** (Diagram 2) shown below.

REMEMBER: Red light has a **LONGER WAVELENGTH** (and lower frequency) than blue light.

Diagram 1: Spectrum from the Sun

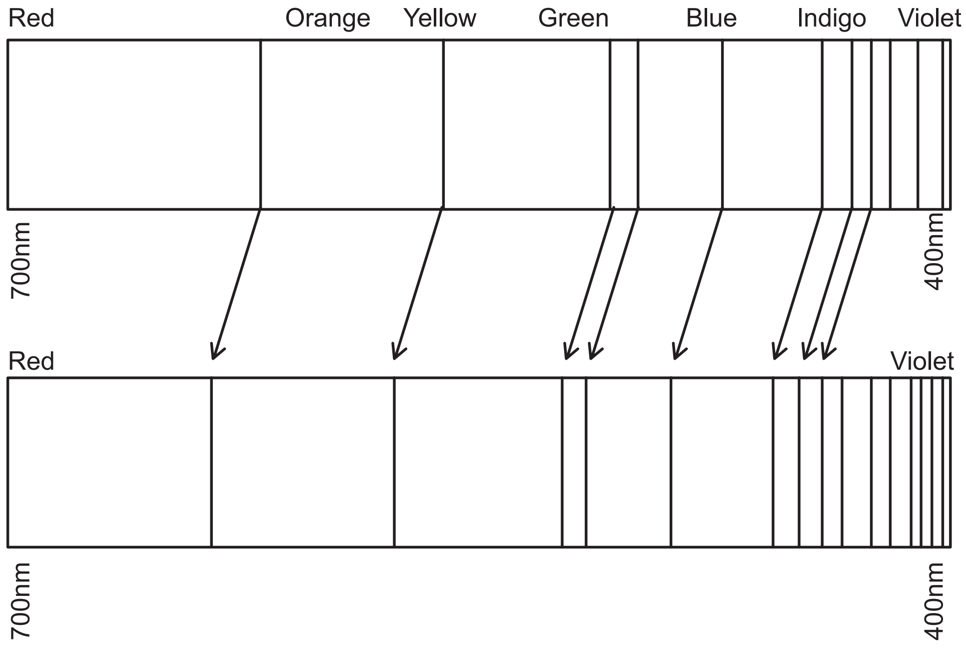


Diagram 2: Spectrum from a distant galaxy

The **SAME** spectral lines in the light coming from the SUN are **ALSO** in the light coming from the DISTANT GALAXY.

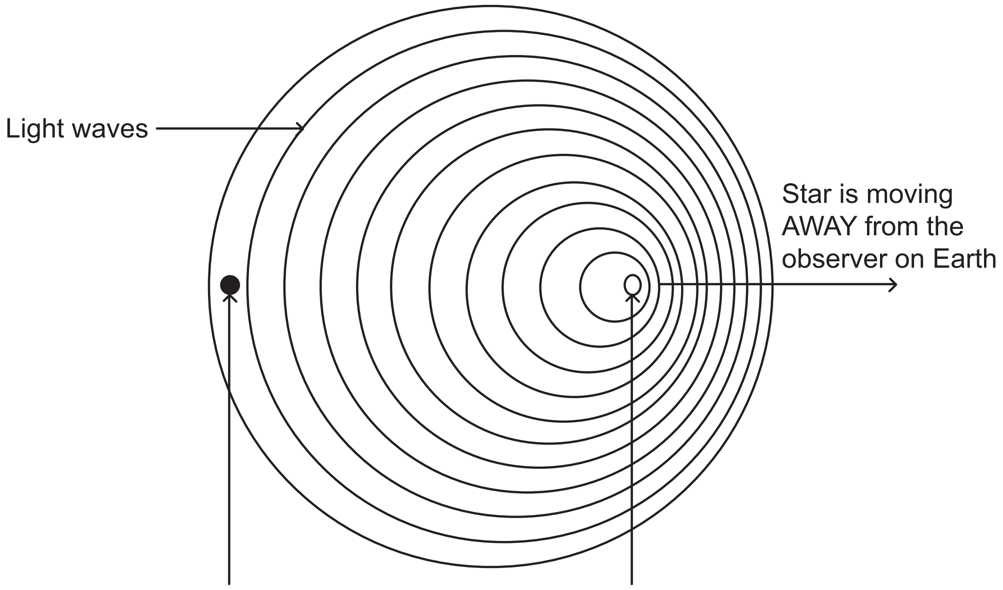
HOWEVER, in the light coming from the DISTANT GALAXY, these **SAME** spectral lines are SHIFTED TOWARDS the RED END of the visible spectrum.

This means that the **SAME** spectral lines coming from the DISTANT GALAXY are observed to have a **LONGER WAVELENGTH** (and a lower frequency).

We say that the same spectral lines coming from the distant galaxy are **RED SHIFTED**.

We use the Doppler Effect to explain why the same spectral lines have a longer wavelength (are red shifted).

Consider a distant galaxy which is **MOVING AWAY** from Earth. The wave fronts of light **behind** the galaxy are **further apart**.



We observe the light coming from the galaxy to have a longer wavelength than expected.

According to the Doppler Effect, the distant galaxy is moving away from Earth.

The light coming from many observed galaxies is red shifted. This is evidence that the Universe is **EXPANDING**.

2. BLUESHIFT

Consider the light waves in front of the moving galaxy. The waves are compressed in front of the galaxy. Suppose the observer is in front of the moving galaxy. The light observed would have a shorter wavelength (and higher frequency) than expected.

If the SAME spectral lines coming from a distant galaxy are **SHIFTED TOWARDS THE BLUE END** of the visible spectrum, then the light coming from that galaxy has a SHORTER WAVELENGTH than expected. According to the Doppler Effect this galaxy must be **MOVING TOWARDS** the Earth.

There are faraway active galaxies that show a blue shift in their spectral lines.

CHALLENGE LEVEL QUESTIONS

a. Now that learners have tried the basic questions, they are ready to deal with more challenging questions.

b. These questions require learners to explain red and blue shift and how this is evidence that the universe is expanding.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done/what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

Key Teaching:

a. Redshift means that the spectral lines coming from a galaxy are shifted towards the red end of the visible spectrum. The light coming from the galaxy has a longer wavelength (and lower frequency) than expected.

b. If the light coming from the galaxy is red shifted then the galaxy is moving away from Earth.

c. Most stars and galaxies show a redshift. This evidence that the Universe is expanding.

d. Blueshift means that the spectral lines coming from a galaxy are shifted towards the blue end of the visible spectrum. The light coming from the galaxy has a shorter wavelength (and higher frequency) than expected.

e. If the light coming from the galaxy is blue shifted then the galaxy is moving towards Earth.

4. Read the two observations below.

(a) Most stars and galaxies show a redshift.

(b) Stars and galaxies that are further away from us show a greater red-shift.

4.1. Suggest what observation (a) tells us about our universe.

4.2. Suggest what observation (b) tells us about our universe.

Solution:

4.1. The Universe is expanding.

4.2. The Universe is expanding at a greater rate further away.

5. Consider the spectral lines from the Sun and the Andromeda galaxy shown below:

Spectra from the sun

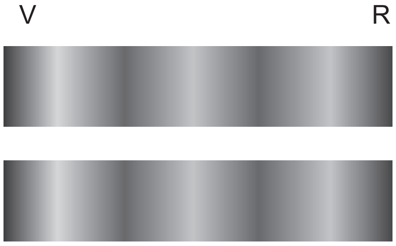
Spectra from Andromeda

Suggest what the spectral lines from the Andromeda galaxy tells us about it?

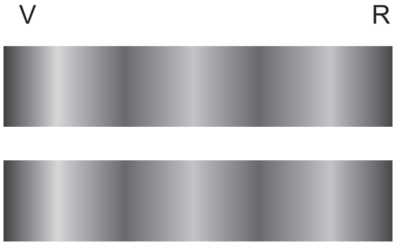
Solution:

The spectral lines from the Andromeda galaxy are shifted towards the blue end of the visible spectrum. The wavelength emitted by the galaxy is shorter than expected. The galaxy is moving towards Earth.

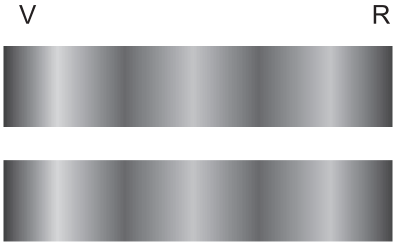
6. Consider the spectra shown below of three different galaxies. In each case the top spectrum represents our Sun.



Galaxy A



Galaxy B



Galaxy C

6.1. Which of the galaxies are emitting red shifted spectral lines?

6.2. Which of the galaxies are moving away from the Earth?

6.3. Which of the galaxies are moving towards Earth?

6.4. Which of the galaxies are moving away at the greatest speed?

Solution:

6.1. A and C

6.2. A and C

6.3. B

6.4. C

CHECKPOINT

At this point in the topic, learners should have mastered:

1. Describing and explaining red and blueshift by applying the Doppler Effect.
2. An explanation of how redshift is evidence of an expanding Universe.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: The Atom: building block of all matter: Questions 5-8

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

CONSOLIDATION

- Learners can consolidate their learning by completing; Worksheet Pack: **Doppler Effect Consolidation Exercise.**
- Photocopy the exercise sheet for the learners. If that is not possible, learners will need to copy the questions from the board before attempting to answer them.
- The consolidation worksheet should be marked by the teacher so that she/he is aware of each learner's progress in this topic.
- Please remember that further consolidation should also be done by completing the examples available in the textbook.
- **It is important to note that this consolidation exercise is NOT scaffolded.**

- **It should not be administered as a test, as the level of the work may be too high to in its entirety.**

ADDITIONAL VIEWING / READING

In addition, further viewing or reading on this topic is available through the following web links:

1. https://www.youtube.com/watch?v=kdiHmSWI2Ks

   Doppler Effect

2. https://www.youtube.com/watch?v=vDvIhiCnatE

   Doppler Effect with light

3. https://www.youtube.com/watch?v=I1Bdp2tMFsY

   How ultrasound works

TOPIC 7: Rate and Extent of Reaction

A INTRODUCTION

- This topic runs for 4 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Rates and Extent of Reaction forms part of the content area Chemical Change (Chemistry).
- Chemical Change counts as 60% in the final exam.
- Rates and Extent of Reaction counts approximately 15% of the final examination.
- For any chemical reaction to occur, reacting particles must collide and make contact with each other. This topic is going to focus on these collisions and what makes these collisions successful, as well as looking at how quickly these chemical reactions will take place. This is known as the Rate and extent of chemical reactions. We will be looking at what factors will influence the rate of the reaction, how we measure the rate of this reaction as well as what mechanisms are important in understanding chemical reaction rates.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.
2. Chalk.
3. Grade 12 Chemistry Examination Data Sheet.
4. Periodic Table.

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. A4, 3 Quire exercise book, for notes and exercises.
2. Scientific calculator – Sharp or Casio calculators are highly recommended.
3. Black/blue ink Pen.
4. Coloured highlighters.
5. Ruler.

B SEQUENTIAL TABLE

PRIOR KNOWLEDGE	CURRENT	LOOKING FORWARD
Grade 10	**Grade 11**	**Grade 12**
• An understanding of energy levels and orbitals. • An understanding of the meaning of kinetic energy.	• An understanding of bond energies • An understanding of exothermic and endothermic chemical reactions. • An understanding of energy changes during a chemical reaction and enthalpy of reaction	• Rate and extent of reaction can be applied in topics coming up on Chemical Equilibrium and Acids and Bases

C

GLOSSARY OF TERMS

Please note: The highlighted definitions and laws are ones that learners must be able to state and are given in the CAPS document. For examination purposes, learners must know these definitions and laws by heart, and must write them exactly as they appear here.

TERM	DEFINITION
Activation energy	The minimum energy required for a reaction to take place
Reaction rate	the measure of how fast a chemical reaction takes place
Collision theory	The theory that describes the mechanism and process of what happens when reacting particles collide during a chemical reaction
Collision frequency	How often particles will collide with each other per unit time
Orbital overlap	When particles collide and their outermost orbital overlap with each other to begin the chemical reaction
Successful/effective collision	A collision between two reacting particles in the correct orientation and where there is enough kinetic energy to allow for orbital overlap to occur
Unsuccessful/non-effective collision	A collision between two reacting particles not in the correct orientation and where there is not enough kinetic energy to allow for orbital overlap to occur
Concentration	The measure of the amount of substance per unit volume of water measured in mol.dm-3
Temperature	The measure of the amount of heat energy within a system which directly relates to the amount of kinetic energy a reacting particle will possess.
Surface area	The amount of contact surface that is present in a system
Pressure	The measure of the force per unit area exerted by a gas particle on the sides of the container
Catalyst	A chemical substance that is added to a reaction to lower the activation energy of the system without itself undergoing any chemical or physical change
Law of conservation of mass	States that the total mass within a closed system before a chemical reaction is the same as the total mass after the reaction. That is, the total mass of the reactants will be equal to the total mass of the products
Turbidity	Refers to the amount of transparency of a liquid due to the formation of a solid precipitate during a chemical reaction.
Maxwell-Boltzmann distribution graph	A graphical representation of the distribution of reacting particles with a certain specific amount of kinetic energy within the reacting system.

D

ASSESSMENT OF THIS TOPIC

- *This topic can be assessed using short class tests or through marked worksheets. I would suggest that a formal test is done at the end of the section to ensure that the learners do understand the work taught. This must also be included in the mid-year examination and will be examined in the final matric examination. he types of questions suited to this section could be in the form of multiple choice style questions, matching phrase style questions and direct response style questions. See worksheets later for examples of these.*

E BREAKDOWN OF TOPIC AND TARGETED SUPPORT OFFERED

- *Please note that this booklet does not address the full topic – only targeted support related to common challenges is offered.*
- *For further guidance on full lesson planning, please consult CAPS, the NECT Planner & Tracker and the textbook.*

TIME ALLOCATION	SUB TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
2 hours	Rate of reaction and factors affecting rate	123	a. The meaning of reaction rate b. Explanation of the Collision theory c. Explanation of the criteria required for a successful/effective collision d. Listing the factors that affect reaction rate e. How these factors affect the reaction rate through collision theory
1 hour	Measuring rate of reaction	123	a. Looking at the 3 methods that can be used to measure reaction rate • Mathematically • Experimentally • Graphically
1 hour	Mechanism of reaction rate and catalysis	124	a. Explanation of the concept of activation energy b. Using and explaining graphical techniques to represent the number of particles that will have kinetic energy equal to or greater than the activation energy- Maxwell Boltzmann distribution curves. c. Explaining the effect of temperature and catalyst on the number of particles having this necessary energy of activation

F

TARGETED SUPPORT PER SUB TOPIC

1. RATE OF REACTION AND FACTORS AFFECTING RATE

INTRODUCTION

Certain chemical reactions proceed very slowly while others proceed extremely quickly. Why does this happen? This is what we know as **reaction rate**, the measure of how fast a chemical reaction takes place and we are going to explore the fundamental principles as to why this happens. This sub topic is going to explain the reason why certain reactions occur at different rates and what factors are responsible for causing this. It will also explore and explain a fundamental concept of all chemical reactions known as the Collision Theory whose criteria must be fulfilled before any chemical reaction can take place at all.

CONCEPT EXPLANATION AND CLARIFICATION: RATE OF REACTION AND THE COLLISION THEORY

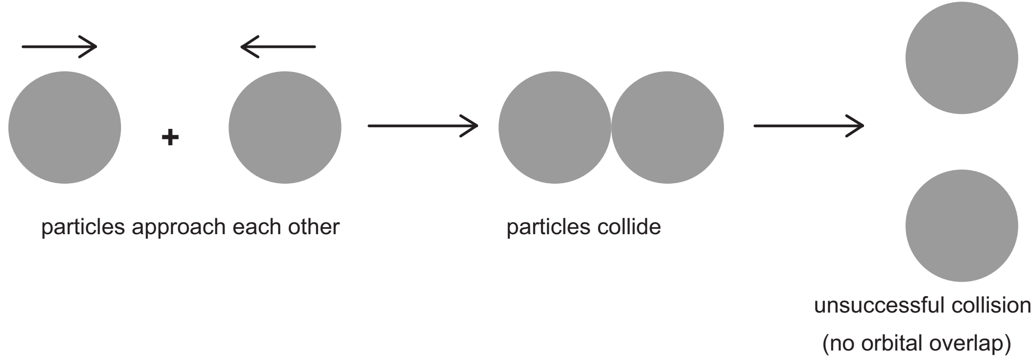
As you begin this topic, it is very important that you give an explanation of what is meant by the term “rate of reaction”. Explain to the leaners that it describes how quickly **either** products are formed in a reaction or how quickly reactants are used up in a reaction. At this stage. It is suggested that teachers take a short amount of time to talk a bit about the word “rate”. The learners would have heard this term in their physics modules and now ask them if they can remember to what the term “rate” refers. Explain to them that rate refers to the concept of “per unit time”, in other words how fast products are formed per unit time or how fast reactants are used up per unit time. The learners should now begin to realise the difference between a fast rate of reaction and a slow rate of reaction based on this concept of “per unit time”. It is very important that the learners always refer to “per unit time” when talking about rates of reaction.

At this point, it is important to explain to the learners the basic mechanism of how a reaction takes place. This is known as the **Collision Theory** and learners must realise that for a reaction to occur between any atoms, molecules or ions in a system, these particles must first collide. The rate of collision or how many particles collide per unit time is called the **collision frequency**. Now emphasise to the learners that not every collision between these particles will produce a chemical reaction. Two important factors must present:

1. There must be enough energy in the system to produce a successful/effective collision.
2. The particles must collide in the correct orientation.

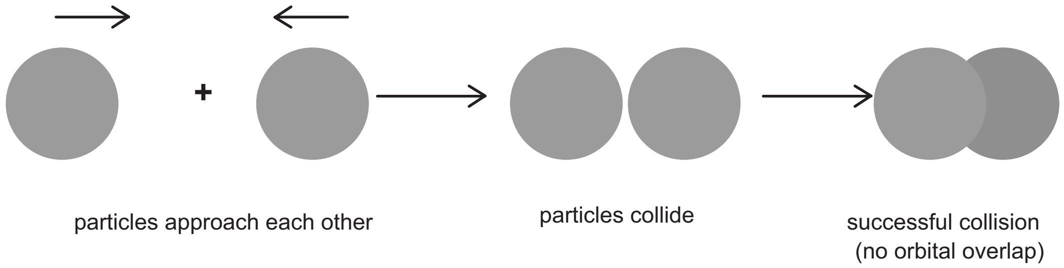
A successful/effective collision is firstly described as one when there is enough energy in the system to allow for the outermost orbitals of the reacting particles to overlap which now starts the reaction process. Secondly, the particles must be positioned in space in the correct orientation to allow for this orbital overlap to be successful. Thus the number of successful/effective collisions per unit time will be the measure of the rate of the chemical reaction. These diagrams illustrate the concept of successful/effective and unsuccessful/non-effective collisions between particles.

Unsuccessful/non-effective collisions per unit time



With an unsuccessful collision, no orbital overlap occurs and the particles simply move away from each other.

Success/effective collisions per unit time



CONCEPT EXPLANATION AND CLARIFICATION: RATE OF REACTION AND THE FACTORS THAT EFFECT THIS REACTION RATE

Now that the learners understand Collision Theory, it is now time to introduce the learners to what factors will influence the rate of a chemical reaction. Explain to the learners that there are FIVE factors which affect reaction rate, namely:

- Temperature
- Concentration (only affects substances in solution)
- Surface area (only affects substances in the solid phase)
- Pressure (only affects substances in the gas state)
- Catalysts

Here is a breakdown of each factor explaining the key points:

Concentration

Make sure that the learners know that concentration refers to the number of particles(moles) per unit volume of solvent. Explain to them that if the solution has a low concentration, that there is a small number of particles per unit volume and a high concentration, there are a large number of particles per unit volume.

Low concentration: Explain that there are fewer collisions per unit time hence a smaller chance of successful/effective collision occurring thus a slow rate of reaction.

High concentration: Explain that there are now many more collisions per unit time hence a much greater chance of successful collisions taking place thus causing a fast rate of reaction

Temperature

Here the learners need to be aware that as the temperature of the system changes, so does the amount of kinetic energy that the particles have within that system changes as well. This affects the speed at which the particles move. Highlight the following

High temperature: the particles move with high speed and have a large amount of energy. This results in a high **collision frequency** as well as many particles having enough energy to have successful/effective collisions. This will result in a high reaction rate.

Low temperatures: the particles move with low speed and have less energy. This results in a low collision frequency as well as many particles not having enough energy to have successful/effective collisions. This will result in a low reaction rate.

Surface area

Here the leaners need to be aware that a solid broken up into many small pieces will have a greater surface area than a solid in a large chunk. Highlight the following:

Greater surface area: the more points of contact are present for the reacting particles to collide, hence a higher collision frequency and a faster rate of reaction.

Smaller surface area: fewer points of contact are present for the reacting particles to collide, hence a lower collision frequency and a slower rate of reaction.

Pressure

It is important for the learners to know that gas pressure is affected by the number of gas particles per unit volume of container. Large number of particles per unit volume of container causes a high gas pressure whereas a low number of gas particles per unit volume, the less the gas pressure. Highlight the following:

High pressure: gas particles will collide more often (high collision frequency) thus greater chance of successful/effective collisions per unit time, hence fast reaction rate.

Low pressure: gas particles will collide less often (low collision frequency) thus smaller chance of successful/effective collisions per unit time, hence slow reaction rate.

Catalyst

The learners must know that a catalyst increases the rate of a chemical reaction without itself undergoing a chemical change. It does this by lowering the **activation energy** for the reaction.

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the equation, but not to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. Name 5 factors that will affect the rate of a chemical reaction.

   Solution:

Concentration	Temperature
Surface area	Pressure
Catalyst	

2. Explain what is meant by the term ‘collision frequency’

   Solution:

   This is the measure of how many particles will collide with each other in a set amount of time. That is, the number of collisions per unit time.

3. Give two reasons why a collision between reacting particles may not be successful.

   Solution:

1) The reaction particles may not have enough average kinetic energy that will allow for orbital overlap upon collision.

2) The reacting particles may not collide with the correct orientation.

4. Explain how an increase in temperature affects the rate of a chemical reaction.

Solution

The higher the temperature, the greater the average kinetic energy of the particles in the system. This leads to a higher collision frequency which increases the chances of a successful/effective collision, thus an increase in the rate of reaction.

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic questions, they are ready to deal with more challenging questions.

b. These questions require learners to manipulate the equation to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

Key Teaching:

a. In these more challenging examples, learners must apply knowledge to an unseen situation.

1. Consider the following chemical reaction:

$$Zn(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2(g)$$

State 4 ways in which the rate of reaction can be increased.

Solution:

a) Crush the Zn into a powder (smaller surface area)

b) Increase the concentration of the HCl(aq) solution

c) Heat the reaction mixture (Increase the temperature)

d) Add a catalyst

2. Consider the following reaction

$$H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$$

State 3 ways in which the rate of reaction can be decreased.

Solution:

a) Lower the pressure of the gas mixture

b) Reduce the concentration of the gas mixture

c) Cool the reaction mixture down.

3. Explain the following that occurs in nature

3.1. It is easier to start a fire with small twigs than with large pieces of wood

3.2. A candle will burn faster in a slight breeze

3.3. Milk that is left in the sun rapidly turns sour

Solution:

3.1. Small twigs will expose a much larger surface area to be ignited compared to large pieces of wood.

3.2. More oxygen particles will be able to support the burning of the candle. That is, the concentration of oxygen has increased.

3.3. The increase in temperature will increase the collision frequency with the reacting particle responsible for the chemical reaction that turns milk sour.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. Have an understanding of two main criteria of the Collision theory.
2. Understand what is meant by collision frequency.
3. Understand what criteria are needed for successful collision compared to an unsuccessful collision.
4. Be able to identify the factors that influence the rate of a chemical reaction.
5. Understand how these factors influence the rate of a chemical reaction.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Rate and Extent of Reaction– Worksheet Multiple Choice Questions 1-4 and Long questions 1-4

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

1. MEASURING RATES OF REACTION

INTRODUCTION

Now that there is an understanding of the concept of reaction rate and what criteria affect the rate of a chemical reaction, we must now turn to how we measure this reaction rate and not merely to observe it. In this sub topic we will explore the three main methods that are used to measure reaction rate and how we can use it effectively in the classroom. It is important for the learners to know that there are THREE main ways that the rate of a chemical reaction can be determined, namely

1. Mathematically
2. Experimentally
3. Graphically

TOPIC 7: Rate and Extent of Reaction

CONCEPT EXPLANATION AND CLARIFICATION: MATHEMATICAL MEASURING OF THE RATE OF A CHEMICAL REACTION

Here the learners need to me made aware that one is actually able to calculate the rate of a chemical reaction and not simply just observe how fast or slow the reaction is proceeding.

There are 2 ways in which this can be done:

a) $\text{Rate} = \frac{\text{change in concentration of reactants}}{\text{time}}$

b) $\text{Rate} = \frac{\text{change in concentration of products}}{\text{time}}$

It is important for the learners to note that when reactants change concentration, it is the decrease in concentration of the reactants or the increase in concentration of the products that is measured.

CONCEPT EXPLANATION AND CLARIFICATION: EXPERIMENTAL MEASURING OF THE RATE OF A CHEMICAL REACTION

Introduce the learners to different experimental techniques that can be used to measure the rate of a chemical reaction

- The change in mass of the contents of a reaction vessel if one of the products is a gas and allowed to leave the reaction vessel. Here the learners need to be told that the mass of a reaction vessel containing the reactants is measure at the start of the reaction and then the loss of mass in measured per unit time. The data can be collected and tabulated. For example:

0	150	0
30	140	10
60	132	18
90	125	25
120	120	30

Get the learners to see that the loss of mass become less and less as time continues. That is, in the first 30s, loss of mass is 10g but in the last 30s, the loss of mass is only 5g. This shows that the reaction is slowing down.

NOTE: The learners must be aware that if one of the products is not a gas, there will be no change on mass of the reaction vessel as no products can leave. Thus, the **law of conservation of mass** will apply.

- If one of the products is a gas, then one can collect the gas using a gas syringe and measure the volume of gas collected per unit time. The data can also be tabulated:

0	0
30	8
60	12
90	16
120	18

Once again, show the learners that the volume of gas being collected per unit time decreases. In the first 30s, the gas volume collected is $8cm^3$ but in the last 30s, the volume collected is only $2cm^3$ indicating that the reaction rate is slowing down.

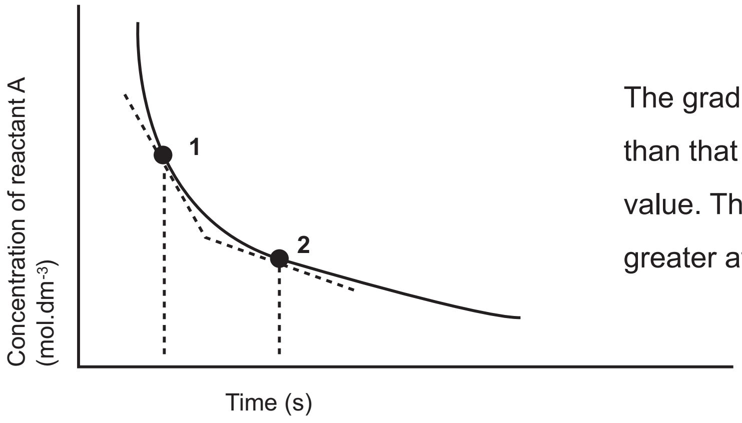
- Lastly, introduce the learners to measuring reaction rate by measuring the rate of precipitate formation through **turbidity**. Turbidity is the measure of light that is able to pass through a solution and if a precipitate is formed as a product, then how quickly the precipitate is formed will affect how much light is able to pass through, that is, the turbidity of the solution.

CONCEPT EXPLANATION AND CLARIFICATION: GRAPHICAL MEASURING OF THE RATE OF A CHEMICAL REACTION

Using results from experimentation, indicate to the learners that graphical representations can be drawn and by calculating the gradient of the curve at that point will allow one to obtain the rate of the chemical reaction. Consider the reaction

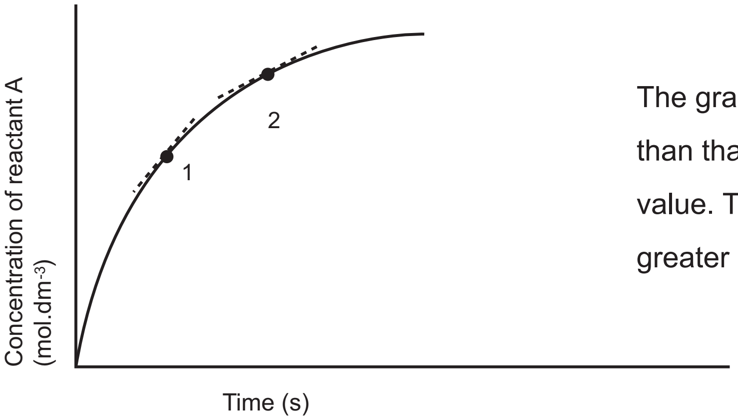
$$A + B \longrightarrow C + D$$

If the learners graphically drew the graph for the loss of concentration of reactant A, then the following graph would be obtained



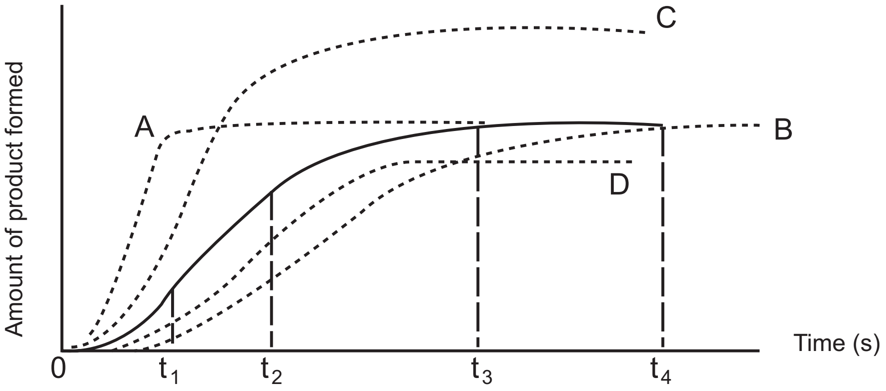
The gradient of the line at point 1 is steeper than that of point 2, hence will have a greater value. The rate of reaction will thus be greater at point 1 compared to point 2.

If the learners graphically drew the graph for the increase of concentration of product C, then the following graph would be obtained



The gradient of the line at point 1 is steeper than that of point 2, hence will have a greater value. The rate of reaction will thus be greater at point 1 compared to point 2.

Learners also need to be shown how a graph can be used to explain changing conditions that take place in a chemical reaction. Consider the graph below:



Show the learner the graph as represented by the solid line. Explain to them the shape of the graph in terms of the varying reactions rates as shown by the different gradients of the graph:

- 0 – t1: Increasing rate of reaction as graph curves upwards due to increasing number of effective collisions per unit time.
- t1 – t2: Straight line representing constant rate of reaction as number of collisions per unit time remains constant.
- t2 – t3: Decreasing reaction rate as reactant particles are used up hence decreasing the number of collisions per unit time.
- t3 – t4: Reaction rate is zero as there are no collisions per unit time as one of the reacting substances has run out stopping the chemical reaction.

Once the learners are confortable reading the reaction curve and are able to identify the different gradients and their meaning in terms of reaction rate, now move onto the curves labelled A, B and C. Explain to the learners that these curves represent changing the reaction conditions by changing the factors that affect the rate of a chemical reaction. This can immediately be seen the changing gradients of the graph.

Graph A: This shows an increase in the rate of the reaction although the amount of final product remains the same at the end of the reaction. This could be due to 3 factors, either an increase in the temperature at which the reaction takes place, an increase in the surface area of one of the reacting substances or an increase in the pressure at which the reaction takes place if the reacting substances are gases.

Graph B: This shows a decrease in the rate of the reaction although the amount of final product remains the same at the end of the reaction. This could be due to 3 factors, either a decrease in the temperature at which the reaction takes place, a decrease in the surface area of one of the reacting substances or a decrease in the pressure at which the reaction takes place if the reacting substances are gases.

Graph C: This graph shows two things, namely an increase in rate of reaction as well as an increase in the amount of product formed at the end of the reaction. This is a typical graph that is produced if you increase the concentration of one of the reacting substances. There will thus be more collisions per unit time as there are now a greater number of particles per unit volume hence a reaction rate increase. As there are more reactant particles in the system, there will be more product formed and the graph will show an increase in amount of product at the end of the reaction.

Graph D: This graph is very similar to graph B yet the amount of product is less than the original. This will be due to a decrease in concentration of one of the reacting substances. There will thus be more collisions per unit time as there are now a greater number of particles per unit volume hence a reaction rate increase. As there are more reactant particles in the system, there will be more product formed and thus the graph will show an increase in amount of product at the end of the reaction.

Spend some time with the learners ensuring that they are able to interpret these different curves on the graph and match them with the different change in condition.

TOPIC 7: Rate and Extent of Reaction

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the equation, but not to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. Initially the concentration of the reactant hydrochloric acid in a reaction vessel was $0,1 \text{mol.dm}^{-3}$. After 3 minutes it has decreased to $0,04 \text{mol.dm}^{-3}$. What is the rate of reaction?

Solution:

$$\text{Rate} = \frac{\text{change in concentration of HCl}}{\text{time}}$$

$$= \frac{0,04 - 0,1}{180}$$

$$= 0,00033 \text{ mol.dm}^{-3}.\text{s}^{-1}$$

NOTE

a) The change in concentration is always final concentration – initial concentration.

b) The answer is negative which indicates that a reactant is being used up.

c) the unit of rate of reaction is mol.dm^{-3}*.s*$^{-1}$

2. Consider the following chemical reaction:

$$3H_2(g) + N_2(g) \longrightarrow 2NH_3(g)$$

Calculate the rate of reaction if a concentration of $NH_3(g)$ of $0,357 \text{mol}$ is measured in the reaction vessel after 4,5 minutes.

Solution:

$$\text{Rate} = \frac{\text{change in concentration of products}}{\text{time}}$$

$$= \frac{0,357 - 0}{270}$$

$$= 0,00132 \text{mol.dm}^{-3}.\text{s}^{-1}$$

NOTE

a) The change in concentration is always final concentration – initial concentration.

b) The answer is positive which indicates that a product is being formed.

c) the unit of rate of reaction is mol.dm^{-3}*.s*$^{-1}$

CHALLENGE LEVEL QUESTIONS

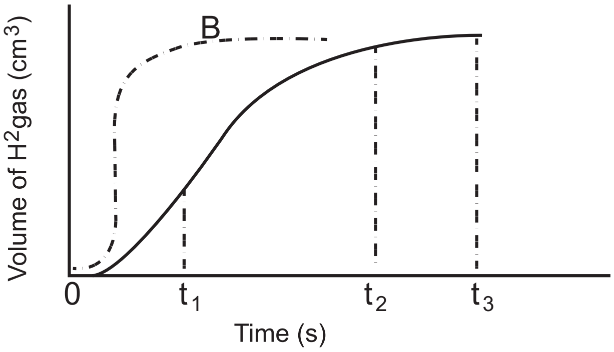
a. Now that learners have mastered the basic questions, they are ready to deal with more challenging questions.

b. These questions require learners to apply their knowledge.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

1. 5g of zinc metal is added to 30g of hydrochloric acid solution of $2 mol.dm^{-3}$ to produce hydrogen gas. The volume of gas collected is plotted on a graph (labelled A) as shown below and the zinc metal is in excess:



1.1. For curve A, explain what is happening to the rate of reaction between the following times:

a) 0 and t1

b) t1 and t2

c) t2 and t3

1.2. Explain why the reaction rates are changing between the above mentioned times

1.3. A second experiment is performed using exactly the same amounts of zinc and hydrochloric acid with the same concentration. The corresponding result is represented by the graph labelled B. Give three possible reasons, with explanations, as to what reaction conditions must have changed to produce curve B.

1.4. Explain why that despite the change to the reaction conditions in the second experiment, the volume of hydrogen gas produced has not changed.

1.5. Using graph A as the original, draw the curves on the same set of axes if the following changes were made to the reaction conditions:

a) concentration of hydrochloric acid is increased to $0,3 mol.dm^{-3}$ (labelled C).

b) concentration of hydrochloric acid was decreased to $1,5 mol.dm^{-3}$ (labelled D).

Solution:

1.1. a) Rate of reaction starts to increase (graph is curving upwards)

b) Rate of reaction remains constant for a little while (straight line) and then starts to decrease (graph starts to curve)

c) Rate is now zero (graph is flat and horizontal)

1.2. a) Reactants are at highest concentration. Maximum number of effective collisions hence rate of reaction at highest. Energy released and increase in temperature increases rate of reaction.

b) Number of effective collisions per unit time remains constant until reactants begin to get used up. Number of effective collisions per unit time starts to decrease, reducing rate of reaction.

c) One of the reactants has been used up causing the reaction to stop thus the of reaction becomes zero.

1.3. 1. Increase the temperature of the reacting mixture. There will be greater number of collisions per unit time, reaction rate will be faster and thus production of H_2 gas per unit time will be greater.

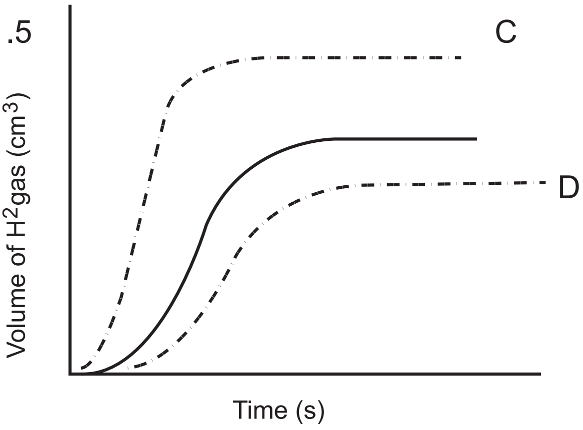
2. Use the same mass of zinc powder to increase the surface area of the metal. Greater the surface area of the metal, the greater the number of collisions per unit time of reacting particles. This will cause reaction rate to be faster and a greater volume of H_2 gas produced per unit time.

3. Use a catalyst to lower the activation energy required for a successful collision. This will increase the number of collisions per unit time increasing the rate of

reactions and producing more H_2 gas per unit time.

1.4. The starting amount of zinc metal and concentration of hydrochloric acid remains the same in both experiments, hence the amount of H_2 gas produced will remain the same. It will just be produced faster due to more collisions per unit time.

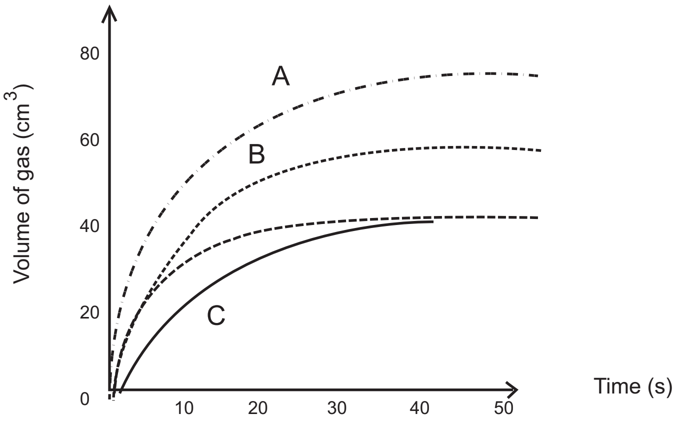
1.5



Greater concentration of HCl thus more collisions per unit increasing rate of reaction. Also, more reactant particles per unit volume of acid resulting in greater volume of hydrogen gas produced.

Lower concentration of HCl thus fewer collisions per unit time decreasing rate of reaction. Also less reactant particles per unit volume of acid resulting in smaller volume of hydrogen gas produced.

2. The graphs below (labelled A, B and C show the results of three experiments in which EXCESS sodium bicarbonate reacted with $200cm^3$ of $0,1mol.dm^{-3}$ hydrochloric acid



Which of the graphs (A – C) would match the reaction conditions shown in the table below?

2.1	25	0,1	200
2.2	40	0,2	200
2.3	40	0,1	300

Solution:

2.1 C The temperature of the system has decreased thus a slower rate of reaction due to less number of collisions per unit time.

2.2 A The concentration of the acid has doubled thus greater rate of reaction due to more collisions per unit time as well as more gas produced being due to more reactant particles per unit volume in the system

2.3 B Reaction rate will remain the same as both temperature and concentration remains the same. Increase in volume of gas produced as using a greater volume of acid.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. The three methods of how to measure the rate of a chemical reaction.
2. Be able to do a calculation to determine the rate of reaction based on amount of reactants used up or amount of products formed.
3. The shapes of a rate graph to explain how the different gradients reflect the change in rate of a chemical reaction.
4. How the change in reaction rate conditions are shown graphically on a reaction rate Graph.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Rate and extent of reaction: Long questions 3 and 4

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

3. MECHANISM OF REACTION AND OF CATALYSTS

INTRODUCTION

This sub topic is going to reinforce the concept of Collision Theory and explain to the learners the importance of activation energy in a chemical reaction with respect to the amount of kinetic energy present in the system. Learners will also be introduced to the Maxwell-Boltzmann distribution curve which is a graphical method of representing the specific amount energy that particles possess in a chemical system and what numbers of particles will have sufficient activation energy to react. Learners will also be introduced in more detail to the use of a catalyst and how a catalyst will influence the rate of a chemical reaction, as well as how it will affect the Maxwell-Boltzmann distribution curve.

TOPIC 7: Rate and Extent of Reaction

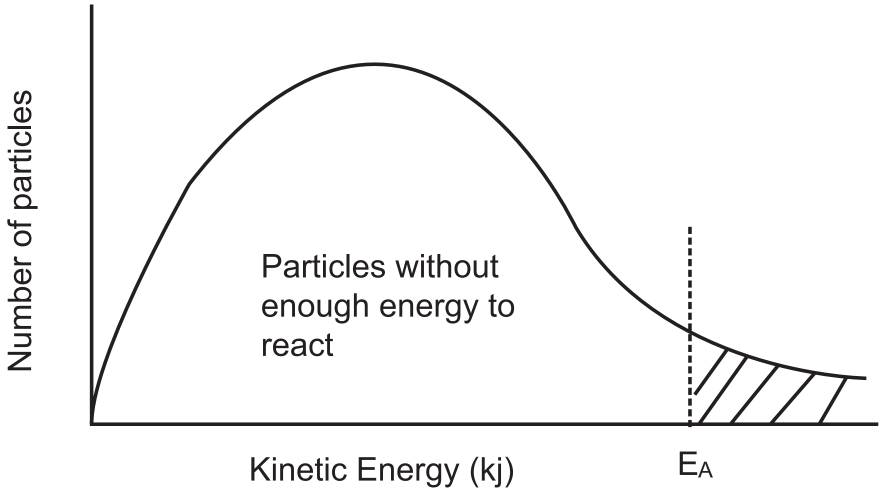
CONCEPT EXPLANATION AND CLARIFICATION: MECHANISM OF REACTION AND OF CATALYSTS

In this sub-topic, the learners are introduced to the detail of what happens when two reacting particles collide. Remind the leaners that for a successful/effective collision to take place, the particles must:

1. Collide with enough kinetic energy to allow for orbital overlap to occur.
2. Collide with the correct orientation.

This means that there has to be a minimum amount of energy in the system to allow for the collision to be successful. This is when you introduce the term **activation energy (E_A)** to describe this minimum amount of energy that is needed for a successful/effective collision to occur. (see glossary of terms for definition). In other words, reacting particles colliding with kinetic energy less than the activation energy will not have a successful collision whereas reacting particles with kinetic energy equal to or greater than the activation will have a successful collision.

Once the learners have understood this concept, it is now time to introduce to the learners to the distribution of energy within a reacting system. It is important to explain to them that within a chemical system, energy is **not** evenly distributed. In other words, not all particles possess the minimum kinetic energy needed for a successful collision. Some particles have quite low kinetic energy while some particles have very high kinetic energy. We thus talk about the **average distribution of kinetic energy** within the system. Once the learners have grasped this concept, introduce them to the energy distribution graph also known as the Maxwell-Boltzmann distribution graph which illustrates this energy variation.

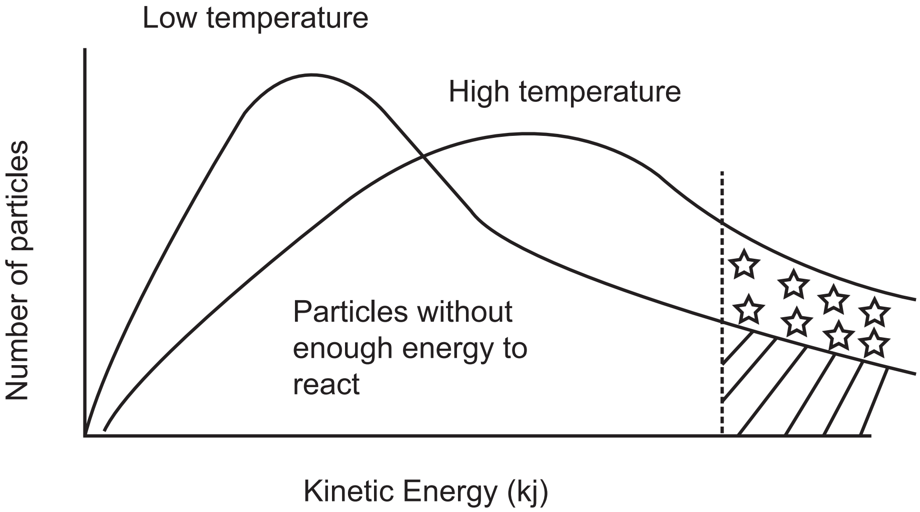


Explain to the learners the shape of the graph and what the shape represents:

1. A Maxwell-Boltzmann distribution graph represents the average kinetic energy distribution of all the particles within the reacting system.
2. The curve thus represents the number of particles with that specific average amount of kinetic energy.
3. From the shape of the curve, learners should be able to see that the majority of the reacting particles have a fairly low amount of kinetic energy and the number of particles with higher amounts of kinetic energy gets less and less.
4. At a certain point, the average kinetic energy in the system will be equal to the activation needed to allow for a successful collision which is represented by the dashed line on the graph
5. The number of particles greater than the activation energy is represented by the shaded area will all have sufficient kinetic energy for a successful collision.

Effect of temperature on the Maxwell-Boltzmann distribution

This is a very important application of the Maxwell-Boltzmann graph and the learners need to understand graphically how the number of particles that have enough kinetic energy to react are affected by increasing the temperature and how it is represented on the graph.

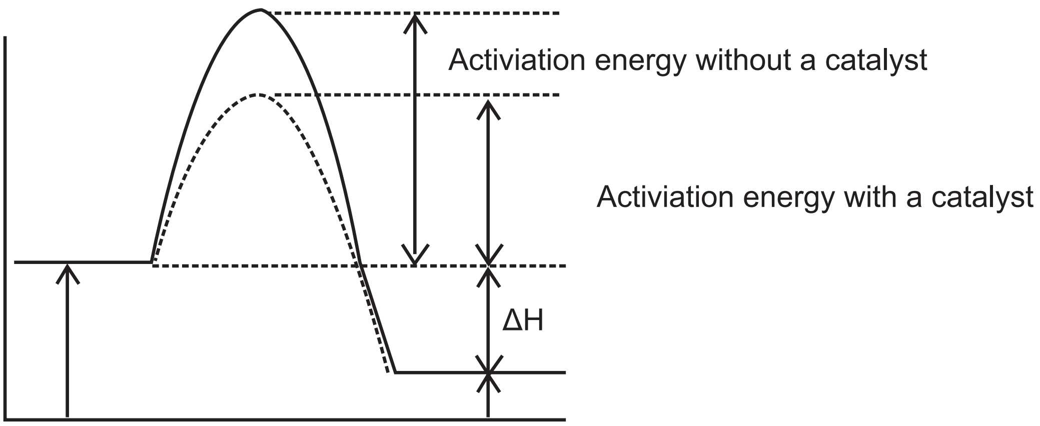


Work with this graph and show the learners that at the lower temperature that a very large amount of particles do not have enough energy to react. Only those with kinetic energy greater than the activation energy will have successful collisions. However, at higher temperatures, show the learners that the graph is pushed more to the right due to the fact that more particles will have energy equal to, or greater than, the activation energy. This is represented by that area under the graph as indicated by the stars ★.

Make sure that the learners now see that the number of particles with sufficient kinetic energy is now the total of the shaded area and the area represented by the stars, thus a much higher number of particles with the minimum activation energy and thus a far greater number of successful collision per second.

The mechanism of a catalyst when added to a chemical reaction and the Maxwell-Boltzmann graph

Revise with the learners what is meant by a catalyst and make sure that they learn the definition in the glossary. Expand a little on how a catalyst works by emphasising that a catalyst work by providing an alternative energy pathway to the reactants. This simply means that the catalyst lowers the required activation energy need by the reactants to have a successful collision. In other words, there will be more successful collisions per unit time as the amount of energy required is less.



Use this graph to allow the learners to see that the activation energy has been decreased upon the addition of a catalyst.

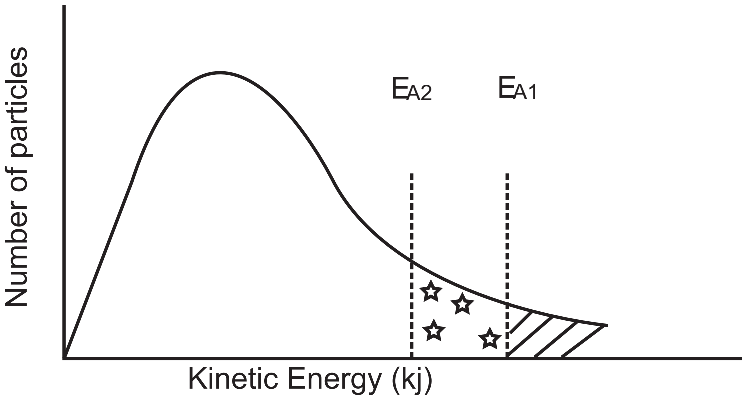
Also point out to the learners that the enthalpy of the reaction, ΔH, is not affected by the addition by the catalyst. Show them on the graph that eventhough the activation energy is less, that the ΔH value remain exactly the same. Revise with the learners the calculation of ΔH:

$$\Delta H = \text{Energy of the products}\,(E_{prod}) - \text{Energy of the reactants}\,(E_{react})$$

If the ΔH value is negative, then reaction is exothermic

If the ΔH value is positive, then the reaction is endothermic

Now show the learners the effect of a catalyst on a Maxwell-Boltzmann distribution graph



Explain to the learners that the graph is now showing TWO activation energies:

- E_{A1} representing the activation energy of the uncatalysed reaction.
- E_{A2} representing the activation energy of the catalysed reaction

Ensure that the learners can see that E_{A2} has a lower energy value indicating that the particles require less kinetic energy to reach the minimum energy required for a successful collision. Thus there will be more particles able to react with less energy as represented by the total area under the graph (shaded area + ★ area). As a result, the reaction will proceed more quickly.

Some important points about catalysts:

Learners will benefit if teachers gave them this list of important facts about catalysts:

- Catalysts increase the rate of a chemical reaction.
- Catalysts function by providing an alternative energy pathway in the reaction by lowering the activation energy.
- Catalysts do not undergo a chemical or physical change in a reaction.
- Catalysts does not change the enthalpy of a reaction.
- Catalysts do not affect the amount of product formed.

TOPIC 7: Rate and Extent of Reaction

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the equation, but not to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. Define the term ‘activation energy’

   Solution:

   The minimum amount of energy required for a reaction to take place.

2. What effect does a catalyst have on the activation energy in a reaction?

   Solution:

   Catalyst lowers the amount of activation energy need in a chemical reaction to have a successful collision by providing an alternative energy pathway for the reactants to follow.

3. What chemical or physical change happens to a catalyst during a chemical reaction?

   Solution:

   No change at all. A catalyst does not undergo any chemical or physical change as it only provides an alternative energy pathway in the reaction.

4. Briefly explain what is a Maxwell-Boltzmann distribution curve is and what is the importance of this type of graph?

   Solution:

   This is a graphical representation of the distribution of the number of particles within a system based on the amount of kinetic energy they possess. It is important as it allows one to see how many particles will possess the minimum activation energy required for a successful collision per unit time to occur.

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic questions, they are ready to deal with more challenging questions.

b. These questions require learners to **apply** knowledge.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

1. The Maxwell-Boltzmann curve below shows the distribution of molecular energies of reacting molecules in a chemical reaction at low temperature.

1.1. Define activation energy.

Solution:

The minimum energy required for a reaction to take place.

1.2. State what is represented by the shaded area shown on the above graph.

Solution:

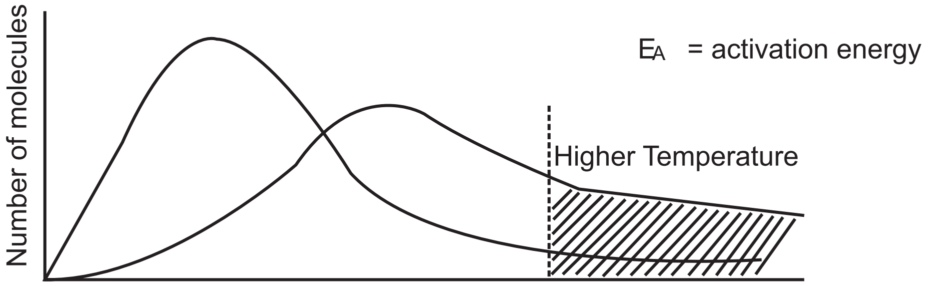
The fraction (number) of molecules (particles) with energy equal to or greater than the activation energy.

OR … enough energy to form products.

OR … to collide successfully/react.

1.3. On the same set of axes draw the Maxwell-Boltzmann curve and then a new curve indicating the distribution of molecular energies at a **higher temperature**. Use of a SHARP, DARK pencil is recommended.

Solution:



1.4. Use the graph you have drawn in Question 1.3 to EXPLAIN the effect of an Increase in temperature on reaction rate.

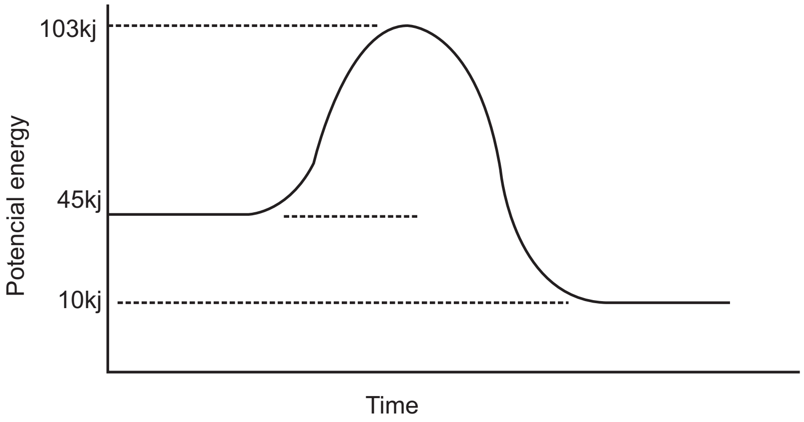
Solution:

More of the molecules will have kinetic energy (equal to or) greater than the activation energy (as shown by larger shaded area under graph). This will lead to more effective collisions per second which leads to a faster reaction rate.

2. Students conduct the following experiment between copper (II) oxide and sulfuric acid.

$$CuO(s) + H_2SO_4(aq) \longrightarrow CuSO_4(aq) + H_2O(l)$$

H_2SO_4 is allowed to react completely with an unknown mass of copper(II)oxide at a temperature of 50 ºC. The potential energy profile for this reaction is illustrated below.



2.1. Is this reaction exothermic or endothermic? Explain your answer.

Solution:

It is exothermic. The energy of the products after the reaction is less than

energy of reactants before the reaction, hence energy must have been released.

2.2. Calculate the activation energy required for the reaction to take place.

Solution:

$$\begin{aligned}\text{Activation energy} &= 103 - 45 \\ &= 58\text{kJ}\end{aligned}$$

2.3. What is the change in enthalpy for this reaction?

Solution:

$$\begin{aligned}\Delta H &= 10 - 45 \\ &= -35\text{kJ}\end{aligned}$$

2.4. The concentration of the sulfuric acid is decreased. Using collision theory, explain what will happen to the rate of the reaction.

Solution:

Decrease in concentration will result in fewer collisions per unit time of sulfuric acid particles with the copper(II) oxide particles. This will lead to a decrease in the rate of reaction.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. What is meant by activation energy.
2. How kinetic energy is distributed within a reacting system and represented by the Maxwell-Boltzmann distribution graph.
3. How an increase in temperature affects the number of reacting particles with the necessary kinetic energy to react.
4. How the catalyst reduces the amount of activation energy required for a successful collision to take place.
5. How the lowering of the activation energy by a catalyst affects its position on the Maxwell-Boltzmann graph.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Rates and Extent of Reaction : Multiple choice question 5 and Long Question 1

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

ADDITIONAL VIEWING / READING

In addition, further viewing or reading on this topic is available through the following web links:

1. https://www.youtube.com/watch?v=uCaD4-tVR7E
   Video on rates of reaction theory.
2. https://www.youtube.com/watch?v=6HCGWhWMEMI
   Video on factors that affect the rate of a chemical reaction.
3. https://www.youtube.com/watch?v=_nZdXfMEQxA
   Video on effect of temperature on rate of chemical reaction.
4. https://www.youtube.com/watch?v=AWmBXQMPGfQ
   Video on the effect of concentration on rate of chemical reaction.

TOPIC 8: Chemical Equilibrium

A INTRODUCTION

- This topic runs for 8 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Energy forms part of the content area Chemical Change (Chemistry).
- Chemical Change counts as approximately 60% in the final exam.
- Chemical equilibrium counts approximately 15% of the final examination.
- Chemical equilibrium is a section of Chemical Change that leads on directly from Rates and Extent of Chemical Reactions. It introduces the concept of chemical reversibility, that is, reactions that form products and then these products can react to form the original reactants once again. The topic will explore the various systems that explain chemical equilibrium as well as the factors that will affect a system in chemical equilibrium.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.
2. Chalk.
3. Grade 10 Physics Examination Data Sheet.

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. A4, 3 Quire exercise book, for notes and exercises.
2. Scientific calculator – Sharp or Casio calculators are necessary.
3. Pen and pencil.
4. Chemistry information sheet.

B SEQUENTIAL TABLE

PRIOR KNOWLEDGE	CURRENT
Grades 10-11	**Grade 12**
• Writing and balancing chemical reactions. • Quantitative aspects of chemical change involving calculating the number of moles of a substance. • Quantitative aspects of chemical change involving calculating the concentration of a solution	• Understanding the concepts of rates of chemical reactions.

C GLOSSARY OF TERMS

Please note: The highlighted definitions and laws are ones that learners must be able to state and are given in the CAPS document. For examination purposes, learners must know these definitions and laws by heart, and must write them exactly as they appear here.

TERM	DEFINITION
Le Chatelier's Principle	A change in any of the factors that determine equilibrium conditions of a system will cause the system to change in such a manner as to reduce or counteract the effect of the change.
Open System	Matter and energy can enter and leave the system
Closed System	Matter and energy cannot leave the system
Forward reaction	The reaction that takes place when reactants are converted into products in a chemical system
Reverse/back reaction	The reaction that takes place when products are converted back into reactants within a chemical system
Reversible reactions	Reactions which take place when reactants are converted into products and the products are able to be concerted back into reactants.
Dynamic chemical equilibrium	This is when the rate of the forward reaction is equal to the rate of the reverse reaction in a chemical system
Evaporation	The process of phase change whereby liquid particles are able to change into gas particles
Condensation	The process of phase change whereby gas particles are able to change back into the liquid phase
Equilibrium constant expression	This is the mathematical expression which shows the ratio of the product of the concentration of products to the product of concentration of reactants, bith raised to the power of their balancing numbers when the system in in dynamic equilibrium
KC value	The common term used to describe the value obtained from calculating the ration from the equilibrium contsnt expression
R.I.C.E. table	The table used to calculate the equilibrium amounts/ concentrations of reactants and products if not all information is provided in the dynamic equilibrium state
Common ion effect	This takes place when a compound is added to a system in dynamic chemical equilibrium and that compound contains an ion that is already present in the equilibrium system

D ASSESSMENT OF THIS TOPIC

- This topic can be assessed using short class tests or through marked worksheets. I would suggest that a formal test is done at the end of the section to ensure that the learners do understand the work taught. This must also be included in the mid-year examination and will be examined in the final matric examination. he types of questions suited to this section could be in the form of multiple choice style questions, matching phrase style questions and direct response style questions. See worksheets later for examples of these.

TOPIC 8: Chemical Equilibrium

E BREAKDOWN OF TOPIC AND TARGETED SUPPORT OFFERED

- *Please note that this booklet does not address the full topic – only targeted support related to common challenges is offered.*
- *For further guidance on full lesson planning, please consult CAPS, the NECT Planner & Tracker and the textbook.*

TIME ALLOCATION	SUB TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
2 hours	Chemical Equilibrium and factors affecting equilibrium	125	a. Open and closed systems b. Reversible reactions c. Dynamic equilibrium d. Application of the concepts of reversibility and dynamic equilibrium to chemical systems e. Factors that affect equilibrium position
4 hours	Equilibrium constant	125	a. The equilibrium constant expression b. Equilibrium constant calculations and the significance of the KC expression
2 hours	Application of equilibrium principles	126	a. Using le Chatelier’s Principle to explain the changing equilibrium conditions b. Interpreting simple equilibrium graphs c. Addition of a catalyst to a system in dynamic chemical equilibrium d. How the factors that influence chemical equilibrium affect the equilibrium constant (KC) e. Applying equilibrium principles to important industrial applications, namely the Haber Process and the Contact Process.

TARGETED SUPPORT PER SUB TOPIC

1. CHEMICAL EQUILIBRIUM AND FACTORS AFFECTING EQUILIBRIUM

INTRODUCTION

Before a proper understanding of what the phenomenon of Chemical equilibrium is achieved, learners need to be taught some of the fundamental concepts that are used within the section. Here it is very important for learners to be familiar with terms such as:

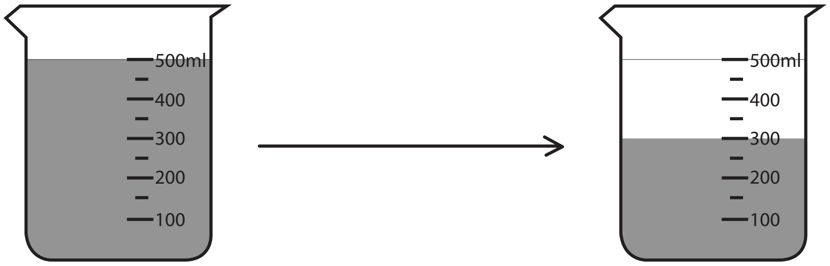
- Open and closed system
- Reversible reactions
- Dynamic equilibrium.

This sub-topic will explain these terms, what they mean and why they are so important in the module

CONCEPT EXPLANATION AND CLARIFICATION: OPEN AND CLOSED SYSTEMS

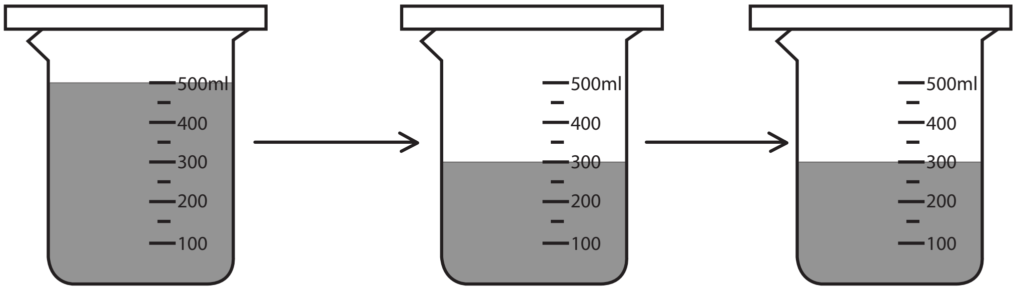
A very simple way to introduce this topic to the learners is to start with them considering a beaker of water left out in the sun over a period of time. You will notice that the water level will drop from its original level to a lower level over that period of time. The extent of the drop in water level will be dependent on the how long that beaker was left in the sun. This is due to the process of evaporation and water molecules escape into the atmosphere. Explain to the learners that what we have here is known as an **open system.**

Open system: Matter and energy can enter and leave the system



Evaporation of water out of a beaker left in the sun

However, if we place that same beaker of water in the sun and place a lid over the beaker, you will notice that the water level still will drop, but after a while the water level will remain unchanged eventhough the beaker continues to remain in the sun. It appears that the process of evaporation has stopped, or has it?



It is important to explain to the learners that the process of evaporation has not stopped.
It is continuing exactly as would be expected, however, due to the lid over the beaker, the particles of water vapour are trapped in the space above the liquid. Explain to the learners that what we have here is known as a **closed system**.

Closed system: Matter and energy cannot leave the system

CONCEPT EXPLANATION AND CLARIFICATION: REVERSIBLE REACTIONS

But what is happening within that closed system. Explain to the learners that the particles that have evaporated into the gas/vapour phase are able to collide with the liquid surface and thus return to the liquid state (condensation). As more and more water particles evaporate into the gas/vapour phase, so more and more particles are able will collide with the surface of the liquid and condense. This is known as **reversibility** and tell the learners that we say that the evaporation-condensation process is **reversible**, that is, the liquid is able to evaporate from the liquid phase and change to a gas/vapour phase while, at the same time, the gas/vapour is able to condense and change its phase back to a liquid.

$$\text{Liquid} \longrightarrow \text{gas/vapour}$$

$$\text{Liquid} \longleftarrow \text{gas/vapour}$$

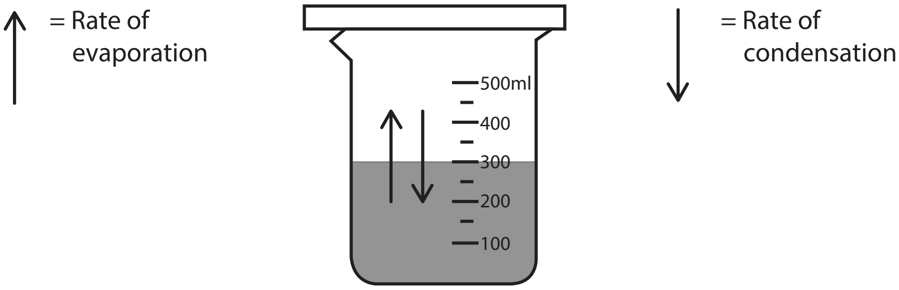
Tell the learners that this is known as phase reversibility. Thus we can write the change of phase as a phase equation where we introduce a set of double arrows. It is important to tell the learners that by placing a double set of arrows in an equation, that it shows that there is **reversibility**.

$$\text{Liquid} \rightleftharpoons \text{gas/vapour}$$

The double arrows must be of equal length.

CONCEPT EXPLANATION AND CLARIFICATION: DYNAMIC EQUILIBRIUM

The next very important point to stress to the learners is that as the phase change occurs, a point will be is reached when the number of particles that are evaporated from the surface of the liquid will equal the number of particles colliding with the surface and condensing. When this happens, a state of **equilibrium** is said to have been reached. This change of phase from liquid to vapour and vice versa can be measured as a function of time, hence we can now say that the rate of evaporation will equal the rate of condensation. When this happens we say that a state of **dynamic equilibrium** has been reached.



- **Equilibrium** thus refers to when two opposite processes are occurring simultaneously
- **Dynamic equilibrium** refers to when these processes occur simultaneously processes occur at the same rate

Learners must now be shown how dynamic equilibrium is indicated within a system by introducing the double half arrows. This double half arrows are only used when dynamic equilibrium is established. Thus, in the example of the changing phases of water, dynamic equilibrium is shown as:

$$\text{Liquid} \rightleftharpoons \text{vapour}$$

The double half arrows refer to the state of dynamic equilibrium where the rate of the forward process of evaporation is equal to the rate of the back/reverse process of condensation. It is important to note that both these processes are occurring simultaneously

CONCEPT EXPLANATION AND CLARIFICATION: APPLICATION OF THE CONCEPTS OF REVERSIBILITY AND DYNAMIC EQUILIBRIUM TO CHEMICAL SYSTEMS

Once the learners have understood the above concepts applied to a phase change, it is important for the learners to apply these concepts to chemical reactions that are in equilibrium. We have clearly seen how phase changes can be deemed as reversible and that we can establish a situation of **dynamic phase equilibrium** – but how does this work in chemical reactions?

Consider a sample of ammonium chloride (NH_4Cl). Ammonium chloride, a white powder, can be easily heated in a test tube and decomposes under heat to form ammonia gas (NH_3) and hydrogen chloride gas (HCl). The decomposition equation is

$$NH_4Cl(s) \longrightarrow NH_3(g) + HCl(g)$$

However, the presence of white powder at the mouth of the test tube shows that the NH3 gas and HCl gas must have recombined chemically under cooler conditions

$$NH_4Cl(s) \longleftarrow NH_3(g) + HCl(g)$$

Thus a chemically reversible reaction has taken place upon heating of ammonium chloride, hence the reaction equation can be written as follows:

$$NH_4Cl(s) \rightleftarrows NH_3(g) + HCl(g)$$

Ensure that the learners now see this as a **reversible chemical reaction**. If this reaction was performed in a **closed system**, then a state of dynamic chemical equilibrium would be reached where the **rate of the forward decomposition reaction** would be equal to the **rate of the reverse/back recombination reaction**.

$$\boxed{NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)}$$

Once again, ensure that thºe learners see the use of “half arrows” in the chemical equation. These “half arrows” show that the chemical reaction is now in a state of dynamic chemical equilibrium. In other words, a mixture of reactants and products whose concentrations no longer change time, yet both the forward and reverse/back reactions are continuously occurring within the system. One half arrow represents the rate of the forward reaction while the other half arrow represents the rate of the reverse or back reaction. Half arrows of equal length denote that the both the rate of the forward and reverse/back reactions are equal and that the reactions are occurring simultaneously.

In summary, use these bullet points to reinforce the concept of dynamic chemical equilibrium.

- For any chemical reaction to be in dynamic chemical equilibrium, the chemical reaction must be reversible.
- The forward reaction represents the conversion of reactants to products
- The back/reverse reaction represents the conversion of products to reactants
- Dynamic chemical equilibrium is established when the rate of the forward reaction equals the rate of the back/reverse reaction.

CONCEPT EXPLANATION AND CLARIFICATION: FACTORS THAT AFFECT THE EQUILIBRIUM POSITION

At this point, the learners should be comfortable with:

- the concept of chemically reversible reactions
- Open and closed systems
- dynamic chemical equilibrium

Now teachers need to tell the learners that any reversible chemical reaction that is in a state of dynamic chemical equilibrium will be affected by certain factors. This is known as **changing**

the equilibrium position which will cause the forward or the reverse/back reaction to either increase or decrease. In other words, this will thus change the rates of both the forward and reverse/back reactions and the reaction **will not** be in dynamic chemical equilibrium anymore. At this point, learners just need to learn which factors will cause this change in equilibrium position. The factors are:

- change in concentration or either reactant or product
- change in temperature of the system
- change in pressure of the system (this applies only to gases)

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the equation, but not to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. Explain the difference between an open and a closed system.

   Solution

   Open system: Matter and energy can enter and leave the system

   Closed system: Matter and energy cannot leave the system

2. What is meant by the term “reversible reaction”?

   Solution

   This is a reaction where reactants are used to form products and then the products react to form reactants.

3. What is meant when a system is in dynamic equilibrium?

   Solution

   This is when the rate of the forward reaction is equal to the rate of the reverse reaction.

4. How do we represent a system that is in dynamic equilibrium? Use the equation below show your answer.

$$A + B \rightleftharpoons C + D$$

Solution

Through the use of double half arrows

$$A + B \rightleftharpoons C + D$$

5. Name the three factors that are able to change the equilibrium position of a system in dynamic chemical equilibrium.

Solution

1. Change in concentration
2. Change in temperature
3. Change in pressure (gaseous systems only)

CHECKPOINT

At this point in the topic, learners should have mastered:

1. The difference between an open and closed system.
2. What is meant by a reversible reaction.
3. What is meant by a system in dynamic equilibrium.
4. What is meant by a dynamic chemical equilibrium.
5. How a system in dynamic chemical equilibrium is represented in a chemical equation.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Multiple Choice 1 – 5 and Long Questions 1 - 4

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

TOPIC 8: Chemical Equilibrium

2. THE EQUILIBRIUM CONSTANT

INTRODUCTION

It is important for the learners to understand that the equilibrium constant is defined as being a ratio of the concentration of the products over the concentration of the reactants for a reaction that is in equilibrium. The equilibrium constant, represented by the symbol K_C, is very useful to chemists as it allows the chemist to monitor the progress of the reaction to see whether the formation of the products or the formation of the reactants is favoured. In this subtopic, learners are going to be shown how to calculate this K_C value and learn how to explain the significance of high and low values of this constant

CONCEPT EXPLANATION AND CLARIFICATION: THE EQUILIBRIUM CONSTANT EXPRESSION

Teachers should begin this section of concept clarification by writing down a general chemical equation in symbolic on the board, including the coefficients representing the balancing numbers:

$$aA + bB \rightleftharpoons cC + dD$$

Remind the learners that the equilibrium constant expression is a ratio of the product of concentration of the products to the product of concentration of reactants. Hence the general equilibrium expression (K_c) is:

$$K_c = \frac{[\text{products}]}{[\text{reactants}]}$$

$$K_c = \frac{[C]^c.[D]^d}{[A]^a.[B]^b}$$

The brackets [ ] are used to represent the concentration of the substances in mol.dm-3

The balancing number coefficients, a, b, c and d are used to raise the concentrations to the power of these coefficients

Understanding the importance of phases in writing a K_C expression.

At this point emphasise to the learners that there is an important criterion that must be remembered when it comes down to writing the K_C expression. Every chemical reaction in equilibrium is written with its state symbol included. For example:

$$3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g)$$

Here we can see that all reactants and products are in the gas phase and the KC expression for this equilibrium will be: $K_C = \frac{[NH_3]^2}{[H_2]^3.[N_2]}$

However, when it comes to chemical substances in the liquid (l) or solid (s) phases, they are considered to be pure substances. Learners mus appreciate that pure substances do not have any measureable concentration and thus they cannot be included in the K_C expression. Thus, for a pure liquid and a pure solid, we assume these substances to have a value equal to one. For example

$$C(s) + CO_2(g) \ = 2CO(g)$$

Here the KC expression will be: $K_C = \frac{[CO]^2}{1.[CO_2]}$

Therefore $K_C = \frac{[CO]^2}{[CO_2]}$

Here we can see that the [C] is not included and the number 1 is placed into the expression. This is due to C being in the solid phase and thus no measurable concentration

If a substance is in the aqueous phase which means that the substance is dissolved in water, then it will have a measureable concentration and will be included in the K_C expression. To summarise, the learners must know:

- Liquids and solids are considered to be pure substances and thus will have no measurable concentration.
- Pure liquids and pure solids will have a value of 1 given to them in the K_C expression and will thus not influence the calculation.
- Only substances that are in the gas (g) or aqueous (aq) phases have measurable concentrations and are included in the K_C expression.

CONCEPT EXPLANATION AND CLARIFICATION: EQUILIBRIUM CONSTANT CALCULATIONS AND THE SIGNIFICANCE OF THE K_C VALUE

Now that the learners are able to write down the correct equilibrium expressions, then it is time to make the learners practice these calculations. There is one very important factor to explain to the learners, and that is that the equilibrium expression can only be calculated once the chemical reaction is in **dynamic equilibrium**. Learners must practice reading the question and establishing from the question if the system is in dynamic equilibrium of not.

Give the leaners the following worked example:

Question:

Hydrogen and iodine are mixed in a closed reaction vessel and and allowed to react at a constant temperature of 425 ºC according to the following reaction.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

After reaching equilibrium, the reaction mixture was analysed and the following concentrations were measured:

$[H_2] = 1,14 mol.dm^{-3}$ $[I_2] = 2,61 mol.dm^{-3}$ $[HI] = 8,41 mol.dm^{-3}$

Calculate the value of the equilibrium constant at this temperature.

Answer:

Step 1: Check the phases of the reactant and products to see if any pure solids or pure liquids are present. All reactants and products are gases and thus can be included in the K_C calculation.

Step 2: Write down the K_C expression

$$K_C = \frac{[HI]^2}{[H_2].[I_2]}$$

Step 3: Check to see if the concentrations are measured at equilibrium or not. In this example, the concentrations given are all at equilibrium, thus learners can substituted directly into the expression and the K_C calculated.

$$K_C = \frac{(8,41)2}{(1,14).(2,61)}$$

$K_C = 23,77$ at 425ºC

<u>The significance of the K_C value</u>

This is a good time for teachers to discuss with the learners the significance of the K_C value. As this is a ratio of products to reactants, the size of the numerator and denominator is very important.

- If the numerator (product concentration) and denominator (reactant concentration) are equal, then the K_C value will be equal to 1
- If there is a large numerator (product concentration) and a small denominator (reactant concentration), then the value of K_C will be greater than 1
- If there is a small numerator (product concentration) and a large denominator (reactant concentration), the value of K_C will be less than 1

Now teachers need to explain to the learners what this all means

$K_C = 1$: This means that the starting and finishing concentrations of both reactant and product are the same which means that both forward and reverse/back reactions are equal from the start of the reaction.

$K_c > 1$: This indicates that more product is formed during the reaction while using up the reactant. This means that the forward reaction has been favoured before dynamic equilibrium is established.

$K_c < 1$: This indicates that more reactant is formed during the reaction while using up the product. This means that the reverse/back reaction has been favoured before dynamic equilibrium is established.

Once the learners are able to understand how to write the K_c expression correctly, substitute in and calculate a K_c value as well as interpret the magnitude of K_c, then it is important to show the learners calculations when information is given for the reaction before equilibrium is established. These are known as “complex equilibrium calculations” and they have to follow a special technique to get the information into the correct format at equilibrium.

Consider the following worked example:

Question:

$0,5\text{mol}$ of hydrogen and $0,5\text{mol}$ of oxygen are placed in a 200cm^3 container at $150°\text{C}$ and allowed to react to reach equilibrium according to the chemical equation below:

$$2H_2(g) + O_2(g) = 2H_2O(g)$$

At equilibrium, 9,6g of O_2 remains. Calculate the value of K_c for the reaction.

Answer:

Step 1: Check the phases of the reactant and products to see if any pure solids or pure liquids are present. All reactants and products are gases and thus can be included in the K_c calculation.

Step 2: Write down the K_c expression

$$K_c = \frac{[H_2O]^2}{[H_2]^2 . [O_2]}$$

Step 3: Check to see if the amounts that are measured at equilibrium or not. It can be clearly seen that the starting amounts of H_2 and O_2 are not initially at equilibrium, and there is only a mass of O_2 given at equilibrium.

Now that the learners can see that the values given are NOT at dynamic equilibrium, learners need to be shown how to use the Equilibrium Table, often known as the “R.I.C.E.” Table, to perform the next steps in the calculation. Also, learners need to be told that they can use mole values on the Table and not always concentration amounts at this stage. The R.I.C.E. table uses letters to stand for 4 rows that are used in the Table which allows for the successful calculation of the equilibrium amounts of both reactant and product.

R:	Ratio	This represents the mole ratio of the reactants and products as given by the balancing numbers in the equation.
I:	Initial	This represents the starting amounts of reactant present in the syetem before the reaction proceeds.
C:	Change	This represents how much reactant is used up as well as how much product is formed according to the mole ration of the reactants and products.
E:	Equilibrium	This represents the final amount of reactant and product now present at equilibrium. If this is in moles, then the equilibrium concentration needs to be calculated from this for final calculation.

Step 4: Draw up the R.I.C.E. table

	$2H_2(g)$	$O_2(g)$	$2H_2O(g)$
Ratio **(R)**	2	1	2
Initial **(I)**	0,5mol	0,5mol	0mol
Change **(C)**	-0,4mol	- 0,2mol	+0,4mol
Equilibrium **(E)**	0,1mol	0,3mol	0,4mol

Step 5: Now show the learners how to do the individual calculations based on the three steps shown in the boxes below.

1) Calculate the amount of $O_2(g)$ used up in the reaction ($0,5-0,3=0,2\text{mol}$)

2) Take the amount of $O_2(g)$ used ($0,2\text{mol}$) and, apply the mole ratio to calculate the amount of $H_2(g)$ used up and the amount of $H_2O(g)$ formed. ($H_2:O_2=2:1$, thus $0,4\text{mol}$ of H_2 used ; $O_2:H_2O = 1:2$, thus $0,4\text{mol}$ of H_2O formed). Use "-" for reactants as using then up, use "+" for products as they are being formed.

3) Now, for the reactants, the calculation will be initial amounts minus the used amounts will give you the equilibrium amounts

Step 6: Calculate the equilibrium concentrations using $c = \frac{n}{V}$

$[H_2] = 0,5 mol.dm^{-3}$ $[O_2] = 1,5 mol.dm^{-3}$ $[H_2O] = 2 mol.dm^{-3}$

Step 7: Substitute into the K_C expression

$$K_C = \frac{(2)^2}{(0,5)^2(1,5)}$$

$K_C = 10,67$ at 150ºC

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the equation, but not to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. Write equilibrium expressions for the following chemical reactions in dynamic chemical equilibrium.

   1.1 $3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g)$

   1.2 $2NO(g) + O_2(g) \rightleftharpoons 2NO_2(g)$

   1.3 $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O$

Solution:

1.1 $K_C = \frac{[NH_3]^2}{[H_2]^3.[N_2]}$

1.2 $K_C = \frac{[NO_2]^2}{[NO]^2.[O_2]}$

1.3 $K_C = \frac{[NO]^4.[H_2O]^6}{[NH_3]^4.[O_2]^5}$

2. A mixture of H_2 and I_2 are allowed to react at 4480C.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

When equilibrium was established, the concentrations were found to be the following :

$[H_2] = 0,46 mol.dm^{-3}$

$[I_2] = 0,39 mol.dm^{-3}$

$[HI] = 3 mol.dm^{-3}$

Calculate the value of K_c

Solution:

$$K_c = \frac{[HI]^2}{[H_2].[I_2]}$$

$$= \frac{(3)^2}{(0,46).(0.39)}$$

$K_C = 50,17$ at 448ºC

all concentrations given are at equilibrium therefore can be substituted directly into the K_C expression

3. Consider the following reaction in a state of equilibrium

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

Initially 0,4 moles of SO_2 and 0,2 moles of O_2 were added to a $1,5 dm^3$ container at 300K. The reaction then reaches equilibrium.

3.1. How many moles of SO_3 are present in the container at the start of the reaction?

3.2. If 0,15 moles of SO_3 is formed at equilibrium, how many moles of SO_2 and O_2 are:

a) used up in the formation of SO_3

b) left at equilibrium?

3.3. Calculate the concentrations of SO_2, O_2 and SO_3 at equilibrium

3.4. Calculate the equilibrium constant for this reaction at 300K

Solution:

3.1. 0 moles. At the start of the reaction there is no product formed.

3.2.

	$2SO_2$	O_2	$2SO_3$
Ratio	2	1	2
Initial	0,4	0,2	0
Change	−0,15	−0,075	+0,15
Equilibrium	0,25	0,125	0,15

a) $SO_2 = 0,15mol$

$O_2 = 0,075mol$

b) $SO_2 = 0,25mol$

$O_2 = 0,125mol$

3.3. $SO_2: c = \frac{n}{V}$

$$= \frac{0,25}{1,5}$$

$$c = 0,166mol.dm^{-3}$$

$O_2: c = \frac{n}{V}$

$$= \frac{0,125}{1,5}$$

$$c = 0,083mol.dm^{-3}$$

$SO_3: c = \frac{n}{V}$

$$= \frac{0,15}{1,5}$$

$$c = 0,1mol.dm^{-3}$$

3.4. $K_C = \frac{[SO_3]^2}{[SO_2]^2[O_2]}$

$$= \frac{(0,1)^2}{(0,166)^2(0,083)}$$

$$= 4,36 \text{ at } 300K$$

4. The following reaction reaches equilibrium in a $2dm^3$.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

At equilibrium, it was found that there are 10 moles of N_2O_4 in the container. If K_c for the reaction is 0,05, calculate the number of moles of NO_2 in the container at equilibrium.

Solution

$$K_C = \frac{[NO_2]^2}{[N_2O_4]}$$

$$[NO_2] = \sqrt{K_C.[N_2O_4]}$$

$$[NO_2] = 0,25mol.dm^{-3}$$

$$N_2O_4: c = \frac{n}{V}$$

$$= \frac{10}{2}$$

$$c = 5mol.dm^{-3}$$

$$\text{Now } c = \frac{n}{V}$$

$$n = cV$$

$$= 0,25 \times 2$$

$$n = 0,5mol$$

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic calculations, they are ready to deal with more challenging questions.

b. These questions require learners to **manipulate** the equation to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

1. Consider the hypothetical reaction given below

$$X(g) + Y(g) \rightleftharpoons XY(g) \qquad \Delta H < 0$$

0,5mol of X and 0,3mol of Y are initially placed in a reaction vessel of $2dm^3$ and allowed to react to form XY to reach equilibrium at 200ºC. 0,2mol of XY was formed

1.1. How much of X and Y was used up in the reaction?

1.2. How much of X and Y was left once equilibrium was established?

1.3. Calculate the concentration of X, Y and XY at equilibrium

1.4. Calculate the K_c value for the reaction.

1.5. What would happen to the value of K_c if the reaction vessel was heated to 500ºC? Explain your answer using le Chatelier's Principle.

Solution:

	X	Y	XY
Ratio	1	1	1
Initial	0,5	0,3	0
Change	-0,2	-0,2	+0,2
Equilibrium	0.3	0,1	0,2

1.1. Both X and Y had 0,2mol used up as the reaction ration of X:Y is 1:1

1.2. X = 0,3mol

Y = 0,1mol

1.3. X: $c = \frac{n}{V}$ $= \frac{0,3}{2}$ C = $0,15$mol.dm^{-3}

Y: $c = \frac{n}{V}$ $= \frac{0,1}{2}$ c = $0,05$mol.dm^{-3}

XY: $c = \frac{n}{V}$ $= \frac{0,2}{2}$ c = $0,1$mol.dm^{-3}

1.4. $K_C = \frac{[XY]}{[X].[Y]}$

$= \frac{0,1}{0,15 \times 0,05}$

$K_C = 13,33$ at 200ºC

1.5. Only temperature affect K_C. If was heated to 500ºC, according to le Chatelier's Principle. the reverse/back reaction would be favoured to counter the effect of the change as the reverse/back reaction is endothermic. This means that the concentration of XY would decrease while the concentrations of X and Y would increase. This would cause the K_C to decrease.

2. Consider the following reaction at equilibrium

$$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$$

Initially, 1mol of CO reacts with 3mol of H_2 in a 10dm^3 container at 900ºC.

Equilibrium is reached with 0,4mol CH_4 equilibrium mixture.

2.1. How many moles of H_2O were formed at equilibrium?

2.2. How many moles of H_2 was used in the equilibrium?

2.3. How much CO and H_2 were left in the reaction vessel at equilibrium

2.4. Calculate K_c for the reaction.

Solution:

	CO	$3H_2$	CH_4	H_2O
Ratio	1	3	1	1
Initial	1	3	0	0
Change	-0,4	-1,2	+0,4	+0,4
Equilibrium	0,6	1,8	0,4	0,4
Concentration $c = \frac{n}{V}$	$0,06$mol.dm^{-3}	$0,18$mol.dm^{-3}	$0,04$mol.dm^{-3}	$0,04$mol.dm^{-3}

2.1. $CH_4 = 0{,}4mols$ The reaction ration of $CH_4 : H_2O = 1 : 1$

2.2. $H_2 = 1{,}2mols$ The reaction ratio of $CH_4 : H_2 = 1 : 3$

2.3. $CO = 0{,}6mols$

$H_2 = 1{,}8mols$

2.4. $$K_C = \frac{[CH_4].[H_2O]}{[CO].[H_2]^3}$$

$$= \frac{(0{,}04).(0{,}04)}{(0{,}06).(0{,}18)^3}$$

$K_C = 4{,}57$ at 900ºC

CHECKPOINT

At this point in the topic, learners should have mastered:

1. How to write the equilibrium constant for different reactions.
2. How to calculate the equilibrium constant for reactions that are in dynamic equilibrium as well as not initially in dynamic chemical equilibrium.
3. The significance of the magnitude of the KC value.
4. How to draw up a R.I.C.E. table to assist in determining the equilibrium concentrations of substances whose amounts/concentrations were not initially in dynamic equilibrium.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Multiple Choice 1 – 5 and Long Questions 1 - 4

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

3. APPLICATION OF EQUILIBRIUM CONSTANT

INTRODUCTION

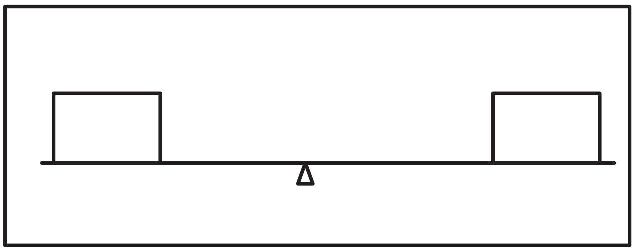
This sub-topic will now look at how dynamic chemical equilibrium is affected by external factors that will alter the equilibrium position of the chemical reaction and cause that reaction to change its equilibrium position to counteract the change. This is where the learners will be introduced to le Chatelier's Principle to explain these changes and how to counteract these changes. Learners will also be introduced to graphical representation of equilibrium system as well as industrial applications of where chemical equilibrium systems are used in modern industry.

CONCEPT EXPLANATION AND CLARIFICATION: USING LE CHATELIER'S PRINCIPLE TO EXPLAIN CHANGING EQUILIBRIUM CONDITIONS

Remind the learners that in sub-topic 1 at the beginning of this module, it was mentioned that there are 3 factors that could change the position of system that is in dynamic chemical equilibrium. In other words, they will disrupt the rates of the forward and reverse/back reactions. Explain to the learners that it was the French engineer and chemist, Henri le Chatelier who understood how a system in dynamic equilibrium would react if one of the factors was introduced into the system. It became known as le Chatelier's Principle and defined as follows:

> A change in any of the factors that determine equilibrium conditions of a system will cause the system to change in such a manner as to reduce or counteract the effect of the change.

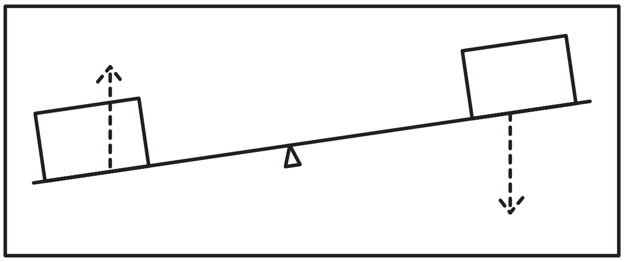
It is important to simplify this for the learners as they do find this quite difficult to grasp. Teachers can use a very simple technique to help the learners understand what le Chatelier's Principle actually means.



The learners need to think of a object, like a see-saw, where everything is in balance.

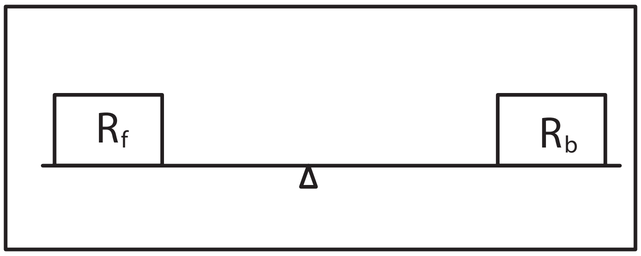
R_f represents the rate of the forward reaction and R_b represents the rate of the back reaction

Here the see-saw is balance, meaning that the rate of the forward reaction (R_f) is equal to the rate of the back/reverse reaction (R_b).



If the see-saw goes out of balance, then one side will go up and the other side will go down.

Going “out of balance” relates to the influence that one of these factors will have on a system in chemical equilibrium where it will cause a change the equilibrium position. The see-saw will always want to try and get back to its original state of balance, that is, its original state of equilibrium.



The arrows above show what must happen to the reaction rates to bring the system back into balance

This relates to counteracting the effect of the change of equilibrium position, in other words, favouring either the forward or reverse/back reaction to re-establish the system back into chemical equilibrium. In the example above, the forward reaction must increase and the back/reverse reaction must decrease to bring the two rates back “in balance”, that is, into equilibrium.

Once the learners are comfortable using this idea to understand le Chatelier’s Principle, then teachers can start to use examples to explain the influence of these factors. It is suggested using the general equation $A(g) + B(g) \rightleftharpoons C(g) + D(g)$ in all examples

1. **Change in concentration**

As can be seen in the equation, the system is in dynamic chemical equilibrium. There are two ways to change the concentration in a chemical system, either by **increasing the concentration** of one of the substances or **decreasing the concentration** of one of the substances. It is important here to show the learners a simple 4-step layout of how to answer these types of questions. For example:

a) Increasing the concentration of B:

i) Identify the change : There has been an increase in the concentration of B in the system.

ii) Apply le Chatelier's Principle : According to le Chatelier's Principle, the system will change in such a way as to counteract the effect of the change.

iii) Explanation : Thus the equilibrium position must change to favour the reaction that reduces the concentration of B. This means that the forward reaction must be favoured to use up the excess B.

iv) Conclusion : Thus the concentration of products C and D will increase while concentration of reactant A will decrease and equilibrium will be re-established.

This way of answering the le Chatelier's Principle can thus be used in explaining Temperature and Pressure factors

2. **Change in temperature**

When it comes to changing the temperature at which the equilibrium is established, it is important to explain to the learners that they must be able to first identify whether the forward and reverse/back reactions are exothermic or endothermic in the equilibrium. This is done by looking at the enthalpy of the reaction. For example:

$$A(g) + B(g) \rightleftharpoons C(g) + D(g) \qquad \Delta H < 0$$

Here the learners must realise that the position of the enthalpy information on the right tells you that the forward reaction is exothermic, that is, energy is released from the reaction causing an increase in the temperature of the system. This means that the reverse/back reaction must be endothermic causing a decrease in temperature in the system.

Getting the learners to understand this is very important when it comes to counteracting the effect of the change.

b) Increasing the temperature of the system

i) Identify the change : There has been an increase in the temperature of the system.

ii) Apply le Chatelier's Principle : According to le Chatelier's Principle, the system will change in such a way as to counteract the effect of the change.

iii) Explanation : Thus the equilibrium position must change to favour the reaction that will decrease the temperature of the system. As the forward reaction is exothermic which puts heat energy into the system, the reverse/back reaction which is endothermic must be favoured to use up the excess heat.

iv) Conclusion : Thus the concentration of products C and D will decrease while concentration of reactants A and B will increase and equilibrium will be re-established.

This logic can thus be applied for a decrease in temperature where the forward reaction (exothermic) will then be favoured to counteract the reduction in heat energy. The forward reaction will thus put heat energy back into the system.

3. **Changing the pressure in gaseous systems**

Remind the learners that when it comes to the factor of pressure, only those substances in the reaction in the gaseous phase may be considered. Use this example to explain the concept to them:

$$3A_2(g) + B_2(g) \rightleftharpoons 2AB_3(g)$$

Explain to the learners that the important consideration that needs to be made before applying the factor of pressure is to look at the mole ratio of the gaseous reactants and products. In the above example, there is a total of 4moles of gas supplied by the reactants and 2 moles of gas supplied by the products.

The learners need to see that if the forward reaction is favoured, the number of moles decreases from 4 moles to 2moles while if the reverse/back reaction is favoured, then the number of moles increases from 2 mole to 4 moles As gas pressure is directly proportional to the number of moles of gas present in the system, the forward reaction represents a decrease in gas pressure while the reverse/back reaction represents an increase in gas pressure.

Pressure increases and decreases are generally caused by changing the volume of the reacting container. A decrease in container volume will cause an increase in pressure in the system as well as increase the collision frequency of the reacting particles as they will be colliding in a much smaller space. An increase in container volume will cause a decrease in pressure in the system as well as a decrease the collision frequency of the reacting particles as they will be colliding in a much smaller space.

Consider the following change in equilibrium conditions

c) Decreasing the pressure of the system by increasing the volume of the container.

i) Identify the change : There has been an decrease in the pressure of the system.

ii) Apply le Chatelier's Principle : According to le Chatelier's Principle, the system will change in such a way as to counteract the effect of the change, that is, increase the pressure.

iii) Explanation : Thus the equilibrium position must change to favour the reaction that will increase the pressure of the system. The reverse reaction will be favoured as there is an increase in number of moles from 2 moles of product to 4 moles of reactant.

iv) Conclusion : Thus the amount of products AB2 will decrease while the amount of reactants A2 and B2 will increase and equilibrium will be re-established.

Explain to the learners that this will be exactly the opposite if the pressure un this system is increased which would cause the forward reaction to be favoured, producing a smaller number of moles of product to reduce the pressure.

At this point, extra practice needs to be done with the learners so that they can apply le Chatelier's Principle to a variety of different examples where the factors are changed.

Finally, in this sub-topic, talk to the learners about the **Common Ion Effect**. This is when a compound is added to a system in dynamic equilibrium and that compound contains an ion that is already present in the equilibrium system. For example:

$$CoCl_4^{2-} + 6H_2O \rightleftharpoons [Co(H_2O)_6]^{2+} + Cl^-$$

If some sodium chloride solution $(NaCl(aq))$ is added, then a common ion (Cl^-) is added to the equilibrium mixture. This is handled in exactly the same way as if we are changing the concentration of the Cl^- ions in solution. Le Chatelier's Principle will apply and the equilibrium position will change to favour the reverse/back reaction to remove the excess Cl^- ions from solution and re-establish equilibrium.

CONCEPT EXPLANATION AND CLARIFICATION: INTERPRETING EQUILIBRIUM GRAPHS

Equilibrium systems can be represented by graphical means in two ways:

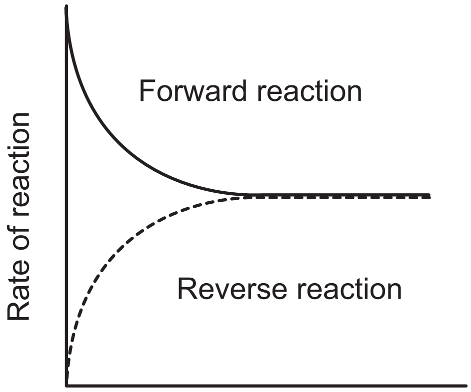
1. Rate of reaction vs time
2. Concentration vs time

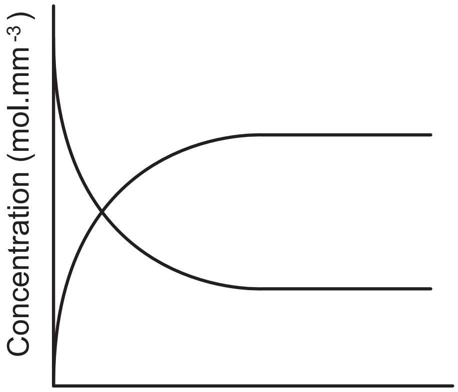
Learners need to be show how these graphs are drawn and how they can be used to explain various changes that happen within the equilibrium system. Consider the following reaction involving the reaction of two $NO_2(g)$ molecules with themselves to form the product $N_2O_4(g)$:

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H < 0$$

Once equilibrium has been established, the amount /concentrations of both N_2O_4 and NO_2 no longer changes and remains constant with time. The system is dynamic N_2O_4 is being converted to NO_2 whilst NO_2 is being converted to N_2O_4 at the same rate.

Show and explain to the learners how this reaction can graphically be represented using both types of graphs.



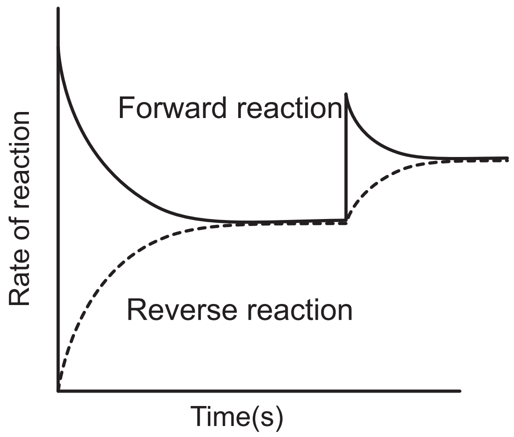


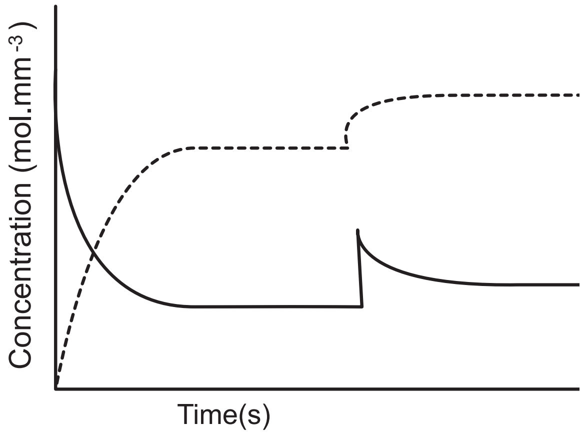
The rate at which NO_2 is reacted decreases with time (forward reaction) while the rate of formation of N_2O_4 increases with time. Dynamic chemical equilibrium is reached when both rate of decomposition and rate of formation are equal and can be seen when the two lines become parallel to each other and parallel to the time axis.

The concentration of NO_2 decreases while the concentration of N_2O_4 increases during the course of the reaction. Dynamic chemical equilibrium is indicated when the concentrations no longer change with time and the two representative lines become parallel with each other and to the time axis.

Teachers must ensure that the learners are familiar with the shapes for both graphs. Once they are comfortable with this, they can be introduced to see how the graphs will change when the various factors are introduced to upset the equilibrium and how the graph shape shows the re-establishment of the equilibrium. Use the example given above with the $NO_2(g)/N_2O_4(g)$ system. Here are some examples of what the graphs will look like by changing some of the factors:

1. Increase the concentration of NO_2: An increase in the concentration of NO_2 will upset the equilibrium and according to le Chatelier's Principle, the forward reaction will be favoured to counteract the effect of the change,

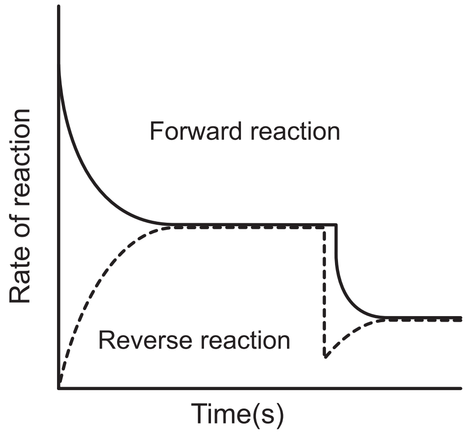


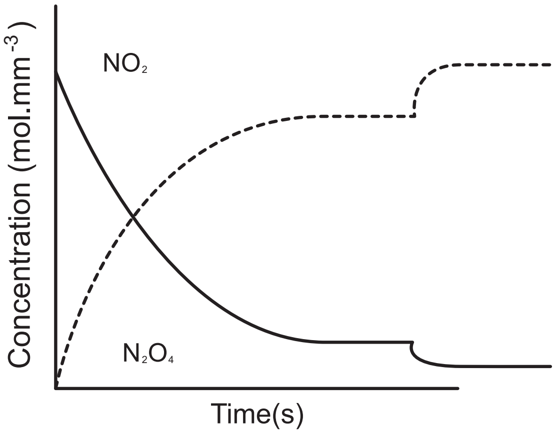


Here the learners need to see that the rate of the forward reaction has increased rapidly as according to le Chatelier's Principle, the forward reaction will be favoured to counteract the change. The reverse/back reaction will also increase but much slower as by adding more NO_2, it will increase the collision frequency. Note that equilibrium will be re-established.

Here the learners need to see that there will be an increase in the concentration of N_2O_4 as the forward reaction is favoured, and the concentration will decrease for the NO_2 as the excess is used up. NOTE: Very important for the learners to see that the reacting ratio of 2:1 must reflect on the graph. If 2 moles of NO_2 is used up to re-establish equilibrium, then 1 mole of N_2O_4 is produced at equilibrium.

2. Decrease the temperature of the system: Decreasing the temperature will remove heat energy from the system. The forward reaction is exothermic as indicated by the ΔH in the equation. This means that the forward reaction will be favoured as it will add heat energy to the system to replace the loss in energy.



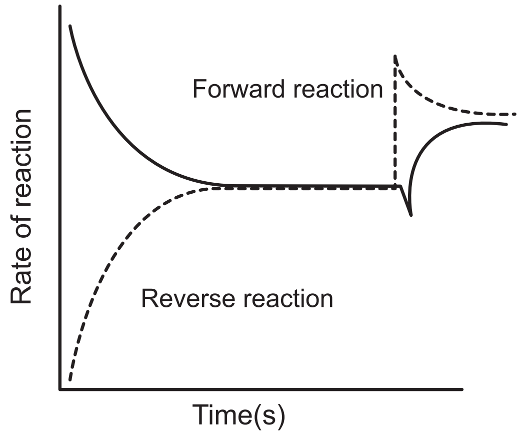


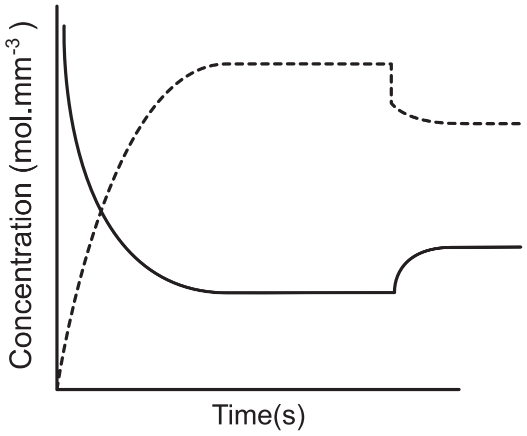
Here the learners need to notice two things:

1. Due to decrease in temperature, rate of **both** forward and reverse/back reactions will decrease simultaneously as there is less energy in the system.
2. The rate of the reverse/back reaction will then decrease more than the forward reaction to counteract the change. Equilibrium is thus re-established at a lower rate

In this graph, as the reverse/back reaction is favoured, the concentration of N_2O_4 will decrease while the concentration of NO_2 will increase. Important to note that because the reaction ratio of $NO_2:N_2O_4$ is 2:1, then the amount of NO_2 formed will be double that of N_2O_4 used.

3. Decreasing the pressure of the system: A decrease in the pressure (by increasing the volume of the container) will cause the reverse/back reaction to be favoured as to counteract the change in pressure, the reaction must proceed to favour a greater number of moles of gas.





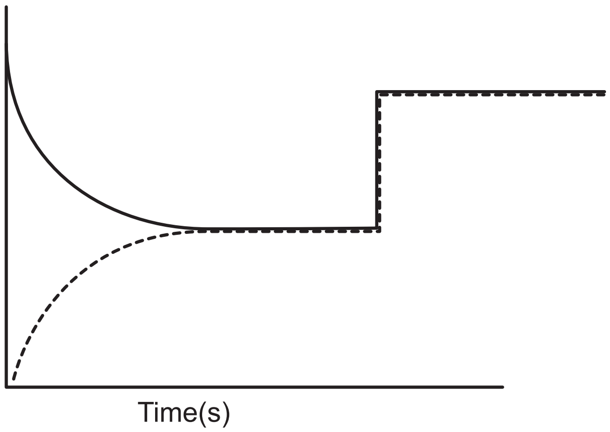
Once again, the learners need to see that initially the rate of both forward and reverse/back reactions decrease slightly due to a decreased collision frequency (greater volume), but then the reverse/back reaction rate increase more than the forward reaction rate to favour the reaction that produces greater number of moles of gas which increase the pressure (counteracts the change)	Initially the concentration of both NO_2 and N_2O_4 decreases as the volume of the container gets larger hence the small drop represented on the graph. With the reverse/back reaction favoured, the concentration of NO_2 will increase while the concentration of N_2O_4 will decrease. Again, learners to see that because of the $NO_2:N_2O_4$ is 2:1, concentration increase of NO_2 will be double the concentration decrease of N_2O_4

CONCEPT EXPLANATION AND CLARIFICATION: ADDITION OF A CATALYST TO A SYSTEM IN DYNAMIC CHEMICAL EQUILIBRIUM

Explain to the learners that this is NOT one of the factors of what will cause a change in a chemical equilibrium system, but it it important to note what will happen when it is added. Remind the learners as to what a catalyst does in a chemical reaction in that it will cause the rate of the reaction to increase without itself undergoing a chemical change. In other words, it will provide an alternative energy pathway for the reaction. (Revise Topic 7: Rate and extent of reaction).

Explain that in a system where there are reversible reactions, the addition of a catalyst will cause BOTH the forward and revers/back reaction rates to increase. This means that the chemical equilibrium will be reached faster than without a catalyst. If the system is already in dynamic equilibrium, explain to the learners that both the forward and reverse/back reactions will increase simultaneously, but neither will be favoured as a catalyst does not change the equilibrium conditions. Le Chatelier's Principle will not apply.

Show the learners how this is drawn graphically:



Here it can be seen that when a catalyst is added, both forward and reverse/back reactions increase simultaneously and then equilibrium is re-established at the higher rate.

Teachers must now use the ideas and concepts shown in these examples to show the learners the graphical representations when other changes of concentration, temperature and pressure occur in the system.

CONCEPT EXPLANATION AND CLARIFICATION: HOW THE FACTORS THAT INFLUENCE CHEMICAL EQUILIBRIUM AFFECT THE EQUILIBRIUM CONSTANT (K_c)

Refresh the learners' memory with regards to the significance of the K_c value in terms of telling us where the equilibrium position is lying. In other words, if the K_c value is less than equal to or greater than 1. This is explained in detail in Topic 2 of this module.

What learners now need to be taught is whether the change in equilibrium condition will affect the value of K_c. What is significant for the learners to know is that ONLY a change in temperature can alter the equilibrium constant. This is because when temperature is altered, there is a change in equilibrium position to favour either the forward or reverse/back reaction. This will then alter the concentrations of both reactant and product, and since the K_c expression is based on the ration of concentration of products to concentration of reactants, then there has to be change in the K_c value. This very simple table is able to summarise the change quite easily.

Temperature increases	More products formed as forward reaction is favoured and reactants will decrease. K_c will increase as there will be a larger numerator an a small denominator	More reactants will form as the reverse/back reaction is favoured and products will decrease. K_c will decrease as there is a smaller numerator and a larger denominator.
Temperature decreases	More reactants will form as the reverse/back reaction is favoured and products will decrease. K_c will decrease as there is a smaller numerator and a larger denominator.	More products formed as forward reaction is favoured and reactants will decrease. K_c will increase as there will be a larger numerator an a small denominator.

The question that learners may well ask is why do changes in concentration and pressure not affect the value of K_c? This can be quite complicated to answer, but the best way to attempt it is to say that a change in concentration is done by isolating one of reactants and products and causing it to increase or decrease. This will then cause the equilibrium position to shift either favouring the forward or reverse/back reaction to reduce the change in concentration. Now with all the other changes in concentration taking pace as a result of this, as well as the reactant or product that was originally changed, the ratio of concentration of products to reactants will remain constant, hence no change to the to the K_c value.

Changing the pressure is usually done by changing the volume of the reaction flask to cause more or less collisions of the gas particles with the walls of the container. As the reaction volume changes, this in actual fact also changes the concentration of the gases.

Then it stands to reason that if changing the concentration does not affect the K_c value, then neither will the change in pressure.

CONCEPT EXPLANATION AND CLARIFICATION: APPLICATION OF EQUILIBRIUM PRINCIPLES TO IMPORTANT INDUSTRIAL APPLICATIONS

The topic concludes with having a look at two important industrial application and the learners must know both these applications. They are:

1. Haber Process: The industrial process of making ammonia gas (NH_3) from nitrogen (N_2) and hydrogen (H_2).
2. The Contact Process: The industrial process given to the formation of sulphuric acid

The Haber Process

This is a very simple chemical equilibrium system with a very simple chemical reaction:

$$N_2(g) + 3H_2(g) \qquad\qquad 2NH_3(g) \qquad\qquad \Delta H < 0$$

However, what is very important for the learners to understand is that two critical factors are used in industry to control the production of ammonia gas

1. **Temperature**: As the forward reaction is exothermic, then by lowering the temperature of the system, the forward reaction would be favoured due to le Chatelier's Principle. This would produce much more ammonia gas. However, it is important for the learners to note that there is a critical point where the temperature cannot be lowered to far. This is due to the fact that the reaction rates of the equilibrium would then become too slow and the time taken to produce the ammonia gas would take too long. Thus, a compromise is made where a temperature of approximately 450ºC is used which is low enough to allow for the forward reaction to be favoured, but not as low as to slow down the reaction rate too much.
2. **Pressure**: A high pressure would also favour the forward reaction as there are 4 moles of reactant and 2 moles of product, so according to le Chatelier's Principle, an increase in pressure would favour the forward reaction to produce fewer moles of ammonia. Explain to the learners that there is a practical issue associated with this as high pressure industrial

systems are very expensive to build. This would affect the profitability of the production process thus a balance has to be made between yield and cost. To accomplish this, moderate pressures are used of around 200 atmospheres which still favours the production of ammonia, but still within budget.

A third factor is also considered although it will not affect the equilibrium through le Chatelier's Principle, and that is the addition of a catalyst t the system. A catalyst is added to speed up the rate of forward and reverse/back reaction to allow the equilibrium to be established quicker.

The Contact Process

Explain to the learners that this is the industrial process that is used to make sulphuric acid. There are 4 steps in the process and that the learners must learn these steps so that they can explain the whole process of production. The one step that is very important is Step 2 which is the equilibrium step and is catalysed by vanadium pentoxide (V_2O_5):

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H < 0$$

The factors that will affect this equilibrium reaction are exactly the same as in the Haber Process, namely a decrease in temperature and an increase in pressure. The same reasons apply here as with the Haber process.

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the equation, but not to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. State le Chatelier's Principle

   Solution:

   A change in any of the factors that determine equilibrium conditions of a system will cause the system to change in such a manner as to reduce or counteract the effect of the change.

2. Name three external conditions that have a direct influence on the state of chemical

equilibrium within a system.

Solution:

1. Change in concentration
2. Change in temperature
3. Change in pressure (gaseous systems only)

3. How will the addition of a catalyst to a system in dynamic chemical equilibrium affect that equilibrium?

Solution:

A catalyst will cause the rates of both the forward and reverse/back reactions to occur quicker and thus allow the equilibrium to be established quicker. It does not cause a change in the reaction conditions.

4. During the Haber process, the following dynamic chemical equilibrium was established

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H < 0$$

4.1. How does the rate of the forward reaction compare with the rate of the reverse reaction?

4.2. The pressure in the container is increased. How does this affect the equilibrium? Explain this in terms of le Chatelier's principle.

4.3. If the temperature of the mixture is decreased, what happens to the concentration of N_2 in the equilibrium mixture? Explain in terms of le Chatelier's principle.

4.4. What effect will the use of a catalyst have on the equilibrium?

4.5. If H_2 is removed from the system, what affect does this have on the equilibrium? Explain in terms of le Chatelier's principle.

Solution:

4.1. Both reaction rates are equal

4.2. The forward reaction will be favoured to shift the equilibrium to the right. According to le Chatelier's Principle, if an increase in pressure changes the equilibrium, the system will react to counteract that change, that is, favour the reaction that reduces pressure in the system. The forward reaction converts 4 moles of gas to 2 moles of gas thus producing fewer moles of gas and reducing the pressure.

4.3. N_2 concentration will decrease. According to le Chatelier's Principle, a decrease in temperature will cause the system to counteract the decrease in energy by favouring the reaction that puts energy back into the system. The forward reaction is exothermic thus the forward reaction will be favoured reducing the concentration of reactants and increasing concentration of products.

4.4. No effect on the equilibrium position. Catalyst will just speed up the rates of forward and revers/back reaction equally allowing for the the equilibrium to be established faster.

4.5. Removing H_2 will reduce the concentration of H_2 in the system. According to le Chatelier's Principle, a decrease in the concentration of H_2 will cause the equilibrium position to change to counteract the change to the equilibrium conditions. Thus the reverse/back reaction will be favoured to put more H_2 back into the system to increase the concentration and re-establish the equilibrium in the system.

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic questions, they are ready to deal with more challenging questions.

b. These questions require learners to **apply knowledge**.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

TOPIC 8: Chemical Equilibrium

1. The following reaction is in equilibrium

$$4X(g) + Y_2(g) \rightleftharpoons 2X_2Y(g) \qquad \Delta H > 0$$

   1.1. Is the forward reaction exothermic or endothermic? Explain

   1.2. How will the equilibrium concentration of Y_2 be influenced if the temperature is decreased? Explain in terms of le Chatelier's principle.

   1.3. How will the equilibrium be affected if X_2Y is removed from the system? Explain your answer in terms of le Chatelier's Principle.

   1.4. How will the equilibrium be affected if the pressure of the system is decreased? Explain your answer.

   Solution:

   1.1. Endothermic. The ΔH value (enthalpy of reaction) is greater than 0 thus will be Positive.

   1.2. Increase. According to le Chatelier's Principle, a decrease in temperature will cause the reaction to counteract the change by favouring the reaction that will put energy back into the system. The reverse/back reaction is exothermic thus the reverse/back reaction will be favoured causing an increase in the concentration of Y_2.

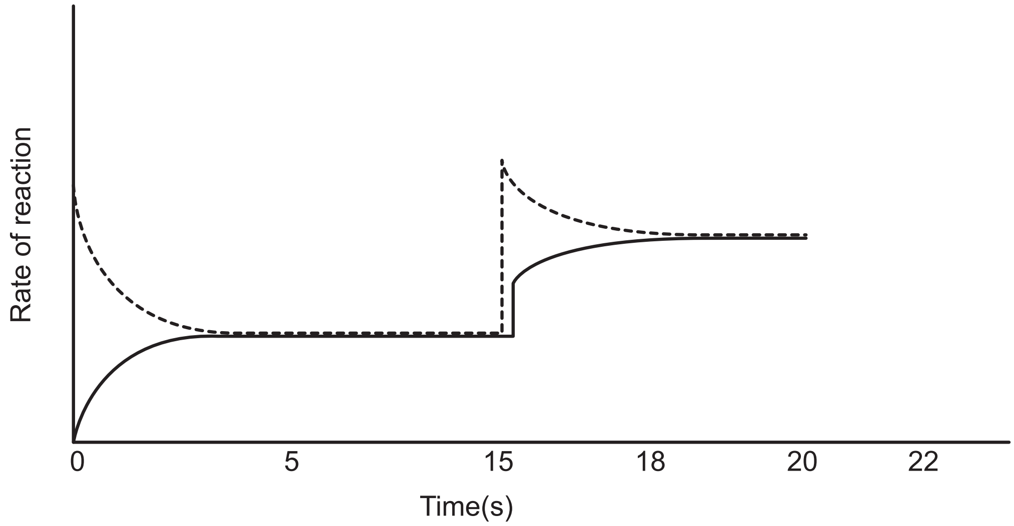
   1.3. Equilibrium position will shift to favour the forward reaction. According to le Chatelier's Principle, a decrease in the concentration of X_2Y will cause the reaction to counteract the change by favouring the reaction that will put X_2Y back into the system. Thus the forward reaction will be favoured.

   1.4. Equilibrium position will shift to favour the reverse/back reaction. According to le Chatelier's Principle, a decrease in the pressure of the system will cause the reaction to counteract the change by favouring the reaction that will increase the pressure of the system. As there are a total of 5mols of reactant gas and 2mols of product gas, the reverse/back reaction is favoured as it will produce more moles of gas causing an increase in pressure.

2. Methanol vapour reaches equilibrium at 350K according to the following equation

$$CH_3OH(g) \rightleftharpoons CO(g) + 2H_2(g)$$

   15 minutes after the start of the reaction the temperature is raised to 500K. The following rates vs time graph for the reaction was obtained.



2.1. Give the reaction equation represented by the solid line

2.2. Is the reaction represented by the dotted line endothermic or exothermic? Explain your answer.

2.3. What has happened to the reaction at t = 5mins?

2.4. Explain why both reactions rates increase at t = 15mins.

2.5. Why will the reaction represented by the dotted line increase more than the reaction represented by the solid line at t = 15mins?

2.6. What has now happened to the reaction at t = 18mins?

2.7. A catalyst is now added at t = 20mins. Sketch what the graph would look like between t = 20 and t = 22mins.

Solution:

2.1. $CO(g) + 2H_2(g) \longrightarrow CH_3OH$

2.2. An increase in temperature must now favour the reaction that will counteract the increase in heat energy in the system and absorb the excess energy. The forward reaction has increased its rate much more than the reverse/back reaction, thus the forward reaction must be an endothermic reaction.

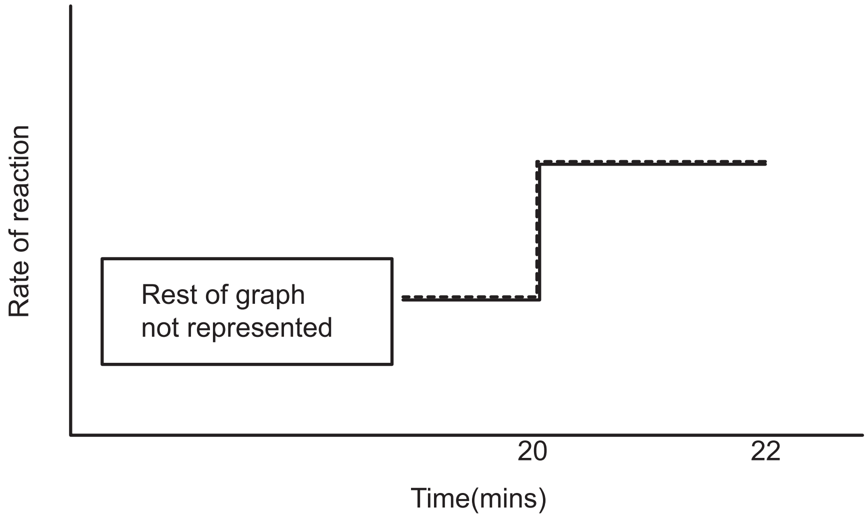
2.3. The reaction reached a state of dynamic chemical equilibrium.

2.4. An increase in temperature will put heat energy in the system. Reaction rate increases due to an increase in energy, thus both reaction rates will initially increase before the system counteracts the increase.

2.5. The forward reaction is favoured to counteract the increase in temperature.

2.6. Equilibrium has been re-established

2.7.



CHECKPOINT

At this point in the topic, learners should have mastered:

1. The understanding of le Chatelier's Principle.
2. The application of le Chatelier's Principle to changing equilibrium conditions of concentration, temperature and pressure (in gases).
3. Graphical representations of equilibrium systems showing graphically how rate of reaction and concentration graphs change when the factors affecting chemical equilibrium change.
4. How the factors that influence chemical equilibrium affect the equilibrium constant (K_c).
5. The application of equilibrium principles to important industrial applications, namely the Haber Process and the Contact Process.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Multiple Choice 1 – 5 and Long Questions 1 - 4

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

TOPIC 8: Chemical Equilibrium

ADDITIONAL VIEWING / READING

In addition, further viewing or reading on this topic is available through the following web links:

1. https://www.youtube.com/watch?v=4-fEvpVNTIE

   This link focuses on le Chatelier's Principle. It is a video clip from the Khan Academy.

2. https://www.youtube.com/watch?v=BPDkl92NCUs

   This link is another on le Chatelier's Principle. This is a video link.

3. https://www.youtube.com/watch?v=RjFW3smI1fY

   This is a really nice video clip that shows some practical demonstrations involving le Chatelier's Principle.

Topic 9: Acids and Bases

A INTRODUCTION

- This topic runs for 8 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Acids and Bases forms part of the content area Chemical Change(Chemistry).
- Chemical Change counts as 60% in the final exam.
- Acids and Bases counts approximately 12% to 14% of the final examination.
- Acid and base chemistry play a vitally important role in the chemistry of our everyday lives. We are exposed to many different acids and bases, for example, bases are found in soaps. Washing powders and cleaning products where acids are found in natural fruits, vinegar and even produced in our stomachs to aid in digestion. This section will look at the important factors associated with acid-base chemistry and give understand of how acids and bases work.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard/whiteboard.
2. Chalk/whiteboard pens.
3. Grade 12 Chemistry Examination Data Sheet.
4. Calculator
5. Pens, pencils and ruler

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. A4, 3 Quire exercise book, for notes and exercises.
2. Scientific calculator – Sharp or Casio calculators are highly recommended.
3. Pen, pencils, ruler.

B SEQUENTIAL TABLE

PRIOR KNOWLEDGE	CURRENT
Grade 10-11	**Grade 12**
• Writing of correct chemical formulae. • Balancing of chemical equations. • Being able to calculate the number of moles of a substance present form the mass of substance present. • Be able to calculate concentration of a substance given the mass of substance present. • Solve basic mathematical problems. • Be able to manipulate a mathematical equation to make one variable the subject of the formula	• Understanding concepts of equilibrium and reversible reactions. • Understand le Chatelier's Principle to apply to acid-base equilibriums. • Understand principles of electrochemistry in terms of conductivity

C GLOSSARY OF TERMS

Please note: The highlighted definitions and laws are ones that learners must be able to state and are given in the CAPS document. For examination purposes, learners must know these definitions and laws by heart, and must write them exactly as they appear here.

TERM	DEFINITION
Acid	An acid is a proton donor.
Base	A base is a proton acceptor.
Hydrolysis	This is the ability of ions to react with water molecules, thus altering the pH of the solution.
Salt	This is an ionic compound produced by the reaction of an acid with a base.
Ionisation	When a molecular substance dissolves in water to form aqueous ions for the first time.
Dissociation	When an already ionic substance dissolves in water to form aqueous ions.
Protolysis / protolytic reactions	The name given to the acid-base reaction that involves the simultaneous exchange of protons between acidic and basic substances.
Acid-base reaction	A reaction between an acid and a base where a simultaneous exchange of protons takes place in the reaction.
Aqueous solution	The name given to the solution that contain ions dissolved in water.
Hydronium ion	The ion formed when a proton, which is released by an acidic substance, reacts with water.
Conjugate acid-base pair	These are pairs of acids and bases that differ from each other by one proton in a protolytic reaction.
Ampholytes	A substance that is able to acts as both an acid or a base in an acid-base reaction.

Topic 9: Acids and Bases

Strong acid	An acid that almost completely ionises in water to form a very high concentration of H_3O^+ ions.
Weak acid	An acid that will only partially ionise in water to form a much lower concentration of H_3O^+ ions in solution.
Strong base	A base that will almost completely dissociate in water to form a very high concentration of OH^- ions in solution.
Weak base	A base that will only partially dissociate in water to form a much lower concentration of OH^- ions in solution.
Concentrated acid/base	An acid or base that has a high number of moles of solute to a small amount of water in solution.
Dilute acid/base	An acid or base that has a high amount of water in solution to a small amount of solute.
Conductivity	is the measure of the ability of a solution containing ions to conduct electrical current.
Monoprotic acid	An acid that is able to donate only one proton upon ionisation.
Polyprotic acid	An acid that is able to release more than one proton upon ionisation.
Monobasic base	A base that is able to release only one OH^- ion upon dissociation, for example, $NaOH$ or KOH.
Dibasic base	A base that is able to release two OH^- ions upon dissociation, for example, $Ca(OH)_2$ or $Mg(OH)_2$.
Polybasic bases	These are bases that have more than one OH^- group in their structure
Neutralisation reaction	A reaction where an acid is reacted with a base and both acid and basic properties of the reactants are cancelled out.
Acidic salt	The salt formed from a strong acid and a weak base that will produce an acidic solution due to hydrolysis.

Basic salt	The salt formed from a strong base and a weak acid that will produce a basic solution due to hydrolysis.
Neutral salt	The salt formed from a strong acid and a strong base that will produce a neutral solution and where no hydrolysis will take place.
Auto-ionisation	The ability of a substance to ionise with itself.
pH	The measure of the potency of the hydronium ion in solution.
Indicator	These are substances that show different colours in acidic and basic solution which allows one to determine whether a solution is acidic or basic.
Titration	The analytical technique used to perform an acid-base reaction where determining the unknown concentration of an acid or a base.
Standard solution	A solution that has an accurately known concentration.
Standardisation	The point in the titration when the H_3O^+ ions and OH^- ions are cancelled out completely.
Equivalence point/end-point	The point in the titration when the H_3O^+ ions and OH^- ions are cancelled out completely.

D ASSESSMENT OF THIS TOPIC

- This topic can be assessed using short class tests or through marked worksheets. I would suggest that a formal test is done at the end of the section to ensure that the learners do understand the work taught. This must also be included in the mid-year examination and will be examined in the final matric examination. The types of questions suited to this section could be in the form of multiple choice style questions and direct response style questions. See worksheets later for examples of these.

Topic 9: Acids and Bases

E BREAKDOWN OF TOPIC AND TARGETED SUPPORT OFFERED

- *Please note that this booklet does not address the full topic – only targeted support related to common challenges is offered.*
- *For further guidance on full lesson planning, please consult CAPS, the NECT Planner & Tracker and the textbook.*

TIME ALLOCATION	SUB TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
1 hour	Acid – Base models	127	a. The Arrhenius and Lowry-Bronsted Acid-Base Models b. Conjugate acid-base pairs
1 hour	Acid-Base terminology	127 and 128	a. Explaining Strong and Weak Acids, Strong and Weak Bases b. Using ionisation and dissociation equilibria to identify strong and weak acids and bases. c. Measuring strength of acid and bases using conductivity of acidic and basic solutions d. Measuring strength of acid and bases using rates of reaction. e. The difference between concentrated and dilute acids an bases.
2 hours	Acid-Base reactions and the concept of hydrolysis	127 and 128	a. Looking at acid-base reactions b. Introduction to the concept of hydrolysis
2 hours	The concept of pH	127	a. The auto-ionisation of water b. Understanding pH and pH calculations
2 hours	Acid-Base titrations and the use of indicators in a titration	127	a. Understanding indicators b. Understanding acid-base titrations and acid-base calculations

F

TARGETED SUPPORT PER SUB TOPIC

1. ACIDS – BASE MODELS

INTRODUCTION

In order to understand how acids and bases work within chemical systems, it is important for the learners to know what is meant by an acid and a base and how chemical compounds are classified as acids or bases. Acid-base models explain the theory behind what makes acids and bases.

CONCEPT EXPLANATION AND CLARIFICATION: THE ARRHENIUS AND LOWRY-BRONSTED ACID-BASE MODELS

Start the section off by explaining to the learners that to understand what we mean by the term ACID or BASE can be explained through two **scientific models**. What these model attempt to show us is what makes an acid, an acid and what makes a base, a base.

The Arrhenius Model

Explain to the learners that the Swedish chemist, Svante Arrhenius was the first person to come up with a model to explain these two types of chemicals. What is crucial for the learners to understand is that Arrhenius stated the following:

- Acids are substances that produce hydrogen ions in solution
- Bases are substances that produce hydroxide ions in solution

Show the learners two examples of this:

1. ACID: $HCl \longrightarrow H^+ + Cl^-$ This process is known as **ionisation**
2. BASE: $NaOH \longrightarrow Na^+ + OH^-$ This process is known as **dissociation**

It is very important for the learners to know the difference between ionisation and dissociation

Ionisation: The process whereby covalent molecules will produce ions in solution for the first time

Dissociation: The process where ionic compounds break up into their individual ions in solution.

The Lowry-Bronsted Model

This model followed the Arrhenius model in around 1923 where the two scientists, Thomas Lowry and Johannes Bronsted improved on the ideas of Arrhenius. Arrhenius's model had certain limitations in that it could only explain acids and bases when dissolved in water, whereas Lowry and Bronsted were able to explain acids and bases in both solid and liquid phases, hence the improvements.

Importantly, explain to the learners that there is not a big change in the workings of an acid or base. The new definition of acids and bases are:

- Acids are proton donors
- Bases are proton acceptors

Lowry and Bronsted refined this based on the formation of the hydrogen ion (H^+). The hydrogen ion is essentially is a proton (a hydrogen atom without an electron). Thus, if an acidic substance reacts, a hydrogen ion is released in a reaction. In other words, it is donated from the parent molecule. Now this proton cannot exist by itself and is highly reactive. It will then react with another molecule which then becomes the proton acceptor. In other words, that molecule becomes the base. Thus, it is very important to explain to the learners that according to Lowry and Bronsted, there has to be simultaneous exchange of protons (H^+ ions). This means that if there is a simultaneous exchange, then every reaction of this type can be classified as an acid-base reaction and this exchange of protons is known as protolysis. Use the following example to explain this to the learners:

$$HCl + NH_3 \rightleftharpoons NH_4^+ + Cl^-$$

Here the learners should be able to see that the HCl has donated its proton to the NH_3 molecule, hence HCl is acting as the acid (proton donor) and NH_3 is acting as the base (proton acceptor). We can see many other examples of these acid-base reactions happening and it is important for the learners to recognise the proton exchange mechanism taking place.

Ionisation reaction equations of molecular acids and molecular bases in water

Additional examples can be seen in the ionisation equations of soluble acid and base molecules in water. These form what are known as aqueous solutions as the products are now dissolved in water.

$$HCl(g) + H_2O(i) \rightleftharpoons H_3O^+(aq) + Cl^-(aq) \qquad \text{Ionisation Reaction 1}$$

$$NH_3(aq) + H_2O(aq) \rightleftharpoons NH_4^+(aq) + OH^-(aq) \qquad \text{Ionisation Reaction 2}$$

Here the learners can see that H^+ ions are being exchanged in each of these ionisation reactions. Reaction 1 represents the ionisation of a molecular acid (HCl), whereas Reaction 2 represents the ionisation of a molecular base (NH_3).

IMPORTANT:

1. The learners need to look carefully at the ionisation of the acid. Arrhenius stated that acids release H^+ ions into solution. Here we can see that the H^+ has reacted with the H_2O molecule to produce the H_3O^+ ion as a product. This is called the hydronium ion and the hydronium ion is the same as the H^+ in solution. Remember that the H^+ ion cannot exist by itself in solution, hence:

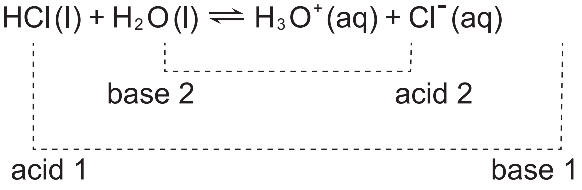
   $$H^+ + H_2O \rightleftharpoons H_3O^+$$

   Thus, whenever learners see the presence of the hydronium ion (H_3O^+), it represents the proton (H^+) released by the acid molecule confirming the presence of an acidic solution

2. The learners need to see that in the ionisation of the NH_3 molecule, the NH_3 accepts a proton from the water making the NH_3 a basic substance (proton acceptor). Also important to see that the OH^- ion is present conforming the presence of a basic solution.

CONCEPT EXPLANATION AND CLARIFICATION: CONJUGATE ACID-BASE PAIRS

In the sub-topic above, it has been carefully explained the significance of the Lowry-Bronsted model and the existence of acid- base reactions which support their theory that there is a simultaneous donating and acceptance of protons (H^+) in an acid-base reaction. From that understanding come the existence of what are known as **conjugate acid-base reaction pairs**. Explain to the learners that the term **'conjugate'** means that a substance differs from another substance by a single proton. Thus, a conjugate acid-base pair is where the substances differ from each other by a single proton within that acid-base reaction. Consider the example below:



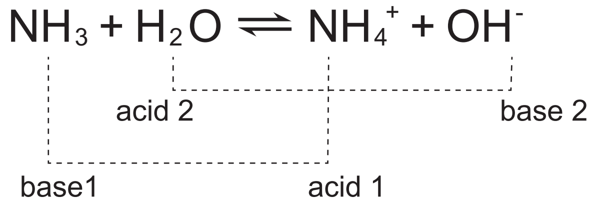
$$HCl(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + Cl^-(aq)$$

Here the learners need to be shown the two different conjugate acid base pairs:

HCl and Cl^- : HCl is the acid as it is the proton donor which then make Cl^- the conjugate base. It can be clearly seen that Cl^- differs from HCl by a single proton but is known as a conjugate base as it will act as a base (proton acceptor) in the reverse reaction. (acid 1---base 1)

H_2O an H_3O^+ : H_2O is the base as it is the proton acceptor which makes H_3O^+ the conjugate acid. It can be clearly seen that H_3O^+ differs from H_2O by a single proton but is known as a conjugate acid as it will act as an acid (proton donor) in the reverse reaction. (base 2---acid 2)

Now look at the following example:



$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

Here we can identify the conjugate acid base pairs as follows:

NH_3 and NH_4^+ : NH_3 is acting as the base thus will be the proton acceptor, which make the NH_4^+ the conjugate acid. It can be clearly seen that the NH_4^+ differs from the NH_3 by a single proton (H^+) and thus will act as an acid (proton donor) in the reverse reaction. (base 1 --- acid 1)

H_2O and OH^- : H_2O is acting as the acid thus will be the proton donor which then make OH^- the conjugate base. It can be clearly seen that OH^- differs from H_2O by a single proton (H^+) and thus will act as a base (proton acceptor) in the reverse reaction. (acid 2 --- base 2).

Explain to the learners that what is interesting her is that water is used in both these acid-base reactions. Now draw the attention of the learners to the fact that water is acting as a base in the one reaction, but as an acid in the other. Explain to them that substances like this are known as ampholytes, that is, substance that are able to act as either an acid or a base. They can either donate or accept protons.

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the equation, but not to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

Topic 9: Acids and Bases

1. According to the Arrhenius model, explain what is meant by an acid and a base

   Solution:

   An acid is a substance that produces hydrogen ions in solution

   A base is a substance that produces hydroxide ions in solution

2. According to the Lowry-Bronsted model, explain what is meant by an acid and a base

   Solution:

   An acid is a proton donor

   A base is a proton acceptor

3. Explain the difference between the terms ionisation and dissociation.

   Solution:

   Ionisation: the process whereby covalent molecules, when dissolved in water, will produce ions for the first time

   Dissociation: the process whereby ionic compounds break up into their individual ions in solution.

4. What is meant by the term 'protolysis' and why is it important in acid-base chemistry?

   Solution:

   This is a chemical reaction where an exchange of protons takes place between substance. All acid-base reactions are classified as protolytic reactions as according to Lowry-Bronsted theory, these reactions involve a proton donor and a proton acceptor, thus exchanging protons in the reaction.

5. Explain what is meant by the hydronium ion and why does this ion form in solution.

   Solution:

   The hydronium ion is given by the formula $H3O^+$ and is formed when the H^+ ion, released by an acidic molecule, reactions with the water molecule of the solvent. H^+ ions are protons and cannot exist by themselves in nature. They are highly reactive and will thus react with water to produce the hydronium ion.

6. Write ionisation reactions for the following:

    6.1. HCl dissolved in water to form hydrochloric acid

    6.2. Ammonia gas dissolved in water to form ammonium hydroxide

Solution:

6.1. $HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$

6.2. $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

7. a) Explain what is meant by conjugate acid-base pairs in an acid-base reaction

    b) Using question 5 above, identify the conjugate acid-base pairs in each reaction

    c) What do you notice about the chemical behaviour of water in each of these reactions?

    d) What term is given to substances like water which behave in this manner

Solution:

a) These are pairs of substance that differ from each other by a single proton in the chemical reaction.

b) acid HCl and conjugate base Cl^- : base H_2O and conjugate acid H_3O^+

base NH_3 and conjugate acid NH_4^+ : acid H_2O and conjugate base OH^-

c) Water is able to act as both an acid and a base in an acid-base chemical reaction.

d) Ampholyte

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic calculations, they are ready to deal with more challenging questions.

b. These questions require learners to manipulate the equation to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

1. Classify the following compounds as either acids or bases:

   a) NaOH

   b) HNO_3

   c) H_3PO_4

   d) H_2CO_3

   e) KOH

   f) NH_3

   Solution:

   a) Base

   b) Acid

   c) Acid

   d) Acid

e) Base

f) Base

2. Identify the conjugate acid-base pairs in the following reactions

   a) $H_2SO_4 + H_2O \rightleftharpoons H_3O^+ + HSO_4^-$

   b) $NH_3 + HCl \rightleftharpoons NH_4^+ + Cl^-$

   c) $CO_3^{2-} + H_2O \rightleftharpoons OH^- + HCO_3^-$

   Solution:

   a) $H_2SO_4 + H_2O \rightleftharpoons H_3O^+ + HSO_4^-$

      acid: H_2SO_4 conjugate base: HSO_4^-

      base: H_2O conjugate acid: H_3O^+

   b) $NH_3 + HCl \rightleftharpoons NH_4^+ + Cl^-$

      acid: HCl conjugate base: Cl^-

      base: NH_3 conjugate acid: NH_4^+

   c) $CO_3^{2-} + H_2O \rightleftharpoons OH^- + HCO_3^-$

      acid: H_2O conjugate base: OH^-

      base: CO_3^{2-} conjugate acid: HCO_3^-

3. What is the conjugate acid of:

   a) OCl^-

   b) H_2O

   Solution:

   a) $HOCl$

   b) H_3O^+

4. What is the conjugate base of:

   a) $HClO_2$

   b) H_2O

Solution:

a) ClO_2^-

b) OH^-

Key Teaching:

a. In these more challenging examples, learners need to identify and indicate the conjugate acid-base pairs within a single equation.

b. Once learners have done this, they should then list the acid-base pairs underneath the equation.

c. In questions 3 and 4, remind the learners that conjugate acid base pairs differ only by one hydrogen, therefor a conjugate acid will have an extra hydrogen whereas a conjugate base will have a hydrogen less.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. The difference between the Arrhenius acid-base model and Lowry-Bronsted acid-base model.
2. What is meant by a conjugate acid-base pair.
3. Being able to identify conjugate acid-base pairs in an acid-base reaction equation.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Acids and Bases Multiple Choice Questions 1 - 5 and Long Questions 1.1 – 1.12

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

2. ACID – BASE TERMINOLOGY

INTRODUCTION

Learners must be made aware that there are a number of important concepts as well as terminology associated with acid-base chemistry. This sub –topic will cover the essential concepts that must be understood before moving onto the more complex aspects of acids and bases. Learners must learn which acids and bases are strong and weak so that they can better understand their chemistry when they react together. They must also be comfortable using the ionisation and dissociation equilibrium equations to identify strong and weak acids and bases. One of the most important concepts is to understand the difference between strength of acids and bases and the concentration of acids and bases. This is a big area of misunderstanding and will be covered in detail in the sub-topic.

CONCEPT EXPLANATION AND CLARIFICATION: EXPLAINING STRONG AND WEAK ACIDS, STRONG AND WEAK BASES

It is very important for the learners to distinguish between the different strengths of acids and bases. In other words, what makes an acid strong and what makes an acid weak. In simple terms, it has to do with the amount of ionisation or dissociation that takes place in solution. Remind the learners that acids are molecular structures and thus will ionise, bases are ionic structures and thus will dissociate and also remind them of the definitions that were supplied in the first sub-topic.

Now, allow the learners to use this understanding to differentiate between strong and weak acids or bases:

Strong acids: an acid that will tend toward complete ionisation to produce a large concentration of H_3O^+ ins in solution.

$$HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$$

Show the learners that the equilibrium favours the forward reaction and lies to the right producing large amount of product. This means that there will be a high concentration of H_3O^+ ions in solution

Weak acid: an acid that will only partially ionise in solution to produce a low concentration of H_3O^+ ions in solution.

$$CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$$

Show the learners that the equilibrium favours the reverse/back reaction and lies to the left producing large amount of reactant and very little product. This means that there will be a low concentration of H_3O^+ ions in solution

At this point it would be a good idea to supply the learners with a list of what we consider strong acids as well as examples of weak acids.

Formula	Name of acid	
HCl	Hydrochloric acid	These 3 acids are the most commonly used strong acids
HNO_3	Nitric acid	
H_2SO_4	Sulfuric acid	
HF	Hydrofluoric acid	These 4 acids are examples of some of the weak acids
H_2CO_3	Carbonic acid	
CH_3COOH	Ethanoic acid	
H_3PO_4	Phosphoric acid	

It is important for the learners to notice that all acids will have at least one hydrogen atom within their structure. This hydrogen atom is the proton that will be donated as the hydrogen ion (H^+). We classify the acids according to the number of hydrogen ions that they are able to donate. In other words:

- HCl has one hydrogen in its structure, thus we call this a **monoprotic acid**. (mono = one, protic = proton)
- H_2SO_4 has two hydrogen atoms in its structure, thus we call this a **diprotic acid**. (di = two, protic = protons)
- H_3PO_4 has three protons in its structure, thus we call this a **triprotic acid**. (tri = three, protic = protons)

With this type of terminology, the diprotic and triprotic acids are now classified as **polyprotic acids** where the word ”poly” means “many”

Strong bases: a base that will tend towards complete dissociation in solution

$$NaOH \rightleftharpoons Na^+ + OH^-$$

Once again, but this time with a strong base, the forward reaction lies far to the right with very little reverse/back reaction taking place. This means that there is a very high concentration of OH^- ions present in solution.

Weak bases: a base that will only partially dissociate in solution

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

Once again, but this time with a weak base, the reverse reaction lies far to the left with very little forward reaction is taking place. This means that there is a very low concentration of OH^- ions present in solution.

At this point it would be a good idea to supply the learners with a list of what we consider strong acids as well as examples of weak acids.

Formula	Name of base	
$NaOH$	Sodium hydroxide	These 3 bases are the most commonly used strong bases
KOH	Potassium hydroxide	
$LiOH$	Lithium hydroxide	
$Ca(OH)_2$	Calcium hydroxide	These 3 bases are examples of some of the weak bases
$Mg(OH)_2$	Maganesium hydroxide	
NH_4OH	Ammonium hydroxide	

It is suggested that learners learn these different acids and bases and be able to identify which of them will be strong and which will be weak.

It is important for the learners to notice that these will have at least one hydroxide ion within their structure. This hydroxide ion is the ion that is released into solution which makes the solution basic.

- $NaOH$ has one hydroxide ion in its structure, thus we call this a **monobasic base**. (mono = one, basic = hydroxide ion)
- $Mg(OH)_2$ has two hydroxide ions in its structure, thus we call this a **dibasic base**. (di = two, basic = hydroxide ions)

Learners can also be told that bases with more than one OH^- group are known as **polybasic bases**

Learners will notice that all these bases have hydroxide ions in their structure. What is very important for the learners to know is that the Group I hydroxides, namely $NaOH$, KOH and $LiOH$ are classified by a special name. They are called alkalis and this word is very specific to the Group I hydroxides ONLY.

Topic 9: Acids and Bases

CONCEPT EXPLANATION AND CLARIFICATION: USING IONISATION AND DISSOCIATION EQUILIBRIA TO IDENTIFY STRONG AND WEAK ACIDS AND BASES

Apart from learning which acids and bases are strong or weak, learners are able to use equilibrium principles and knowledge of equilibrium constants as learnt in the previous topic on Chemical Equilibrium to identify the strength of acids and bases. This is a very important technique and teachers must spend a little bit of time on his concept.

ACIDS: Consider the ionisation equilibrium of hydrochloric acid:

Note: H_2O is not Included as it is a pure liquid

$$HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$$

The equilibrium expression for this acid will be: $K_c = \frac{[H_3O^+][Cl^-]}{[HCl]}$

As HCl is a strong acid, there will be a very high concentration of H_3O^+ and Cl^- ions and a very low concentration of HCl in the system. As this equilibrium is specifically for an acid, the K_C value gets renamed as the **ionisation constant for the acid** and is given the symbol K_a where the "a" indicates that it is the acid ionisation constant. Thus for a strong acid, the K_a value will be very high due to a very large numerator and a low denominator. This will be true for all strong acids.

Weak acids will follow exactly the same thinking process and equilibrium, but will have very low ionisation constants (K_a values) as they only undergo partial ionisation. Consider the example of a weak acid that was used earlier

$$CH_3COOH + H_2O \rightleftharpoons H_3O^+ + CH_3COO^-$$

This means very low concentrations of H_3O^+ and CH_3COO^- as products and a high concentration of CH_3COOH which is the unionised acid molecule. The K_a expression will be:

$$K_a = \frac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]}$$

Thus, there will be a very low numerator and a very high denominator making the K_a value very small. For example, have a look at the K_a values for the two examples used above:

$K_a \text{ for } HCl = 1{,}02 \times 10^3$	(very high value hence strong acid)
$K_a \text{ for } CH_3COOH = 1{,}82 \times 10^{-5}$	(very low value hence weak acid)

BASES: Consider the dissociation equilibrium for $NaOH$

$$NaOH(s) \rightleftharpoons Na^+(aq) + OH^-(aq)$$

The equilibrium expression for this base will be $K_C = [Na^+].[OH^-]$

NaOH is a solid and thus will have concentration equal to 1. It thus will not appear in the K_C expression

As NaOH is a strong base, there will be a very high concentration of OH^- and Na^+ ions and a very low concentration of NaOH in the system due to the almost complete dissociation of the NaOH compound. As this equilibrium is specifically for a base, the K_C value gets renamed as the **ionisation constant for the base** and is given the symbol K_b where the "b" indicates that it is the base dissociation constant. Thus for a strong acid, the K_b value will be very high due to a very large numerator and a low denominator. This will be true for all strong bases.

Weak bases will follow exactly the same thinking process and equilibrium considerations, but will have much lower dissociation constants (K_b values) as they only undergo partial dissociation. Consider the example of a weak acid that was used earlier

$$Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + OH^-(aq)$$

This means very low concentrations of OH^- and Ca^{2+} as products which is the unionised acid molecule. The K_b expression will be:

$$K_a = [Ca^{2+}].[OH^-]$$

Thus, there will be a much smaller K_b value for the base. For example, have a look at the K_b values for the two examples used above:

K_b for NaOH $= 1,25 \times 10^2$ (very high value hence strong base)

K_b for $Ca(OH)_2 = 4,26 \times 10^2$ (very low value hence weak base)

In conclusion, learners can easily tell whether an acid or base is strong or weak by looking at the K_a or K_b value of the respective acid or base. Any K_a or K_b value less than 1will indicate that the acid or base will be weak.

CONCEPT EXPLANATION AND CLARIFICATION: MEASURING STRENGTH OF ACID AND BASES USING CONDUCTIVITY OF ACIDIC AND BASIC SOLUTIONS

This is another technique that learners must be taught to measure the strength of an acid or a base. Firstly, learners need to know what is meant by the term 'conductivity'.

Conductivity is the measure of the ability of a solution containing ions to conduct electrical current.

Explain to the learners that the greater the number of ions present in a solution, the better will be the conductivity of that solution.

Strong acids which have a very high ability to undergo ionisation will produce a large number of ions in solution whereas a weak acid which has a low/[partial ability to undergo ionisation, will produce less ions in solution and thus will not have a high conductivity.

Exactly the same applies to bases which will depend on the ability to dissociate.

Strong bases will fully dissociate and this many ions in solution giving a high degree of conductivity.

Weak bases will partially dissociate and thus fewer ions in solution giving a much lower degree of conductivity.

Also, it is important for the learners to see that electrical conductivity can be different if you are using a strong monoprotic acid compared a strong polyprotic acid. Give the learners the examples of HCl and H_2SO_4 and make then write the ionisation equations for each:

$$HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$$

$$H_2SO_4 + H_2O \rightleftharpoons 2H_3O^+ + SO_4^{2-}$$

Show the learners that in the ionisation of H_2SO_4, there are two hydronium ions produced compared to the one of HCl which then increases the number of free ions in solution making sulfuric acid have a higher conductivity compared to hydrochloric acid.

CONCEPT EXPLANATION AND CLARIFICATION: MEASURING STRENGTH OF ACID AND BASES USING RATES OF REACTION

Learners can also predict the strength of an acid or base based on the rate of reaction.

A strong acid will react much faster than a weak acid of the same concentration. This is due to the fact that for a strong acid with a high degree of ionisation, there are more ions in solution and thus the number of effective collisions per unit time will be much greater. This is again exactly the same with strong bases where the high degree of dissociation producing a high concentration of ions, hence a greater change of effective collisions per unit time.

CONCEPT EXPLANATION AND CLARIFICATION: THE DIFFERENCE BETWEEN CONCENTRATED AND DILUTE ACIDS AND BASES

One of the biggest misconception is that learners have is that they confuse strength of acids and bases with the concentration of acids or bases. Many students think that a concentrated acid or base will be strong and a dilute acid or base will be weak. Take time now to fully explain to the learners the critical difference between these two concepts.

- As has just been explain, the strength of an acid or base is measured due to its ability to ionise or dissociate in water.
- When it comes to the comes to concentrated r dilute acids, this is the measure of how

much water is present in the system.

As the learners will know, concentration is measured by the mathematical operation $c = \frac{n}{V}$

From the equation, it is clear that concentration depends on two factors, namely

1. The number of moles of acid or base present
2. The volume of solvent (water) present.

This means that:

- If there is a small amount of water present in the solution, this will make the concentration of the solution high. This is called a concentrated solution.
- If there is a large amount of water present in the solution, the volume of water will be high which will make the concentration of the solution low. This will thus be a more dilute solution.

In no way does the amount of water present in the system affect the amount of ionisation or dissociation of the acid or base and thus learners must be comfortable in understanding this before moving onto other aspects of acids or bases. Both strong and weak acids or bases can be concentrated or dilute.

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic questions that learners will be required to answer at this stage in the topic.
b. Their purpose is to familiarise the learners with the content.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Learners must copy the question as well as the solution into their workbook.

1. Explain the difference between a strong acid and a weak acid and give two examples of each type of acid.

   Solution:

   Strong acid: This is an acid that tends towards complete ionisation when placed in water. Examples would be $HCl / H_2SO_4 / HNO_3$

   Weak acid: This is an acid that will only undergo partial ionisation when placed in water. Examples would be $CH_3COOH / H_2CO_3 / H_3PO_4$

2. Explain the difference between a strong base and a weak base and give two examples of each type of base.

   Solution:

   Strong base: This is a base that will undergo complete dissociation when placed in water. Examples would be $LiOH / NaOH / KOH$

   Weak base: This is a base that will only undergo partial dissociation when placed in water. Examples would be $Ca(OH)_2 / Mg(OH)_2 / NH_4OH$

3. What is meant by a polyprotic acid and give two examples of these types of acids.

   Solution:

   This is an acid that has more than one hydrogen atom in its structure that can be ionised in solution

   Examples: $H_2PO_4 / H_2CO_3 / H_3PO_4$

4. What is meant by the term "alkali"?

   Solution:

   This is a base which is specifically a group I hydroxide. Examples of this will be $NaOH$, KOH and $LiOH$

5. What is meant by a monobasic alkali and give two examples of these types of bases.

   Solution:

   This is a base which has a Group I metal cation in its structure as well as only one hydroxide ion associated with this cation.

   Example: $NaOH / KOH / LiOH$

6. Explain the difference between a concentrated acid and a dilute acid.

   Solution:

   Concentrated acid: This is an acid that has a small amount of water in the system

   Dilute acid: This is an acid that has a large amount of water present in the system

7. Can a strong base be made weaker by adding water to the base? Explain your answer

   Solution:

   No. The strength of an acid is only dependent on the amount of ionisation that takes place.

Strong acids will tend towards complete ionisation irrespective of how much water is in the system, thus adding extra water will only be diluting the acid, not affecting its strength.

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic questions, they are ready to deal with more challenging questions.

b. These questions require learners to apply knowledge.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

1. Explain what is meant by the term "ionisation equilibrium"

   Solution:

   This is the equilibrium established during the ionisation process where a molecular substance forms ions in solution for the first time. Example:

   $HCl + H_2O \rightleftharpoons H_3O^+ + Cl^-$

2. Write down the ionisation equilibrium equation for sulfuric acid in water

   Solution:

   $H_2SO_4 + 2H_2O \rightleftharpoons 2H_3O^+ + SO_4^{2-}$

3. Write down the ionisation equilibrium expression for this reaction

   Solution:

   $K_a = \frac{[H_3O^+]^2[SO_4^{2-}]}{[H_2SO_4]}$ Note: water is a pure liquid therefore has concentration equal to 1

4. What is meant by the term "dissociation equilibrium"? Using KOH as an example, write down the dissociation equilibrium expression for this base.

   Solution:

   This is the equilibrium formed when an ionic substance is dissolved in water to form aqueous ions in solution

   $KOH(s) \rightleftharpoons K^{+}(aq) + OH^{-}(aq)$

5. What is meant by the terms "K_a" and "K_b" values

   Solution:

   K_a is the ionisation constant for an acid

   K_b is the dissociation constant for a base

6. Why are these K_a and K_b values so important in acid-base chemistry

   Solution:

   These size of the value of these constants tell us the extent of ionisation / dissociation that has taken place in water. This indicates the relative strength of an acid or base in solution.

   A large K_a / K_b value indicates a strong acid or base

   A small K_a / K_b value indicates a weak acid or base

7. If a base has a very high K_b value, what does that mean?

   Solution:

   This means that it is a strong base and will undergo almost complete dissociation in water

8. Determine whether the following pairs of acids or bases are strong or weak. Then explain how their ionisation/dissociation equilibrium constants will compare based on their relative strengths.

   8.1. CH_3COOH and HNO_3

   8.2. $NaOH$ and $Ca(OH)_2$

   Solution

   8.1. CH_3COOH is a weak acid whereas HNO_3 is a strong acid. CH_3COOH will have a small K_a value where HNO_3 will have a large K_a value.

8.2. $NaOH$ is a strong base whereas $Ca(OH)_2$ is a weak base. $NaOH$ will have a large K_b value whereas $Ca(OH)_2$ will have a small K_b value.

9. Which sample in each of the following pairs will conduct electricity the easiest?

9.1. HCl or H_2CO_3

9.2. $Ca(OH)_2$ or $NaOH$

9.3. HNO_3 or H_2SO_4

Solution:

9.1. HCl: HCl is a stronger acid than H_2CO_3 thus will fully ionise to produce a very high number of ions is solution, this will conduct electricity very easily in comparison to the weak acid H_2CO_3 which will only partially ionise.

9.2. $NaOH$: This is a strong base thus will dissociate fully compared to $Ca(OH)_2$ which is a weak base. Strong base will therefore conduct electricity more easily.

9.3. H_2SO_4: Even though both are strong acids, H_2SO_4 is a diprotic acid, thus will release more H_3O^+ ions into solution compared to HNO_3. This will allow for easier conductivity.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. The difference between a strong and a weak acid.
2. The difference between a strong and a weak base.
3. Being able to identify name strong and weak acids and bases.
4. Polyprotic and polybasic acids and bases.
5. What is meant by ionisation and dissociation equilibria.
6. The use of these equilibria to identify strong and weak acids and bases.
7. Being able to write ionisation and dissociation equilibria expressions for acids and bases.
8. Seeing how conductivity is affected depending if you have a solution of an acid or base.
9. How the rate of reaction is affected by the strength of an acid or base.
10. The difference between a concentrated and dilute acid or base.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Acids and Bases Multiple Choice Questions 1 - 5 and Long Questions 1.1 – 1.12

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

3. ACID – BASE REACTIONS AND THE CONCEPT OF HYDROLYSIS

INTRODUCTION

In this sub-topic, learners will be introduced to the various types of acid-base reactions, in particular looking at the salt which is formed as a product. Here, learners will be introduced to the concept of salt hydrolysis where the ions of the salt have the ability to interact with the solvent, water, to create solutions that can either be acidic, basic or neutral. Examples will be done with the learners to help them understand the hydrolysis concept.

CONCEPT EXPLANATION AND CLARIFICATION: LOOKING AT ACID-BASE REACTIONS

Once the learners are comfortable with the understanding of the introductory concepts of acids and bases, we can now look at how acids an bases reaction with each other. Explain to the learners hat there is a general reaction mechanism that can be taught to make the understanding of these reactions much easier. The general reaction is:

$$\text{acid} + \text{base} \longrightarrow \text{salt} + \text{water}$$

This means that no matter what type of acid or base is used, the products that will form will always be a salt and water. These reactions are known as **neutralisation reactions** as the properties of both the acid and the base are cancelled out, hence 'neutralised'.

The question that must now be put to the learners is: What do we mean by the term **"salt"**? A salt is the product of an acid-base reaction where the hydrogen in the acid molecule is replaced by the metal cation of the base. For example:

- The salt $NaCl$ is produced from the acid HCl and the base $NaOH$. The H from the HCl is replaced by the Na^+ ion from the $NaOH$
- The salt K_2SO_4 is produced from the acid H_2SO_4 and the base KOH. The H's from the H_2SO_4 are replaced by the K^+ ions from the KOH.

Now that learners have understood what makes up a salt, teachers can now look at the acid-base reactions that take place. Here we look at 5 main types of acid- base reactions:

1. Acids reacting with metal oxides (where the metal oxide will be the base)

$$\boxed{\text{acid} + \text{metal oxide} \longrightarrow \text{salt} + \text{water}}$$

Useful metal oxides are Na_2O, K_2O and CaO.

An example of such a reaction will be:

$$2HCl + K_2O \longrightarrow 2KCl + H_2O$$

where KCl will be the salt formed.

2. Acids reacting with metal hydroxides (where the metal hydroxide will be the base)

$$\boxed{\text{acid} + \text{metal hydroxide} \longrightarrow \text{salt} + \text{water}}$$

Useful metal hydroxides are $NaOH$, KOH and $Ca(OH)_2$

An example of such a reaction will be:

$$H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$$

where Na_2SO_4 will be the salt formed.

3. Acids reaction with metal carbonates (where the metal carbonate will be the base)

$$\text{acid} + \text{metal carbonate} \longrightarrow \text{salt} + \text{water} + \text{carbon dioxide}$$

Useful metal carbonates are Na_2CO_3 , $CaCO_3$ and K_2CO_3

An example of such a reaction will be:

$$\boxed{2HNO_3 + CaCO_3 \longrightarrow Ca(NO_3)_2 + 2H_2O + CO_2}$$

where $Ca(NO_3)_2$ will be the salt formed. It is important to note that in this type of reaction, CO_2 is formed as an additional product.

4. Acids reacting with metal hydrogen carbonates (where the metal hydrogen carbonate will act as the base)

$$\boxed{\text{acid} + \text{metal carbonate} \longrightarrow \text{salt} + \text{water} + \text{carbon dioxide}}$$

Useful metal carbonates are $NaHCO_3$, $KHCO_3$ and $Mg(HCO_3)_2$

An example of such a reaction will be:

$$2HCl + Mg(HCO_3)_2 \longrightarrow MgCl_2 + 2H_2O + CO_2$$

where $MgCl_2$ will be the salt formed. It is important to note that in this type of reaction, CO_2 is formed as an additional product in the same way as it was formed when the metal carbonate reacted.

Now, for the fifth and last reaction, explain to the learners that although a salt is formed as one of the products, it is not a classic acid-base reaction but is classified as a Redox reaction. It is important for the learners to see that hydrogen gas is given off in this reaction and that water is not formed as one of the products.

5. Acid reaction with metal

$$\boxed{\text{Acid} + \text{metal} \longrightarrow \text{salt} + \text{hydrogen}}$$

Useful metals such as Zn, ca and Mg can be used

$$2HCl + Zn \longrightarrow ZnCl_2 + H_2$$

CONCEPT EXPLANATION AND CLARIFICATION: INTRODUCTION TO THE CONCEPT OF HYDROLYSIS

Now that the learners have seen different acid–base reactions and know what is meant by the term ‘salt’, this becomes a good place to introduce the concept of hydrolysis. As mentioned earlier in this sub-topic, when acids and bases react with each other to cancel out the properties of each other to produce a **neutral solution**, that is, a solution that has neither acid or base particles present.

However, the water in which the salt dissolved is able to react with the aqueous ions of the salt in solution through a process known as hydrolysis. This reaction with the water will depend if the cation or the anion of the salt originated from a strong or weak parent acid, or a strong or weak parent base. Depending on the strength of these ions in solution will determine whether hydrolysis will take place. Consider the following examples:

Example 1

Sulfuric acid reacts with magnesium hydroxide to form magnesium sulphate and water according to the following reaction:

$$H_2SO_4 + Mg(OH)_2 \longrightarrow MgSO_4(aq) + H_2O$$

Here the salt $MgSO_4$ will be found as aqueous ions in solution, that is, dissociated in water

$$MgSO_4 \longrightarrow Mg^{2+}(aq) + SO_4^{2-}(aq)$$

Consider each ion in solution. These ions come from the weak base $(Mg(OH)_2)$ and the strong acid (H_2SO_4). We know that strong acids and bases will almost fully ionise/dissociate, but weak acids/bases will only partially ionise in solution. This means that the ion from the weak base, Mg^{2+}, will undergo hydrolysis with water according to the following reaction:

$$Mg^{2+} + 2H_2O \longrightarrow Mg(OH)_2 + 2H^+$$

The ion now forms $Mg(OH)_2$ in solution, a partially dissociated base, by reacting with the water and leaving H^+ ions in the solution. This means that excess H^+ will affect the neutrality of the solution. If there is an excess of H^+ (H_3O^+) present, the solution will become acidic.

This means that hydrolysis has occurred with the salt in solution causing the solution to become acidic. The salt is thus known as an **acidic salt** because it will increase the acidity of the solution.

In other words, the salt of a strong acid and a weak base will form an **acidic salt** as it will cause hydrolysis to occur making the solution acidic

Example 2

Ethanoic acid reacts with sodium hydroxide to form sodium ethanoate and water according to the following reaction:

$$CH_3COOH + NaOH \longrightarrow CH_3COONa(aq) + H_2O(l)$$

Here the salt CH_3COONa will be found as aqueous ions in solution, that is, dissociated in water

$$CH_3COONa \longrightarrow Na^+(aq) + CH_3COO^-(aq)$$

Consider each ion in solution. These ions come from the strong base $(NaOH)$ and the weak acid (CH_3COOH). We know that strong acids and bases will almost fully ionise/dissociate, but weak acids/bases will only partially ionise/dissociate in solution. This means that the ion from the weak acid CH_3COO^- will undergo hydrolysis with water according to the following reaction:

$$CH_3COO^- + H_2O \longrightarrow CH_3COOH + OH^-$$

The ion now forms CH_3COOH in solution, a partially ionised acid, by reacting with the water and leaving OH^- ions in the solution. This means that excess OH^- ions will affect the neutrality of the solution. If there is an excess of OH^- present, the solution will become basic.

This means that in this example, hydrolysis has occurred with the salt in solution causing the solution to become basic. The salt is thus known as a **basic salt** because it will increase the basic nature of the solution.

In other words, the salt of a strong base and a weak acid will form a **basic salt** as it will cause hydrolysis to occur making the solution basic

Example 3

Hydrochloric acid reacts with sodium hydroxide to form sodium chloride and water according to the following equation:

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

Here the salt $NaCl$ will be aqueous ions in solution, that is, will be dissociated in water.

$$NaCl \longrightarrow Na^+(aq) + Cl^-(aq)$$

Consider each ion in solution. These ions come from a strong base and a strong acid respectively. We already know that strong acids and strong bases almost fully ionise/dissociate in water thus water will not react with these ions. In other words, hydrolysis will not occur and thus there will be no reaction with water to produce any excess in $H^+(H_3O^+)$ or OH^- ions. The salt is thus known as a **neutral salt** because it will not affect the acidic or basic nature of the solution.

In other words, the salt of a strong base and a strong acid will form a **neutral salt** as no hydrolysis will occur.

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.
b. Their purpose is to familiarise the learners with the equation, but not to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Learners must copy the question as well as the solution into their workbook.

1. Explain what is meant by the following terms:
    1.1. Neutralisation reaction
    1.2. Salt
    1.3. Acidic salt
    1.4. Neutral salt

Solution:

1.1. This is a reaction between an acid and a base where the properties of both the acid and the base have been cancelled out.

1.2. The product of an acid-base reaction where the hydrogen in the acid molecule is replaced by the metal cation of the base.

1.3. The salt of a strong acid and a weak base.

1.4. The salt of a strong base and a strong acid

2. Name and give the chemical formulae of the products that are formed when:

2.1. Hydrochloric acid reacts with magnesium oxide

2.2. Nitric acid reacts with potassium carbonate

2.3. Sulfuric acid reacts with sodium hydrogen carbonate

Solution:

2.1.	magnesium chloride and water	$MgCl_2$ and H_2O
2.2.	potassium nitrate and water	KNO_3 and H_2O
2.3.	sodium hydrogen carbonate and water	$NaHCO_3$ and H_2O

3. Write balanced equations for the following acid-base reactions

3.1. Carbonic acid reacts with calcium hydroxide

3.2. Ethanoic acid reacts with sodium oxide

3.3. Sulfuric acid reacts with lithium hydrogen carbonate

3.4. Hydrochloric acid reacts with magnesium sulphate

Solution:

3.1. $H_2CO_3 + Ca(OH)_2 \longrightarrow CaCO_3 + 2H_2O$

3.2. $2CH_3COOH + Na_2O \longrightarrow 2CH_3COONa + H_2O$

3.3. $H_2SO_4 + 2LiHCO_3 \longrightarrow Li_2SO_4 + CO_2 + 2H_2O$

3.4. $2HCl + MgCO_3 \longrightarrow MgCl_2 + CO_2 + 2H_2O$

4. Consider the following salts:

$NaCl$ K_2CO_3 $Ca(NO_3)_2$ NH_4Cl

For each salt:

a) Identify which acid and base they are derived.

b) Will the salt be acidic, basic or neutral.

c) Use a hydrolysis equation to support your answer in 4.2 above.

Solution

$NaCl$: a) Hydrochloric acid (HCl) and sodium hydroxide $(NaOH)$

b) Neutral (salt of a strong acid and a strong base)

c) no hydrolysis occurs as is a neutral salt

K_2CO_3 a) carbonic acid (H_2CO_3) and potassium hydroxide (KOH)

b) basic salt (salt of a strong base and a weak acid)

c) $CO_3^{2-} + H_2O \longrightarrow HCO_3^- + OH^-$

$Ca(NO_3)_2$ a) nitric acid (HNO_3) and calcium hydroxide $(Ca(OH)_2)$

b) acidic salt (salt of a strong acid and a weak base)

c) $Ca^{2+} + 2H_2O \longrightarrow Ca(OH)_2 + 2H^+$

NH_4Cl a) hydrochloric acid (HCl) and ammonia (NH_3)

b) acidic salt (salt of a strong acid and a weak base)

c) $NH_4^+ + H_2O \longrightarrow NH_3 + H_3O^+$

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic questions, they are ready to deal with more challenging questions.

b. These questions require learners to **apply** knowledge.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

1. Ammonium chloride hydrolyses in water to form an acidic solution

   1.1. Give a balance equation to show the dissociation of ammonium chloride in water.

   1.2. Explain why the resultant solution is acidic and include the hydrolysis equation in your answer.

   Solution:

   1.1. $NH_4Cl \longrightarrow NH_4^+(aq) + Cl^-(aq)$

   1.2. NH_4Cl is the salt of a strong acid and a weak base. This means that the ion from the weak base NH_4^+ will hydrolyse with water to produce an acidic solution according to the following equation

   $$NH_4^+ + H_2O \longrightarrow NH_3 + H_3O^+$$

   The presence of the H_3O^+ ions in solution will make the solution acidic

2. Phosphoric acid and potassium hydroxide react together in a reaction flask.

   2.1. Name and write the chemical formula of the salt that is produce in this reaction

   2.2. Write down the balanced equation to show the dissociation of this salt in water.

2.3. Will the salt be acidic, basic or neutral? Using an equation, explain your answer.

Solution:

2.1. potassium phosphate (K_3PO_4)

2.2. $K_3PO_4(s) \longrightarrow 3K^+(aq) + PO_4^{3-}(aq)$

2.3. Basic salt. It is the salt of a strong bas e and a weak base, thus the ion from the weak base, PO_4^{3-}, will hydrolyse with water.

$PO_4^{3-} + H_2O \longrightarrow HPO_4^{2-} + OH^-$

Excess of OH^- ions in solution will produce a basic solution

3. The salt potassium nitrate is found in solution after the reaction between an acid an a base. The aqueous ions in solution are $K^+(aq)$ and $NO_3^-(aq)$.

3.1. What is the parent acid and base that produced this salt?

3.2. Is this an acidic, basic or neutral salt? Explain your answer

Solution:

3.3. nitric acid (HNO_3) and potassium hydroxide (KOH).

3.4. Neutral salt. This is a salt that is made from a strong acid and a strong base thus hydrolysis will not occur in solution.

CHECKPOINT

At this point in the topic, learners should have mastered:

1. The different types of acid-base reactions and the products of these acid-base reactions.
2. How to write a balance acid-base reaction from the given reactants.
3. Being able to identify and name the salt produced in the reaction.
4. What is meant by the term hydrolysis.
5. How to write a hydrolysis equation from the ions in solution to explain hydrolysis.
6. Identify from the chemical structure of a salt whether the salt is acidic, basic or neutral.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Acids and Bases Multiple Choice Questions 1 - 5 and Long Questions 1.1 – 1.12

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

7. THE CONCEPT OF pH

INTRODUCTION

pH and the pH scale are terms that has been widely heard of and often used to talk about the strength of an acid or base. In this sub-topic, learners will be taught to calculate the pH of a solution using both an acid and base.

CONCEPT EXPLANATION AND CLARIFICATION: THE AUTO-IONISATION OF WATER

Learners must be made aware that to understand the concept of pH, they must realise that water once again has to be considered for the important role it plays as a solvent in acid-base chemistry. Pure water is able to under a reaction called **auto-ionisation or self-ionisation** where a water molecule is able to transfer a proton (H^+) to another water molecule in the solvent. The auto/self-ionisation equation is as follows.

$$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$

Learners must see that this is an equilibrium reaction thus the K_C expression for this process may be written as follows:

$$K_C = [H_3O^+].[OH^-]$$

This auto/self-ionisation process is extremely weak and thus the K_C value is a very, very small value of 1×10^{-14}. This value however remains constant at room temperature and is known as the **ionisation constant of water** and is given the symbol K_W. Thus the ionisation expression for water can be written as:

$$K_W = [H_3O^+].[OH^-] = 1 \times 10^{-14} \text{ at room temperature}$$

Learners must now be shown how the ionisation expression for water can be mathematically manipulated based on the balancing number ratio of H_3O^+ and OH^- in the equation which is 1:1. Thus the concentrations of H_3O^+ and OH^- for pure water must be:

$$1 \times 10^{-14} = [H_3O^+].[OH^-]$$

$$\text{therefore } [H_3O^+] = 1 \times 10^{-7} \text{mol.dm}^{-3} = [OH^-]$$

What this means is that in pure water, the concentration of both H_3O^+ and OH^- ions are 1×10^{-7} mol.dm^{-3}.

CONCEPT EXPLANATION AND CLARIFICATION: UNDERSTANDING pH AND pH CALCULATIONS

Why is this important? Learners can now be introduced to the pH scale which was developed by Swedish chemist Soren Sorensen. The **pH scale** is a scale that is used to measure the degree of acidity or basicity of a solution. In other words, a measurable scale to see how acidic or how basic a solution actually is. To calculate the pH of a solution, learners must be introduced to the mathematical equation:

$$pH = -\log[H_3O^+]$$

We say that it is the negative logarithm of the concentration of hydronium ions in solution.

Learners now need to see how this mathematical equation can be used to create the pH scale. Consider pure water that has concentration pf H_3O^+ and OH^- ions exactly equal at 1×10^{-7} mol.dm^{-3}. This is known as the neutral point as the ions would cancel each other out exactly at this concentration. Thus, using the equation:

$$\begin{aligned} pH &= -\log[H_3O^+] \\ &= -\log(1 \times 10^{-7}) \\ pH &= 7 \end{aligned}$$

Here we can see the pH of the neutral point is equal to 7.

If the neutral point is upset, then the pH will change according to the concentration of H_3O^+ ions in solution. Show learners the following examples:

Example 1

Calculate the pH of a solution of HNO_3 with a concentration of $0,01 mol.dm^{-3}$

Solution:

To do the calculation, learners must be able to determine the concentration of the H_3O^+ ions in solution. Write down the ionisation equation of HNO_3 in water:

$$HNO_3 + H_2O \rightleftharpoons H_3O^+ + NO_3^-$$

Here, show the learners that the ratio of $HNO_3 : H_3O^+$ is 1:1. Thus the $[H_3O^+] = 0,001 mol.dm^{-3}$

Substitute into the pH equation; $pH = -\log[H_3O^+]$

$$\begin{aligned} &= -\log(0,01) \\ pH &= 2 \end{aligned}$$

Learners can now see that for acidic substances that the pH is less than 7

Example 2

Calculate the pH of a $NaOH$ solution with concentration of $0,001 mol.dm^{-3}$

Solution:

Once again, to do the calculation, learners must be able to determine the concentration of H_3O^+ ions in the solution. However, if we look at the dissociation equation:

$$NaOH(s) \rightleftharpoons Na^+(aq) + OH^-(aq)$$

It can be seen that only OH^- iosn are released. This is where the ionisation constant of water equation becomes very useful:

$$K_W = [H_3O^+].[OH^-]$$

Here learners can see that there is a link between OH^- ions and H_3O^+ ions. As the

$[NaOH]:[OH^-]$ is 1:1, then the $[OH^-] = 0,001 mol.dm^{-3}$.

Thus, apply the K_W expression:

$$1 \times 10^{14} = [H_3O^+].0,001$$

$$[H_3O^+] = \frac{1 \times 10^{-14}}{0,001}$$

$$[H_3O^+] = 1 \times 10^{-11} mol.dm^{-3}$$

$$\text{There fore } pH = -\log[H_3O^+]$$

$$= -\log(1 \times 10^{-11})$$

$$pH = 11$$

Learners can now see that for basic substance that the pH is greater than 7

In summary:

- Acidic solutions will have $pH < 7$ because $[H_3O^+]$ is greater than $1 \times 10^{-7} mol.dm^{-3}$
- Neutral solutions will have $pH = 7$ because $[H_3O^+]$ is equal to $1 \times 10^{-7} mol.dm^{-3}$
- Basic solution will have $pH > 7$ because $[H_3O^+]$ is less than $1 \times 10^{-7} mol.dm^{-3}$
- The lower the pH, the stronger the acid
- The greater the pH, the stronger the base

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the equation, but not to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

Topic 9: Acids and Bases

1. Explain what is meant by the following terms:

   1.1. Auto-ionisation of water

   1.2. Ionisation constant of water

   1.3. pH

   Solution:

   1.1. This is the process whereby water is able to ionise with itself by transferring a proton (H^+) from one water molecule to another in the solvent.

   1.2. This is the K_W value of water which is determined from the auto-ionistaion of water and has a value of 1×10^{-14}

   1.3. This is the measure of the potency(strength) of the hydronium ion concentration in water

2. What is the ionisation expression for water?

   Solution:

   $K_W = [H_3O^+].[OH^-]$

3. From the ionisation expression of water, what are the concentrations of H_3O^+ and OH^- for pure water?

   Solution:

   $[H_3O^+] = 1 \times 10^{-7} mol.dm^{-3} = [OH^-]$

4. Calculate the pH of a hydrochloric acid solution of concentration $0,105 mol.dm^{-3}$

   Solution:

   $pH = -\log[H_3O^+]$

   HCl is a strong acid, thus will ionise almost completely, therefore $[H_3O^+] : [HCl] = 1 : 1$

   Thus $[H_3O] = 0,105 mol.dm^{-3}$

   $pH = -\log(0,105)$

   $pH = 0,98$

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic questions, they are ready to deal with more challenging questions.

b. b. These questions require learners to **apply** knowledge.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

1. $12,55\text{dm}^3$ of hydrogen chloride gas is bubbled through 250cm^3 of water at room temperature. Assuming complete ionisation of the gas in water:

   1.1. Calculate the concentration of the acid solution.

   1.2. Write down the ionisation equation for the gas dissolving in water.

   1.3. Calculate the pH of the solution produced.

Solution:

1.1. $c = \frac{n}{V}$ now $n = \frac{v}{V_m} = \frac{12,5}{22,4} = 0,56\text{mol of } H_2$ gas

$c = \frac{0,56}{0,25}$

$c = 2,24\text{mol.dm}^{-3}$

1.2. $HCl(g) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$

1.3. $pH = \log[H_3O^+]$

$= -\log(2,24)$ $HCl : H_3O^+ = 1 : 1$

$pH = 0,35$

2. 3,5g of potassium hydroxide is dissolved to make up $1,5\text{dm}^3$ of solution. Assuming complete dissociation of the potassium hydroxide:

   2.1. Calculate the concentration of the KOH solution.

   2.2. Write down the dissociation equation if the potassium hydroxide in water.

   2.3. Calculate the pH of the solution.

Solution:

2.1. $c = \frac{n}{V}$ now $n = \frac{m}{M}$ then $n = \frac{3,5}{56} = 0,0625\text{mol of KOH}$

$c = \frac{0,0625}{1,5}$

$c = 0,0417\text{mol.dm}^{-3}$

2.2. $KOH(s) \longrightarrow K^+(aq) + OH^-(aq)$

2.3. $pH = -\log[H_3O^+]$

Now $K_W = [H_3O^+].[OH^-]$ $[KOH] : [OH^-] = 1 : 1$

$[H_3O^+] = \frac{1 \times 10^{-14}}{0,0417}$

$[H_3O^+] = 2,40 \times 10^{-13}\text{mol.dm}^{-3}$

$pH = -\log(2,40 \times 10^{-13})$

$pH = 12,62$

3. 300cm^3 of a $0,1\text{mol.dm}^{-3}$ solution of sulphuric acid is added to 200cm^3 of a $0,5\text{mol.dm}^{-3}$ solution of NaOH at 25ºC.

   3.1. Calculate the number of moles of sulphuric acid and sodium hydroxide present at the start of the reaction.

   3.2. Write done the balanced chemical equation for thus reaction.

   3.3. Using the mole ratios between H_2SO_4 and NaOH, which of the acid and the base will be in excess, and by how much?

   3.4. Calculate the pH of the solution.

Solution:

3.1. H_2SO_4: $c = \frac{n}{V}$ thus $n = c.V = 0.1 \times \frac{300}{1000} = 0,03\text{mol}$

NaOH: $c = \frac{n}{V}$ thus $n = c.V = 0,5 \times \frac{200}{1000} = 0,1\text{mol}$

3.2. $H_2SO_4 + 2NaOH \longrightarrow Na_2SO_4 + 2H_2O$

3.3. $H_2SO_4 : NaOH$

$1 : 2$

$0,03 : n_b$

number of moles of base required $(n_b) = 0,03 \times 2 = 0,06\text{mol}$ according to the ratio

If there is $0,1\text{mol}$ of $NaOH$ present, then $NaOH$ must be in excess by:

$n_b = 0,1 - 0,06\text{mol}$

$n_b = 0,04\text{mol}$

3.4. $pH = -\log[H_3O^+]$

$= -\log(2,5 \times 10^{-15})$

$K_W = [H_3O^+].[OH^-]$

$[H_3O^+] = \frac{1 \times 10^{-14}}{0,04}$

$[H_3O^+] = 2,5 \times 10^{-15}\text{mol.dm}^{-3}$

CHECKPOINT

At this point in the topic, learners should have mastered:

1. The process of auto-ionisation of water.
2. How to write the K_W expression for water.
3. How to calculate the $[H_3O^+]$ and $[OH^-]$ from the K_W expression.
4. The meaning of pH and the pH scale.
5. How to calculate the pH of an acidic and a basic solution using the pH equation and the K_W equation.

Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Acids and Bases Multiple Choice Questions 1 - 5 and Long Questions 1.1 – 1.12

- Check learners' understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

6. ACID – BASE TITRATIONS AND THE USE OF INDICATORS IN A TITRATION

INTRODUCTION

In this last topic, learners need to be introduced to how we use acid-base reactions to calculate the unknown concentration of an acid or base. This process is known as **standardisation** and we use a technique called a **titration** to do this. Here the learners will use a simple mathematical technique known as volumetric analysis to determine the unknown concentration. We will also introduce how to determine the **equivalence point** of a titration by adding an indicator and how an indicator works to tell us when the end-point of the titration has been reached.

CONCEPT EXPLANATION AND CLARIFICATION: UNDERSTANDING INDICATORS

Before we look at the acid-base titrations, and as mentioned in the introduction, learners need to understand how indicators work and why we use indicators in acid-base reactions. The main purpose of an indicator is to show which substance is an acid and which is a base. Indicators have the ability to change colour in acidic and basic solutions, thus a few drops of indicator to an unknown solution, the specific colour of that indicator will give you the answer. Indicators are also used in acid-base titration to show us when the equivalence point or end-point of a titration has been reached.

Equivalence point/end-point: this is the point in the titration where neither H_3O^+ nor OH^- ions are in excess and the solution is neutral. It is also known as the neutralisation point

At this point, it would be a good idea to explain to explain to the learners a little bit of how indicators work. Explain to the learners that indicators are actually weakly acidic substances that we will represent as HIn for ease of writing it down. Indicators will ionise in water according to the following equation:

$$HIn + H_2O \rightleftharpoons H_3O^+ + In^-$$

yellow blue

If we look at the indicator bromothymol blue and test it in acid and base, bromothymol blue is yellow in acid and blue in base. How do these colour changes occur? Once again, application of le Chatelier's Principle explains this:

1. <u>Bromothymol blue in acidic solution</u>: As the indicator is a weak acid, addition to an acid will increase the concentration of H_3O^+ ions in the system, According to le Chatelier's Principle, the reverse/back reaction will be favoured to counteract the increase in concentration

and thus the formation of HIn will be favoured. This molecule gives a yellow colour to the solution, hence bromothymol blue will be yellow in acid.

2. Bromothymol blue in basic solution: On addition of the indicator, the H_3O^+ ions will react with the OH^- ions of the base reducing the concentration of H_3O^+. According to le Chatelier's Principle, the forward reaction will be favoured to counteract the change in H_3O^+ concentration. This means that the In^- ion will be produced and the solution will turn blue, hence bromothymol blue will be blue in base. .

There are another 2 important facts that learners need to know about indicators in the context of acid-base chemistry.

1. They are very important in acid-base reactions where we can use the indicator to show us the neutralisation point, that is, the point when the H_3O^+ ions are cancelled out by the OH^- ions. Here the indicator will show a colour that is in between what it would be in an acid or a base.
2. Indicators are pH specific thus if hydrolysis occurs on salt formation in an acid-base reaction, the correct indicator must be used depending is the salt is an acidic salt, basic salt or a neutral salt.

Here a table of indicators showing their colours in acid and base as well as the pH range where colour change occurs is useful to give to the learners.

Indicator	Colour in acid	Colour in base	pH range for colour change
Methyl Orange	Orange	Yellow	3,1 – 4,4
Methyl Red	Red	Yellow	4,2 – 6,3
Bromothymol blue	Yellow	Blue	7,0 – 8,8
Phenolphthalein	Colourless	Red	8,3 – 10,0

Thus, for acidic salts : methyl orange and methyl red

for neutral salts : bromothymol blue

for basic salts : phenolphthalein

CONCEPT EXPLANATION AND CLARIFICATION: UNDERSTANDING ACID-BASE TITRATIONS AND ACID-BASE CALCULATIONS

Explain to the learners that the main reason as to why we do acid-base titrations is to determine the unknown concentration of an acid or base that we are working with. This technique is known as **standardisation** which uses an acid or base of known concentration to determine the unknown concentration of the other acid or base present.

All titrations work of the principle of determining the neutralisation point between the reacting acid and base. That is, the point where the H_3O^+ ions from the acid in solution exactly cancel out the OH^- ions from the base in solution. This is also known as the **equivalence point** of the titration and represents equal molar amounts of acid and base reacted. Learners now need to be taught that this equal molar amount of acid and base is determined by the mole ratio as per the balancing numbers of the reaction equation. From there, the unknown concentration of the acid or base may be calculated using a mathematical technique called volumetric analysis. Learners need to know that the following important information is required to perform the calculation:

- known concentration of either the reacting acid or base. This is known as the standard solution in the reaction which means that the concentration of that substance is accurately known. This standard solution concentration is represented by the symbols c_a or c_b.
- The exact volume of the solution that is being standardised, either the acid or the base given the symbols V_a or V_b.
- The mole ratio of acid:base as per the balancing number ratio, given by the symbols n_a or n_b.

From there, a mathematical equation known as the **volumetric equation** is developed to allow the learners to determine the unknown concentration, or any other variable that needs to be calculated.

$$\frac{c_a V_a}{c_b V_b} = \frac{n_a}{n_b}$$

Consider the following worked example:

Example

In a titration, $30,0\,cm^3$ of sulphuric acid is neutralised by exactly $40,0\,cm^3$ of a potassium hydroxide solution of concentration $0,200 mol.dm^{-3}$. Calculate the concentration of the sulphuric acid solution.

Solution:

Step 1: write done the balanced chemical equation for the reaction

$$H_2SO_4 + 2KOH \longrightarrow K_2SO_4 + 2H_2O$$

Step 2: Write a list of variables

$c_a = ?$

$V_a = 30,0\,cm^3$

$c_b = 0,200 mol.dm^{-3}$

$V_b = 40,0\,cm^3$

Step 3: Determine the mole ratio between the two reactants.

H_2SO_4 : KOH

1 : 2

Step 4: Write down and substitute into the volumetric equation

$$\frac{c_aV_a}{c_bV_b} = \frac{n_a}{n_b}$$

$$\frac{c_a(30,0)}{(0,200)(40,0)} = \frac{1}{2}$$

$c_a = 0,133 mol.dm^{-3}$

INTRODUCTORY LEVEL QUESTIONS

a. These are the basic questions that learners will be required to answer at this stage in the topic.

b. Their purpose is to familiarise the learners with content.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the calculation to the learners as you complete it on the chalkboard.
- Learners must copy the question as well as the solution into their workbook.

1. Explain what is meant by the following terms:

   1.1. An indicator

   1.2. Equivalence point

   1.3. Standard solution

   1.4. Standardisation

   Solution:

   1.1. These are substances that show different colours in acidic and basic solution which allows one to determine whether a solution is acidic or basic.

1.2. The point in the titration when the H_3O^+ ions and OH^- ions are cancelled out completely.

1.3. A solution of accurately known concentration.

1.4. The point in the titration when the H_3O^+ ions and OH^- ions are cancelled out completely.

2. What volume of a $0,5 mol.dm^{-3}$ solution of HCl is needed to neutralise $25 cm^3$ of a $0,4 mol.dm^{-3}$ solution of NaOH according to the following balanced equation:

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

Solution:

$c_a = 0,5 mol.dm^{-3}$ $n_a = 1$

$V_a = ?$ $n_b = 1$

$C_b = 0,4 mol.dm^{-3}$

$V_b = 25 cm^3$

$$\frac{c_a V_a}{c_b V_b} = \frac{n_a}{n_b}$$

$$V_a = \frac{n_a c_b V_b}{n_b c_a}$$

$$V_a = \frac{1 \times 0,4 \times 25}{1 \times 0,5}$$

$$V_a = 20 cm^3$$

3. $32,5 cm^3$ of a sulphuric acid solution neutralises exactly $25 cm^3$ of a potassium hydroxide solution of concentration $0,6 mol.dm^{-3}$.

3.1. Write the balanced equation for the reaction.

3.2. Calculate the concentration of the acid solution.

3.3. Name a suitable indicator. Explain you answer.

Solution:

3.1. $H_2SO_4 + 2KOH \longrightarrow K_2SO_4 + 2H_2O$

3.2. $c_a = ?$ $n_a = 1$

$V_a = 32,5 cm^3$

$c_b = 0,6 mol.dm^{-3}$

$V_b = 25 cm^3$

$$\frac{c_aV_a}{c_bV_b}=\frac{n_a}{n_b}$$

$$c_a=\frac{n_ac_bV_b}{n_bV_a}$$

$$c_a=\frac{1\times 0{,}6\times 25}{2\times 32{,}5}$$

$$C_a=0{,}23\text{mol.dm}^{-3}$$

3.3. Bromothymol blue. The salt produced is from a strong acid and a strong base, thus will be a neutral salt. From the table, bromothymol blue is sensitive in the pH range approximately 7,0 – 8,8, thus will indicate in the neutral solution

CHALLENGE LEVEL QUESTIONS

a. Now that learners have mastered the basic calculations, they are ready to deal with more challenging questions.

b. These questions require learners to manipulate the equation to change the subject of the formula.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Ensure that learners copy down both the question and the solution into their workbooks.

1. 12,4 g of $NaOH$ is dissolved in $300\,cm^3$ of water to make up a standard solution. $57\,cm^3$ of this solution is used to neutralise $30\,cm^3$ of ethanoic acid (CH_3COOH).

    1.1. What is meant by the term 'standard solution'?

    1.2. Calculate the concentration of the sodium hydroxide standard solution.

    1.3. Write a balanced equation for the reaction.

    1.4. Calculate the concentration of the ethanoic acid.

1.5. Suggest a suitable indicator for this reaction and explain your choice.

Solution:

1.1. This is a solution of accurately known concentration.

1.2.
$$\begin{array}{lll} c = \frac{n}{V} & n = \frac{m}{M} & M(NaOH) = 23 + 16 + 1 \\ c = \frac{0,31}{0,3} & n = \frac{12,4}{40} & \quad = 40\,g.mol^{-1} \\ C = 1,03 mol.dm^{-3} & n = 0,31 mol & \end{array}$$

1.3. $CH_3COOH + NaOH \longrightarrow CH_3COONa + H_2O$

1.4. $c_a = ?$ $\quad n_a = 1$

$V_a = 30\,cm^3$ $\quad n_b = 1$

$C_b = 1,03 mol.dm^{-3}$

$V_b = 57\,cm^3$

$$\frac{c_aV_a}{c_bV_b} = \frac{n_a}{n_b}$$

$$c_a = \frac{n_ac_bV_b}{n_bV_a}$$

$$c_a = \frac{1 \times 1,3 \times 57}{1 \times 30}$$

$$c_a = 1,96 mol.dm^{-3}$$

1.5. Phenolphthalein – The salt produced is from a weak acid and a strong base, thus will be a basic salt. From the table, phenolphthalein is sensitive in the pH range approximately 8,3 – 10,0, thus will indicate in the neutral solution

2. $50\,cm^3$ of a $0,2 mol.dm^{-3}$ solution of NaOH exactly neutralised $30\,cm^3$ of a sulfuric acid solution.

2.1. Write the balanced equation for the reaction.

2.2. What is the pH of the NaOH solution.

2.3. Calculate the concentration of the sulfuric acid solution.

2.4. What indicator would be suitable and explain your choice.

Solution:

2.1. $2NaOH + H_2SO_4 \longrightarrow Na_2SO_4 + 2H_2O$

2.2. $pH = -\log[H_3O^+]$

$= -\log(5x10^{-14}]$

$= 13{,}3$

$K_W = [H_3O^+].[OH^-]$

$[H_3O^+] = \frac{K_w}{[OH^-]}$

$[H_3O^+] = \frac{1 \times 10^{-14}}{0{,}2}$

$[H_3O^+] = 5 \times 10^{-14}\, mol.dm^{-3}$

2.3. $ca = ?$

$n_a = 1$

$V_a = 30\, cm^3$

$n_b = 2$

$c_b = 0{,}2 mol.dm^{-3}$

$V_b = 50\, cm^3$

$$\frac{c_a V_a}{c_b V_b} = \frac{n_a}{n_b}$$

$$c_a = \frac{(n_a c_b V_b)}{(n_b V_a)}$$

$$c_a = \frac{1x0{,}2x50}{2x30}$$

$$c_a = 0{,}17 mol.dm^{-3}$$

2.4. Bromothymol blue. The salt produced is from a strong acid and a strong base, thus will be a neutral salt. From the table, bromothymol blue is sensitive in the pH range approximately 7,0 – 8,8, thus will indicate in the neutral solution

CHECKPOINT

At this point in the topic, learners should have mastered:

1. The meaning of standardisation and titration.
2. The meaning of the term ‘equivalence point’.
3. What is an indicator and how an indicator is used in acid-base chemistry.
4. The pH sensitivity of different indicators and choosing the correct indicator for a particular type of acid-base titration.
5. The volumetric equation and how to use it to calculate the unknown concentration of an acid or base.

Check learners’ understanding of these concepts by getting them to work through:

Worksheet Pack: Acids and Bases Multiple Choice Questions 1 - 5 and Long Questions 1.1 – 1.12

- Check learners’ understanding by marking their work with reference to the memorandum.
- If you cannot photocopy the memorandum for each learner, make three or four copies of it and place these on the walls of your classroom.
- Allow learners time to mark their own work.
- Encourage the learners to learn from the mistakes they make.

CONSOLIDATION

- Learners can consolidate their learning by completing; Worksheet Pack: Energy Consolidation Exercise.
- Photocopy the exercise sheet for the learners. If that is not possible, learners will need to copy the questions from the board before attempting to answer them.
- The consolidation worksheet should be marked by the teacher so that she/he is aware of each learner’s progress in this topic.
- Please remember that further consolidation should also be done by completing the examples available in the textbook.
- It is important to note that this consolidation exercise is NOT scaffolded.
- It should not be administered as a test, as the level of the work may be too high to in its entirety.

Topic 9: Acids and Bases

ADDITIONAL VIEWING / READING

In addition, further viewing or reading on this topic is available through the following web links:

1. https://www.youtube.com/watch?v=Vbh52HDorkc
   Youtube video on General Properties of acids and bases.
2. https://www.youtube.com/watch?v=7qBRIWSA3Yc
   Youtube video on Lowry-Bronsted conjugate acid-base pairs.
3. https://www.youtube.com/watch?v=HdmCagtasYg
   Youtube video on Lowry-Bronsted theory and neutralisation reactions.
4. https://phet.colorado.edu/en/simulation/ph-scale
   pHet simulation on the pH scale.
5. https://phet.colorado.edu/en/simulation/ph-scale-basics
   pHet simulation on the basics of the pH scale.
6. https://phet.colorado.edu/en/simulation/acid-base-solutions
   pHet simulation on acid-base solutions.