PHYSICAL SCIENCES

Grade 12

TERM 3

Content Booklet

TARGETED SUPPORT

Contents

A Message from the NECT

NATIONAL EDUCATION COLLABORATION TRUST (NECT)

Dear Teachers

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

What is NECT?

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

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

What are the Learning programmes?

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

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

The FSS helped the DBE trial the NECT learning programmes so that they could be improved and used by many more teachers. NECT has already begun this embedding process.

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

Let's work together constructively in the spirit of collaboration so that
we can help South Africa eliminate poverty and improve education!
www.nect.org.za

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 Resource Pack 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 questions, 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, surface tension, solubility and rate of evaporation

    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:

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:

Examination Preparation

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

1. Make sure that your learners know exactly when their Physical Science examination will be written.

2. Ask learners to take out their exercise books, and to mark off what must be studied.

3. Go through all their written work, and get them to tick off the work that they must study and practise.

   a. If learners are missing notes, they must copy the missing work from another learner.

   b. As you complete more work during the term that will be in the exam, tell learners to tick it off and to add it to their study plans.

4. If necessary, help learners to work out a study schedule.

   a. Estimate how long learners will need to study all the content required for the examination. This will differ from grade to grade, and from learner to learner.

   b. Be aware that some learners, even in the FET stage, have not yet developed these planning skills.

   c. Tell learners the number of hours that you think they need to study before the examination.

   d. Break this down into the number of hours they should study each week.

   e. Tell learners to think about their own lives and habits, and to work out when they have time to study, and when they study best.

   f. They must then use all of this information to work out their study and revision plan.

USEFUL REVISION RESOURCES

1. **Assessment Section of the Resource Pack**

    a. The Assessment Sections of the Resource Packs that form part of this series may be used as a very useful examination preparation tool.

    b. These sections include a 'bank' of questions for each topic at the different conceptual levels.

    c. If your province or district provides standardised tests and exams, use the questions in these sections as revision and exam preparation for learners.

    d. Remember to carefully explain the question structure and meaning, together with the mark allocation.

2. **Vodacom e-school**

    a. If learners have a Vodacom number, they are eligible to use the Vodacom e-school as a free service, i.e. no data costs:
    http://www.vodacom.co.za/vodacom/test-templates/eschool-two

    b. This e-school includes Physical Science lessons as part of its curriculum.

    c. Tell learners how to access this useful resource.

3. **DBE Grade 12 'Mind the Gap' Study Guides**

    a. Grade 12 learners can access the 'Mind the Gap' Study Guides
    on the DBE website: https://www.education.gov.za/Curriculum/
    LearningandTeachingSupportMaterials(LTSM)/MindtheGapStudyGuides.aspx

    b. This series includes Grade 12 study guides for:

        i. Physical Science: Physics

        ii. Physical Science: Chemistry

    c. These guides include an overview of the Grade 12 examination structures, useful study techniques, a guide to question types, a comprehensive list of question words / terms, as well as a summary of key content and skills.

    d. Consider downloading a copy of these guides, and making copies for Grade 12 learners if possible.

    e. Alternately, tell learners how to access this useful resource.

TOPIC 10:
Electric circuits

A   Introduction

- This topic runs for 4 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Electric circuits forms part of the content area Electricity and Magnetism (Physics).
- Electricity and Magnetism counts as 37 % in the final Physics Examination (Paper 1).
- Electric circuits counts approximately 10 % to 15% of the final examination.
- Electric circuits covered in grade 11 are examinable (Ohm's law, Power and Energy) in grade 12.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.

2. Chalk.

3. Grade 12 Physics Examination Data Sheet.

4. Batteries, many connecting wires, several resistors of different values, several voltmeters, several ammeters and switches.

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. An A4 3-quire exercise book, for notes and exercises.

2. Scientific calculator – Sharp or Casio calculators are highly recommended.

3. Pen.

4. Grade 12 Physics Examination Data Sheet.

B Sequential Table

PRIOR KNOWLEDGE	PRIOR KNOWLEDGE	CURRENT
GRADE 10	GRADE 11	GRADE 12
• emf, terminal potential difference (terminal pd) • Current • Measurement of voltage (pd) and current • Resistance • Resistors in series • Resistors in parallel	• Ohm's Law • Power, Energy • Resistors in series • Resistors in parallel combination	• Internal resistance and series and parallel networks

TOPIC 10

C Glossary of Terms

TERM	DEFINITION
Potential difference	The work done per coulomb of charge to move the charge between two points in the circuit.
Resistance	The ratio of the potential difference across a resistor to the current in the resistor.
Current	The rate of flow of charge.
emf	The total energy supplied by the battery per coulomb of charge moved through the battery.
Ohm's Law	The current through a conductor is directly proportional to the potential difference across the conductor provided the temperature of the conductor remains constant.
Power	The rate at which work is done or energy is transferred.

D   Assessment of this Topic

- This topic is assessed by class/control tests as well as in 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.
- Prescribed experiment for formal assessment: (part 1 and part 2) Part 1: Determine the internal resistance of a battery. Part 2: 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.
- Recommended Practical Investigation for informal assessment: Set up a series parallel network with an ammeter in each branch and the external circuit and voltmeters across each resistor, branch and battery. Position switches in each branch and the external circuit. Use this circuit to investigate short circuits and open circuits.

E   Breakdown of Topic and Targeted Support Offered

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

TIME ALLOCATION	SUB-TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
4 hour	Internal resistance and series and parallel networks	129	a. Explanation of emf and terminal potential difference. b. Explanation of the potential difference across the internal resistance of the battery. c. The effect of increasing or decreasing the external resistance on the terminal potential difference. d. Revision of series and parallel circuits. e. Practice applying Ohm's law and revision of power and energy. f. Numerous practice questions.

F   Targeted Support per Sub-topic

## 1. INTERNAL RESISTANCE AND SERIES AND PARALLEL CIRCUITS

INTRODUCTION

In grades 10 and 11, all electrical circuit problems were simplified by ignoring the resistance of a battery. In grade 12 we will learn to solve problems in which the battery has internal resistance (r).

CONCEPT EXPLANATION AND CLARIFICATION:

1.1   Internal Resistance (r)

A real battery has internal resistance (r). Draw the following diagram on the board of a battery with internal resistance (r):
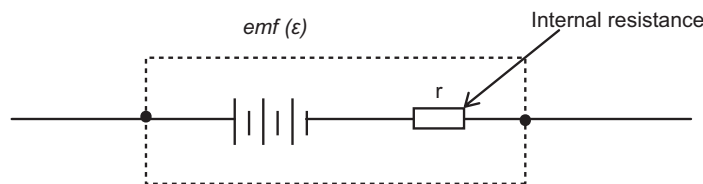
The battery has an emf (ε) and internal resistance (r).

emf is defined as the total energy supplied by the battery per coulomb of charge moved through the battery.

When a battery is connected to a circuit, with charge flowing through the battery, electrical energy is dissipated because of the internal resistance (r) of the battery.

A small amount of the electrical energy supplied by the battery is converted into heat energy because of the internal resistance of the battery.

A battery of emf (ε) is connected to an external circuit which has resistance. The resistance in the external circuit (R) is called the load.

Draw the following diagram on the board and IDENTIFY the different parts of the circuit.
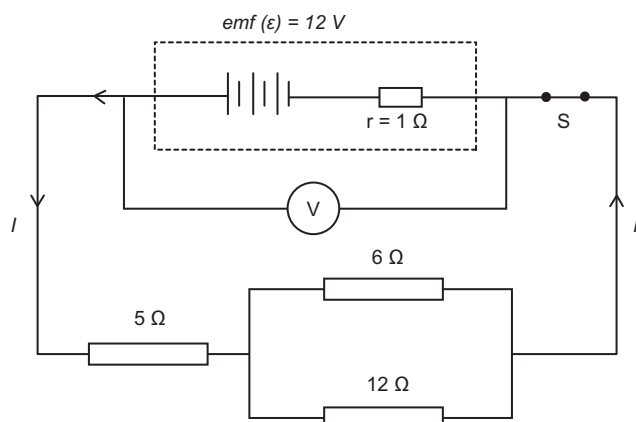
The emf of the battery is **12 V**. The internal resistance (r) of the battery is **1 Ω.**

WHEN THE SWITCH S IS OPEN:

The **voltmeter V** will read the emf of the battery (V = 12 V).

WHEN THE SWITCH S IS CLOSED:

Charge now flows through the battery. With a current (I) through the battery, there will be a POTENTIAL DIFFERENCE across the internal resistance (r) of the battery.

$V_{internal\ resistance} = Ir$

The **voltmeter V** will **NO LONGER** read the emf of the battery.

The voltmeter V now reads the TERMINAL POTENTIAL DIFFERENCE (V_{load}). In other words, the voltmeter V now reads the potential difference across the external circuit.

The internal resistance (r) is **IN SERIES** with the external resistance (R).

REMEMBER: Potential difference is divided among resistors in series.

Therefore, the potential difference across the external circuit (V_{load}) **PLUS** the potential difference across the internal resistance ($V_{internal\ resistance}$) is **EQUAL TO** the **emf** of the battery:

$emf = V_{load} + V_{internal\ resistance}$

If the current in the circuit is I, then:

The reading on the voltmeter (V) is:

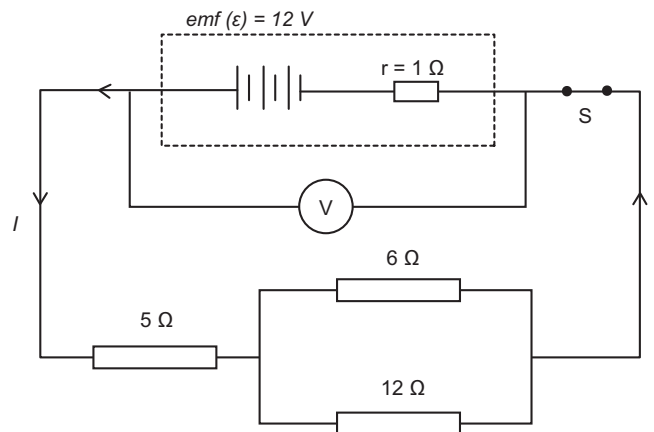$V = V_{load} = IR$ (Where R is the resistance of the external circuit)

$emf = V_{load} + V_{internal\ resistance}$

$emf = IR + Ir$

$emf = I(R + r)$ (This equation is found on the data sheet)

Note: $V_{internal\ resistance} = Ir$

All the resistors OUTSIDE the battery make up the **EXTERNAL RESISTANCE** (the load, R).

Calculate the resistance in the external circuit:

First calculate the equivalent resistance of the parallel network (R_p):

$\frac{1}{R_p} = \frac{1}{6} + \frac{1}{12}$
$\frac{1}{R_p} = \frac{3}{12}$
$R_p = \frac{12}{3} = 4\,\Omega$

The parallel network is connected **IN SERIES** with the 5 Ω resistor.

The resistance in the **EXTERNAL CIRCUIT** (R) is: R=5+4=9 Ω

Calculate the current in the battery:

The circuit current can be calculated using the emf of the battery and the TOTAL RESISTANCE in the ENTIRE CIRCUIT.

The total resistance in the entire circuit is the **SUM** of the external resistance (R) and the internal resistance (r) of the battery:

$R_{total} = R + r = 9 + 1 = 10\,\Omega$

emf=I(R+r)

$I = \frac{emf}{(R+r)} = \frac{12}{10} = 1,2\,A$

Calculate the reading on the voltmeter (V), the terminal potential difference:

$V = V_{load} = IR$

V = (1,2)(9) = 10,8 V

NOTICE that the voltmeter reading (10,8 V) is **LESS THAN** the emf of the battery (12 V).

Ask your learners where the MISSING 1,2 V is found.

The missing 1,2 V is found across the internal resistance of the battery (r).

$V_{internal\ resistance} = Ir$

$V_{internal\ resistance} = (1,2)(1) = 1,2V$

Another method of calculating the voltmeter reading (V) is to **SUBTRACT** $V_{internal\ resistance}$ from the emf of the battery:

$V = V_{load} = emf - V_{internal\ resistance}$

$V_{load} = 12 - 1,2$

$\qquad = 10,8\ V$

The potential difference across the internal resistance is often referred to as the 'LOST' VOLTS. These volts are not lost; this is the work done per coulomb of charge in the battery. It is the reason the battery heats up.

When the switch **S** is **CLOSED**, the terminal potential difference (V) will be **LESS THAN** the emf of the battery because the voltage across the internal resistance is **NOT AVAILABLE** to the external circuit.

1.2 Increasing the external resistance (R)
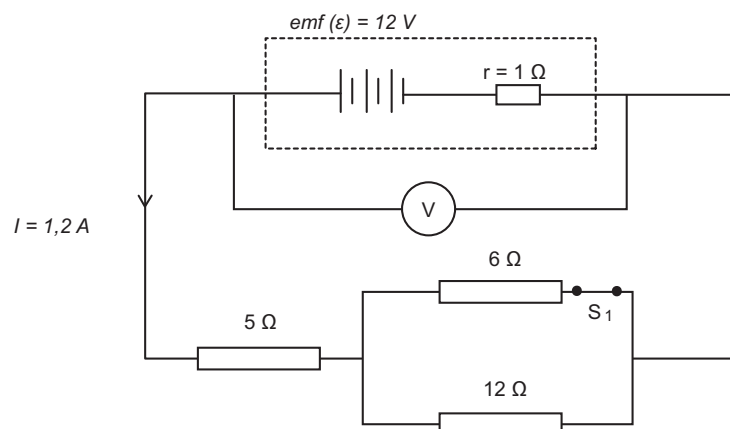
Consider the given circuit again.

The current in the circuit is **I = 1,2 A.** (Calculated earlier)

The resistance in the external circuit is **R = 9 Ω**.   (Calculated earlier)

Suppose we **INCREASE** the resistance in the external circuit.

Ask your learners how this could be achieved.

The resistance in the external circuit can be **increased** by:

1. ADDING ANOTHER RESISTOR IN SERIES with the 5 Ω resistor.

2. OPENING SWITCH S_1 . Opening S_1 , has the effect of removing resistors is parallel. This removes a pathway for the charge to flow in and therefore increases the resistance in the circuit.

SUPPOSE the switch S_1 is OPENED.

The resistance in the external circuit has increased:

The 12 Ω resistor is now in series with the 5 Ω resistor.

R = 5 + 12 = 17 Ω   (Before S_1 was opened, R = 9 Ω)

If the RESISTANCE IN THE EXTERNAL CIRCUIT has INCREASED, THEN the CIRCUIT CURRENT (I) must DECREASE:

$I = \dfrac{emf}{(R+r)} = \dfrac{12}{17} = 0,71\,A$ (Before S_1 was opened, I = 1,2 A)

The potential difference across the internal resistance ($V_{internal\ resistance}$) must DECREASE.

$V_{internal\ resistance} = Ir$ (r is constant and I has decreased)

$V_{internal\ resistance} = (0,71)(1) = 0,71\,V$ (Before S_1 was opened, $V_{internal\ resistance} = 1,2\,V$)

There is LESS voltage lost across the internal resistance of the battery (r).

Therefore there is a GREATER potential difference across the external resistance (V_{load}).

$V = V_{load} = emf - V_{internal\ resistance}$ (emf is constant and $V_{internal\ resistance}$ has decreased)

$V = V_{load} = 12 - 0,71 = 11,29\ V$ (Before S_1 was opened, V = 10,8 V)
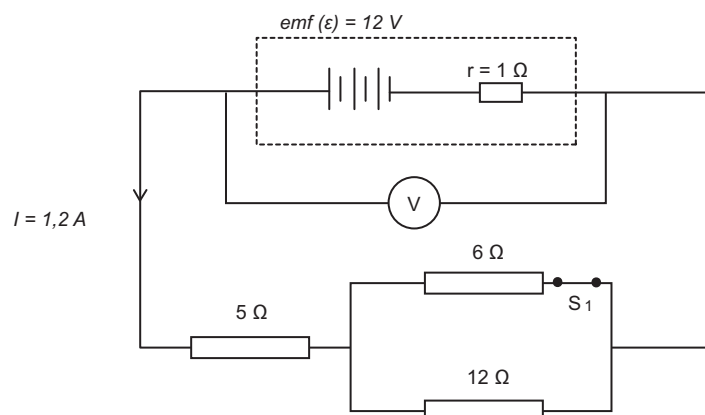
IN SUMMARY:

If the resistance (R) in the external circuit is INCREASED, then the circuit current (I) will DECREASE.

There are FEWER volts lost across the internal resistance (r) ($V_{internal\ resistance} = Ir$)

There are MORE volts available across the external resistance. ($V_{load} = emf - V_{internal\ resistance}$)

1.3   Decreasing the external resistance (R)

Consider the given circuit again.

emf (ε) = 12 V
r = 1 Ω
I = 1,2 A
V
6 Ω
5 Ω
S 1
12 Ω

The current in the circuit is **I = 1,2 A**. (Calculated earlier)

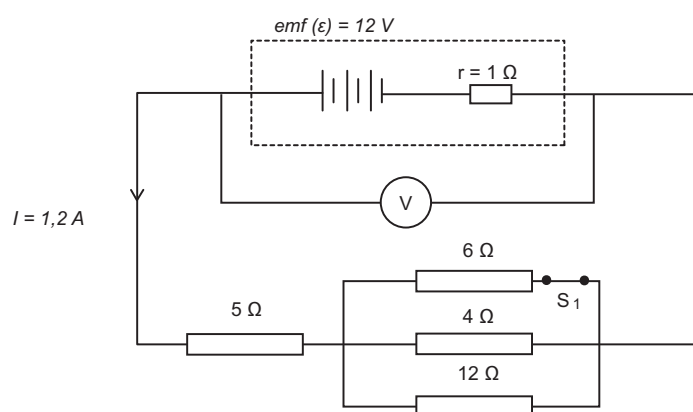The resistance in the external circuit is **R = 9 Ω**.   (Calculated earlier)

Suppose we **DECREASE** the resistance in the external circuit.

Ask your learners how this could be achieved.

The resistance in the external circuit can be **decreased** by:

1.   REMOVING A RESISTOR IN SERIES.

2.   ADDING ANOTHER RESISTOR IN PARALLEL. Adding resistors in parallel means there are more pathways for the charge to flow in and therefore reduces the resistance in the circuit.

SUPPOSE we add a 4 Ω resistor in parallel with the existing parallel resistors.

emf (ε) = 12 V
r = 1 Ω
I = 1,2 A
V
6 Ω
5 Ω
4 Ω
S 1
12 Ω

The resistance in the external circuit has decreased:

$$\frac{1}{R_p} = \frac{1}{6} + \frac{1}{4} + \frac{1}{12} = \frac{1}{2}$$
$$R_p = \frac{2}{1} = 2\,\Omega$$

$R = 5 + 2 = 7\,\Omega$ \hspace{2cm} (Before, R = 9 Ω)

If the RESISTANCE IN THE EXTERNAL CIRCUIT has DECREASED, THEN the CIRCUIT CURRENT (I) must INCREASE:

$$I = \frac{emf}{(R + r)} = \frac{12}{8} = 1,5A$$ \hspace{1cm} (Before, I = 1,2 A)

The potential difference across the internal resistance ($V_{internal\ resistance}$) must INCREASE.

$V_{internal\ resistance} = Ir$ \hspace{0.5cm} (r is <u>constant</u> and I has <u>increased</u>)

$V_{internal\ resistance} = (1,5)(1) = 1,5\,V$ \hspace{0.5cm} (Before, $V_{internal\ resistance} = 1,2\,V$)

There is <u>MORE</u> voltage lost across the internal resistance of the battery (r).

Therefore there is LESS potential difference across the external resistance (V_{load}).

$V = V_{load} = emf - V_{internal\ resistance}$ \hspace{0.5cm} (emf is <u>constant</u> and $V_{internal\ resistance}$ has <u>increased</u>)

$V = V_{load} = 12 - 1,5 = 10,5\,V$ \hspace{0.5cm} (Before, V=10,8 V)

IN SUMMARY:

If the resistance (R) in the external circuit is DECREASED, then the circuit current (I) will INCREASE.

There are MORE volts lost across the internal resistance (r) ($V_{internal\ resistance} = Ir$)

There are FEWER volts available across the external resistance. ($V_{load} = emf - V_{internal\ resistance}$)

Work through the following example to develop your learners understanding:

1. Consider the circuit below. The internal resistance of the battery cannot be ignored.
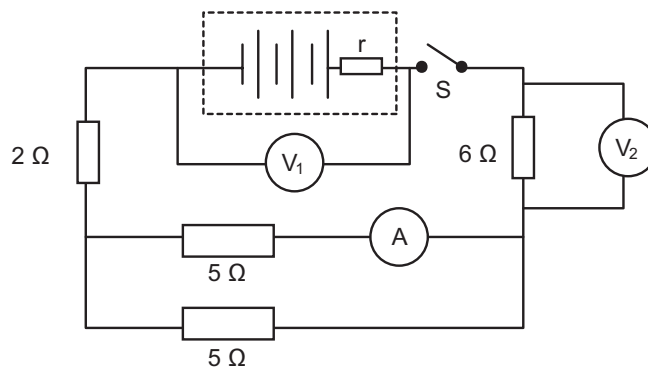
With the switch S open, the reading on the voltmeter V_1 is 9 V

When the switch is closed, the ammeter reads 400 mA.

1.1   What is the emf of the battery?

Solution:

emf = 9 V

1.2   Calculate the total resistance in the external circuit.

Solution:

$$\frac{1}{R_p} = \frac{1}{5} + \frac{1}{5}$$

$$\frac{1}{R_p} = \frac{2}{5}$$

$$R_p = \frac{5}{2} = 2{,}5 \ \Omega$$

$$R = 2 + 2{,}5 + 6 = 10{,}5 \, \Omega$$

1.3   Calculate the internal resistance of the battery.

Solution:

The current in the circuit is:

$$I = 0{,}4 + 0{,}4 = 0{,}8 \text{ A}$$

$$\text{emf} = I(R + r)$$

$$9 = 0{,}8(10{,}5 + r)$$

$$11{,}25 = 10{,}5 + r$$

$$r = 0{,}75 \, \Omega$$

1.4   Calculate the reading on the voltmeter V_1.

Solution:

$$V_1 = V_{load} = IR$$

$$V_1 = (0{,}8)(10{,}5) = 8{,}4 \text{ V}$$

1.5   Explain why the reading on voltmeter V_1 changes when the switch S is closed.

Solution:

There is a current I through the battery.

There is a potential difference across the internal resistance of the battery, $V_{internal\ resistance}$.

Work is done per coulomb of charge inside the battery, therefore, less work can be done per coulomb in the external circuit.

1.6 The 6 Ω resistor is replaced with a 4 W light bulb which works at full power. V_2 now reads 2 V. Calculate the new reading on the ammeter.

Solution:

$P = VI$

$I = \dfrac{P}{V} = \dfrac{4}{2} = 2$ A

Therefore, the ammeter reads 1 A. (Current splits equally in the parallel branches).

1.7 Explain why the reading on the voltmeter V_1 decreases when the 6 Ω resistor is replaced with the 4 W bulb.

Solution:

The current in the circuit has increased, therefore $V_{internal\ resistance}$ increases.
$(V_{internal\ resistance} = Ir)$

There are less volts available across the external resistance.

The terminal potential difference (V_{load}) will decrease, $V_1 = V_{load} = emf - V_{internal\ resistance}$


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 concepts of emf, terminal potential difference (V_{load}) and potential difference across the internal resistance ($V_{internal\ resistance}$).
   - the equation, emf = I(R + r).

How to tackle these questions in the classroom:

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

1. In the circuit diagram represented alongside, a battery of emf 30 V and unknown internal resistance r is connected to resistors, as shown. Ignore the resistance of the ammeter and the connecting wires.
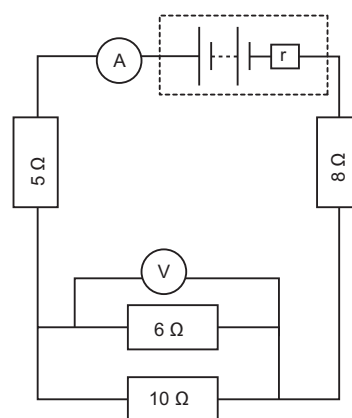
The current passing through the 10 Ω resistor is 0,6 A.

Calculate the:

1.1 equivalent resistance of the two resistors in parallel.

1.2 current through the 8 Ω resistor.

1.3 calculate the power dissipated in the 5 Ω resistor.

1.4 internal resistance of the battery.

Solution:

1.1 $\dfrac{1}{R_p} = \dfrac{1}{6} + \dfrac{1}{10} = \dfrac{4}{15}$

$R_p = \dfrac{15}{4} = 3,75 \ \Omega$

1.2 The ratio of resistances in parallel is:

10 Ω   :   6 Ω

The current divides in the inverse ratio to resistance:

6   :   10

0,6 A :   1 A

$I_{6\Omega} = 1$ A

Therefore, the current in the 8 Ω resistor is the sum of the currents in each branch of the parallel network.

$I_{8\Omega} = 1 + 0,6 = 1,6$ A

OR $V_{6\Omega} = V_{10\Omega}$

$I_{6\Omega} = I_{10\Omega} R_{10\Omega}$

$I_{6\Omega}(6) = (0,6)(10)$

$I_{6\Omega} = I$ A

1.3 $P = I^2 R = (1,6)^2(5) = 12,8$ W

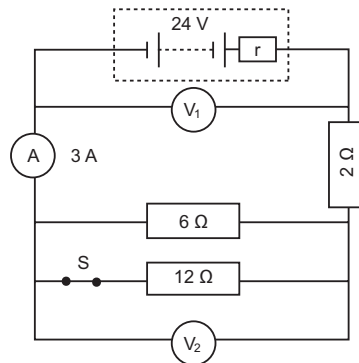**1.4** The resistance in the external circuit is:

$R = 5 + 3,75 + 8 = 16,75\,\Omega$

$emf = I(R + r)$

$30 = 1,6(16,75 + r)$

$18,75 = 16,75 + r$

$r = 2\,\Omega$

2. Consider the circuit diagram below. The ammeter reads 3 A, while the battery has an emf of 24 V and an internal resistance r.

Switch S is closed.

Calculate:

2.1 the effective resistance of the parallel combination of resistors.

2.2 the reading on the voltmeter V_1.

2.3 the internal resistance of the battery.

2.4 the reading on the voltmeter V_2.

2.5 switch S is now opened.

Without any further calculations, predict whether the readings on each of the following will INCREASE, DECREASE or REMAIN UNCHANGED. Give a reason for the answer in each case.

2.5.1 The reading on the ammeter A.

2.5.2 The reading on the voltmeter V_1.

2.5.3 The reading on voltmeter V_2.

Solution:

2.1 $\dfrac{1}{R_p} = \dfrac{1}{6} + \dfrac{1}{12} = \dfrac{1}{4}$

$R_p = \dfrac{4}{1} = 4\,\Omega$

2.2 The resistance in the external circuit is:

$R = 2 + 4 = 6\,\Omega$

$V_1 = V_{load} = IR = (6)(3) = 18\ V$

2.3 $V_{internal\ resistance} = emf - V_{load}$

$Ir = 24 - 18$

$(3)r = 6$

$r = 2\,\Omega$

2.4 $V_2 = IR_p = (3)(4) = 12\ V$

2.5.1 Decrease.
Total resistance in the circuit has increased. Current is inversely proportional to total resistance at constant emf.

2.5.2 Increases.
With a decrease in current, there are fewer volts 'lost' across the internal resistance of the battery. $V_{internal\ resistance} = Ir$
As the emf is constant and $V_{internal\ resisrance}$ is smaller, V_{load} will be bigger.
$V_1 = V_{load} = emf - V_{internal\ resistance}$

2.5.3 Increases.
There is less current through the 2 Ω resistor.
The potential difference across the 2 Ω resistor will decrease. Also, the potential difference across the 6Ω resistor increases as V_{load} has increased and V_2 has decreased.
$V_6 = V_{load} - V_2$

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 concepts of emf, terminal potential difference and potential difference across the internal resistance.
    - the equation, emf = I(R + r).
   - Ohm's law.
    - the concepts of power and energy.

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 questions and answer them correctly in their workbooks.

KEY TEACHING:

a. Real batteries have internal resistance (r).

b. A potential difference exists across the internal resistance. This voltage is not available to the external circuit.

c. When current passes through the battery, the terminal potential difference will be less than the emf of the battery, due to the drop of potential across the internal resistance of the battery.

d. When the external resistance increases, there will be less current through the battery and less work will be done ber coulomb of charge inside the battery. The terminal potential difference will increase.

e. When the external resistance decreases, there will be more current through the battery and higher drop of potential across the internal resistance of the battery ie. more work is done per coulomb of charge inside the battery. The terminal potential difference will decrease.

3. In the circuit diagram shown, the battery has an emf of 12 V and an internal resistance of 0,8 Ω. The resistance of the ammeter and connecting wires may be ignored.
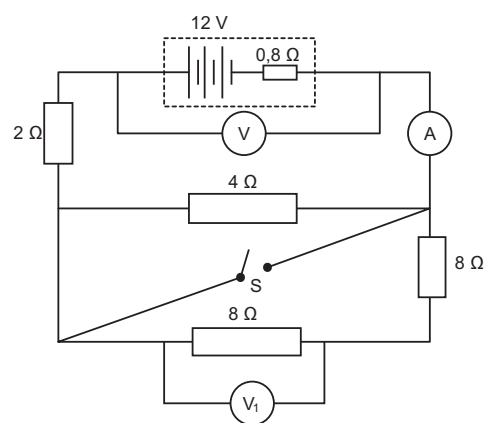
Switch S is open.

Calculate the:

3.1 effective resistance of the circuit.

3.2 reading on the ammeter.

3.3 reading on the voltmeter V_1.

3.4 rate at which energy is dissipated in the battery.

3.5 What would happen to the reading on voltmeter V if switch S is closed? Write INCREASE, DECREASE or REMAIN UNCHANGED. Explain the answer.

Solution:

3.1 $\frac{1}{R_p} = \frac{1}{16} + \frac{1}{4} = \frac{5}{16}$

$R_p = \frac{16}{5} = 3,2$

$R_{ρνραχ} = 2 + 3,2 + 0,8 = 6\,Ω$

3.2 $emf = I(R + r)$

$I = \frac{emf}{(R + r)} = \frac{12}{6} = 2\,A$

3.3 Ratio of resistances:

$4\,Ω$: $16\,Ω$

1 : 4

Current divides in the inverse ratio:

4 : 1

$\frac{2A}{4} = 0,4$

$1,6$: $0,4$

$V = RI = (8)(0,4) = 3,2\,V$

OR $\quad V_{4\Omega} = V_{16\Omega}$

$I_{4\Omega}R_{4\Omega} = I_{16\Omega}R_{16\Omega}$

$I_{4\Omega} = I_{16\Omega}\dfrac{I_{16\Omega}}{R_{4\Omega}}$

$I_{4\Omega} = I_{16\Omega}\left(\dfrac{16}{4}\right)$

$I_{4\Omega} = 4I_{16\Omega}$

$I_T = I_{4\Omega} + I_{16\Omega}$

$2 = 5I_{16\Omega}$

$I_{16\Omega} = 0,4\text{ A}$

$V = IR$

$V = (0,4)(8)$

$V = 3,2\text{ V}$

OR $\quad V_p = IR_p$

$V_p = (2)(3,2)$

$V_p = 6,4\text{ V}$

$\therefore V_{8w} = \dfrac{6,4}{2}$

$= 3,2\text{ V}$

**3.4** $P = I^2r$

$P = (2)^2(0,8) = 3,2\text{ W}$

3.5 When S is closed, the parallel network is short-circuited.

In other words, the resistance of the parallel network becomes zero.

The resistance in the circuit has increased.

Current through the battery has decreased.

The drop of potential across the internal resistance of the attery is lower.

$V_{\text{internal resistance}} = Ir$

The emf to the battery is constant, therefore the difference of emf minus potential difference across the infternal resistance is greater.

$V = V_{\text{load}} = emf - V_{\text{internal resistance}}$

Hence V will increase.

4. In the circuit shown, two 60 Ω resistors connected in parallel are connected in series with a 25 Ω resistor. The battery has an emf of 12 V and an internal resistance of 1,5 Ω.
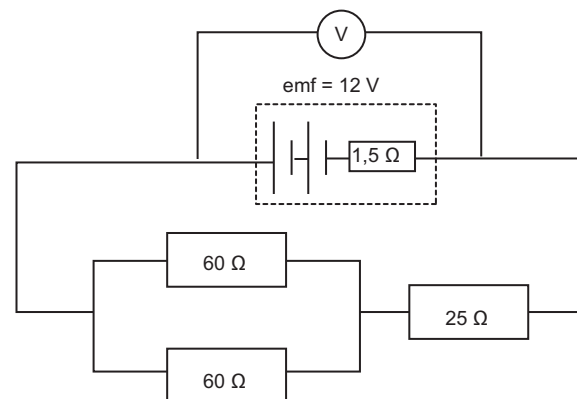
Calculate the:

4.1 equivalent resistance of the parallel combination.

4.2 total current in the circuit.

4.3 potential difference across the parallel resistors.

4.4 power provided to each 60 Ω resistor.

4.5 How would the reading on the voltmeter change if another 60 Ω resistor was connected in parallel with the existing 60 Ω resistors? Write INCREASE, DECREASE or REMAIN UNCHANGED. Explain the answer.

Solution:

4.1 $\dfrac{1}{R_p} = \dfrac{1}{60} + \dfrac{1}{60} = \dfrac{1}{30}$

$R_p = \dfrac{30}{1} = 30\,\Omega$

4.2 $I = \dfrac{emf}{(R+r)} = \dfrac{12}{(55+1,5)} = 0,21\,A$

4.3 $V_p = IR_p = (30)(0,21) = 6,4\,V$

4.4 $P = \dfrac{V^2}{R} = \dfrac{(6,3)^2}{60} = 0,68\,W$

4.5 Resistance in the external circuit would decrease as the parallel resistance has decreased because an alternative pathway has been provided.

Current would increase.

Greater drop of potential across the internal resistance of the battery.

$V_{internal\ resistance} = Ir$

emf is constant, hence the emf minus $V_{internal\ resistance}$ is smaller.

$V = V_{load} = emf - V_{internal\ resistance}$

Reading on voltmeter would decrease.

CHECKPOINT

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

1. The concepts of emf, terminal potential difference and potential difference across the internal resistance.

2. Applying the equation, *emf* = *I*(R+r).

3. How changes in the external resistance affect the terminal potential diference.

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

Resource Pack: Electric circuits Worksheet: Questions 1–5. (Pages 4–7).

- 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: Topic 10: Electric Circuits: 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 exercise 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 the 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=Che8SRxp92I
   emf and internal resistance

2. https://www.youtube.com/watch?v=hPQp-hZbc48
   emf and internal resistance

3. https://www.youtube.com/watch?v=x2EuYqj_0Uk
   Series and parallel circuits

TOPIC 11:
Electrodynamics

A   Introduction

- This topic runs for 8 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Electrodynamics forms part of the content area Electricity and Magnetism (Physics).
- Electricity and Magnetism counts as 37 % in the final Physics Examination (Paper I).
- Electrodynamics counts approximately 8 % to 10 % of the final examination.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.

2. Chalk.

3. Grade 12 Physics Examination Data Sheet.

   Optional extras:

4. Enamel coated copper wire, 4 large ceramic block magnets, cardboard (packaging), large nail, 1,5 V 25 mA light bulb. These materials can be used to make a simple generator.

5. 2 pieces of thin aluminium strips 3 cm × 6 cm, 1,5 m of enamel coated copper wire, 2 lengths of copper wire, a ring magnet (from an old speaker) a 6 cm × 15 cm block of wood, sandpaper and thumb tacks. These materials can be used to make a simple electric motor.

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. An A4 3-quire exercise book, for notes and exercises.

2. Scientific calculator – Sharp or Casio calculators are highly recommended.

3. Pen.

4. Grade 12 Physics Examination Data Sheet.

B   Sequential Table

PRIOR KNOWLEDGE	PRIOR KNOWLEDGE	CURRENT
GRADE 10	GRADE 11	GRADE 12
• Magnetic field of permanent magnets • Poles of permanent magnets, attraction and repulsion, magnetic field lines	• Magnetic field associated with current carrying wires • Faraday's law	• Electrical machines (generators, motors) • Alternating current

C   Glossary of Terms

TERM	DEFINITION
Magnetic flux	The product of the magnetic field (B) and the cross-sectional area (A) the field lines pass through: $\phi = BA\cos\theta$ Where θ is the angle between the magnetic field (B) and the normal to the loop of area A.
Faraday's law	The magnitude of the induced emf across the ends of a conductor is directly proportional to the rate of change in the magnetic flux linkage.
Split ring (commutator)	A device which ensures that the direction of the current in a coil is reversed every half revolution (180° of revolution).
Root mean square voltage V_{rms}	The rms value of AC voltage is equivalent to the DC voltage necessary to deliver the same power.
Root mean square current I_{rms}	The rms value of alternating current is equivalent to the direct current necessary to deliver the same power.
Coil	A series of loops of a conductor (insulated copper wire) often wound around a core. One loop of wire is referred to as a turn and a coil consists of one or more turns.
emf	The work done per unit charge by the source (battery). It is equal to the potential difference measured across the terminals of a battery when no charges are flowing in the circuit.
Magnetic field	A region in space where a magnet or ferromagnetic material will experience a force (non-contact).
Electromagnetic induction	Electromagnetic induction occurs when a current is induced in a closed conducting loop when there is a change in the magnetic flux passing through the surface area of the conducting loop.
Conventional current	Conventional current is the rate of flow of positive charge from the positive terminal of the cell to the negative terminal.
Torque	A turning force exerted on a coil. Magnetic forces exerted in opposite directions on the opposite sides of the coil cause the coil to rotate.
AC	Alternating current reverses direction periodically. Moving charges keep switching direction repeatedly in the circuit. The magnitude of the alternating current also changes repeatedly.
AC voltage	Voltage that alternates repeatedly between a positive maximum value and a negative maximum value.
DC	Direct current, electrons flow in one direction in the circuit.
DC voltage	A voltage which produces direct current.
Frequency	The number of complete cycles per second.
Maximum voltage V_{max}	The peak voltage produced in an AC circuit.

Maximum current I_{max}	The peak current in an AC circuit.
Root mean square voltage V_{rms}	The rms value of AC voltage is equivalent to the DC voltage necessary to deliver the same power.
Root mean square current I_{rms}	The rms value of alternating current is equivalent to the direct current necessary to deliver the same power.
Average power P_{av}	The average power delivered by an AC source.

D Assessment of this Topic

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

E Breakdown of Topic and Targeted Support Offered

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

TIME ALLOCATION	SUB-TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
4 hour	Electrical machines (generators and motors)	130 – 131	a. Explanation of how an AC generator works. b. Explanation of how a DC generator works. c. Graphs of output voltage versus time and current versus time for both AC and DC generators. d. Explanation of how a DC motor works. e. Explanation of how an AC motor works. f. Numerous practice questions.
4 hour	Alternating current	131	g. Explanations of peak AC voltage and peak AC current. h. Explanations of rms voltage and rms current. i. Explanation of the average power delivered by an AC source. j. Numerous practice questions.

F   Targeted Support per Sub-topic

1. ELECTRIC GENERATORS

INTRODUCTION

An electric generator converts mechanical energy into electrical energy. Electricity is an essential part of our daily lives. It drives industry and allows our economy to grow and develop.

CONCEPT EXPLANATION AND CLARIFICATION

1.1   AC GENERATOR

Draw a simplified diagram of an AC generator on the board.

A single coil of wire (**ABCD**) is placed in the magnetic field. Slip rings are connected to each end of the coil of wire. Carbon brushes make contact with the slip rings and are connected to the external circuit (bulb).
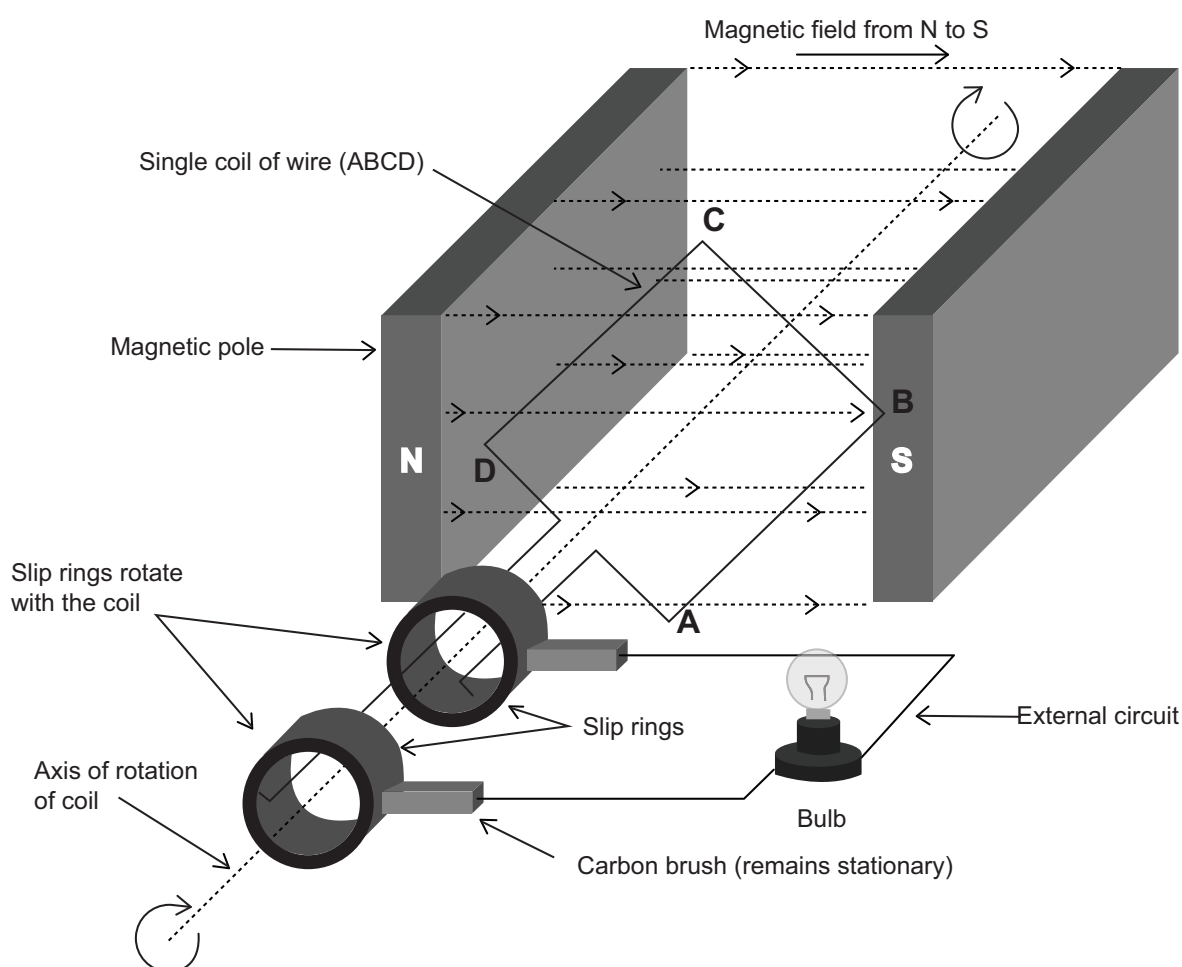
TOPIC 11

Magnetic field from N to S

Single coil of wire (ABCD)

C

Magnetic pole

B

N   D   S

A

Slip rings rotate with the coil

Slip rings

Axis of rotation of coil

External circuit

Bulb

Carbon brush (remains stationary)

Diagram 1 : Parts of an altering current (AC) generator

When the coil is rotated (mechanical energy), the slip rings move with the coil. The carbon brushes remain stationary and press against each slip ring, therefore the coil is connected to the external circuit (bulb).

The coil is now rotated THROUGH THE MAGNETIC FIELD between the permanent magnets.
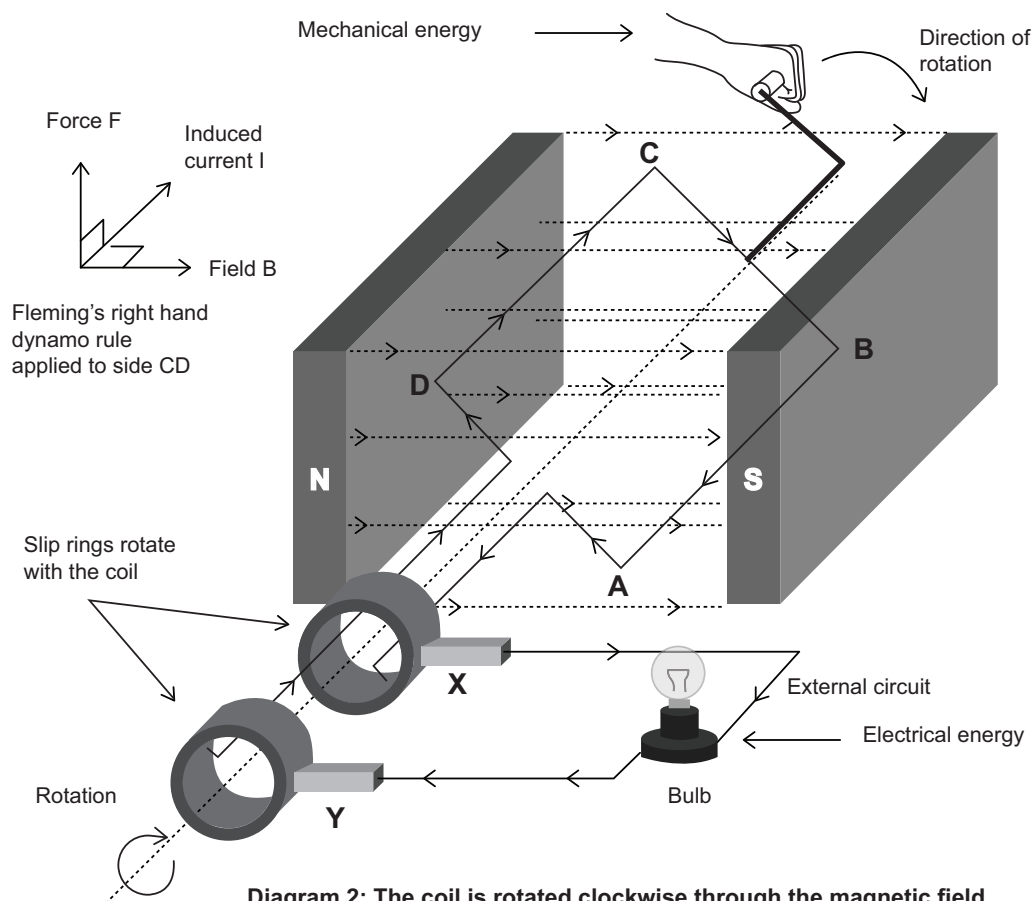

Diagram 2: The coil is rotated clockwise through the magnetic field

As the coil is rotated THROUGH the magnetic field, the **MAGNETIC FLUX** (φ) passing through the SURFACE AREA OF THE COIL is **CHANGING**.

An **emf** is **INDUCED** in the coil which in turn INDUCES A CURRENT in the coil. The bulb lights up.

This principle is known as **ELECTROMAGNETIC INDUCTION**.

An electric generator converts **MECHANICAL ENERGY** (rotation) into **ELECTRICAL ENERGY** (an induced current).

FLEMING'S RIGHT HAND DYNAMO RULE is used to determine the direction of the induced current in the conductor.

Fleming's Right Hand Dynamo Rule:

Using your **RIGHT HAND**; hold your thumb, first finger and second finger at right angles to each other as shown below.
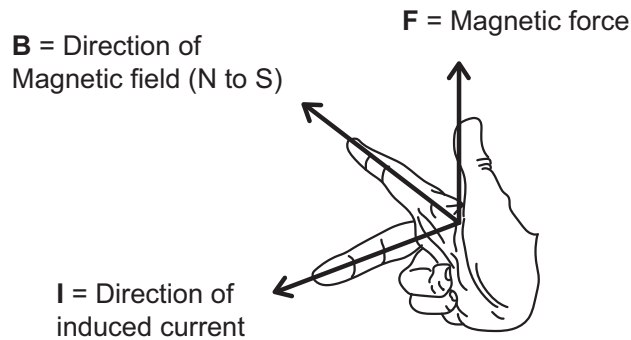

Diagram 3: Fleming's RIGHT HAND dynamo rule

Your THUMB must point in the direction of the MOTION (**Force F**)

Your FIRST FINGER shows the direction of the **magnetic field (B)**, North to South.

Your SECOND FINGER will then show the direction of the INDUCED CURRENT (**Current I**).

REFER TO DIAGRAM 2 AGAIN.

Side **CD** of the coil is FORCED UPWARDS. According to Fleming's right hand dynamo rule, the direction of the INDUCED CURRENT is from **D to C** in the coil.

Side AB of the coil is FORCED DOWNWARDS. According to Fleming's right hand dynamo rule, the direction of the INDUCED CURRENT is from **B to A** in the coil.

The direction of the induced current **IN THE COIL** is **DCBA**.

The direction of the current in the **EXTERNAL CIRCUIT** is from **X to Y**.

As the coil is rotated through the magnetic field, the **MAGNETIC FLUX** (φ) passing through the surface area of the coil is **CHANGING**.

Draw the following graph on the board (Diagram 4).

The graph shows how the **magnetic flux** changes with **time** as the coil rotates.
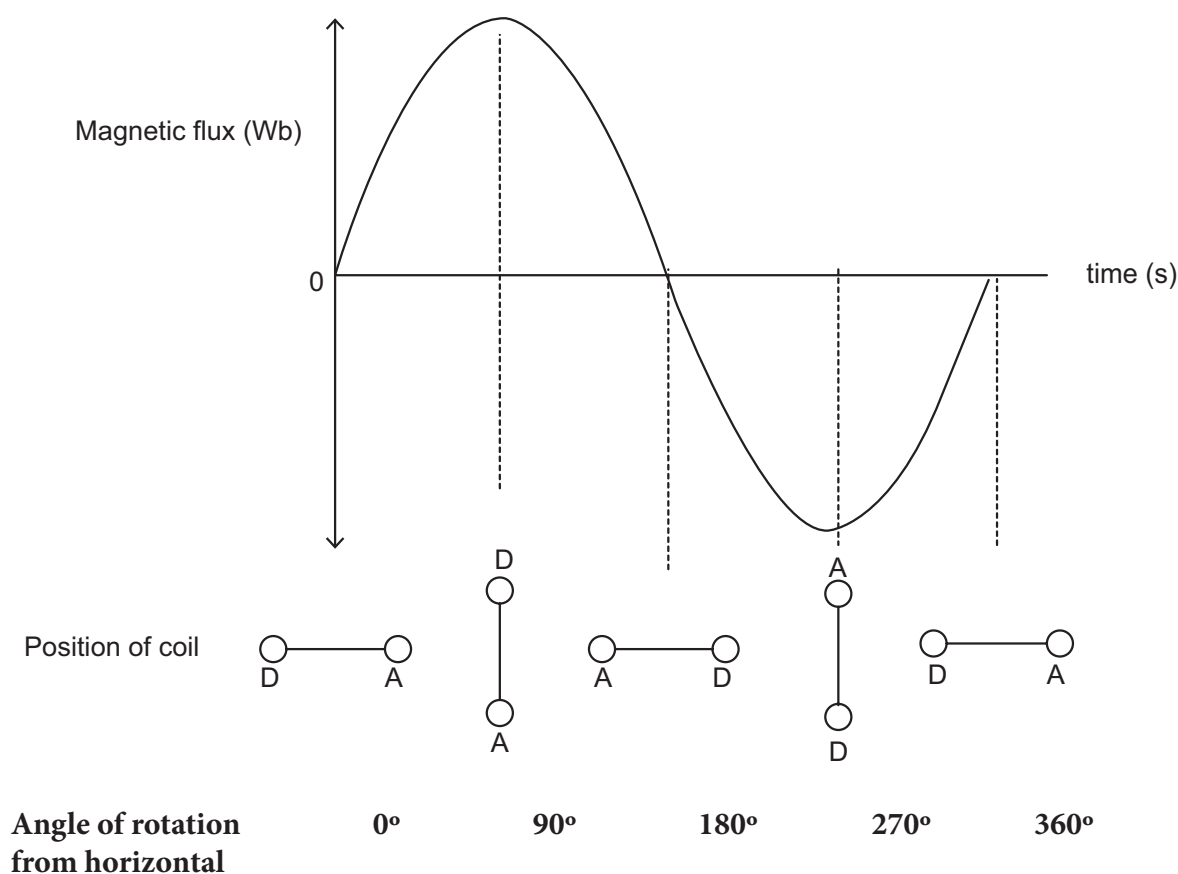
| Angle of rotation from horizontal | 0º | 90º | 180º | 270º | 360º |

Diagram 4: Graph to show how magnetic flux (φ) through the coil changes with the position of the coil

Emphasise the following points to your learners:

a. When the PLANE OF THE COIL is PARALLEL to the MAGNETIC FIELD, **MAGNETIC FLUX** through the coil is **ZERO**.

b. When the PLANE OF THE COIL is PERPENDICULAR to the MAGNETIC FIELD, **MAGNETIC FLUX** through the coil is a **MAXIMUM**.

Now get your learners to understand the following:

The GRADIENT (slope) of the magnetic flux (φ) versus time (t) graph is:

$$\text{gradient} = \frac{\Delta y}{\Delta x} = \frac{\Delta \phi}{\Delta t}$$

The **GRADIENT** of the magnetic flux (φ) versus time (t) graph is equal to **THE RATE OF CHANGE OF MAGNETIC FLUX**.

The **gradient** (slope) of the graph is a **maximum** when the coil is **parallel** to the magnetic field lines.

The **gradient** (slope) of the graph is a **zero** when the coil is **perpendicular** to the magnetic field lines.

Emphasise the following points to your learners:

a. When the PLANE OF THE COIL is PARALLEL to the MAGNETIC FIELD, **THE RATE OF CHANGE OF MAGNETIC FLUX** ($\frac{\Delta\phi}{\Delta t}$) is a **MAXIMUM**.

b. When the PLANE OF THE COIL is PERPENDICULAR to the MAGNETIC FIELD, **THE RATE OF CHANGE OF MAGNETIC FLUX** through the coil is **ZERO**.

Remind your learners of the statement of **Faraday's law**:

The MAGNITUDE of the emf INDUCED in a coil is DIRECTLY PROPORTIONAL to the RATE OF CHANGE OF MAGNETIC FLUX.

$$\text{emf} = -N\frac{\Delta\phi}{\Delta t}$$

Now make the connection between the **rate of change of magnetic flux** and the **induced emf** in the coil:

a. When the PLANE OF THE COIL is PARALLEL to the MAGNETIC FIELD, **THE RATE OF CHANGE OF MAGNETIC FLUX** ($\frac{\Delta\phi}{\Delta t}$) is a **MAXIMUM**, therefore according to Faraday's law, the **INDUCED emf** is a **MAXIMUM**.

b. When the PLANE OF THE COIL is PERPENDICULAR to the MAGNETIC FIELD, **THE RATE OF CHANGE OF MAGNETIC FLUX** through the coil is **ZERO**, therefore according to Faraday's law, the **INDUCED emf** is **ZERO**.

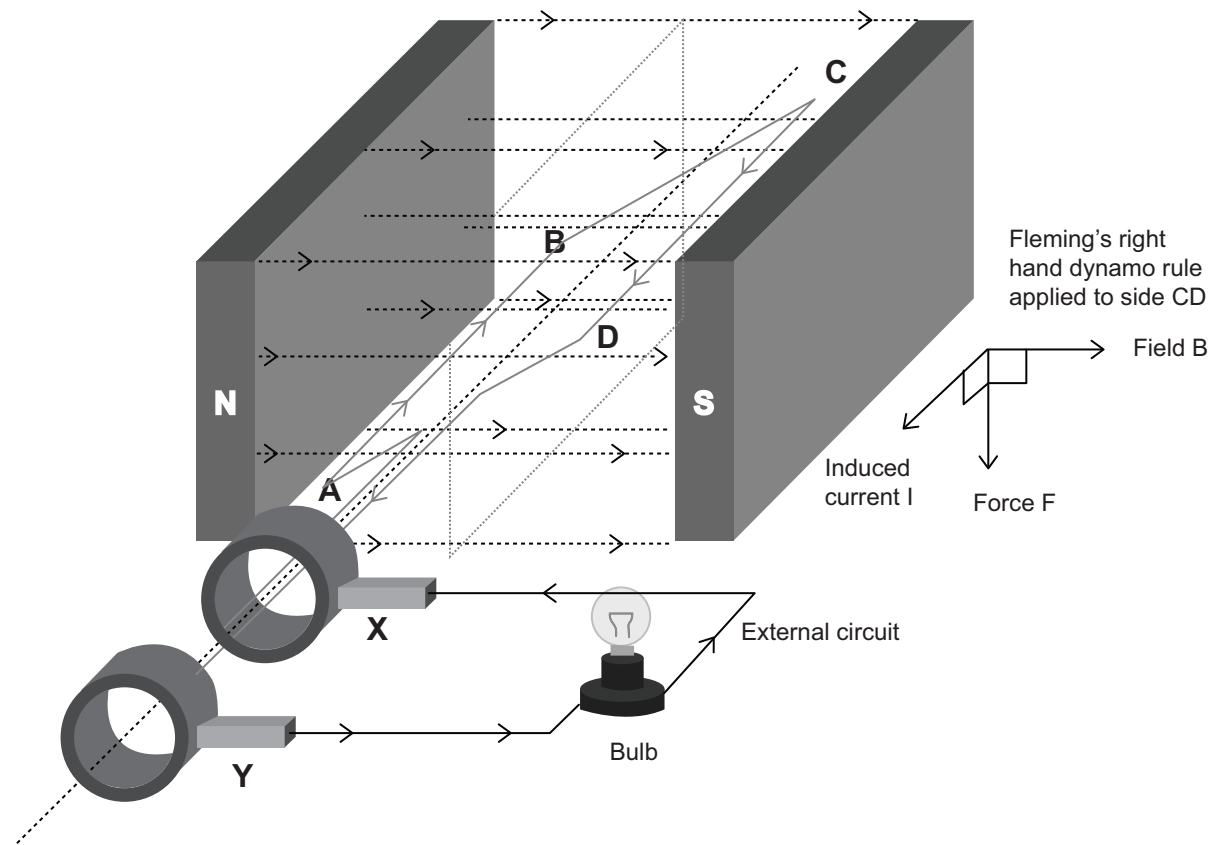Diagram 5 below shows the coil rotating past the vertical position.

Diagram 5: The direction of the unduced current is reversed as the coil is rotated past the vertical position

Side **CD** of the coil is FORCED DOWNWARDS. According to Fleming's right hand dynamo rule, the direction of the INDUCED CURRENT is from **C to D** in the coil.

Side **AB** of the coil is FORCED UPWARDS. According to Fleming's right hand dynamo rule, the direction of the INDUCED CURRENT is from **A to B** in the coil.

The direction of the induced current **IN THE COIL** is **ABCD**.

The direction of the current in the **EXTERNAL CIRCUIT** is from **Y to X**.

Emphasise this point to your learners:

The DIRECTION of the INDUCED CURRENT is **REVERSED** after the coil moved through the vertical position.

Before the coil reached the **vertical position**, the induced current direction in the coil was **DCBA**.

After the coil passed through the **vertical position**, the induced current direction in the coil is **ABCD**.

The graph below (Diagram 6) shows how the INDUCED CURRENT in the coil varies over one full revolution (cycle) of the coil (**starting** in the **horizontal** position).
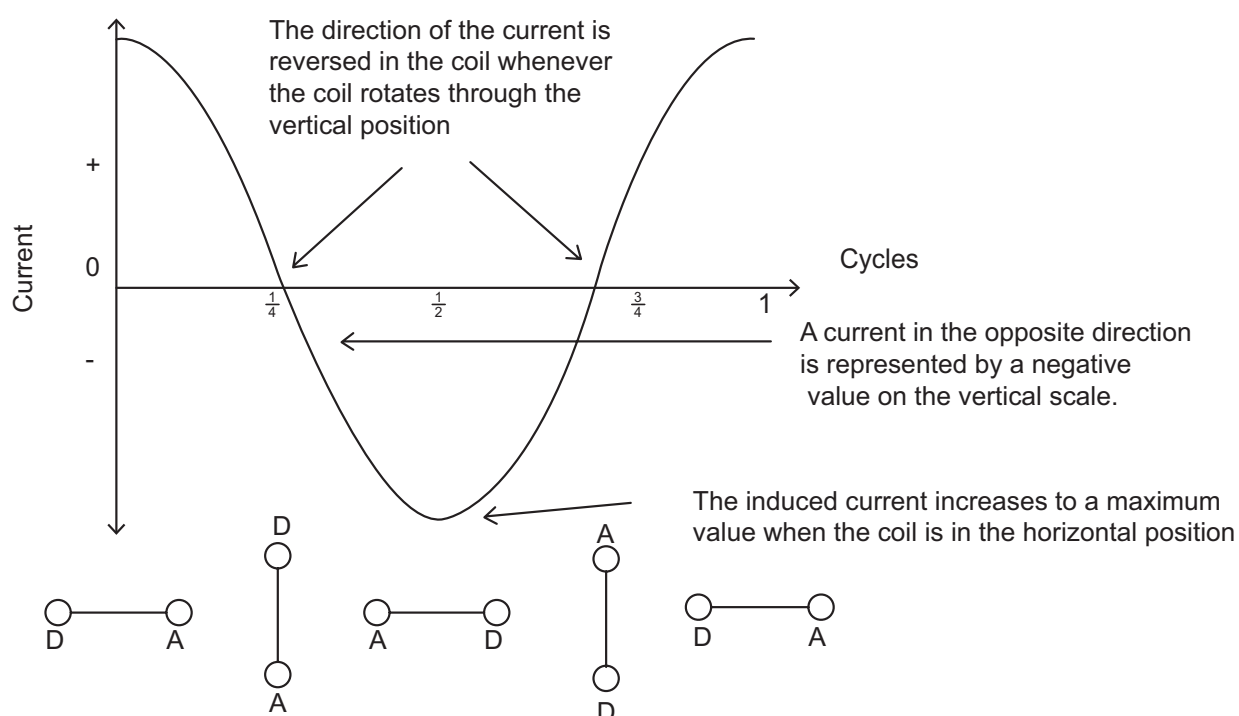

Diagram 6: The graph of induced current in the coil versus the position of coil for one complete revolution of the coil.

Notice that the **DIRECTION** of the **INDUCED CURRENT** is **REVERSED** whenever the coil passes the **VERTICAL POSITION**.

The **INDUCED CURRENT** reaches its **MAXIMUM** value whenever the coil rotates through the **HORIZONTAL POSITION**. (Zero magnetic flux and maximum emf).

This graph represents an **ALTERNATING CURRENT** (AC). The MAGNITUDE and the DIRECTION of the current are CHANGING as the coil is rotated.

Diagram 7 below shows how the INDUCED EMF varies with the position of the coil for one complete revolution of the coil (**starting** in the **horizontal** position).
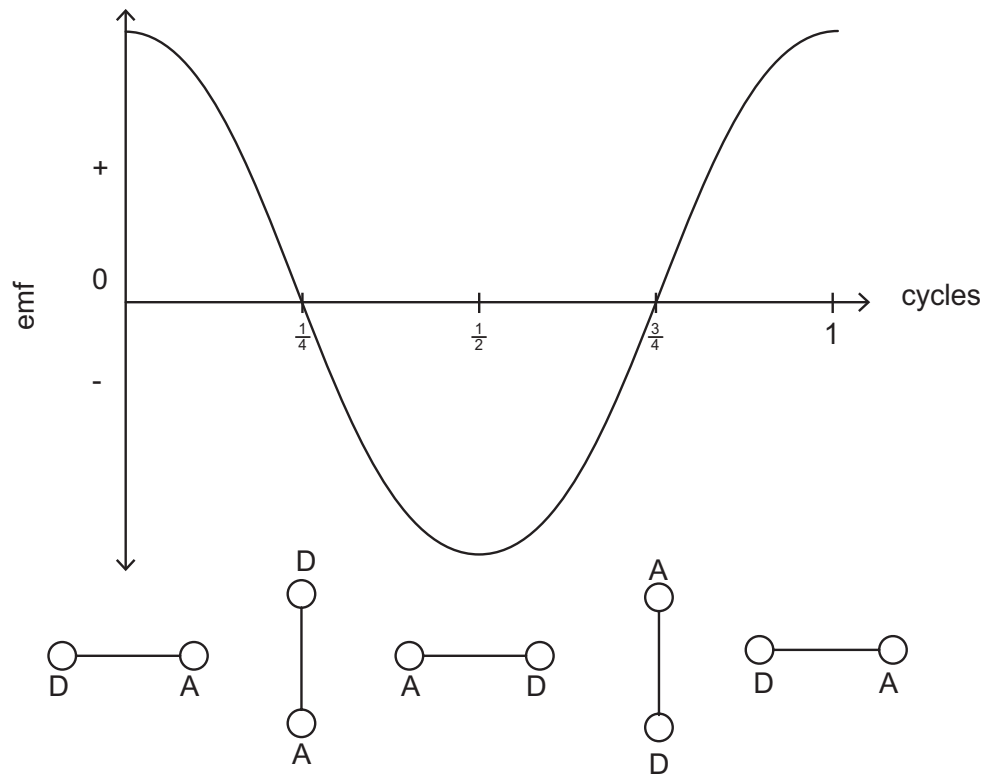

Diagram 7: The graph of induced emf in the coil versus the position of the coil for one complete revolution of the coil.

This **CHANGING emf** induces an ALTERNATING CURRENT (AC) in the coil. This alternating current is directed through the external circuit by means of carbon brushes. An electric generator that produces alternating current is called an ALTERNATOR.

In an **AC generator**:

a. An alternating current is induced IN THE COIL.

b. Using **SLIP RINGS** ensures there is also an alternating current in the EXTERNAL CIRCUIT.

The purpose of the **SLIP RINGS** is to ensure that the direction of the current in the external circuit is the **SAME AS** the direction of the current in the coil, therefore the slip rings ensure that the direction of the induced current in the external circuit reverses (changes) direction every half cycle (alternate).

Your learners must know some of the uses of AC generators:

1. They are used by power plants to convert the kinetic energy of hot, pressurized steam into electrical current. This occurs for coal-fired power plants as well as nuclear power plants. Hydroelectric power plants use mechanical energy of water to spin a generator.

2. Your car uses an alternator to recharge the battery when you are driving.

3. Diesel generators are used to supply power when power is not available.

4. A moving coil microphone. Sound waves make a coil move. As the coil moves in a magnetic field a current is induced and this varying current can be amplified and fed to a loudspeaker.

1.2   DC GENERATOR

A DC (direct current) generator is designed to produce **DIRECT CURRENT** in the **external circuit**.

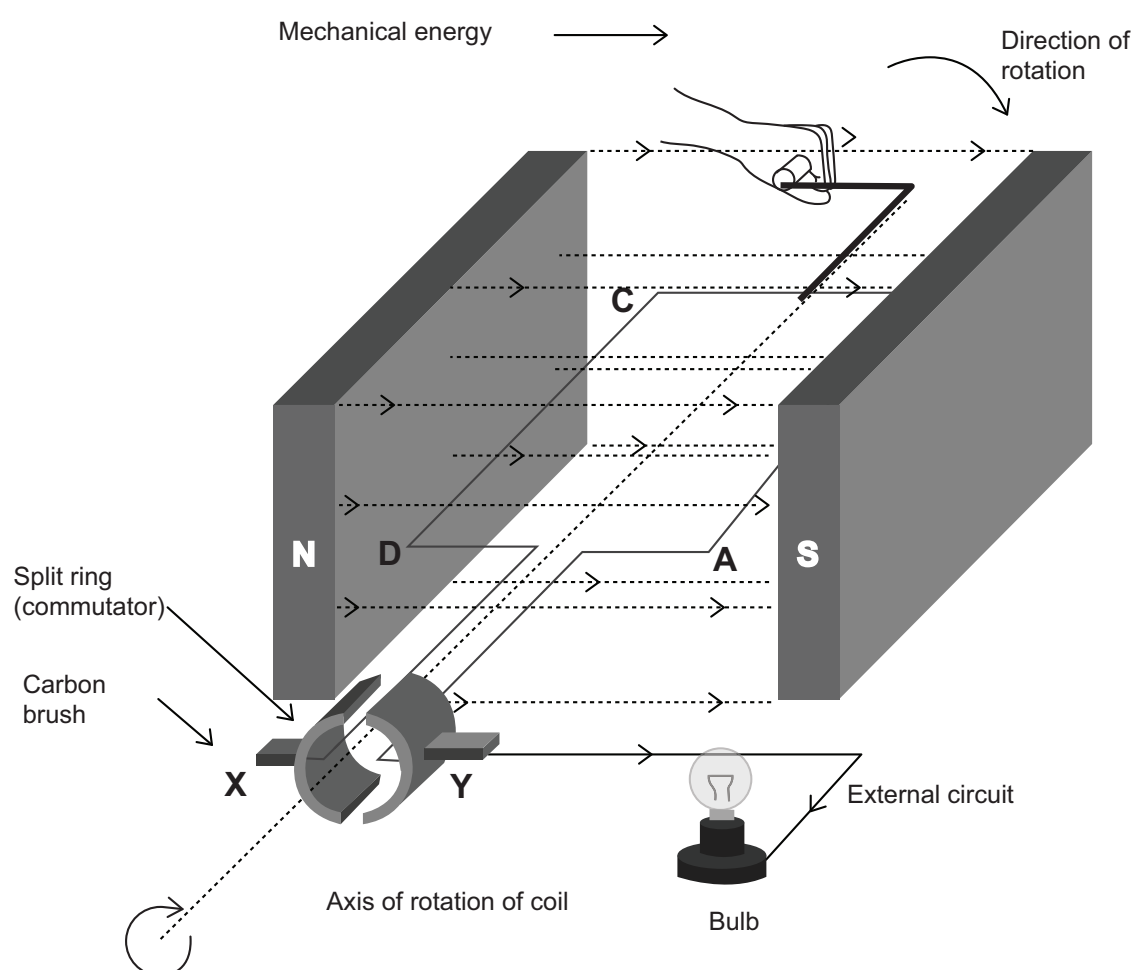Draw diagram 8 on the board to show the parts of **direct current (DC) generator.**

Diagram 8: The parts of a DC generator.

Emphasise that in a DC generator, the slip rings are **replaced** by a **Split ring (commutator)**. A split ring (commutator) is a metal ring that has been split into two halves. There is a gap between the two halves of the ring.

Remind your learners that an alternating current (AC) is induced in the coil as it is rotated through the magnetic field (explained earlier).

BUT, the split ring (commutator) ensures that the **DIRECTION** of the **CURRENT** in the **EXTERNAL CIRCUIT** does **NOT CHANGE**.

Draw the following diagrams and explain how the split ring (commutator) works.

When the coil is rotated **clockwise** (diagram 9), the direction of the induced current in the coil is **DCBA** (Fleming's right hand dynamo rule).
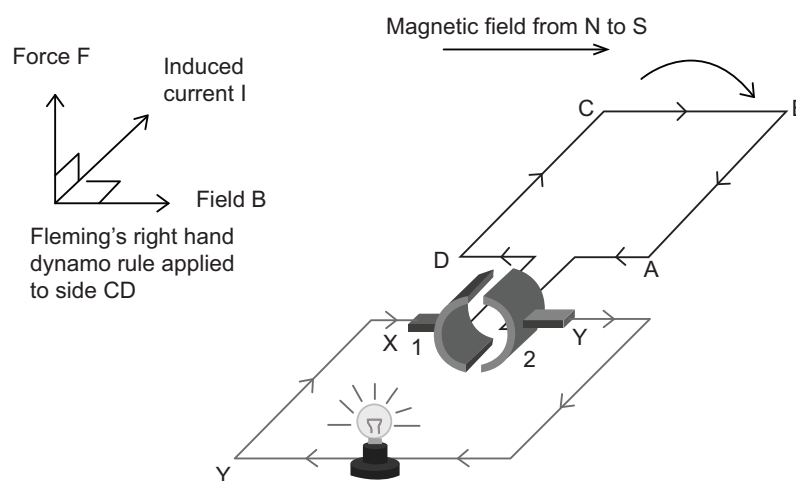
Diagram 9: The direction of the current in the external circuit is from Y to X

Let's label the two halves of the split ring (commutator) **1** and **2**.

The direction of the induced current in the coil is <u>towards</u> **half 2** of the split ring (commutator).

The **half 2** of the split ring (commutator) makes contact with carbon brush **Y**.

The direction of the current is from **Y to X** in the EXTERNAL CIRCUIT.

The coil reaches the vertical position (diagram 10) and the induced current in the coil is ZERO.

Magnetic field from N to S

Diagram 10: Zero current in the coil when it passes through the vertical position.

As the coil reaches the vertical position, there is zero current in the coil (the magnetic flux is maximum but the induced current is zero).

Half 2 of the split ring (commutator) is about to make contact with carbon brush Y.

In diagram 11 below, the coil has moved past the vertical position and, as explained earlier, the induced current reverses its direction in the coil (ABCD).

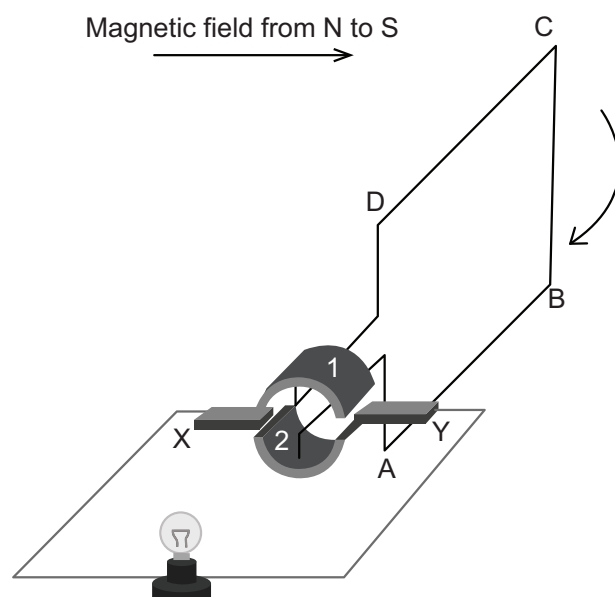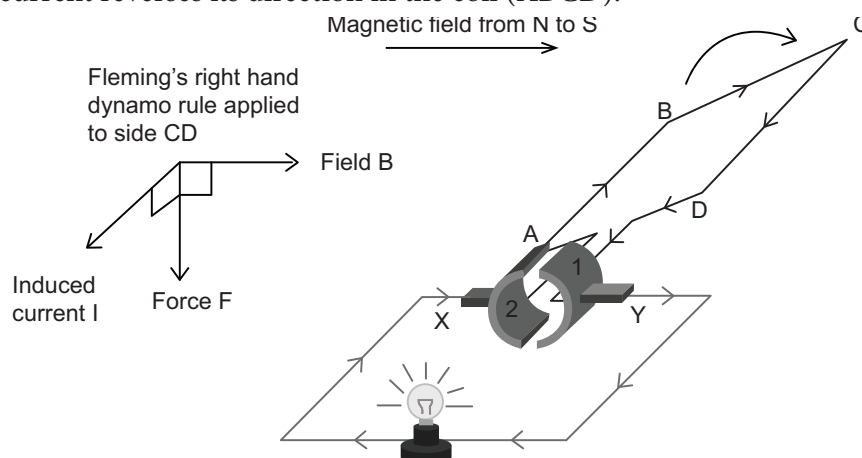**Diagram 11: The direction of the current in the <u>external circuit</u> is <u>still</u> from Y to X.**

The induced current has reversed its direction in the coil (**ABCD**).

The direction of the current is now **towards** **half 1** of the split ring (commutator).

The **half 1** of the split ring (commutator) makes contact with carbon brush **Y**.

The direction of the current is <u>**STILL**</u> from **Y to X** in the EXTERNAL CIRCUIT.

The function of the **SPLIT RING (COMMUTATOR)** in a DC generator is to ensure that the DIRECTION of the CURRENT in the EXTERNAL CIRCUIT **remains the same**.

This is known as direct current (DC).

Diagram 12 shows how the current in the external circuit of a DC generator varies with the position of the coil for one full revolution.
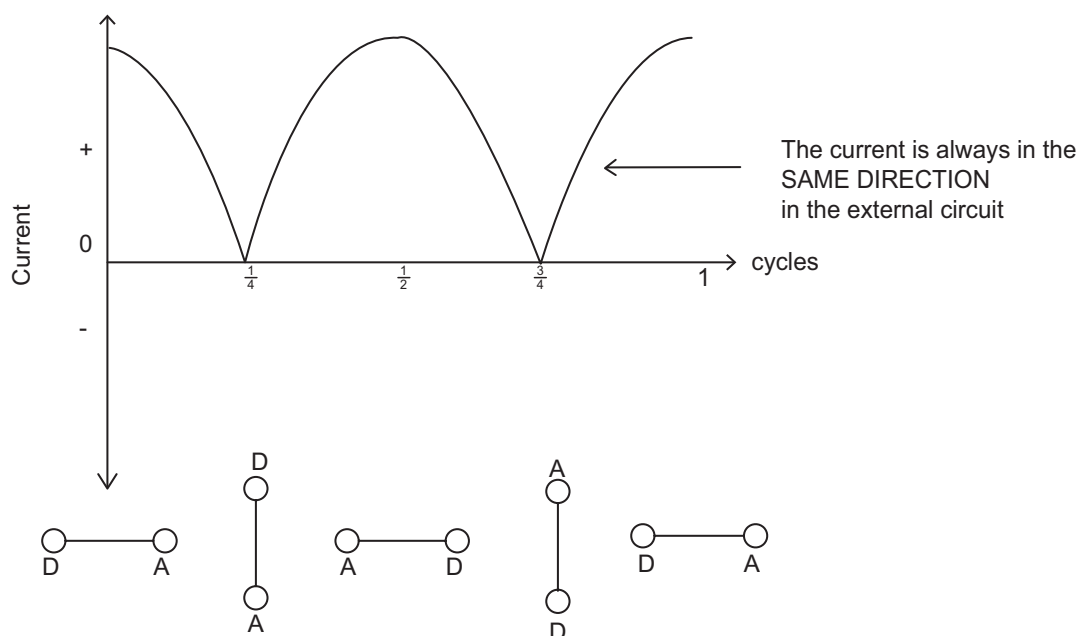
Diagram 12: The graph of current in the external circuit versus position of the coil for a DC generator.

Notice that the current in the external circuit of a DC generator:

a. Never changes direction.

b. Varies in magnitude as the induced emf in the coil varies in magnitude.

In a DC generator:

a. Alternating current (AC) is induced IN THE COIL.

b. Direct current (DC) is established in the EXTERNAL CIRCUIT.

Your learners must know some uses of a DC generator:

1. Torches use a DC generator to produce light by shaking or otherwise moving the torch on a regular basis.

2. On a bicycle, a dynamo is used to power the lights.

3. DC generators are used to store energy in batteries (charge the battery).

INTRODUCTORY LEVEL QUESTIONS

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

2. Their purpose is to familiarise the learners with the parts of an electric generator and the principle of electromagnetic induction.
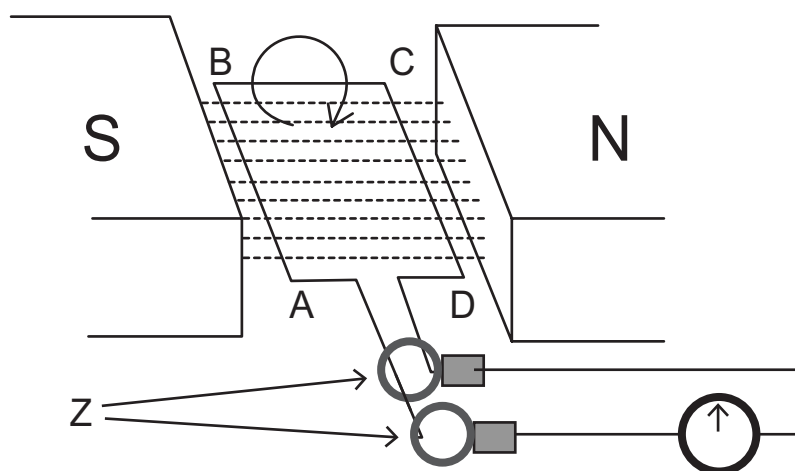
How to tackle these questions in the classroom:

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

---

1. The diagram below shows a highly simplified generator.

1.1 Name the fundamental principle on which generators work.

1.2 State the energy conversions that take place in an electric generator.

1.3 Is this an AC generator or a DC generator? Give a reason for your answer.

1.4 Give the function of the parts labelled Z.

1.5 Name and state the law that states the relationship between the induced emf and the rate of change of magnetic flux in the coil.

1.6 Explain briefly how an emf is induced in the coil as it rotates.

1.7 Name the rule that can be used to determine the direction of the induced current in the coil.

1.8 The coil is rotated in a clockwise direction. What is the direction of the induced current in the coil when it is in the position shown in the diagram? State either ABCD or DCBA.

1.9 It takes 0,01 ms to rotate the coil through 90˚. The maximum induced emf is 50 V. Draw a neat sketch graph of induced emf versus time for 0,04 ms of this generators operation, beginning with the position given in the diagram at t = 0.

1.10 What structural change must be made to this generator to convert it into a DC generator?

Solution:

1.1 Electromagnetic induction.

1.2 Mechanical energy is converted into electrical energy.

1.3 AC generator. It uses slip rings.

1.4 To ensure that the current in the external circuit is alternating current.

1.5 Faraday's law.

1.6 As the coil is rotated through the magnetic field, the magnetic flux passing the surface area of the coil is changing. An emf is induced in the coil.

1.7 Fleming's right hand dynamo rule.

1.8 DCBA

1.9
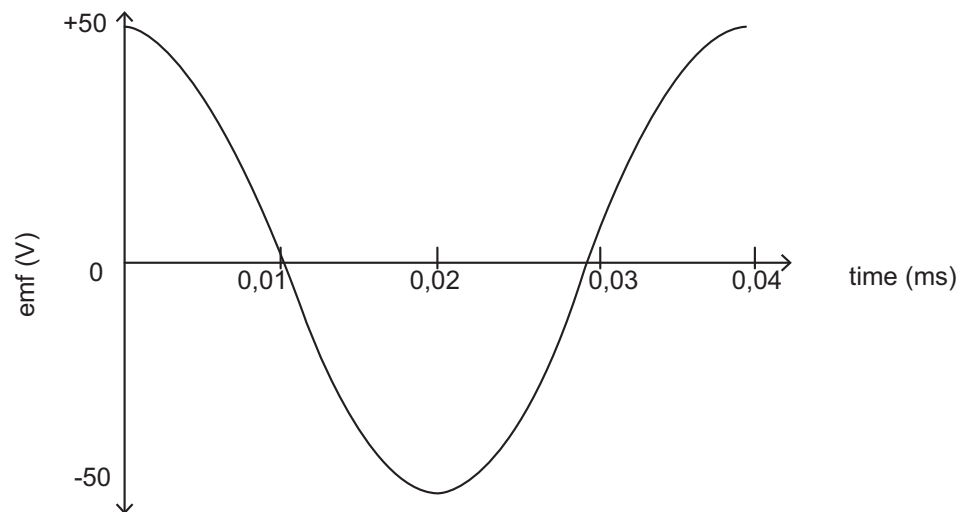
1.10 Replace the slip rings with a split ring or commutator.

CHALLENGE LEVEL QUESTIONS

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

2. These questions require learners to explain how a DC generator works.

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 questions and answer them correctly in their workbooks.

KEY TEACHING:

1. In these more challenging questions, learners must explain how a DC generator works and draw graphs of current versus time in the coil and in the external circuit.

2. Learners need to use their understanding of magnetic flux, electromagnetic induction and Faraday's law to predict changes in the speed of rotation of the coil.

2. The diagram below shows an electric generator.
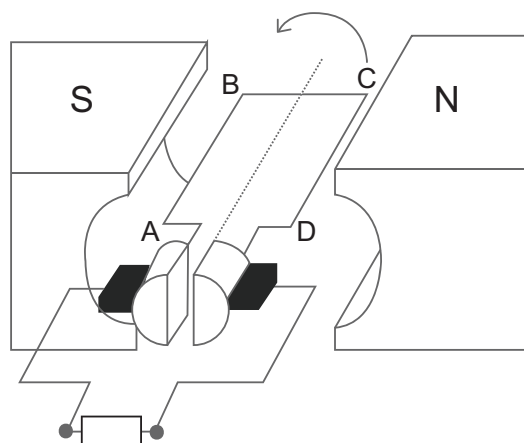
2.1 What type of electric generator is shown above?

2.2 Give a reason for your answer.

2.3 Name the principle on which generators work.

2.4 Explain how an emf is induced in the coil.

2.5 If the loop is rotated in the direction shown, determine the direction of the induced current in the coil as it approaches the vertical position. Write ABCD or DCBA.

2.6 State the position of the coil when:

    2.6.1 the magnetic flux through the coil is a maximum.

    2.6.2 the rate of change of magnetic flux is a maximum.

2.7 Draw a neat sketch graph of induced current in the coil versus time for the one complete revolution of the coil. Start the graph with the coil in the position shown in the diagram.

2.8 Draw a neat sketch graph of current versus time through the resistor for one complete revolution of the coil. Start the graph with the coil in the position shown in the diagram.

2.9 State Faraday's law in words.

2.10 On the same graph as question 2.8 sketch a second line (dotted line) to show how the current in the resistor varies with time if the coil is rotated at half the original speed.

Solution:

2.1 DC generator.

2.2 It uses a split ring (commutator).

2.3 Electromagnetic induction.

2.4 As the coil is rotated through the magnetic field, the magnetic flux passing the surface area of the coil is changing. An emf is induced in the coil.

2.5 ABCD

    2.6.1 The plane of the coil is perpendicular to the magnetic field lines (the vertical position).

    2.6.2 When the plane of the coil is parallel to the magnetic field lines (the horizontal position).

2.7
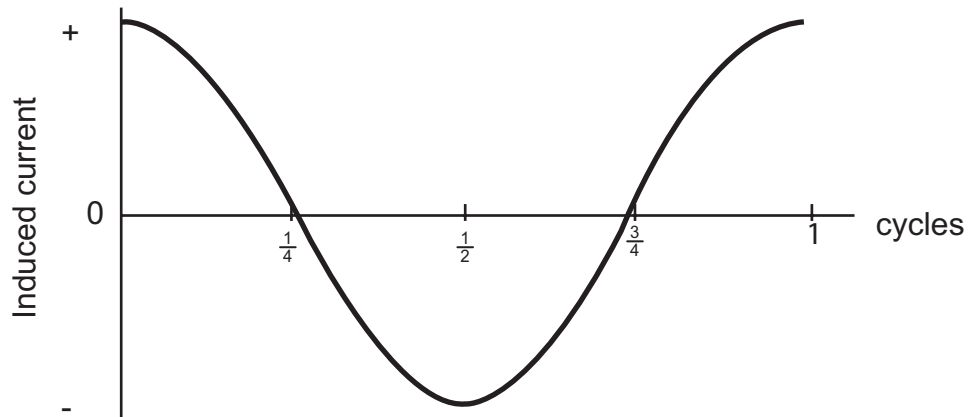
2.8
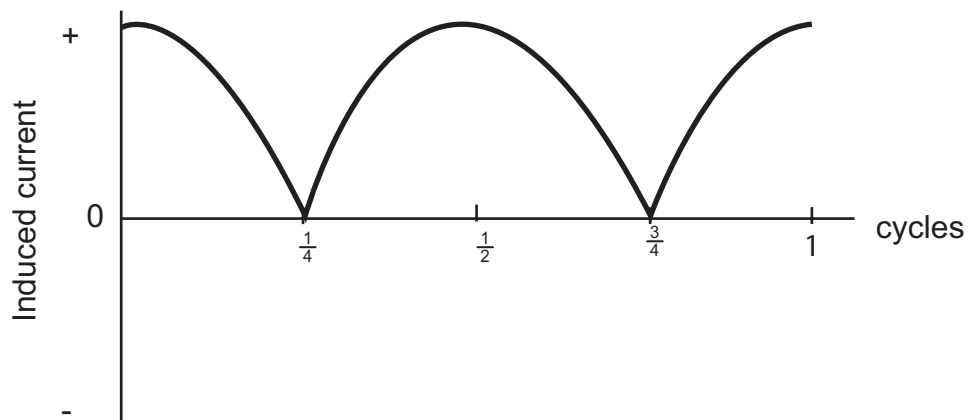
2.9 The magnitude of the induced emf in a coil is directly proportional to the rate of change of magnetic flux linkage.

2.10
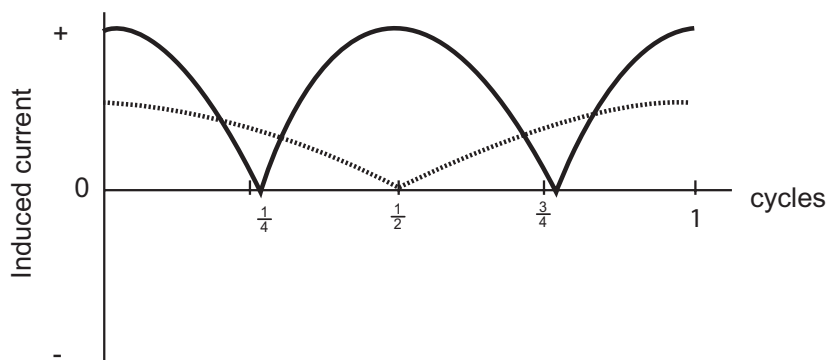
CHECKPOINT

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

1. Identifying the different parts of an AC and DC generator.

2. Explaining how magnetic flux passing through the coil is changing as the coil rotates.

3. Explaining how both AC and DC generators work.

4. Using Fleming's right hand dynamo rule to determine the direction of the induced current in the coil.

5. Using Faraday's law to explain the magnitude of the induced emf in the coil.

6. Describing how a split ring (commutator) works in a DC generator.

7. Drawing graphs of emf versus time and current versus time for both AC and DC generators.

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

Topic 11: Resource Pack: Electrodynamics Worksheet: Questions 1–4. (Pages 17–18).

• 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.

2. ELECTRIC MOTORS

INTRODUCTION

Electric motors convert electrical energy to mechanical energy. We use electric motors in everyday life e.g. fans, washing machines, starter motor for cars, etc.

CONCEPT EXPLANATION AND CLARIFICATION

Firstly remind your learners of the **MOTOR EFFECT.**

When a **current carrying conductor** is placed in a **magnetic field**, the conductor will experience a **magnetic force**.

Draw diagram 1 on the board.
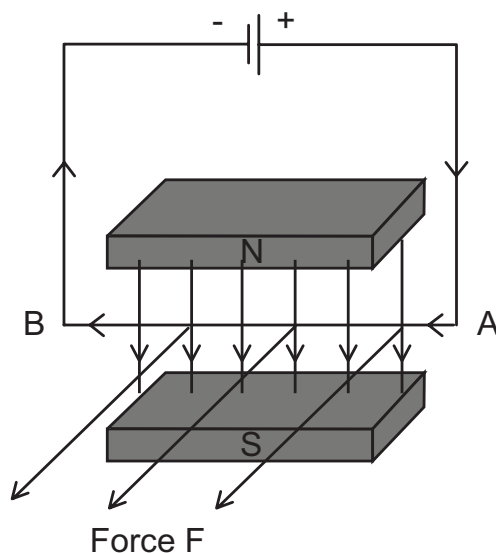
Diagram 1: A current-carrying conductor AB is placed in a magnetic field.

The charges that are moving along the conductor experience a **MAGNETIC FORCE**.

This magnetic force is **greatest** when the conductor is placed at **right angles** to the magnetic field (the current is perpendicular to the magnetic field).

The **direction** of the magnetic force F is at **right angles** to both the direction of the current and the direction of the magnetic field.

The force on the moving charges will be **ZERO** when the direction of the current is **parallel** to the magnetic field lines.

The direction of the magnetic force on the current-carrying conductor in the magnetic field is found using **Fleming's left hand motor rule**.

Fleming's left hand motor rule

Fleming's left hand motor rule is used to determine the **DIRECTION OF THE MAGNETIC FORCE** on the current carrying conductor placed in a magnetic field.

Use diagram 2 to explain how this rule works.

F = Force

B = Direction of the magnetic field (N to S)

I = Current
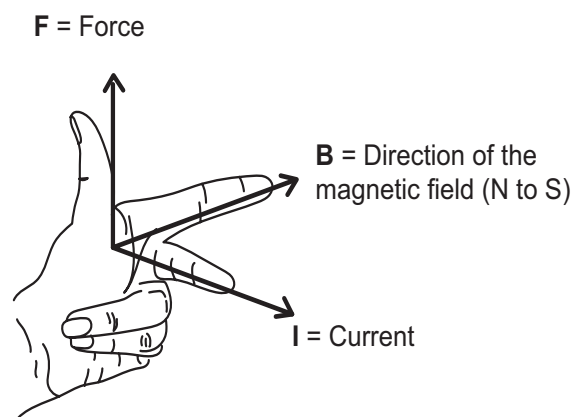
Diagram 2: Applying Fleming's LEFT HAND motor rule

Using your **LEFT HAND**, position you thumb, first finger and second finger at right angles to each other as shown in diagram 2.

The **first finger** must point in the direction of the **magnetic field (B)** (from north to south).

The **second finger** must point in the direction of **conventional current (I)** (from + to −).

The thumb will then point in the direction of the **magnetic force (F).**

Get your learners to apply Fleming's left hand motor rule to **diagram 1**, to verify the direction of the magnetic force.

2.1   DC ELECTRIC MOTOR

Draw a diagram of the parts of a DC ELECTRIC MOTOR on the board (diagram 3):

A coil is placed in a uniform magnetic field. A split ring (commutator) is connected to the ends of the coil. Carbon brushes make contact with the split ring (commutator).

A **DC POWER SOURCE** is connected to the carbon brushes as shown below.

Force F

Fleming's left hand
motor rule applied
to side CD.

Field B

Current I

Force

Direction of
rotation

C

B

N D

A S

Current I

Force

Field B

Fleming's left hand
motor rule applied
to side AB.

Force F

Split ring (commutator)

2

X 1 Y

- +

DC source

Electrical energy (DC source) is converted
into mechanical energy (rotation)
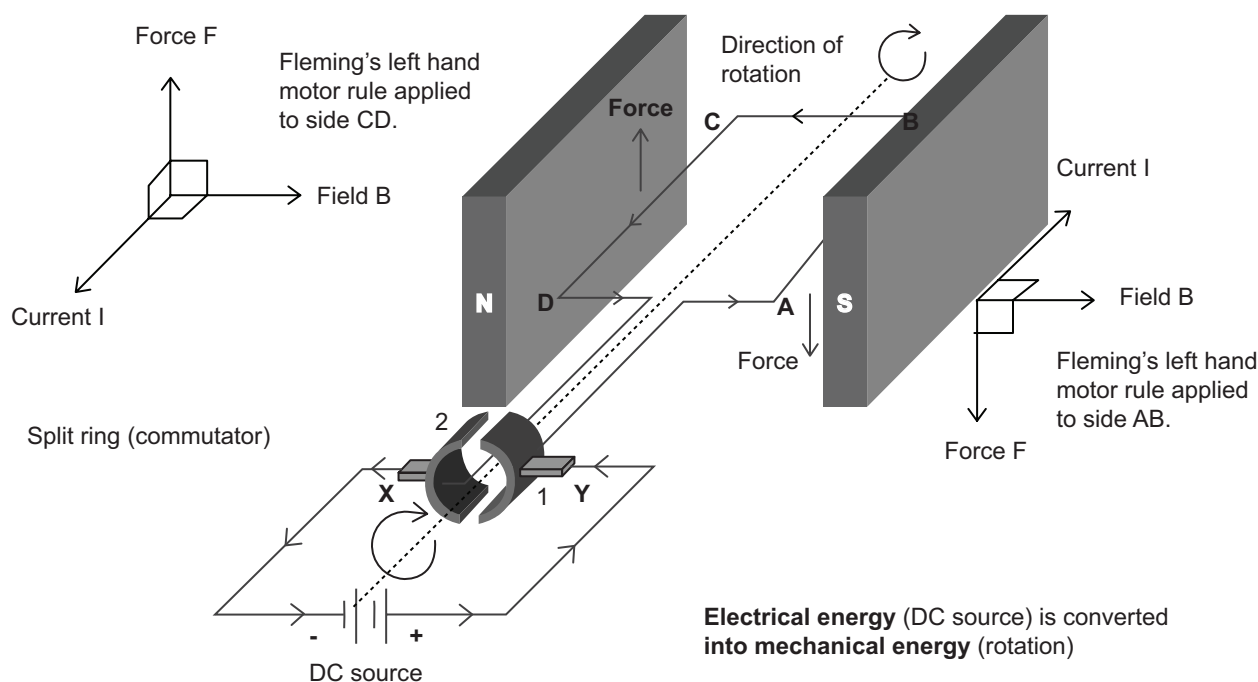
Diagram 3: The parts of a DC electric motor.

The diagram starts with the battery.

Remind your learners that **CONVENTIONAL CURRENT** is the flow of charge from the **positive** terminal (+) to the **negative** terminal (-) of the battery.

Current is directed into **half 2** of the split ring (commutator). The direction of conventional current in the coil is **ABCD**.

The two sides **AB** and **CD** carry current at **right angles** to the magnetic field.

Sides **AB** and **CD** will both experience a **MAGNETIC FORCE** in **OPPOSITE DIRECTIONS**.

According to Fleming's left hand motor rule, side **AB** will experience a force DOWNWARDS and side **CD** will experience a force UPWARDS as shown in **diagram 3**.

The two sides **AB** and **CD** experience forces in opposite directions. This causes the opposite ends of the coil to experience a **TORQUE** (the turning effect of a force around a pivot). The coil will rotate clockwise.

The coil begins to rotate clockwise and reaches the VERTICAL POSITION in **diagram 4** below.
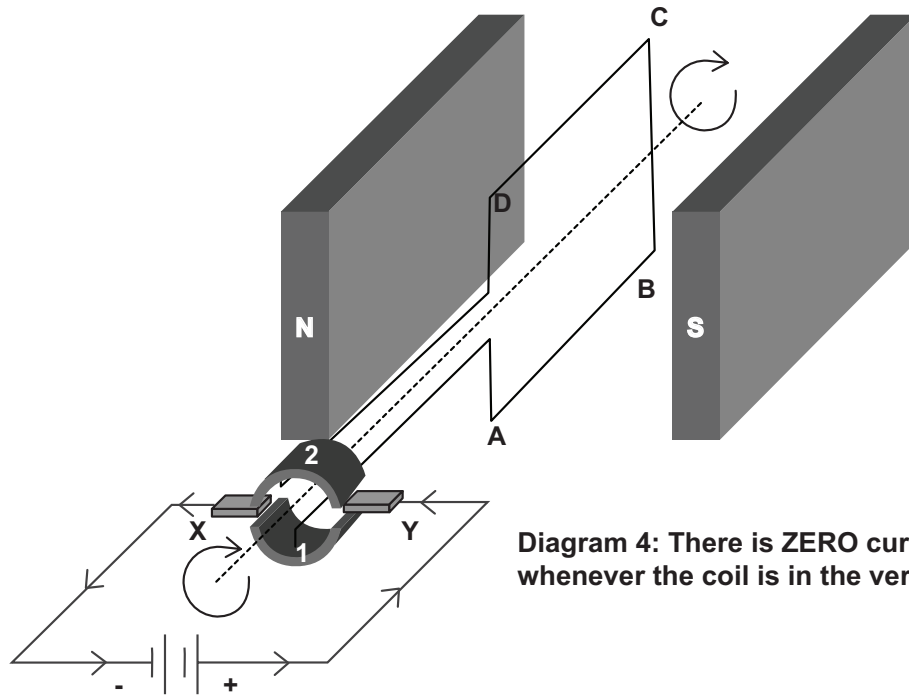
Diagram 4: There is ZERO current in the coil whenever the coil is in the vertical position

As the coil rotates through the vertical position, the carbon brushes no longer make contact with the split ring (commutator) and there is ZERO current in the coil.

The momentum of the rotating coil takes it past the vertical position as shown in **diagram 5** due to inertia. The coil cannot change its state of motion instantaneously.
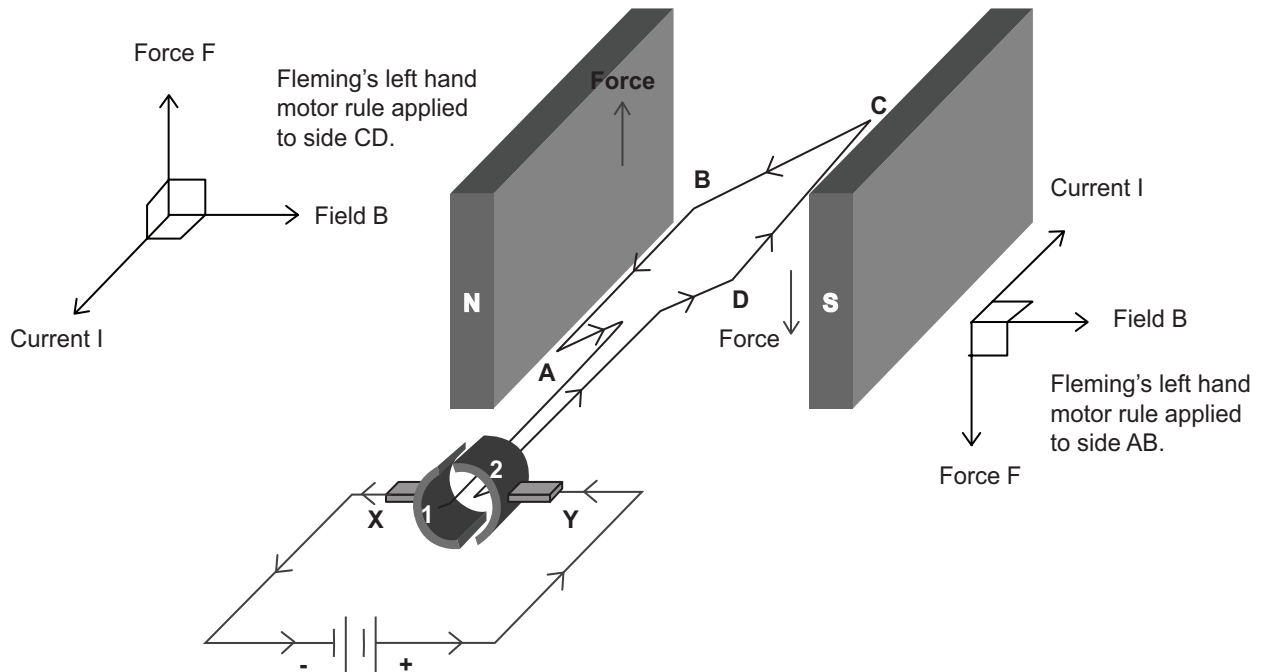
Diagram 5: The direction of the current in the coil has reversed after passing through the vertical position.

Emphasise the fact that the current in the coil has **REVERSED ITS DIRECTION** in the coil.

The current is now directed into **half 1** of the split ring (commutator). The direction of the current in the coil is now **DCBA**.

Side **AB** now experiences a force UPWARDS (according to Fleming's left hand motor rule) and side **CD** experiences a force DOWNWARDS.

This ensures that the coil continues to spin in the same direction (clockwise) as shown in **diagram 5**.

The function of a split ring (commutator) in a DC motor

The split ring (commutator) REVERSES the direction of the current in the coil EVERY HALF REVOLUTION (180° of revolution). The current in the coil is reversed whenever the coil rotates through the VERTICAL POSITION. This ensures that the coil continues to spin in the same direction.

Factors which affect the power of an electric motor

The **magnetic force** that turns the coil of the motor can be increased in the following ways:

1. INCREASING THE STRENGTH OF THE MAGNETIC FIELD. Use stronger magnets.

2. INCREASE THE CURRENT IN THE COIL.

3. INCREASE THE NUMBER OF WINDINGS IN THE COIL. Each winding will experience the same force, increasing the total force on the coil.

4. WRAP THE COIL AROUND AN IRON CORE.

5. USING SEVERAL COILS WOUND AT SLIGHTLY DIFFERENT ANGLES around an iron core.

2.2 AC ELECTRIC MOTOR

An AC motor is driven by an **ALTERNATING CURRENT**.

An AC source produces an alternating current in the coil as shown in **diagram 6**.
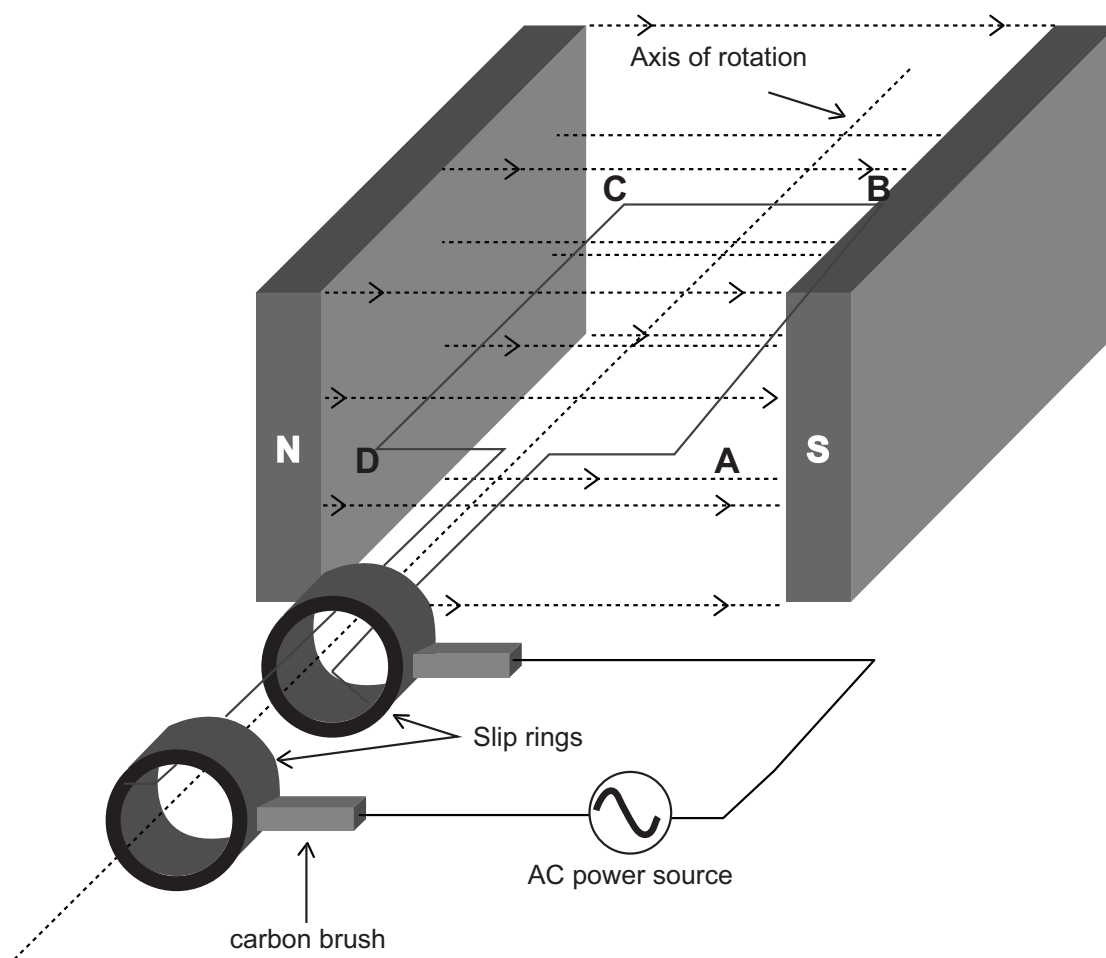
Diagram 6: The parts of an AC electric motor

Emphasise to your learners that an AC motor uses two **SLIP RINGS**. The two slip rings rotate with the coil.

An **ALTERNATING CURRENT** is passed through the coil, generating a torque on the coil. Since the current is ALTERNATING, the motor will run smoothly in the same direction.

The current in the coil must REVERSE ITS DIRECTION when the coil passes through the VERTICAL POSITION.

Alternating current changes direction periodically. The coil will therefore rotate in the same direction and its speed of rotation will depend on the frequency of the alternating current. The frequency of the alternating current refers to how many times it changes direction per second.

INTRODUCTORY LEVEL QUESTIONS

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

2. Their purpose is to familiarise the learners with Fleming's left hand motor rule and the different types of electric motors.

How to tackle these questions in the classroom:

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

---

1. Use Fleming's left hand motor rule to determine the direction of the magnetic force acting on the current carrying conductor in each of the following cases:

1.1

$$\boxed{S} \quad \bullet \quad \boxed{N}$$

1.2

$$\boxed{S} \quad \times \quad \boxed{N}$$

1.3

$$\boxed{S} \quad | \quad \boxed{N}$$

1.4

$$\boxed{N} \quad | \quad \boxed{S}$$
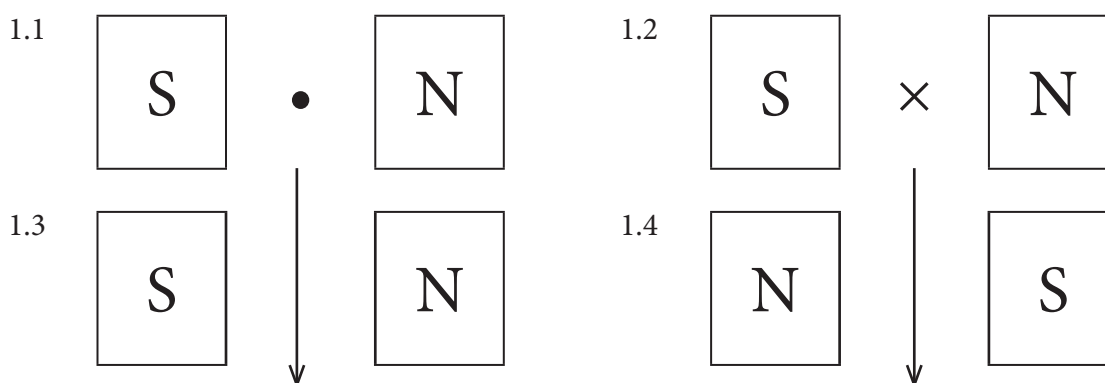
Solutions:

1.1 Downwards.

1.2 Upwards.

1.3 Into the page.

1.4 Out of page.

2. The force on a current carrying conductor placed in a magnetic field can be measured using the apparatus given below. The conductor (wire) is fixed in place between the poles of a magnet which is placed on a scale.

$$\boxed{S} \quad \odot \quad \boxed{N}$$
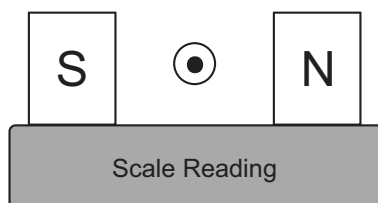
Scale Reading

2.1 State the direction of the force experienced by the conductor in the magnetic field.

2.2 Explain the origin of the force on the conductor in the magnetic field (i.e. explain why it experiences a force).

2.3 The reading on the scale when there is no current in the conductor is 2,0 N. State whether the reading on the scale INCREASES or DECREASES when current passes through the conductor in the direction shown in the diagram.

2.4 Explain your answer to Question 2.3.

2.5 State two ways of increasing the force experienced by the conductor in the magnetic field.

Solution:

2.1 Downwards.

2.2 When current passes through a conductor, a magnetic field is set up around the conductor. This magnetic field around the conductor interacts with the magnetic field between the magnets creating a magnetic force on the conductor.

2.3 Decreases.

2.4 The magnets exert a magnetic force downwards on the conductor. According to Newton's third law, the conductor exerts a magnetic force upwards on the magnets.

The downward force on the scale has decreased.

2.5 Increase the current in the conductor.

Use stronger magnets.

3. A simple electric motor is shown below.
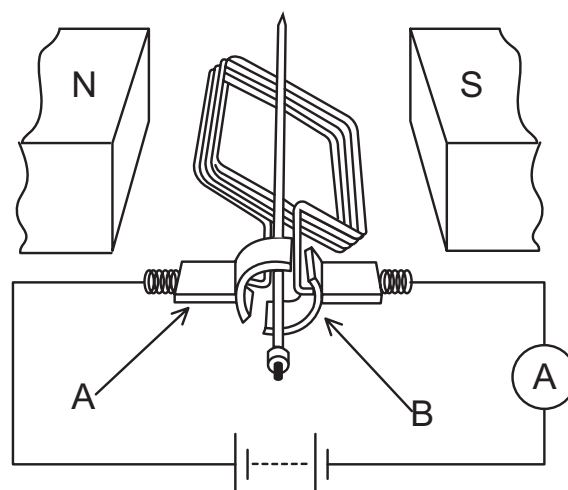
3.1 Is this an AC or DC electric motor? Explain your answer.

3.2 Describe the energy conversion that takes place during the operation of an electric motor.

3.3 Give the names and briefly describe the functions of the components labelled A and B.

3.4 Determine whether the coil is rotating clockwise or anticlockwise at the moment shown in the diagram.

Solution:

3.1 DC electric motor. It uses a split ring or commutator and it uses a DC power source.

3.2 Electrical energy is converted into mechanical energy.

3.3 A: Carbon brush. It makes contact with the split ring allowing current to pass through the coil.

B: Split ring or commutator. It reverses the direction of the current in the coil when it passes through the vertical position.

3.4 Anticlockwise.

CHALLENGE LEVEL QUESTIONS

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

2. These questions require learners to show their understanding of how AC and DC electric motors work.

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 questions and answer them correctly in their workbooks.

KEY TEACHING:

1. In these more challenging examples, learners must apply their knowledge of the motor effect.

2. Learners must apply their knowledge of how the DC electric motor works.

---

4. The diagram below shows a simplified DC electric motor.
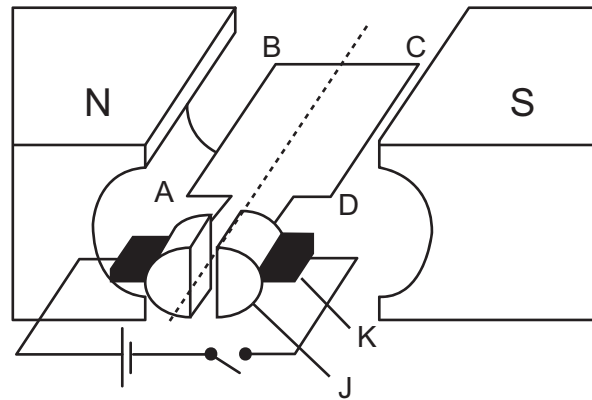
4.1 Name the principle on which the electric motor operates.

4.2 State the energy conversion which takes place in an electric motor.

4.3 Give a reason why section BC in the above diagram does NOT experience a magnetic force whilst the coil is in the position as shown.

4.4 Name the part labelled K.

4.5 Name the part labelled J and state its function.

4.6 In which direction will the coil rotate, CLOCKWISE or ANTI-CLOCKWISE?

4.7 State two ways in which the speed of rotation of the coil can be increased.

4.8 What changes must be made to convert this DC electric motor into an AC electric motor?

Solution:

4.1 Motor effect.

4.2 Electrical energy into mechanical energy.

4.3 The direction of the current is parallel to the direction of the magnetic field.

4.4 Carbon brush.

4.5 Split ring (commutator). It reverses the direction of the current in the coil whenever the coil passes through the vertical position.

4.6 Clockwise.

4.7 Use stronger magnets.

Increase the current in the coil.

Wrap the turns around an iron core.

Increase the number of turns in the coil.

4.8 Replace the DC power source with an AC power source.

Replace the split ring (commutator) with slip rings.

5. A learner built a DC motor as shown below. She has made several mistakes. The motor does not work.
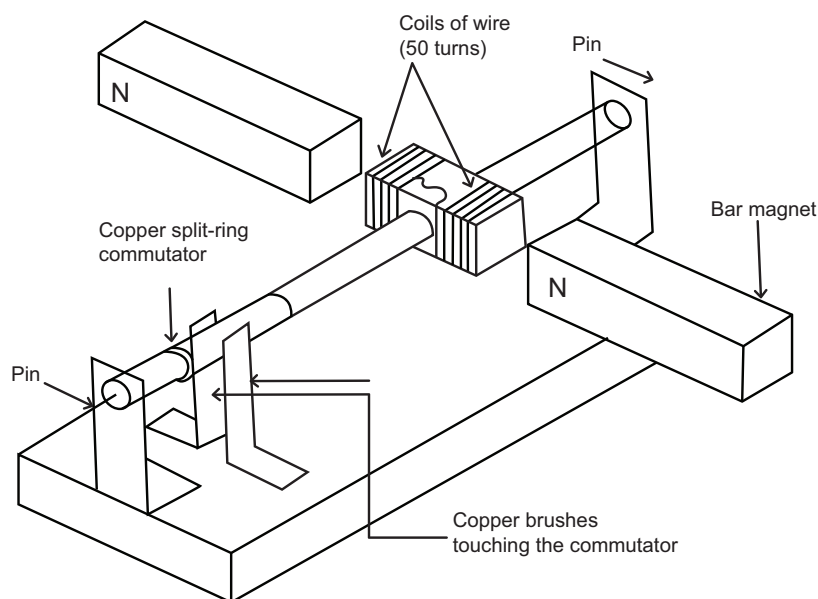
Identify two mistakes the learner has made.

Solution:

The coil is not connected to the split ring (commutator).

There is no DC power source.

6. The diagram below represents a simplified sketch of an electric DC motor.

6.1 Name the component which ensures continuous rotation of the coil of this electric motor.

6.2 Name the part of this motor which becomes an electromagnet when the motor is in operation.

6.3 In which direction will the coil spin? Answer CLOCKWISE or ANTICLOCKWISE.

6.4 Name the rule used to find your answer in question 6.3.

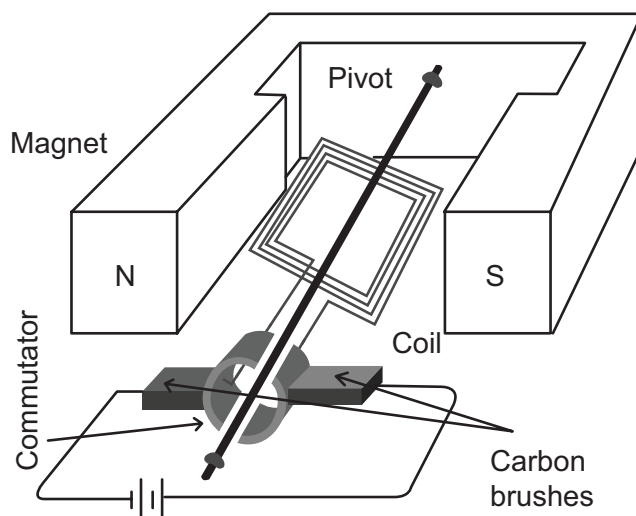**6.5** What property of the carbon-graphite brushes makes it a suitable material for its role in the motor?

The battery is now removed and replaced with a voltmeter and the coil is spun manually.

6.6 What kind of device is it operating as now?

6.7 Explain why the voltmeter reading increases when the coil is spun faster.

Solution:

6.1 Split rings (commutator).

6.2 The coil.

6.3 Clockwise.

6.4 Fleming's left hand motor rule.

6.5 Good conductor of electricity.

6.6 DC generator.

6.7 Spinning the coil faster increases the rate of change of magnetic flux. According to Faraday's law, there will be a greater induced emf in the coil.

CHECKPOINT

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

1. The use of Fleming's left hand motor rule.

2. Explaining how AC and DC electric motors work.

3. How to increase the speed of rotation of an electric motor.

4. Listing the uses of AC and DC electric motors.

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

**Topic 11: Resource Pack: Electrodynamics Worksheet: Questions 5–6.
(Pages 18–19).**

- 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.

3. ALTERNATING CURRENT

INTRODUCTION

Your learners need to understand the difference between peak voltage and root mean square (rms) voltage, peak current and rms current. They must also learn to calculate the average power delivered by an AC voltage.

CONCEPT EXPLANATION AND CLARIFICATION

AC electric generators at power plants generate alternating current. This alternating current is transported to our homes along the national power grid.

The electricity supplied to our homes in South Africa has a peak output voltage of approximately 311 V.

This means that the output voltage alternates repeatedly between a positive maximum value (+311 V) and a negative maximum value (– 311 V).

This changing voltage produces an alternating current. The frequency of the alternating current is 50 Hz.

This means that the direction of the current changes 50 times per second. Draw **diagrams 1 and 2** on the board to show how AC voltage and alternating current vary with time.
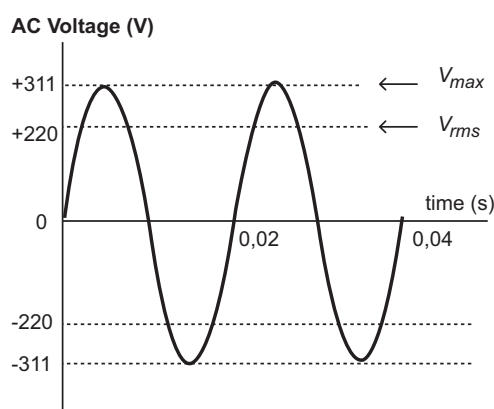
Diagram 1: Graph of AC Voltage versus time

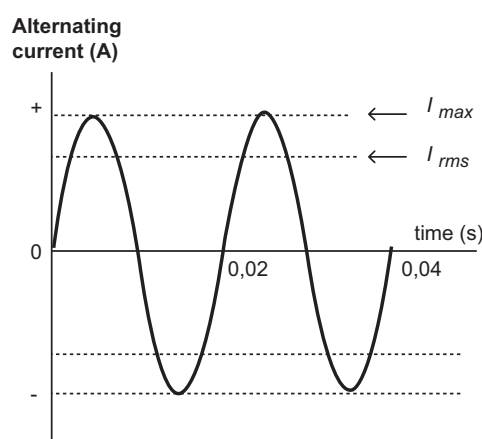**Diagram 2: Graph of alternating current versus time**

The AC voltage is continually changing from zero up to a positive peak voltage (V_{max}), through zero to a negative peak voltage and back to zero again **(Diagram 1)**.

The cycle repeats itself every 0,02 s. The period (T) of the wave is 0,02 s

The frequency of the AC voltage in a South African household is 50 Hz.

$$f = \frac{1}{T} = \frac{1}{0,02} = 50\,Hz$$

The alternating current is also changing periodically, from zero to a positive peak current (I_{max}), through zero to a negative peak current and back to zero again **(Diagram 2)**.

Average power in an AC circuit

In an electrical circuit, power is defined as the rate at which electrical energy is transferred. Remind your learners that the unit of power is the watt (W) $1W = 1J{\cdot}s^{-1}$

In a purely resistive circuit (only containing resistors), energy will be dissipated in the resistors.

Remind your learners that the power delivered by a DC source (battery) is calculated using: P=V.I

In a **DC CIRCUIT**, both the terminal voltage (V) of the battery and the current (I) in the circuit are not changing.

HOWEVER, when dealing with an **AC POWER SOURCE**, the magnitude of the voltage (V) and current (I) both vary between zero and a maximum value **(Diagrams 1 and 2)**.

Therefore the **POWER** delivered by the AC source will also vary between **zero** and a **maximum** value as shown in **diagram 3**.
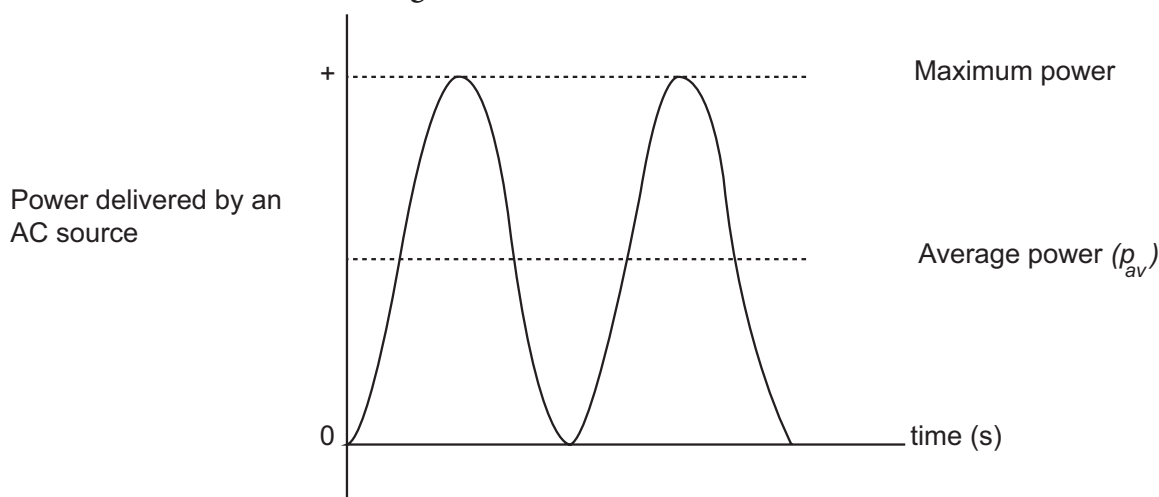
Diagram 3: Power delivered by an AC source versus time

When calculating the **AVERAGE POWER** delivered by an AC source, we CANNOT use the average AC voltage and average alternating current as both these values are zero.

To calculate the **AVERAGE POWER** delivered by an AC source, we use the **root mean square** (rms) values of voltage and current:

The root mean square voltage is calculated using: $V_{rms} = \dfrac{V_{max}}{\sqrt{2}}$

The rms value of AC voltage is equivalent to the DC voltage necessary to deliver the same power.

If the peak voltage from the AC power source is 311 V, then

$V_{rms} = \dfrac{V_{max}}{\sqrt{2}} = \dfrac{311}{\sqrt{2}} = 219,91\,V$

This is the equivalent DC voltage that would deliver the same power.

The root mean square current (I_{rms}) is calculated using: $I_{rms} = \dfrac{I_{max}}{\sqrt{2}}$

The rms value of alternating current is equivalent to the direct current necessary to deliver the same power.

If the peak current supplied by an AC power source is 15 A, then

$I_{rms} = \dfrac{I_{max}}{\sqrt{2}} = \dfrac{15}{\sqrt{2}} = 10,61\,A$

This is the equivalent DC current that would deliver the same power.

rms values for AC voltage and current are a means of comparing AC to DC.

The average power delivered by an AC power source is:

$P_{av} = V_{rms}\,I_{rms}$

OR

$P_{av} = V_{rms}\,I_{rms} = (\dfrac{V_{max}}{\sqrt{2}})(\dfrac{I_{max}}{\sqrt{2}}) = \dfrac{1}{2}V_{max}\,I_{max}$

The **AVERAGE POWER** dissipated in a **resistor R** is:

$P_{av} = I_{rms}^{2}\,R$

$P_{av} = \dfrac{V_{rms}^{2}}{R}$

INTRODUCTORY LEVEL CALCULATIONS

1. These are the basic calculations that learners will be required to perform at this stage in the topic.
2. Their purpose is to familiarise the learners with the equations for rms voltage and rms current, as well as average power delivered.

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 questions and answer them correctly in their workbooks.

---

1.   **1.1.** Suppose a DC power source with a voltage of 50 V is connected to a 10 Ω resistor. How much power will this load dissipate?

   1.2. Now suppose the same 10 Ω resistor is connected to an AC power source with a peak voltage of 50 V. Will the resistor dissipate the same amount of power, more power, or less power? Use a calculation to justify the answer.

   Solution:

   1.1 $P = \dfrac{V^{2}}{R} = \dfrac{(50)^{2}}{10} = 250\,W$

1.2 Less than. Since rms voltage is less than peak voltage.

$$V_{rms} = \frac{V_{max}}{\sqrt{2}} = \frac{50}{\sqrt{2}} = 35,36 \text{ V}$$

$$Pav = \frac{V_{rms}^2}{R} = \frac{(35,36)^2}{10} = 125,03 \text{ W}$$

2. The voltage from a wall socket oscillates between the positive and negative peak voltages, resulting in an rms voltage of 240 V.

2.1 Calculate the peak voltage supplied by the AC power source.

2.2 A 100 W light bulb is connected to the wall socket. Calculate the resistance of the light bulb.

2.3 Calculate the peak current in the light bulb.

Solution:

2.1 $V_{max} = \sqrt{2}\, V_{rms} = \sqrt{2}\,(240) = 339,41 \text{ V}$

2.2 $P_{av} = \frac{(V_{rms})^2}{R}$

$100 = \frac{(240)^2}{100}$

$R = 576 \ \Omega$

2.3 $P_{av} = V_{rms}\, I_{rms}$ $I_{rms} = \frac{I_{max}}{\sqrt{2}}$

$100 = (240)\, I_{rms}$

$I_{rms} = 0,42 \text{ A}$ $0,42 = \frac{I_{max}}{\sqrt{2}}$

$I_{max} = 0,59 \text{ A}$

CHALLENGE LEVEL QUESTIONS

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

2. These questions require learners to take readings from a graph and perform calculations.

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 questions and answer them correctly in their workbooks.

KEY TEACHING:

1. In these more challenging examples, learners must take readings of peak voltage and current from a graph.

2. Learners must calculate, rms voltage and rms current, resistance and average power delivered.

3. The graph below shows how an AC voltage varies will time.
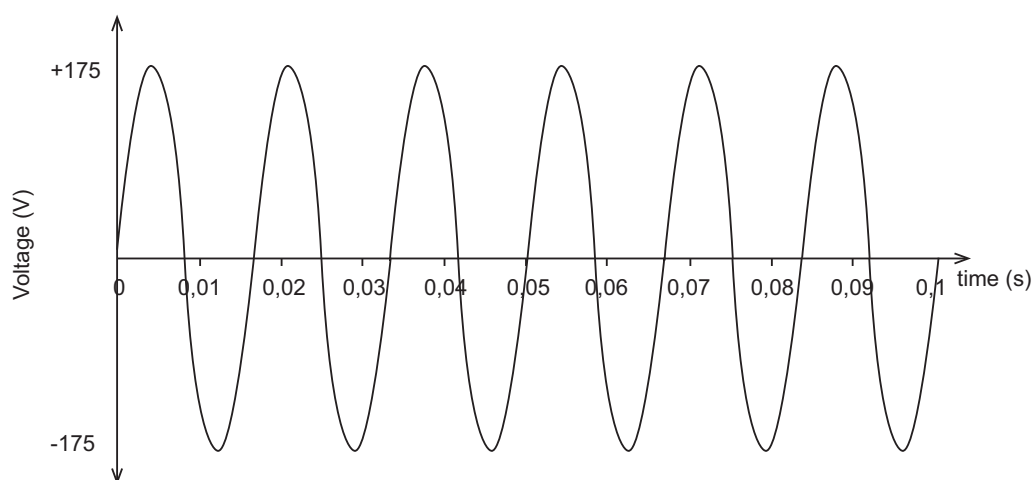
3.1 What is the peak voltage?

3.2 What is the root-mean square voltage?

3.3 Using the graph, determine the period of the oscillating voltage?

3.4 Calculate the frequency of this AC voltage.

3.5 A 20 Ω light bulb is connected to the wall socket. Calculate the peak current through the light bulb.

Solution:

3.1 $V_{max} = 175\,V$

3.2 $V_{rms} = \dfrac{V_{max}}{\sqrt{2}} = \dfrac{175}{\sqrt{2}} = 123,74\,V$

3.3 3 complete oscillations takes 0,05 s.
Period is the time taken to complete one oscillation.
$$T = \frac{0,05\,s}{3\text{ oscillations}} = 0,0167\,s$$

3.4 $f = \dfrac{1}{T} = \dfrac{1}{0,0167} = 60\,Hz$

3.5 $P_{av} = V_{rms}\,I_{rms}$

$P_{av} = \dfrac{V_{rms}^2}{R} = \dfrac{(123,74)^2}{20} = 765,58\,W$

$I_{rms} = \dfrac{P_{av}}{V_{rms}} = \dfrac{765,58}{123,74} = 6,19\,A$

$I_{rms} = \dfrac{I_{max}}{\sqrt{2}}$

$I_{max} = \sqrt{2}\,I_{rms} = \sqrt{2}\,(6,19) = 8,75\,A$

4. AC through a 40 Ω light bulb as function of time is shown below.
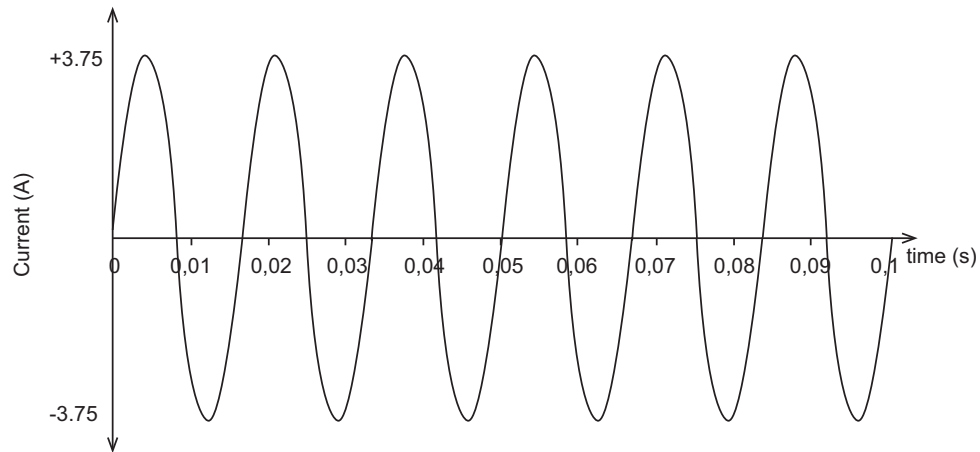
4.1 Using the graph, determine the peak current.

4.2 Calculate the root-mean square current.

4.3 Using the graph, determine the frequency of the alternating current.

4.4 Calculate the average power dissipated in the 40 Ω light bulb.

Solution:

4.1 $I_{max} = 3,75\,A$

4.2 $I_{rms} = \dfrac{I_{max}}{\sqrt{2}} = \dfrac{3,75}{\sqrt{2}} = 2,65\,A$

4.3 3 complete oscillations take 0,05 s.

Period is the time taken to complete one oscillation.

$$T = \frac{0,05\,s}{3\ \text{oscillations}} = 0,0167\,s$$

$$f = \frac{1}{T} = \frac{1}{0,0167} = 60\,Hz$$

4.4 $P_{av} = I_{rms}^2\,R = (2,65)^2(40) = 280,90\,W$

CHECKPOINT

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

1. The calculation of peak and rms voltage.

2. The calculation of peak and rms current.

3. The calculation of the average power delivered by an AC voltage.

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

**Topic 11: Resource Pack: Electrodynamics Worksheet: Questions 7–11.
(Pages 20–21).**

- 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; **Topic 11: Resource Pack: Electrodynamics Consolidation Exercise (Pages 22–25).**
- 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 exercise 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=GLjhXGFnVCE
    rms voltage and current

2. https://www.youtube.com/watch?v=pgzc4aU_HeY
    rms voltage and current

3. https://phet.colorado.edu/en/simulation/legacy/generator
    pHet simulation on generators

TOPIC 12:

Optical Phenomena and Properties of Matter

A   Introduction

- This topic runs for 6 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Optical phenomena and properties of materials forms part of the content area Matter and Materials (Physics).
- Matter and Materials counts as 10 % in the final Physics examination (Paper 1).
- Optical phenomena and properties of materials counts approximately 10 % of the final examination.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.

2. Chalk.

3. Grade 12 Physics Examination Data Sheet.

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. An A4 3-quire exercise book, for notes and exercises.

2. Scientific calculator – Sharp or Casio calculators are highly recommended.

3. Pen.

4. Grade 12 Physics Examination Data Sheet.

B   Sequential Table

PRIOR KNOWLEDGE	CURRENT
GRADE 10	GRADE 12
• Wavelength, frequency, amplitude, period, wave speed • Dual (particle/wave) nature of EM radiation • EM spectrum • Nature of EM radiation as particle – energy of a photon related to frequency and wavelength	• Photoelectric effect • Emission and absorption spectra

C   Glossary of Terms

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

TERM	DEFINITION
Frequency (f)	The number of complete waves that pass a point per second.
Wavelength (λ)	The distance between two consecutive points on a wave that are in phase.
Photoelectric effect	The process whereby electrons are ejected from a metal surface when light of suitable frequency is incident on that surface.
Photon	A particle representing a quantum of light.
Threshold (cut-off) frequency (f_o)	The minimum frequency of light needed to emit electrons from a certain metal surface.
Work function (W_o)	The minimum energy needed for an electron to be emitted from the surface of a metal.

D   Assessment of This Topic

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

E   Breakdown of Topic and Targeted Support Offered

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

TIME ALLOCATION	SUB-TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
4 hour	Photoelectric effect	132-133	**a.** Explanation of photoelectric effect. **b.** Explanation of threshold frequency, work function and maximum kinetic energy. **c.** Explanation of variations in frequency or intensity of light and its effect on the maximum kinetic energy of the photoelectrons. **d.** Explanation of how a photocell works as well as stopping voltage.
2 hour	Emission and absorption spectra	133	**a.** Explanation of the formation of atomic line emission and absorption spectra. **b.** Calculation the energy of an emitted photon when an electron makes a transition within an atom.

F Targeted Support per Sub-topic

1. PHOTOELECTRIC EFFECT

INTRODUCTION

The photoelectric effect cannot be explained if we consider light to ONLY be a wave. Einstein explained the photoelectric effect by considering light to have a particle nature.

CONCEPT EXPLANATION AND CLARIFICATION

We are focussing on the ELECTRONS that are found in the OUTERMOST ENERGY LEVEL of the metal atoms.

In order for an electron to escape from the surface of a metal, the electron must be given enough ENERGY to escape.

PHOTOELECTRIC EMISSION is the release of electrons from the surface of a metal when electromagnetic radiation (light) is incident (shone) onto its surface.

The electrons emitted from the metal surface are called **PHOTOELECTRONS**.

1. Light consists of a stream of energy packets called PHOTONS.

A photon is a particle representing a QUANTUM of light energy.

The energy of each photon of light is calculated using: **$E = hf$**

where f is the frequency of the light being shone on the metal surface. Frequency is measured in hertz (Hz).

h is Planck's constant: $h = 6,63 \times 10^{-34}$ J·s

Remember the equation to calculate the speed of lights is: $c = f\lambda$

where c is the speed of light in a vacuum: $c = 3 \times 10^8$ m·s^{-1}

This is the speed of ALL electromagnetic waves in a vacuum (or through air).

λ is the wavelength of the light. Wavelength is measured in metres (m).

Remember: $1nm = 10^{-9}$ m $420nm = 420 \times 10^{-9}$ m

$\lambda = \dfrac{c}{f}$

∴ The energy of each photon of light is also calculated using: $E = \dfrac{hc}{\lambda}$

The frequency of ultraviolet light is $2,50 \times 10^{15}$ Hz.

The wavelength of red light is 680 nm.

Calculate the energy of a photon of UV and red light.

UV light: $E = hf = (6,63 \times 10^{-34})(2,50 \times 10^{15}) = 1,66 \times 10^{-18}$ J

Red light: $E = \dfrac{hc}{\lambda} = \dfrac{(6,63 \times 10^{-34})(3 \times 10^8)}{680 \times 10^{-9}} = 2,93 \times 10^{-19}$ J

IMPORTANT:

a. The energy of a photon (E) is DIRECTLY PROPORTIONAL to the frequency (f) of the light. The greater the frequency of light used, the greater the energy of each incoming photon.

b. The energy of a photon (E) is INVERSELY PROPORTIONAL to the wavelength (λ) of the light. The longer the wavelength of light used, the lower the energy of each photon.

c. In the visible part of the electromagnetic spectrum, RED light has the longest wavelength and VIOLET light has the shortest wavelength.

d. In the visible part of the electromagnetic spectrum, RED light has the lowest frequency and VIOLET light has the largest frequency.

2. The energy of a photon is transferred to the electron in the metal atom

NOT ALL FREQUENCIES of light cause electrons to be ejected from the surface of a metal.

The **THRESHOLD FREQUENCY** (f_o) (cut-off frequency) is the **MINIMUM FREQUENCY** of light needed to emit electrons from a certain metal surface.

If the frequency of the light is **LESS THAN** the threshold frequency, **NO ELECTRONS** will be ejected. The energy of the incident photon is **NOT ENOUGH** for the electron to escape from the metal.

The threshold frequency depends on the **TYPE OF METAL USED**. Some metals hold onto their electrons more strongly than others.

If the frequency of the light is **EQUAL TO or GREATER THAN** the threshold frequency, electrons **WILL BE EMITTED** from the metal surface. The energy of the incident photon is **ENOUGH** for the electron to escape from the metal.

The threshold frequency corresponds to the **MAXIMUM WAVELENGTH** of light that will result in photoelectric emission. **LONGER** wavelengths of light **WILL NOT** result in photoelectric emission.

3. The work function (W_o) of a metal.

If the frequency of the incident light is **EQUAL TO** the threshold frequency (f_o) of the metal, then the energy of the photon is **JUST ENOUGH** for the electron to be EMITTED from the surface of the metal.

The minimum energy needed for an electron to be emitted from the surface of a metal is called the WORK FUNCTION (W_o) of the metal.

The work function of a metal is calculated using: $\mathbf{W_o = hf_o}$

Calculate the work function of sodium which has a threshold frequency of $\mathbf{5,43 \times 10^{14}}$ Hz.

$W_o = hf_o = (6,63 \times 10^{-34})(5,43 \times 10^{14}) = 3,60 \times 10^{-19}$ J

The work function of zinc is $6{,}93 \times 10^{-19}$ J**. Calculate the threshold frequency of zinc.**

$$W_o = hf_o$$
$$6{,}93 \times 10^{-19} = (6{,}63 \times 10^{-34})(f_o)$$
$$f_o = 1{,}05 \times 10^{15} \text{ Hz}$$

4. Maximum kinetic energy of the ejected electrons $E_{k(max)}$

If the frequency of the incident radiation is **GREATER THAN** the threshold frequency (f_o), then the energy of each photon will be **GREATER THAN** the work function of the metal.

ALL of the energy of the incident photon (E) is transferred to the electron.

<u>SOME</u> of the energy of the incoming photon (E) is used to move the electron to the surface of the metal (work function); the remaining energy of the photon is transferred to the electron as **KINETIC ENERGY**. The electron will be ejected with **KINETIC ENERGY**.

Electrons in the outermost energy level of the metal atom will be ejected with the MAXIMUM KINETIC ENERGY.

$$\text{Energy of photon} = \text{Work function} + \text{maximum kinetic energy}$$

$$\mathbf{E = W_o + E_{k(max)}}$$

The threshold frequency of caesium is $\mathbf{4{,}71 \times 10^{14} \text{ Hz}}$ **.**

Calculate the maximum speed of an ejected electron when blue light of wavelength 420 nm is shone on the caesium surface.

$$E = W_o + E_{k(max)}$$

$$\frac{hc}{\lambda} = hf_o + E_{k(max)}$$
$$\frac{(6{,}63 \times 10^{-34})(3 \times 10^{8})}{420 \times 10^{-9}} = (6{,}63 \times 10^{-34}).(4{,}71 \times 10^{14}) + \frac{1}{2}mv^2_{max}$$
$$4{,}736 \times 10^{-19} = 3{,}123 \times 10^{-19} + \frac{1}{2}(9{,}11 \times 10^{-31})v^2_{max}$$

$$1{,}613 \times 10^{-19} = 4{,}555 \times 10^{-31}v^2_{max}$$

$$v^2_{max} = 3{,}541 \times 10^{11}$$

$$v_{max} = 5{,}95 \times 10^{5} \text{ m·s}^{-1}$$

5. Intensity (brightness) of the electromagnetic radiation

INCREASING the INTENSITY (brightness) OF THE LIGHT that is shone onto the metal surface, INCREASES the NUMBER OF PHOTONS arriving on the metal surface PER SECOND.

If MORE PHOTONS are arriving on the metal surface PER SECOND then MORE ELECTRONS will be EJECTED PER SECOND. Note: One photon is absorbed by one electron.

A CHANGE IN THE INTENSITY of the light **DOES NOT** change the frequency or the wavelength of the light.

A change in the intensity of the light **WILL NOT CHANGE** the ENERGY of the incoming photons.

For example, when dim red light of wavelength 410 nm is shone onto sodium metal, NO ELECTRONS are ejected.

What will happen when we shine very bright red light of the same wavelength onto sodium?

NO ELECTRONS ARE EJECTED. The frequency of the red light is lower than the threshold frequency of sodium metal. The energy of the incident photons is less than the work function of sodium metal. Increasing the intensity of the red light will not change the energy of the incident photons.

Suppose we now shine dim blue light of wavelength 480 nm onto the sodium surface. ELECTRONS ARE EJECTED.

What will happen when we shine very bright blue light of the same wavelength onto sodium?

MORE PHOTONS are arriving per second, therefore MORE ELECTRONS will be ejected per second.

How will the maximum kinetic energy of the ejected electrons change when we shine very bright blue light onto the sodium surface?

There will be NO CHANGE in the MAXIMUM KINETIC ENERGY of the ejected electrons. This is because there is no change in the energy of the incident photons.

$E_{k(max)} = E - W_o$

When the intensity of the light is changed, there is NO CHANGE in the ENERGY (E) of the incident photons and NO CHANGE in the WORK FUNCTION (W_o) of the metal.

How will the maximum kinetic energy of the ejected electrons change when we shine ultraviolet light onto the sodium surface?

The frequency of the light is HIGHER, therefore the energy of the incident photons is HIGHER. The work function of sodium is CONSTANT. There will be more energy left over as kinetic energy. The maximum kinetic energy of the ejected electrons will INCREASE.

6. Photosensitive vacuum tube (photocell).

The photoelectric effect can be demonstrated using a photosensitive vacuum tube (photocell) as shown below:
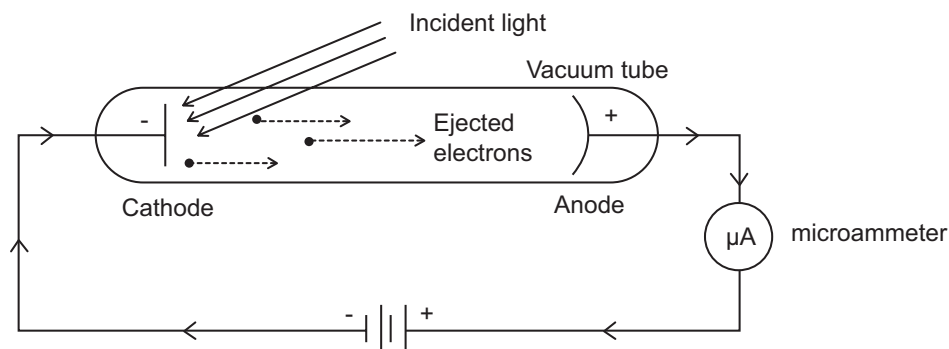
When light shines on the cathode (−), electrons are emitted from the cathode and are attracted to the anode (+). Electrons move in the vacuum tube from cathode to anode. The microammeter will register a current.

Suppose we shine BLUE LIGHT OF LOW INTENSITY on the cathode and the microammeter registers a current.

What will happen to the reading on the ammeter if we increase the intensity of the blue light?

More photons are arriving on the cathode surface per second. More electrons will be ejected per second. The ammeter reading will INCREASE.

What will happen to the reading on the ammeter if we increase the frequency of the incident light?

The ammeter reading remains constant.

7. Stopping voltage. Not in CAPS. For teacher knowledge.

If we reverse the polarity of the of the adjustable DC power source, we can measure the maximum kinetic energy of the ejected electrons as shown below.
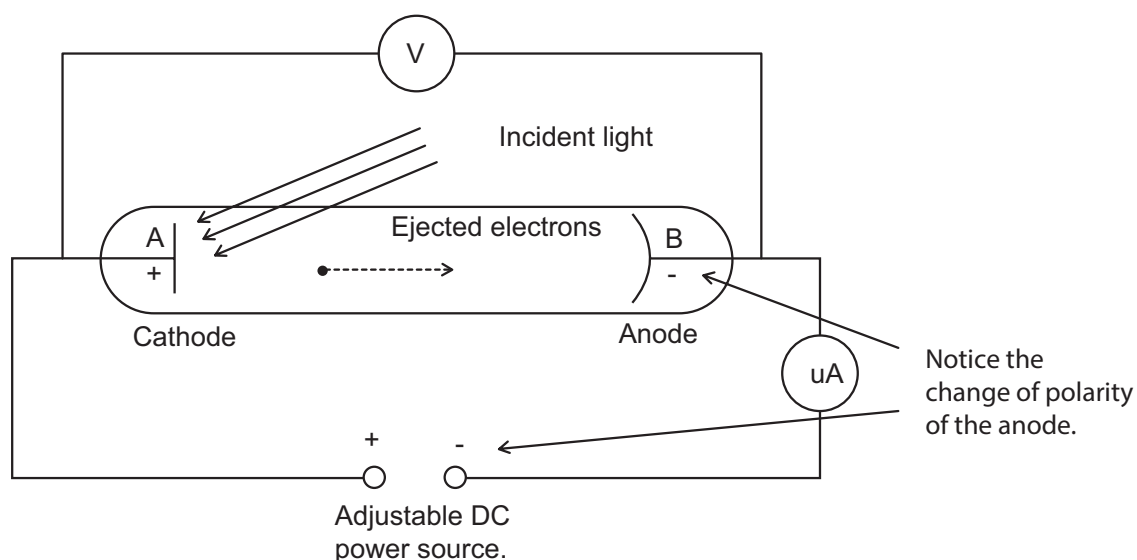
The phototube is now used in reverse. A potential difference is now applied between A and B so that terminal B is now negative with respect to A.

Electrons are ejected from electrode A (+) with maximum kinetic energy and travel towards electrode B (-). As the electron moves from A to B, it is repelled from B and attracted to A. The electric field does work on it, converting its kinetic energy into electric potential energy. The electron slows down and its kinetic energy decreases.

The voltage between A and B can be adjusted to stop the electron as it reaches B.

If the voltage between A and B is gradually increased, the current measured by the microammeter decreases and eventually becomes zero. This means that no electrons arrive at terminal B. This minimum voltage necessary to stop the electrons is known as the stopping voltage.

The stopping voltage is therefore a measure of the maximum kinetic energy of the photoelectrons.

If light of a higher frequency is used, then the stopping voltage increases. This means that the electrons are ejected with a greater maximum kinetic energy.

If the experiment is repeated with light of greater intensity but the same frequency, the current in the microammeter increases but the value of the stopping voltage is unchanged. This means that the maximum kinetic energy of the photoelectrons does not depend on the intensity of the radiation.

The following conclusions can be drawn from this demonstration:
1. The ejected electrons have a RANGE OF KINETIC ENERGIES, from zero to some maximum value $E_{k(max)}$.
2. If the FREQUENCY of the incident radiation is INCREASED, the MAXIMUM KINETIC ENERGY of the photoelectrons also INCREASES.
3. If the frequency of the incident radiation is CONSTANT, then the MAXIMUM KINETIC ENERGY of the photoelectrons is UNAFFECTED by INTENSITY of this radiation.

8. Significance of the photoelectric effect

The photoelectric effect is significant because it suggests that light consists of particles. The wave theory of light could not explain all the observations made in the photoelectric effect. The photoelectric effect changed scientists understanding of light and allowed them to develop the quantum theory of light. They quantum theory of light proposes that light consists of particles (packets of energy called quanta). Today scientists understand that light has a dual nature (a wave nature and a particle nature).

INTRODUCTORY LEVEL QUESTIONS

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

b. Their purpose is to familiarise the learners with the calculation of the energy of a photon, threshold frequency, work function and the maximum kinetic energy of the ejected electron.

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 questions and answer them correctly in their workbooks.

---

1. Define the following terms:
   1.1 photoelectric effect.
   1.2 threshold frequency.
   1.3 work function.

Solution:

1.1 The process whereby electrons are ejected from a metal surface when light of suitable frequency is incident on that surface.

1.2 The minimum frequency of light needed to emit electrons from a certain metal surface.

1.3 The minimum energy needed for an electron to be emitted from the surface of a metal.

2. Calculate the energy of a photon of red light with a wavelength of 700 nm.

Solution:

2. $E = \dfrac{hc}{\lambda} = \dfrac{(6,63 \times 10^{-34})(3 \times 10^{8})}{700 \times 10^{-9}} = 2,84 \times 10^{-19} \, J$

3. Calculate the energy of a photon of blue light with a frequency of $5,40 \times 10^{14} \, Hz$.

Solution:

$E = hf = (6,63 \times 10^{-34})(5,40 \times 10^{15}) = 3,58 \times 10^{-18} \, J$

4. The work function of potassium is $3,66 \times 10^{-19}$ J.

    4.1 Calculate the threshold frequency for potassium.

    4.2 Calculate the longest wavelength of light for which photoelectric emission will occur.

    4.3 This metal is irradiated with ultra-violet radiation of wavelength 220 nm.

    4.4 Calculate the maximum kinetic energy of the emitted electrons.

    4.5 Calculate the maximum speed of the emitted electrons.

Solutions:

4.1
$$W_o = hf_o$$
$$3,66 \times 10^{-19} = 6,63 \times 10^{-34} f_o$$
$$f_o = \frac{3,66 \times 10^{-19}}{6,63 \times 10^{-34}} = 5,52 \times 10^{14} \text{ Hz}$$

4.2 $c = f\lambda$
$$\lambda = \frac{3 \times 10^8}{5,52 \times 10^{14}} = 5,43 \times 10^{-7} \text{ m}$$

4.3.1. $E = W_o + E_{k(max)}$
$$\frac{hc}{\lambda} = W_o + E_{k(max)}$$
$$E_{k(max)} = \frac{hc}{\lambda} - W_o$$
$$E_{k(max)} = \frac{(6,63 \times 10^{-34})(3 \times 10^8)}{220 \times 10^{-9}} - 3,66 \times 10^{-19}$$
$$E_{k(max)} = 5,38 \times 10^{-19} \text{ J}$$

4.3.2. $E_k = \frac{1}{2}mv_{max}^2 = 5,38 \times 10^{-19}$ J
$$\frac{1}{2}(9,11 \times 10^{-31})v_{max}^2 = 5,38 \times 10^{-19}$$
$$v_{max}^2 = 1,181 \times 10^{12}$$
$$v_{max} = 1,09 \times 10^6 \text{ m·s}^{-1}$$

5. Ultra-violet radiation of frequency $1,65 \times 10^{15}$ Hz is shone onto a metal plate. The maximum kinetic energy of the ejected electrons is $2,8 \times 10^{-19}$ J.

    5.1 Calculate the energy of one photon.

    5.2 Calculate the work function of the metal.

Solution:

    5.1 $E = hf = (6,63 \times 10^{-34})(1,65 \times 10^{15}) = 1,09 \times 10^{-18}$ J

    5.2 $E = W_o + E_{k(max)}$

        $W_o = E - E_{k(max)}$

        $W_o = 1,09 \times 10^{-18} - 2,8 \times 10^{-19}$

        $W_o = 8,14 \times 10^{-19}$ J

CHALLENGE LEVEL QUESTIONS

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

b. These questions require learners to calculate the energy of a photon, threshold frequency, work function and the maximum kinetic energy of the ejected electron.

c. These questions also require learners to predict and explain what will happen if the frequency or wavelength or intensity of the incident light is changed.

d. Learners need to understand how a photocell works.

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 questions and answer them correctly in their workbooks.

TOPIC 12

KEY TEACHING

a. Calculate the energy of a photon of light when given the frequency of the wavelength of the incident light. $E = hf = \frac{hc}{\lambda}$.

b. Calculate the work function of a metal, given the threshold frequency. $W_o = hf_o$.

c. The work function of a metal corresponds to a maximum wavelength of light for photoelectric emission to occur.

d. Calculate the maximum kinetic energy and maximum speed of an ejected electron. $E = W_o + E_{k(max)}$.

6. In the diagram shown alongside, electrons are released from a metal plate when light of a certain frequency is shone on its surface.
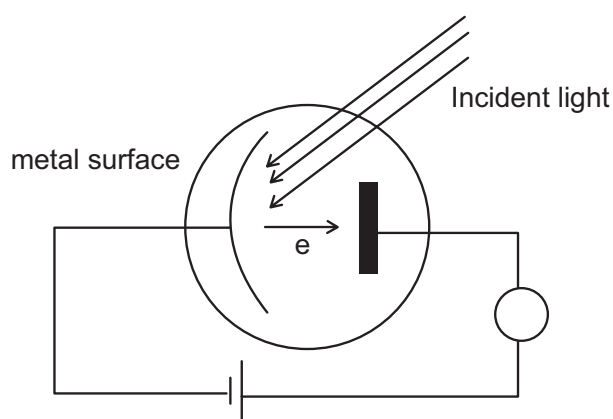
6.1 Name the phenomenon described above.

6.2 The frequency of the incident light on the metal plate is $6,16 \times 10^{14}\,Hz$ and electrons are released with a maximum kinetic energy of $5,6 \times 10^{-20}\,J$.

Calculate the:

  6.2.1 energy of the incident photons.

  6.2.2 threshold frequency of the metal plate.

6.3 The brightness of the incident light is now increased. What effect will this change have on the following: (Write INCREASES, DECREASES or REMAINS THE SAME).

  6.3.1 the reading on the ammeter? Explain your answer.

  6.3.2 the kinetic energy of the released photoelectrons? Explain the answer.

Solution:

6.1 Photoelectric effect.

6.2.1 $E = hf = (6,63 \times 10^{-34})(6,16 \times 10^{14}) = 4,08 \times 10^{-19}$ J

6.2.2 $E = W_o + E_{k(max)}$

$W_o = E - E_{k(max)}$

$W_o = 4,08 \times 10^{-19} - 5,6 \times 10^{-20}$

$W_o = 3,52 \times 10^{-19}$ J

$W_o = hf_o$

$f_o = \dfrac{W_o}{h} = \dfrac{3,52 \times 10^{-19}}{6,63 \times 10^{-34}} = 5,31 \times 10^{14}$ Hz

6.3.1 Increases.
More photons are arriving at the metal surface per second.
More electrons are ejected per second.
More charge is arriving at the anode per unit time.

6.3.2 Remains the same.
The frequency of the light has NOT changed.
Therefore the energy of the incident photon has not changed.

7. During an investigation, light of different frequencies is shone onto the metal cathode of a photocell. The maximum kinetic energy of the emitted photoelectrons is measured. The graph below shows the results obtained.

Graph of kinetic energy versus frequency
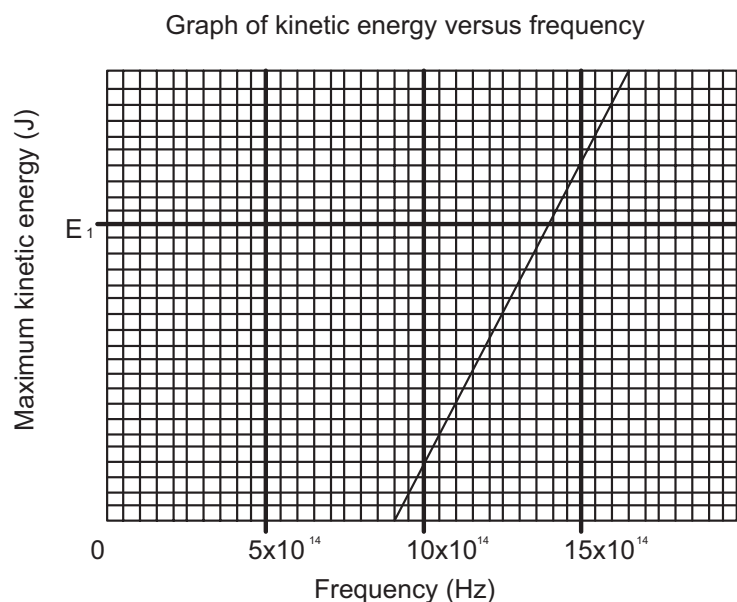
7.1 For this investigation, write down the following:

7.1.1 dependent variable.

7.1.2 independent variable.

7.1.3 controlled variable.

7.2 Define the term "threshold frequency".

7.3 Use the graph to obtain the threshold frequency of the metal used as the cathode in the photocell.

7.4 Calculate the maximum kinetic energy at E_1 shown on the graph.

7.5 How would the maximum kinetic energy calculated in question 7.4 be affected if light of a higher intensity is used? Write down only INCREASES, DECREASES or REMAINS THE SAME.

Solution:

7.1.1 Maximum kinetic energy.

7.1.2 Frequency.

7.1.3 Type of metal.

7.2 The minimum frequency of light needed to emit electrons from a certain metal surface.

7.3 The threshold frequency is the x intercept.

This corresponds to an electron which is set free from the metal surface with zero kinetic energy.

$f_o = 9 \times 10^{14}$ Hz

7.4 $f = 14 \times 10^{14}$ Hz

$E = W_o + E_{k(max)}$

$hf = W_o + E_{k(max)}$

$E_{k(max)} = hf - hf_o$

$E_{k(max)} = (6,63 \times 10^{-34})(14 \times 10^{14}) - (6,63 \times 10^{-34})(9 \times 10^{14})$

$E_{k(max)} = 3,32 \times 10^{-19}$ J

7.5 Remains the same.

CHECKPOINT

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

1. The calculation of the energy of a photon of light.

2. The calculation of the work function of a metal.

3. The calculation of the maximum kinetic energy and maximum speed of an emitted photoelectron.

4. How a photocell works.

5. Predicting the changes that would occur if the frequency, wavelength or intensity of the light was changed.

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

Topic 12: Resource Pack: Optical phenomena and properties of matter: Worksheet: Questions 1–3. (Pages 32–33).

- 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.

TOPIC 12

2. EMISSION AND ABSORPTION SPECTRA

INTRODUCTION

Spectra are important in astronomical spectroscopy for detecting the presence of elements calculating red shifts.

CONCEPT EXPLANATION AND CLARIFICATION

2.1 Atomic line emission spectra

Hydrogen gas is put in a gas discharge tube and a high voltage is applied to the discharge tube. The hydrogen gas EMITS LIGHT.

The light coming from the discharge tube is passed through a prism and analysed. The following spectrum is produced.

410 nm   434 nm   486 nm   656 nm

This type of spectrum is known as an ATOMIC LINE EMISSION SPECTRUM. Hydrogen gas, when excited by a high voltage has produced FOUR distinct lines in the visible part of its spectrum.

Each line corresponds to a PARTICULAR WAVELENGTH of light emitted by the hydrogen atoms.

Where do these lines come from and how are they produced?

In order to answer this question, we need to understand that there are energy levels within the hydrogen atom. The diagram below shows the energy levels within a hydrogen atom.

Potential energy (J)

0 J
n = 6 $- 6.1 \times 10^{-20}$ J
n = 5 $- 8.7 \times 10^{-20}$ J
n = 4 $- 1.4 \times 10^{-19}$ J
n = 3 $- 2.4 \times 10^{-19}$ J
n = 2 $- 5.5 \times 10^{-19}$ J

Electron in the lowest
energy level (ground state)

n = 1 $- 2.179 \times 10^{-18}$ J
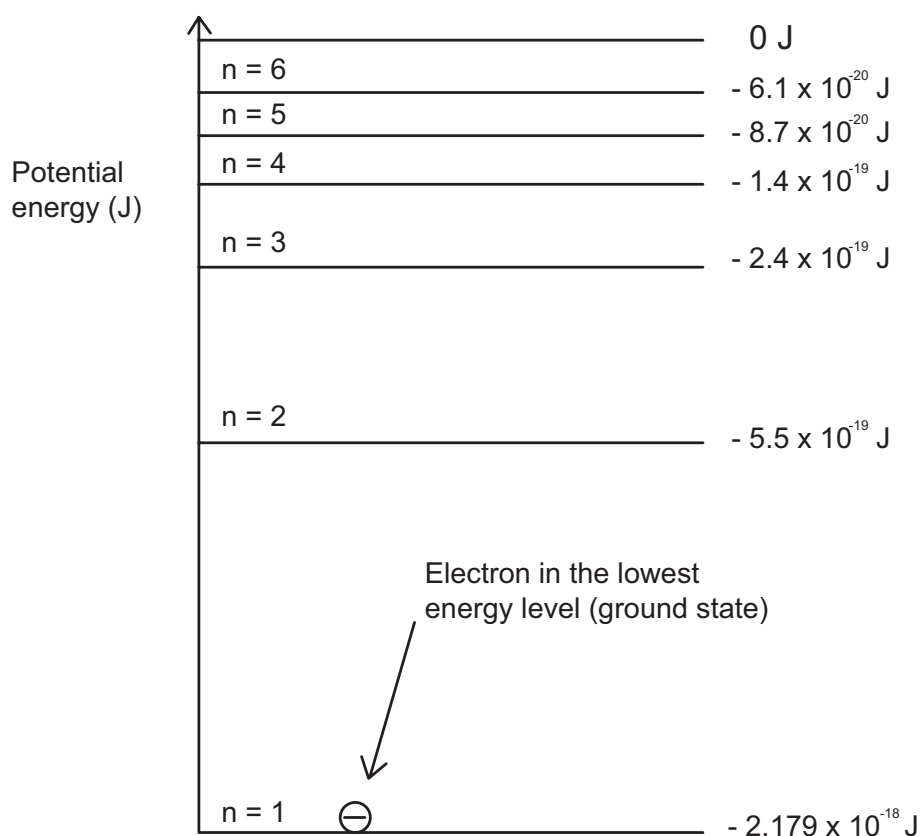
The electron is in the ground state. The electron is in the 1st energy level (n = 1). If the electron is in the 1st energy level it has the lowest possible energy.

In order for the electron to be in a higher energy level, IT MUST GAIN ENERGY.

When a high voltage is applied to the discharge tube, the ELECTRON GAINS ENERGY and jumps to a HIGHER ENERGY LEVEL within the hydrogen atom.
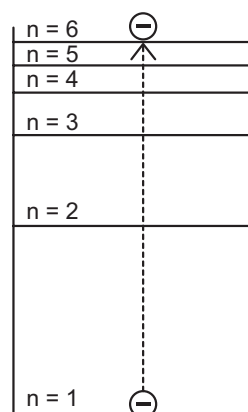
The electron has gained energy and jumped to a higher energy level.

The electron is in energy level n = 6. When the electron falls from a higher energy level (n = 6) to a lower energy level (n = 2), it MUST LOSE ENERGY. The electron loses energy by emitting a PHOTON OF LIGHT.
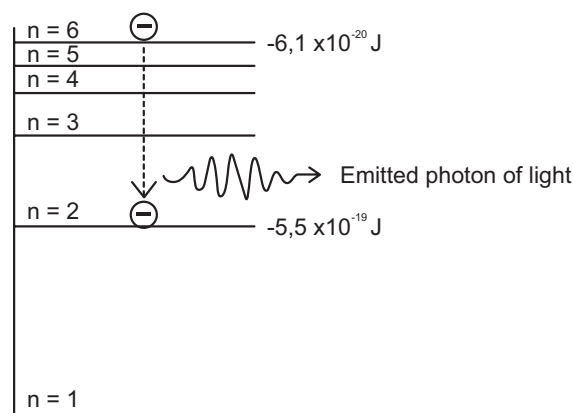
The electron falls from a higher energy level to a lower energy level and emits a photon of light.

The energy of the emitted photon (E) is equal to the difference in energy between the two energy levels ($E_6 - E_2$):

$E = E_6 - E_2$

$E = -6,1 \times 10^{-20} - (-5,5 \times 10^{-19})$

$E = -6,1 \times 10^{-20} + 5,5 \times 10^{-19}$

$E = 4,89 \times 10^{-19} \, J$

This emitted photon corresponds to a particular WAVELENGTH of light:

$E = \dfrac{hc}{\lambda}$

$\lambda = \dfrac{hc}{E} = \dfrac{(6,63 \times 10^{-34})(3 \times 10^{8})}{4,89 \times 10^{-19}}$

$\lambda = 4,10 \times 10^{-7} \, m$

$\lambda = 410 \times 10^{-9} \, m$

$\lambda = 410 \, nm$

This wavelength of 410 nm corresponds to the <u>VIOLET</u> line in the line emission spectrum.

When an electron makes a TRANSITION (falls) from a higher energy level to a lower energy level, a photon of light is emitted. The energy of the photon is EQUAL TO the DIFFERENCE IN ENERGY between the two energy levels.

The electron transitions that produce VIOLET, BLUE, LIGHT BLUE and RED LINES in the hydrogen line emission spectrum are shown below:
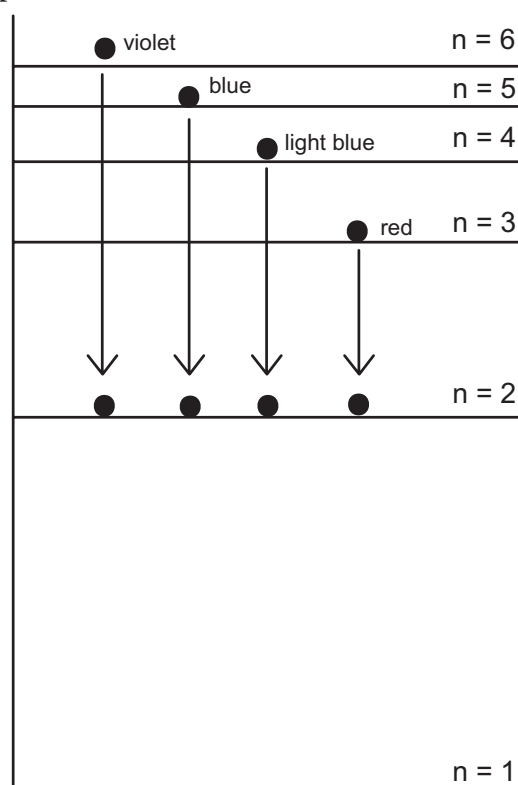
Each element produces its own UNIQUE line emission spectrum. The atomic line emission spectrum for mercury (Hg) is shown below.
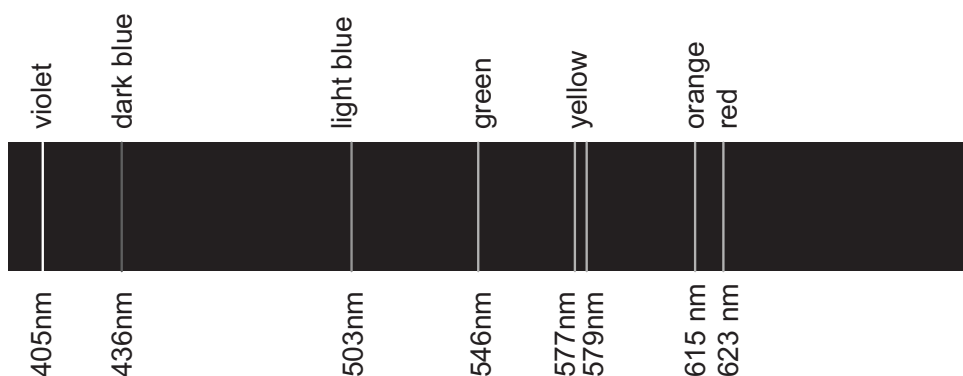
No two elements have the same line emission spectrum; the line emission spectrum of an element is like a fingerprint for that element. Astronomers are therefore able to analyse the light coming from distant stars and identify the different elements that are found in these stars.

2.2 Atomic absorption spectra

WHITE LIGHT is passed through a COLD GAS such as hydrogen gas at low pressure. The light is passed through a prism and the spectrum of white light is then analysed.

The following ATOMIC LINE ABSORPTION SPECTRUM is produced for hydrogen.

All the wavelengths of visible light are present in the spectrum EXCEPT four distinct wavelengths.

The same wavelengths that hydrogen emits from a gas discharge tube are MISSING in the line absorption spectrum.

Why are these wavelengths of light missing?

As the white light passes through the cold hydrogen gas, the electron in the hydrogen atom absorbs the energy of a photon of violet light and makes a transition (jumps) to a higher energy level (e.g. n = 2 to n = 6).
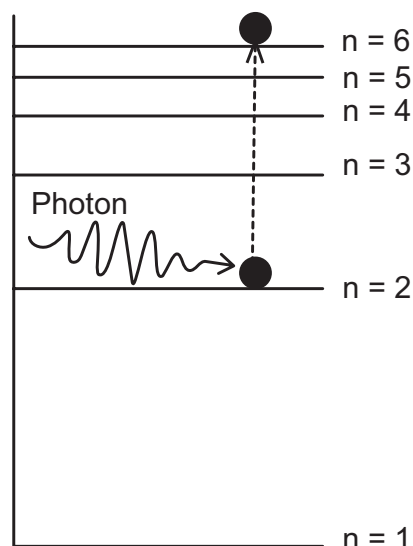
This wavelength of violet light (410 nm) has been ABSORBED BY THE ELECTRON and therefore does not pass through the cold hydrogen gas. This wavelength of light is now MISSING from the spectrum.

The energy of the incoming photon must be EXACTLY EQUAL to the energy difference between the two levels.

If the energy of the photon does not match the exact energy required to make the upward transition, then the electron will fall back down and release this energy as a photon of light.

The result is that only photons with specific energies will be absorbed by the electrons in the hydrogen atoms.

INTRODUCTORY LEVEL QUESTIONS

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

b. Their purpose is to familiarise the learners with atomic line emission and absorption spectra.

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 questions and answer them correctly in their workbooks.

1. Briefly explain how the following spectra are formed:
    1.1 atomic line emission spectrum.
    1.2 atomic line absorption spectrum.

Solution:

1.1 In a hot gas, electrons in the atoms makes transitions from higher to lower energy levels. The electrons must lose energy. This energy is emitted as photons of light which correspond to particular wavelengths in the line emission spectrum.

1.2 When white light is passed through a cold gas, the electrons in the atoms absorb particular photons of light. The electrons make transitions to higher energy levels. These wavelengths of light are missing in the line absorption spectrum.

2. An electron makes a transition from an energy level of $-2,24 \times 10^{-19}$ J to one of $-2,56 \times 10^{-19}$ J in an atom. Calculate the wavelength of the emitted radiation.

Solution:

2. $E = E_2 - E_1$

$E = -2,24 \times 10^{-19} - (-2,56 \times 10^{-19})$

$E = -2,24 \times 10^{-19} + 2,56 \times 10^{-19}$

$E = 3,2 \times 10^{-20}$ J

This emitted photon corresponds to a particular WAVELENGTH of light:

$E = \dfrac{hc}{\lambda}$

$\lambda = \dfrac{hc}{E} = \dfrac{(6,63 \times 10^{-34})(3 \times 10^{8})}{3,2 \times 10^{-20}}$

$\lambda = 6,22 \times 10^{-6}$ m

3. Diagram 1 below shows some of the possible energy emissions as excited electrons in a hot gas fall to lower energy levels. (Level n = 4 has the highest energy).
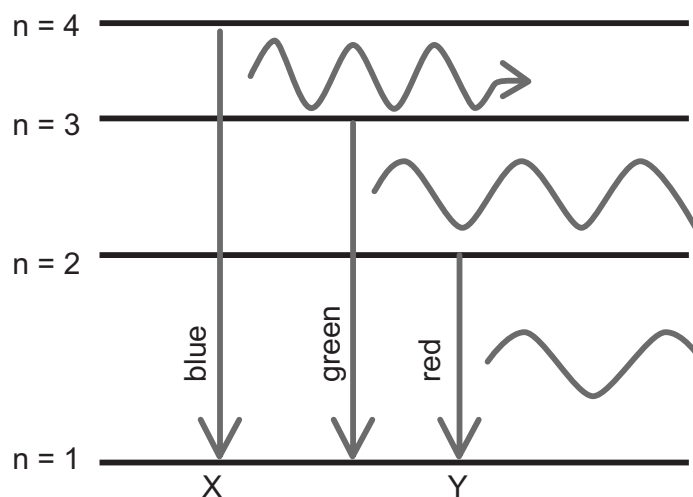
Diagram 1

Diagram 2 below shows the line emission spectrum produced. The white lines indicate the wavelengths at which light was observed.

Increasing wavelength ➔   **A**
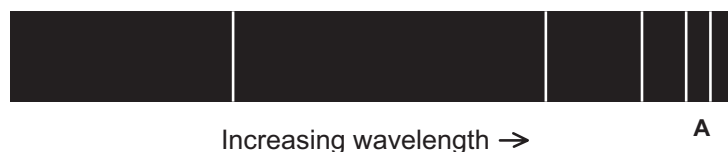
Diagram 2

3.1 Which of the emissions, X or Y (diagram 1) is most likely to correspond to spectral line A in diagram 2? Explain your answer.

3.2 Write down ONE important use of spectra.

Solution:

3.1 Y

Transition Y corresponds to the lowest energy difference between the two energy levels.

The energy of the emitted photon is inversely proportional to the wavelength of the emitted light.

The lower the energy of the emitted photon, the longer the wavelength of light.

3.2 Spectra are important in astronomical spectroscopy for detecting the presence of elements and calculating red shifts.

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 explain the formation of atomic line emission and absorption spectra as well as perform calculations.

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 questions and answer them correctly in their workbooks.

KEY TEACHING:

a. Atomic line emission spectra are formed from hot gases when excited electrons in the atom fall to lower energy levels and emit light of distinct wavelengths.

b. The energy of the emitted photon is equal to the difference in energy between the two levels.

c. Atomic absorption spectra are formed when white light is passed through a cold gas and electrons absorb photons of light and make transitions to higher energy levels. These wavelengths of light are missing in the absorption spectrum.

4. Light from a white filament of a lamp is focussed on a tube containing sodium vapour. When the spectrum produced is analysed, two black lines appear in the yellow part of the spectrum as shown in the diagram below.
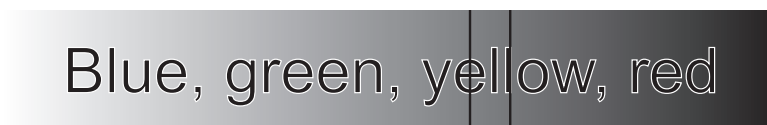
4.1 Which type of spectrum is shown above?

4.2 Explain why these two wavelengths of light are missing from the spectrum.

4.3 Which colour of light will be emitted by sodium vapour when it is heated?

The diagram shows the spectrum obtained when sodium vapour is heated.

yellow

4.4 Which type of spectrum is shown above?

4.5 Explain how these two spectral lines are formed?

The wavelengths of the two bright yellow lines in the spectrum of sodium are 589,0 nm and 589,6 nm.

4.6 Which of these two spectral lines has the higher frequency?

4.7 Which spectral line corresponds to a photon of highest energy being emitted?

4.8 Calculate the energy of a photon of light emitted in question 4.7.

Solution:

4.1 Atomic line absorption spectrum.

4.2 Electrons in the sodium atom absorb photons of energy which corresponds to these wavelengths of light and make transitions to higher energy levels.

4.3 Yellow light.

4.4 Atomic line emission spectrum.

4.5 Excited electrons in the sodium atom make transitions to lower energy levels and emit photons of light which correspond to those two wavelengths of light.

4.6 The shorter wavelength (589,0 nm) corresponds to the higher frequency of light.

4.7 The shorter wavelength (589,0 nm) corresponds to the higher energy photon emitted.The energy of a photon is inversely proportional to the wavelength of light.

4.8 $E = \dfrac{hc}{\lambda} = \dfrac{(6,63 \times 10^{-34})(3 \times 10^{8})}{589 \times 10^{-9}}$

$E = 3,38 \times 10^{-19}\, J$

5. A fluorescent tube is filled with mercury vapour at low pressure. In order to emit electromagnetic radiation, the mercury atoms must first be excited. The lowest energy levels of a mercury atom are shown below. The diagram is not to scale.

n = 4 ———————————— -0,26 x 10^{-10} J   Potential
n = 3 ———————————— -0,59 x 10^{-18} J   energy
n = 2 ———————————— -0,88 x 10^{-18} J

Ground state   n = 1 ———————————— -2,18 x 10^{-18} J
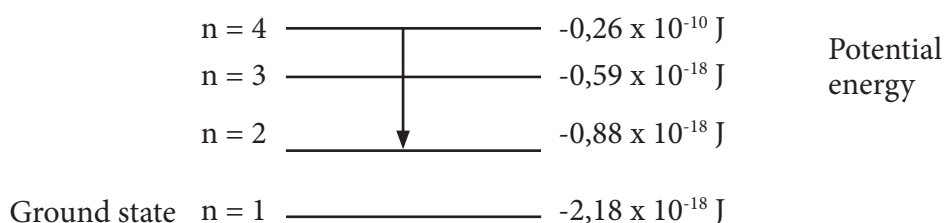
5.1 Calculate the frequency of an emitted photon due to an electron transition from energy level n = 4 to energy level n = 2.

5.2 Between which two energy levels will an electron transition emit light of a longer wavelength than that in question 5.1? Explain your answer.

Solution:

5.1 $E = E_4 - E_2$

$E = -0,26 \times 10^{-18} - (-0,88 \times 10^{-18})$

$E = -0,26 \times 10^{-18} + 0,88 \times 10^{-18}$

$E = 6,2 \times 10^{-19}\, J$

$E = hf$

$f = \dfrac{E}{h} = \dfrac{6,2 \times 10^{-19}}{6,63 \times 10^{-34}}$

$f = 9,35 \times 10^{14}\, Hz$

5.2 n = 4 to n = 3

There is a smaller energy difference. A photon of lower energy is emitted. This corresponds to a longer wavelength.

CHECKPOINT

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

1. Explaining how atomic line emission and absorption spectra are formed.

2. The calculation of the energy of the emitted photon and the corresponding wavelength or frequency of light emitted.

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

Worksheet Pack: Optical phenomenon and properties of materials Worksheet: Questions 4–5. (Pages 33–34).
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: Topic 12: Optical phenomena and properties of matter Consolidation Exercise. (Pages 35–38).**
- 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.**

TOPIC 12

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=vuGpUFjLaYE
   Photoelectric effect

2. https://www.youtube.com/watch?v=v-1zjdUTu0o&t=2s
   Demonstration of photoelectric effect

3. https://www.youtube.com/watch?v=1uPyq63aRvg
   Atomic absorption and line emission spectra

4. https://phet.colorado.edu/en/simulation/legacy/photoelectric
   Superb pHet simulation of the photoelectric effect. You are able to change the colour and intensity of the light and make observations.

TOPIC 13:
Electrochemical Reactions

A   Introduction

- This topic runs for 8 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Energy forms part of the content area Chemical Change (Chemistry).
- Chemical Change (Chemistry) counts as 60 %
- Electrochemistry counts approximately 21 % of the final Chemistry Examination (Paper 2).
- Electrochemistry is a branch of chemistry that examines the specific type of chemical reactions that involve the transfer of electrons within those reactions. These reactions occur when we transfer chemical energy to electrical energy as well as when we transfer electrical energy to chemical energy. The electrochemical processes of oxidation and reduction are responsible for the existence of the galvanic and electrolytic cells where these energy changes occur. This topic will seek to provide understanding of how these processes take place as well as examine the specific chemistry taking place within each electrochemical cell. We will also look at applications of where these cells can be used.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.

2. Chalk.

3. Grade 12 Physics Examination Data Sheet.

4. Table of Standard Electrode Potentials.

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. An A4 3-quire exercise book, for notes and exercises.

2. Scientific calculator – Sharp or Casio calculators are highly recommended.

3. Pen.

4. Table of Standard Electrode Potentials.

B   Sequential Table

PRIOR KNOWLEDGE	CURRENT
GRADE 10-11	**GRADE 12**
• Redox reactions • Revise concept of oxidation numbers	• Rates of chemical reaction • le Chatelier's Principle and chemical equilibrium

C   Glossary of Terms

TERM	DEFINITION
Electrolyte	A substance of which the aqueous solution contains ions OR a substance that dissolves in water to give a solution that condusts electricity.
Galvanic cell	A cell in which chemical energy is converted into electrical energy. A galvanic (voltaic) cell has self-sustaining electrode reactions.
Electrolytic cell	a cell in which electrical energy is converted into chemical energy.
Oxidation	Electron transfer involving the loss of electrons. An increase in oxidation number.
Reduction	Electron transfer involving the gain of electrons. A decrease in oxidation number.
Oxidising agent	The chemical substance that gains electrons in a REDOX chemical reaction and is thus undergoing reduction.
Reducing agent	The chemical substance that loses electrons in a REDOX chemical reaction and is thus undergoing oxidation.
Anode	The electrode in an electrochemical cell where oxidation takes place.
Cathode	The electrode in an electrochemical cell where reduction takes place.
le Chatelier's Principle	A change in any of the factors that determine equilibrium conditions of a system will cause the system to change in such a manner as to reduce or counteract the effect of the change.
REDOX reaction	An electrochemical reaction that involves both reduction and oxidation taking place simultaneously.
Electrode	Electrical conductor through which an electric current enters or leaves and electrochemical cell or medium.
Salt bridge	The apparatus that connects the two half-cells together in a galvanic cell and maintains half-cell neutrality.

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Half-cell neutrality	The term used when there is a balance of cations and anions in solution: creating an electrically neutral solution.
Net electrochemical reaction	The overall or complete chemical reaction showing the combined oxidation and reduction reactions that take place in the cell.
Cell notation	A short hand representation showing the anode and cathode electrochemical processes taking pace in the galvanic cell.
Dynamic chemical equilibrium	When the rate of the forward reaction is equal to the ate of the reverse/back reaction in a closed system.
Standard hydrogen electrode	The reference electrode assigned the cell potential of 0,00 V and where we can compare all other half-cells to this standard.
Standard Electrode Potential	The potential difference measured under standard conditions when an electrode is connected to the standard hydrogen half-cell.
Cell emf	The total potential difference of a galvanic cell.
Electroplating	The process of coating one metal onto another metal object by means electrolysis.
Electrorefining	A purification technique of extracting a metal from an impure sample and then electroplating that metal onto an electrode by means of electrolysis.
Membrane Cell	A type of electrolytic cell that is used in the Chlor-Alkali industry that uses an ion exchange membrane to separate the anodic and cathodic compartments in the cell.
Brine	This is a concentrated salt solution, usually sodium chloride.
Ion exchange membrane	This is used in the membrane cell and is ion selective in terms of only allowing certain ions to pass through it.
Bauxite	This is the impure ore that contains aluminium oxide in the impure form and from which aluminium metal is eventually extracted.
Cryolite	This is a substance that is added to aluminium oxide that lowers the melting point of the aluminium oxide to reduce very high electricity consumption.

D   Assessment of this Topic

This topic can be assessed using short class tests or through marked worksheets. It is suggested that a formal test is done at the end of the section to ensure that the learners understand the work taught. This topic will examined in the preliminary and in the final matric examination.

- There may be mulitple-choice type questions and problems to solve, where learners are expected to show their method, give some explanation and/or write definitions or laws.

E   Breakdown of Topic and Targeted Support Offered

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

TIME ALLOCATION	SUB-TOPIC	CAPS PAGE NUMBER	TARGETED SUPPORT OFFERED
2 hour	Electrolytic cells and galvanic cells	134	a. The structure of the galvanic cell. b. The structure of the electrolytic cell.
2 hour	Understanding the processes and redox reactions taking place in cells	136	a. The REDOX process taking place in the galvanic cell. b. The REDOX process taking place in the electrolytic cell.
1 hour	Relation of current and potential to rate and equilibrium	135	a. The relationship between current in an electrochemical cell and rate of reaction. b. Potential difference and cell equilibrium. c. Using le Chatelier's Principle to explain the relationship between concentration of ions in solution: and cell equilibrium.
2 hour	1. Standard electrode potential 2. Writing of equations representing oxidation and reduction half reactions and redox reactions	136 and 137	a. Standard electrode potentials. b. The standard hydrogen electrode and measuring standard electrode potentials. c. Using the Table of Standard Reduction potentials to determine the emf of the standard galvanic cell. d. Writing equations representing REDOX reactions. e. Describing the decomposition of copper chloride in an electrolytic cell. f. Describing the electrolytic process of electroplating. g. Describing the electrorefining of impure copper metal.
1 hour	Oxidation numbers and application of oxidation numbers	137	a. What oxidation numbers are and how they are derived. b. Why oxidation numbers are so valuable. c. The production of chlorine in the Chlor-Alkali industry. d. The recovery of aluminium metal from bauxite.

F   Targeted Support per Sub-topic

1. ELECTROLYTIC CELLS AND GALVANIC CELLS

INTRODUCTION

In Grade 11, learners would have looked at the concept of redox chemistry. What we are now going to do is to apply the understanding of this chemistry to more practical elements in electrochemistry, namely looking at the two electrochemical cells. The **galvanic** cell will show the learners how chemical energy is converted into electrical energy while the **electrolytic cell** will show the learners how electrical energy is converted into chemical energy.

### CONCEPT EXPLANATION AND CLARIFICATION: THE STRUCTURE OF A GALVANIC CELL

Begin the concept of the galvanic cell by giving the learners a brief outline as to where the galvanic cell got its name and the basic processes that take place in the cell. Explain to them that the galvanic cell was named after the famous Italian chemist, Luigi Galvani, and it produces an electric current by a **spontaneous** REDOX reaction i.e. chemical energy is converted into electrical energy through the processes of oxidation and reduction. These cells are self-sustaining in that the energy required for the cell to operate comes directly from the chemical reaction within the cell itself. These chemical reactions are REDOX reactions in that there have to be two parts to the galvanic cell: one part of the cell where oxidation occurs, and one part of the cell where reduction occurs. The galvanic cell consists of two half-cells, each half-cell represents a specific electrochemical process. A half-cell is made by placing an electrode into an electrical conducting solution known as an electrolyte. It is important for the learners to know that the half-cell must contain a metal electrode which is in contact with the electrolyte that contains that particular metal's ions in solution. For example:

- a copper half-cell: copper electrode in a copper solution (electrolyte) (contains $Cu^{2+}(aq)$ ions)
- a zinc half-cell: zinc electrode in a zinc solution (electrolyte) (contains $Zn^{2+}(aq)$ ions)

The two half-cells in a galvanic cell are linked by an essential structure called a salt bridge. The functions of the salt bridge are:

1. It joins the two half-cells together to complete the circuit in the galvanic cell.

2. It acts as an 'ionic pump' to allow ions to flow into the half-cells to maintain electrical neutrality in each half-cell. (More details will be provided later in the module on this specific function).

At this point, it is important for the learners to see a diagram of a galvanic cell. Here, the copper-zinc galvanic cell is the easiest and best example for the learners to learn how the galvanic cell works.
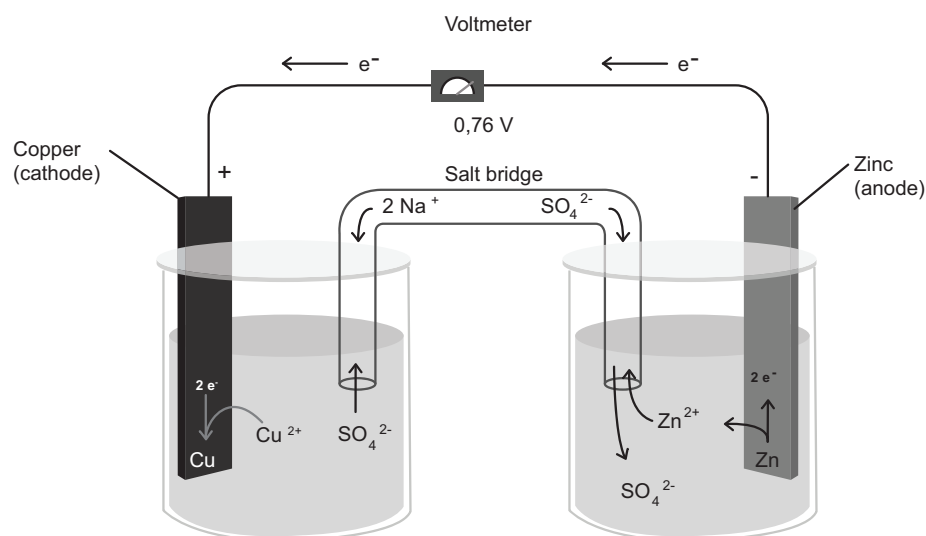
Here the learners can clearly see the two half-cells, namely copper and zinc, that are joined by the salt bridge. The two half-cells are also connected to a voltmeter. Show the learners that there is now a complete circuit and when the galvanic cell is functioning, the voltmeter will measure the potential difference between the two half-cells.

Also show the learners from the diagram that oxidation takes place in the one half-cell (zinc) and reduction is taking place in the other half-cell (copper). How one determines which half-cell undergoes which process will be explained later.

Tell the learners that the electrode in the half-cell which undergoes oxidation is called the anode which represents the negative half-cell (−), while the electrode in the half-cell which undergoes reduction is called the cathode which represents the positive (+) half-cell.

Anode: The electrode of the half-cell which undergoes oxidation.

Cathode: The electrode of the half-cell which undergoes reduction.

An easy way for them to remember this is by using the following:

ANOX: at the ANode there will be OXidation

REDCAT: REDuction will happen at the CAThode

Learners also need to be reminded about, and to understand the concept of oxidising and reducing agents. They would have learned this in Grade 11, but it would be beneficial if it was covered once again as electrochemical cells are explained through the workings of oxidation, reduction, oxidising agents and reducing agents.

Oxidising agent: This is the chemical substance that gains electrons in a REDOX chemical reaction and is thus undergoing reduction.

Reducing agent: This is the chemical substance that loses electrons in a REDOX chemical reaction and is thus undergoing oxidation.

These terms will be used when we explain the processes and REDOX reactions that take place in the cells.

Briefly mention the salt bridge again with regards to the salt bridge being filled with a saturated solution of a salt that is very soluble in water but also will not react chemically with the electrolytes. The learners will be able to see from the diagram that ions are flowing between the salt bridge and the half-cell electrolytes. It is very important for the learner to know that the flow of these ions represents the flow of charge in the circuit thus creating an electric current in the circuit. NB Electrons do not flow in the solutions or salt bridge.

CONCEPT EXPLANATION AND CLARIFICATION: THE STRUCTURE OF AN ELECTROLYTIC CELL

Explain to the learners that the electrolytic cell is a **non-spontaneous** electrochemical cell where electrical energy is converted into chemical energy; that is, an electric current is passed through an electrolyte and a chemical reaction is produced. This is the exact opposite to the galvanic cell. The word "electrolysis" literally means to **break up by means of an electric current.** (Lysis is the Latin word meaning "to separate" or "to split"). You will remember the very simple example from Grade 10 when studying the section on Synthesis and Decomposition reactions. There an electric current was passed through an aqueous solution of copper (II) chloride ($CuCl_2$) by means of two carbon electrodes and solid copper (Cu) and gaseous chlorine (Cl_2) were formed. Thus electrolytic reactions were considered to be decomposition reactions and fully supported the basic meaning of electrolysis.
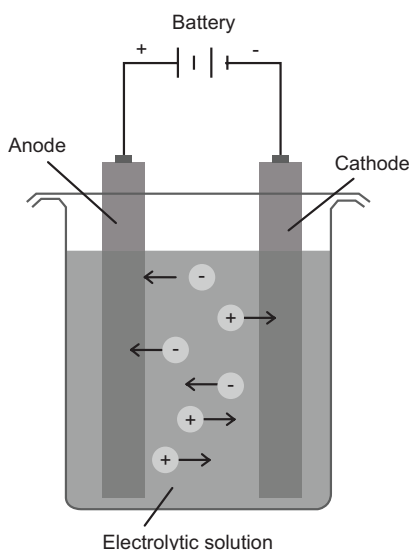
In the diagram alongside, explain to the learners that the electrolytic cell consists of both electrodes placed into the same electrolyte which is contained in the beaker.

- In the beaker is the electrolyte with two electrodes, usually made of carbon or some other inert material, inserted directly in contact with the solution.
- Each electrode is connected to the terminals of a power source thus becoming the anode (+) and the cathode (−).
- Anions in solution are attracted towards the anode.
- Cations in solution are attracted to the cathode.

It is important for the learners to see that the anode and cathode in the electrolytic cell have changed polarities compared with those in the galvanic cell. That is, the anode is now the positive electrode (+) and the cathode is now the negative (-) electrode. However, learners must also understand that the process of oxidation and reduction still proceeds in exactly the same way as in the galvanic cell. Oxidation is the loss of electrons and reduction is the gain of electrons. That is, oxidation will still occur at the anode (ANOX) and reduction will still occur at the cathode (REDCAT). These electrode reactions are sustained by a constant supply of electrical energy which thus allows for the conversion of electrical energy to chemical energy.

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 concepts.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Learners must copy down the questions and answer them correctly in their workbooks.

1. What is the difference between a galvanic and an electrolytic cell in terms of energy transfers that take place in the cell?

   Solution:

   Galvanic cell: Chemical energy is converted into electrical energy.

   Electrolytic cell: Electrical energy is converted into chemical energy.

2. What is meant by the term 'half-cell'?

   Solution:

   This is the structure formed when an electrode (either an anode or cathode) is placed into a conducting solution called an electrolyte.

3. What name is given to the electrode where oxidation takes place in a galvanic cell?

   Solution:

   Anode.

4. What name is given to the electrode where reduction takes place in a galvanic cell?

   Solution:

   Cathode.

5. When it comes to comparing the anode and cathode in a galvanic cell and an electrolytic cell, what similarities and what differences are present between these two types of electrochemical cells?

   Solution:

   Differences: In the galvanic cell, the anode is the negative electrode and the cathode is the positive electrode.
   In the electrolytic cell, the anode is the positive electrode and the cathode is the negative electrode.

   Similarities: The electrochemical processes at each electrode remains the same. Oxidation occurs at the anode and reduction occurs at the cathode.

CHECKPOINT

At this point in the topic, learners should:

1. understand the basic structure of the galvanic cell.

2. understand the basic structure of the electrolytic cell.

3. have an understanding of the concepts of oxidation and reduction.

4. have an understanding of the concepts of oxidising and reducing agents.

5. be able to identify the anode and the cathode in an electrochemical cell.

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

Resource Pack: Topic 12: Electrochemical Reactions Worksheet: Questions 1–3. (Page 43).

- 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.

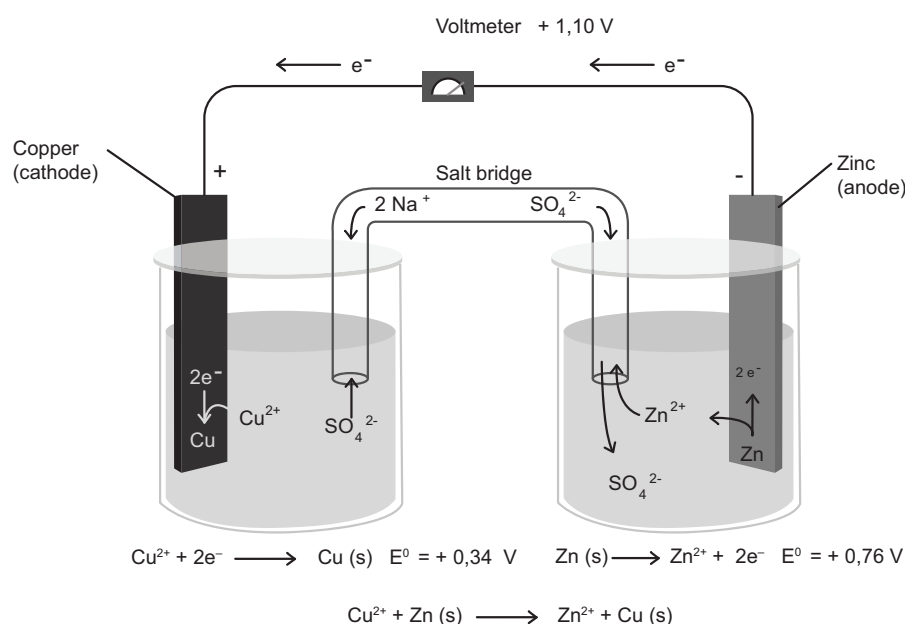## 2. UNDERSTANDING THE PROCESSES AND REDOX REACTIONS TAKING PLACE IN CELLS

INTRODUCTION

Now that the learners have a basic understanding of what galvanic and an electrolytic cells are, it is time to look at the electrochemical processes that take place in each cell. In this section, the learners will learn to identify the processes of reduction and oxidation which take place in each cell as well as at which electrodes these processes occur. Learners will also be taught the movement of ions through the solutions as well as the function of the salt bridge in the galvanic cell. There will also be an explanation of the cell notation used to represent the galvanic cell.

CONCEPT EXPLANATION AND CLARIFICATION: THE REDOX PROCESSES TAKING PLACE IN THE GALVANIC CELL (INDIRECT ELECTRON TRANSFER)

Learners need to be shown the exact electrochemistry that takes place in the galvanic cell. The first thing that learners need to do is to be able to identify the anode and the cathode in the cell; that is, which cell will undergo oxidation and which cell will undergo reduction. The easiest example to use is the Copper-Zinc (Cu-Zn) electrochemical cell.

The Cu-Zn electrochemical cell consists of two half-cells. The Cu half-cell consists of a copper electrode placed in an electrolyte of $CuSO_4$, (that is, containing $Cu^{2+}(aq)$ ions) while the Zn half-cell consists of a zinc electrode placed in an electrolyte of $ZnSO_4$, (that is, containing $Zn^{2+}(aq)$ ions). This is illustrated in the diagram below:

$$Cu^{2+} + 2e^- \longrightarrow Cu\ (s)\quad E^0 = +\ 0{,}34\ \ V \qquad Zn\ (s) \longrightarrow Zn^{2+} +\ 2e^-\quad E^0 = +\ 0{,}76\ V$$

$$Cu^{2+} + Zn\ (s) \longrightarrow Zn^{2+} + Cu\ (s)$$

Begin the teaching of this by considering the chemistry that is taking place in the cell to explain the potential difference that now exists between the two half-cells. This potential difference is created based on the ability of the half-cells to undergo a redox reaction. It is this potential difference between the two half-cells that causes the electrons to flow through the conducting wires from anode to cathode and provides a reading on the voltmeter. The mere fact that there is a reading on the voltmeter, suggests that there must be a conversion of chemical energy into electrical energy, hence a REDOX reaction must be occurring in the cell. What we must do is identify which half-cell is undergoing oxidation and which half-cell is undergoing reduction. In other words, learners must identify the <u>anode</u> and the <u>cathode</u> correctly. This is where the proper use and understanding of the Table of Half reactions is essential to identify the reducing and oxidising agents within the cell.

Step 1:

Identify the two half reactions on the Table 4B and write them down in order exactly as they appear on the table.

$$Zn^{2+} + 2e^- \rightleftharpoons Zn$$
$$Cu^{2+} + 2e^- \rightleftharpoons Cu$$

The zinc half-reaction is higher than the copper half reaction thus must be written as such.

Step 2:

If we look at the right hand side of the table and compare the positions of Cu and Zn, we can see that Zn is higher up the Table 4B on the right hand side.

$Zn^{2+} + 2e^- \rightleftharpoons Zn$ Higher up on the right hand side

$Cu^{2+} + 2e^- \rightleftharpoons Cu$ Lower down on the right hand side
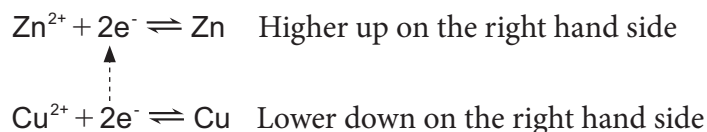
This means that Zn is a stronger reducing agent than Cu. The stronger the reducing agent, the greater will be the tendency to undergo oxidation in comparison to the weaker reducing agent. Thus Zn will be oxidised. The half reaction is now written from right to left to indicate a loss of electrons (oxidation):

$Zn \longrightarrow Zn^{2+} + 2e^-$ (oxidation half reaction)

Step 3:

If we look at the left hand side of the table and compare the positions of Cu^{2+} and Zn^{2+}, we can see that Cu^{2+} is lower down the Table 4B on the left hand side:

$Zn^{2+} + 2e^- \rightleftharpoons Zn$

$Cu^{2+} + 2e^- \rightleftharpoons Cu$
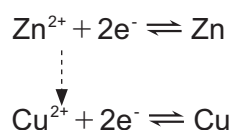
This means that Cu^{2+} is a stronger oxidising agent than Zn. The stronger the oxidising agent, the greater will be the tendency to undergo reduction in comparison to the weaker oxidising agent. Thus Cu^{2+} will be reduced. The half reaction is now written from left to right to indicate a gain of electrons (reduction):

$Cu^{2+} + 2e^- \longrightarrow Cu$ (reduction half reaction)

This means that even though the two half-cells are not in direct contact with each other, electrochemical processes can still take place within each half-cell. In the Zn half-cell there will be **oxidation**; in the Cu half-cell, **reduction** as indicated by the half reactions written under each half-cell shown in the diagram above.

From this, we can identify the anode and the cathode (ANOX and REDCAT)

Anode: Zn half-cell $Zn \longrightarrow Zn^{2+} + 2e^-$

Cathode: Copper half-cell $Cu^{2+} + 2e^- \longrightarrow Cu$

Now spend some time with the learners making sure they understand what happens in each half-cell.

In the Zn half-cell

Oxidation will take place where Zn atoms present in the metal electrode are oxidised to Zn^{2+} cations. This process releases two electrons onto the electrode while the Zn^{2+} cations move into aqueous solution as part of the electrolyte. The Zn electrode now starts to

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disintegrate or corrode as the Zn metal is slowly converted into Zn^{2+} cations thus causing a decrease in mass of the electrode.

$$Zn \longrightarrow Zn^{2+} + 2e^{-} \quad \ldots\ldots\ldots\ldots \textbf{Oxidation}$$

Thus the Zn electrode becomes known as the **ANODE** or negative electrode as electrons are deposited on this electrode.

In the Cu half-cell

Electrons released from the oxidation process happening at the Zn electrode (anode) move through the external circuit due to the potential difference set up between the two cells. When they arrive at the Cu electrode, the Cu^{2+} ions in the electrolyte are attracted to them and reduction takes place. The Cu^{2+} cations are converted into Cu atoms and copper metal plates this electrode. This is an example of electroplating and will cause the copper electrode to increase in mass.

$$Cu^{2+} + 2e^{-} \longrightarrow Cu \quad \ldots\ldots\ldots\ldots \textbf{Reduction}$$

Thus the Cu electrode becomes known as the **CATHODE** or positive electrode

From here, the two processes of reduction and oxidation may be combined to form what is known as the **net electrochemical reaction**.

Oxidation: $Zn \longrightarrow Zn^{2+} + 2e^{-}$

Reduction: $Cu^{2+} + 2e^{-} \longrightarrow Cu$
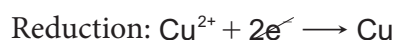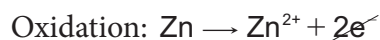
Learners must be told that it is very important to check that there is electron balance in the system; that is, that the number of electrons being lost due to oxidation is equal to the number of electrons being gained by reduction. In this example, there are 2 electrons lost and 2 electrons gained, thus there is electron balance.

Electrons may now be cancelled as seen above and the net reaction may be written:

$$Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Cu(s)$$
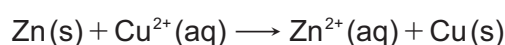
Standard conditions

The electrochemical cell must operate under the following standard conditions:

- concentration of electrolytes is 1 mol·dm^{-3}.
- pressure, if gas electrode is used, is 1 atmosphere.
- temperature of solutions is 25 °C.

CONCEPT EXPLANATION AND CLARIFICATION: THE FUNCTION OF THE SALT BRIDGE IN A GALVANIC CELL.

A salt bridge is a simple structure which is generally made from a glass U-tube which is filled with a saturated solution of an electrolyte, most often potassium nitrate (KNO_3) or sodium sulphate (Na_2SO_4), with cotton wool plugging each end of the tube. Learners must

be told that these type of electrolytes are chosen due to the very <u>weak oxidising ability</u> of the ions in solution, thus they will not become involved in the electrochemical process within the cell. In other words, the K^+ (aq) Na^+ (aq), SO_4^{2-} (aq) or NO_3^- (aq) ions will tend not to undergo reduction or oxidation which means that they will not influence the oxidation or reduction processes occurring in the half-cells.

Salt bridge solution: made from saturated KNO_3 which releases K^+ and NO_3^- ions into solution

Cotton wool plugs
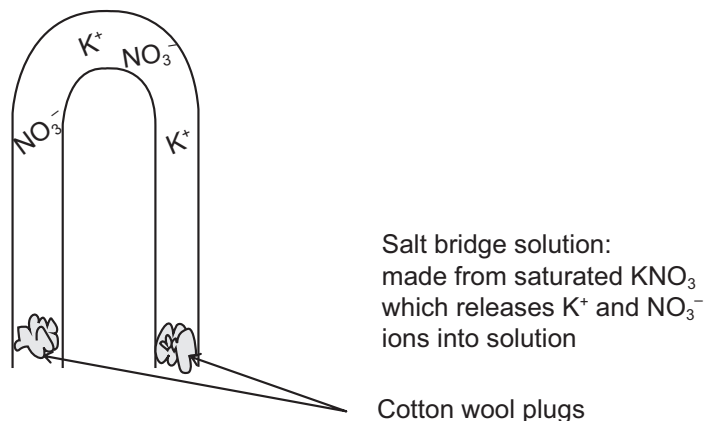
The **TWO** important functions of the salt bridge are:

1. it links the two half-cells together in order to **complete the circuit** within the entire electrochemical cell. This means that ions are able to flow through the salt bridge hence creating conductivity between the two half-cells.

2. it maintains **half-cell neutrality** within each half-cell in the circuit. Maintaining half-cell neutrality is vital for the efficient functioning of the cell and must be very carefully explained............Let's take our Cu-Zn electrochemical cell as the example.

- In each half-cell before the cell starts functioning there is a balance between the cations and anions in solution.

     <u>Zn half-cell</u> : Zn^{2+} and SO_4^{2-} ions are present in a 1 : 1 ratio

     <u>Cu half-cell</u> : Cu^{2+} and SO_4^{2-} ions are present in a 1 : 1 ratio

- As the cell functions, each half-cell is undergoing an electrochemical process. Oxidation occurring at the anode and reduction occurring at the cathode. This now upsets the cationic and anionic balance within each half-cell.

     <u>Anode</u>   : Zn^{2+} cationic concentration increases due to the oxidation process thus there are too many cations in solution compared to anions and the balance is upset. The solution becomes positive.

     <u>Cathode</u>   : Cu^{2+} cationic concentration decreases due to the reduction process thus there are too few cations in solution compared to anions and the balance is upset. The solution becomes negative.
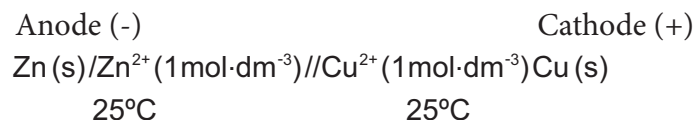
- The salt bridge now functions to stabilise and maintain the half-cell neutrality by acting as an ionic pump to allow for free flow of cations and anions from and through the salt bridge into the respective half-cells to maintain the ionic balance and hence the neutrality.

CONCEPT EXPLANATION AND CLARIFICATION: USING CELL NOTATION TO REPRESENT A GALVANIC CELL.

Once the learners are comfortable with this theory, they can be introduced to the short way of representing the galvanic cell. Diagrammatically, it can become difficult to continuously have to keen on drawing the entire cell to show the various processes occurring, hence the introduction of the cell notation as a short-hand way of representing the cell. The learners need to know certain basic rules for writing the cell notation:

- Cell notations are always written from ANODE to CATHODE
- Each half-cell reaction is represented by a diagonal line to show an electrochemical reaction e.g. Zn/Zn^{2+}.
- The salt bridge is represented by two parallel lines (//).
- The cell standard conditions are included in the cell notation if requested. Concentration of 1 mol·dm^{-3} is indicated with the ions in solution and the temperature is of 25°C is placed under each half-cell.

Thus, for the standard Cu-Zn electrochemical cell, the cell notation can be written as

$$\text{Anode (-)} \qquad\qquad\qquad \text{Cathode (+)}$$
$$Zn\,(s)/Zn^{2+}\,(1mol\cdot dm^{-3})//Cu^{2+}\,(1mol\cdot dm^{-3})\,Cu\,(s)$$
$$\text{25°C} \qquad\qquad\qquad \text{25°C}$$

CONCEPT EXPLANATION AND CLARIFICATION: THE REDOX PROCESSES TAKING PLACE IN THE ELECTROLYTIC CELL. (DIRECT ELECTRON TRANSFER)

As mentioned earlier, the electrolytic cell is a non-spontaneous cell where electrical energy is converted into chemical energy i.e. an electric current is passed through an electrolyte solution and a chemical reaction is produced.

Consider the basic outline of an electrolytic cell illustrated below:

$$X^- \rightarrow X + e^-$$

$$M^+ + e^- \rightarrow M$$
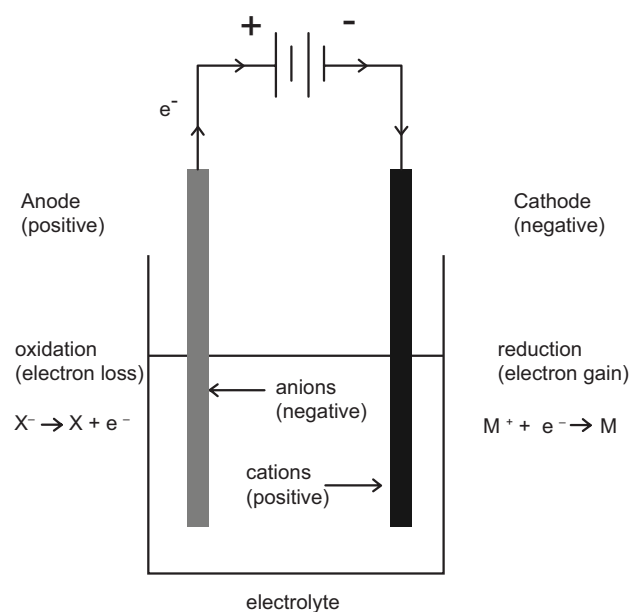
The cell consists of the following items.

- An energy supply in the form of an external power supply.
- Two inert electrodes that are placed together into the electrolyte.
- An electrolyte containing an solution of ions – either aqueous or molten.

In the electrolytic cell, electrical energy is converted into chemical energy. This conversion takes place when an electric current is passed through the electrolyte using a pair of electrodes identified as the cathode and the anode. Each electrode attracts ions which are oppositely charged to the charge on the electrode. Positive cations are attracted to the negative cathode and negative anions to the positive anode. It is at the surface of the electrode where the electrochemical reaction takes place involving the loss and gain of electrons (oxidation and reduction) and where the electrical energy is converted into chemical energy.

- The positive electrode attracts the negative anions towards it. Electrons are lost from the negative ions hence oxidation takes place at the positive electrode. This makes the positive electrode the ANODE. You will remember that oxidation always occurs at the anode (ANOX).
- The negative electrode attracts the positive cations towards it. Electrons are gained by the cations hence reduction takes place at the negative electrode. This makes the negative electrode the CATHODE. You will remember that reduction always occurs at the cathode (REDCAT).

Note: The polarities of the anode and cathode swap around compared to the galvanic cells. Even though this does happen, the electrochemical processes still remain the same at all times.

ANOX : **AN**ode = **OX**idation

REDCAT : **RED**uction = **CAT**hode

Electrolysis can take place in either aqueous solutions or "melts". Melts are molten ionic crystal lattices that will now release the ions held together by the strong electrostatic forces of attraction that exist with the lattice.

Now let's look at the TWO ways that electrolysis can take place:
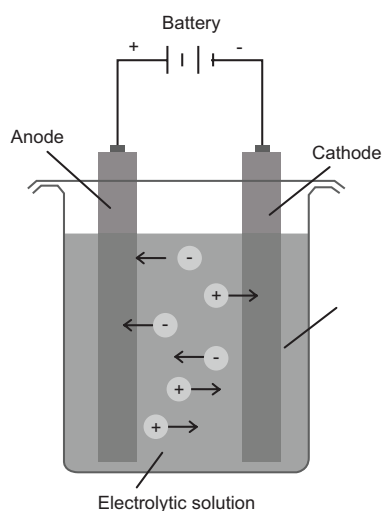
If we take an aqueous solution of copper chloride ($CuCl_2(aq)$) we will have the following ions in solution:

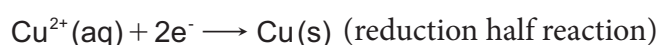$$CuCl_2(s) \longrightarrow Cu^{2+}(aq) + 2Cl^-(aq)$$
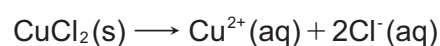
$Cl^-(aq)$ ions will be attracted to the ANODE.

$Cu^{2+}(aq)$ ions will be attracted to the CATHODE.

Let's now consider the electrochemistry at the electrodes. Firstly, consider the positions of the anions and cations on the Standard Redox Table. According to their positions on the Table 4B, the reaction is non-spontaneous – however, with the addition of electrical energy to the electrolyte, an electrochemical reaction occurs.

(Electrical energy is converted to chemical energy.)

$2Cl^-(aq) \longrightarrow Cl_2(g) + 2e^-$ (oxidation half reaction)

$Cu^{2+}(aq) + 2e^- \longrightarrow Cu(s)$ (reduction half reaction)

$2Cl^-(aq) + Cu^{2+}(aq) \longrightarrow Cl_2(g) + Cu(s)$ (net electrochemical reaction)

Thus, at the ANODE, chlorine gas will bubble off whilst at the CATHODE, copper metal will coat the electrode (electroplate).

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 important concepts of electrochemistry.

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 questions and answer them correctly in their workbooks.

1. Name the REDOX processes that take place in an electrochemical cell and explain what each of these processes represent.

 Solution:

 Oxidation and reduction.

 Oxidation is the process where electrons are lost in the reaction.

 Reduction is the process where electrons are gained in the reaction.

2. What are the standard conditions that an electrochemical cell must operate under?

 Solution:

 Concentration of electrolyte is 1 mol·dm^{-3}.

 Temperature is 25°C.

 If a gas electrode is used, then gas pressure must be 1 atmosphere.

3. Explain what is meant by the anode and the cathode in an electrochemical cell.

 Solution:

 The anode is the electrode where oxidation takes place.

 The cathode is the electrode where reduction takes place.

4. What is the simple way of remembering which electrochemical processes happen at which electrode in an electrochemical cell?

 Solution:

 Anode: ANOX standing for oxidation at the anode.

 Cathode: REDCAT standing for reduction at the cathode.

5. Explain what is meant by the term 'salt bridge'.

Solution:

The salt bridge is that piece of apparatus that joins the two half-cells together in a galvanic cell and is filled with an electrolyte, it completes the circuit and maintains half-cell neutrality.

6. A salt bridge is filled with an electrolytic solution that contains metal ions of very weak oxidising ability. Explain why this is done.

Solution:

The electrolyte in the salt bridge must not react with the electrolyte in either of the half-cells as this will affect the transfer of electrons. Thus an electrolyte containing a very weak oxidising agent must be used so that the metal cation will not be reduced at any stage. The electrolyte will only function to provide half-cell connectivity as well as assisting in maintaining half-cell neutrality.

7. Name two chemical substances that would be suitable to use as electrolytes in a salt bridge.

Solution:

Sodium nitrate ($NaNO_3$) or potassium nitrate (KNO_3) where the Na^+ and K^+ cations are very weak oxidising agents. Please note: Nitrates are used as all nitrates are soluble in water.

CHALLENGE LEVEL QUESTIONS

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

b. These questions require learners to think critically.

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 questions and answer them correctly in their workbooks.

KEY TEACHING:

a. In these more challenging examples, learners will be exposed to more thinking type questions which will involve multilevel thinking skills and explanations.

b. Leaners must read the questions carefully and make sure that they identify the specific parts of the question that require more detailed answers.

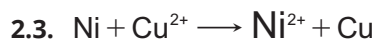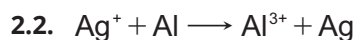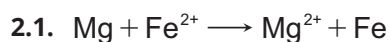1. Consider the following half reactions taken form the table of half reactions:

$$Al^{3+} + 3e^- \rightleftharpoons Al$$

$$Ni^{2+} + 2e^- \rightleftharpoons Ni$$

1.1. In the construction of a galvanic cell, which metal will be the stronger reducing agent? Explain your answer.

1.2. Ni^{2+} is considered to be a stronger oxidising agent than Al^{3+}. Explain your answer.

1.3. Which metal will act as the anode and which metal will act as the cathode? Explain your answer.

1.4. Write down the half reactions that occur at the anode and at the cathode.

1.5. Write down the net cell reaction for this galvanic cell.

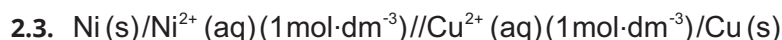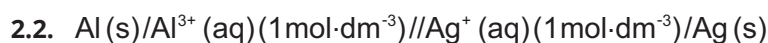**1.6.** Write down the cell notation for the galvanic cell under standard conditions.

Solution:

1.1. Aluminium(Al). Al is higher on the right hand side of the Table of Half Reactions (4B) which makes it a stronger reducing agent. This means that Al will undergo oxidation more easily that nickel (Ni) and thus will make the Al electrode the anode in the galvanic cell.

1.2. Ni^{2+} is lower on the left hand side of the Table of Half Reactions (4B) compared to Al^{3+} which makes it a stronger oxidising agent. This means that Ni^{2+} will be more easily reduced compared to Al^{3+} and thus the Ni electrode will act as the cathode in the galvanic cell.

1.3. Anode = Al
Cathode = Ni

1.4. Anode: oxidation $Al \longrightarrow Al^{3+} + 3e^-$
Cathode: reduction $Ni^{2+} + 2e^- \longrightarrow Ni$

1.5. $2Al + 3Ni^{2+} \longrightarrow 2Al^{3+} + 3Ni$

1.6. $Al\,(s)/Al^{3+}\,(aq)(1\,mol\cdot dm^{-3})//Ni^{2+}\,(aq)(1\,mol\cdot dm^{-3})/Ni\,(s)$ at 25°C

2. Write cell notations to represent the following net cell reactions of different galvanic cells under standard conditions.

2.1. $Mg + Fe^{2+} \longrightarrow Mg^{2+} + Fe$

2.2. $Ag^+ + Al \longrightarrow Al^{3+} + Ag$

2.3. $Ni + Cu^{2+} \longrightarrow Ni^{2+} + Cu$

Solution:

2.1. $Mg(s)/Mg^{2+}(aq)(1 mol \cdot dm^{-3})//Fe^{2+}(aq)(1 mol \cdot dm^{-3})/Fe(s)$

2.2. $Al(s)/Al^{3+}(aq)(1 mol \cdot dm^{-3})//Ag^+(aq)(1 mol \cdot dm^{-3})/Ag(s)$

2.3. $Ni(s)/Ni^{2+}(aq)(1 mol \cdot dm^{-3})//Cu^{2+}(aq)(1 mol \cdot dm^{-3})/Cu(s)$

3. Consider the electrolysis of an aqueous solution of silver bromide.

3.1. Write down the dissociation equation for silver bromide.

3.2. Which ions will be attracted to the anode and the cathode in the cell?

3.3. What will you observe happening at each electrode?

3.4. Write down the half reactions occurring at each electrode.

3.5. Write down the net cell reaction.

Solution:

3.1. $AgBr(s) \longrightarrow Ag^+(aq) + Br^-(aq)$
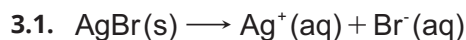
3.2. Anode: $Br^-(aq)$
Cathode: $Ag^+(aq)$

3.3. At the anode: Br_2 liquid will be formed as the Br^- will be oxidised
At the cathode: Ag metal will be formed and will coat the electrode as the Ag^+ is reduced.

3.4. Anode: $2Br^- \longrightarrow Br_2 + 2e^-$
Cathode: $Ag^+ + e^- \longrightarrow Ag$

3.5. $2Br^- + 2Ag^+ \longrightarrow Br_2 + 2Ag$

CHECKPOINT

At this point in the topic, learners should be able to:
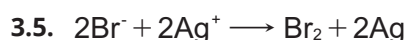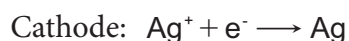
1. understand the REDOX processes that take place in a galvanic cell.

2. understand the REDOX processes taking place in the electrolytic cell.

3. understand the function of the salt bridge in a galvanic cell.

4. write cell notation to represent a galvanic cell.

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

Resource Pack: Topic 13: Electrochemical Reactions: Worksheet: Questions 4–8. (Pages 44–45).

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.

3. RELATION OF CURRENT AND POTENTIAL TO RATE AND EQUILIBRIUM

INTRODUCTION

When an electrochemical cell is in operation, learners will be shown the relationship between the amount of current in the cell and the rate of the chemical reactions that take place within the cell. They will also look at how the spontaneous cell reaction in the galvanic cell is a reversible reaction and how, as it approaches equilibrium, the cell potential is affected. In the last part of this topic, learners will be exposed to the effect of change in the concentration of the ions in solution and how le Chatelier's Principle is applied under these conditions. Learners will also see that once equilibrium is reached within the galvanic cell, that the cell is termed to be "flat" and the cell emf will thus be zero.

CONCEPT EXPLANATION AND CLARIFICATION: THE RELATIONSHIP BETWEEN CURRENT IN AN ELECTROCHEMICAL CELL AND RATE OF REACTION

Explain to the learners that in both the galvanic as well as electrolytic cells, the current in the cell has a direct relationship on the functioning chemistry within the cells and vice versa.

In the galvanic cell:

Under standard conditions, the cell has a maximum cell emf (E°_{cell}) based on the standard electrode potentials of the half-cells that form the galvanic cell. The question that now arises is whether the cell is able to maintain this potential difference throughout its period of functioning? In any galvanic cell, it is seen that with continuous use, the magnitude of the cell emf decreases the longer the cell functions which means that the magnitude of the current within the cell will also decrease as current is directly proportional to potential difference. (Remind the learners about Ohm's law which they learned about in physics).

What will cause this decrease in current? This is directly related to the rate at which the oxidation and reduction processes take place at each of the electrodes. If the rate of reaction decreases at each electrode, then the rate of electron transfer will also decrease thus there will be less current in the cell. Thus, explain to the learners that this means that current in the circuit is directly proportional to the rate at which oxidation and reduction reactions take place.

In the electrolytic cell:

It is important for the learners to remember that this cell has an energy source and that the magnitude of current is determined by the potential difference supplied by the energy source. The greater the potential difference that is provided by the electrical source, the greater or stronger will be the current produced. The stronger current will thus allow an increase in the rate of the reactions that take place at the electrodes. This means that the rate of oxidation at the anode as well as the rate of reduction at the cathode will both increase and both reaction products produced at either electrode will be produced faster. In other words, the greater the current in an electrolytic cell, the greater the rate of reaction that takes place at the electrodes.

Now conclude with the learners that it can be seen that for both the galvanic as well as the electrolytic cells, there exists a directly proportional relationship between current and the rate of reaction in an electrochemical cell.

CONCEPT EXPLANATION AND CLARIFICATION: POTENTIAL DIFFERENCE AND CELL EQUILIBRIUM

This can be a very confusing relationship for the learners to understand. Take time to explain these concepts clearly and carefully.

Firstly, it is important for the learners to note that even though we indicate all the electrochemical reactions with a single arrow, by nature all these reactions are reversible. Thus under isolated conditions, these reactions can reach equilibrium.

Once the learners understand that, then explain to them that the value of the cell potential is at a maximum when the cell has just been connected and no reversible reactions have yet taken place. Over a period of time, when the cell is functioning, the effects of the reverse reaction become more significant. Consider the following example within a copper-zinc galvanic cell.

In the beginning the standard cell potential for this cell is 1,10 V which is its maximum. This means that the net cell reaction can be written as:

$$Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Cu(s)$$
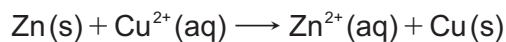
As the cell functions, the rate of the reverse reactions of each process starts to become significant which means that Zn^{2+} ions start to become reduced back to Zn and Cu starts to become oxidised back to Cu^{2+} as indicated below. This will cause the cell emf to start to decrease.

$$Zn(s) + Cu^{2+}(aq) \rightleftharpoons Zn^{2+}(aq) + Cu(s)$$
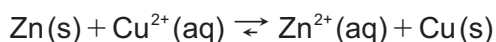
A point will thus be established when the rate of the forward reactions will become the same as the rate of the reverse reactions. At this point there will be a state of dynamic chemical equilibrium which means that the exchange of electrons in the forward reaction will take place equally as fast as in the reverse reaction causing a complete drop in cell potential in the system. There will be a zero net exchange of electrons.

$$Zn(s) + Cu^{2+}(aq) \rightleftharpoons Zn^{2+}(aq) + Cu(s)$$
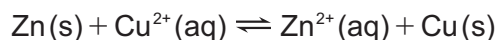
This means that the emf of the cell will now be equal to zero.

Conclude with the learners that a galvanic cell will become "flat" when a state of dynamic equilibrium exists between the forward and reverse REDOX reactions and that there is a zero net loss or gain of electrons taking place within the half-cells.

CONCEPT EXPLANATION AND CLARIFICATION: USING lE CHATELIER'S PRINCIPLE TO EXPLAIN THE RELATIONSHIP BETWEEN CONCENTRATION OF IONS IN SOLUTION AND CELL EQUILIBRIUM

Once again, take time to explain this concept to the learners as this is an important application of principles of chemical equilibrium to electrochemistry.

Use the example of the Cu-Zn galvanic cell once again.

$$Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Cu(s)$$
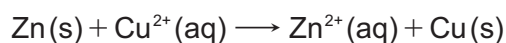
When the cell is functioning, the concentration of Cu^{2+} ions will decrease in the reactants while the concentration of Zn^{2+} ions in the products will increase. This causes a disturbance in the system and according to le Chatelier's Principle, the equilibrium position will change to reduce or minimise the effect of the changing concentrations and remove the disturbance. Thus the reverse reaction will be favoured to increase the Cu^{2+} concentration

in the reactants as well as to reduce the Zn^{2+} concentration in the products until equilibrium is established in the system.

Explain to the learners that dynamic equilibrium is now established and the rate of the forward reaction will be equal to the rate of the reverse reaction within the cell and thus the cell potential (V_{cell}) will be zero as there is no net transfer of electrons in the cell and the cell is "flat".

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 concepts.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the question to the learners as you complete it on the chalkboard.
- Learners must copy down the questions and answer them correctly in their workbooks.

---

1. In a galvanic cell, if the potential difference in the cell is at a maximum, what can you conclude about the magnitude of the current in the cell? Explain your answer.

   Solution:

   The current in the cell will be at a maximum, as current is directly proportional to potential difference as per Ohm's law (V α I).

2. How does the magnitude of the current in the cell affect the rate of reaction of the electrochemical processes in the cell?

   Solution:

   In a galvanic cell, the current is determined by the rate of oxidation and reduction taking place at the electrodes, thus the greater the rate of reaction, the higher the current. (Current is directly proportional to rate of reaction).

   In an electrolytic cell, the rate of oxidation and reduction at the electrodes is dependent on the magnitude of the electric current in the circuit. (Rate of reaction is directly proportional to the current).

3. Under what conditions will a galvanic cell become "flat" and the potential difference in that cell will be 0 V?

Solution:

A galvanic cell will become flat when $E^\circ_{cell} = 0,00\,V$. This means that a state of dynamic equilibrium exists in the cell where the rate of the forward reaction is equal to the rate of the reverse/back reaction. There is thus no net exchange of electrons in the cell and the cell potential difference is zero.

4. State le Chatelier's Principle.

Solution:

A change in any of the factors that determine equilibrium conditions of a system will cause the system to change in such a manner as to reduce or counteract the effect of the change.

5. Consider the following net cell reaction:

$$Mg + 2Ag^+ \longrightarrow Mg^{2+} + 2Ag$$
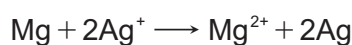
5.1. When a galvanic cell is functioning, what happens to the concentration of the Ag^+ and Mg^{2+} within the cell?

5.2. Using le Chatelier's Principle, explain what happens to the concentration of the ions as the cell continues to function.

5.3. What will eventually happen to the cell in terms of dynamic chemical equilibrium and how this will affect the magnitude of the cell potential within the cell?

Solution:

5.1. The concentration of the Ag^+ ions will decrease and the concentration of the Mg^{2+} ions will increase.

5.2. According to le Chatelier's Principle, an decrease in concentration of reactant ions and an increase in concentration of product ions will cause the reverse/back reaction to be favoured. This means that the concentration of Ag^+ will increase and the concentration of Mg^{2+} ions will decrease to establish equilibrium. Once this is established, the concentrations of both ions will remain constant.

5.3. Dynamic equilibrium will eventually be established in the system and this will cause the cell potential to equal zero. This is when the cell becomes "flat".

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 / 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 the learners copy down the questions and answer them correctly in their workbooks.

1. A zinc-silver cell has a potential difference of 1,56 V under standard conditions. The cell is allowed to run for 3 hours and the potential difference drops to 1,45 V. Use le Chatelier's Principle to explain why this happens.

   Solution:

   As the cell functions, the concentration of reactant ions (silver ions) decreases and the concentration of product ions (zinc ions) increases. According to le Chatelier's Principle, the reverse reaction will be favoured to favour the back reaction to compensate for the change in concentrations of the reactant and product ions. This will result in a decrease in the cell potential as the cell will be approaching dynamic chemical equilibrium.

2. Explain what will happen to the current flowing through the above galvanic cell as a result of allowing the cell to run for that length of time.

   Solution:

   As the cell potential decreases, so will the current in the circuit because V α I.

3. After several days, the cell potential reads 0,00 V. Explain, using le Chatelier's Principle, why this occurs.

   Solution:

   As the cell operates, so the concentration of the reactant ions decreases and concentration of the product ions increases. According to le Chatelier's Principle, the system responds to counteract this change, thus the rate of the reverse reaction will

increase. After a certain amount of time, the rate of the forward reaction will equal the rate of the reverse reaction thus establishing dynamic chemical equilibrium. When this is established, the potential difference of the cell will equal zero which means that there will be no current and hence the cell will be "flat".

CHECKPOINT

At this point in the topic, learners should be able to:

1. understand the relationship between current in an electrochemical cell and rate of reaction.

2. relate cell potential difference and dynamic chemical equilibrium within a cell.

3. use le Chatelier's Principle to explain the relationship between concentration of ions in solution and the cell equilibrium.

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

Resource Pack: Topic 13: Electrochemical Reactions Worksheet: Question 11. (Page 47).

- 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.

TOPIC 13

4. STANDARD ELECTRODE POTENTIALS AND THE WRITING OF EQUATIONS REPRESENTING THE REDOX REACTIONS WITHIN AN ELECTROCHEMICAL CELL

INTRODUCTION

In this topic, learners will be taught the concept of the standard electrode potential and how the standard electrode potential is determined for each substance by using the standard hydrogen half-cell. They will also be taught how these standard electrode potentials are used to calculate the cell emf of a standard galvanic cell and the significance of why the cell emf must be a positive value. Learners will also be able to predict which half-cell undergoes oxidation and which undergoes reduction based on the values of the standard electrode potential and then use these REDOX reactions to write an overall or net cell reaction by combining the two half reactions. Learners will also be taught, using half reactions, the

electrolytic processes of the decomposition of copper chloride and electroplating as well as the refining of pure copper from the sample of impure copper ore.

CONCEPT EXPLANATION AND CLARIFICATION: STANDARD ELECTRODE POTENTIALS

Explain to the learners that what they have been able to do is to use the Table of Half reactions to accurately predict which electrode will undergo oxidation and which will undergo reduction; that is, they have been able to predict the anode and the cathode in an electrochemical cell.

They have also learned that when a voltmeter is connected across the terminals of the anode and cathode of a galvanic cell, that there is a potential difference that exists between the two half-cells. This potential difference of a galvanic cell depends on the metals that are used as electrodes in each half-cell.

Now tell the learners that this is called the cell potential difference or cell potential which has the symbol $E°_{cell}$. It can be measured by looking at the difference between the standard electrode potentials of the two half-cells in the galvanic cell. Learners must note that it is the existence of this cell potential that causes electrons to flow between the two electrodes in the external circuit from anode to cathode. Each half-cell has its own characteristic standard electrode potential for this cell potential difference to exist. These standard electrode potentials, given the symbol $E°$ and pronounced as "E nought", are values measured using a reference electrode. The standard electrode is the hydrogen gas electrode operating under standard conditions.

Explain to the learners that we use the term "standard" because the half-cell potentials are always measured under the standard conditions:

- temperature of 25°C (298K).
- concentration of electrolyte in the half-cells must be 1 mol·dm^{-3}.
- if a gas electrode is used, then the gas pressure must be 101,3 kPa of pressure (1 atmosphere).

CONCEPT EXPLANATION AND CLARIFICATION: THE STANDARD HYDROGEN ELECTRODE AND MEASURING STANDARD ELECTRODE POTENTIALS

The standard hydrogen electrode is used as the reference electrode. This means that when it is connected up to another half-cell, the potential of the other half-cell is relative to that of the hydrogen electrode. This means that the hydrogen electrode is assigned a reference potential of 0,00 V.
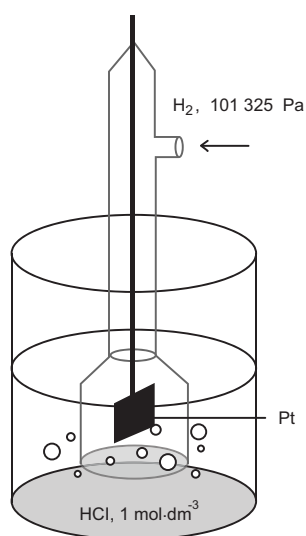
Draw the diagram of the standard hydrogen electrode as shown alongside for the learners. Explain that the half-cell consists of a platinum electrode placed into an acid solution which acts as the electrolyte. This is usually dilute 1 mol·dm^{-3} hydrochloric acid as it is a strong acid solution which provides a high concentration of H_3O^+ (H^+) ions in solution. Hydrogen gas is bubbled into the electrolyte in the half-cell under standard atmospheric pressure. Explain to the learners that platinum is used as the electrode as platinum is very unreactive and will provide a surface for the hydrogen gas to exchange electrons as it flows over the platinum surface.

This will set up a half-reaction equilibrium: $2H^+(aq) + 2e^- \rightleftharpoons H_2(g)$.

This shows that the gas can be oxidised to H^+ ions or H^+ ions reduced to H_2 gas at the surface of the platinum metal.

Show the learners that the cell notation for the standard hydrogen electrode is given as the following $H_2(1atm)Pt(s)/H^+(1 \text{ mol·dm}^{-3})$:

- Here the pressure of the gas is indicated as 1 atmosphere (1 atm).
- The inert platinum (Pt(s)) indicated is where the H_2 gas makes contact with the electrode when bubbled through.
- The concentration of the acidic electrolyte containing H^+ ions is 1 mol·dm^{-3}.
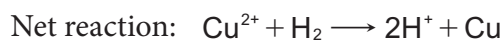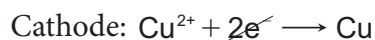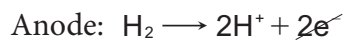
Explain to the learners that to measure the standard electrode potential of a half-cell, the half-cell is now connected to the standard hydrogen electrode.
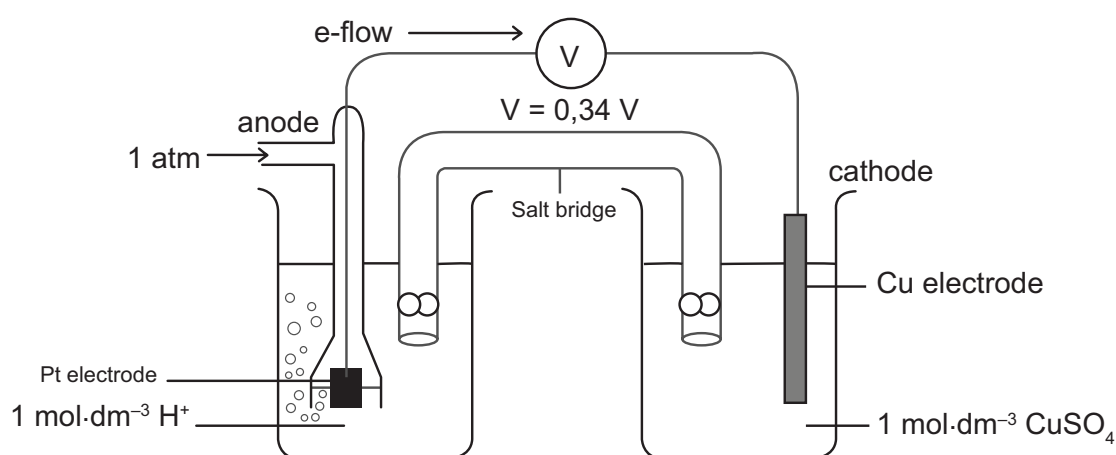
Use the above diagram for the learners to understand how the standard electrode potential is measured. When the copper half-cell is connected, the voltmeter reading will read

+0,34 V. Because the hydrogen electrode is given a reference potential of 0,00 V, the value of 0,34 V for copper is now called the standard cell potential for copper. That is, the E^o value for copper is 0,34 V. Hence: $Cu^{2+} + 2e^- \rightleftharpoons Cu$ $E^o = +0,34 \, V$

Now show the learners the full REDOX reaction:

Anode: $H_2 \longrightarrow 2H^+ + 2e^-$

Cathode: $Cu^{2+} + 2e^- \longrightarrow Cu$

Net reaction: $Cu^{2+} + H_2 \longrightarrow 2H^+ + Cu$

The reading on the voltmeter will be the half-cell potential (E^o). The sign, either positive or negative, is determined by whether oxidation or reduction occurs in the other half-cell with respect to the standard hydrogen electrode. Should the metal electrode whose half-cell potential is being determined, happens to be a stronger reducing agent than the hydrogen electrode, it will favour oxidation and will thus act as the anode. This will give it a negative half-cell potential. Should the metal electrode whose half-cell potential is being determined, happen to be a weaker reducing agent than hydrogen, it will favour reduction and will thus act as the cathode. This will give it a positive half-cell potential.

It's important for the learners to be able to write the cell notation of the electrochemical cell when the standard hydrogen electrode is used to determine the half-cell potential. Explain to the learners that, by convention, one always places the standard hydrogen electrode as the anode of the cell, even though it may be acting as a cathode. It is only under these circumstances that this is done and never anywhere else. Consider the following examples to measure standard electrode potentials:

Copper electrode potential: The standard electrode potential is +0,34 V. Here the standard hydrogen electrode will be the anode and the cell notation will be:

$$H_2(1atm)Pt(s)/H^+(1mol \cdot dm^{-3})//Cu^{2+}(1mol \cdot dm^{-3})/Cu(s)$$

Zinc electrode potential: The standard electrode potential for Zn is -0,76 V. Here the standard hydrogen electrode is acting as the cathode, however, we still write it in the position of the anode so that the negative sign is obtained. Thus the cell notation will be:

$$H_2(1atm)Pt(s)/H^+(1mol \cdot dm^{-3})//Zn^{2+}(1mol \cdot dm^{-3})/Zn(s)$$

Now that the learners understand how a standard electrode potential is determined, explain to them that these potentials are known as Reduction Potentials. This simply means that because the standard hydrogen electrode is always indicated as the anode, the other attached electrode will always be seen as the cathode, and this is where reduction occurs (REDCAT). Hence the name reduction potential, and hence the formation of the Table of Standard Reduction Potentials. Remind the learners that this table is always given to them in an examination and places in order the substance with the most negative standard reduction potential at the top of the table to the substance with the most positive standard reduction potential at the bottom of the table. In other words, the strongest reducing agent has the most negative standard reduction potential and the weakest reducing agent

has the most positive standard reduction potential. Give each learner a copy of the Table of Standard Reduction Potentials (4B) and show them how the table shows decreasing standard reduction potentials from lithium as the strongest reducing agent,

$$Li^+ + e^- \rightleftharpoons Li \qquad E^o = -3,05 \, V$$

to fluoride at the bottom of the table as the weakest reducing agent.

$$F_2 + 2e^- \rightleftharpoons 2F^- \qquad E^o = +2,87 \, V$$
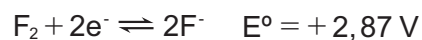
This can be summarised in the following way:

- The magnitude of the E^o value indicates how easy it is for a substance to undergo oxidation or reduction
- The more negative the E^o value, the greater the tendency to undergo oxidation.
- The less negative (more positive) the E^o value, the greater the tendency to undergo reduction.

CONCEPT EXPLANATION AND CLARIFICATION: USING THE TABLE OF STANDARD REDUCTION POTENTIALS TO DETERMINE THE emf OF THE STANDARD GALVANIC CELL

The galvanic cell makes uses of a REDOX electrochemical reaction to convert chemical energy into electrical energy. This electrical energy can be determined by calculating the cell potential of the cell, or what is known as the cell emf and given by the symbol E^o_{cell}.

It is calculated by subtracting the standard reduction potential of the anode from the standard reduction potential of the cathode according to the following equation:

$$E^o_{cell} = E^o_{cathode} - E^o_{anode}$$

Thus for a Cu-Zn galvanic cell, the emf of the cell under standard conditions, will be:

$$E^o_{cell} = E^o_{cathode} - E^o_{anode}$$

$$E^o_{cell} = +0,34 - (-0,76)$$

$$E^o_{cell} = +1,10 \, V$$

It is very important to note that the E^o_{cell} value is positive which means that it will be a spontaneous electrochemical reaction under standard conditions. If the E^o_{cell} value is calculated to be a negative value, then the reaction is non-spontaneous and will need electrical energy to proceed. In other words, this will now become an electrolytic cell.

CONCEPT EXPLANATION AND CLARIFICATION: WRITING EQUATIONS REPRESENTING REDOX REACTIONS

At this point learners will have a good understanding of the concept of standard electrode potentials and their importance. Once again, remind the learners that they are a measure of the ability of a particular substance to gain or lose electrons in a REDOX reaction.

These standard electrode potentials can thus be used to predict which half-cell in a galvanic cell will be able to undergo oxidation and which half-cell will be able to undergo reduction. Use the example of a copper–silver galvanic cell and explain to the learners that this can be done by following some very simple steps:

1. Identify the reactants in both half-cells on the Table of Standard Reduction Potentials (4B).

2. Write down the half reactions exactly as they stand on the Table in their exact order as they appear on the Table. Indicate the standard electrode potentials as well.

$$Cu^{2+} + 2e^- \rightleftharpoons Cu \qquad E^o = +0,34 \text{ V}$$
$$Ag^+ + e^- \rightleftharpoons Ag \qquad E^o = +0,80 \text{ V}$$

3. Now allow the learners to look at the E^o values. Help them to identify that the E^o value for the Cu half reaction is less positive than that of the Ag half reaction. This means that Cu is a stronger reducing agent than Ag and thus Cu will undergo oxidation more easily than the Ag.

4. Conclude with the learners that the Cu half-cell will be the anode where oxidation occurs which means that the Ag half-cell must be the cathode where reduction occurs.

5. Now write the oxidation and reduction half reactions based on this deduction:

$$\text{Oxidation:} \quad Cu \longrightarrow Cu^{2+} + 2e^-$$
$$\text{Reduction:} \quad Ag^+ + e^- \longrightarrow Ag$$

6. Check to see that the electrons are balanced. In this case, Cu loses $2e^-$ whereas Ag^+ only gains $1e^-$. Thus, show the learners that they must now multiply the Ag^+ half reaction through by a factor of 2 to allow for the electrons to be balanced:

$$\text{Oxidation:} \quad Cu \longrightarrow Cu^{2+} + 2e^-$$
$$\text{Reduction:} \quad 2Ag^+ + 2e^- \longrightarrow 2Ag$$
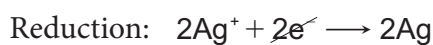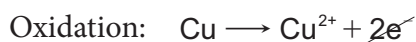
7. Now write the net overall cell reaction by combining the two half reactions together:

$$\text{Net reaction:} \quad Cu + 2Ag^+ \longrightarrow Cu^{2+} + 2Ag$$

CONCEPT EXPLANATION AND CLARIFICATION: DESCRIBING THE DECOMPOSITION OF COPPER CHLORIDE IN AN ELECTROLYTIC CELL USING THE HALF REACTIONS

Once again, remind the learners that an electrolytic cell is where electrolysis takes place and where electrical energy is converted into chemical energy. The electrolytic cell consists of a single cell where two non-reactive electrodes, normally graphite, are dipped into an electrolytic solution. An electric current is allowed to pass through the electrolyte. This causes the ions in the electrolyte to move to either the positive or negative electrode. Remind the learners:

- Oxidation occurs at the anode (positive electrode) ANOX.
- Reduction occurs at the cathode (negative electrode)   REDCAT.

In the decomposition of copper chloride, explain to the learners that the electrolyte contain copper cations and chloride anions.

$$CuCl_2 \longrightarrow Cu^{2+} + 2Cl^-$$
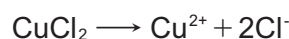
This means Cl^- ions will be attracted to the positive electrode (anode) where oxidation will take place, and Cu^{2+} will be attracted to the negative electrode (cathode) where reduction will take place. Allow the learners to write down these two processes by identifying the half reactions from the Table of Standard Electrode Potentials:

Oxidation: $2Cl^- \longrightarrow Cl_2 + 2e^-$

Reduction: $Cu^{2+} + 2e^- \longrightarrow Cu$

Check to see that the electrons are balanced and then write down the net cell reaction:

$$Cu^{2+} + 2Cl^- \longrightarrow Cl_2 + Cu$$

Now calculate the cell potential (E^o_{cell}) for the reaction:

$$E^o_{cell} = E^o_{cathode} - E^o_{anode}$$
$$= +0,34 - (+1,36)$$
$$E^o_{cell} = -1,02 \text{ V}$$

It can be clearly seen that the negative E^o_{cell} value shows that the cell is non spontaneous. Explain to the learners once again that the cell will only function if energy is thus supplied to it in the form of electrical energy.
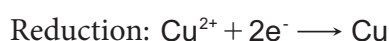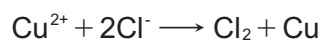
CONCEPT EXPLANATION AND CLARIFICATION: DESCRIBING THE ELECTROLYTIC PROCESS OF ELECTROPLATING

Tell the learners that electroplating is the process of coating one metal with another metal by using the process of electrolysis. Generally more unreactive metals are used in this process and silver and copper are often used. As it is the metal that needs to be electroplated, this process will occur at the cathode of the electrolytic cell. Consider the example of the electroplating of a fork with silver metal.
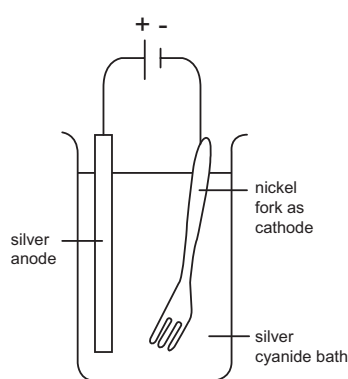
Here a fork is suspended in an electrolyte containing Ag^+ ions. The Ag^+ ions are attracted to the cathode where they are reduced to Ag metal which then coats the fork.

$$Ag^+ + e^- \rightleftharpoons Ag$$

Oxidation occurs at the anode. Here the anode is made out of pure silver which is oxidised.

$$Ag \rightleftharpoons Ag^+ + e^-$$

Once again, the two processes occur simultaneously and Ag^+ ions are continuously added to the electrolyte.

CONCEPT EXPLANATION AND CLARIFICATION: DESCRIBING THE ELECTROREFINING OF IMPURE COPPER METAL

Explain to the learners that this electrolysis technique known as **electrorefining** is a purification process that happens in industry where impure copper is refined (purified) into pure copper and the impurities are removed. It is a similar technique to electroplating - the impure copper is placed at the anode of the cell while the pure copper is formed at the cathode of the cell. The electrolyte once again must contain the common metal ion of Cu^{2+}, thus copper sulphate ($CuSO_4$) is used.
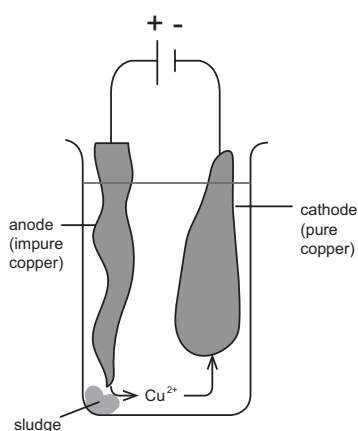
At the anode, the impure copper metal is oxidised to copper cations and the cations now go into solution as part of the electrolyte.

$$Cu \longrightarrow Cu^{2+} + 2e^-$$

The impurities that are not oxidised, fall to the bottom of the reaction vessel as a sludge which is then removed for further purification. (The sludge contains gold, platinum and/or silver and other valuable metals.)

At the cathode, copper cations in solution are reduced to copper metal which plates onto the electrode.

$$Cu^{2+} + 2e^- \longrightarrow Cu$$

Impurities such as Zn and Fe that may have been oxidised to Zn^{2+} and Fe^{2+} remain in solution as they are weaker oxidising agents than Cu^{2+} and will not be reduced:

$$Net\ reaction: \quad Cu + Cu^{2+} \longrightarrow Cu^{2+} + Cu$$

INTRODUCTORY LEVEL QUESTIONS

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

b. Their purpose is to familiarise the learners with the basic concepts in electrochemistry.

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 questions and answer them correctly in their workbooks.

---

1. Explain what is meant by the phrase "standard electrode potential of a substance"?

   Solution:

   A standard electrode potential is the potential difference of an electrode measured under standard conditions that indicates the electrode's relative ability, compared with the hydrogen electrode, to either gain or lose electrons in an electrochemical process.

2. What conditions must be obeyed when setting up the hydrogen electrode to measure standard half-cell potentials?

   Solution:

   The concentration of the electrolyte must be 1 mol·dm^{-3}, the temperature of the electrolyte must be 25°C and the hydrogen gas pressure must be 1 atmosphere.

3. What is the function of the platinum metal in the standard hydrogen electrode?

   Solution:

   The platinum is an inert metal which provides a surface to allow electron exchange to take place.

4. What is the reference potential for the standard hydrogen electrode and why is this value important?

   Solution:

   Reference potential is 0,00 V and is important in that it allows the electrode potential of other substances to be measured relative to this value. Thus the value obtained will be the standard electrode potential of that substance.

TOPIC 13

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5. Write down the cell notation for the standard hydrogen electrode.

Solution:

$Pt(s)/H_2(g)(1\,atm)/H^+(aq)(1\,mol \cdot dm^{-3})$
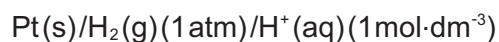
6. What is the meaning of the cell emf of a galvanic cell?

Solution:

The cell emf is the measure of the overall cell potential and indicates the amount of energy per unit charge that the cell contains due to the electrochemical reactions that are occurring within that cell.

7. Calculate the cell emf ($E^o{}_{cell}$) of a Ag-Fe galvanic cell.

Solution:

$E^o{}_{cell} = E^o{}_{cathode} - E^o{}_{anode}$

Fe is is the stronger reducing agent thus will be oxidised, hence is the anode. This makes Ag the cathode.

$E^o{}_{cell} = +0,80 - (-0,44)$

$E^o{}_{cell} = +1,24\ V$

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 / 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 learners copy down the questions and answer them correctly in their workbooks.

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1. Calculate the cell potential (E^o_{cell}) for the following galvanic cells under standard conditions:

   1.1. An iron – zinc cell.

   1.2. A magnesium – copper cell.

   1.3. An aluminium – mercury cell.

   1.4. A chlorine – nickel cell.

   Solution:

   1.1. $E^o_{cell} = E^o_{cathode} - E^o_{anode}$ Zn = anode ; Fe = cathode

   $= -0,44 - (-0,76)$

   $E^o_{cell} = +0,32$ V

   1.2. $E^o_{cell} = E^o_{cathode} - E^o_{anode}$ Mg = anode ; Cu = cathode

   $= +0,34 - (-2,36)$

   $E^o_{cell} = +2,70$ V

   1.3. $E^o_{cell} = E^o_{cathode} - E^o_{anode}$ Al = anode ; Hg = cathode

   $= +0,85 - (-1,66)$

   $E^o_{cell} = +2,51$ V

   1.4. $E^o_{cell} = E^o_{cathode} \, E^o_{anode}$ Ni = anode ; Cl_2 = cathode

   $= +1,36 - (-0,27)$

   $E^o_{cell} = +1,63$ V

2. Determine the cell emf for the following galvanic cells under standard conditions:

   2.1. $Ca(s)/Ca(aq)(1\,mol \cdot dm^{-3})//Cu^{2+}(aq)(1\,mol \cdot dm^{-3})/Cu(s)$

   2.2. $Mn(s)/Mn^{2+}(aq)(1\,mol \cdot dm^{-3})//Pb^{2+}(aq)(1\,mol \cdot dm^{-3})/Pb(s)$

   2.3. $Fe(s)/Fe^{2+}(aq)(1\,mol \cdot dm^{-3})//Ag^+(aq)(1\,mol \cdot dm^{-3})/Ag(s)$

   Solution:

   2.1. $E^o_{cell} = E^o_{cathode} - E^o_{anode}$ Ca = anode ; Cu = cathode

   $= +0,34 - (-2,87)$

   $E^o_{cell} = +3,21$ V

   2.2. $E^o_{cell} = E^o_{cathode} - E^o_{anode}$ Mn = anode ; Pb = cathode

   $= -0,13 - (-1,18)$

   $E^o_{cell} = +1,05$ V

   2.3. $E^o_{cell} = E^o_{cathode} - E^o_{anode}$ Fe = anode ; Ag = cathode

   $c = +0,80 - (-0,44)$

   $E^o_{cell} = 1,24$ V

3. The standard electrode potential (E°) for nickel is determined under standard conditions to be −0,25 V while that of copper is determined to be + 0.34 V using the standard hydrogen electrode as the reference electrode.

   3.1. What is meant by the term "reference electrode"?

   3.2. What is the cell potential of the reference electrode?

   3.3. What are the standard conditions for the standard hydrogen electrode?

   3.4. Explain why the E° values of nickel and copper will be negative and positive respectively when these half-cells are connected to the standard hydrogen electrode.

   3.5. Write down the cell notation notations for each of the cells (nickel and copper) when connected to the standard hydrogen electrode.

Solution:

3.1. This is the electrode that is used to compare the standard electrode potential to the other electrode. The reference electrode is always assigned a value of 0,00 V which then means that the value of the potential difference of the galvanic cell will be the standard electrode potential of the other electrode.

3.2. 0,00 V

3.3. Concentration of electrolyte = 1 mol·dm^{-3}

Temperature of electrolyte = 25°C

Pressure of H_2 gas = 1 atmosphere or 101,3 kPa

3.4. When these half-cells are connected to the standard hydrogen electrode, a negative electrode potential indicates that this half-cell is the anode. This means that the metal, Ni, will be a stronger reducing agent compared to H_2 and will thus be oxidised allowing H_2 to be reduced.
 The positive electrode potential of Cu indicates that Cu is a weaker reducing agent than H_2 which means that H_2 will be oxidised.

3.5. Nickel : $(Pt(s))/H_2(g)(1\,atm)/H^+(aq)(1\,mol·dm^{-3})//Ni^{2+}(aq)(1\,mol·dm^{-3})/Ni(s)$

Copper: $(Pt(s))/H_2(g)(1\,atm)/H^+(aq)(1\,mol·dm^{-3})//Cu^{2+}(aq)(1\,mol·dm^{-3})/Cu(s)$

KEY TEACHING:

a. In these more challenging examples, learners will be exposed to more thinking type questions which will involve multilevel thinking skills and explanations.

b. Leaners must read the questions carefully and make sure that they identify the specific parts of the question that require more detailed answers.

CHECKPOINT

At this point in the topic, learners should have an understanding of :

1. the concept of standard electrode potentials.

2. the standard hydrogen electrode and how we use the standard hydrogen electrode to measure standard electrode potentials.

3. how to use the Table of Standard Reduction Potentials (4B) to determine the emf of a standard galvanic cell.

4. how to write equations representing REDOX reactions.

5. how to describe the decomposition of copper chloride in an electrolytic cell using half reactions.

6. how to describe the electrolytic process of electroplating.

7. how to describe the purification of impure copper metal using the technique of electrorefining.

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

Resource Pack: Topic 13: Electrochemical Reactions Worksheet: Questions 9–10. (Pages 45–46).

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.

TOPIC 13

5. OXIDATION NUMBERS AND APPLICATION OF OXIDATION NUMBERS

INTRODUCTION

Explain to the learners that the concept of oxidation numbers, also known as oxidation state, was covered in Grade 11. This is a very useful technique in electrochemistry as it provides a way of keeping track of the movement of electrons in a REDOX reaction. We are able to work out how many electrons are lost during the oxidation process as well as gained in the reduction process by simply looking at the change in oxidation number of a particular atom in a compound. Tell the learners that we will be speaking about the extent of "electron richness" or "electron deficiency" an atom has in a chemical compound.

Learners must be aware of the Oxidation Number rules that are covered in the topic to assist with identifying oxidation numbers.

CONCEPT EXPLANATION AND CLARIFICATION: OXIDATION NUMBERS AND THE APPLICATION OF OXIDATION NUMBERS

Begin this section by getting the learners to revise a few Grade 11 concepts with regards to electron arrangement in a molecular structure.   When a molecule is formed, the number of electrons present in the molecule depends entirely on the type of atoms bonded in the molecule. Consider the HCl molecule:
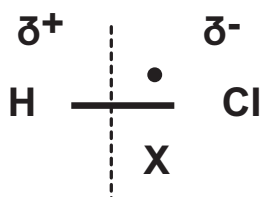
This molecule is easily recognisable from the Grade 11 section on molecular polarity where the concept of electronegativity was discussed in some detail. As can be seen, there is an asymmetric distribution of charge in the covalent bond – hence the molecule develops two distinct regions of charge, namely δ+ and δ-. Thus, the molecule is considered to be POLAR.

The Cl atom attracts the bonded pair of electrons much more strongly to itself compared to the H atom due to its higher electronegativity. This means that the Cl atom will be electron rich whilst the H atom will be electron deficient. This measure of *electron richness or deficiency* is what is termed OXIDATION NUMBER and this can now be indicated by assigning an oxidation number (ON) to each atom within a molecule.

> **Oxidation number:** This is a number that is used to describe how electron rich or electron deficient an atom is within a molecule.

Thus, if we look at the HCl example:

The Cl atom has pulled the bonding pair closer to itself and is 'richer' by 1 electron, thus it will now have ON = -1 .The H atom has had its 1 electron pulled away from itself and is thus 'deficient' by 1 electron, thus will now have ON = +1.

IMPORTANT NOTE: Negative oxidation numbers represent electrons pulled towards atoms; positive oxidation numbers represent electrons pulled away from atoms.

Example 1: Water – H_2O
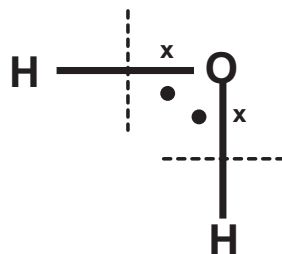
The O atom has pulled both bonding pairs towards itself as it has a higher electronegativity value than the H atoms, hence O has an ON = -2 as it has two extra electron pulled towards itself. Each H atom will now have an ON = +1 as each H atom has had 1 electron pulled away from itself.

Example 2 : Ammonia – NH_3
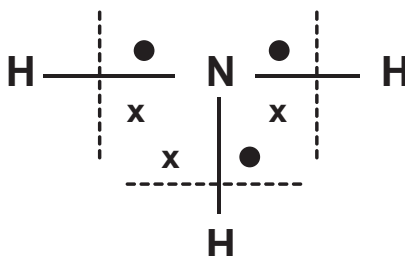
The N atom has pulled all three bonding pairs towards itself. Hence has an ON = −3.

Each H atom has 1 electron pulled away from itself, thus will have an ON = +1.

In summary … The value of the oxidation number of an atom in a molecule is equal to the number of electron pairs it attracts within a bond or the number of electron pairs that are pulled away from it.

Simple rules for determining oxidation numbers in a molecule

It is far quicker and easier to apply a few simple rules to determine the oxidation number of each atom in a molecule than to try and calculate it from a molecular diagram and electronegativity comparison. These rules are listed below.

TOPIC 13

Rules for determining oxidation numbers

- The oxidation state of an element that is not bonded is zero. This applies whatever the structure of the element – whether it is, for example, Xe or Cl_2 or S_8, or whether it has a giant structure like carbon or silicon.
- The sum of the oxidation states of all the atoms or ions in a neutral compound is zero.
- The sum of the oxidation states of all the atoms in an ion is equal to the charge on the ion.
- For an ion the oxidation number is equal to the charge on the ion e.g. for Cu^{2+} it is +2.
- Some elements almost always have the same oxidation states in their compounds:

ELEMENT	USUAL OXIDATION STATE	EXCEPTIONS
Group 1 metals	always +1	
Group 2 metals	always +2	
Oxygen	usually –2	Except in peroxides e.g. H_2O_2 where it is –1 and F_2O where it is +2
Hydrogen	usually +1	Except in metal hydrides where it is –1 e.g. NaH
Fluorine	always –1	
Chlorine	usually –1	Except in compounds with O or F

Now, the most important thing about these rules is that you do not have to rewrite them out, but rather to apply them to test your understanding about Oxidation Numbers. Let's look at a few simple worked examples.

Example 1: What is the oxidation number of S in H_2S?
- H_2S is a molecule and thus the total oxidation number = 0.
- Assign the oxidation numbers to each known atom in the molecule above the atom.
- H has as oxidation number of +1

    +1
    H_2S

but there are two hydrogen atoms giving a total of –2. S must have an oxidation number of –2.
i.e. (+2)+(−2) = 0 in order for the molecule to be neutral.

Example 2: What is the oxidation number of N in N_2O?
Oxygen has an ON of −2 therefore both nitrogen atoms together must have a charge of +2. Each nitrogen atom must then have an ON of +1.

Example 3: What is the oxidation number of Mn in KMnO$_4$ and MnO$_2$?

In MnO$_2$, each oxygen atom has an ON of −2, totalling −4, therefore manganese must have an ON of +4.

It is important to note that atoms of the same element can have different oxidation numbers as these atoms can be bonded differently in different substances. The worked example 3 shows this clearly where Mn has oxidation numbers of +7 and +4 respectively.

Why are Oxidation Numbers so valuable? They can very easily and conveniently be used to predict whether a particular chemical reaction is in fact an electrochemical (redox) reaction as well as show how many electrons were involved in the Redox processes. This is done by simply comparing oxidation numbers of all the chemical species in a chemical reaction. If the oxidation number changes for a particular atom, then there must have been a transfer of electrons – either electrons lost (oxidation) or electrons gained (reduction). Remember – both oxidation and reduction occur simultaneously, thus there has to be a change in the oxidation numbers of both chemical substances.

Consider the following chemical reaction:

$$Mg \ + \ HCl \longrightarrow MgCl_2 \ + \ H_2$$
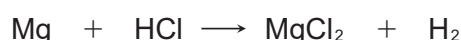
Step 1: Assign *Oxidation Numbers* to all the atoms in the chemical species involved in the reaction

$$\overset{0}{Mg} \ + \ \overset{+1\ -1}{HCl} \longrightarrow \overset{+2\ \ -1}{MgCl_2} \ + \ \overset{0}{H_2}$$
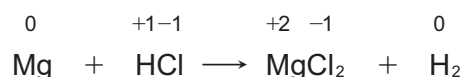
Step 2: Identify and link those atoms whose oxidation numbers have changed

$$\overset{0}{Mg} \ + \ \overset{+1\ -1}{HCl} \longrightarrow \overset{+2\ \ -1}{MgCl_2} \ + \ \overset{0}{H_2}$$

Step 3: Identify the electrochemical processes and quantify the number of electrons involved in each process

$$\overset{0}{Mg} \ + \ \overset{+1\ -1}{HCl} \longrightarrow \overset{+2\ \ -1}{MgCl_2} \ + \ \overset{0}{H_2}$$

Oxidation – loss of $2e^-$ Reduction – gain of $1e^-$
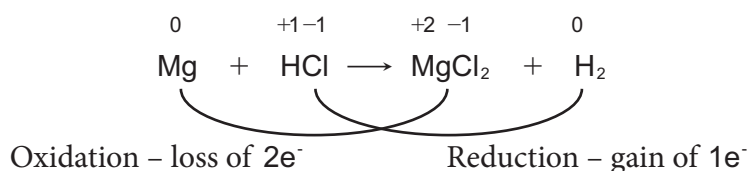
Cl$^-$ will be the spectator ion in this reaction as it does not change oxidation number.

Thus – from simply tracking the change in oxidation number, you can now write down the electrochemical half reactions:
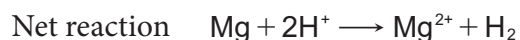
Oxidation : $Mg \longrightarrow Mg^{2+} + 2e^-$

Reduction : $H^+ + e^- \longrightarrow H_2$ (x2)

Net reaction $Mg + 2H^+ \longrightarrow Mg^{2+} + H_2$

CONCEPT EXPLANATION AND CLARIFICATION: THE PRODUCTION OF CHLORINE IN THE CHLOR-ALKALI INDUSTRY

This is a huge industry that forms a large part of the South African economy. It is a specialised industry that focuses on the production of chlorine gas (Chlor) and sodium hydroxide (Alkali) while hydrogen gas is produced as a by-product of the process. The Chlor-Alkali industry uses an electrolytic technique to produce these chemical products and the industry is acknowledged by the fact that there are several ways in which these products can be obtained. What is extremely important is that all these techniques use electrolysis to extract the products as well as using a solution known as **brine** as the starting material.

> **What is brine?** Brine is a highly concentrated solution of sodium chloride (NaCl). It provides a very large number of chloride ions (Cl^-) and sodium ions (Na^+) which are electrochemically reacted to produce chlorine gas (Cl_2) and sodium hydroxide (NaOH) as products.

The most popular electrochemical industrial method used in the Chlor-Alkali industry is the Membrane Cell which has replaced the other more outdated, expensive and environmentally hazardous apparatus that were used in previous years, namely the Diaphragm Cell and the Mercury Cell. We will now look at each of these cells in detail to compare and contrast their design and industrial impact on society.

1. The Membrane Cell

This is the newest of the Chlor-Alkali processes which relies on an **ion-exchange membrane** to separate the sodium and chloride ions of the sodium chloride solution. The ion-exchange membrane is a fluoropolymer which contains certain chemical groups attached to its main structure that allows it to be ion selective to certain positive ions (cations) in its exchange mechanism. This means that in the membrane cell, sodium ions (Na^+) are selectively transported through the membrane while other ions in solution are blocked or prevented from moving through.
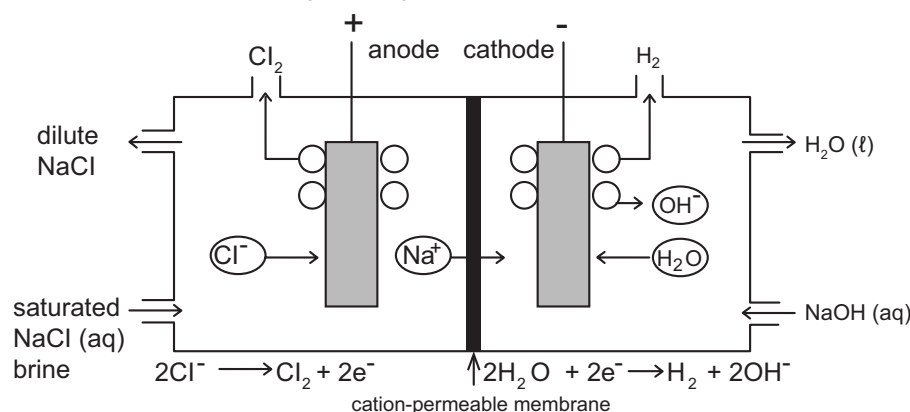
As can be seen in the diagram above, the cell consists of two half-cells or compartments separated from each other by the ion selective (ion exchange) membrane. The anodic compartment (+) is filled with the brine solution while the cathodic compartment (-) is filled with pure water. The membrane is placed midway between them only allowing the Na^+ ions present in the brine solution to permeate through it from the anodic to the cathodic compartments.

In the anodic compartment

Cl^- ions from the concentrated brine solution are attracted to the positively charged anode where oxidation of the ions takes place forming chlorine gas which then bubbles off from the electrode surface and is immediately extracted out of the anodic compartment.

$$2Cl^-(aq) \longrightarrow Cl_2(g) + 2e^-$$
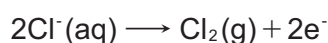
It is important to observe that the brine solution is continuously recycled in the compartment as the Cl^- ions are used up in the oxidation process, thus keeping a continually high concentration of Cl^- ions in the compartment at all times. This allows for a high concentration of Cl_2 gas to be produced quickly and efficiently.

In the cathodic compartment

Here the chemistry is a bit more exciting! Remember that the Na^+ ions have selectively moved through the membrane into the pure water inside the compartment. These cations would be expected to be attracted to the negative charged electrode, however there now exists a competition for electrons between the Na^+ ions and H_2O molecules present. H_2O is a much stronger oxidising agent than the Na^+ ions, thus H_2O molecules are selectively discharged at the cathode in lieu of Na^+.

$$2H_2O(l) + 2e^- \longrightarrow 2OH^-(aq) + H_2(g)$$
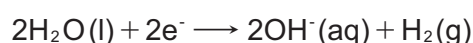
Hydrogen gas is thus produced in the cathodic compartment and is immediately extracted out of the compartment. The OH^- ions that are produced by the reduction reaction remain in aqueous solution with the Na^+ ions that passed through the ion exchange membrane forming a solution of sodium hydroxide $(NaOH)$ which is able to be extracted. The concentration of the $NaOH$ solution is approximately 40% by volume. Fresh water is continually added at the top of the compartment to allow for maximum reduction of H_2O.

Overall electrochemical reaction

Oxidation: $2Cl^- \longrightarrow Cl_2 + 2e^-$

Reduction: $2H_2O + 2e^- \longrightarrow 2OH^- + H_2$

Net reaction: $2Cl^- + 2H_2O \longrightarrow Cl_2 + 2OH^- + H_2$
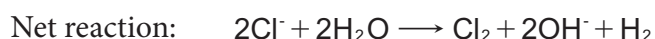
If we now include the Na^+ ions that remain un-reacted in a spectator ion capacity, we can also write the overall chemical reaction as:

$$2Na^+ + 2Cl^- + 2H_2O \longrightarrow Cl_2 + 2Na^+ + 2OH^- + H_2$$

OR

$$2NaCl + 2H_2O \longrightarrow Cl_2 + 2NaOH + H_2$$
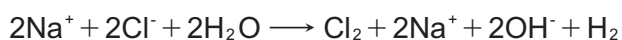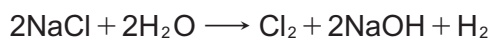
With all industrial processes, there are numerous factors to consider in terms of the impact these cells might have on society and the environment. Below are listed a few factors to consider:

Advantages

- The membrane cell does not need frequent cleaning and replacement of parts.
- There is very little harmful impact on the environment as the membrane is environmentally friendly.
- A high purity of NaOH flows out of the cathodic compartment.
- Much cheaper to run the membrane cell compared to any of the other cells used in the industry.

CONCEPT EXPLANATION AND CLARIFICATION: THE RECOVERY OF ALUMINIUM METAL FROM BAUXITE

Industrially, this extraction is in South Africa done by the industrial giant ALUSAF which has a massive smelter at Richards Bay and is arguably one of the largest smelting and extraction plants in the world. Aluminium is found in the mineral known as **bauxite** which contains primarily aluminium oxide (Al_2O_3) in an impure form. Bauxite is not found naturally in South Africa but is found in vast quantities in Australia and thus it is imported into SA to be extracted and purified.

The extraction process is via electrolysis of molten aluminium oxide.

Step 1

Bauxite is treated with sodium hydroxide to convert the impure Al_2O_3 into aqueous aluminium hydroxide ($Al(OH)_3$) thus extracting the aluminium from the ore. The $Al(OH)_3$ is then heated to temperatures in excess of 1 000°C causing the aluminium hydroxide to be converted back into pure aluminium oxide (Al_2O_3) known as alumina.

Step 2

The alumina is melted to release the ions from the crystal lattice so that the extraction of aluminium can take place. The problem is that alumina has a melting point of over 2 000°C which requires huge amounts of energy and is therefore very expensive, extremely hazardous and environmentally unfriendly. To alleviate this problem the alumina is dissolved in a substance known as **cryolite (sodium aluminium hexafluoride – Na_3AlF_6)** which only has a melting point of 950° which is significantly less than that of pure alumina.
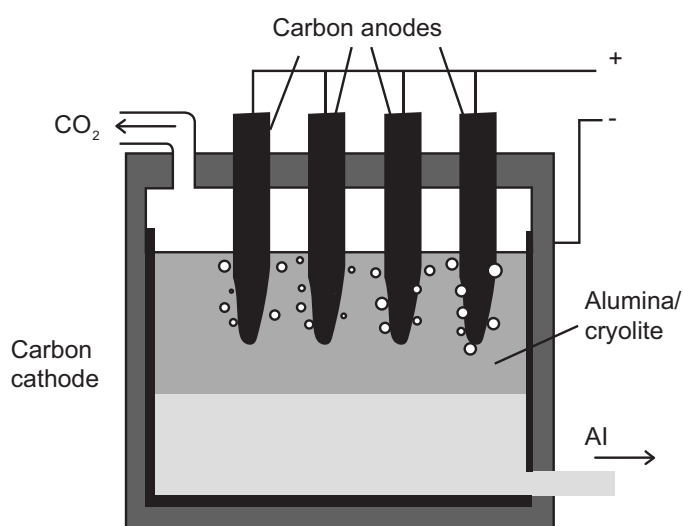
Step 3

The molten alumina/cryolite mixture is placed into a reaction vessel where carbon electrodes are lowered into the melt. The electrodes are connected to the positive terminal of an external power supply making them the **anode**.

At the cathode, reduction of the Al^{3+} ions in the melt to Al takes place.

Reduction: $Al^{3+} + 3e^- \longrightarrow Al$ $(\times 4)$
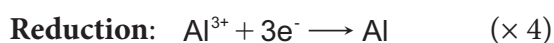
At the anode, oxidation of the O^{2-} ions in the melt to O_2 gas takes place. The O_2 gas immediately reacts with the carbon electrodes to form carbon dioxide gas (CO_2).

Oxidation: $2O^{2-} \longrightarrow O_2 + 4e^-$ $(\times 3)$

Net reaction: $4Al^{3+} + 6O^{2-} \longrightarrow 4Al + 3O_2$
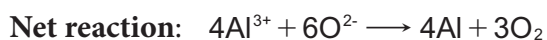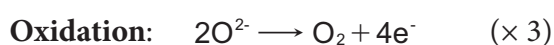
However, due to the electrodes being made from carbon, a secondary chemical reaction occurs with the oxygen gas. This causes the formation of carbon dioxide gas which is environmentally unfriendly as it is a greenhouse gas.

$$C + O_2 \longrightarrow CO_2$$
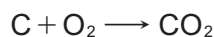
It also causes the electrodes of the reaction vessel to get used up quickly and they have to be replaced at great expense.

Environmental and energy issues associated with the recovery of aluminium

- The process consumes a large amount of electricity and thus causes the production of aluminium to be expensive.
- CO_2 is emitted as a waste product which when released into the atmosphere is environmentally damaging (global warming). This is due to the process having to use carbon electrodes. On average, approximately 380 billion tons of CO_2 worldwide is released into the atmosphere as a result of this process, hence there is a significant challenge to find electrodes that can conduct and are chemically inert enough at elevated temperatures in molten cryolite.
- Fluoride emissions from the breaking up of the cryolite during electrolysis are harmful to human health.
- Due to high production costs, recycling of aluminium products becomes highly desirable as it is far cheaper to recycle the metal than to manufacture it. This is an environmental advantage due to reduction of litter as well as saving energy costs. Recycled aluminium only require 5 % of the energy needed to manufacture it.

> **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 concepts of the topic.
>
> **How to tackle these questions in the classroom:**
>
> - Work through these examples with learners.
> - Explain each step of the question to the learners as you complete it on the chalkboard.
> - Learners must copy down the questions and answer them correctly in their workbooks.

1. Determine the oxidation numbers of the underlined elements in the following examples

    1.1. $\underline{Fe}O$

    1.2. $\underline{S}O_3$

    1.3. $\underline{N}H_3$

    1.4. $H_2\underline{S}O_4$

    1.5. $\underline{Fe}O_3$

Solution:

    1.1. Fe = +2

    1.2. S = +6

    1.3. N = -3

    1.4. S = +6

    1.5. Fe = +6

2. Using oxidation numbers, identify the oxidation and reduction processes in the following reactions.

    2.1. $K + H_2O \longrightarrow KOH + H_2$

    2.2. $HgO \longrightarrow Hg + O_2$

Solution:

    2.1.

$$\overset{0}{K} + \overset{+1\ -2}{H_2O} \longrightarrow \overset{+1-2+1}{KOH} + \overset{0}{H_2}$$

oxidation / reduction

    2.2.

$$\overset{+2\ -2}{HgO} \longrightarrow \overset{0}{Hg} + \overset{0}{O_2}$$

oxidation / Reduction
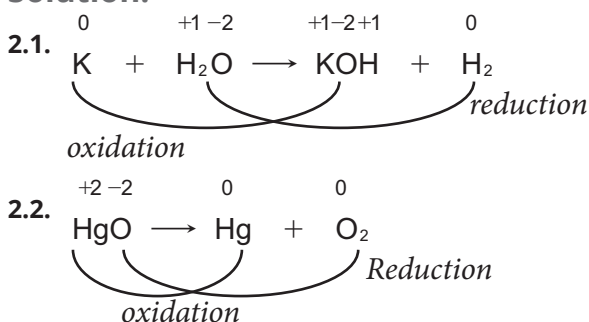
3. Answer the following questions on the extraction of aluminium from its impure ore.

3.1. What is bauxite?

3.2. What is cryolite and explain the function of this substance in the extraction of aluminium.

3.3. Copy and complete the equations for the reactions occurring at the anode and cathode and write the net reaction:
Anode: $2O^{2-}$
Cathode: $Al^{3+} + 3e^-$
Net reaction: $4Al^{3+} + 6O^{2-}$

3.4. The carbon anodes have to be replaced from time to time. What is the reason for this and give a balanced equation to support your answer.

Solution:

3.1. Bauxite is the impure ore which contains impure aluminium oxide.

3.2. Cryolite is a substance which is added to the mixture of aluminium oxide (alumina) to lower the melting point of the alumina and thus reduce energy costs.

3.3. Anode: $2O^{2-} \longrightarrow O_2 + 4e^-$

Cathode: $Al^{3+} + 3e^- \longrightarrow Al$

Net reaction: $4Al^{3+} + 6O^{2-} \longrightarrow 4Al + 3O_2$

3.4. The electrodes are made of carbon. Oxygen gas produced at the anode reacts with the carbon to form carbon dioxide $C + O_2 \longrightarrow CO_2$. This causes the electrodes to be eaten away which means that they will have to be replaced after continuous periods of use.

4. To restore an old war medal, a thin layer of silver metal is electroplated onto the medal to improve its appearance.

4.1. What type of electrochemical cell is used to perform this task?

4.2. Will the medal be the anode or the cathode in the cell? Explain your answer.

4.3. Name a suitable electrolyte that must be used in this cell.

4.4. What metal must the other electrode in the cell be made of to ensure a successful electroplating process? Explain why this metal must be used.

4.5. Write down the oxidation and reduction half reactions that must take place at each electrode.

4.6. Write down the net cell reaction for this process.

Solution:

4.1. An electrolytic cell.

4.2. Cathode. Silver ions (Ag^+) will be reduced from the electrolyte to form silver metal. $Ag^+ + e^- \longrightarrow Ag$ at the surface of the cathode. The silver metal will then electroplate onto the medal and restore it.

4.3. Silver nitrate.

4.4. The other electrode (anode) must be made out of pure silver. Oxidation occurs at the anode thus $Ag \longrightarrow Ag^+ + e^-$. This allows Ag^+ ions to be returned to the electrolyte to replace the Ag^+ ions that are reduced to silver metal at the cathode. The electroplating process will thus be able to continue without running out of Ag^+ ions.

4.5. Anode: $Ag \longrightarrow Ag^+ + e^-$

Cathode: $Ag^+ + e^- \longrightarrow Ag$

4.6 Net reaction: $Ag + Ag^+ \longrightarrow Ag^+ + Ag$

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 / 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 learners copy down the questions and answer them correctly in their workbooks.


KEY TEACHING:

a. In these more challenging examples, learners will be exposed to more thinking type questions which will involve multilevel thinking skills and explanations.

b. Leaners must read the questions carefully and make sure that they identify the specific parts of the question that require more detailed answers.

1. Impure aluminium oxide is purified to pure aluminium oxide from which pure aluminium metal can be extracted at temperatures as high as 1 000 °C.

    1.1. What name is given to the impure ore that contains the aluminium oxide?

    1.2. What is added to the impure aluminium oxide to extract the aluminium out of the ore and name the product formed in this reaction?

    1.3. How is this product converted back to pure aluminium oxide?

    1.4. What name is given to this pure form of aluminium oxide?

    1.5. Briefly explain how the pure aluminium oxide is converted into pure aluminium.

    1.6. Write the oxidation and reduction half reactions that take place at each electrode and then write the net chemical reaction.

    1.7. Carbon dioxide is produced at the anode of the electrolytic cell. Explain why the production of this gas is a problem to the environment.

Solution:

1.1. Bauxite.

1.2. Sodium hydroxide is added to form aluminium hydroxide which extracts the aluminium out of the impure sample.

1.3. The aluminium hydroxide is heated to temperatures in excess of 1 000 °C which decomposes the aluminium hydroxide to pure aluminium oxide.

1.4. Alumina.

1.5. Alumina is placed into an electrolytic cell with a mixture of cryolite and heated so that the aluminium oxide melts to release individual Al^{3+} and O^{2-} ions into the molten solution. The cryolite reduces the temperature which is needed to melt the aluminium oxide. Electrical energy is passed through the molten solution and the Al^{3+} will be attracted to the cathode while O^{2-} will be attracted to the anode.

1.6. Anode: $2O^{2-} \longrightarrow O_2 + 4e^-$
Cathode: $Al^{3+} + 3e^- \longrightarrow Al$
Net reaction: $4Al^{3+} + 6O^{2-} \longrightarrow 4Al + 3O_2$

1.7. Carbon dioxide is a greenhouse gas which when released into the atmosphere, will cause global warming.

2. The electrolysis of brine is the basis of the Chlor-Alkali process, a major industrial process producing hydrogen, chlorine and sodium hydroxide.

DIAGRAM OF A MEMBRANE CELL
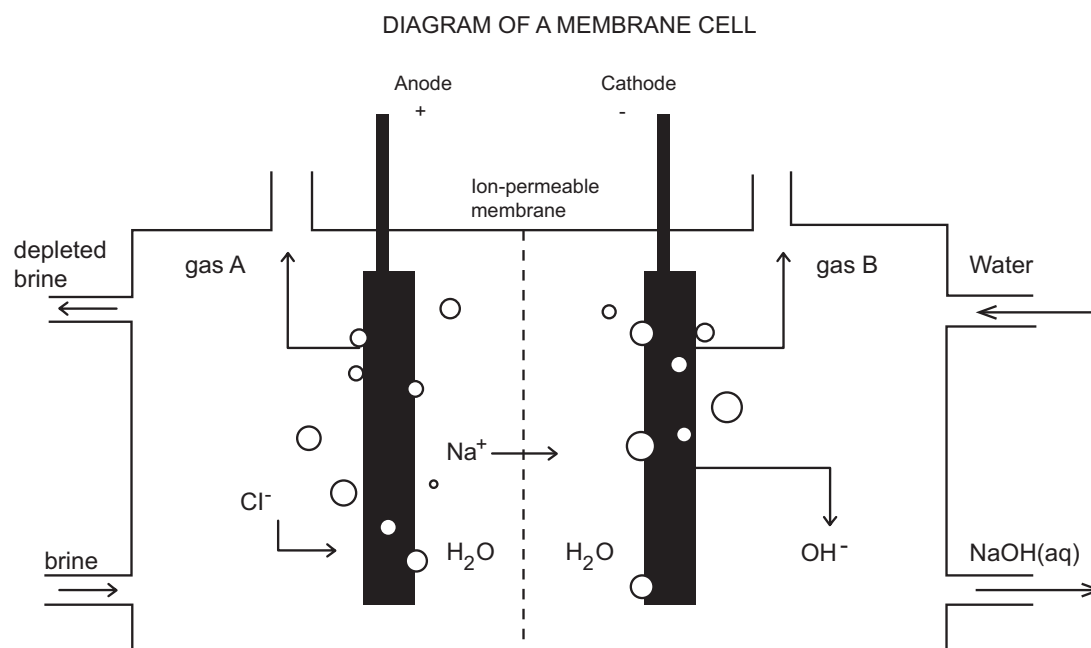
2.1. What is meant by the term 'brine'?

2.2. Explain how the ion permeable membrane functions in this cell.

2.3. Sodium cations (Na^+) are found in the cathodic compartment of the membrane cell, yet they do not undergo reduction to form sodium metal, instead hydrogen gas is produced. Using half reactions, explain why this occurs.

2.4. State TWO advantages that the membrane cell has over any other cell in the Chlor-Alkali industry.

Solution:

2.1. This is a concentrated salt solution, usually sodium chloride $(NaCl)$

2.2. The membrane is ion selective meaning that it will only allow certain ions through and block other ions. In this cell it will allow the Na^+ ions through but prevent the Cl^- ions from passing through.

2.3. In solution, Na^+ and H_2O are both electrochemically active. Na^+ is a much weaker oxidising agent than H_2O which means that H_2O will undergo reduction much more easily at the cathode according to the following half reaction:

$$2H_2O + 2e^- \longrightarrow H_2 + 2OH^-$$
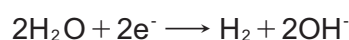
As can be seen H_2 gas is a product of this reduction reaction which explains why H_2 is produced.

2.4. Minimal harmful impact on the environment as the membrane is environmentally friendly.

A high purity of $NaOH$ is produced in the cell.

It is much cheaper to run than any other cell as it has less electricity costs.

CHECKPOINT

At this point in the topic, learners should have an understanding of

1. the concept of oxidation numbers and applying oxidation numbers to individual atoms in a compound.

2. why oxidation numbers are so useful and using oxidation numbers to identify oxidation and reduction reactions in an electrochemical equation.

3. the production of chlorine in the Chlor-Alkali industry using specifically the membrane cell.

4. the extraction of aluminium from bauxite and the importance of the addition of cryolite to the mixture.

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

Resource Pack: Topic 13: Electrochemical Reactions Worksheet: Questions 12–14. (Pages 47–49).

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: Electrochemical Reactions Consolidation Exercise (Pages 50–56).**
- Photocopy the consolidation exercise 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 exercise 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=Rt7-VrmZuds&t=205s
    This is a video which covers the general concept of electrochemistry and REDOX reductions.

2. https://www.youtube.com/watch?v=RX6rh-eeflM
    This video revises the concepts of redox reactions and oxidation number.

3. https://www.youtube.com/watch?v=a2v7ph3kLXo
    This video covers the important aspects of the galvanic cell and salt bridge.

4. https://www.youtube.com/watch?v=7uIIq_Ofzgw
    This video focuses specifically on the concept of electrolysis and the electrolytic cell

5. https://www.youtube.com/watch?v=qqmKqpA61GI
    This video shows an application of electrolysis, specifically, the electrorefining of copper.

6. https://www.youtube.com/watch?v=mvDHeYI-a00
    This video focuses on the extraction of aluminium.

TOPIC 14:
Chemical Industry

A   Introduction

- This topic runs for 6 hours.
- For guidance on how to break down this topic into lessons, please consult the NECT Planner & Tracker.
- Energy forms part of the content area Chemical Systems (Chemistry).
- Chemical Systems counts as 7,5 % in the final Chemistry Examination (Paper 2).
- The Chemical Industry counts approximately 7,5 % of the final examination.
- Food security is one of the most critical problems that countries around the world are trying to address as a matter of urgency. With a rapidly increasing population, more food must be produced on a mass scale, and with this comes the necessity to provide nutrients to the soil to sustain healthy growth of plants and crops. This module focuses on the importance of synthetic fertilizers and the contribution that the fertilizer industry makes to our daily lives. We will be looking at the benefits as well as the dangers of fertilizer production.

CLASSROOM REQUIREMENTS FOR THE TEACHER

1. Chalkboard.

2. Chalk.

3. Calculator.

4. Pen and paper.

CLASSROOM REQUIREMENTS FOR THE LEARNER

1. An A4 3-quire exercise book, for notes and exercises.

2. Scientific calculator – Sharp or Casio calculators are highly recommended.

3. Pen.

B   Sequential Table

PRIOR KNOWLEDGE	CURRENT
GRADE 11	GRADE 12
• Writing and balancing of equations • Writing of chemical equations	• Chemical equilibrium

C   Glossary of Terms

TERM	DEFINITION
Eutrophication	The excessive richness of nutrients in a body of water due to fertilizer run-off from adjacent land which causes dense growth of algae or plants and the death of animal life from lack of oxygen.
Non-mineral nutrients	Nutrients that are made up from the surroundings, namely carbon, hydrogen and oxygen, that combine to provide essential nutrients to plants. These are CO_2 and H_2O.
Primary nutrients	Nutrients that plants must absorb in large quantities that are primarily responsible for the healthy growth of the plant.
Secondary nutrients	These are nutrients that plants will absorb in much smaller quantities and are not as essential for healthy plant growth.
Trace or micro-nutrients	These are nutrients that are sometimes absorbed by the plants.
Guano	These are bird droppings that were first used as fertilizer which provided a rich source of nitrogen and phosphorus.
Bone meal	This is made from crushed animal bones that provides a very high level of phosphorus essential for root development of a plant.
Potash	A mixture of potassium oxide and potassium hydroxide.
N:P:K ratio	A ratio of primary/essential nutrients that is displayed on the front of a fertilizer bag to indicate the percentage by weight of these nutrients in the fertilizer.
Fractional distillation	The technique of extracting out individual portions or fractions from the air by means of lowering the temperature in the system to condense out each fraction based on their individual boiling points.
Haber Process	The name of the industrial process to produce ammonia gas.
Contact Process	The name of the industrial process to produce sulfuric acid.
Ostwald Process	The name of the industrial process to produce nitric acid.
SASOL	South Africa Synthetic Oil Liquid.
SASOL – Lurgi Process	The name of the industrial process of producing hydrogen gas from low grade coal under high temperatures and pressures.
Oleum	Also known as fuming sulfuric acid, is produced when sulfur trioxide is bubbled through existing sulfuric acid ($H_2S_2O_7$).
LAN	Limestone ammonium nitrate.

TOPIC 14

D   Assessment of this Topic

This topic can be assessed using short class tests or through marked worksheets. It is suggested that a formal test is done at the end of the section to ensure that the learners understand the work taught. This will be examined in the final matric examination.

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
6 hour	The Fertilizer Industry Soil and Plant nutrients	138	a. The importance of soil and plant nutrients to sustain growth.
	The functions of N, P and K in plants	139	a. Examining the importance of N,P and K in plants. b. Examining the source of N,P and K. c. interpreting the N:P:K ratio.
	Manufacturing fertilizers and commercial fertilizer production	139	a. Fractional distillation of air to produce nitrogen gas. b. The Haber process to produce ammonia gas. c. The Ostwald process to produce nitric acid. d. The Contact process to produce sulfuric acid. e. The production of phosphoric acid and super phosphates. f. Production of nitrogen based fertilizers such as ammonium nitrate, ammonium sulfate and urea. g. SASOL and the production of fertilizers and explosives.
	Environmental impact of fertilizer use	140	a. The impact of the use of inorganic fertilizers on humans and the environment. b. The problems of eutrophication.

F   Targeted Support per Sub-topic

1. SOIL AND PLANT NUTRIENTS

INTRODUCTION

As mentioned earlier, food security is a concern that many countries throughout the world are addressing as a matter of urgency. To grow enough plants and crops to feed an ever-increasing world population is a priority of most governments. This sub-topic introduces the important factors that are required for healthy growth of plants and crops, namely what must be present in soil to ensure healthy plant growth.

CONCEPT EXPLANATION AND CLARIFICATION: THE IMPORTANCE OF SOIL AND PLANT NUTRIENTS TO SUSTAIN PLANT GROWTH

As the learners begin this new topic, they must take note of the importance of soil in sustaining plant growth. It is important for them to realise that soil is used by the plants to provide physical support, water and nutrients for plants. Learners must know that soil contains a mixture of inorganic and organic material as well as large amounts of open space. There are also many different micro-organisms that contribute to the nutritional value of the soil.

Explain to the learners that for plants to survive, there will be three non-mineral nutrients that are essential, namely carbon (C), hydrogen (H) and oxygen (O). These three non-mineral elements combine to provide CO_2 and H_2O for the plants

Now explain to the learners that there are three primary nutrients that plants also need to survive, namely nitrogen (N), phosphorus (P) and potassium (K). These nutrients dissolve in the water in the soil and thus can be easily absorbed by the roots of the plants. Plants use large amounts of these primary nutrients as they are essential for their growth and thus they may have to be replaced by either natural or artificial means at certain stages of the plants growth cycle.

There are also secondary nutrients which the learners can study but tell them that they are not as essential as plants use much less of them. They are calcium (Ca), magnesium (Mg) and sulfur(S) and learners can also be taught that trace nutrients or micro-nutrients are also sometimes used by the plants. Examples of these are iron (Fe), boron (B), copper (Cu) and zinc (Zn).

It is important to note that these nutrients often get depleted from the soil and have to be replaced on a regular basis. This is where fertilizers become so important to supplement the soil when it runs low in these nutrients.

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 subject material to provide important knowledge on what makes healthy soil essential for healthy plant growth.

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 questions and answer them correctly in their workbooks.

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1. What are the non-mineral nutrients that are essential for plant growth and are found in the soil and what do they combine to form?

   Solution:

   Carbon, hydrogen and oxygen.

   They can combine to form CO_2 and H_2O.

2. What are the three primary nutrients that plants need to survive?

   Solution:

   Nitrogen (N)   Phosphorus (P)   Potassium (K)

3. What is significant about these nutrients in terms of plants being able to absorb them?

   Solution:

   These nutrients are soluble in water thus making it easy for the plants to absorb them through the roots.

4. Name three secondary nutrients that the plants use. Why are they called secondary nutrients?

   Solution:

   Secondary nutrients are not essential for the plants to survive and grow, so plants use much less of them. Examples of secondary nutrients are calcium, magnesium and sulfur.

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5. Name four micronutrients that are absorbed by the plant.

Solution:

Iron, boron, copper and zinc.

6. Why are fertilizers needed in our agricultural society?

Solution:

Plants need the essential nutrients to grow and survive. Fertilizers are needed to replenish these nutrients in the soil especially after continuous use as soil will eventually lose these nutrients.

KEY TEACHING:

a. This is a very short section thus it is important for the learners to get a basic understanding of the importance of soil and the different types of plant nutrients.

b. This understanding will assist learners to realise the functions of essential nutrients and how these nutrients are produced in later sub-topics.

2. THE FUNCTIONS OF N, P AND K IN PLANTS

INTRODUCTION

In order for plants and crops to grow healthily, they need to have an adequate supply of primary or essential nutrients to sustain this growth to provide the maximum benefit to the consumers. This sub-topic will look at the importance of the essential nutrients, namely nitrogen (N), phosphorus (P) and potassium (K) in sustaining healthy plant growth, the source of these nutrients as well as looking at how the amounts of these nutrients are represented on fertilizer bags to consumers.

CONCEPT EXPLANATION AND CLARIFICATION: EXAMINING THE IMPORTANCE OF N, P AND K IN PLANTS

Learners must know that there are 3 primary nutrients that are essential for plant growth, namely nitrogen, phosphorus and potassium. Learners must be taught the basic fundamentals of these essential nutrients:

Nitrogen: Nitrogen is made available to plants in the form of nitrates (NO_3^-) and through ammonium compounds (NH_4^+). Nitrogen is the building block of proteins which then allow the plants to make healthy stems and leaves. Leafy vegetables are particularly in need of adequate supplies of nitrogen. The growth of a plant will be severely stunted if it does not get enough nitrogen as cell division cannot happen without nitrogen.

Phosphorus: Phosphorus is not found as a free element in soil but in minerals such as phosphates (PO_4^{3-}) and orthophosphates (HPO_4^{2-}). Phosphorus is a major component in the DNA structure of the plant cells as well as in the energy carriers ADP and ATP. These energy carriers are specifically important in photosynthesis where food for the plant is made by harnessing the sun's energy. Without sufficient phosphorus, plant growth will be stunted as food cannot be manufactured successfully. Phosphorus is also essential for seed germination, root development in young plants as well as in seed and fruit development.

Potassium: Plants will absorb potassium through the potassium ion (K^+). Potassium can act as a catalyst in many metabolic processes and functions to regulate the use of water. Potassium is needed to help in the development of flower production as well as improve the quality of fruit and seeds. Potassium chloride (KCl) and potassium nitrate (KNO_3) are very good sources of potassium.

CONCEPT EXPLANATION AND CLARIFICATION: EXAMINING THE SOURCE OF N, P AND K AND INTERPRETING THE NPK RATIO

Explain to the learners that bird droppings known as guano were first used as a rich source of nitrogen and phosphorus as these droppings contained very high concentrations of nitrates and phosphates/orthophosphates. Bone meal also has a very high level of phosphorus. Superphosphates were developed in the United Kingdom. Phosphate containing rocks were treated with sulfuric acid to make the superphosphate.

Potash is made up of potassium oxide (K_2O) and potassium hydroxide (KOH). It was initially supplied by Germany up until the first World War before it was stopped due to the war. Today, most of the potassium minerals come from Canada, the USA and Chile.

It is important for the learners to know that in South Africa, there is no readily available source of potash and that we import the potassium salts such as potassium nitrate (KNO_3) and potassium sulfate (K_2SO_4).

CONCEPT EXPLANATION AND CLARIFICATION: INTERPRETING THE N:P:K RATIO

Explain to the learners that when it comes to commercial fertilizers, the percentage amount of nitrogen, phosphorus and potassium, known as the N:P:K ratio, is generally displayed on the outside of all fertilizer bags. What this represents is the amount of these essential nutrients expressed as a percentage by weight. Let's look at an example of how this works:

Example 1: Consider a bag of fertilizer with an N:P:K ratio of 2:3:2 (22). Now what does this mean?

Firstly, look at the number in brackets next to the ratio. This represents the total percentage of these elements in the bag where the rest of the fertilizer in the bag is simply made up of filler. Thus, in this example, there is 22 % essential nutrients and 78 % filler. This filler is often just sand, lime or gypsum.

Now, work with the learners to calculate the total percentages of N, P and K in the bag.

- **Step 1**: Add up the total value of the parts of the ratio. Thus $2 + 3 + 2 = 7$. What this means is that 2 parts of a total of 7 contains nitrogen, 3 parts of the total of 7 contains phosphorus and 2 parts of the total of 7 contains potassium. These 3 elements make up 22 % of the total mass of the fertilizer.
- **Step 2**: Calculate the percentage of N, P and K from this information:

  N: $\dfrac{2}{7} \times 22 = 6,29\,\%$

  P: $\dfrac{3}{7} \times 22 = 9,43\,\%$

  K: $\dfrac{2}{7} \times 22 = 6,29\,\%$

Example 2: Consider a fertilizer with an N:P:K ratio of 3:1:5 (26)

Thus, there are 3 parts of a total of 9 of N, 1 part of a total of 9 of P and 5 parts of a total of 9 of K. This means that the percentage of NPK in the fertilizer will be:

  N: $\dfrac{3}{9} \times 26 = 8,67\,\%$

  P: $\dfrac{1}{9} \times 26 = 2,89\,\%$

  K: $\dfrac{5}{9} \times 26 = 14,4\,\%$

A discussion with the learners at this point regarding the importance of adding the correct N:P:K ratio fertilizer to soil is a good idea. Here you can discuss the importance of knowing what deficiencies are present in the soil and adding the fertilizer with the correct ratio. This will prevent upsetting the balance of the elements and "over-fertilizing" the soil which could make the soil toxic to plant life.

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> **INTRODUCTORY LEVEL QUESTIONS**
>
> **a.** These are the basic questions and calculations that learners will be required to perform at this stage in the topic.
>
> **b.** Their purpose is to familiarise the learners with the basic theory as well as showing the learners how to perform a simple mathematical calculation to determine the percentage NPK in fertilizer.
>
> **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 questions and answer them correctly in their workbooks.

1. Name the essential elements responsible for the growth of a plant.

   Solution:

   Nitrogen (N), phosphorus (P) and potassium (K).

2. What is potash? What element is present in potash that is used for plant growth?

   Solution:

   Potash is made up of potassium oxide and potassium hydroxide. It contains the element potassium which is one of the essential elements for plant growth.

3. What is guano and what plant nutrient is guano rich in?

   Solution:

   Guano comes from bird droppings and is rich in nitrogen and phosphorus.

4. Bone meal contains high levels of which essential plant nutrient?

   Solution:

   Phosphorus.

5. A fertilizer bag has the following information printed on it:

   NPK = 2:1:3 (35)

   Calculate the percentages of each nutrient in the bag.

Solution:

$\qquad$ N $\qquad \frac{2}{6} \times 35 = 11{,}66\,\%$

$\qquad$ P $\qquad \frac{1}{6} \times 35 = 5{,}83\,\%$

$\qquad$ K $\qquad \frac{3}{6} \times 35 = 17{,}5\,\%$

CHALLENGE LEVEL QUESTIONS

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

b. These questions require learners to **manipulate** the equation to change the subject of the formula.

How to tackle these questions in the classroom:

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

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1. What are the three major elements required for healthy growth of plants? What do the plants use each of these elements for? What are the natural sources for each of these elements?

Solution:

Nitrogen (N): healthy stems and leaves: guano.

Phosphorus(P): root development and seed germination: guano.

Potassium: development of flower production: potash.

2. A farmer has his soil tested and is told that the soil is lacking in potassium. He is given the choice of two organic fertilizers. The choices have the following NPK ratio information:
   - 2:4:1 (30)
   - 1:2:4 (30)

   Which fertilizer is most likely to fulfil the nutrient requirements? Explain your answer.

   Solution:

   The 1:2:4 (30) fertilizer. There is a high value for potassium in the NPK ratio thus there will be a high percentage of potassium in the fertilizer.

3. Calculate the total percentage of N, P and K in the two bags of fertilizer in the above question.

   Solution:

   Bag 1: 2:4:1 (30)   N $\frac{2}{7} \times 30 = 8,6\,\%$

                         P $\frac{4}{7} \times 30 = 17,14\,\%$

                         K $\frac{1}{7} \times 30 = 4,29\,\%$

   Bag 2: 1:2:4 (30)   N $\frac{1}{7} \times 30 = 4,29\,\%$

                         P $\frac{2}{7} \times 30 = 8,6\,\%$

                         K $\frac{4}{7} \times 30 = 17,14\,\%$

KEY TEACHING:

a. Here it is essential that the learners have a good understanding of the essential nutrients N,P and K, what each nutrient is responsible for in maintaining healthy plant growth and from where these nutrients were originally sourced.

b. They also need to know how to determine the NPK ratio that is written on all fertilizer bags that consumers are able to purchase.

CHECKPOINT

At this point in the topic, learners should have a good understanding of:

1. the importance of healthy soil and what nutrients go into making a healthy soil.

2. what is known as a primary, secondary and a trace/micro-nutrient.

3. the important role that the primary nutrients N, P and K have on healthy plant and crop development.

4. where these primary nutrients were sourced before the production of synthetic fertilizers.

5. how to interpret the NPK ratio and how to determine the percentage composition of each primary nutrient in a bag of fertilizer.

3. MANUFACTURING FERTILIZERS AND COMMERCIAL FERTILIZER PRODUCTION

INTRODUCTION

Natural sources of fertilizers are fast running out hence the need for the production of these essential nutrients by industrial means. This sub-topic will look at the industry that makes these nutrients as well as the specific processes that are required to produce specific chemicals that are reacted to form these nutrients.

CONCEPT EXPLANATION AND CLARIFICATION: EXAMINING THE IMPORTANCE OF N, P AND K IN PLANTS

Explain to the learners that nitrogen gas (N_2) is the first vital ingredient of fertilizers. The air around us is the most abundant source of N_2 and thus it was vital to try and extract this N_2. The technique known as **fractional distillation** was developed to extract the N_2 out of the air. Fractional distillation is the process where portions of a medium, known as fractions, are separated out from the medium. In air, these fractions are distilled or condensed out from the air by lowering the temperature until each fraction liquefies according to its specific boiling point, and it is then removed. Remind the learners that air contains 78% nitrogen thus is a free and readily available source of N_2. It is important to learn that there are 4 other substances that can also be extracted out of the air using this technique, namely, carbon dioxide (CO_2), oxygen (O_2), water (H_2O) and certain noble gases such as argon (Ar). These are known as "fractions" or portions of the whole, hence this is where the technique gets the name of fractional distillation.

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The N_2 gas is then used in various other processes to produce ammonia gas (NH_3), nitric acid (HNO_3) and nitrates (NO_3^-).

CONCEPT EXPLANATION AND CLARIFICATION: THE HABER PROCESS TO PRODUCE AMMONIA (NH_3)

Explain to the learners that before any nitrates are able to be formed, the N_2 gas must be converted into more usable forms so that it can ultimately end up forming a nitrate. This is where the production of ammonia gas (NH_3) is so important and this is done through the Haber Process, named after the German scientist Fritz Haber who developed this technique.

Here nitrogen and hydrogen are reacted together under pressure and heated to form ammonia gas. It is important to note that the hydrogen gas (H_2) is industrially obtained through the SASOL-Lurgi process where low grade coal is subjected to extremely high temperature and pressures in the presence of steam and oxygen. The resulting gases produced are carbon monoxide (CO) and hydrogen (H_2). This H_2 gas is used in the Haber process.

Explain to the learners the chemistry behind the formation of ammonia by the following equation:

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$
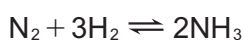
The reaction takes place in the presence of an iron (Fe) or iron oxide (FeO) catalyst.

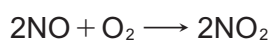Ammonia is used in the production of nitric acid which goes directly onto the production of nitrates.

CONCEPT EXPLANATION AND CLARIFICATION: THE OSTWALD PROCESS TO PRODUCE NITRIC ACID (HNO_3)

Nitric acid is produced in industry by the Ostwald Process. It consists of a stepwise process to get the final product. It is very important for the learners to learn these reaction steps and to be able to write them out

Step 1: This involves the ammonia (NH_3) that was produced in the Haber Process. It is known as the catalytic oxidation of ammonia as it involves the use of a platinum gauze catalyst to speed up the reaction rate. The product nitrogen monoxide (NO) is produced as a result.

$$4NH_3 + 5O_2 \rightleftharpoons 4NO + 6H_2O$$

Step 2: The nitrogen monoxide is then reacted with oxygen to produce nitrogen dioxide, a brown and irritating gas that can affect the lungs.

$$2NO + O_2 \longrightarrow 2NO_2$$

Step 3: The nitrogen dioxide is collected and reacted with steam to produce nitric acid and a further amount of nitrogen monoxide.

$$3NO_2 + H_2O \longrightarrow 2HNO_3 + NO$$
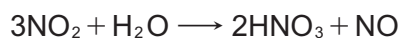
The NO is recycled back to be used in Step 2 again.

Conclude with the learners that the nitric acid (HNO_3) is now used to make various soluble nitrates such as ammonium nitrate and potassium nitrate which are used in commercial fertilizers.

CONCEPT EXPLANATION AND CLARIFICATION: THE CONTACT PROCESS TO PRODUCE SULFURIC ACID (H_2SO_4)

Here we study the production of sulfuric acid as it plays an important role in the formation of fertilizers such as ammonium sulfate as well as phosphoric acid which is used to manufacture phosphates. The process is known as the Contact Process and learners must be able to distinguish the 3 steps in the process.

Step 1: Here raw sulfur powder is burned in the presence of oxygen to form sulfur dioxide gas (SO_2).

$$S + O_2 \longrightarrow SO_2$$
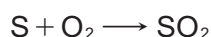
Step 2: In this step, the SO_2 is reacted with oxygen again in the presence of a vanadium pentoxide catalyst (V_2O_5) at a temperature of approximately 450 °C to from sulfur trioxide (SO_3).

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$
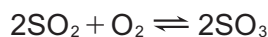
Step 3: Here the SO_3 is bubbled through existing sulfuric acid to form a substance called oleum ($H_2S_2O_7$) or better known as fuming sulfuric acid.

$$SO_3 + H_2SO_4 \longrightarrow H_2S_2O_7$$
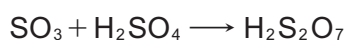
Step 4: Here the oleum is simply diluted with water and sulfuric acid is formed.

$$H_2S_2O_7 + H_2O \longrightarrow 2H_2SO_4$$

Sulfuric acid is now used in industrial reactions to produce sulfates of which ammonium sulfate is an important fertilizer.

CONCEPT EXPLANATION AND CLARIFICATION: THE PRODUCTION OF PHOSPHORIC ACID (H_3PO_4) AND SUPERPHOSPHATES

It is important for the learners to know that sulfuric acid is used to produce phosphoric acid where sulfuric acid is reacted with the mineral fluorapatite ($Ca_5F(PO_4)_3$):

$$Ca_5F(PO_4)_3 + 5H_2SO_4 + 10H_2O \longrightarrow 5CaSO_4.2H_2O + HF + 2H_3PO_4$$
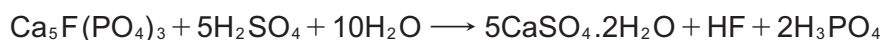
Here the phosphoric acid produced can be used to make a superphosphate.

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Superphosphates are phosphorus rich fertilizers that are used to stimulate root growth in plants. In the soil, the superphosphate is gradually decomposed to release soluble phosphorus which is absorbed by the roots of the plant. An example of a superphosphate is calcium hydrogen phosphate ($Ca(H_2PO_4)_2$) and is produced from ground phosphate rock:

$$3Ca_3(PO_4)_2CaF_2 + 4H_3PO_4 + 9H_2O_9 \longrightarrow Ca(H_2PO_4)_2 \cdot 9H_2O + CaF_2$$
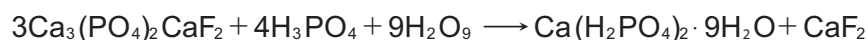
CONCEPT EXPLANATION AND CLARIFICATION: PRODUCTION OF NITROGEN BASED FERTILIZERS SUCH AS AMMONIUM NITRATE, AMMONIUM SULFATE AND UREA

Ammonium nitrate: Learners need to know that ammonium nitrate is produced when nitric acid is reacted with ammonia according to the following equation:

$$HNO_3 + NH_3 \longrightarrow NH_4NO_3$$
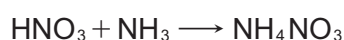
The reaction is very violent and exothermic and the product not only can be used as a valuable fertilizer, but as an explosive as well. Tell the learners that often terrorist bombs are made from ammonium nitrate which is why many countries demand a licence for the manufacture and distribution of ammonium nitrate.

Ammonium sulfate is a very good fertilizer for alkaline soils and learners need to realise that not only does it provide valuable nitrogen for the plants, but also is able to adjust the soil pH as well. Ammonium sulfate is produced as follows:

$$2NH_3 + H_2SO_4 \longrightarrow (NH_4)_2SO_4$$
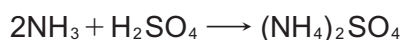
Urea with the chemical formula $(NH_2)_2CO$ is a nitrogen based fertilizer that is used extensively in farming and releases very few pollutants into the environment. It is produced by treating silver isocyanate with ammonium chloride according of the following reaction:

$$AgNCO + NH_4Cl \longrightarrow (NH_2)_2CO + AgCl$$
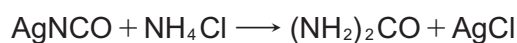
Learners just need to note that the formula for urea may also be written as H_2NCONH_2

CONCEPT EXPLANATION AND CLARIFICATION: SASOL AND THE PRODUCTION OF FERTILIZERS AND EXPLOSIVES

Explain to the learners that SASOL is involved in many diverse operations which include mining, synthetic fuels and chemicals. It is this chemical operation under SASOL that produce fertilizers and explosives.

LAN or limestone ammonium nitrate is produced by SASOL as well as pure ammonium nitrate. These products are used both in the agricultural industry as well as the mining industry where these products are used as fertilizers as well as explosives.

INTRODUCTORY LEVEL QUESTIONS

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

b. Their purpose is to familiarise the learners with the fertilizer industry and to allow the learners to improve their knowledge of what important processes are required to manufacture the various essential nutrients required by plants and crops.

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 questions and answer them correctly in their workbooks.

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1. What is meant by the term "fractional distillation"?

   Solution:

   The technique which is used to isolate and remove each component or fraction from a mixture based on lowering the temperature to individually condense out each fraction based on their boiling points.

2. Name four fractions that can be separated from air by fractional distillation.

   Solution:

   1) carbon dioxide   2) oxygen   3) water   4) noble gases (argon)

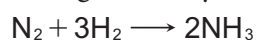3. What chemical is produced by the Haber process?

   Solution:

   Ammonia gas (NH_3).

4. What reactants are required for the Haber process, write a balanced chemical equation for this reaction and name a catalyst that is used in the reaction.

   Solution:

   Nitrogen and hydrogen.
   $N_2 + 3H_2 \longrightarrow 2NH_3$
   Iron or iron oxide.

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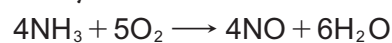**5.** What chemical does the Ostwald process produce?

Solution:

Nitric acid *(HNO₃)*.

6. What is the name of the first step of the Ostwald process and write a balanced equation for this step.

Solution:

Catalytic oxidation of ammonia.

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$$

7. State two uses of the product of the Ostwald process.

Solution:

Used to make fertilizers such as ammonium nitrate and potassium nitrate.

Used to make explosives.

8. Name the industrial process that makes sulfuric acid and name the catalyst that is used in the process.

Solution:

The Contact Process.
Vanadium pentoxide.

9. What is a superphosphate, what element is found in a superphosphate and what do plants use superphosphates for?

Solution:

They are phosphorus rich fertilizers that are used to stimulate root growth in plants.

10. Name two other products that SASOL is famous for producing besides petrol.

Solution:

Fertilizers and explosives.

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 / 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 learners copy down the questions and answer them correctly in their workbooks.

1. The Haber process is used for the manufacture of ammonia.

   1.1. Write down a balanced equation for the reaction that takes place.

   1.2. How are the raw materials needed for the process obtained?

   1.3. Under what conditions does the reaction occur?

   Solution:

   1.1. $N_2 + 3H_2 \longrightarrow 2NH_3$

   1.2. N_2 is obtained by the fractional distillation of air.
   H_2 is obtained from the SASOL-Lurgi process where low grade coal is reacted with steam and oxygen to produce H_2 as one of the products.

   1.3. High pressure and low temperatures.

2. The Contact Process is used for the industrial preparation of sulfuric acid.

   2.1. Name the product formed when sulfur is burned in pure oxygen in step 1.

   2.2. Write a balanced equation when the product in step 1 is reacted with pure oxygen in step 2.

   2.3. What catalyst is used in step 2?

   2.4. What name is given to the product when the product from step 2 is bubbled through concentrated sulfuric acid?

   2.5. Write an equation to show how sulfuric acid is formed in the final step of the Contact process.

Solution

2.1. Sulfur dioxide.

2.2. $2SO_2 + O_2 \longrightarrow 2SO_3$

2.3. Vanadium pentoxide (V_2O_5).

2.4. Oleum or fuming sulfuric acid.

2.5. $H_2S_2O_7 + H_2O \longrightarrow 2H_2SO_4$.

KEY TEACHING:

a. Learners should now have a good understanding of the various industrial processes and an appreciation that the fertilizer industry is a massive industry world-wide.

b. Learners need to be able to individually separate and appreciate the different industrial processes as well as realise that there are many industrial processes that make different chemicals that are then reacted together to form the fertilizer.

CHECKPOINT

At this point in the topic, learners should have an understanding of:

1. the key industrial processes of commercial fertilizer production.

2. the technique of fractional distillation to extract nitrogen from the atmosphere.

3. the major industrial processes, namely the Haber, Ostwald and Contact processes to produce the raw materials for fertilizer production

4. the production of the important fertilizers containing ammonium nitrate, ammonium sulfate and urea.

5. The production of phosphoric acid and the superphosphates.

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4. ENVIRONMENTAL IMPACT OF FERTILIZER USE

INTRODUCTION

As with any substances, there comes various advantages and disadvantages to the use of fertilizers. The effective and responsible use of fertilizers can bring significant benefits to mankind's development, yet the abuse of these substances can have quite devastating effects on the surrounding environment. This sub-topic examines a few of these key issues.

CONCEPT EXPLANATION AND CLARIFICATION: THE IMPACT OF THE USE OF INORGANIC FERTILIZERS ON HUMANS AND ON THE ENVIRONMENT

Tell the learners that there are two main types of fertilizers, namely <u>organic</u> and <u>inorganic</u> fertilizers. Explain to them that organic fertilizers are derived from plant remains or animal excretions such as compost and animal manure. This makes them a natural fertilizer and free from synthetic produced chemicals.

Explain to the learners that inorganic fertilizers are manufactured in factories by chemical means and the content of those fertilizers are carefully controlled by the manufacturers. This means that farmers can purchase exactly the right type of fertilizer for their crops and ensure that the ever increasing demand for food is always met. By adding fertilizer to the ground, soil can be used over and over again without ever running low on the essential nutrients required for successful growth. Learners need to know that the use of inorganic fertilisers has a severe impact on the environment and on our health.

- When it rains, inorganic fertilizers run into our river and dam systems causing death to the living organisms present there.
- Fertilizers cause soil acidification which decreases nutrient availability.
- Many inorganic fertilizers contain heavy metals which are toxic to the human body, such as cadmium which is carcinogenic (causes cancer).

They can have additional health effects on humans:

- They house bad bacteria such as salmonella and E.coli which can cause severe pain, vomiting and diarrhoea in humans and animals.
- Reproductive problems and birth defects have been caused by inorganic fertilizers that get into the drinking water.
- As mentioned earlier, heavy metals can be associated with inorganic fertilizers. Mercury, lead and uranium are additional heavy metals that are extremely toxic to the human body. They affect the kidneys, lungs and brains of humans leading to severe damage to these organs and even death.

CONCEPT EXPLANATION AND CLARIFICATION: THE PROBLEM OF EUTROPHICATION

Eutrophication is a process whereby water systems such as rivers, lakes and dams receive excess nutrients to stimulate excessive plant growth, especially in the rapid growth of green algae on the surface of the water. This is called an algal bloom. Learners need to be made aware of this severe problem as so much oxygen is removed from the water that many living organisms such as fish, die off due to suffocation.

The problem is caused due to the solubility of the fertilizer as it has to be soluble to be absorbed by the roots of the plant. If too much fertilizer is applied, then there is excessive run-off when heavy rains occur and soluble nitrates plus other nutrients are leached from the soil and enter the rivers and streams.

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Much of our drinking water comes from these rivers and dams and learners need to appreciate that in the rural communities, much of that water in not purified. Even with purified water, nitrates are not removed in the purification process.

Fertilizers are not the only causes of eutrophication. Sewerage and washing detergents like washing powders can also supply excessive nutrients for eutrophication to occur. Washing powders contain a large amount of superphosphates which combined with nitrates, will cause an extensive problem.

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 concept.

How to tackle these questions in the classroom:

- Work through these examples with learners.
- Explain each step of the question to the learners as you complete it on the chalkboard.
- Learners must copy down the questions and answer them correctly in their workbook.

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1. What is the difference between an organic and an inorganic fertiliser?

   Solution:

   Organic fertilizer is a natural fertilizer made from natural plant and animal products. Inorganic fertilizer is a factory produced fertilizer that places synthetic nutrients into its product.

2. What impact does the use of inorganic fertilizers have on the environment? Name three examples.

   Solution:

   1. Run off of fertilizer when it rains causing death to living organisms.

   2. Cause soil acidification which decreases nutrient availability.

   3. Contains heavy metals which are toxic to animals and the environment.

3. How does the use of inorganic fertilizers affect humans?

Solution:

There are various health issues that humans are affected by due to the use of inorganic fertilizers. These can be:

1. salmonella and E.coli contamination of the fertilizer which can have severe heath side effects.

2. cause reproductive problems and birth defects.

3. heavy metal poisoning by mercury, lead and uranium.

4. What does the term "eutrophication" mean?

Solution:

This describes the excessive richness of nutrients in various rivers, lakes and dams that is caused by fertilizer run-off from adjacent lands which causes a dense growth of algae or plants in those systems and can kill animal life in those systems as well.

5. Name two major problems of eutrophication in our rivers and dams.

Solution:

The rapid growth of algae on the surface of the water.

The removal of oxygen from the water causing aquatic life to die.

6. What role do fertilizers play in the problem of eutrophication?

Solution:

If too much fertilizer is applied, there is excessive run-off of this fertilizer during heavy rains which then makes its way into the water systems. This then provides the nutrients for the growth of green algae.

7. Besides fertilizers, what other factors can also contribute to the problem of eutrophication.

Solution:

Sewerage and washing detergents provide many nutrients for eutrophication to occur.

KEY TEACHING:

a. At this point, learners need to appreciate the extensive problem that these inorganic fertilizers pose.

b. Farming techniques need to be closely monitored to prevent over fertilization.

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CHECKPOINT

At this point in the topic, learners should have an understanding of:

1. the difference between organic and inorganic fertilizers

2. the issues with eutrophication

3. the environmental impact that eutrophication delivers in our water systems

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

Resource Pack: Topic 14: Chemical Industry Worksheet: Questions 1–4. (Pages 63–65).

- 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 the **Chemical Industry: Consolidation Exercise in the Resource Pack. (Pages 66–69)**.
- Photocopy the consolidation exercise 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 exercise 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=IXBgB689aYg
   This is a Mindset Learn video that looks at the Chemical Industry as a whole.

2. https://www.youtube.com/watch?v=foM6sTkxPNM
   This video deals with the production of nitric acid by the Ostwald Process.

3. https://www.youtube.com/watch?v=xjLUJ-7m5v8
   This video deals with the production of sulfuric acid by the Contact Process.

4. https://www.youtube.com/watch?v=mBH_l74TQ4Y
   This video deals with the production of ammonia by the Haber Process.

5. https://www.youtube.com/watch?v=UGqZsSuG7ao
   A fun animated video that shows the dangers of eutrophication.

6. https://www.youtube.com/watch?v=6LAT1gLMPu4
   A more serious video on eutrophication.