PHYSICAL SCIENCES

Grade 11

TERM 2

Content Booklet

TARGETED SUPPORT

Contents

A Message from the NECT

NATIONAL EDUCATION COLLABORATION TRUST

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). The FSS helped the DBE trial the NECT Maths, Science and language learning programmes so that they could be improved and used by many more teachers. NECT has already begun this scale-up process in its Provincialisation Programme. The FSS teachers remain part of the programme, and we encourage them to mentor and share their experience with other teachers.

Teachers with more experience of 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

PROGRAMME ORIENTATION

Programme Orientation

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

- A Content Booklet: Targeted Support
- A Resource Pack Booklet which consists of worksheets, a guide to formal experiments and/or investigations, formal assessment support.
- A DVD with a video of the formal experiments and/or investigation.
- A set of posters.

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 marking guidelines 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 experiments and/or investigations, together with learners' worksheets and marking guidelines.
9. Providing guidance on how to structure formal assessment tasks.
10. Providing a 'bank' of questions and marking guidelines 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*** that states for how long the topic runs 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 practice 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 teach the words and their meanings explicitly 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 Section of the Resource Pack.
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 modelled 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 Section of the Resource Pack.
      - 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 Section of the Resource Pack. 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.

THE WORKSHEET SECTION OF THE RESOURCE PACK

1. The Worksheet Booklet has different worksheets and corresponding marking guidelines 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 ***marking guidelines*** supplied. Either do this together as a whole class, or display copies of the marking guidelines 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 marking guidelines, so that they fully understand how to answer questions in tests and exams.
5. At the end of each topic, there is a ***consolidation exercise*** and marking guidelines. This worksheet is a consolidation exercise of all the concepts covered in the topic. The consolidation exercise is NOT scaffolded and it is 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 marking guidelines.

THE FORMAL EXPERIMENTS AND/OR INVESTIGATIONS AND DVD

1. The following experiments or investigations 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: Verification of Newton's 2nd Law: 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
     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 experiments and investigations 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 experiment (or investigation) learners' worksheets. Learners should complete the observations and results section of the worksheet while watching the video, and then work on their own to analyse and interpret these as instructed by the questions that follow on the worksheet.

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. **Please note that you will only be given these posters once**. It is important for you to make these posters as durable as possible. Do this by:
    a. Writing your name on all posters
    b. 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 SECTION OF THE RESOURCE PACK

1. A separate Assessment Section is provided for Grade 10, Grade 11 and Grade 12.
2. This section provides you with a ‘bank’ of sample assessment questions for each topic.
3. These are followed by the marking guidelines for all the different questions that details the allocation of marks.
4. The level of cognitive demand is indicated for each question (or part of a question) in the marking guidelines as [CL1] for cognitive level 1 etc.

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 Section of the Resource Pack
   d. 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, 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.

   c. **Finally, 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 Worksheets for the topic, including the Consolidation Exercise.
      - Make notes in your Planner & Tacker to show where you will include the targeted support teaching and activities. You may choose to replace some textbook activities with work from the targeted support programme, but, be careful not to leave anything out!

   d. **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.

e. 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 practice exercises for each key concept.
- Time to correct and remediate each key concept.
- Time for a consolidation exercise.

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 PREPARATION

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:

ORIENTATION

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:

Creating a Positive Learning Environment

The best learning takes place when learners feel safe and confident enough to participate. It is up to you, as the teacher, to create the kind of atmosphere that will promote discussion and learning. Below are some tips to help you with this important challenge:

1. **Work constantly to create the atmosphere that you want.** It takes time for teachers and learners to understand and adopt the behaviours required for a safe, positive classroom. Don't give up if it doesn't happen straight away – keep working towards creating a feeling of emotional safety in your classroom.

2. **Take an interest in learners' work.** Most of the time, you will probably get learners to correct their own work, either by working through the solutions on the chalkboard, or by posting up the marking guidelines for learners to see. However, it is a good idea to look through learners' exercise books from time to time. This allows you to verify that your learners are doing their work, and are on track. It is also a time for you to show interest in learners' progress. Tell learners when you are pleased or impressed with their progress or efforts. This shows learners that you are interested, supportive, and that you value their work.

3. **Establish and implement ground rules.** Work out a set of ground rules for your classroom – it is a good idea to do this together with the learners.
   - Tell learners that you need a set of ground rules to set the tone for the classroom, and to manage how you work together.
   - Ask learners to contribute their ideas for the ground rules. As a learner makes a suggestion, write it down. Do not reject anyone's suggestion at this point.
   - When everyone has contributed their ideas, read through the list together. Eliminate duplicate ideas. If there are key rules missing, ask prompting questions, to try and get learners to suggest them.
   - Finally, ask learners if they are all prepared to accept and live by these rules. If there is a rule that needs to be adjusted or removed, do so. Make it clear that these are their rules, and that they have accepted them, and must therefore abide by them.
   - Also talk to learners about self-moderation. This means that you accept that they are young adults, and that they should not need a teacher to tell them how to behave. By this stage of their lives, they should be able to assess if their behaviour is out-of-line, and to adjust or self-moderate their behaviour.
   - Whilst you should expect learners to self-moderate their behaviour by the FET stage, if a learner behaves really badly, particularly in a way that makes another learner feel bad or unsafe, you need to implement consequences.
   - Learners need to know that you will take action against harmful behaviour. If you do not do this, it will be difficult for learners to trust you.

4. **Correct mistakes clearly, but without derision.** When learners make mistakes, thank them for trying, but point out that a mistake has been made. Correct the mistake clearly and quickly, and then move on. Do not labour the point – learners must see that it is perfectly acceptable to make mistakes as long as one tries.

5. **Tell learners if you do not know something.** Learners appreciate it when teachers are honest, and say things like, 'I'm not really sure. Does anyone else know? Should we look up the answer?'

6. **Model the kind of behaviour you expect in your class.** We often hear the phrase 'respect is earned', or 'respect is a two-way street', but we don't always think about what that means.
   - The simplest explanation is to model the behaviour that you expect from your learners, and to treat them the way that you want to be treated.
   - Be punctual and prepared for lessons; work diligently; keep your space clean, tidy and organised; never use your cell phone in class; look after your apparatus and resources; greet learners; be considerate of their feelings; praise learners for a job well done; thank learners for going the extra mile; and go the extra mile yourself.
   - This may not be reciprocated immediately, but in time, learners will learn from your model, and will begin to behave as you do within your environment.
   - Feel free to hold an open, honest discussion with learners about this concept. Let learners know that you will try to always treat them with consideration and respect, and that you will always work hard for them.
   - Let your learners know that you will appreciate them trying to do the same.

7. **Move around the classroom.** As learners work, walk around the classroom. Use this opportunity to stop and look at individual learner's work. Stop and discuss challenges – help individual learners as much as you can. Look out for problems between learners, and deal with issues that arise. Get to know your learners better. If tension is building between learners, put a stop to the argument. Then, if appropriate, find time for the learners to talk it out while you mediate.

8. **Laugh with your learners.** If you can find something to laugh about with your learners, do so! This is an excellent way to bond with learners, and to make them feel closer to you. Laughter is also an excellent way to break down tensions, and to get learners to relax.

9. **Leave your problems outside of the classroom.** Learners pick up on your stress, anxiety and unhappiness, and this can affect them negatively. Try your best to be in the habit of leaving your problems at the classroom door, and to focus on your learners once you are inside the classroom.

10. **Praise your learners for their efforts.** This is one of the easiest and most effective behaviours that you can implement.
    - Praise learners not for their achievements, but for their efforts. This will encourage learners to try and do more.
    - This is known as building a 'growth mindset'. This means that learners believe that they can learn and progress.
    - The opposite of a growth mindset is a 'fixed mindset', where learners believe they are born with a certain ability, and that they cannot change this.

TOPIC 2:
Momentum and Impulse

A Introduction

- This topic runs for 13 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Momentum and Impulse forms part of the content area Mechanics (Physics).
- Mechanics counts 42 % in the final Paper 1 Examination (Physics).
- Momentum and Impulse counts approximately 10% of the final Paper 1 Examination (Physics).

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.
2. Chalk.
3. Grade 12 Physics Examination Data Sheet.
4. Materials for prescribed experiment: Air-track with blower. Two trolleys, pulley, two photogates, two retort stands, dual timer, metre-stick, black card, set of equal weights OR Two spring-loaded trolleys, stop-watch, meter-stick, two barriers.
5. Materials for informal assessment: Newton's Cradle.

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 KNOWLEDGE
GRADE 10	**GRADE 11**	**GRADE 12**
• Vectors and scalars • Motion in one dimension • Instantaneous velocity and the equations of motion • Graphs of motion	• Newton's Laws and Application of Newton's Laws.	• Momentum • Newton's second law expressed in terms of momentum • Conservation of momentum and Elastic and Inelastic collisions • Impulse

C Glossary of Terms

TERM	DEFINITION
Momentum	The product of an object's mass and its velocity.
Newton's second law in terms of momentum	The net (or resultant) force acting on an object is equal to the rate of change of momentum of the object in the direction of the net force.
The law of conservation of linear momentum	The total linear momentum of an isolated system remains constant (is conserved).
Impulse	The product of the net force acting on an object and the time the net force acts on the object.
A system	A group of two or more objects that interact is called a system.
Internal forces	The forces between objects found inside the system (e.g. action-reaction pairs of forces).
External force	The forces from objects found outside the system (e.g. a frictional force).
Isolated system	An isolated system is one on which the net external force acting on the system is zero.
Elastic collision	A collision in which kinetic energy <u>is</u> conserved. Momentum is also conserved.
Inelastic collision	A collision in which kinetic energy <u>is not</u> conserved. Momentum is conserved.

D Assessment of this Topic

- This topic is assessed by informal and control tests, as well as in the midyear, preliminary and the final 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.
- Prescribed Experiment for formal assessment: *Verify the Conservation of Linear Momentum.*

E Breakdown of Topic and Targeted Support Offered

TIME ALLOCATION	SUB-TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
2 hours	Momentum	99	**a.** The use of signs to represent the direction of momentum and change in momentum vectors. **b.** Calculation of momentum and change in momentum.
2 hours	Newton's second law expressed in terms of momentum	99	**a.** Applying the law of conservation of linear momentum to various types of collisions. **b.** Explanation of elastic and inelastic collisions and the necessary practice that is needed.
5 hours	Conservation of momentum and Elastic and Inelastic collisions.	100	**a.** Explanation of impulse and the impulse-momentum theorem. **b.** Applying the impulse-momentum theorem to various types of collisions.
4 hours	Impulse	101	**a.** Explanation of impulse and the impulse-momentum theorem. **b.** Applying the impulse-momentum theorem to various types of collisions.

F Targeted Support per Sub-topic

1. MOMENTUM

INTRODUCTION

We will eventually express Newton's second law in terms of momentum. In this sub-topic we learn about the momentum vector and that the momentum of an object will change when a net force acts on an object.

CONCEPT EXPLANATION AND CLARIFICATION

Definition of momentum (p): The product of an object's mass and its velocity.

The momentum of an object (p) is calculated by using: $p = mv$ where m is the mass of the object (measured in kg) and v is the velocity of the object (measured in m·s^{-1}).

Remember that velocity (v) is a vector quantity. **Momentum (p) is also a vector quantity**. The momentum vector should be correctly expressed with a magnitude, a unit and a direction.

The ***direction*** of the momentum vector is the same as the ***direction of the velocity vector***. In other words, the direction in which an object is moving **IS** the direction of the momentum vector.

The ***unit*** of momentum is : $p = mv = kg \cdot m \cdot s^{-1}$ (stated as "kilograms metres per second")

Ask your learners to consider a car and a bus moving with the same velocity. Which of the vehicles has the greater momentum? The bus has a larger mass and therefore a greater momentum. If the bus is at rest, then the momentum of the bus is zero. Objects at rest have zero momentum because they have zero velocity.

Work through the following example with your learners:

A blue whale of mass 150 000 kg is moving east through the water at 2 m·s^{-1}. A dolphin of mass 150 kg is moving west at 12 m·s^{-1}. Calculate the momentum of each animal.

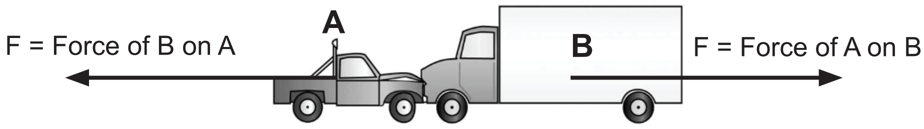
Choose east as positive:

Blue whale: $p = mv = (150\,000)(+2) = +300\,000 = 3{,}0\ \mathrm{kg \cdot m \cdot s^{-1}}$ east

Dolphin: $p = mv = (150)(-12) = -1\,800 = 1\,800\ \mathrm{kg \cdot m \cdot s^{-1}}$ west

What happens during a collision?

When a small truck **A** collides with a large truck **B**, the small truck exerts a force F on the large truck. According to Newton's third law, the large truck will exert a force **equal** in magnitude but opposite in direction on the small truck F as shown in the diagram below.



The forces that act on each object during a collision, only act for a short time interval and they ***change the momentum of each object***.

The ***velocity*** of each truck ***will change*** during the collision. It could slow down rapidly (decrease in velocity) or even bounce backwards (change the direction of its velocity).

Remember: According to Newton's second law, when a net force acts on an object it will accelerate.

When an object accelerates, its ***velocity will CHANGE***. If the velocity of the object is changing, then its ***momentum will CHANGE***.

Change in momentum $\triangle p$

In everyday situations, almost no object has a constant momentum because its velocity is usually not constant. Friction slows objects down, objects such as aeroplanes accelerate down runways and vehicles are involved in collisions.

Ask your learners to provide examples of situations in which the ***momentum*** of the object is ***changing***. Examples include:

A car collides into a wall and comes to rest.

A tennis ball is moving towards a player and the ball is hit back in the opposite direction.

A car travels at the same speed, BUT if its direction changes then its momentum is changing.

What causes the object's momentum to change? When a **net force** acts on an object, its momentum will change.

The ***change in momentum*** $(\triangle p)$ of an object is calculated by subtracting its initial momentum (p_i) ***from*** its final momentum (p_f) :

$\triangle p = p_f - p_i$

$\boldsymbol{\triangle p = mv_f - mv_i}$

where:

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

v_i is the initial velocity of the object immediately before the collision (measured in m·s^{-1})

v_f is the final velocity of the object immediately after the collision (measured in m·s^{-1})

TOPIC 2

Momentum is a VECTOR quantity. CHANGE in momentum Δp is also a VECTOR quantity.

A tennis ball with a mass of 60 g is travelling horizontally at 15 m·s⁻¹. The ball is struck by a racquet and moves horizontally at 20 m·s⁻¹ in the opposite direction. What is the magnitude and direction of the change in momentum of the tennis ball?

Train your learners to always <u>draw a labelled diagram</u> of the problem:

Since velocity and momentum are vectors, we need to make a choice of direction:

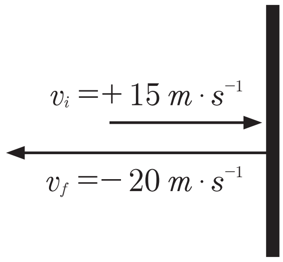
Choose towards the racquet as positive:

$\Delta p = mv_f - mv_i$

$\Delta p = (0{,}06)(-20) - (0{,}06)(+15)$

$\Delta p = -1{,}2 - 0{,}9$

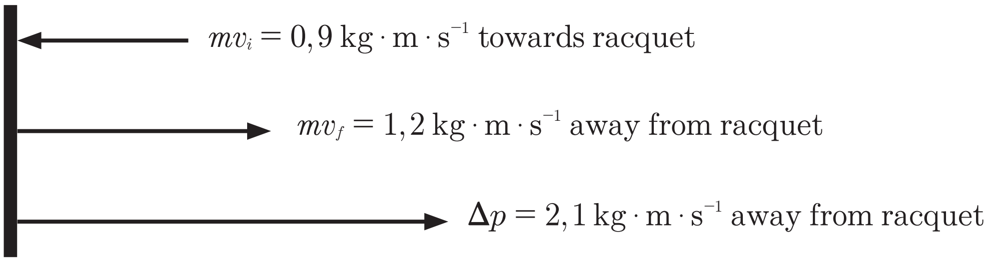
$\Delta p = -2{,}1$



The negative sign indicates the <u>direction</u> of the <u>change in momentum</u> of the ball (away from the racquet).

$\therefore \Delta p = 2{,}1\ \text{kg} \cdot \text{m} \cdot \text{s}^{-1}$ away from the racquet

Get your learners to draw each momentum vector as shown below:



During the collision with the racquet, the momentum of the ball ***decreased*** in magnitude from 0,9 kg·m·s⁻¹ to ZERO and then the momentum of the ball increased from ZERO to 1,2 kg·m·s⁻¹ in the opposite direction.

The momentum of the ball changed ***in magnitude*** by 2,1 kg·m·s⁻¹. The direction of the change in momentum is "away from the racquet". **The direction of the change in momentum of an object is the SAME as the direction of the net force acting on that object.**

INTRODUCTORY LEVEL QUESTIONS

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

b Learners should make a choice of direction and apply this choice to direction of velocity, momentum and change in momentum vectors.

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 down the question and answer it correctly in their workbooks.

1. Define momentum.

2. A 700 kg car has a constant velocity of 3 m·s^{-1} west.

2.1 Calculate the magnitude and direction of the momentum of the car.

2.2 What is the momentum of the car while travelling east at double the speed?

2.3 By what factor would the momentum of the car change if its mass was doubled?

2.4 By what factor would the momentum of the car change if its speed was halved?

3. During a football training session, a player passes a soccer ball of mass 0,43 kg along the ground to his goalkeeper. The ball rolls at 3 m·s^{-1} towards the goalkeeper and he immediately kicks it straight back towards the player. The ball leaves the goalkeeper's boot with a speed of 5 m·s^{-1}. Ignore any effects of friction.

3.1 Calculate the initial and final momentum of the soccer ball.

3.2 Calculate the change in momentum of the soccer ball.

3.3 Draw a labelled momentum vector diagram to illustrate the initial, final and change in momentum vectors for the soccer ball.

Solutions

1. The product of the mass and velocity of an object.

2. **2.1** Choose west as positive: $p = mv = (700)(+3) = +2\,100 = 2\,100\ \text{kg}\cdot\text{m}\cdot\text{s}^{-1}$ west

2.2 $p = mv = (700)(-6) = -4\,200 = 4\,200\ \text{kg}\cdot\text{m}\cdot\text{s}^{-1}$ east

2.3 $p = mv$

$p_{new} = (2m)v = 2(mv) = 2p$ Momentum will double

2.4 $p_{new} = m\left(\frac{1}{2}v\right) = \frac{1}{2}(mv) = \frac{1}{2}p$ Momentum is halved

3. **3.1** Choose towards goalkeeper as positive:

$p_i = mv_i = (0,43)(+3) = 1,29\ \text{kg} \cdot \text{m} \cdot \text{s}^{-1}$ towards goalkeeper

$p_f = mv_f = (0,43)(-5) = -2,15 = 2,15\ \text{kg} \cdot \text{m} \cdot \text{s}^{-1}$ away from goalkeeper

3.2 $\Delta p = mv_f - mv_i$

$\Delta p = (0,43)(-5) - (0,43)(+3)$

$\Delta p = -2,15 - 1,29$

$\Delta p = -3,44$

$\Delta p = 3,44\ \text{kg} \cdot \text{m} \cdot \text{s}^{-1}$ away from goalkeeper

3.3 $\longleftarrow$ $mv_i = 1,29\ \text{kg} \cdot \text{m} \cdot \text{s}^{-1}$ towards goalkeeper

$\longrightarrow$ $mv_f = 2,15\ \text{kg} \cdot \text{m} \cdot \text{s}^{-1}$ away from goalkeeper

$\longleftarrow$ $\Delta p = 3,44\ \text{kg} \cdot \text{m} \cdot \text{s}^{-1}$ away from goalkeeper

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 be creative and to think independently about possible solutions.

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 the question and answer it correctly in their workbooks.

KEY TEACHING

a. In these more challenging examples, learners must make a choice of direction.

b. Velocity and momentum are vectors, therefore a ***sign*** and a ***magnitude*** are important when substituting into an equation.

c. Change in momentum (Δp) is a vector, therefore the sign should be interpreted as a direction.

d. Train your learners to draw a diagram of the motion before and after the collision to better understand the problem.

4. A 0,2 kg ball is dropped and hits the ground with a speed of 6 m·s^{-1}. The ball bounces upwards with a speed of 4 m·s^{-1}. Calculate the change in momentum of the ball.

5. A bullet of mass 20 g is fired from a rifle. The bullet passes through a plank of wood while travelling east. Its speed decreases from 300 m·s^{-1} before it hit the plank to 180 m·s^{-1} as it emerges out of the other side of the plank. Calculate:

5.1 The initial momentum of the bullet.

5.2 The final momentum of the bullet.

5.3 The change in momentum of the bullet.

6. During launch, the momentum of a rocket increases by a factor of 3 while its mass is halved. The velocity of the rocket is initially 20 m·s^{-1} upwards. What is the final velocity of the rocket?

7. During a crash test, car A of mass *m* travelling with speed 3*v* collides with a wall and bounces off the wall with a speed *v*. Car B of mass 3*m* travelling with speed *v* collides with the wall and is brought to rest. Which car experiences the greatest change in momentum? Explain your answer.

TOPIC 2

Solutions

4. Choose down as positive:

$\Delta p = mv_f - mv_i$

$\Delta p = (0,2)(-4) - (0,2)(+6)$

$\Delta p = -0,8 - 1,2$

$\Delta p = -2$

$\Delta p = 3,44 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$ upwards

5.1 Choose east as positive:

$p_i = mv_i = (0,02)(+300) = 6 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$ east

5.2 $p_f = mv_f = (0,02)(+180) = 3,6 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$ east

5.3 $\Delta p = mv_f - mv_i$

$\Delta p = 3,6 - 6$

$\Delta p = -2,4$

$\Delta p = 2,4 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1}$ west

6. $p_i = mv_i = m(20) = 20\,m$

$p_f = \left(\frac{1}{2}m\right)v_f = 3p_i = 3(20m) = 60m$

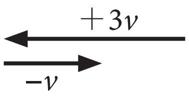
$\left(\frac{1}{2}m\right)v_f = 60m$

$\frac{1}{2}v_f = 60$

$v_f = 120 \text{ m} \cdot \text{s}^{-1}$ upwards

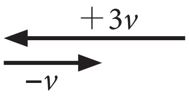
7. Choose towards the wall as positive:

Car A: *m*



$\Delta p = mv_f - mv_i$
$\Delta p = m(+3v) - m(-v)$
$\Delta p = 3mv + mv = 4mv$

Car B: 3*m*



$\Delta p = mv_f - mv_i$
$\Delta p = 3m(+v) - m(0)$
$\Delta p = 3mv$

Car A experiences the greatest change in momentum

CHECKPOINT

1. The calculation of momentum as a vector quantity.
2. The calculation of change in momentum as a vector quantity.
3. Drawing initial, final and change in momentum vectors.

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

Worksheet Pack: Momentum and Impulse 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 time for feedback.
- Encourage the learners to learn from the mistakes they make.

2. NEWTON'S SECOND LAW EXPRESSED IN TERMS OF MOMENTUM

INTRODUCTION

In reality, the net force acting on an object during a collision is not constant. It is therefore difficult to measure the average net force. It is easier to measure the velocity of an object before and after the collision. We therefore need to express Newton's second law in terms of momentum.

CONCEPT EXPLANATION AND CLARIFICATION

Get your learners to recall the statement of Newton's second law:

Newton's second law: When a net force is applied to an object of mass, *m*, it accelerates in the direction of the net force. The acceleration (*a*) is directly proportional to the net force and inversely proportional to the mass.

Work through the following derivation step by step with your learners:

The equation for Newton's second law is: $F_{net} = ma$ (1)

When a net force acts on an object it will accelerate. Get your learners to recall the definition of acceleration: Acceleration is the rate of change of velocity.

The equation for acceleration is: $a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t}$ (2)

Explain that when we substitute equation (2) into (1) we get:

$$F_{net} = m\left(\frac{v_f - v_i}{\Delta t}\right)$$

But we already know that: $\Delta p = mv_f - mv_i$

Newton's second law becomes: $F_{net} = \frac{\Delta p}{\Delta t}$

This is Newton's second law expressed in terms of momentum.

Newton's second law: The net force acting on an object is equal to the rate of change of momentum of the object in the direction of the net force.

where: F_{net} is the net force acting on the object (measured in N).

Δp is the change in momentum of the object (measured in kg·m·s^{-1}).

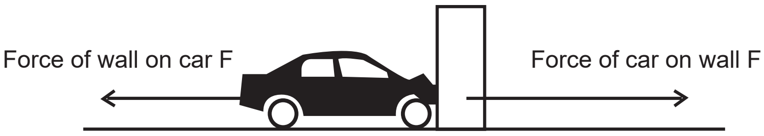
Δt is the time interval over which the momentum of an object changes, or the length of time for which the net force acts (measured in s).

Discuss and explain the following ***types of motion*** with your learners:

1. **An object is travelling forward and is involved in a collision.**

For example, in a crash test, a car of mass 900 kg is travelling east at 10 m·s^{-1} when it collides with a wall and comes to rest. The collision lasts for **1,2 s**.

The car exerts a (forward) force F on the wall.
According to Newton's third law, the wall exerts an equal (backward) force F on the car.



If we ignore friction during the collision, then this ***backward*** force F on the car is the ***net force*** acting on the car.

The momentum of the car will ***change*** (decrease) in a ***short time interval*** of **1,2 s**.

If we choose east to be positive:

The change in momentum of the car is:

$$\begin{aligned}\Delta p &= mv_f - mv_i \\ \Delta p &= (900)(0) - (900)(+10) \\ \Delta p &= 0 - 9\,000 \\ \Delta p &= -9\,000 \\ \Delta p &= 9\,000\ \text{kg}\cdot\text{m}\cdot\text{s}^{-1}\ \text{west}\end{aligned}$$

The momentum of the car has decreased by 9 000 kg·m·s^{-1}.

The ***rate*** at which the ***momentum*** of the car is ***changing*** is:

$$\frac{\Delta p}{\Delta t} = \frac{9\,000\ \text{kg}\cdot\text{m}\cdot\text{s}^{-1}}{1{,}2s}$$
$$\frac{\Delta p}{\Delta t} = -7\,500\ \text{kg}\cdot\text{m}\cdot\text{s}^{-2}$$

In other words, the momentum of the car is <u>decreasing</u> at 7 500 kg·m·s^{-1} **per second**.

This is the average ***net*** backward ***force*** acting on the car: $F_{net} = -7\,500$
$= 7\,500\ \text{N west}$

2. An object is travelling forward and is struck from behind.

For example, a car of mass 900 kg is travelling east at 5 m·s^{-1} when hit from behind by another vehicle. The 900 kg car moves at 9 m·s^{-1} east after the collision. The collision lasts for **0,8 s**.

If we ignore friction during the collision, then this <u>**forward**</u> force F on the car is the <u>**net force**</u> acting on the car.

The momentum of the car will ***change*** (increase) in a ***short time interval*** of **0,8 s**.

If we choose forward to be positive:

The change in momentum of the car is:

$$\begin{aligned}\Delta p &= mv_f - mv_i \\ \Delta p &= (900)(+9) - (900)(+5) \\ \Delta p &= 8\,100 - 4\,500 \\ \Delta p &= 3\,600\ \text{kg}\cdot\text{m}\cdot\text{s}^{-1}\ \text{east}\end{aligned}$$

The momentum of the car has ***increased*** by 3 600 kg·m·s^{-1}.

The ***rate*** at which the ***momentum*** of the car is ***changing*** is: $\frac{\Delta p}{\Delta t} = \frac{3\,600\ \text{kg} \cdot \text{m} \cdot \text{s}^{-1}}{0{,}8\ \text{s}}$

$$\frac{\Delta p}{\Delta t} = 4\,500\ \text{kg} \cdot \text{m} \cdot \text{s}^{-2}$$

In other words, the momentum of the car is ***increasing*** by 4 500 kg·m·s^{-1} **per second**.

This is the average ***net*** forward ***force*** acting on the car: $F_{net} = 4\,500$ N east

The momentum of an object will only change when a net force acts on that object.

INTRODUCTORY LEVEL QUESTIONS

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

b Learners should make a choice of direction and identify the initial velocity before the collision and the final velocity after the collision.

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 down the question and answer it correctly in their workbooks.

1. A bullet of mass 30 g is fired from a rifle. The bullet leaves the rifle with a speed of 1 200 m·s^{-1} travelling east. The bullet is in the barrel for 0,02 s.

1.1 Calculate the change in momentum of the bullet.

1.2 Calculate the average net horizontal force acting on the bullet while being fired.

1.3 What is the average net horizontal force acting on the rifle? Explain your answer.

2. A bullet (mass 30 g) travelling horizontally at 400 m·s^{-1} east hits a stationary wooden block of mass 10 kg. The bullet becomes embedded in the wooden block. The block and bullet move east at 3 m·s^{-1} after the collision. The collision lasts for 0,05 s.

2.1 Calculate the average net horizontal force acting on the bullet during the collision.

2.2 What is the average net horizontal force acting on the wooden block during the collision?

Solutions

1.1 Choose east as positive:

$\Delta p = mv_f - mv_i$

$\Delta p = (0,030)(+1\,200) - (0,030)(0)$

$\Delta p = 36 - 0$

$\Delta p = 36 \text{ kg} \cdot \text{m} \cdot \text{s}^{-1} \text{ east}$

1.2 $F_{net} = \dfrac{\Delta p}{\Delta t}$

$F_{net} = \dfrac{mv_f - mv_i}{\Delta t}$

$F_{net} = \dfrac{+36}{0,02}$

$F_{net} = 1\,800 \text{ N east}$

1.3 The rifle exerts a forward force F on the bullet. According to Newton's third law, the bullet exerts an equal backward force F on the rifle. If there are no other forces present, the average net horizontal force on the rifle is 1800 N west.

2.1 $F_{net} = \dfrac{\Delta p}{\Delta t}$

$F_{net} = \dfrac{mv_f - mv_i}{\Delta t}$

$F_{net} = \dfrac{(0,030)(+3) - (0,030)(+400)}{0,05}$

$F_{net} = \dfrac{0,09 - 12}{0,05}$

$F_{net} = -238,20$

$\therefore F_{net} = 238,2 \text{ N west}$

2.2 According to Newton's third law, the net force on the wooden block is:

$F_{net} = 238,20 \text{ N east}$

CHALLENGE LEVEL QUESTIONS

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

How to tackle these questions in the classroom:

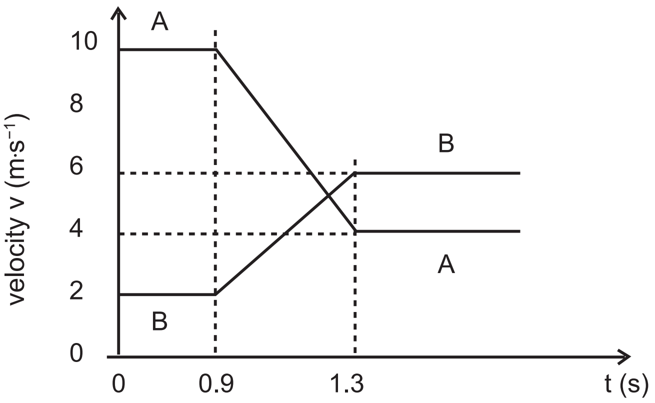
- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' 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 the question and answer it correctly in their workbooks.

3. A stuntman of mass 75 kg falls from a helicopter and lands on an airbag. He is travelling downwards at 45 $m \cdot s^{-1}$. He collides with the airbag and comes to rest in 0,25 s.

3.1 Calculate the average net force acting on the stuntman during the collision.

3.2 Determine the acceleration of the stuntman during the collision.

4. Railway carriage A, of mass 20 000 kg, crashes into the back of railway carriage B which is travelling in the same direction as A on a straight level track. The graph shows how the velocity of each railway carriage varies with time.



Ignore frictional forces between the railway carriages and the track during the collision. Ignore air resistance.

4.1 Calculate the magnitude of the change in momentum of railway carriage A between 0,9 s and 1,3 s.

4.2 Calculate the average net force experienced by railway carriage A between 0,9 s and 1,3 s.

4.3 Calculate the mass of railway carriage B.

Solutions

3.1 Choose down as positive:

$$F_{net} = \frac{\Delta p}{\Delta t}$$

$$F_{net} = \frac{mv_f - mv_i}{\Delta t}$$

$$F_{net} = \frac{(75)(0) - (75)(+45)}{0,25}$$

$$F_{net} = \frac{0 - 3\,375}{0,25}$$

$$F_{net} = -13\,500$$

therefore $F_{net} = 13\,500$ N upwards

3.2 Choose forward as positive:

$$F_{net} = ma$$

$$a = \frac{F_{net}}{m} = \frac{-13\,500}{80} = 168,75$$

therefore, a = 168,75 m·s^{-2} upwards

4.1 Choose forward as positive:

$$\Delta p = mv_f - mv_i$$

$$\Delta p = (20\,000)(+4) - (20\,000)(+10)$$

$$\Delta p = 80\,000 - 200\,000$$

$$\Delta p = -120\,000$$

therefore $\Delta p = 120\,000$ kg·m·s^{-1} opposite to direction of motion

4.2 $$F_{net} = \frac{\Delta p}{\Delta t}$$

$$F_{net} = \frac{-120\,000}{0,4}$$

$$F_{net} = -300\,000$$

therefore $F_{net} = 300\,000$ N backwards

4.3 Since friction is ignored and according to Newton's third law, Carriage B experiences a net forward force of the same magnitude as that on A.

$$F_{net} = \frac{\Delta p}{\Delta t}$$

$$+300\,000 = \frac{m(+6) - m(+2)}{0,4}$$

$$300\,000 = \frac{4m}{0,4}$$

$$4m = (300\,000)(0,4)$$

$$m = 3\,000 \text{ kg}$$

CHECKPOINT

At this point in the topic, learners should have masteredthe following skills:

1. The calculation of momentum and change in momentum.
2. Use + and – signs to specify the direction of initial and final velocities.
3. Interpreting the sign of a final answer.
4. Stating Newton's second law expressed in terms of momentum.
5. The calculation of the average net force on an object using Newton's second law expressed in terms of momentum.
6. Know that when a net force acts on an object, the momentum of the object will change.

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

Worksheet Pack: Momentum and Impulse 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 time for feedback.
- Encourage the learners to learn from the mistakes they make.

3. CONSERVATION OF LINEAR MOMENTUM AND ELASTIC AND INELASTIC COLLISIONS

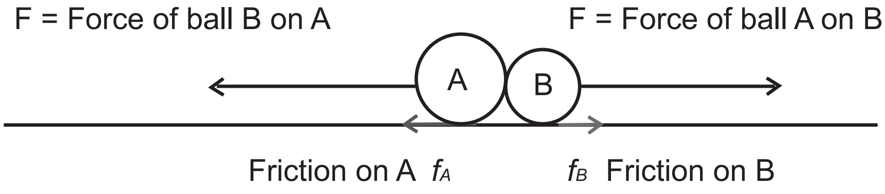
INTRODUCTION

At this point in the topic you should explain what an isolated system is and how we apply the law of conservation of momentum to both elastic and inelastic collisions.

CONCEPT EXPLANATION AND CLARIFICATION

A group of two or more objects that interact is called a **<u>system</u>**. Ask your learners to think of examples of a system. Two balls collide on a pool table, two cars collide on a tar road, a rocket fires its engines in deep space and a hunter firing a bullet from his rifle.

A system of colliding objects will experience horizontal forces that will change the momentum of each object, as shown below:



One force is ***friction*** and the other is the force due to the actual collision (e.g. the force of A on B).

Keep reminding your learners of the following fact:

During a collision object A exerts a force (F) on object B. According to Newton's third law, object B exerts an equal force on object A in the opposite direction.

These action-reaction forces exerted by the objects on each other during the collision are known as ***internal forces***.

Internal forces are forces between objects found inside the system.

An ***external force*** such as friction also acts on each object during the collision. Since the actual collision time is *very short*, the effect of friction on the change in momentum of the colliding bodies is very small and can be ignored. Friction or other external forces also become negligible because the force of impact is so large in comparison to these external forces.

External forces are forces from objects found outside the system.

When the mass of a system is constant and no net external force acts on the system, the system is said to be ***isolated***. An isolated system is defined as a system on which the net external force acting on the system is zero.

If a net external force acts on a system of colliding bodies, then the ***total momentum*** of the system WILL CHANGE during the collision.

If we **IGNORE all external forces**, then the ***total momentum*** of the system **WILL NOT CHANGE**.

This means that the total momentum of an *isolated system* WILL NOT change during a collision.

For this to be true, the total momentum of the colliding objects *immediately before* the collision/explosion must be equal to the total momentum of the colliding objects *immediately after* the collision/explosion. This leads us to the statement of the law of conservation of momentum.

3.1 The law of conservation of linear momentum

Write the law of linear conservation of momentum on the board.

Law of conservation of linear momentum: The total linear momentum of an isolated system remains constant (is conserved).

Suppose two objects A and B collide, then the total momentum immediately ***before*** the collision is the ***vector sum*** of the individual momenta of object A and B:

$$p_{before} = p_A + p_B = m_A v_{Ai} + m_B v_{Bi}$$

The total momentum immediately ***after*** the collision is the ***vector sum*** of the individual momentum of object A and B after the collision:

$$p_{after} = p_A + p_B = m_A v_{Af} + m_B v_{Bf}$$

In an isolated system, linear momentum is conserved:

$$\varepsilon p_{before} = \varepsilon p_{after}$$

$$m_A v_{Ai} + m_B v_{Bi} = m_A v_{Af} + m_B v_{Bf}$$

Work through the following three introductory questions with your learners to develop their ability to apply the law of conservation of momentum to colliding bodies.

INTRODUCTORY LEVEL QUESTIONS

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

b. Their purpose is to familiarise the learners with the law of conservation of momentum.

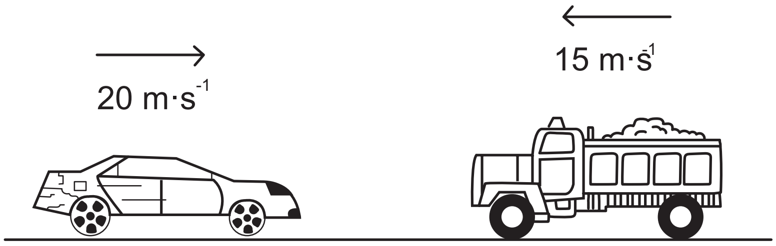
How to tackle these questions in the classroom:

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

TOPIC 2

1 Objects collide and stick together

The diagram below shows a car of mass 800 kg travelling at 20 m·s⁻¹ east and a truck of mass 1 500 kg travelling at 15 m·s⁻¹ west on the same road. Ignore the effects of friction.



The vehicles collide head-on and stick together during the collision.

Calculate the velocity of the car-truck system immediately after the collision.

Solution:

There are separate masses ***before*** the collision (800 kg and 1500 kg).

There is ONLY ONE MASS ***after*** the collision (2300 kg).

Choose east as positive:

$$\varepsilon p_{before} = \varepsilon p_{after}$$
$$m_C v_{Ci} + m_T v_{Ti} = m_{total} v_f$$
$$(800)(+20) + (1\,500)(-15) = (2\,300)\,v_f$$
$$16\,000 - 22\,500 = 2\,300 v_f$$
$$-6\,500 = 2\,300 v_f$$
$$v_f = -2,83$$

therefore $v_f = 2,83$ kg·m·s⁻¹ west

The car-truck system will stick together and move west at 2,83 m·s⁻¹ immediately after the collision.

VERY IMPORTANT

Compare the ***change in momentum*** of each vehicle:

$$\Delta p_{car} = mv_f - mv_i$$
$$\Delta p_{car} = (800)(-2,826) - (800)(+20)$$
$$\Delta p_{car} = -2\,260,8 - 16\,000 = -18\,264$$
$$\Delta p_{car} = 18\,261 \text{ kg·m·s}^{-1} \text{ west}$$

$$\Delta p_{truck} = mv_f - mv_i$$
$$\Delta p_{truck} = (1\,500)(-2,826) - (1\,500)(-15)$$
$$\Delta p_{truck} = -4\,239 + 22\,500$$
$$\Delta p_{truck} = 18\,261 \text{ kg·m·s}^{-1} \text{ east}$$

The change in momentum of the car (18 261 kg·m·s⁻¹ west) is **EQUAL TO** but **OPPOSITE IN DIRECTION** to the change in momentum of the truck (18 261 kg·m·s⁻¹ east).

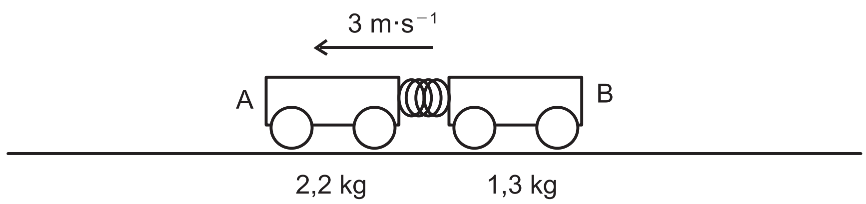
$\Delta p_{car} = -\Delta p_{truck}$

$\Delta p_{car} + (-\Delta p_{truck}) = 0$

The change in momentum of the system is ZERO.

2. Objects are exploded apart

Two trolleys A and B are moving to the left on a frictionless horizontal surface at 3 m·s⁻¹ as shown in the diagram below. Trolley A of mass 2,2 kg is connected to trolley B of mass 1,3 kg by means of a compressed spring. Ignore the mass of the spring.



The compressed spring between the trolleys is released and trolley B moves to the right at 2 m·s⁻¹.

Calculate the magnitude and direction of the velocity of trolley A immediately after the spring is fully released.

There is ONLY ONE MASS <u>before</u> the explosion (3,5 kg).

There are two separate masses after the explosion (2,2 kg and 1,3 kg).

Choose left as positive:

$\varepsilon p_{before} = \varepsilon p_{after}$

$m_T v_i = m_A v_{Af} + m_a v_{af}$

$(3,5)(+3) = (2,2)v_{Af} + (1,3)(-2)$

$10,5 - 2,2v_{Af} - 2,6$

$13,1 = 2,2v_{Af}$

therefore $v_{Af} = 5,96$ m·s⁻¹ to the left

Trolley A will move at 5,96 m·s⁻¹ to left immediately after the spring is fully released.

Compare the ***change in momentum*** of each trolley:

$\Delta p_A = mv_f - mv_i$

$\Delta p_A = (2,2)(+5,955) - (2,2)(+3)$

$\Delta p_A = 13,1 - 6,6$

$\Delta p_A = 6,5$

therefore $\Delta p_A = 6,50$ kg·m·s⁻¹ left

$\Delta p_a = mv_f - mv_i$

$\Delta p_a = (1,3)(-2) - (1,3)(+3)$

$\Delta p_a = -2,6 - 3,9$

$\Delta p_a = -6,50 \text{ kg·m·s}^{-1}$

therefore $\Delta p_a = 6,50 \text{ kg·m·s}^{-1}$ right

The change in momentum of the trolley A (6,50 kg·m·s^{-1} left) is **EQUAL TO** but **OPPOSITE IN DIRECTION** to the change in momentum of the trolley B (6,50 kg·m·s^{-1} right).

$\Delta p_A = -\Delta p_a$

$\Delta p_A + \Delta p_a = 0$

3. Objects collide and remain separate after the collision

A 0,3 kg volleyball is thrown horizontally at 2 m·s^{-1} west and it strikes a stationary basketball of mass 0,6 kg. The volleyball rebounds east at 0,8 m·s^{-1}. What is the velocity of the basketball immediately after the collision?

There are two separate objects ***before*** the collision and two separate objects ***after*** the collision.

Choose west as positive:

$\varepsilon p_{before} = \varepsilon p_{after}$

$m_v v_{Vi} + m_B v_{Bi} = m_v v_{Vi} + m_B v_{Bf}$

$(0,3)(+2) + (0,6)(0) = (0,3)(-0,8) + (0,6)\,v_{Bf}$

$0,6 + 0 = (0,3)(-0,8) + (0,6)\,v_{Bf}$

$0,6 = -0,24 + 0,6 v_{Bf}$

$0,84 = 0,6 v_{Bf}$

$v_{Bf} = 1.4$

therefore $v_{Bf} = 1,4 \text{ m·s}^{-1}$ west

The basketball moves at 1,4 m·s^{-1} west immediately after the collision.

Compare the **change in momentum** of each ball:

$\Delta p_{Volley\ ball} = mv_f - mv_i$

$\Delta p_{Volley\ ball} = (0,3)(-0,8) - (0,3)(+2)$

$\Delta p_{Volley\ ball} = -0,24 - 0,6$

$\Delta p_{Volley\ ball} = -0,84$

therefore $\Delta p_{Volley\ ball} = 0,84 \text{ kg·m·s}^{-1}$ east

$\Delta p_{Basket\ ball} = mv_f - mv_i$

$\Delta p_{Basket\ ball} = (0,6)(+1,4) - (0,6)(0)$

$\Delta p_{Basket\ ball} = 0,84 \text{ kg·m·s}^{-1}$ west

$\Delta p_{Volley\ ball} = -\Delta p_{Basket\ ball}$

3.2 Inelastic collisions

When objects collide, they sometimes deform (change shape), make a sound, give off light, stick together or heat up a little during the collision.

Any of these observations indicate that the **total kinetic energy** of the system ***before*** the collision is ***not the same*** as the **total kinetic energy *after*** the collision.

These collisions are known as ***inelastic collisions***.

During an **inelastic collision**, kinetic energy is ***not*** conserved.

Only momentum is conserved in an ***inelastic collision***.

Elastic collisions

An **elastic collision** is defined as one in which ***kinetic energy is conserved***.

In other words, there is **no loss of kinetic energy** during the collision.

The ***sum*** of the kinetic energies of each of the objects ***before the collision*** would be exactly ***equal*** to the sum of the kinetic energies of each of the objects ***after the collision***.

In an **elastic collision**:

1. Kinetic energy is conserved, ***and***
2. Momentum is conserved.

Work through the following example with your learners to develop their understanding of elastic and inelastic collisions.

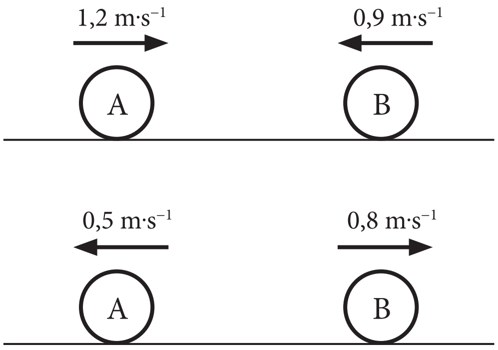
INTRODUCTORY LEVEL QUESTIONS

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 elastic and inelastic collisions.

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 down the question and answer it correctly in their workbooks.

4. A 0,2 kg pool ball A travelling at 1,2 m·s^{-1} east strikes a second 0,2 kg pool ball B moving west at 0,5 m·s^{-1}. Ball A moves at 0,5 m·s^{-1} east after the collision. Ball B moves off at ,8 m·s^{-1} east.



Determine if the collision is elastic.

Solution:

Remind your learners that kinetic energy is a ***scalar quantity***. We simply ***add*** the magnitude of the kinetic energy of each ball ***before*** and ***after*** the collision.

Calculate the total kinetic energy of the balls **before the collision**:

Ball A:

$$E_K = \frac{1}{2}mv^2 = \frac{1}{2}(0,2)(1,2)^2 = 0,144 \text{ J}$$

Ball B

$$E_K = \frac{1}{2}mv^2 = \frac{1}{2}(0,2)(0,9)^2 = 0,081 \text{ J}$$

The total kinetic energy before the collision is the sum of the kinetic energies of each ball:

Total kinetic energy ***before*** the collision:

Calculate the total kinetic energy **after the collision**.

Ball A:

$$E_K = \frac{1}{2}mv^2 = \frac{1}{2}(0,2)(0,5)^2 = 0,025 \text{ J}$$

Ball B

$$E_K = \frac{1}{2}mv^2 = \frac{1}{2}(0,2)(0,8)^2 = 0,0641 \text{ J}$$

Total kinetic energy ***after*** the collision: $E_K = 0,025 + 0,064 = 0,089 = 0,09 \text{ J}$

The total kinetic energy of the balls ***before*** the collision (0,23 J) is ***not equal*** to the total kinetic energy of the balls ***after*** the collision (0,09 J).

Therefore, this collision is inelastic.

Kinetic energy has been converted to other forms of energy such as sound and heat energy.

CHALLENGE LEVEL QUESTIONS

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

b. These questions require learners to apply the law of conservation of momentum and to determine whether or not a collision is elastic.

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.
- Learners must copy down the question and answer it correctly in their workbooks.

KEY TEACHING

a. Emphasise the importance of choosing a direction, either + or –.

b. Draw a diagram if it is not given.

c. Stress the importance of using the correct sign for the velocity before and after the collision.

d. Each object involved in a collision will experience EQUAL but OPPOSITE ***net forces***.

e. Each object involved in a collision will experience EQUAL but OPPOSITE ***changes in momentum***: $\Delta p_A = -\Delta p_B$

f. Kinetic energy is a scalar quantity.

5. Car A of mass 1 000 kg, stationary at a traffic light, is hit from behind by car B of mass 1 200 kg, travelling west at 18 m·s^{-1}. Car A moves west at 12 m·s^{-1} immediately after the collision.

5.1 State the law of conservation of linear momentum.

5.2 Calculate the velocity of car B immediately after the collision.

5.3 Calculate the change in momentum of car A.

5.4 State the magnitude and direction of the change in momentum of car B.

5.5 Determine if this was an elastic collision.

Solutions

5.1 The total linear momentum of an isolated system remains constant (is conserved).

5.2 Choose west as positive:

$\varepsilon p_{before} = \varepsilon p_{after}$

$m_A v_{Ai} + m_B v_{Bi} = m_A v_{Af} + m_B v_{Bf}$

$(1\,000)(0) + (1\,200)(+18) = (1\,000)(+12) + 1\,200\ v_{Bf}$

$21\,600 = 12\,000 + 1\,200\ v_{Bf}$

$1\,200\ v_{Bf} = 9\,600$

therefore $v_{Bf} = 8\ \text{m·s}^{-1}$ west

5.3 $\Delta p_A = mv_f - mv_i$

$\Delta p_A = (1\,000)(+12) - (1\,000)(0)$

$\Delta p_A = 12\,000\ \text{kg·m·s}^{-1}$ west

5.4 $\Delta p_B = 12\,000\ \text{kg·m·s}^{-1}$ east

5.5 $E_{k\,before} = \frac{1}{2}m_A v_a^2 + \frac{1}{2}m_B v_B^2$

$E_{k\,before} = 0 + \frac{1}{2}(1\,200)(18)^2 = 194\,400\ \text{J}$

$E_{k\,after} = \frac{1}{2}m_A v_a^2 + \frac{1}{2}m_B v_B^2$

$E_{k\,after} = \frac{1}{2}(1\,000)(12)^2 + \frac{1}{2}(1\,200)(8)^2 = 72\,000 + 38\,400 = 110\,400\ \text{J}$

Therefore this is an inelastic collision.

6. A bullet of mass 20 g is fired from a stationary rifle of mass 3 kg. Assume that the bullet moves horizontally. Immediately after firing, the rifle recoils (moves back) with a velocity of 1,4 m·s^{-1}.

6.1 Calculate the speed at which the bullet leaves the rifle.

6.2 How does the change in momentum of the bullet compare to the change in momentum of the rifle?

The bullet strikes a stationary 5 kg wooden block on a frictionless horizontal table. The bullet becomes embedded in the wooden block.

6.3 Calculate the speed of the bullet-block system after the collision.

6.4 How does the change in momentum of the bullet compare to the change in momentum of the block?

Solutions

6.1 Choose forward as positive:

$\varepsilon p_{before} = \varepsilon p_{after}$

$m_t v_i = m_r v_{rf} + m_b v_{bf}$

$(3{,}020)(0) = (3)(-1{,}4) + (0{,}020)\, v_{bf}$

$0 = -4{,}2 + 0{,}020\, v_{bf}$

$4{,}2 = 0{,}020\, v_{bf}$

$v_{bf} = 210\ \text{m·s}^{-1}$ west

6.2 The change in momentum of the bullet is equal to the change in momentum of the rifle but opposite in direction.

6.3 Choose forward as positive:

$\varepsilon p_{before} = \varepsilon p_{after}$

$m_b v_{bi} + m_W v_{Wi} = (m_b + m_W)\, v_{fT}$

$(0{,}020)(+210) + (5)(0) = (0{,}020 + 5{,}020)\, v_{fT}$

$4{,}2 + 0 = 5{,}020\, v_{fT}$

$4{,}2 = 5{,}020\, v_{fT}$

$v_{fT} = 0{,}84\ \text{m·s}^{-1}$

6.4 The change in momentum of the bullet is equal to the change in momentum of the block but opposite in direction.

CHECKPOINT

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

1. Applying the law of conservation of momentum
2. Determining whether a collision is elastic or inelastic. Check learners' understanding of these concepts by getting them to work through:

Worksheet Pack: Momentum and Impulse 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 for feedback.
- Encourage the learners to learn from the mistakes they make.

4. IMPULSE

INTRODUCTION

At this point in the topic you should introduce a new vector, *the impulse of a force*, to your learners. Then derive the impulse-momentum theorem and apply it to collisions.

CONCEPT EXPLANATION AND CLARIFICATION

4.1 Impulse-Momentum Theorem

Write down the equation for Newton's second law in terms of momentum on the board.

$F_{net} = \dfrac{\Delta p}{\Delta t}$

Multiply both sides of the equation by Δt : $F_{net}\,\Delta t = \Delta p$ (1)

The ***left hand*** side of this equation is: $\boldsymbol{F_{net}.\Delta t}$

$\boldsymbol{F_{net}\Delta t}$ is a ***vector*** quantity known as IMPULSE.

Your learners must know the definition of impulse.

Impulse: The product of the net force acting on an object and the time the net force acts on the object.

The unit for impulse is: N.s

Refer to equation (1) again:

The right hand side of this equation is: $\boldsymbol{\Delta p}$

In other words, Impulse is EQUAL TO the change in momentum of an object.

Show your learners that the N.s and kg.m·s^{-1} are equivalent units:

$1N \cdot s = 1\,(m \cdot a)\,(s) = 1\,(kg)\,(m \cdot s^{-2}) \cdot (s) = 1$ kg·m·s^{-1}

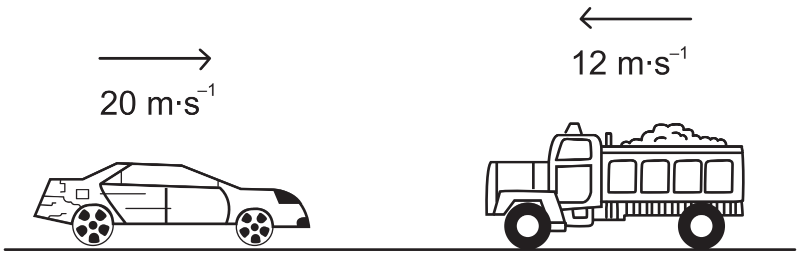
This is referred to as the Impulse-Momentum theorem:

$F_{net}\Delta t = \Delta p$

$F_{net}\Delta t = mv_f - mv_i$

Now apply the impulse-momentum theorem to the following example:

A car of mass 800 kg travelling at 20 m·s^{-1} east collides with a truck of mass 3 000 kg travelling at 12 m·s^{-1} west. The collision lasts for 0,5 s. After the collision the truck is moving at 4 m·s^{-1} west.



Calculate the impulse provided to the truck during the collision.

Choose west as positive:

$F_{net}\Delta t = \Delta p$

$F_{net}\Delta t = mv_f - mv_i$

$F_{net}\Delta t = (3\,000)(+4) - (3\,000)(+12)$

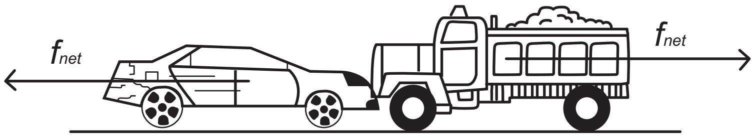
$F_{net}\Delta t = +12\,000 - 36\,000$

Therefore the impulse is 24 000 N·s east.

During the collision, an impulse of **24 000 N·s** is provided to the truck in the **easterly** direction.

The change in momentum of the truck is: $\Delta p = 24\,000$ kg·m·s^{-1} east

Draw the following diagram of the ***collision*** on the board:



Each object involved in the collision experiences the **SAME NET FORCE**, but opposite in direction (according to Newton's third law).

The contact time (Δt) is the **SAME** for both objects.

The magnitude of the net force on each object is the same AND the contact time is the same, therefore each object experiences the **SAME IMPULSE** (but opposite in direction):

$impulse_{CAR} = F_{net}\Delta t$

$impulse_{TRUCK} = -F_{net}\Delta t$

VERY IMPORTANT FACTS FOR ANY COLLISION:

1. Each object involved in the collision will experience an EQUAL but OPPOSITE **NET FORCE**.
2. Each object involved in the collision will experience an EQUAL but OPPOSITE **IMPULSE**.
3. Each object involved in the collision will experience an EQUAL but OPPOSITE **CHANGE OF MOMENTUM**.

What is the impulse provided to the car during the collision?

$impulse_{TRUCK} = -24\,000$ N·s

Therefore: $impulse_{CAR} = +24\,000$ N·s $= 24\,000$ N·s west

What is the change in momentum of the car during the collision?

Impulse = change in momentum

$\Delta p_{CAR} = 24\ 000\ \text{kg·m·s}^{-1}$ west

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 impulse-momentum 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 down the question and answer it correctly in their workbooks.

1. A 70 kg male ice skater is facing a 65 kg female ice skater. They are at rest on the ice. They push off each other with a force of 150 N for 1,2 s and move in opposite directions. The female skater moves to the left and the male skater moves to the right.

1.1 Calculate the impulse provided to the female skater.

1.2 What is the impulse provided to the male skater?

1.3 What is the change in momentum of the female skater?

1.4 What is the change in momentum of the male skater?

1.5 How would the impulse provided to the female skater change if her mass was doubled?

2. A dancer of mass 45 kg leaps into the air and lands feet first on the ground. She lands on the ground with a downward velocity of 4 m·s^{-1}. As she lands, she bends her knees and comes to a complete stop in 0,22 seconds.

2.1 Define the term *impulse* of a force.

2.2 Calculate the impulse provided to the dancer during the collision with the ground.

2.3 Calculate the net force acting on the dancer as she lands.

3. A bullet of mass 0,03 kg is fired into a block of wood. The velocity of the bullet just before impact is 400 m·s^{-1}.

3.1 What is the impulse provided to the bullet?

3.2 Calculate the time the bullet took to come to rest if it experienced a net force of 200 N.

Solutions

1.1 Choose to the right as positive:

$\text{Impulse} = F_{net}\Delta t = (-150)(1,2) = -180$

Therefore, impulse = 180 N·s to the left.

1.2 $F_{net}\Delta t = 180$ N·s to the right

1.3 $F_{net}\Delta t = \Delta p$

$\Delta p_{female} = -180$

therefore $\Delta p_{female} = 180$ kg·m·s^{-1} to the left

1.4 $\Delta p_{male} = +180$

therefore $\Delta p_{male} = 180$ kg·m·s^{-1} to the right

1.5 NO CHANGE.

The same net force acts on the female for the same length of time.

2.1 The impulse of a net force is the product of the net force acting on an object and the time the net force acts on the object.

2.2 Choose down as positive:

$F_{net}\Delta t = \Delta p$

$F_{net}\Delta t = mv_f - mv_t$

$F_{net}\Delta t = (45)(0) - (45)(+4)$

$F_{net}\Delta t = 0 - 180$

$F_{net}\Delta t = -180$

Therefore $F_{net}\Delta t = 180$ N·s upwards

2.3 $F_{net}\Delta t = \Delta p$

$F_{net}\Delta t(0,22) = -180$

$F_{net}\Delta t = \frac{-180}{0,22}$

$F_{net}\Delta t = -818,18$

Therefore $F_{net} = 818,18\text{ N}$ upwards

TOPIC 2

3.1 Choose forward as positive:

$F_{net}\Delta t = mv_f - mv_i$

$F_{net}\Delta t = (0{,}03)((0) - (0{,}03)(+400)$

$F_{net}\Delta t = 0 - 12$

$F_{net}\Delta t = -12$

Therefore $F_{net}\Delta t = 12$ N·s opposite to the direction of motion

3.2 $F_{net}\Delta t = \Delta p$

$(-200)\Delta t = (-12)$

$\Delta t = \frac{-12}{-200} = 0{,}06\ s$

4.2 Safety considerations

The purpose of seat belts and airbags in vehicles is to change the momentum of the passenger over a longer period of time, thus reducing the net force acting on the passenger. Write the equation for Newton's second law in terms of momentum on the board:

$$F_{net} = \frac{\Delta p}{\Delta t}$$

The important relationship in this equation is:

For a constant change in momentum, the net force F_{net} is ***inversely proportional*** to the contact time (Δt).
If the passenger is ***not*** wearing a seat belt, the passenger will be brought to rest during the collision in a very short time interval.

The ***shorter*** the ***contact time*** (Δt), the ***greater*** the ***net backward force*** on the passenger (for a constant change in momentum).

If the passenger collides with the ***seat belt***, the momentum will change over a ***longer period of time***. If (Δt) ***increases*** then the net backward force acting on the passenger will ***decrease***. This will decrease the risk of injury to the passenger.

Crumple zones in the front end of cars will also improve the safety of passengers

Crumple zones have two effects:

1. Increase the time taken to change the momentum of the car, thus reducing the net backward force on the car and passengers.
2. Prevent the car from bouncing backwards during the collision. Cars that don't bounce backwards during a collision experience a ***smaller change in momentum*** and therefore a smaller net backward force.

Often the braking system of large trucks overheats and fails through excessive use. Engineers construct emergency escape pathways called arrestor beds to safely slow down vehicles with failed braking systems. An **arrestor bed** is a gravel filled pathway that runs next to a main road. Arrestor beds ensure the momentum of the truck is changed (decreased to zero) over a ***long time interval***.

Work through the following example to highlight the points above:

A passenger (mass of 80 kg), not wearing a seat belt, travelling at 30 m·s^{-1} is involved in a collision. She strikes the steering wheel which brings her body to a stop in 0,04 s.

Calculate the average net force that the steering wheel exerts on her during the collision.

Choose forward as positive:

$F_{net}\Delta t = \Delta p$

$F_{net}\Delta t = mv_f - mv_t$

$F_{net}(0,04) = (80)(0) - (80)(+30)$

$F_{net}(0,04) = 0 - 2\,400$

$F_{net}\dfrac{2\,400}{0,04} = -60\,000$

Therefore $F_{net} = 60\,000\text{ N}$ backwards

Suppose the passenger was wearing a seatbelt. This time her body is stopped in 0,2 s. Calculate the average net force of the seat belt on the passenger.

$F_{net}\Delta t = mv_f - mv_t$

$F_{net}(0,2) = (80)(0) - (80)(+30)$

$F_{net}(0,02) = 0 - 2\,400$

$F_{net}\dfrac{2\,400}{0,02} = -120\,000$

Therefore $F_{net} = 12\,000\text{ N}$ backwards

The net backward force acting on the passenger has been reduced, thus reducing the risk of injury.

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 impulse-momentum theorem.

TOPIC 2

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.
- Learners must copy down the question and answer it correctly in their workbooks.

KEY TEACHING

a The impulse of a force is a vector quantity.

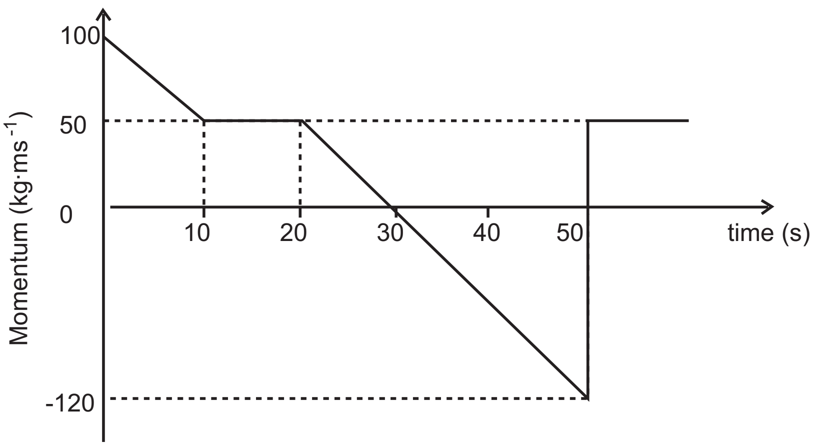
b The impulse of a force is equal to the change in momentum of an object.

c Each object involved in the collision will experience an EQUAL but OPPOSITE NET FORCE.

d Each object involved in the collision will experience an EQUAL but OPPOSITE IMPULSE.

e Each object involved in the collision will experience an EQUAL but OPPOSITE CHANGE OF MOMENTUM.

4. The momentum versus time graph of object A, originally moving horizontally east, is shown below



4.1 Write down the definition of impulse.

4.2 The net force acting on object A is zero between t = 10 s and t = 20 s. Use the graph and a relevant equation to explain why this statement is TRUE.

4.3 What does the gradient of the graph represent? Justify your answer.

4.4 Calculate the magnitude and direction of the impulse that object A experiences between t = 20 s and t = 50 s.

4.5 Calculate the average net force acting on A between t = 20 s and t = 50 s.
At t = 50 s, object A collides with another object, B, which has a momentum of 70 kg·m·s^{-1} east.

4.6 Use the information from the graph and the relevant principle to calculate the momentum of object B after the collision.

5. A ball of mass 150 g is dropped onto the floor. It strikes the floor at a speed of 6,2 m·s^{-1}. The ball bounces straight upwards at a velocity of 3,62 m·s^{-1}. The ball is in contact with the ground for 0,05 s.

5.1 Calculate the magnitude and direction of the impulse of the net force applied to the ball during its collision with the floor.

5.2 Calculate the upward force of the floor on the ball during the collision.

6. A car is involved in a collision and is brought to rest. How will the magnitude of the net force acting on the car be affected in each of the following cases? Explain your answer in each case.

6.1 The car is brought to rest over a longer time interval.

6.2 The car is travelling at a greater speed before the collision and is brought to rest in the same time interval.

6.3 The car rebounds after the collision in the same time interval.

Solutions

4.1 The impulse is the product of the net force acting on an object and the time the net force acts on the object.

4.2 The momentum of A is <u>not changing</u> during t = 10 s to t = 20 s.

$\Delta p = 0$

$F_{net} = \frac{\Delta p}{\Delta t} = \frac{0}{10} = 0 \text{ N}$

4.3 $gradient = \frac{\Delta y}{\Delta x} = \frac{\Delta p}{\Delta t} = F_{net}$

The gradient = the average net force acting on A

TOPIC 2

4.4 Choose east as positive:

$F_{net}\Delta t = \Delta p$

$F_{net}\Delta t = mv_f - mv_i$

$F_{net}\Delta t = (-120) - (+50)$

$F_{net}\Delta t = -170$

$F_{net}\Delta t = 170$ N·s west

4.5 $F_{net} = \dfrac{\Delta p}{\Delta t} = \dfrac{-170}{30} = -5,67$

$F_{net} = 5,67$ west

4.6 $\Delta p_A = mv_f - mv_i$

$\Delta p_A = +50 - (-120) = +170$ kg·m·s^{-1}

The change in momentum of B is equal in magnitude but opposite in direction to the change in momentum of A.

$\Delta p_B = mv_f - mv_i$

$-170 = mv_f - (+70)$

$mv_f = -170 + 70 = -100$

Therefore $mv_f = 100$ kg·m·s^{-1} east

5.1 Choose down as positive:

$F_{net}\Delta t = \Delta p$

$F_{net}\Delta t = mv_f - mv_i$

$F_{net}\Delta t = (0,15)(-3,62) - (0,15)(+6,2)$

$F_{net}\Delta t = -0,543 - 0,93$

$F_{net}\Delta t = -1,47$

Therefore impulse = 1,47 N·s upwards

5.2 $F_{net} = \dfrac{\Delta p}{\Delta t} = \dfrac{-1,47}{0,05} = -29,4 = 29,4\ \text{N}$

$F_{net} = F_{floor} - \text{w}$

$-29,4 = F_{floor} - (0,15)(9,8)$

$-29,4 = F_{floor} - 1,47$

$F_{floor} = -29,4 + 1,47 = -27,93$

Therefore $F_{floor} = 27,93$ upwards

6.1 $F_{net} = \dfrac{\Delta p}{\Delta t}$

Δp of the car is the same.

Δt has increased.

F_{net} will decrease. The net force is inversely proportional to the contact time.

6.2 Δp of the car has increased.
Δt is the same.
F_{net} will increase. The net force is directly proportional to the change in momentum.

6.3 Δp of the car has increased.
Δt is the same.
F_{net} will increase. The net force is directly proportional to the change in momentum.

CHECKPOINT

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

1. Calculating impulse.
2. Applying the impulse-momentum theorem.
3. Explaining the physics of seat belts, airbags and arrestor beds.

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

Worksheet Pack: Momentum and Impulse Worksheet: Questions 7-9

- 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 for feedback.
- Encourage the learners to learn from the mistakes they make.

CONSOLIDATION

- Learners can consolidate their learning by completing; **Worksheet Pack: Momentum and Impulse 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 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=XFhntPxow0U
   Conservation of linear momentum
2. https://www.youtube.com/watch?v=uMYAc04D0ak
   Impulse-momentum theorem
3. https://www.youtube.com/watch?v=8OB8eIPgEkQ
   Elastic and inelastic collisions
4. https://phet.colorado.edu/en/simulation/legacy/collision-lab
   pHet simulation – collisions and momentum introduction

TOPIC 3:

Vertical Projectile Motion in One Dimension

A Introduction

- This topic runs for 5 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Vertical projectile motion in one dimension forms part of the content area Mechanics (Physics).
- Mechanics counts 42% in the final Physics (Paper 1) examination.
- Vertical projectile motion in one dimension counts approximately 3.75 % of the final Physics Examination (Paper 1).

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.
2. Chalk.
3. Grade 12 Physics Examination Data Sheet.
4. Ticker tape apparatus, ticker timer, mass, platform. You could include automated data logging apparatus as alternative materials.

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	CURRENT
GRADE 10-11	**GRADE 12**
• Introduction to vectors & scalars • Reference frame, position, displacement and distance • Velocity, acceleration • Instantaneous velocity • Description of motion in words, diagrams, graphs and equations	• Vertical projectile motion (1D) represented in words, diagrams, equations and graphs

C Glossary of Terms

TERM	DEFINITION
Free-fall	Motion when the only force acting on the object is the gravitational force.
Distance	The total path length travelled.
Displacement	The difference in position in space.
Speed	The total distance travelled per total time
Velocity	The rate of change of position.
Acceleration	The rate of change of velocity.
Position	Position is measured relative to a reference point.

D Assessment of this Topic

- This topic is assessed by informal and 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 experiment for informal assessment: Investigate the motion of a falling body. Draw a graph of position vs. time and velocity vs. time for a free-falling object AND use the data to determine the acceleration due to gravity.

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
5 hours	Vertical projectile motion (1D) represented in words, diagrams, equations and graphs	102-103	**a.** Explanation of free-fall and the acceleration due to gravity. **b.** Numerous worked examples using equations of motion. **c.** Explanation of x-t, v-t and a-t graphs. **d.** Meaning of the gradient of x-t and v-t graphs. **e.** Meaning of the area under a v-t graph. **f.** Numerous exercises for practice.

F Targeted Support per Sub-topic

1. FREE-FALL

INTRODUCTION

CONCEPT EXPLANATION AND CLARIFICATION

1.1 Free-fall

In this topic we **IGNORE AIR RESISTANCE** (air friction).

A free-falling object is an object that is moving under the sole influence of the Earth's gravitational force. In other words, an object is in a state of ***free-fall*** when **the only force acting on it is the gravitational force**.

Draw the free-body diagram on the board of a *ball thrown vertically upwards*:

Emphasise that the ball has ***ALREADY LEFT THE THROWER'S HAND*** and that the only force acting on the ball throughout its motion, is the ***GRAVITATIONAL FORCE*** (the weight of the ball).

The gravitational force **IS** the ***NET FORCE*** acting on the ball.

Remind your learners that according to Newton's second law, an object will accelerate in *the direction* of the net force.

The weight acts downwards therefore the **acceleration** of a free-falling object is ***ALWAYS DOWNWARDS*** (toward the Earth).

Emphasise these important points about free-fall:

1. Free-falling objects ***do not*** experience air resistance (frictional force).
2. All free-falling objects (near the surface of the Earth) always accelerate ***DOWNWARDS*** at 9,8 $m \cdot s^{-2}$.

Learners ***incorrectly*** think that the word "fall" means that the object must be falling.

In fact, an object in free-fall can be ***moving upwards, be at rest*** (at the highest point in its motion) or ***moving downwards***.

Remind your learners of the definition of acceleration: **The rate of change of velocity.**

In other words, acceleration tells us **"how much the velocity is changing by every second"** and whether the velocity is decreasing or increasing.

We know that the acceleration due to gravity is $g = 9{,}8\ \text{m·s}^{-2}$ downwards

What does this mean?

$$a = \frac{\Delta v}{\Delta t} = \frac{9{,}8\ \text{m} \cdot \text{s}^{-1}}{1\ \text{s}}$$

The ***velocity*** of a free-falling object ***will change*** by 9,8 m·s^{-1} during every second of its motion.

If an object in free-fall is ***MOVING DOWNWARDS*** it is ***ACCELERATING DOWNWARDS*** and its ***VELOCITY MUST INCREASE*** by 9,8 m·s^{-1} during every second of its motion.

Suppose a ball is ***dropped*** from the edge of a very high cliff. Draw the following table on the board and get your learners to complete the table of the *instantaneous velocity* of the ball at *each second* of its motion.

TIME	VELOCITY	DIRECTION OF VELOCITY
0	0	None
1 s	9,8 m·s^{-1}	Downwards
2 s	19,6 m·s^{-1}	Downwards
3 s	29,4 m·s^{-1}	Downwards
4 s	39,2 m·s^{-1}	Downwards

Emphasise the fact that when the object is **MOVING DOWNWARDS** it is **ACCELERATING DOWNWARDS** and its **VELOCITY WILL INCREASE** in magnitude.

If an object in free-fall is ***MOVING UPWARDS*** it is ***ACCELERATING DOWNWARDS*** and its ***VELOCITY MUST DECREASE*** by 9,8 m·s^{-1} during every second of its motion.

Suppose a ball is ***thrown upwards*** with an initial velocity of 40 m·s^{-1}. Draw the following table on the board and get your learners to complete the table of the *instantaneous velocity* of the ball at *each second* of its motion.

TIME	VELOCITY	DIRECTION OF VELOCITY
0	0	Upwards
1 s	30,2 m·s^{-1}	Upwards
2 s	20,4 m·s^{-1}	Upwards
3 s	10,6 m·s^{-1}	Upwards
4 s	0,8 m·s^{-1}	Upwards

TOPIC 3

Emphasise the fact that when the object is **MOVING DOWNWARDS** it is **ACCELERATING DOWNWARDS** and its **VELOCITY WILL INCREASE** in magnitude.

If an object in free-fall is ***MOVING UPWARDS*** and it is ***ACCELERATING DOWNWARDS*** then its ***VELOCITY MUST DECREASE*** by 9,8 m·s^{-1} during every second of its motion.

1.3 Equations of motion for vertical projectile motion

Show your learners the **equations of motion** for vertical projectile motion on the Physics Data Sheet (they must be given this data sheet in all physics assessments).

Write the equations of motion on the board:

$$v_f = v_i + a\Delta t$$
$$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$$
$$v_f^2 = v_i^2 + 2a\Delta y$$
$$\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$$

Emphasise the meaning of <u>each symbol</u>:

v_i = the initial velocity of an object (VECTOR)

v_f = the final velocity of an object (VECTOR)

a = the acceleration of an object (VECTOR) = g = 9,8 m·s^{-2} DOWNWARDS (VECTOR)

Δy = the displacement of an object in the vertical plane (VECTOR)

Δt = time interval (SCALAR)

Remind your learners that all of these quantities are **VECTORS** (except Δt).

This means that they MUST choose a direction as positive at the beginning of the problem, e.g. UP IS POSITIVE.

VERY IMPORTANT

If the learners choose **UP AS POSITIVE**, then a = −9,8 m·s^{-2} **ALWAYS**

If the learners choose **DOWN AS POSITIVE**, then a = $+$9,8 m·s^{-2} **ALWAYS**

The only way to improve their ability to use equations of motion is PRACTICE. Work through the following questions step by step with your learners.

INTRODUCTORY LEVEL QUESTIONS

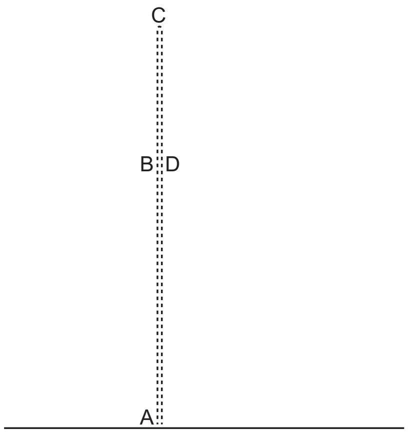
a. These are the basic calculations that learners will be required to perform at this stage in the topic.

b. Their purpose is to familiarise the learners with the equations of motion and the use of positive or negative signs for each vector.

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 down the question and answer it correctly in their workbooks.

1. An object is projected vertically upwards at 50 m·s^{-1} from point A. It reaches is maximum height at point C before returning to its point of release.



1.1 The object takes 3 s to reach point B. Calculate the velocity of the object at point B.

Solution

Choose up as positive:

Write down what you are given:

v_i = $+50$ m·s^{-1}

v_f = ?

a = $-9{,}8$ m·s^{-2}

Δy = ?

Δt = 3 s

Select an equation:

$v_f = v_i + a\Delta t$	Write equation
$v_f = (+50) + (-9{,}8)(3)$	Substitute values
$v_f = +50 - 29{,}4$	Solve for the unknown
$v_f = +20{,}6$	Ensure answer has unit and direction

Therefore $v_f = 20{,}6\ \text{m·s}^{-1}$

1.2 Calculate the position of the object at 3s (point B).

Solution

Position is measured relative to a reference point. It is important to choose a reference point. Let's choose point A as our reference point. Point A has a position of $\boldsymbol{x = 0}$

$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$	Write equation
$\Delta y = (+50)(3) + \frac{1}{2}(-9{,}8)(3)^2$	Substitute values
$\Delta y = 150 - 44{,}1 = +105{,}9\ \text{m} = 105{,}9\ \text{m}$ above point A	Ensure answer has unit and direction

The positive answer for displacement indicates that the object is ABOVE the reference point A.

1.3 What is the velocity of the object at its highest point C?

Solution

The ball comes to rest at its highest point. The velocity of the ball is ZERO at its highest point.

1.4 What is the acceleration of the object at its highest point C?

Solution

The acceleration of the object is ALWAYS 9,8 m·s^{-2} DOWNWARDS THOUGHOUT its entire motion.

The acceleration of the object at the ***highest point*** is **9,8 m·s^{-2} downwards**.

1.5 Calculate the time taken for the object to reach its highest point C.

Solution

Write down what you are given:

$v_i = +50\ \text{m·s}^{-1}$

$v_f = ?$

$a = -9{,}8\ \text{m·s}^{-2}$

$\Delta y = ?$

$\Delta t = ?$

Select an equation:

$$v_f = v_i + a\Delta t$$
$$0 = (+50) + (-9,8)\Delta t$$
$$-50 = -9,8\Delta t$$
$$\Delta t = 5,10 \text{ s}$$

It takes 5,10 s for the object to reach its highest point.

1.6 How long does it take the object to return to point A after being released?

Solution

The time taken from point of release (A) to its highest point (C) IS EQUAL TO the time taken to fall from its highest point (C) back down to its point of release (A).

In other words: **Time up = Time down**

The object takes 5,10 s to reach its maximum height. Therefore, it will take 5,10 s to fall back to the point of release.

$$\Delta t = \text{time up} + \text{time down} = 5{,}10 + 5{,}10 = 10{,}2 \text{ s}$$

1.7 Calculate the maximum height reached by the object.

Solution

$$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$$
$$\Delta y = (+50)(5,10) + \frac{1}{2}(-9,8)(5,10)^2$$
$$\Delta y = 255 - 127,449$$
$$\Delta y = 127,55 \text{ m}$$

OR

$$v_f^2 = v_i^2 + 2a\Delta y$$
$$0 = (+50)^2 + 2(-9,8)\Delta y$$
$$-2\,500 = -19,6\Delta y$$
$$\Delta y = 127,55\, m$$

OR

$$\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$$
$$\Delta y = \left(\frac{(+50) + 0}{2}\right)(5,10) \qquad \Delta y = 127,55 \text{ m}$$

TOPIC 3

1.8 Calculate the time taken for the object to reach point D.

Solution

The position of point D is the SAME as the position of point B.

The displacement of the object at point D is the SAME as the displacement of the object at point B.

Time from A to C = 5,1 s
Time from C to D = 3 s

Therefore: Time from A to C = 5,1 − 3 = 2,1 s

Therefore: Time from C to D = 2,1 s

Time from A to D = 5,1 + 2,1 = 7,2 s

OR

IMPORTANT

The velocity at B = +20,6 = 20,6 m·s^{-1} upwards (From Question 1.1)

Therefore:
The velocity at D = −20,6 = 20,6 m·s^{-1} downwards
$v_f = -20,6\ \text{m·s}^{-1}$

The position of point D is the SAME as the position of point B.

The displacement of the object at point D is the SAME as the displacement of the object at point B.

$\Delta y = +105,9\ \text{m}$ (From Question 1.2)

$$+105,9 = \left(\frac{(+50)+(-20,6)}{2}\right)\Delta t$$

$$+105,9 = 14,7\Delta t$$

$$\Delta t = 7,20\ \text{s}$$

OR

$$v_f = v_i + a\Delta t$$

$$-20,6 = (+50) + (-9,8)\Delta t$$

$$-70,6 = -9,8\Delta t$$

$$\Delta t = 7,20\ \text{s}$$

1.9 Find the position of the object at 3,5 s.

Solution

$$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$$

$$\Delta y = (+50)(3,5) + \frac{1}{2}(-9,8)(3,5)^2$$

$$\Delta y = 175 - 60,025$$

$$\Delta y = +114,98 = 114,98 \text{ m above point A}$$

1.10 At what time(s) will the object be 80 m above point A?

Solution

$$v_f^2 = v_i^2 + 2a\Delta y$$
$$v_f^2 = (+50)^2 + 2(-9,8)(+80)$$
$$v_f^2 = 2\,500 - 1\,568$$
$$v_f^2 = 932$$

There are ***TWO SOLUTIONS*** to this equation:

$v_f = +30,53 = 30,53$ m·s⁻¹ upwards

AND

$v_f = -30,53 = 30,53$ m·s⁻¹ downwards

Find the times for these velocities:

$$v_f = v_i + a\Delta t$$

$$+30,56 = (+50) + (-9,8)\Delta t$$

$$-19,44 = -9,8\Delta t$$

$$\Delta t = 1,98 \text{ s}$$

AND

$$v_f = v_i + a\Delta t$$

$$-30,56 = (+50) + (-9,8)\Delta t$$

$$-80,56 = -9,8\Delta t$$

$$\Delta t = 8,22 \text{ s}$$

1.11 What is the velocity of the object when it returns to point A?

Solution

The initial velocity of the object at A was 50 m·s^{-1} upwards, therefore the velocity that it returns with is **50 m·s^{-1} *downwards.***

TOPIC 3

1.12 Complete the following table with your learners:

Time (s)	Velocity ($m \cdot s^{-1}$)	Direction of velocity	Displacement (m)	Acceleration ($m \cdot s^{-2}$)	Direction of acceleration
0	50	upwards	0	9,8	downwards
3	20,6	upwards	105,9	9,8	downwards
5,1	0	none	127,55	9,8	downwards
7,2	20,6	downwards	105,9	9,8	downwards
10,2	50	downwards	0	9,8	downwards

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 use their understanding of free-fall, acceleration due to gravity and equations of motion.

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.
- Learners must copy down the question and answer it correctly in their workbooks.

KEY TEACHING

a. Make a choice of direction e.g. Up is positive.

b. Draw a diagram, if necessary.

c. Choose a reference point $x = 0$.

d. Write down all the given and known quantities.

e. Choose a suitable equation.

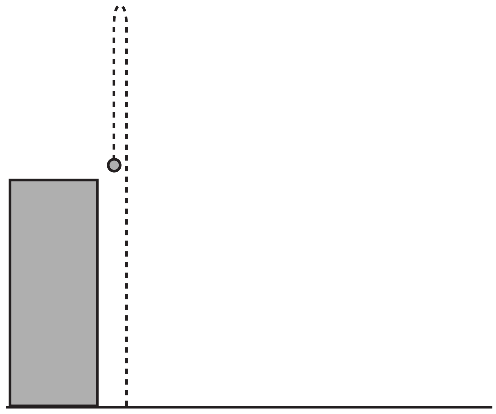
f. For free-fall: the direction of the acceleration is ALWAYS DOWNWARDS.

g. Velocity at the highest point of the motion is ZERO.

h. When an object returns to its point of release, the time taken for the upward motion is EQUAL TO the time taken for the downward motion.

i. During free-fall, the velocity of the object will DECREASE on the way up and INCREASE on the way down.

2. A child throws a coin vertically upwards from the window of a high building with an initial velocity of 15 m·s^{-1}. It strikes the ground travelling at 35 m·s^{-1}. Ignore the effects of air resistance.



2.1 Describe the motion of the coin.

2.2 Calculate the time taken for the coin to reach its maximum height above the ground.

2.3 Calculate the time taken for the coin to reach the ground.

2.4 Calculate the height of the building.

2.5 Calculate the distance that the coin has travelled when it hits the ground.

2.6 Calculate the position of the coin relative to the top of the building at 4 s.

Solutions

2.1 Constant (uniform) acceleration downwards.

2.2 Choose up as positive:

$v_f = v_i + a\Delta t$

$0 = (+15) + (-9,8)\Delta t$

$-15 = -9,8\Delta t$

$\Delta t = 1,53 \text{ s}$

2.3 $v_f = v_i + a\Delta t$

$-35 = (+15) + (-9,8)\Delta t$

$-50 = -9,8\Delta t$

$\Delta t = 5,10 \text{ s}$

2.4 $v_f^2 = v_i^2 + 2a\Delta y$

$(-35)^2 = (+15)^2 + 2(9,8)\Delta y$

$1\,225 = 225 - 19,6\Delta y$

$1\,000 = -19,6\Delta y$

$\Delta y = -51$

Therefore the height of the building is 51 m.

OR

$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$

$\Delta y = (+15)(5,1) + \frac{1}{2}(-9,8)(5,1)^2$

$\Delta y = 76,5 - 127,449$

$\Delta y = -50,5$

Therefore the height of the building is 51 m.

OR

$\Delta y = \left(\frac{v_i + v_f}{2}\right)\Delta t$

$\Delta y = \left(\frac{(+15) + (-35)}{2}\right)(5,1)$

$\Delta y = (-10)(5,1)$

$\Delta y = -51$

Therefore the height of the building is 51 m.

2.5 From top of building to maximum height:

$v_f^2 = v_i^2 + 2a\Delta y$

$0 = (+15)^2 + 2(-9,8)\Delta y$

$0 = 225 - 19,6\Delta y$

$-225 = -19,6\Delta y$

$\Delta y = +11,48$

Distance travelled $=$ 11,48 $+$ 11,48 $+$ 51 = 73,96 m.

2.6 Reference point is the top of the building

$\Delta y = v_i\Delta t + \frac{1}{2}a\Delta t^2$

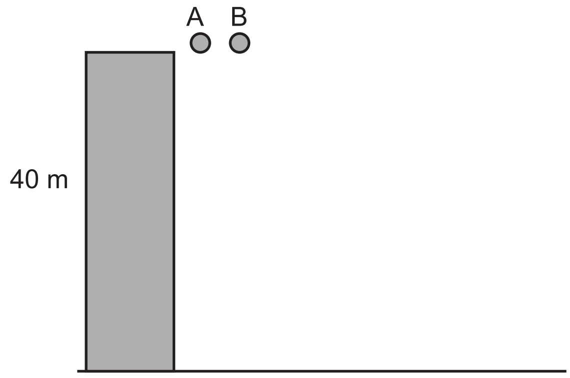
$\Delta y = (+15)(4) + \frac{1}{2}(-9,8)(4)^2$

$\Delta y = 60 - 78,4$

$\Delta y = -18,4$

Therefore the position of the coin is 18,4 m below the top of the building

3. Ball A is thrown downwards at 8 m·s^{-1} from the top of a 40 m high building. At the same instant, ball B is dropped from the same point. Ignore the effects of friction.



3.1 Describe what is meant by free-fall.

3.2 Calculate the distance between the two balls after 1,5 s.

3.3 How much longer will ball B take to hit the ground after ball A has hit the ground?

Solutions

3.1 When the only force acting on the object is the gravitational force.

3.2 Choose down as positive:

Ball A:

$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$

$\Delta y = (+8)(2) + \frac{1}{2}(+9,8)(2)^2$

$\Delta y = 16 + 19,6$

$\Delta y = 35,6$ m

Ball B:

$\Delta y = v_i \Delta t + \frac{1}{2} a \Delta t^2$

$\Delta y = (0)(2) + \frac{1}{2}(+9,8)(2)^2$

$\Delta y = 10 + 19,6$

$\Delta y = 19,6$ m

Distance between balls $=$ 35,6 $-$ 19,6 $=$ 16 m

3.3 **Ball A**:

$v_f^2 = v_i^2 + 2a\Delta y$

$v_f^2 = (+8)^2 + 2(+9,8)(+40)$

$v_f^2 = 64 + 784$

$v_f^2 = 848$

$v_f = v_i + a\Delta t$

$$+29,12 = (+8) + (+9,8)\Delta t$$
$$21,12 = 9,8\Delta t$$
$$\Delta t = 2,16 \text{ s}$$

Ball B:

$$v_f^2 = v_i^2 + 2a\Delta y$$
$$v_f^2 = 0^2 + 2(+9,8)(+40)$$
$$v_f^2 = 0 + 784$$
$$v_f^2 = 784$$
$$v_f = 28 \text{ m·s}^{-1}$$
$$v_f = v_i + a\Delta t$$
$$+28 = (0) + (+9,8)\Delta t$$
$$28 = 9,8\Delta t$$
$$\Delta t = 2,86 \text{ s}$$
$$\Delta t = 2,86 - 2,16 = 0,70 \text{ s}$$

Ball B will hit the ground 0,7 s after ball A hits the ground.

4. A hot air balloon is rising at a constant speed of 5 m·s^{-1} when a sandbag is dropped from the hot air balloon. The sand bag strikes the ground after 5 seconds. Ignore the effects of friction.

4.1 Calculate the velocity of the sand bag when it strikes the ground below.

4.2 What is the height of the hot air balloon above the ground when the sand bag is released?

Solutions

4.1 Choose upward as positive:

$$v_f = v_i + a\Delta t$$
$$v_f = (+5) + (-9,8)(5)$$
$$v_f = 5 - 49$$
$$v_f = -44$$
$$v_f = 44 \text{ m.s}^{-1} \text{ downwards}$$

4.2 $\Delta y = v_i\Delta t = +\frac{1}{2}a\Delta t^2$

$$\Delta y = (+5)(5) + \frac{1}{2}(-9,8)5^2$$
$$\Delta y = 25 - 122,5$$
$$\Delta y = -97,5$$

The sand bag fell 97,5 m below the point of its release.

The balloon was 97,5 m above the ground

CHECKPOINT

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

1. Make a choice of direction e.g. upward is positive.
2. Draw a diagram, if necessary.
3. Choosing a reference point $x = 0$.
4. Write down all the given and known quantities.
5. Choose a suitable equation.
6. For free-fall: the direction of the acceleration is ALWAYS DOWNWARDS.
7. Velocity at the highest point of the motion is ZERO.
8. When an object returns to its point of release, the time taken for the upward motion is EQUAL TO the time taken for the downward motion.
9. During free-fall, the velocity of the object will DECREASE on the way up and INCREASE on the way down.

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

Worksheet Pack: Vertical projectile motion in one dimension Worksheet: 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 for feedback
- Encourage the learners to learn from the mistakes they make.

2. GRAPHS OF MOTION

INTRODUCTION

Build on the foundation of the work done in grade 10. Keep reminding your learner's that free-fall is simply constant acceleration. The direction of the acceleration is ALWAYS downwards.

CONCEPT EXPLANATION AND CLARIFICATION

IMPORTANT

Remind your learners that in grade 10 they learnt <u>3 rules</u> that should be remembered when dealing with graphs of motion.

Write these three rules on the board:

RULE 1:

The **GRADIENT** of a **POSITION** (x) versus **TIME** (t) graph is **EQUAL TO THE VELOCITY** (v) of that object.

RULE 2:

The **GRADIENT** of a **VELOCITY** (v) versus **TIME** (t) graph is **EQUAL TO THE ACCELERATION** (a) of the object.

RULE 3:

The **AREA UNDER** a **VELOCITY** (v) versus **TIME** (t) graph is **EQUAL TO THE DISPLACEMENT** (Δx) of the object.

When graphing vertical projectile motion, we are simply graphing *free-fall*. Free-fall is simply ***CONSTANT ACCELERATION DOWNWARDS.***

Work through the following example with your learner's to improve their understanding of these three rules.

2.1 ***A ball is THROWN UPWARDS and FALLS BACK DOWN***

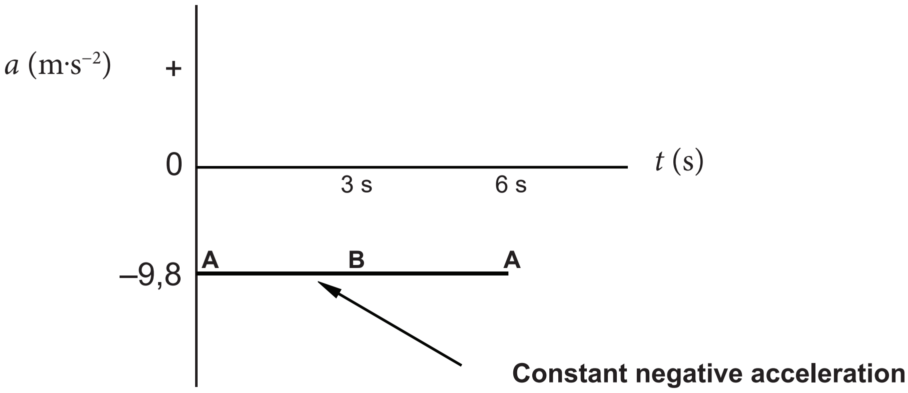
Begin with the ***ACCELERATION versus TIME*** graph.

The **acceleration versus time** graph is very easy to draw because the ball is in *free-fall*, which means the *acceleration* of the ball is **ALWAYS 9,8 m·s^{-2} DOWNWARDS**.

If we choose *UPWARDS* to be positive, then $a = -9{,}8$ m.s^{-2}.

In other words, the ***acceleration*** of the ball is **CONSTANT** and **NEGATIVE**.

Suppose the ball takes ***3 s to reach its maximum height*** (**A** to **B**) then it will take ***3 s to fall*** back down (**B** to **A**) to its point of release.



Now take your learners through the ***VELOCITY versus TIME*** graph for the entire motion of the ball:

The ball is being ***thrown upwards***, therefore the ball must have a ***positive initial velocity***.

Let's suppose the ball is **thrown upward at 20** m·s⁻¹. The initial velocity of the ball at t = 0 is +20 m·s⁻¹.

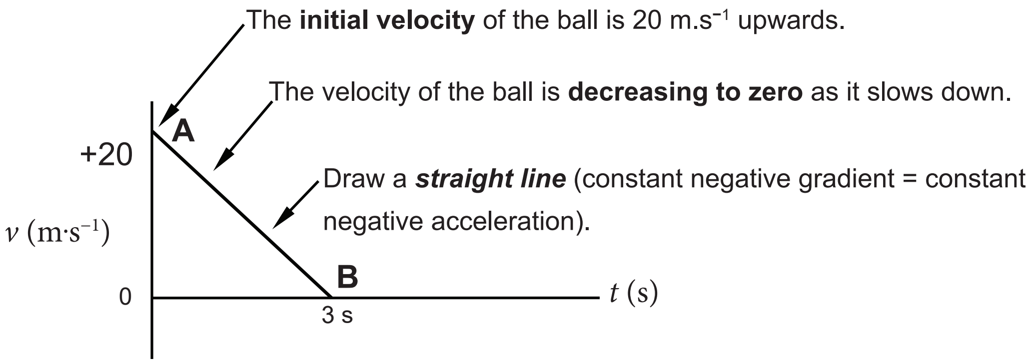
So we need to ***start the graph*** at +20 m·s⁻¹ on the vertical axis.

Remind the learners that the velocity of the ball must ***decrease to ZERO*** while it is moving upwards (**A** to **B**).

Remind the learners that the **GRADIENT** of the ***v-t graph*** must represents the **ACCELERATION** of the ball (**RULE 2**).

The acceleration of the ball is **CONSTANT** and **NEGATIVE**, therefore the **GRADIENT** is **CONSTANT** (a *straight line*) and **NEGATIVE** (a straight line with a *negative slope*).

Draw the velocity versus time graph for the ***UPWARD*** motion (**A** to **B**):



Now consider the ***DOWNWARD*** motion of the ball (**B** to **A**) as it falls back to its point of release.

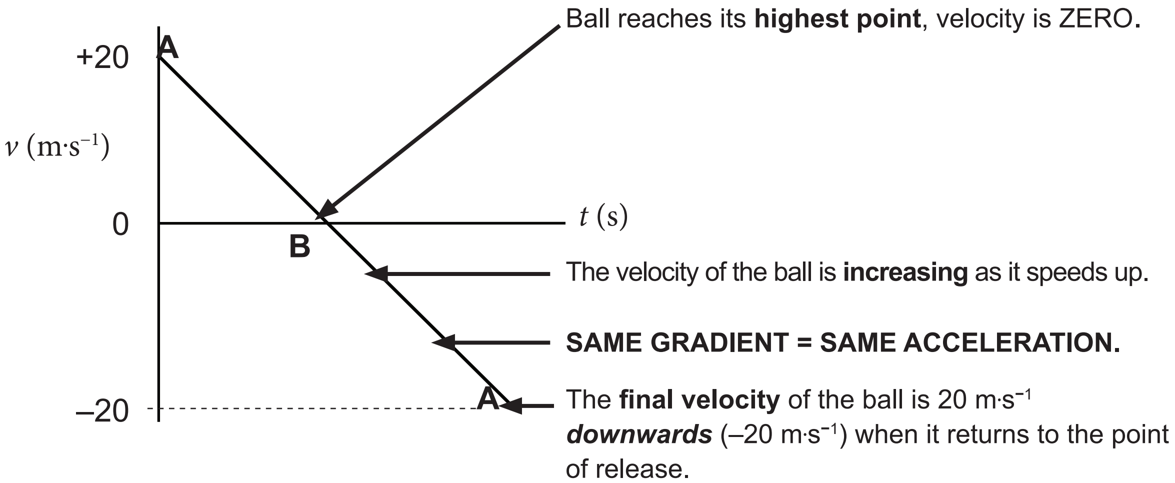
At its highest point **B**, the velocity of the ball is **ZERO**.

The velocity of the ball then begins to **INCREASE** as it falls (**B** to **A**).

Remind your learners that the velocities of the ball are now **NEGATIVE VALUES** (downwards was chosen as the negative direction).

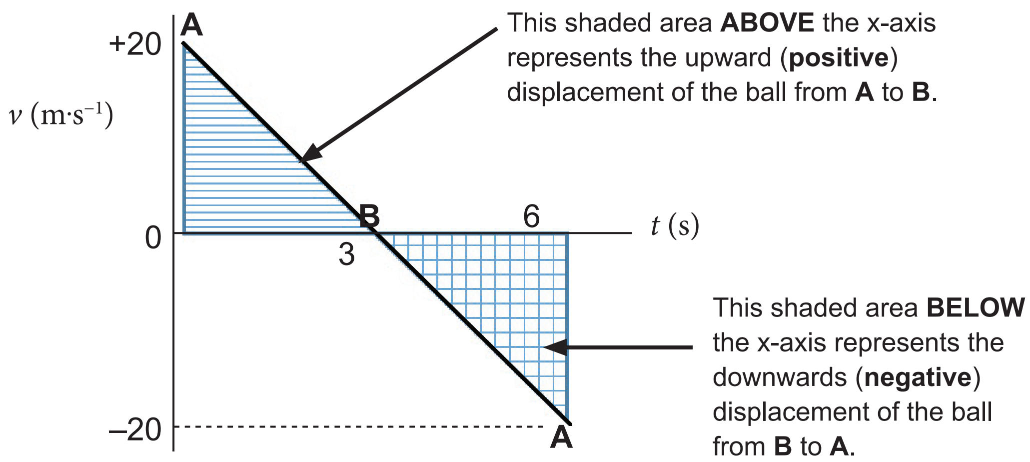
The **NEGATIVE SIGN** is simply the **DIRECTION** in which the ball is moving.

The ***GRADIENT MUST NOT CHANGE*** because the acceleration of the ball has not changed. The acceleration of the ball is ***STILL*** 9,8 m·s⁻² DOWNWARDS.



Remind your learners of ***RULE 3***:

The ***AREA*** under a **VELOCITY** versus **TIME** graph is **EQUAL TO** the ***DISPLACEMENT*** of the ball.



The **DISPLACEMENT** of the ball from **A** to **B** is calculated as follows:

$\Delta x = \text{AREA under the velocity} - \text{time graph}$

$\Delta x = \text{area of the triangle}$

$\Delta x = \frac{1}{2} \times \text{base} \times \text{height}$

$\Delta x = \frac{1}{2} \times (3) \times (+20) = +30 = 30 \text{ m above the point of release A}$

The **DISPLACEMENT** of the ball from **B** back to **A** is calculated as follows:

$\Delta x = \text{AREA under the velocity} - \text{time graph}$

$\Delta x = \text{area of the triangle}$

$\Delta x = \frac{1}{2} \times \text{base} \times \text{height}$

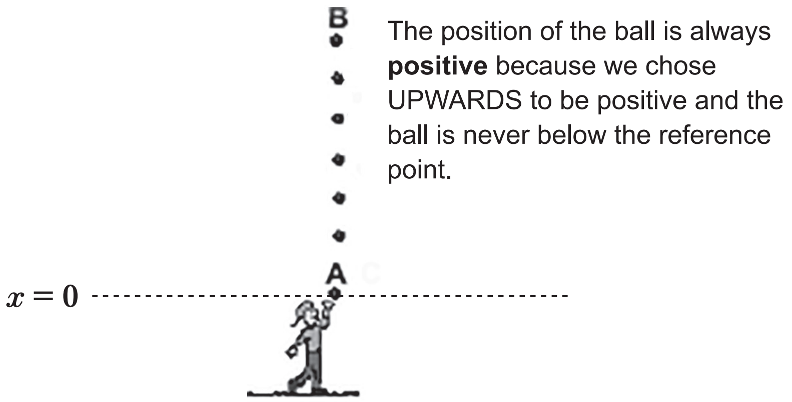
$\Delta x = \frac{1}{2} \times (3) \times (-20) = -30 = 30 \text{ m below the highest point B}$

The resultant displacement of the ball is ZERO.

Now take your learners through the **<u>POSITION versus TIME</u>** graph for the motion of the ball:

FIRSTLY they need to choose a **REFERENCE POINT** $(x = 0)$

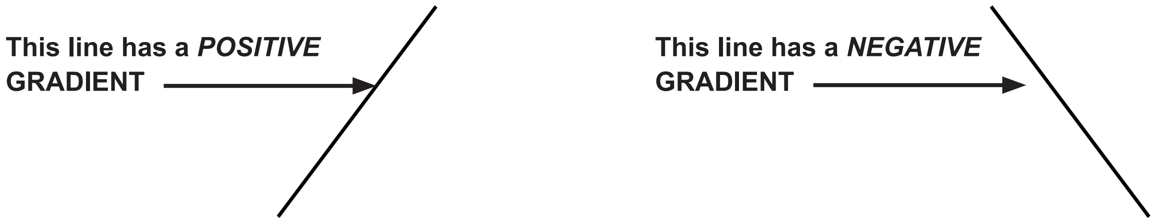
Let's choose the **<u>release point</u> A** as the reference point $(x = 0)$



In this example, the ball is **ALWAYS ABOVE** the reference point **A**. Since we chose **UPWARDS** to be **POSITIVE**, the position of the ball is **ALWAYS POSITIVE**.

The position of the ball would be **NEGATIVE**, **ONLY** if it fell **BELOW** the reference point **A**.

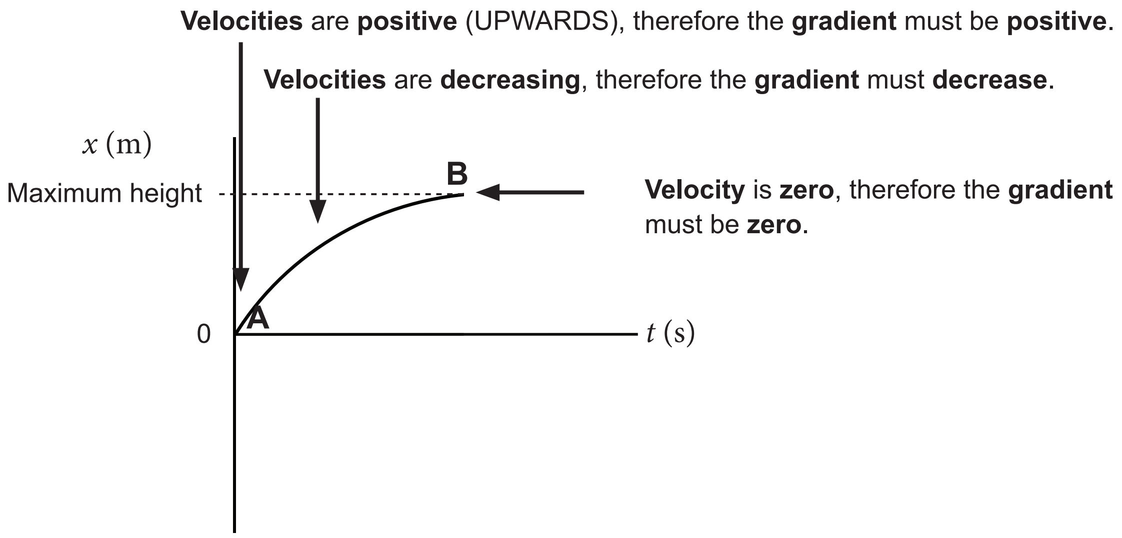
Remind your learners what a **POSITIVE** and a **NEGATIVE GRADIENT** look like:



Remind your learners that the ***GRADIENT*** of a **position versus time** graph represents the ***VELOCITY*** of the ball.

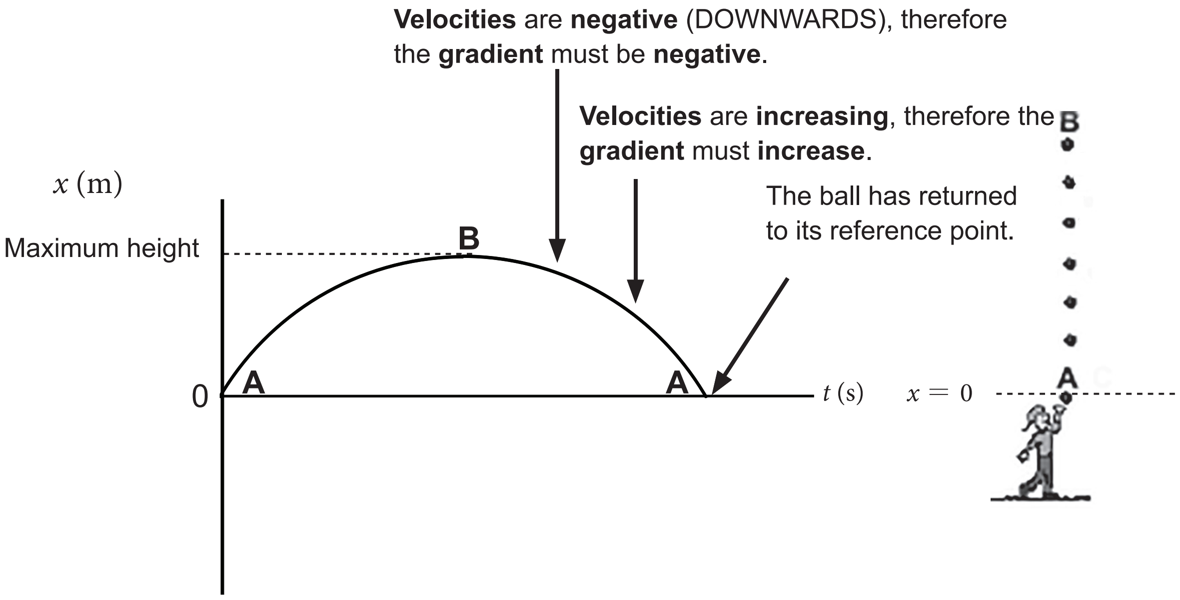
On the way **UP** (**A** to **B**):

1. The ball is moving **AWAY** from the reference point **A**. Its position is becoming **MORE POSITIVE**.
2. The **VELOCITY** of the ball is **POSITIVE** and **DECREASING**.
3. Therefore, the **GRADIENT** of the **x-t graph** must be **POSITIVE** and **DECREASING**.



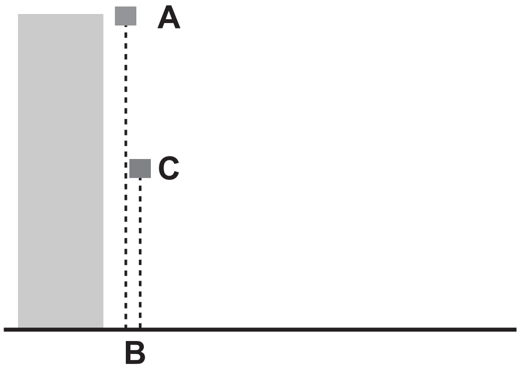
On the way **DOWN** (**B** to **A**):

1. The ball is moving **TOWARDS** the reference point **A**. Its position is becoming **LESS POSITIVE**.
2. The **VELOCITY** of the ball is **NEGATIVE** (changed direction) and **INCREASING**.
3. Therefore the **GRADIENT** of the **x-t graph** must be **NEGATIVE** and **INCREASING**.



2.2 A ball is DROPPED and BOUNCES

Consider a ball, which is dropped from a high cliff (point A), hits the ground (point B) and bounces back up and reaches a maximum height (point C).



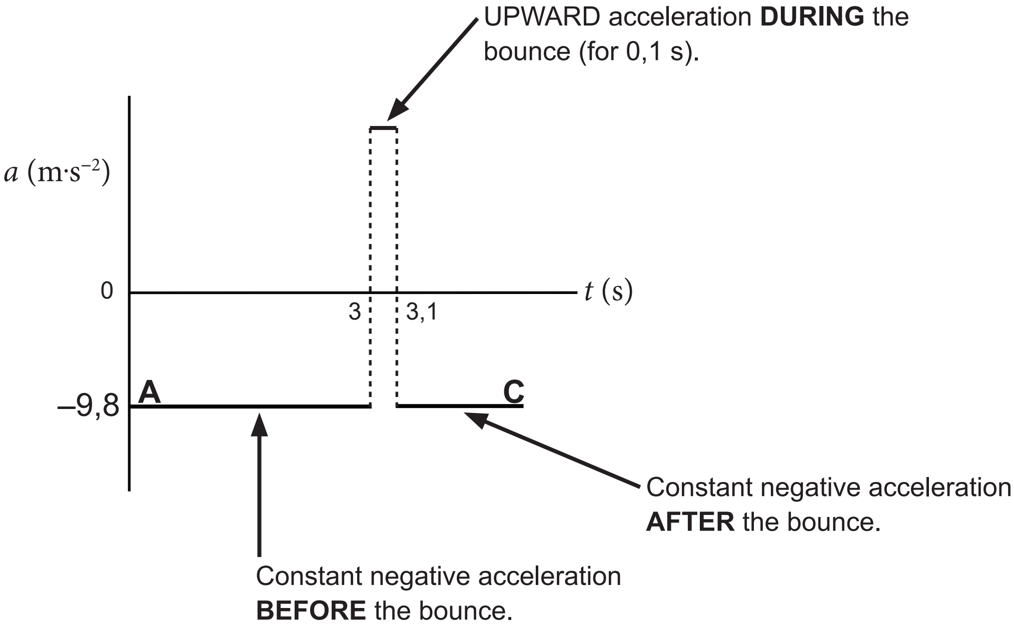
Suppose we choose <u>DOWN</u> as <u>NEGATIVE</u>:

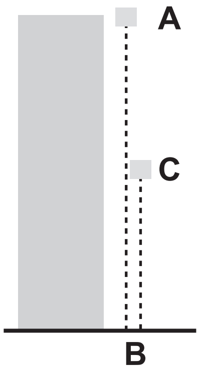
Let's draw the ACCELERATION versus TIME graph:

The ball is in free-fall for the entire motion, EXCEPT when it hits the ground.

The acceleration of the ball must ALWAYS be $-9,8\ m \cdot s^{-2}$, EXCEPT when it hits the ground.

Suppose the ball takes **3 s** to hit the ground and is in contact with the ground for **0,1 s**:



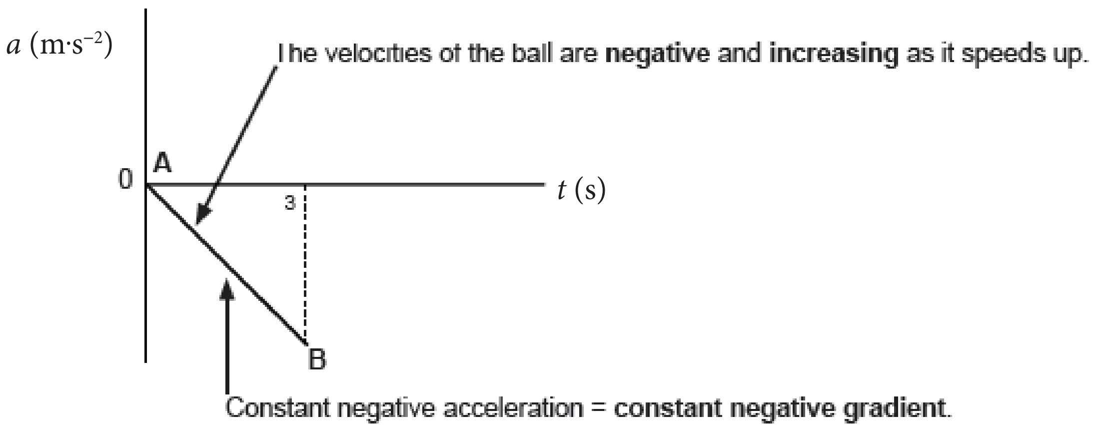


Let's draw the **VELOCITY versus TIME** graph:

FIRSTLY the **initial velocity** of the ball is **ZERO** at **A** (it is dropped).

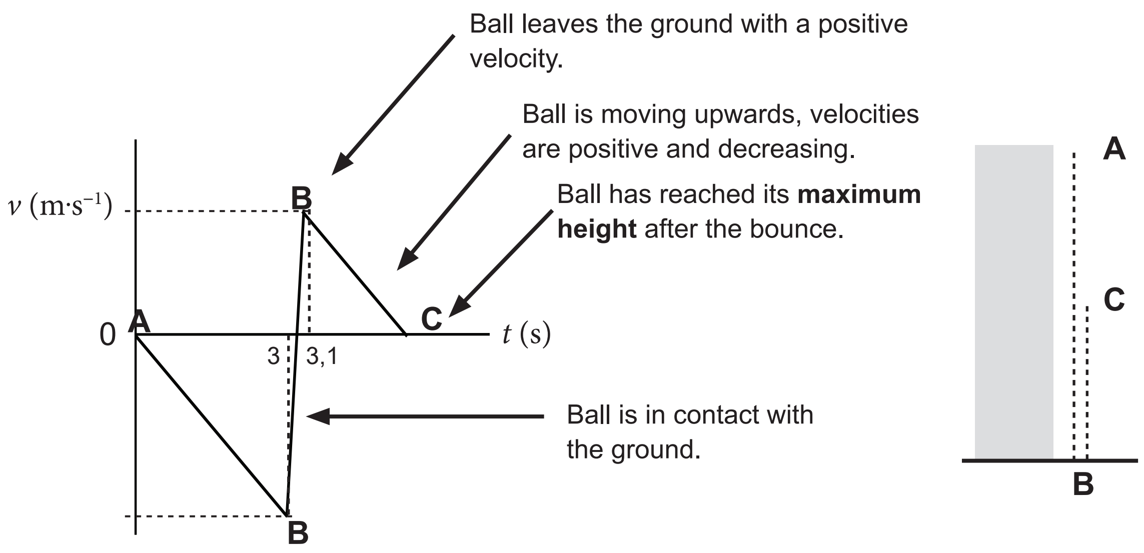
As the ball **falls** from **A to B**, the **VELOCITIES** are **NEGATIVE** (DOWNWARD) and **INCREASING**.

The **ACCELERATION** of the ball is **CONSTANT** and **NEGATIVE**, therefore the **GRADIENT** is **CONSTANT** (straight line) and **NEGATIVE** (slope).



After the ball has bounced at **B**, the ball **CHANGES DIRECTION** and starts moving **UPWARDS** (**B** to **C**).

When the ball moves upwards from **B** to **C**, the **VELOCITIES** are **POSITIVE** (UPWARD) and **DECREASING**.

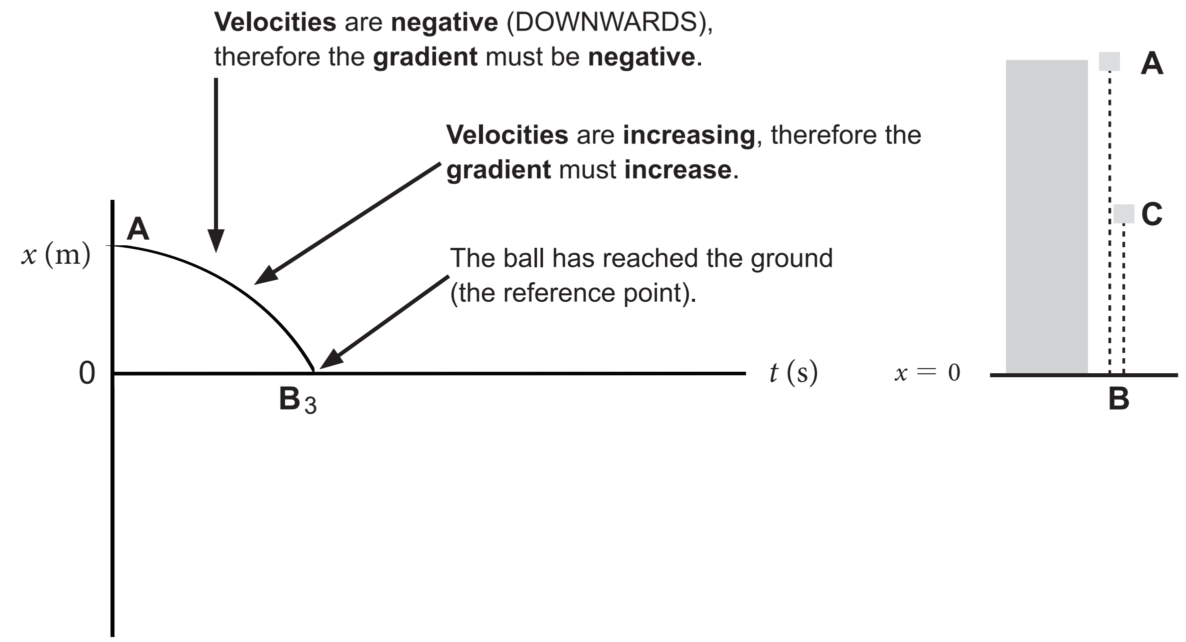


Let's draw the **POSITION versus TIME** graph:

Choose the **GROUND** as the reference point (**B**): $(x = 0)$

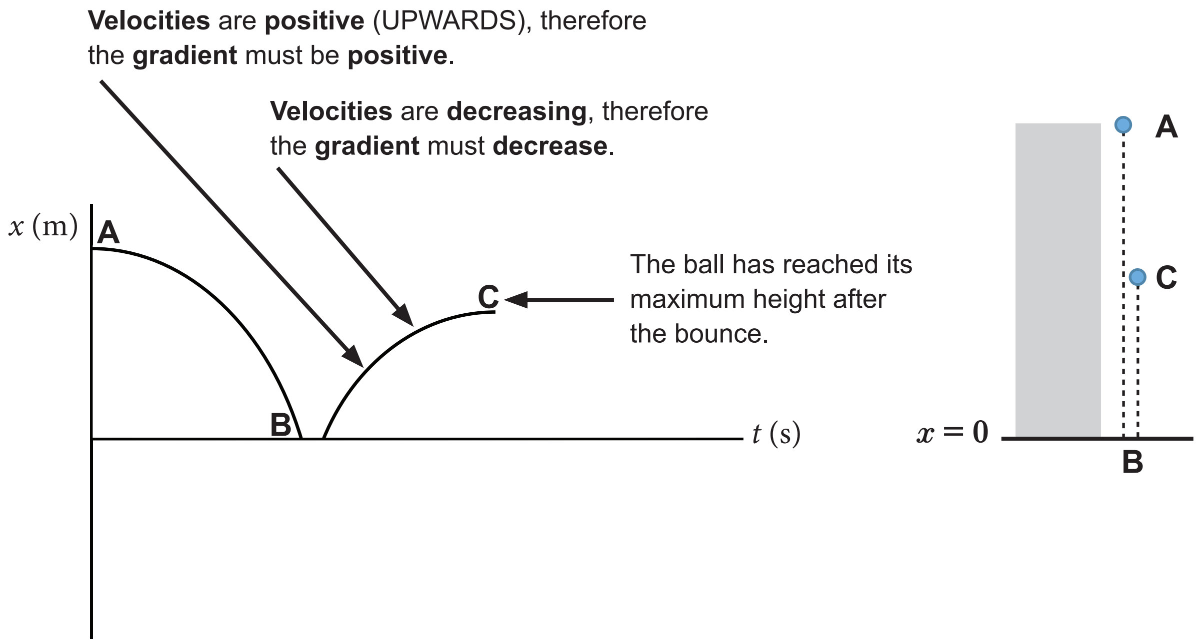
Remember **UPWARDS** is **POSITIVE**. The ball is ALWAYS above **B**, therefore its position values will always be positive.

As the ball falls from **A** to **B**, The velocities are **NEGATIVE** (DOWNWARDS) and **INCREASING**.



After the ball has bounced at **B**, the ball **CHANGES DIRECTION** and starts moving **UPWARDS** (**B** to **C**). The ball is moving **AWAY** from its reference point **B**.

When the ball moves upwards from **B** to **C**, the **VELOCITIES** are **POSITIVE** (UPWARD) and **DECREASING**.



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 familiarise the learners with the basic shapes when drawing x-t, v-t and a-t graphs.

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 down the question and answer it correctly in their workbooks.

1. A ball is thrown vertically upwards from the edge of a cliff X, its reaches its maximum height at Y and the ball hits the ground below at Z. Draw the following graphs for the entire motion of the ball. Label each graph with the letters X, Y and Z.

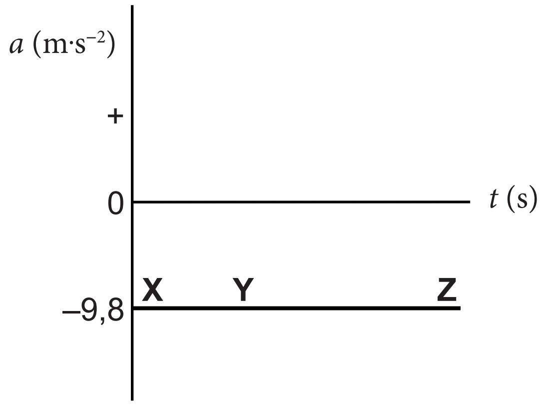
1.1 Acceleration versus time graph.

1.2 Velocity versus time graph.

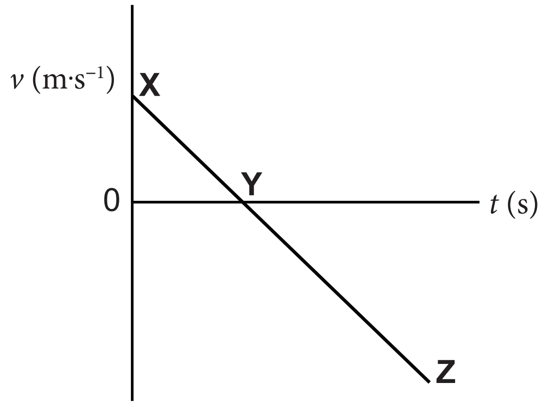
1.3 Position versus time graph. Take the ground as the reference point.

Solution

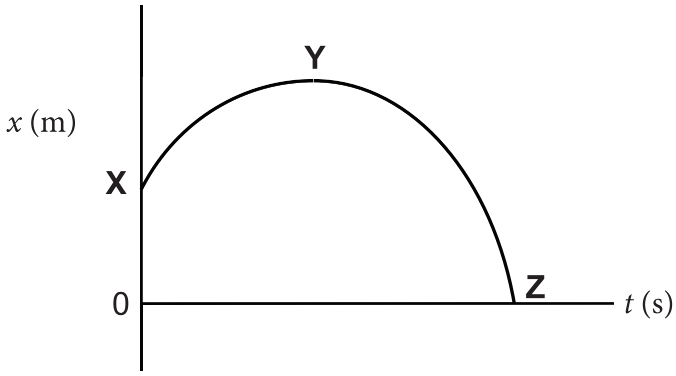
1.1 Choose UPWARDS as positive:



1.2



1.3



CHALLENGE LEVEL QUESTIONS

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

b. These questions require learners to draw more detailed x-t, v-t and a-t graphs by labelling the graphs with calculated values using equations of motion.

c. Given a-t, v-t or x-t graphs, interpret the motion and calculate values from the graph.

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.
- Learners must copy down the question and answer it correctly in their workbooks.

KEY TEACHING

a. In these more challenging examples, learners must interpret graphs.

b. If a graph is given, check if UPWARDS is positive or negative.

c. Look out for a given reference point. This will be important when drawing the x-t graph.

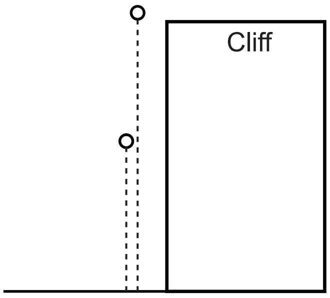
d. Divide the motion into segments, e.g. upward and downward motion.

e. When drawing an x-t graph, ensure that the gradient matches the sign of the velocity.

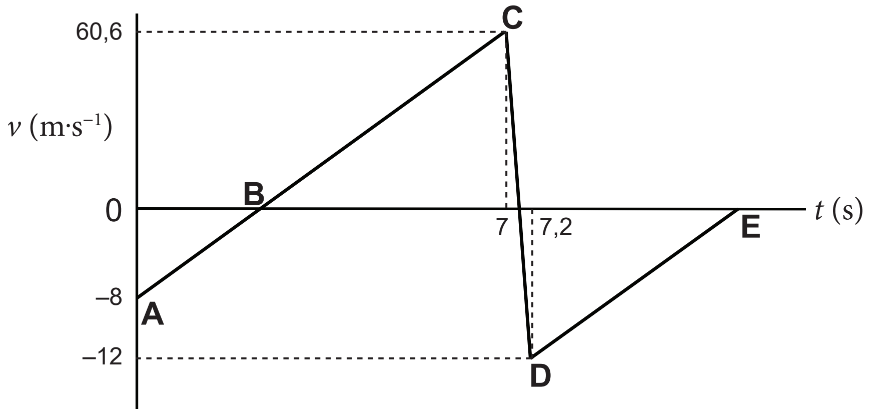
f. The gradient of a v-t graph is equal to the acceleration of the object.

g. The area under a v-t graph is equal to the displacement of the object.

2. An object is projected vertically upwards from the top of a cliff. The object hits the ground at the base of the cliff and bounces upwards as shown in the diagram below.



The velocity versus time graph of the motion of the object is shown below:



2.1 What is the magnitude and direction of the initial velocity of the object?

2.2 Describe the motion of the object during the first 7 s.

2.3 Use your graph to calculate the magnitude and direction of the acceleration of the object in the time interval:

2.3.1 0 – 7 s

2.3.2 7 – 7,2 s

2.4 Calculate the time taken for the object to reach point B.

2.5 Use your graph to determine how long it took the object to travel form its highest point to the bottom of the cliff.

2.6 Use the graph to calculate the height of the cliff.

2.7 Where is the object in its motion at time E?

2.8 Draw a position versus time graph for the entire motion. Take the point of release as the reference point. Label your graph with the following values:
- The value of the time taken for the object to reach its maximum height.
- The height of the cliff.
- Points A, B, C, D and E.

Solutions

2.1 From the graph, UPWARDS is NEGATIVE.
8 m·s^{-1} upwards

2.2 Constant acceleration downwards.

2.3.1 $a = \text{gradient} = \frac{\Delta y}{\Delta x} = \frac{v_f - v_i}{\Delta t} = \frac{60,6-(-8)}{7} = \frac{68,6}{7} = 9,8$ m·s^{-2} downwards

2.3.2 $a = \text{gradient} = \frac{\Delta y}{\Delta x} = \frac{v_f - v_i}{\Delta t} = \frac{-12-(+60,6)}{0,2} = \frac{-72,6}{0,2} = -363$
therefore $a = 363$ m·s^{-2} upwards

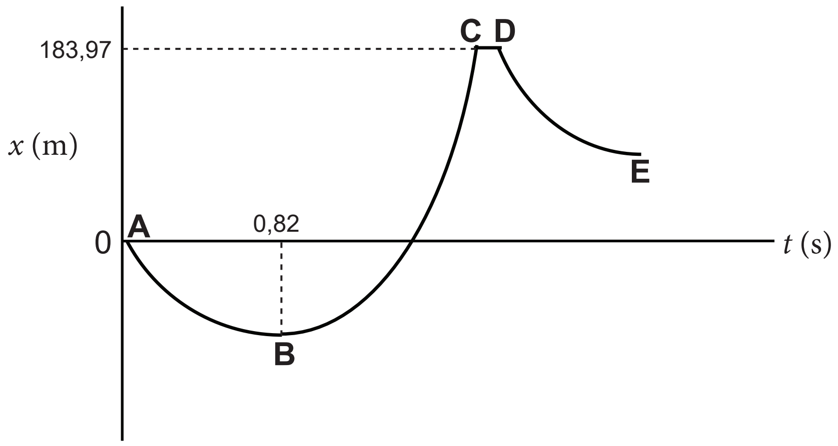
2.4 $v_f = v_i + a\Delta t$
$0 = (-8) + (+9,8)\Delta t$
$8 = 9,8\Delta t$
$\Delta t = 0,82$ s

2.5 $\Delta t = 7 - 0,82 = 6,18$ s

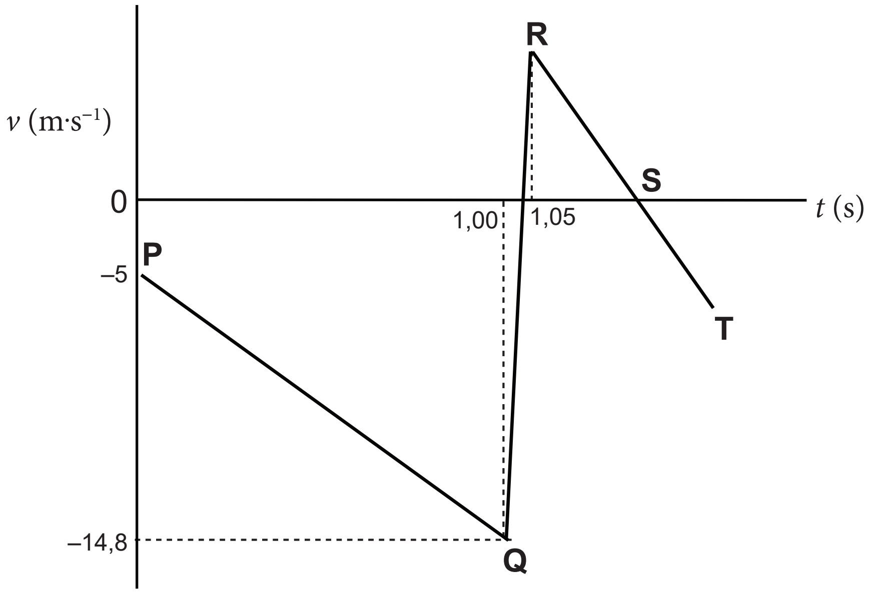
2.6 $\Delta x = \text{area under graph} = \frac{1}{2}(0,82)(-8) + \frac{1}{2}(6,18)(60,6)$
$\Delta x = -3,28 + 187,254$
$\Delta x = 183,97$ m below point of release
Height of cliff = 183,97 m

2.7 The object has reached its maximum height above the bottom of the cliff after the bounce.

2.8 From the v-t graph, ***UPWARDS* is *NEGATIVE***:



3. The following diagram shows the velocity versus time graph for a ball that bounces when it collides with the ground during an experiment.



3.1 Is the ball initially dropped, thrown upwards or thrown downwards? Explain your answer.

3.2 Describe the motion of the ball from P to Q.

3.3 At which point on the graph does the ball reach its maximum height after the bounce?

3.4 Use the graph to determine the magnitude and direction of the acceleration of the ball during the first second of its motion.

3.5 Use the graph to calculate the height from which the ball was released above the ground.

3.6 For how long (in seconds) is the ball in contact with the ground?

3.7 Your friend looks at the graph and says that segment P to Q is drawn to scale but segment R to T is not. Do you agree? Explain your answer.

3.8 Draw a position versus time graph for the entire motion of the ball. Take the point of release as the reference point. Provide the following labels for your graph.
- The height of the ball when released.
- The time taken to hit the ground.
- Labels P, Q, R, S and T.

3.9 Draw an acceleration versus time graph for the entire motion of the ball. No values need to be shown.

Solutions

3.1 Thrown downwards. Velocities are increasing after release.

3.2 Constant acceleration downwards.

3.3 S (Since the velocity is zero)

3.4 a = gradient $= \frac{\Delta y}{\Delta x} = \frac{v_f - v_i}{\Delta t} = \frac{-14,8-(-5)}{1} = \frac{-9,8}{1} = -9,8 = 9,8$ m·s^{-2} downwards

3.5 Δx = area under graph $= (-5)(1) + \frac{1}{2}(1)(-9,8)$

$\Delta x = -5 - 4,9$

$\Delta x = -9,9 = 9,9$ m below point of release

Height = 9,9 m above the ground

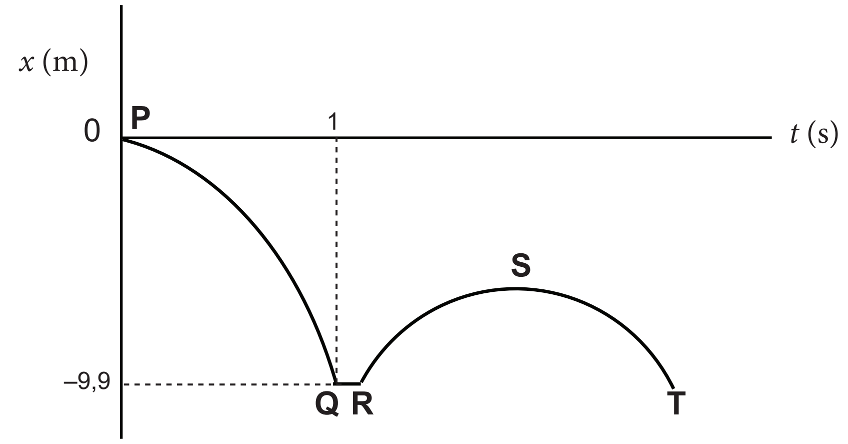
3.6 $\Delta t = 0,05$ s

3.7 Agree.

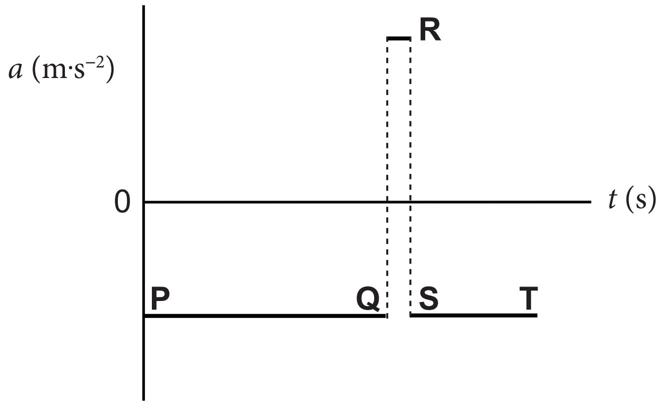
Line RT does not have the same gradient as PQ.

It should have the same gradient (slope) because the ball is in free-fall before and after the bounce.

3.8



3.9



CHECKPOINT

1. At this point in the topic, learners should have mastered the following:
2. The acceleration due to gravity is ALWAYS DOWNWARDS.
3. Drawing x-t, v-t and a-t graphs.
4. Calculating the acceleration from a v-t graph.
5. Calculating the displacement from a v-t graph.

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

Worksheet Pack:
Vertical projectile motion in one dimension 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 for feedback.
- Encourage the learners to learn from the mistakes they make.

CONSOLIDATION

- Learners can consolidate their learning by completing; **Resource Pack, Worksheet: Vertical projectile motion in one dimension 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 use 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=Kpisbb-KVCc&t=1360s
   Equations of motion
2. https://www.youtube.com/watch?v=nJs4HkF9N18&t=103s
   *Graphs of motio*n
3 https://www.youtube.com/watch?v=QADJYB32-eE&list=PL31jJSNW1UoUBlsuSEsxClJkV6aYls6td
   Vertical projectile motion (gravitational force)

TOPIC 4:

Organic Molecules

A Introduction

- This topic runs for 16 hours (12 hours for Organic Chemistry and 4 hours for Organic Macromolecules (plastics and polymerisation).
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Organic molecules forms part of the content area Matter and Materials (Chemistry).
- Matter and Materials counts approximately 30 % in the final Chemistry (Paper 2) examination.
- Organic Chemistry, which is the only Matter and materials component of the Grade 12 syllabus, thus counts approximately 30% of the final Chemistry examination.
- Organic chemistry is the study of the chemistry of carbon based molecules in living structures. Organic molecules form a massive part of the understanding of energy and energy transfers is one of the most important concepts in science and economics in the world today. Mankind needs to find new solutions to solving the problems caused by decades of fossil fuel use. We can only solve problems if we truly understand the basic concepts. This topic presents an introduction to Organic chemistry where identifying, naming and studying organic chemical reactions will be covered

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard or whiteboard

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. A4, 3 Quire exercise book, for notes and exercises.
2. Pen and pencil.
3. Eraser
4. Ruler

B Sequential Table

PRIOR KNOWLEDGE	CURRENT
GRADE 10-11	**GRADE 12**
• Interatomic forces within a chemical bond and Intermolecular forces between compounds. (Grade 11) • Identify and name different intermolecular forces from molecular structures (Grade 11) • Atomic combinations and molecular structure , (Grade 11) • Chemical systems : Exploiting the Lithosphere. (Grade 11) • Covalent bonding (Grade 10) • Balancing of chemical reactions. (Grade 10)	• No prior knowledge required at this stage in Grade 12

TOPIC 4

C Glossary of Terms

TERM	DEFINITION
Homologous Series	A series of organic compounds that can be described by the same general formula OR in which one member differs from the next with a CH_2 group.
Functional Group	A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds
Molecular formua	A chemical formula that indicates the type of atoms and the correct number of each in a molecule
Saturated compound	Compounds in which there are no multiple bonds between C atoms in their hydrocarbon chains
Unsaturated compound	Compounds with one or more multiple bonds between C atoms in their hydrocarbon chains
Structural Isomers	Organic molecules with the same molecular formula but different structural formulae
Organic molecules	Molecules containing carbon atoms
Chain isomers	Same molecular formula, but different types of chains, e.g. butane and 2-methylpropane
Positional isomers	Same molecular formula, but different positions of the side chain, substituents or functional groups on the parent chain, e.g. 1-chloropropane and 2-chloropropane or but-2-ene and but-1-ene
Functional isomers	Same molecular formula, but different functional groups, e.g. methyl methanoate and ethanoic acid
IUPAC	International Union of Pure and Applied Chemists
Parent chain	The main carbon chain present in the compound
Alkyl substituent/alkyl group	A carbon side branch that comes off the parent chain
Vapour pressure	The pressure that organic particles in the gas phase exert on the surface of a liquid
Flammability	The measure of the ese at which a substance burns
Combustion	The burning of a substance in the presence of oxygen
Hydrolysis	A substitution reaction where a haloalkane reaction with a strong base
Catalyst	Substance that speeds up a chemical reaction but does not undergo any chemical change itself
Macromolecule	A molecule that consists of a large number of atoms
Polymer	A large molecule composed of smaller monomer units covalently bonded to each other in a repeating pattern

Monomer	Small organic molecules that can be covalently bonded to each other in a repeating pattern
Free radical	A molecular fragment that has an unpaired electron

D Assessment of this Topic

- This topic is assessed through informal and class tests and in the midyear and final Grade 12 examinations
- Types of questions that are frequently asked to test this topic are :
- Multiple choice type questions
- Explanation of concepts and terminology
- Long structured questions
- Flow diagrams of organic reactions

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
3 hours	Organic molecular structure	99	**Key concepts and possible misconceptions are clarified and explained** **a.** The chemistry of carbon, homologous series, general formula and functional groups **b.** Saturated and unsaturated structures **c.** Non-hydrocarbon structures and functional groups **d.** Branched alkanes and alkenes **e.** Structural isomers
3 hours	IUPAC naming and formulae	105-106	**Key concepts and possible misconceptions are clarified and explained** **a**. Representing organic molecules **b.** Naming organic molecule
1 hours	Structure physical property relationships	106	**Key concepts and possible misconceptions are clarified and explained** **a.** Physical properties and intermolecular forces
1 hour	Applications of organic chemistry	107	**Key concepts and possible misconceptions are clarified and explained** **a.** Combustion and esterification reactions
3 hours	Substitution, addition and elimination	108-114	**Key concepts and possible misconceptions are clarified and explained** **a.** substitution **b.** elimination **c.** addition reactions
4 hours	Plastics and polymers	114-116	**Key concepts and possible misconceptions are clarified and explained** **a.** Addition polymerisation **b.** Condensation polymerisation

1. ORGANIC MOLECULAR STRUCTURES

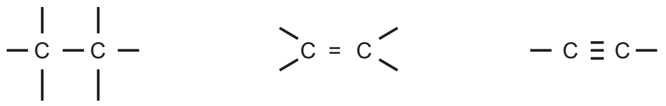
INTRODUCTION

Organic chemistry is the chemistry of carbon based compounds where carbon is considered to be the basic building block of all organic compounds. We find organic compounds in virtually every area of our lives, from the paraffin that is used in stoves, to the gas we use in stoves and heaters, to the petrol we put into our cars, to the composition of the food we eat. Organic chemistry is a huge section in the world of chemistry and this module will look to introduce the basic foundation as to what organic chemistry actually is and examine a few of the millions of organic structures that fill our world.

CONCEPT EXPLANATION AND CLARIFICATION: THE CHEMISTRY OF CARBON, HOMOLOGOUS SERIES, GENERAL FORMULA AND FUNCTIONAL GROUPS

To begin this very large and interesting topic, it is highly recommended that teachers spend a little bit of time looking at the unique features of carbon. Very often learners will ask the question: "Why does carbon and no other atom form the backbone of organic chemistry?" The answer to that is based on these unique features of the C atom.

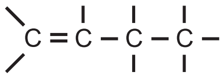
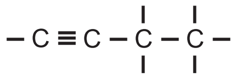
- Carbon has 4 unbonded electrons that are able to make 4 strong covalent bonds.
- Carbon has the ability to bond with itself to form chain or ring structures. This is known as **catenation.**
- Carbon has the ability to make multiple bonds with itself.



single bond   double bond   triple bond

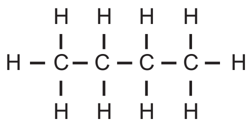
Notice that there must be 4 bonds made to each carbon, and that these bonds must be shown when drawing the **structural formula** of the molecule.

Once the learners have understood these unique features, it is now time to introduce the learners to the different types of organic compounds, how to identify them and then how to illustrate or draw them. The first type or class of organic compounds we need to introduce is known as the **hydrocarbons**. Explain to the learners that the name 'hydrocarbon' simply means that the compounds consist of hydrogen and carbon atoms only. This is when teachers need to introduce the 3 'families' of hydrocarbons to the learners, namely the **alkanes**, **alkenes** and the **alkynes**. The scientific name given to 'families' of organic compound is known as the **homologous series.** To identify these families or homologous series, get the learners to realise that there has to be an identifying characteristic in the compound that places that compound into its homologous series. This identifying characteristic is known as a **functional group** which also forms the centre of chemical reactivity in the compound.

Homologous Series	Alkanes	Alkenes	Alkynes
Functional Group	Carbon to carbon single bond only	Carbon to carbon double bond	Carbon to carbon triple bond
Structure			

The table above summarises the 3 hydrocarbon 'families' or homologous series as well as showing the identifying characteristic or functional group of each. These functional groups can be anywhere in the organic compound, so make sure that the learners do look at the whole structure of the compound when looking for identifying characteristics. Remember that learners are only expected to work with organic compounds to a maximum of 8 carbons.

Get the leaners to draw the structures of different alkanes, alkenes and alkynes making sure that they place hydrogens on all the available bonding sites as these are hydrocarbon molecules. For example:



Now make them count the number of carbon and hydrogen atoms for each homologous series for compounds with different numbers of carbon atoms in their structure, and then show them that each homologous series fits a specific pattern:

Alkanes C_nH_{2n+2}

Alkenes C_nH_{2n}

Alkynes C_nH_{2n-2}

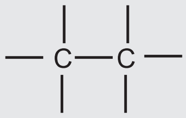
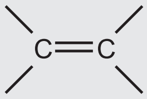
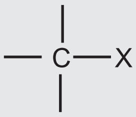
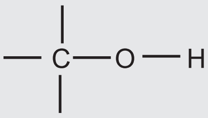
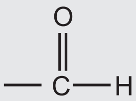
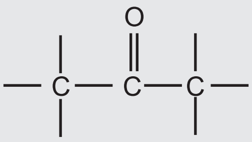
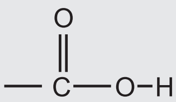
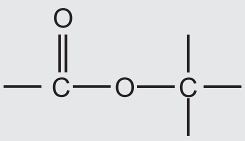
This is known as the **general formula** of the homologous series and all compounds in the same homologous series will obey the same general formula. Get them to practice writing, identifying and drawing hydrocarbon structures by giving then various molecular formulae of hydrocarbons. For example:

C_5H_{12} - 5 carbon alkane as fits the general formula C_nH_{2n+2}

C_3H_6 - 3 carbon alkene as fits the general formula C_nH_{2n}

C_6H_{10} - 6 carbon alkyne as fits the general formula C_nH_{2n-2}

Show the learners that the functional group can be on any carbon, and that the general formula will still apply.

Homologous series	Structure of functional group	
	Structure	**Name**
Alkanes		Only C-H and C-C single bonds
Alkenes		Carbon-carbon double bond
Alkynes		Carbon-carbon triple bond
Haloalkanes	 (X = F, Cℓ, Br, I)	–
Alcohols		Hydroxyl group
Aldehydes		Formyl group
Ketones		Carbonyl group
Carboxylic acids		Carboxyl group
Esters		-

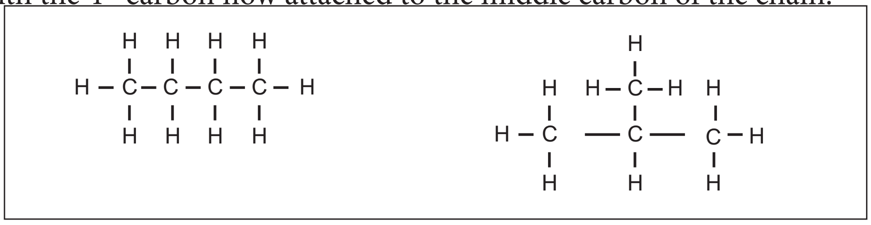
TOPIC 4

Make sure that the learners note the following:

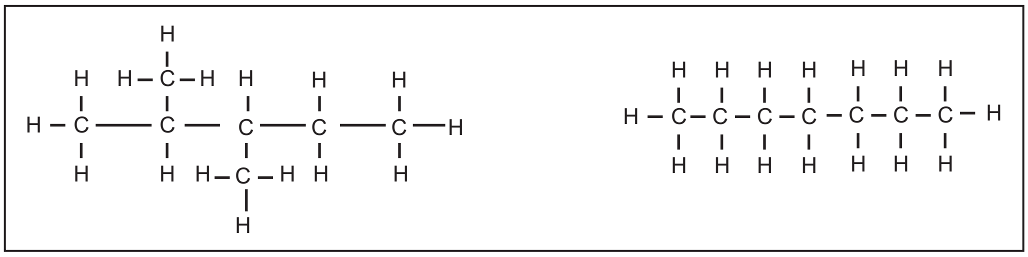
- Halo functional group – the X represents any of the halogen atoms bonded to a carbon atom in the compound.
- Hydroxyl functional group – the name comes from 'hydroxide'.
- A carbonyl group consists of a carbon atom double bonded to an oxygen atom. These occur in carboxylic acids, aldehydes and ketones. ONLY ketones have the carbonyl group as the FUNCTIONAL GROUP.
- Aldehydes have the carbonyl group at the end of their chain, and you can see that there is a hydrogen atom bonded to the carbon atom as well. This particular group of atoms is called a formyl group, and it characterises aldehydes. **This is very important**!!

CONCEPT EXPLANATION AND CLARIFICATION: BRANCHED ALKANES AND ALKENES

Now that the learners are able to identify different functional groups on straight chained compounds, the next step is to introduce to the learners that organic compounds may also be found with side branches. Use alkanes and alkenes to develop this concept by drawing a 4 carbon straight chained alkane with all the hydrogen's attached. Alongside this compound, draw another compound with 4 carbons, but this time with only 3 carbons in the chain with the 4th carbon now attached to the middle carbon of the chain.



Explain to the learners that this is known as a **branch** or a "side chain" and thus these are known as **branched alkanes**. These branches are attached to the main carbon chain, also known as the **parent chain**. The same can happen with alkenes as well. Give learners additional examples with compounds with two side branches and compare them to the straight chain with the same number of carbons.



Branched structure   Straight chain structure

C_7H_{16} – obeys the alkane general formula

For each example, make the learners write down the molecular formula for both the straight and branched chained compounds... and get the learners to see that the molecular formulae are exactly the same for the same number of carbons in the compounds. They also still obey the general formula of C_nH_{2n+2} for alkanes and C_nH_{2n} for alkenes.

Once they have seen this, you are now ready to introduce the concept of ISOMERS.

CONCEPT EXPLANATION AND CLARIFICATION: STRUCTURAL ISOMERS

Structural isomers are two or more organic compounds that have the same molecular formula but different structural formula.

Now introduce to the learners that there are THREE types of structural isomers

- Chain isomers
- Positional isomers
- Functional isomers

Chain isomers – The name "chain" comes from the fact that the chain length and number of branches on the chain can vary for compounds with the same number of carbons. Tell the learners that the examples that they did earlier were all examples of chain isomers. Make sure that learners practice drawing chain isomers when they are given a molecular formula.

Positional isomers – these are isomers where the position of a functional group or side chain is changed on the compound. For example:

C_4H_8 C_4H_8

Here the learners can see that the double bond has moved from the 1st carbon to the 2nd. The double bond has changed its position, hence positional isomer.

Functional isomer – these are isomers where the functional group of the molecule has changed, in other words, the compounds still have the same molecular formula, but belong to a new homologous series. Explain to the learners that there are two sets of functional isomers that can be identified.

1. Carboxylic acids and esters

$C_4H_8O_2$ $C_4H_8O_2$

2. Aldehydes and ketones

C_3H_5O C_3H_6O

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 familiarise the learners with the introductory concepts in organic chemistry.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each question to the learners as you complete it on the chalkboard.
- Learners must copy down the question and answer it correctly in their workbooks.

1. Write down the general formulae for the alkanes, alkenes and the alkynes

Solution

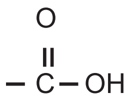
C_nH_{2n+2}	C_nH_{2n}	C_nH_{2n-2}
Alkanes	Alkenes	Alkynes

2. Name the homologous series to which the following functional groups belong and provide the name associated with the functional group

2.1 C – X where X = F, Cl Br or I

2.2 C – O-H

2.3



Solution

2.1 *Alkyl halide* *halo functional group*

2.2 *Alcohol* *hydroxyl functional group*

2.3 *Carboxylic acid* *carboxyl functional group*

3. Name the 3 different types of structural isomers and explain the difference between each.

Solution

Chain isomer – *Same molecular formula, but different types of chains*

Positional isomers – *Same molecular formula, but different positions of the side chain, substituents or functional groups on the parent chain*

Functional isomers – *Same molecular formula, but different functional groups*

CHALLENGE LEVEL QUESTIONS

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

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 and 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.
- Learners must copy down the question and answer it correctly in their workbooks.

1. Explain the following terms:

1.1 Homologous series

1.2 Functional group

1.3 Hydrocarbon

Solution

1.1 *A series of organic compounds that can be described by the same general formula OR in which one member differs from the next with a CH_2 group.*

1.2 *A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.*

1.3 *An organic compound that contains only carbon and hydrogen atoms in its structure*

2. Explain the difference between a straight chain alkane and a branched alkane

Solution

Straight chain alkanes are hydrocarbons where all the carbon atoms in the structure are in a continuous chain with single bonds between the carbon atoms.

Branched alkanes are hydrocarbons where carbon side chains are attached to the parent chain.

3. What name is given to the branch that comes off the carbon chain in branched alkanes?

Solution

Alkyl substituent

4. What is the difference between a saturated and an unsaturated hydrocarbon?

Solution

A saturated hydrocarbon is a hydrocarbon that has only single bonds between all its atoms.

An unsaturated hydrocarbon is a hydrocarbon which has a double or triple bond between one or more of its carbon atoms.

KEY TEACHING

a. In these more challenging questions, learners must be aware of explaining what certain concepts mean as they form the essential understanding of organic chemistry.

b. Learners must know all the homologous series and functional groups in the CAPS document.

c. Learners must be able to draw functional groups and recognise them in a molecular structure

d. Learners must know all three types of structural isomerism.

2. IUPAC NAMING AND FORMULAE

INTRODUCTION

Learners should be able to name organic compounds given the structural formula as well as to be able to draw structural formulae from the name of the organic compound. This sub-topic will explain the different ways of how to represent organic molecules and how to name organic compounds that belong to different homologous series.

CONCEPT EXPLANATION AND CLARIFICATION: REPRESENTING ORGANIC MOLECULES

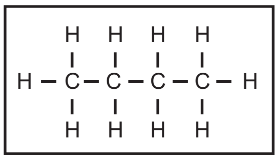
Before you start with the concepts of naming organic molecules, take time now to show the different ways one is able to draw and represent organic molecules. There are three types of formulae which can be used to represent organic molecules:

a. Structural formulae

b. Condensed structural formulae

c. Molecular formulae

Structural formula: This is the FULL representation of the organic compound showing all the bonds to each atom in the molecule. We have been using this particular representation up until this stage as seen in the earlier part of this topic.



Condensed structural formula: This representation is a less complex way of representing the organic compound where the bonds to each of the atoms are not shown. Please note that all the bonds between the carbons and the hydrogen's in the molecule are still present. Looking at the full structural formula of the molecule represented above, show the learners the condensed structural formula of this compound.

$$CH_3CH_2CH_2CH_3$$

Show the learners that the bonds are not present and simply the numbers of hydrogens present around each carbon atom are given by the number written as a subscript.

Molecular formula: This representation shows the total number of carbon and hydrogen atoms in the compound and the bonds are not shown. Once again, use the example above to show the learners the molecular formula.

$$C_4H_{10}$$

CONCEPT EXPLANATION AND CLARIFICATION: NAMING ORGANIC COMPOUNDS

Straight chain organic compounds

Explain to the learners that the name of all organic compounds is based on the number of carbons found in the longest continuous carbon chain within that molecule. Depending on the number of carbon atoms one of the following prefixes is used:

1 x C	meth
2 x C	eth
3 x C	prop
4 x C	but
5 x C	pent
6 x C	hex
7 x C	hept
8 x C	oct

The name is then concluded based on the homologous series to which the compound belongs. This is the suffix or last part of the name and is specific to that compound's homologous series. Here is a list of suffix names:

Alkane	-ane
Alkene	-ene
Alkyne	-yne
Alcohol	-anol
Carboxylic acid	-anoic acid
Ester	-anoate
Aldehyde	-anal
Ketone	-anone

Tell the learners that alkyl halides are slightly different in that the name of the halogen comes before the chain name e.g. chloroethane

Some examples:

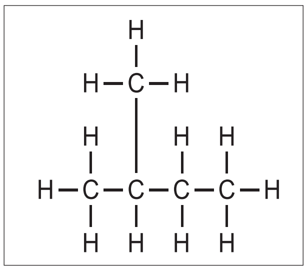
1. a 4 carbon alkane = butane — **but** = 4 x C — **-ane** = belongs to homologous series alkanes
2. a 5 carbon alkyne = pentyne — **pent** = 4 x C — **-yne** = belongs to homologous series alkynes
3. a 3 carbon alcohol = propanol — **prop** = 3 x C — **-anol** = belongs to the homologous series alcohols
4. a 6 carbon carboxylic acid = hexanoic acid — **hex** = 6 x C — **-anoic acid** = belongs to homologous series
5. a 4 carbon alkyl halide with bromine attached = bromobutane — **bromo** = bromine halogen attached — **butane** = 4 x C alkane chain

Branched organic compounds (Single branch)

Remind the learners that organic compounds may have side branches/chains and now introduce the general term given to these side branches, namely **alkyl substituents or alkyl group**. The number of carbons on each alkyl substituent determines the name of the alkyl group. Note the name of the alkyl group ends in -yl.

1 x C side branch = methyl group

2 x C side branch = ethyl group



Show the learners this example and take them through the steps in naming this type of compound.

1. Identify the longest continuous carbon chain and put a block around it. *Here it is 4 carbons long.*

2. Name the longest chain according to the rules. *butane*

3. Identify the alkyl substituent and name it. *methyl*

4. Number the main chain so that the alkyl group is on the ***lowest numbered carbon***. *This will be carbon number 2 as will be the lowest number if numbered from left to right.*

5. Now put the name together. The alkyl group comes before the main chain.

2 - methylbutane

   - This means that on carbon 2, there is a methyl group attached to a butane chain.
   - Also note that a hyphen (-) must separate the number and name ***at all times***.

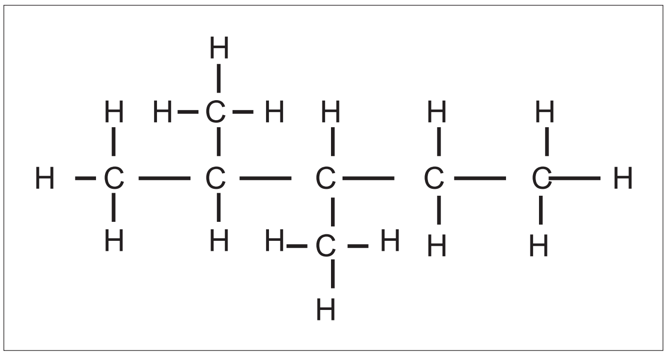
   It is also very important for the learners to be able to write the condensed structural formula for branched chained compounds. This example will be written as follows:

$CH_3CH(CH_3)CH_2CH_3$

   It is important to note that any alkyl groups are placed into the condensed formula in a bracket. The carbon to which the group is attached is always the carbon to the left of the bracket in the formula

Branched chained organic compounds (double branch)

Now move onto examples where there are two branches on the main carbon chain



The naming process is exactly the same, except now both the alkyl groups must be on the lowest carbons on the main chain. The lowest position will be carbon 2 and carbon 3 if numbered from left to right. (If numbered from right to left, it will be carbon 3 and carbon 4 – too high)

Thus the name of this compound will be:

2,3-dimethylpentane

- The position numbers must be separated by a comma (,)
- The word "di" must be placed before the alkyl group name to indicate that there are two alkyl groups in the compound.
- If the alkyl groups are different, they must be placed in alphabetical order e.g. chloro comes before ethyl which comes before methyl.

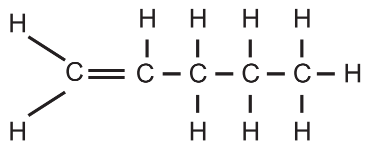
The condensed structural formula for this compound will include:

$CH_3CH(CH_3)CH(CH_3)CH_2CH_3$

Naming alkenes, alkyl halides, alcohols and ketones

Once again tell the learners that the same rules apply, except that it is now the position of the functional group in these compounds that must be indicated with a number in the name.

1. **Alkenes**



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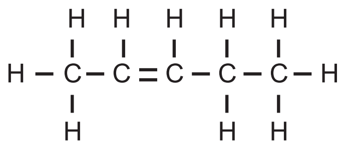


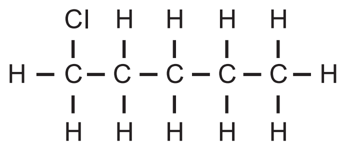
pent-1-ene **pent-2-ene**

Number the main chain so that the double bond (functional group) is on the lowest carbon. This number is indicated between the prefix and the suffix and must be separated by hyphens (-).

The condensed structural formula for these alkenes will be:

$CH_2CHCH_2CH_2CH_3$ $CH_3CH_2CHCHCH_3$

2. **Alkyl halides**



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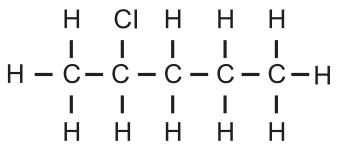


1-chloropentane **2-chloropentane**

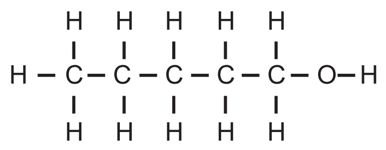
Number the main chain so that the chloro (functional group) is on the lowest carbon.

The condensed structural formulae for these compounds will be:

$CH_2\mathbf{Cl}CH_2CH_2CH_3$ $CH_3CH\mathbf{Cl}CH_2CH_2CH_3$

NOTE: There are no brackets around the Cl atoms as they are not branches.

3. Alcohols



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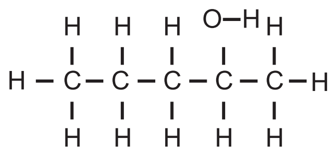
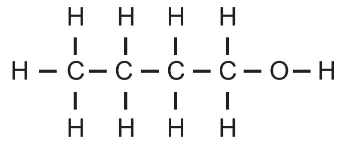


pentan-1-ol **pentan-2-ol**

Number the main chain so that the OH group (functional group) is on the lowest carbon. The number is indicated between the prefix and the suffix of the name. Now introduce the learners to the concept of primary, secondary and tertiary alcohols.

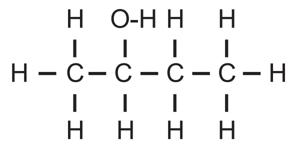
- **Primary alcohols** – These are alcohols where the OH group is placed on the end of the longest carbon chain. i.e. on C-1. The O-H group is attached to ONE carbon atom.

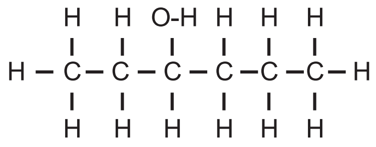


$CH_3\ CH_2\ CH_2\ CH_2OH$

butan-1-ol

- **Secondary alcohols** – These are alcohols where the O-H group is is bonded to a carbon atom which is bonded to TWO carbon atoms.





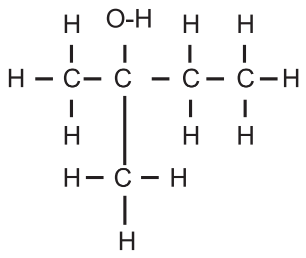
butan-2-ol

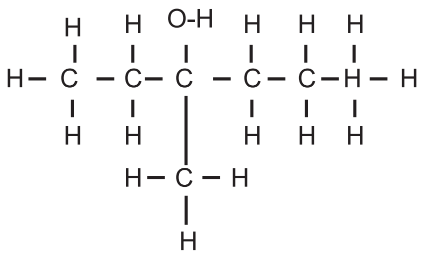
$CH_3CHOHCH_2CH_3$

hexan -3-ol

$CH_3CH_2CHOHCH_2CH_2CH_3$

- **Tertiary alcohols** – These are alcohols where the O-H group is bonded to a carbon atom which is bonded to THREE carbon atoms.





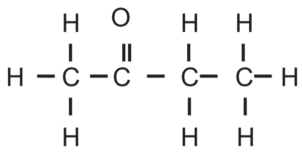
2-methylbutan-2-ol

$CH_3CH_2C(CH_3)OHCH_2CH_3$

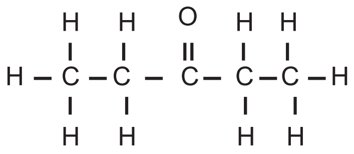
3-methylhexan-3-ol

$CH_3CH_2C(CH_3)OHCH_2CH_2CH_3$

4. Ketones



butan-2-one
$CH_3COCH_2CH_3$

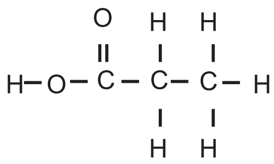


pentan-3-one
$CH_3CH_2COCH_2CH_3$

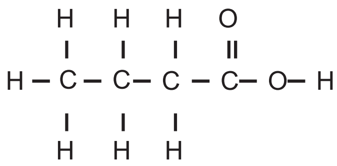
The main chain must be numbered so that the C=O is on the lowest carbon. This position is indicated between the prefix and the suffix of the name.

Naming carboxylic acids and aldehydes

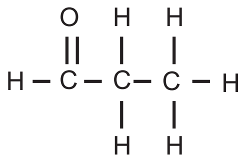
Explain to the learners that both carboxylic acids and aldehydes have functional groups that are terminal, in other words, they will always be at the ends of a carbon chain and thus will occupy position 1 on the chain. The position does not have to be indicated.



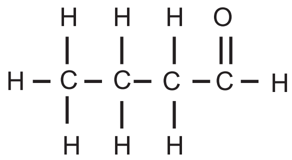
propanoic acid
$HOOCCH_2CH_3$



butanoic acid
$CH_3CH_2CH_2COOH$



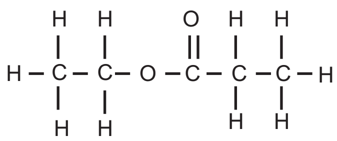
propanal
$CHOCH_2CH_3$



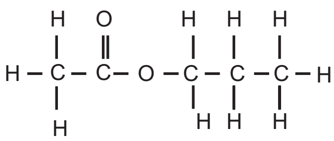
butanal
$CH_3CH_2CH_2CHO$

Naming esters

It must be emphasised that esters are derived from an alcohol and a carboxylic acid. The first part of the name is derived from the alcohol (the part attached to the -O) and is indicated as an alkyl group. The second part of the name is derived from the carboxylic acid and is attached to the C=O. It is indicated as an alkanoate.



ethyl propanoate
$CH_3CH_2OOCCH_2CH_3$



propyl ethanoate
$CH_3COOCH_2CH_2CH_3$

The name is divided up into two parts – the alcohol part is always first followed by the carboxylic acid, and then the entire name is finished with the suffix " – oate". The alcohol name also gets a "yl" attached to it instead on the "-anol" as in the parent alcohol.

methanol + ethanoic acid = methyl ethanoate

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 familiarise the learners with the organic names and to be able to obtain names from both full and condensed structural formulae.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each question to the learners as you complete it on the chalkboard.
- Learners must copy down the question and answer it correctly in their workbooks.

1. Draw structural formulae for the following organic compounds.

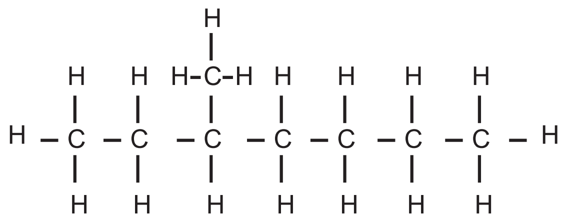
1.1 3-methylheptane

1.2 Butan-2-ol

1.3 Ethyl methanoate

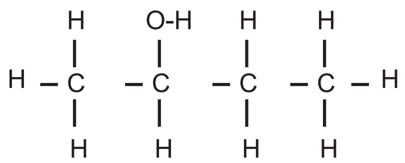
Solutions

1.1



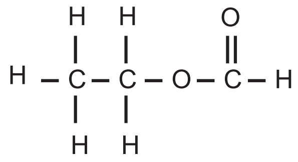
write down the 7x C atoms
place the methyl group on carbon 3
place H atoms on all available bonding sites

1.2



write down the 4 x C atoms
place the OH group on carbon 2
place H atoms on all available bonding sites

1.3



write down the 2 x C atoms of the alcohol and 1 x C atom for the acid

2. Name the following organic molecules : Hint : Draw the structural formula first.

2.1 $CH_3CH(CH_3)CH(CH_3)CH_2CH_3$

2.2 $CH_3CH_2CH_2CHO$

2.3 $CH_3CH_2CH_2CH_2CH_2COOH$

2.4 $CH_2CHCH_2CH_3$

Solutions

2.1 2,3-dimethylpentane *Count the number of C atoms in the parent chain*
Identify the number of alkyl substituents in chain
Identify on which number carbon atoms the methyl groups are found.

2.2 Butanal *Identify the functional group and thus the homologous series.*
Count the number of carbons in the parent chain.

2.3 Hexanoic acid *Identify the functional group and thus the homologous series.*
Count the number of carbons in the parent chain.

2.4 But-1-ene *Identify the functional group and thus the homologous series.*
Count the number of carbons in the parent chain.

CHALLENGE LEVEL QUESTIONS

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

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
- Discuss learners' ideas, and ask probing questions to extend their answers.
- Try to be positive in these interactions, to encourage critical thinking and questioning.
- Learners must copy down the question and answer it correctly in their workbooks.

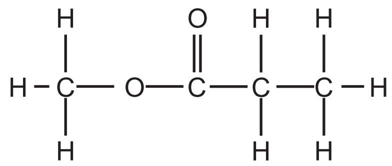
KEY TEACHING

a. In these more challenging examples, learners must be able to draw more complex organic structures using both full structural and condensed structural formulae.

b. Learners must also be able to name organic structures from both full and condensed structural formulae.

1. The structural formula of compound A is shown below. Give its IUPAC name.

Compound A



2. Name and draw structural formulae of the following:

2.1 All the structural isomers of compound A.

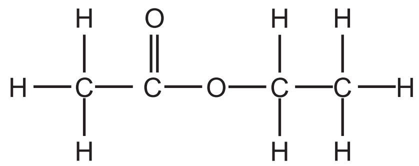
2.2 A functional isomer of compound A.

3. Name the three substances required for the reaction that produces compound A.

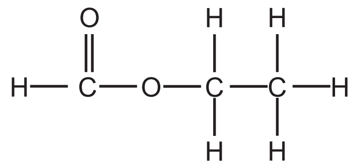
Solutions

1. methyl propanoate

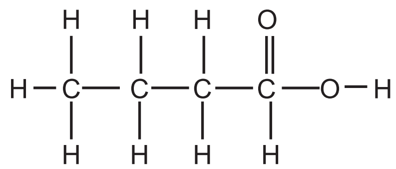
2.1 ethyl ethanoate



propyl methanoate



2.2 butanoic acid



3. Methanol, propanoic acid and concentrated sulfuric acid.

CHECKPOINT

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

1. The understanding of homologous series, functional groups, saturated and unsaturated compounds and isomerism.
2. Be able to write explanations of these terms.
3. The recognition of functional groups in an organic structure to identify the homologous series
4. Be able to explain the difference between chain, positional and functional isomerism
5. The naming of organic compounds and drawing of structural and condensed structural formulae for all homologous series, including straight and branched chain compounds.
6. Have a good knowledge of the different functional groups and be able to identify them in a full or condensed structural formula.
7. Be able to draw both structural and condensed structural formulae when given the IUPAC name of the organic compound.

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

Resource Pack. Worksheet: Organic Worksheet: Multiple choice 1 to 3 and Long Questions 1.1 and 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 for feedback.
- Encourage the learners to learn from the mistakes they make.

3. STRUCTURE PHYSICAL PROPERTIES RELATIONSHIPS

INTRODUCTION

The shape and structure of an organic molecule as well its size and functional groups present are factors that affect its physical properties such as melting point, boiling point and vapour pressure. This sub-topic investigates these physical properties by examining the intermolecular forces that exist between different organic molecules.

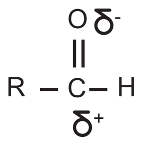
CONCEPT EXPLANATION AND CLARIFICATION: PHYSICAL PROPERTIES AND INTERMOLECULAR FORCES

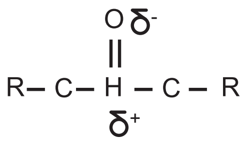
It is important for the learners to have a firm grasp of the Grade 11 work on intermolecular forces and knowledge of how the strength of these intermolecular forces between molecules will affect the physical properties of these molecules, in particular the melting and boiling points and vapour pressure. Revision of London forces, dipole-dipole forces and hydrogen bonding is very important here.

(a) ***Physical properties of non-polar molecules***. Begin this sub-topic by looking at the physical properties of non-polar molecules. Here the learners can be shown different alkanes of various chain lengths. Explain to the learners that alkanes will have the weakest of the intermolecular forces. These will be London Forces resulting from induced dipole-induced dipole interactions. They will thus have very low melting and boiling points. Remind the learners that as the chain length of the alkanes increases, so the size of the molecule increases, hence the electron density around the molecule increases. This provides more points of contact on the molecule for intermolecular forces to form, hence the overall strength of the intermolecular forces increases and the melting and boiling points thus increase.

(b) ***Physical properties and the type of functional groups.*** Consider ethane which is a non-polar molecule and chloroethane which is a polar molecule. Non-polar ethane will have weak London forces between its molecules whereas chloroethane which will have stronger dipole-dipole intermolecular forces.

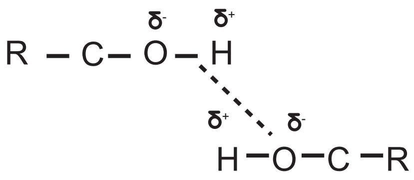
Other molecules that have dipole-dipole intermolecular forces are compounds such as aldehydes, esters and ketones. Indicate that the C=O will be polar and hence will result in dipole-dipole intermolecular forces.



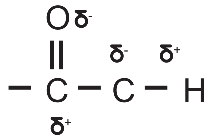


These compounds have stronger intermolecular forces and will have higher melting and boiling points.

Alcohols and carboxylic acids have -O-H groups which will introduce hydrogen bonding between these types of molecules. Alcohols have much higher melting and boiling points than other organic molecules due to these very strong intermolecular forces.



Carboxylic acids have a combination of London, dipole-dipole and hydrogen bonding. They have higher melting points than their corresponding alcohols as there are two sites for hydrogen bonding to occur.



This gives carboxylic acids very high melting and boiling points due to both types of intermolecular forces being present. The high melting and boiling points of carboxylic acids are mainly due to there being two sites for hydrogen bonding, and therefore much stronger intermolecular forces. Some molecules of carboxylic acids are so strongly attracted to each other that they form a "double molecule" which we call a dimer. The increased molecular size of a dimer also results in stronger intermolecular forces. It therefore takes more energy to overcome these forces, so the melting and boiling points occur at higher temperatures.

Compare melting and boiling points of ethane, chloroethane, ethanol, ethanal and ethanoic acid. Learners should see a steady increase in these values as the different types of functional groups influence the strength of the intermolecular forces.

(c) ***Vapour pressure, odour and flammability***. Introduce the relationship between intermolecular forces and **vapour pressure**, **odour** and **flammability**. Make sure that learners understand what is meant by vapour pressure and then use an example of propane and propanol to explain these concepts.

Vapour pressure – Propane has weak London forces present between molecules as is a non-polar molecule whereas propanol has strong hydrogen bonding between molecules and is polar due to the –O-H group. Propane will therefore have a high vapour pressure whereas propanol will have low vapour pressure.

Odour – Compounds with high vapour pressure will have a large amount of molecules in the gaseous phase hence a strong odour whereas compounds with low vapour pressure will have fewer molecules in the gaseous phase, and thus result in less odour.

Flammability – Organic molecules are usually flammable, but the degree of flammability is also influenced by the relative strength of intermolecular forces. The more flammable organic compounds are the ones that have a high vapour pressure, as they have the weakest intermolecular forces.

(d) ***Physical properties and the influence of chain length and branched chains.***
Chain length – The longer (bigger) the chain, the greater the size of the molecule. The larger the molecule, the greater the electron density around the molecule, hence there are more places for intermolecular forces to form. This means that the larger the molecule, the stronger the overall intermolecular forces between the molecules, hence the greater the melting and boiling points. This will also mean that they will have lower vapour pressure.

Compare these properties using molecules of methane, ethane, propane, butane, hexane and octane.

Branched chains – Here the learners must be shown that the more branched the chain, the less the surface area of the molecule. This implies that the intermolecular forces will be weaker and the melting and boiling points will be lower. It will also imply that they will have a higher vapour pressure. Compare pentane, 2-methylbutane and 2,2-dimethylpropane.

INTRODUCTORY LEVEL QUESTIONS

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

b. Their purpose is to familiarise the learners with the basic concepts of physical properties and the factors that can affect these physical properties.

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 down the question and answer it correctly in their workbooks.

TOPIC 4

1. Which substance, propane or ethanol, will have the higher boiling point? Explain your answer.

Solution

For a fair comparison molecules of similar molecular size (mass) should be compared. In this case the independent variable is the functional group, so the controlled variable is molecular size (mass).

Step 1: Compare the TYPE of intermolecular force. Both propane and ethanol have similar molar masses (their molecules are the same size); however propane is a symmetrical hydrocarbon which makes it a non-polar organic compound. There will be weak London Forces between its molecules, Ethanol has an OH group in its structure which will result in strong hydrogen bonding between the molecules.

Step 2: Compare the STRENGTH of the intermolecular forces. London forces between propane molecules are weaker than hydrogen bonds between ethanol molecules.

Step 3: Compare the ENERGY needed to overcome the intermolecular forces.
Hydrogen bonding is a very strong dipole-dipole force thus large amounts of energy will be required to change phase from liquid to gas. Hence, ethanol will have a higher boiling point than propane.

2. Liquid pentane and liquid butanol are placed into separate equal sized containers. Which of these substances will exert the higher vapour pressure at room temperature? Explain your answer

Solution

Pentane is a non-polar hydrocarbon with weak London forces between its molecules. This means that pentane will have a low boiling point resulting in a large number of gas particles in the atmosphere at room temperature, hence a high vapour pressure. Butanol molecules have a hydroxyl (-O-H) group, and therefore these molecules are polar, and have strong hydrogen bonds between them. Therefore is takes more energy to release gas molecules from the surface of butanol than from the surface of pentane. The vapour pressure of butanol is lower than that of pentane.

CHALLENGE LEVEL QUESTIONS

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

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.
- Learners must copy down the question and answer it correctly in their workbooks.

KEY TEACHING

a. In these more challenging examples, learners must be able to compare and contrast intermolecular forces for different molecules in terms of molecular size and differing functional groups.

b. Learners must have full understanding on how physical properties are affected by:

- Polar and non-polar molecules
- Types of functional groups
- Length of carbon chain
- Branched chains

1. Compare the boiling points of propane and hexane and explain why they are different.

Solution

Hexane and propane are both alkanes, therefore they both have the same type of intermolecular forces between their molecules (namely, London forces). Hexane will have a larger boiling point compared to propane. This is due to the fact that hexane contains 6 carbon atoms whereas propane has 3 carbon atoms in its structure. Hexane thus has a larger molecular size, hence a greater electron cloud density around the molecule. The larger the electron cloud, the more points of contact are present for intermolecular forces to be made. This will cause an increase in intermolecular force strength. More energy will be required to overcome the stronger intermolecular forces in hexane and it will thus have a higher boiling point than propane.

2. The boiling point of 2-methylpentane is 60°C whereas the boiling point of 2,3-dimethylbutane is 49°C. Both molecules have a molecular formula of C_6H_{14} Explain why there is a difference in these boiling points.

Solution

The molecule 2,3-dimethylbutane has more branches (alkyl substituents) than 2-methylpentane. This means that its surface area is smaller than that of 2-methypentane. Smaller molecules have fewer points of contact on the molecule. This causes the intermolecular forces to be weaker compared to the less branched molecules. Less energy is needed to overcome the intermolecular forces and thus 2,3-dimethylbutane will have a lower boiling point.

TOPIC 4

CHECKPOINT

At this point in the topic, learners should have a full understanding of the following :

a. The significance that different types of intermolecular forces have on physical properties of compounds

b. How different functional groups gives rise to different strengths of intermolecular forces

c. How boiling point, melting point, vapour pressure, odour and flammability are affected by different intermolecular forces

d. How molecular size affects the physical properties in term of chain length for straight chained compounds.

e. How molecular size affects the physical properties in terms of branched compounds.

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

Resource Pack: Organic Worksheet: Long Questions 2.1 – 2.5

- 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 for feedback.
- Encourage the learners to learn from the mistakes they make.

4. APPLICATION OF ORGANIC CHEMISTRY

INTRODUCTION

Organic molecules undergo a variety of chemical reactions, many of these reactions we see in everyday life. Many organic molecules are able to burn in the presence of oxygen and can act as fuels. Propane and butane are such molecules which are used in gas burners. Esters are formed either naturally or synthetically and due to their very pleasant smell, are used in many different fragrances and flavourants.

CONCEPT EXPLANATION AND CLARIFICATION: COMBUSTION AND ESTERIFICATION REACTIONS

Explain to the learners that they are going to be looking at **combustion** and **esterification** reactions.

Combustion reactions – These reactions involve the burning of hydrocarbons, alcohols and esters in oxygen. These molecules are highly flammable. The reaction products will always be CO_2 and H_2O.

Learners need to know how to balance these reactions. Show them the 3 step technique of balancing the reaction done in the following order:

1. Balance the carbon atoms in the reaction.
2. Balance the hydrogen atoms in the reaction.
3. Balance the oxygen atoms in the reaction (start on the right).

Worked example:	$C_3H_8 + O_2 \longrightarrow$	$CO_2 + H_2O$	$\Delta H < 0$
Step 1: balance C atoms	$C_3H_8 + O_2 \longrightarrow$	$3CO_2 + H_2O$	$\Delta H < 0$
Step 2: balance H atoms	$C_3H_8 + O_2 \longrightarrow$	$3CO_2 + 4H_2O$	$\Delta H < 0$
Step 3: balance O atoms	$C_3H_8 + 5O_2 \longrightarrow$	$3CO_2 + 4H_2O$	$\Delta H < 0$

Discuss with the learners that alkanes are important fuels and that combustion reactions are highly exothermic reactions.

Esterification reactions – Learners should already know from earlier work in organic chemistry that these are reactions between alcohols and carboxylic acids which are catalysed by concentrated sulfuric acid (H_2SO_4). Now introduce the general reaction equation to the learners

alcohol + carboxylic acid $\longrightarrow$ ester + water

It is also known as a condensation reaction due to the formation of water as a product.

Discuss with the learners that the function of the concentrated sulfuric acid (H_2SO_4)

- is a dehydrating agent which removes water from the reaction which allows for the ester to be formed.
- acts as a catalyst by allowing for the speeding up of the esterification reaction.

Discuss with learners that when naming an ester, the alcohol part of the reaction comes first and the second part is derived from the carboxylic acid.

Some examples

- methanol + propanoic acid $\xrightarrow{\text{sulfuric acid}}$ methyl propanoate + water
- butanol + ethanoic acid $\longrightarrow$ butyl ethanoate + water

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 familiarise the learners with the key concepts of combustion and ester formation.

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 down the question and answer it correctly in their workbooks.

1. Write the equation for the complete combustion of:

1.1 propane burning in air

1.2 butane burning in air

Solution

1.1 $C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

1.2 $2C_4H_{10} + 13O_2 \longrightarrow 8CO_2 + 10H_2O$

2. Write word equations for the foll owing reactions:

2.1 ethanol reacts with hexanoic acid

2.2 butanol reacts with methanoic acid

Solution

2.1 ethanol + hexanoic acid $\longrightarrow$ ethyl hexanoate + water

2.2 butanol + methanoic acid $\longrightarrow$ butyl methanoate + water

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 **write and balance** chemical equations for combustion and esterification reactions as well as naming of esters.

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.
- Learners must copy down the question and answer it correctly in their workbooks.

KEY TEACHING

a. In these more challenging questions, learners must be able to write molecular formulae for compounds and then apply them in combustion equations.

b. Learners must also be able to write equations to show how esters are formed from the starting alcohol and carboxylic acids when given the name of the ester.

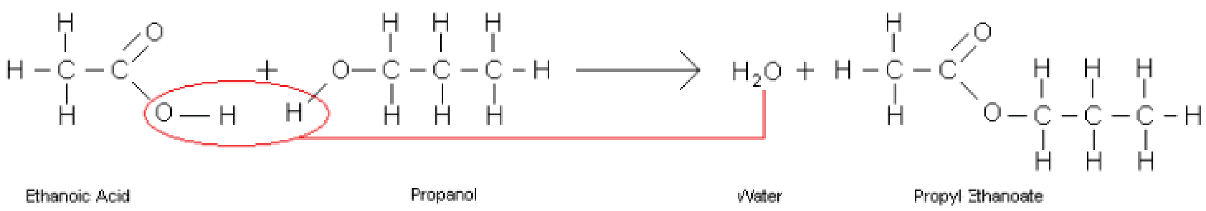
1. Use structural formulae to show how the following esters are formed:

1.1 propyl ethanoate

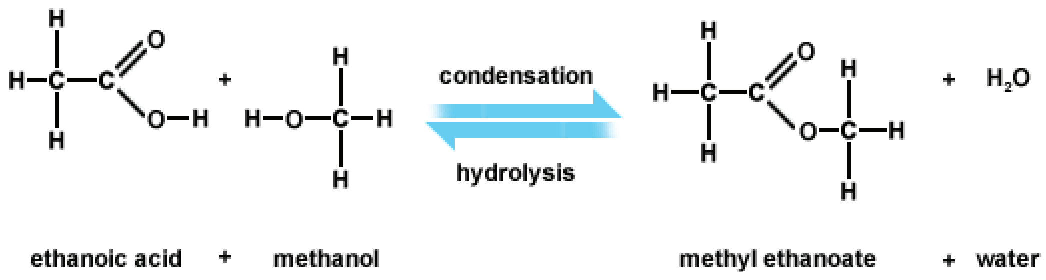
1.2 methyl ethanoate

Solution

1.1 ethanoic acid + proponal $\longrightarrow$ propyl ethanoate + water



1.2 ethanoic acid + methanol ⟶ methyl ethanoate + water



> **CHECKPOINT**
>
> At this point in the topic, learners should have a full understanding of the following :
>
> 1. Combustion reactions of organic compounds
> 2. Writing and balancing combustion reaction equations of organic compounds
> 3. Writing esterification reactions between alcohols and carboxylic acids
>
> Check learners' understanding of these concepts by getting them to work through:
>
> **Resource Pack: Organic Worksheet: 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 for feedback.
> - Encourage the learners to learn from the mistakes they make.

3. SUBSTITUTION, ADDITION AND ELIMINATION

INTRODUCTION

We have already looked at two types of organic reactions, namely combustion reactions and esterification. Now we are going to look at three other types of organic reactions and examine the reaction conditions that are required.

CONCEPT EXPLANATION AND CLARIFICATION: SUBSTITUTION, ELIMINATION AND ADDITION REACTIONS

SUBSTITUTION REACTIONS – Explain to the learners that substitution reactions involve the replacing of one atom or group of atoms with another atom or group of atoms. To make this a bit clearer for them, talk about a soccer match where a player is removed from the playing field and replaced with another. In other words, there is a swapping of atoms or groups of atoms in the reaction.

Tell the learners that there are three types of substitution reactions

1. Reactions of alkanes with halogens (Cl_2 and Br_2) to form alkyl halides
2. Reactions of alcohols with halides (HCl, HBr) to form alkyl halides
3. Reactions of bases (KOH in water) with alkyl halides to form alcohols

Ensure that the learners understand the processes as well as the reaction conditions that are essential for these reactions to take place.

1. Reaction of alkanes with halogens to form alkyl halides

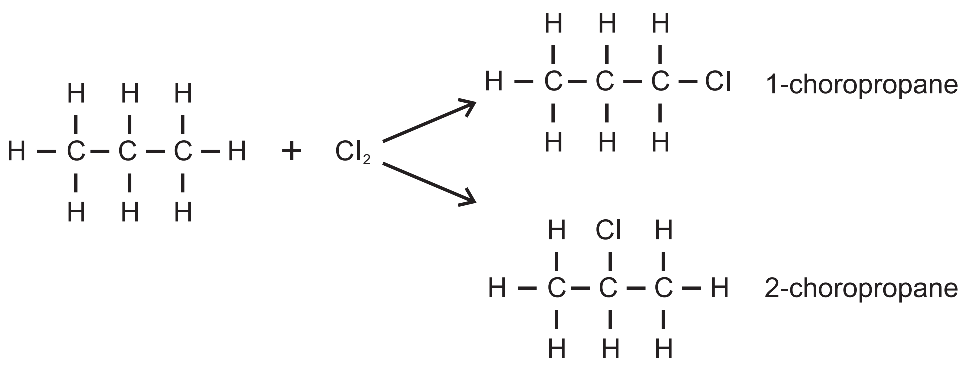
Learners need to know that alkanes are generally very unreactive molecules except for combustion reactions. Thus, they will not easily react with other compounds. However, they will react with halogens in the presence of heat or sunlight to form alkyl halides.

$$CH_4 + Cl_2 \longrightarrow CH_3Cl + HCl$$

Reaction conditions: heat or sunlight

Here a H atom on the methane molecule is substituted by one of the Cl atoms to form chloromethane. The H from the methane then bonds with the remaining Cl atom to form hydrogen chloride.

Please make the learners are aware of what happens when an alkane with more than 2 carbon atoms is reacted. Here the learners must realise that isomers can form and the products formed by the reaction will be a mixture of all the isomers.



2. Reaction of alcohols with halides to form alkyl halides

- Tertiary alcohols react the most easily and this type of substitution reaction will take place ***at room temperature.***
- Primary and secondary alcohols will react, but much more slowly and they need ***high temperatures for this to occur.***

Use structural formulae to show how the –O-H group is replaced by the halogen from the halide to form the alkyl halide and water as the other product.

Tertiary alcohol $CH_3C(CH_3)OHCH_3 + HCl \longrightarrow CH_3C(CH_3)ClCH_3 + H_2O$
Reaction conditions: room temperature

Secondary alcohol $CH_3CHOHCH_2CH_3 + HCl \longrightarrow CH_3CHClCH_2CH_3 + H_2O$
Reaction conditions: heat

Primary alcohol $CH_3CH_2CH_2CH_2OH + HCl \longrightarrow CH_3CH_2CH_2CH_2Cl + H_2O$
Reaction conditions: heat

3. Reaction of alkyl halides with bases to form alcohols

This is the third type of substitution reaction that the learners need to understand where a strong base such as KOH or NaOH is reacted with an alkyl halide to form an alcohol. The learners need to know the reaction conditions for this to proceed. The base must be dissolved in water before being added to the alkyl halide or just water can be added. (If the base is not diluted then elimination will occur). The mixture is then heated moderately.

Learners need to know that these reactions are known as **hydrolysis reactions**

Tertiary alkyl halide $CH_3C(CH_3)BrCH_3 + KOH \longrightarrow CH_3C(CH_3)OHCH_3 + KBr$

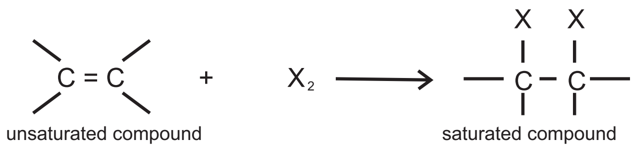
Secondary alkyl halide $CH_3CHClCH_3 + NaOH \longrightarrow CH_3CHOHCH_3 + NaCl$

Primary alkyl halide $CH_3CH_2CH_2CH_2Br + KOH \longrightarrow CH_3CH_2CH_2CH_2OH + KBr$

Reaction conditions: Base dissolved in water, heated moderately with alkyl halide

ADDITION REACTIONS: Explain to the learners that these reactions are exactly as the word describes – this is a reaction where atoms are added to an organic molecule. What is most important to show the learners is that these reactions only occur if there is a double bond between the carbon atoms in the compound (unsaturated compound) and the atoms are added to the carbon atoms on either side of the double bond after breaking the double bond, to form a saturated compound. Alkenes are organic compounds that undergo addition reactions very easily due to the reactive double bond present.

Use this general example to show the learners the basics of how this occurs:



Note: The reaction uses two reactants to produce one product.

Tell the learners that there are 4 types of addition reactions:

1. Hydrogenation – addition of hydrogen (H_2)
2. Halogenation – addition of a halogen (Cl_2, Br_2)
3. Hydrohalogenation – addition of a hydrogen halide (HCl, HBr, HI)
4. Hydration – addition of water (H_2O)

Now explain to the learners each type of addition reaction focusing on the following key concepts including the reaction conditions.

1. Hydrogenation – addition of H_2 to an alkene.

   $$\underset{\text{alkene}}{CH_2 = CH_2} + H_2 \longrightarrow \underset{\text{alkane}}{CH_3 - CH_3}$$

   Reaction conditions: Alkene dissolved in a non-polar solvent with either a platinum (Pt), palladium (Pd) or a nickel (Ni) catalyst in an atmosphere of H_2.

2. Halogenation – addition of a halogen to an alkene (Cl_2 , Br_2).

   $$\underset{\text{alkene}}{CH_2 = CH_2} + Cl_2 \longrightarrow \underset{\text{alkyl halide}}{CH_2Cl - CH_2Cl}$$

   Reaction conditions: The halogen is added directly to the alkene at room temperature.

3. Hydrohalogentaion – addition of a hydrogen halide to an alkene (HCl , HBr, HI).

   $$\underset{\text{alkene}}{CH_2 = CH_2} + HCl \longrightarrow \underset{\text{alkyl halide}}{CH_3 - CH_2Cl}$$

   Reaction conditions: Room temperature in the absence of water.

Markovnikov Rule – Make sure that the learners understand the importance of the Markovnikov rule. This is for alkenes with unsymmetrical structure, in other words where the double bond is not symmetrical in the molecule. For example:

$$\underset{\text{prop-1-ene}}{CH_2 = CH - CH_3} \text{ or } \underset{\text{but-1-ene}}{CH_2 = CH - CH_2 - CH_3}$$

The H of the hydrogen halide will add to the carbon atom that has the most number of H atoms.

4. Hydration – the addition of water (H_2O) to an alkene.

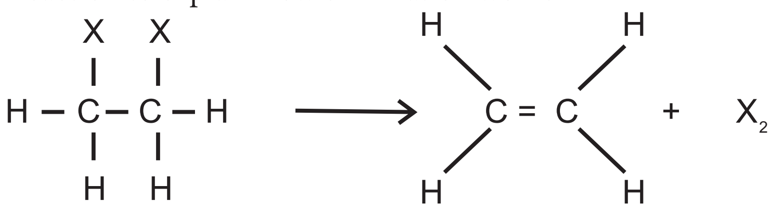
$CH_2 = CH_2$ + $H_2O \longrightarrow CH_3CH_2OH$
alkene alcohol

Reaction conditions: Dilute acid, either sulfuric acid (H_2SO_4) or phosphoric acid (H_3PO_4) where the acid acts as a catalyst.

Note: The Markovnikov Rule also applies to this type of addition reaction.

ELIMINATION REACTIONS – Explain to the learners that this type of reaction involves the removal of atoms from a saturated compound to give you an unsaturated compound. It is exactly the opposite of an addition reaction and will now form a double bond compound as one of the products.

Use this general reaction to explain how elimination works



Tell the learners that there are 3 types of elimination reactions:

1. Dehydrohalogenation
2. Dehydration
3. Cracking

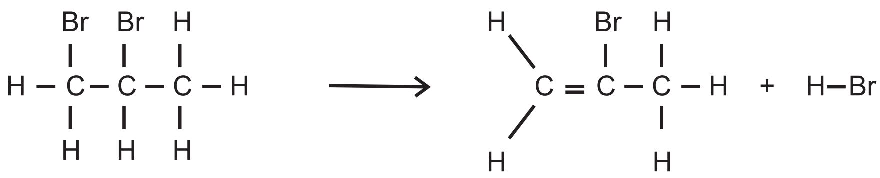
Now explain to the learners each type of elimination reaction focusing on the following key concepts including the reaction conditions.

1. Dehydrohalogenation – the elimination of a hydrogen halide (HCl, HBr) from a molecule.

   $CH_3 – CH_2Br \longrightarrow CH_2 = CH_2$ + HBr
   alkyl halide alkene

   Reaction conditions: Strongly heated under reflux in a concentrated solution of NaOH or KOH in pure ethanol (NaOH or KOH in hot ethanol).

   Learners must also be aware of elimination reactions from compounds where there is more than one elimination product possible. Here, the major product is the one where the H atom is removed from the C atom with the least number of H atoms.



2. Dehydration – the elimination of water (H_2O) from a molecule.

$$CH_3 - CH_2OH \longrightarrow CH_2 = CH_2 \quad + \quad H_2O$$

Reaction conditions: Acid catalysed reaction where the alcohol is heated with excess sulfuric acid (H_2SO_4) or phosphoric acid (H_3PO_4).

As with the dehydrohalogenation, learners must also be aware of elimination reactions from compounds where there is more than one elimination product possible. The major product is the one where the H atom is removed from the C atom with the least number of H atoms.

3. Cracking – the breaking up of large hydrocarbons into smaller, more useful compounds. Explain to the learners that there are 2 types of cracking:

- Thermal cracking - high temperatures and pressures without a catalyst
- Catalytic cracking - lower temperatures and pressures with a catalyst

Now illustrate to the learners how the process of cracking works where a long chain hydrocarbon is broken up to form simpler products. It is important to note that there is no one single reaction for any particular cracking reaction. Here is an example of one type of cracking reaction:

$$C_{12}H_{26} \longrightarrow \underset{\text{ethene}}{C_2H_4} \quad + \quad \underset{\text{propene}}{2C_3H_6} \quad + \quad \underset{\text{butane}}{C_4H_{10}}$$

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 familiarise the learners with the organic reactions and be able identify the different types of reactions.

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 down the question and answer it correctly in their workbooks.

1. Identify the following types of reactions and using condensed structural formula, write balanced equations for the reactions. Name the products formed.

1.1 $CH_2CHCH_2CH_2CH_3 \quad + \quad HBr$

1.2 $CH_3CH_2CH_2OH \quad + \quad HCl$

1.3 Dehalogenation of 1,2-dichlorobutane

Solution

1.1 **Addition:** $CH_2CHCH_2CH_2CH_3$ + $HBr \longrightarrow$ $CH_3CHBrCH_2CH_2CH_3$
2-bromopentane

1.2 **Substitution:** $CH_3CH_2CH_2OH$ + $HCl \longrightarrow$ $CH_3CH_2CH_2Cl$ + H_2O
1-chloropropane

1.3 **Elimination:** $CH_2ClCHClCH_2CH_3 \longrightarrow$ $CH_2CHCH_2CH_3$ + Cl_2
but-1-ene

2. Name the specific type of reactions listed below and identify the starting organic reactant in each:

2.1 X + $KCl \longrightarrow CH_3CH_2CH_2CH_2CH_2Cl$ + KOH

2.2 Y + $H_2O \longrightarrow CH_3CHOHCH_2CH_3$

2.3 Z $\longrightarrow CH_2CHCH_3$ + HBr

Solution

2.1 Substitution X: $CH_3CH_2CH_2CH_2CH_2OH$ (pentan-1-ol)

2.2 Hydration Y: $CH_2CHCH_2CH_3$ (but-1-ene)

2.3 Dehydrohalogenation Z: $CH_3CHBrCH_3$ (2-bromopropane)

CHALLENGE LEVEL QUESTIONS

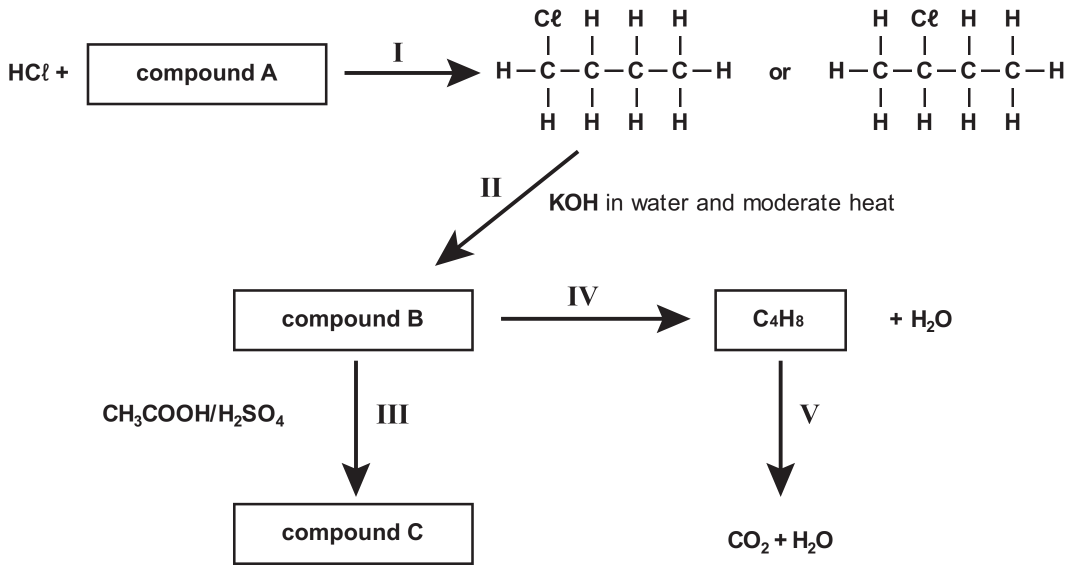
Now that learners have mastered the basic reactions, they are ready to deal with more challenging questions.

- 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.
- Learners must copy down the question and answer it correctly in their workbooks.

KEY TEACHING

- **a.** In these more challenging examples, learners must be able to identify the different types of chemical reactions from the reactants given.
- **b.** They must be able to study a reaction pathway and identify the different reactions happening in the sequence.
- **c.** Learners must be familiar with all the various terminology that is associated with the chemical reactions.
- **d.** Learners must be aware of the various reaction conditions for each reaction.

1. Consider the following sequence of organic reaction



1.1 Identify the type of reaction represented by the numerals I – V.

Solution

I – addition / hydrohalogenation

II – substitution/hydrolysis

III – esterification/elimination/condensation

IV – elimination/dehydration

V – combustion

1.2 Compound B reacts with ethanoic acid to produce product C in the presence of concentrated sulfuric acid, in a warm water bath according to reaction III.

1.2.1 Name compound C.

Solution

Butyl ethanoate

1.2.2 Name the other product that will also be produced in this reaction.

Solution

Water

1.2.3 Give two reasons why sulfuric acid is used in this reaction.

Solution

1. Acts as catalyst (to speed up reaction).
2. To act as a dehydrating agent (to remove H_2O).

1.2.4 Why do you think that a warm water bath is used for heating instead of using a Bunsen burner flame?

Solution

1. Reagent flammable.
2. Warm water bath will heat mixture without coming into contact with flame.
3. Controls heat to prevent alcohol from vapourising too quickly.
4. Warm water bath distributes the heat evenly (any two from above).

1.3 Consider reaction IV.

1.3.1 Name the homologous series to which C_4H_8 belongs.

Solution

Alkene

1.3.2 Using condensed structural formulae, draw and name a positional isomer of C_4H_8.

Solution

But-2-ene $CH_3CHCHCH_3$

1.4 Write down the balanced chemical equation for reaction V.

Solution

$$C_4H_8 + 6O_2 \longrightarrow 4CO_2 + 4H_2O$$

CHECKPOINT

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

1. The identification of different organic reactions based on the reactants given or products formed.
2. The writing of these reactions using full and condensed structural formulae.
3. The naming of the reactants and products.
4. All the terminology associated with these types of chemical reactions.

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

Resource Pack: Organic Worksheet: Multiple choice 4 and 5 and Long Question 3.

- 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 for feedback.
- Encourage the learners to learn from the mistakes they make.

6. PLASTICS AND POLYMERS

INTRODUCTION

We find many different types of polymers in nature as well as man-made polymers which are manufactured in industry and used on a day to day basis in our lives. Plastics are one such example of a man-made polymer that provides enormous benefits to our day to day lives, for example, plastic packets, yet can also have a very negative impact in terms of the harm that they can cause the environment.

CONCEPT EXPLANATION AND CLARIFICATION: ADDITION POLYMERISATION

Before stating what an addition polymer is and how it is formed, it is very important that the learners are given an understanding of what makes up a polymer. A **polymer** is an example of a **macromolecule** made up of huge numbers of individual units called **monomers**. Please ensure that the learners are familiar with this type of terminology before continuing with the section.

Now begin the section by explaining that addition polymerisation is another type of addition reaction where monomer units are added to each other. Use the formation of polyethene (polyethylene) as the example to show how the ethene monomer units are added to each other to form a long chain of repeating ethane units. The learners must see how these units are added together through the formation of a **free radical** and how these free radicals bond together to form the **polymer chain** for polyethene. It is then important to have a discussion with the learners with regards to the industrial use of polyethene in terms of all the products that use this form of plastic. Examples of this would be plastic bottles, plastic bags, plastic toys, electrical insulation and moulded objects. The recycling number of polyethene is important for the learners to know so that they can effectively recycle these plastics.

CONCEPT EXPLANATION AND CLARIFICATION: CONDENSATION POLYMERISATION

Now explain to the learners that there is another type of polymerisation process called condensation polymerisation. Explain that this reaction is different to addition polymerisation as here when the monomer units react, a molecule, e.g. water, is eliminated from the reaction whereas no by-products are formed in addition polymerisation. Condensation polymers are formed when two different types of monomer units react, for example, one with an alcohol functional group and the other with a carboxylic acid functional group. Show the learners that these are exactly the same starting materials in esterification and thus condensation polymerisation is an esterification reaction. This gives these types of polymers the name **"polyesters".** Illustrate this reaction to the learners and compare it with the addition polymerisation reaction.

Have a discussion with the learners regarding the polymer polylactic acid and its starting materials being biologically based. The monomers come from the fermentation of plant materials and not from petroleum products which makes polylactic acid much more environmentally friendly and biodegradable. Discuss with the learners the advantages this has to our environment and where this type of polymer is found in our society.

CONCEPT EXPLANATION AND CLARIFICATION: IDENTIFYING THE TYPE OF POLYMERISATION

This sub-topic concludes with learners being expected to identify the type of polymerisation that is taking place when given the structural formula of a polymer. Explain to the learners that it involves three simple steps, and show the learners with suitable example how these steps are undertaken:

Step 1 – Recognise the repeating unit and place a bracket around it.

Step 2 – Look at the repeating unit and see it there are any carbonyl (=O) or hydroxyl (-OH) groups on the unit. If there are none, then we have identified an addition polymer.

Step 3 – If there are carbonyl or hydroxyl groups on the repeating unit, then we have identified a condensation polymer.

Use the following suitable examples: Polyvinyl chloride (PVC), polyethene, polylactic acid (PLA), polyvinyl acetate (PVA).

INTRODUCTORY LEVEL QUESTIONS

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

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 down the question and answer it correctly in their workbooks.

1. Explain the meaning of the following terms:

1.1 macromolecule

1.2 monomer

1.3 polymer

Solution

1.1 This is a molecule that contains very large numbers of atoms in its structure. Macromolecules are made up of anything from 2 000 to 20 000 carbon atoms in the parent chain.

1.2 This is a molecule that can be bonded with many other identical molecules to form a macromolecule of identical repeating units.

1.3 This is a macromolecular structure that is built up from large numbers or similar repeating units (monomers).

2. Name the type of polymerisation reactions that occurs in the formation of :

2.1 polyethene

2.2 polylactic acid

2.3 polyvinyl chloride

2.4 polyester

Solution

2.1 Addition

2.2 Condensation

2.3 Addition

2.4 Condensation

TOPIC 4

3. Name TWO industrial uses of polyethene.

Solution

1. Used in the production of plastic packets
2. Used in production of electrical insulation

CHALLENGE LEVEL QUESTIONS

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

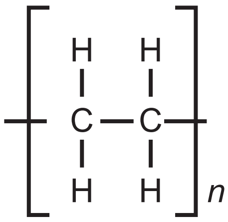
- Work through these examples with learners.
- Tell learners that this is a more challenging version of what they have been doing.
- Write the first example on the chalkboard.
- Ask learners to look at the example and see if they can work out what must be done / what is different.
- Discuss learners' 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

Learners need to understand the difference between an addition and a condensation polymer.

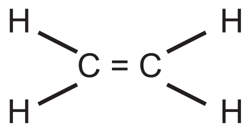
1. Give the structural formula for polyethene.

Solution



2. Give the structural formula for the monomer used to make polyethene.

Solution



CHECKPOINT

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

1. The difference between an addition and a condensation polymer.
2. The understanding of the terms macromolecule, monomer and polymer.
3. The identification of different monomers from a polymer structure.
4. The identification of different types of polymerisation when given the structural formula for a polymer.

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

Resource Pack: Organic Worksheet: Long Questions 4.1 to 4.3

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

CONSOLIDATION

- Learners can consolidate their learning by completing **Resource pack: Worksheet: Organic Chemistry.**
- 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 4

ADDITIONAL VIEWING / READING

In addition, further viewing or reading on this topic is available through the following web links. Links 3 – 6 provide very good video footage of the organic reactions where links 1 and 2 provide

1. What is organic chemistry:
   http://www.chemistryexplained.com/Ny-Pi/Organic-Chemistry.html
2. Drawing organic molecules:
   http://www.chemguide.co.uk/basicorg/conventions/draw.html
3. Addition reactions:
   http://learn.mindset.co.za/resources/physical-sciences/grade-12/organic-reactions/01-addition-reactions
4. Elimination reactions:
   http://learn.mindset.co.za/resources/physical-sciences/grade-12/organic-reactions/02-elimination-reactions
5. Substitution reactions:
   http://learn.mindset.co.za/resources/physical-sciences/grade-12/organic-reactions/03-substitution-reactions
6. Polymerisation reactions:
   http://learn.mindset.co.za/resources/physical-sciences/grade-12/organic-reactions/04-macromolecules-polymer-reactions

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