CHEMISTRY FOR TTCs

TUTOR'S GUIDE

3

OPTION: SME

FOREWORD

Dear tutors,

Rwanda Basic Education Board is honoured to present Year 3 Chemistry tutor's guide which serves as a guide to competence-based teaching and learning to ensure consistency and coherence in the learning of chemistry subject. The Rwandan educational philosophy is to ensure that student teachers achieve full potential at every level of education which will prepare them to be well integrated in society and exploit employment opportunities.

In line with efforts to improve the quality of education, the government of Rwanda emphasizes the importance of aligning teaching and learning materials with the syllabus to facilitate their learning process. Many factors influence what they learn, how well they learn and the competences they acquire. Those factors include the relevance of the specific content, the quality of tutors' pedagogical approaches, the assessment strategies and the instructional materials available. We paid special attention to the activities that facilitate the learning process in which student teachers can develop ideas and make new discoveries during concrete activities carried out individually or with peers. With the help of the tutors, student teachers will gain appropriate skills and be able to apply what they have learnt in real life situations. Hence, they will be able to develop certain values and attitudes allowing them to make a difference not only to their own life but also to the nation.

This is in contrast to traditional learning theories which view learning mainly as a process of acquiring knowledge from the more knowledgeable who is mostly the tutor. In competence-based curriculum, learning is considered as a process of active building and developing of knowledge and understanding, skills and values and attitude by the student teacher where concepts are mainly introduced by an activity, situation or scenario that helps the student teacher to construct knowledge, develop skills and acquire positive attitudes and values.

In addition, such active learning engages student teachers in doing things and thinking about the things they are doing and they are encouraged to bring their own real experiences and knowledge into the learning processes. In view of this, your role is to:

- Plan your lessons and prepare appropriate teaching materials.
- Organize group discussions for student teachers considering the importance of social constructivism suggesting that learning occurs more effectively wh en the student teacher works collaboratively with more knowledgeable and experienced people.

- Engage student teachers through active learning methods such as inquiry methods, group discussions, research, investigative activities and group and individual work activities.
- Provide supervised opportunities for student teachers to develop different competences by giving tasks which enhance critical thinking, problem solving, research, creativity and innovation, communication and cooperation.
- Support and facilitate the learning process by valuing student teachers' contributions in the class activities.
- Guide student teachers towards the harmonization of their findings.
- Encourage individual, peer and group evaluation of the work done in the classroom and use appropriate competence-based assessment approaches and methods. To facilitate you, in your teaching activities, the content of this tutor`s guide is self-explanatory so that you can easily use it. It is divided in 3 parts:

The part 1: Explains the structure of this book and gives you the methodological guidance;

The part 2: Gives the sample lesson plans as reference for your lesson planning process;

The part 3: Provides details about the teaching guidance for each concept given in the student book.

Even though this tutor`s guide contains the answers for all activities given in the learner's book, you are requested to work through each question and activity before judging learner's findings.

I wish to sincerely appreciate all people who contributed towards the development of this tutor`s guide, particularly REB staff who organized the whole process since its inception. Special gratitude goes to the University of Rwanda which provided experts in design and layout services, illustrations and image anti-plagiarism, lecturers and tutors who diligently worked to successful completion of this book. Any comment or contribution would be welcome for the improvement of this textbook for the next edition.

Dr. MBARUSHIMANA Nelson

Director General, REB

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I wish to express my appreciation to all the people who played a major role in development of this Chemistry textbook for year 3. It would not have been successful without active participation of different education stakeholders.

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Special acknowledgement goes to the University of Rwanda which provided experts in design and layout services, illustrations and image anti-plagiarism.

Finally, my word of gratitude goes to the Rwanda Basic Education Board staff particularly those from the Curriculum, Teaching and Learning Resources Department (CTLRD) who were involved in the whole process of in-house textbook writing.

Joan MURUNGI,

Head of Curriculum, Teaching and Learning Resources Department

Table of Contents

PART I. GENERAL INTRODUCTION

1.0. About the tutor's guide

This book is a tutor's guide for Chemistry Year 3 in TTC. It is designed to accompany Year 3 student teacher's book and intends to help tutors in the implementation of competence based curriculum specifically Chemistry syllabus.

As the name says, it is a guide that tutors can refer to when preparing their lessons. Tutors may prefer to adopt the guidance provided but they are also expected to be more creative and consider their specific classes' contexts and prepare accordingly.

The structure of the guide

This section presents the overall structure, the unit and sub-heading structure to help teachers to understand the different sections of this guide and what they will find in each section.

Overall structure

The whole guide has three main parts as follows:

Part I: General Introduction.

This part provides general guidance on how to develop the generic competences, how to integrate cross cutting issues, how to cater for tutors with special educational needs, active methods and techniques of teaching chemistry and guidance on assessment.

Part II: Sample lesson plan

This part provides a sample lesson plan, developed and designed to help the tutor develop their own lesson plans.

Part III: Unit development

This is the core part of the guide. Each unit is developed following the structure below. The guide ends with references.

Each unit is made of the following sections:

- **Unit title:** from the syllabus
- **Key unit competence:** from the syllabus
- **Prerequisites (knowledge, skills, attitudes and values)**

This section indicates knowledge, skills and attitudes required for the success of the unit. The competence-based approach calls for connections between units/

topics within a subject and interconnections between different subjects. The tutor will find an indication of those prerequisites and guidance on how to establish connections.

- **Cross-cutting issues to be addressed**

This section suggests cross-cutting issues that can be integrated depending on the unit content. It provides guidance on how to come up with the integration of the issue. Note that the issue indicated is a suggestion; teachers are free to take another cross-cutting issue taking into consideration the learning environment.

- **Guidance on the introductory activity**

Each unit starts with an introductory activity in the student teacher's book. This section of the tutor's guide provides guidance on how to conduct this activity and related answers. Note that student teacher's may not be able to find the right solution but they are invited to predict possible solutions or answers. Solutions are provided by student teachers gradually through discovery activities organized at the beginning of lessons or during the lesson.

- **List of lessons/sub-heading**

This section presents in a table suggestion on the list of lessons, lesson objectives copied or adapted from the syllabus and duration for each lesson. Each lesson / subheading is then developed.

- **End of each unit**

At the end of each unit the tutor's guide provides the following sections:

- Summary of the unit which provides the key points of content developed in the student's book.
- Additional information which provides additional content compared to the student's book for the tutor to have a deeper understanding of the topic.
- End unit assessment which provides the answers to questions of end unit assessment in the textbook and suggests additional questions and related answers to assess the key unit competence.
- Additional activities: (remedial, consolidation and extended activities). The purpose of these activities is to accommodate each learner (slow, average and gifted) based on end unit assessment results.

Structure of each sub heading

Each lesson/sub-heading is made of the following sections:

Lesson /Sub heading title 1: ……………………………..

- **Prerequisites/Revision/Introduction:**

This section gives a clear instruction to tutor on how to start the lesson

- **Teaching resources**

This section suggests the teaching aids or other resources needed in line with the activities to achieve the learning objectives. Tutors are encouraged to replace the suggested teaching aids by the available ones in their respective schools and based on learning environment.

- **Learning activities**

This section provides a short description of the methodology and any important aspect to consider. It provides also answers to learning activities with cross reference to textbook

- **Exercises/application activities**

This provides questions and answers for exercises/ application activities

1.1 Methodological guidance

1.1.1 Developing competences

Since 2015 Rwanda shifted from a knowledge based to a competency based curriculum for pre-primary, primary and general secondary education and since 2018 for Teacher Training Colleges (TTCs). This called for changing the way of learning by shifting from teacher centered to a learner centered approach. Tutors are not only responsible for knowledge transfer but also for fostering student teachers' learning achievement, and creating safe and supportive learning environment. It implies also that a learner has to demonstrate what he/she is able to do using the knowledge, skills, values and attitude acquired in a new or different or given situation.

The competence-based curriculum employs an approach of teaching and learning based on discrete skills rather than dwelling on only knowledge or the cognitive domain of learning. It focuses on what learner can do rather than what learners know. Learners develop basic competences through specific subject unit competences with specific learning objectives broken down into knowledge, skills and attitudes. These competences are developed through learning activities disseminated in learner-centred rather than the traditional didactic approach. The student teacher is evaluated against set standards to achieve before moving on.

In addition to specific subject competences, student teachers also develop generic competences which are transferable throughout a range of learning areas and situations in life. Below are examples of how generic competences can be developed in Chemistry:

Generic competence	Examples of activities that develop generic competences
Critical thinking	– Observe, record, interpret data recorded during experiments – Choose the best reagent to test for a substance or to distinguish substances
Research and Problem solving	– Research using internet or books from the library – Design a project for making bioplastics – Design a questionnaire for data collection during field visit
Innovation and creativity	– Design an experiment procedure to prove a point – Develop a graph to illustrate information – Design a data collection survey/questionnaire – Conduct experiments with objectives, methodology, observations, results, conclusions – Identify local problems and ways to resolve them
Cooperation, Personal and Interpersonal management and life skills	– Work in Pairs – Small group work – Large group work
Communication	– Organise and present in writing and verbally a complete and clear report of an experiment – Observe, record, interpret the results of a measurement accurately. – Select and use appropriate formats and presentations, such as tables, graphs and diagrams.
Lifelong learning	– Exploit all opportunities available to improve on knowledge and skills. Reading scientific journals to keep updated.

1.1.2 Addressing cross-cutting issues

Among the changes in the competence based curriculum is the integration of cross-cutting issues as an integral part of the teaching learning process as they relate to and must be considered within all subjects to be appropriately addressed. The eight cross cutting issues identified in the national curriculum framework are: Genocide Studies, Environment and Sustainability, Gender, Comprehensive Sexuality Education (CSE), Peace and Values Education, Financial Education, Standardization Culture and Inclusive Education.

Some cross-cutting issues may seem specific to particular learning areas or subjects but the tutor needs to address all of them whenever an opportunity arises. In addition, student teachers should always be given an opportunity during the learning process to address these cross-cutting issues both within and out of the classroom so as to progressively develop related attitudes and values.

Below are examples on how crosscutting issues can be addressed in Chemistry:

Cross-cutting issue	**Examples on how to integrate the cross-cutting issue**
Inclusive education	Involve all student teachers in all activities without any bias. Eg: allow a student teacher with physical disability (using wheelchair) to take notes or lead the team during an experiment.
Gender	Involve both girls and boys in all activities: No activity is reserved only to girls or boys. Teachers should ensure equal participation of both girls and boys during experiments as well as during cleaning and tidying up related activities after experiments.
Peace and Values Education	During group activities, debates and presentations, the teacher will encourage student teachers to help each other and to respect opinions of colleagues.
Standardization culture	– Some lessons involve carrying out experiments. Instructions should be clear for student teachers to always check if they are not using expired chemicals or defective apparatus. – In addition, when performing experiments student teachers have to record data accurately. – For tasks involving calculations, they have to always present accurate results.
Environment and sustainability	– In order to avoid the environment pollution, before, during or after experiments student teachers avoid throwing away chemicals anywhere; special places or appropriate containers should be used. – Student teachers also have to be aware of the impacts of the use of hydrocarbons as fuels, halogenoalkanes, plastics, ... on the environment.
Financial Education	When performing experiments, student teachers avoid waste of chemicals: they have to use the amounts that are just required.

1.2.3. Attention to special educational needs specific to each subject

In the classroom, student teachers learn in different way depending to their learning pace, needs or any other special problem they might have. However, the tutor has the responsibility to know how to adopt his/her methodologies and approaches in order to meet the learning need of each student teacher in the classroom. Also tutors need to understand that student teacher with special needs, need to be taught differently or need some accommodations to enhance the learning environment. This will be done depending to the subject and the nature of the lesson.

In order to create a well-rounded learning atmosphere, tutors need to:

- Remember that children learn in different ways so they have to offer a variety of activities (e.g. role-play, music and singing, word games and quizzes, and outdoor activities)
- Maintain an organized classroom and limits distraction. This will help student teachers with special needs to stay on track during lesson and follow instruction easily.
- Vary the pace of teaching to meet the needs of each child. Some children process information and learn more slowly than others.
- Break down instructions into smaller, manageable tasks. Student teachers with special needs often have difficulty understanding long-winded or several instructions at once. It is better to use simple, concrete sentences in order to facilitate them understand what you are asking.
- Use clear consistent language to explain the meaning (and demonstrate or show pictures) if you introduce new words or concepts.
- Make full use of facial expressions, gestures and body language.
- Pair a child who has a disability with a friend. Let them do things together and learn from each other. Make sure the friend is not over protective and does not do everything for the child. Both children will benefit from this strategy.
- Use multi-sensory strategies. As all children learn in different ways, it is important to make every lesson as multi-sensory as possible. Student teachers with learning disabilities might have difficulty in one area, while they might excel in another. For example, use both visual and auditory cues.

Below are general strategies related to each main category of disabilities and how to deal with every situation that may arise in the classroom. However, the list is not exhaustive because each child is unique with different needs and that should be handled differently.

Strategy to help student teachers with developmental impairment:

- Use simple words and sentences when giving instructions.
- Use real objects that the student teachers can feel and handle. Rather than just working abstractly with pen and paper.
- Break a task down into small steps or learning objectives. The student teachers should start with an activity that s/he can do already before moving on to something that is more difficult.
- Gradually give the student teacher less help.
- Let the student teacher work in the same group with those without disability.

Strategy to help student teacher with visual impairment:

- Help children to use their other senses (hearing, touch, smell and taste) to play and carry out activities that will promote their learning and development.
- Use simple, clear and consistent language.
- Use tactile objects to help explain a concept.
- If the child has some sight, ask them what they can see. Get information from parents/caregivers on how the child manages their remaining sight at home.
- Make sure the child has a group of friends who are helpful and who allow the child to be as independent as possible.
- Plan activities so that children work in pairs or groups whenever possible

Strategy to help student teacher with hearing impairment:

- Strategies to help children with hearing disabilities or communication difficulties
- Always get the child‘s attention before you begin to speak.
- Encourage the child to look at your face.
- Use gestures, body language and facial expressions.
- Use pictures and objects as much as possible.
- Ask the parents/caregivers to show you the signs they use at home for communication use the same signs yourself and encourage other children to also use them.
- Keep background noise to a minimum.

Strategies to help children with physical disabilities or mobility difficulties:

- Adapt activities so that children who use wheelchairs or other mobility aids, or other children who have difficulty moving, can participate.
- Ask parents/caregivers to assist with adapting furniture e.g. The height of a table may need to be changed to make it easier for a child to reach it or fit their legs or wheelchair under.
- Encourage peer support friends can help friends.
- Get advice from parents or a health professional about assistive devices.

1.2.4. Guidance on assessment

Each unit in the tutor’s guide provides additional activities to help student teachers achieve the key unit competence. Results from assessment inform the tutor which student teacher needs remedial, consolidation or extension activities. These activities are designed to cater for the needs of all categories of student teacher; slow, average and gifted student teacher respectively.

Assessment is an integral part of teaching and learning process. The main purpose of assessment is for improvement. Assessment for learning/ **Continuous/ formative assessment** intends to improve student teachers' learning and tutors teaching whereas assessment of learning/summative assessment intends to improve the entire school's performance and education system in general.

Continuous/ formative assessment

It is an ongoing process that arises out of interaction during teaching and learning process. It includes lesson evaluation and end of sub unit assessment. This formative assessment should play a big role in teaching and learning process. The tutor should encourage individual, peer and group evaluation of the work done in the classroom and uses appropriate competence-based assessment approaches and methods.

In Year three textbook, formative assessment principle is applied through application activities that are planned in each lesson to ensure that lesson objectives are achieved before moving on. At the end of each unit, the end unit assessment is formative when it is done to give information on the progress of student teachers and from there decide what adjustments need to be done. Assessment standards are taken into consideration when setting tasks.

Summative assessment

The assessment done at the end of the term, end of year, is considered as summative. The tutor, school and parents are informed on the achievement of educational objectives and think of improvement strategies. There is also end of level/ cycle assessment in form of national examinations.

1.2.5. Student teachers' learning styles and strategies to conduct teaching and learning process

There are different teaching styles and techniques that should be catered for. The selection of teaching method should be done with the greatest care and some of the factors to be considered are: the uniqueness of subjects; the type of lessons; the particular learning objectives to be achieved; the allocated time to achieve the objective; instructional available materials; the physical/sitting arrangement of the classroom, individual student teachers' needs, abilities and learning styles.

There are mainly four different learning styles as explained below:

a) Active and reflective student teachers

Active student teachers tend to retain and understand information best by doing something active with it, discussing or applying it or explaining it to others. Reflective student teachers prefer to think about it quietly first.

b) Sensing and intuitive student teachers

Sensing student teachers tend to like learning facts; intuitive student teachers often prefer discovering possibilities and relationships. Sensors often like solving problems by well-established methods and dislike complications and surprises; intuitive student teachers like innovation and dislike repetition.

c) Visual and verbal student teachers

Visual student teachers remember best what they see-pictures, diagrams, flow charts, time lines, films, demonstrations, etc.; verbal student teachers get more out of words-written and spoken explanations.

d) Sequential and global student teachers

Sequential student teachers tend to gain understanding in linear steps, with each step following logically from the previous one. Global student teachers tend to learn in large jumps, absorbing material almost randomly without seeing connections, and then suddenly "getting it."

1.2.6. Teaching methods and techniques that promote the active learning

The different student learning styles mentioned above can be catered for, if the teacher uses active learning whereby learners are really engaged in the learning process.

What is Active learning?

Active learning is a pedagogical approach that engages students in doing things and thinking about the things they are doing. In active learning, student teachers are encouraged to bring their own experience and knowledge into the learning process.

The role of the tutor in active learning

- The tutor engages student teachers through active learning methods such as inquiry methods, group discussions, research, investigative activities and group and individual work activities.
- He/she encourages individual, peer and group evaluation of the work done in the classroom and uses appropriate competence-based assessment approaches and methods.
- He provides supervised opportunities for student teachers to develop different competences by giving tasks which enhance critical thinking, problem solving, research, creativity and innovation, communication and cooperation.
- Tutor supports and facilitates the learning process by valuing student

teachers' contributions in the class activities.

The role of student teachers in active learning

Student teachers are key in the active learning process. They are not empty vessels to fill but people with ideas, capacity and skills to build on for effective learning. A student teacher engaged in active learning:

- Communicates and shares relevant information with other student teachers through presentations, discussions, group work and other learner-centred activities (role play, case studies, project work, research and investigation)
- Actively participates and takes responsibility for their own learning
- Develops knowledge and skills in active ways
- Carries out research/investigation by consulting print/online documents and resourceful people, and presents their findings
- Ensures the effective contribution of each group member in assigned tasks through clear explanation and arguments, critical thinking, responsibility and confidence in public speaking
- Draws conclusions based on the findings from the learning activities.

Some active techniques that can be used in Chemistry

The teaching methods strongly emphasised in the Competence Based Curriculum (CBC) are active methods. Below are some active techniques that are applied in sciences:

a) Practical work/ experiments:

Many of the activities suggested in the integrated sciences curriculum as well as in the student teacher's book are practical work or experiments.

Practical work is vital in learning integrated sciences; this method gives the student teacher the opportunity to implement a series of activities and leads to the development of both cognitive and hands-on skills. The experiments and questions given should target the development of the following skills in student teacher: observation; recording and report writing; manipulation; measuring; planning & designing.

A practical lesson/Experiment is done in three main stages:

- **Preparation:** Checking materials to ensure they are available and at good state; try the experiment before the lesson; think of safety rules and give instructions to lab technician if you have any.
- **Performance:** sitting or standing arrangement of student teacher; introduction of the experiment: aims and objectives; setting up the apparatus; performing the experiment; write and record the data.

- **Discussion:** observations and interpreting data; make generalisations and assignment: writing out the experiment report and further practice and research.

In some cases, demonstration by the tutor is recommended when for example the experiment requires the use of sophisticated materials or very expensive materials or when safety is a major factor like dangerous experiments and it needs specific skills to be learnt first.

In case your school does not have enough laboratory materials and chemicals, experiments can be done in groups but make sure every student teacher participates. In case your school does not have materials make arrangements with the neighbouring science school of excellence and take your student teachers there for a number of experiments.

b) Research work

Each student teacher or group of student teacher is given a research topic. They have to gather information from internet, available books in the library or ask experienced people and then the results are presented in verbal or written form and discussed in class.

c) Project work

Integrated sciences tutors are encouraged to sample and prepare project works and engage their student teachers in, as many as possible. Student teachers in groups or individually, are engaged in a self-directed work for an extended period of time to investigate and respond to a complex question, problem, or challenge. The work can be presented to classmates or other people beyond the school. Projects are based on real-world problems that capture student teachers' interest. This technique develops higher order thinking as the student teachers acquire and apply new knowledge in a problem-solving context.

d) Field trip

One of the main aims of teaching chemistry in Rwanda is to apply its knowledge for development. To achieve this aim we need to show to student teachers the relationship between classroom science lessons and applied sciences. This helps them see the link between science principles and technological applications.

To be successful, the field visit should be well prepared and well exploited after the visit:

- Before the visit the tutor and student teachers:
- agree on aims and objectives
- gather relevant information prior to visit
- brainstorm on key questions and share responsibilities

- discuss materials needed and other logistical and administrative issues
- discuss and agree on accepted behaviours during the visit
- visit the area before the trip if possible to familiarise yourself with the place

After the visit,

When student teachers come back from trip, the tutor should plan for follow-up. The follow-up should allow student teachers to share experiences and relate them to the prior science knowledge. This can be done in several ways; either: Student teachers write a report individually or in groups and give to the tutor for marking. The tutor then arranges for discussion to explain possible misconceptions and fill gaps. *Or:* Student teachers write reports in groups and display them on the class notice board for everyone to read.

Main steps for a lesson in active learning approach

All the principles and characteristics of the active learning process highlighted above are reflected in steps of a lesson as displayed below.Generally the lesson is divided into three main parts whereby each one is divided into smaller steps to make sure that student teachers are involved in the learning process. Below are those main parts and their small steps:

1. Introduction

Introduction is a part where the tutor makes connection between the current and previous lesson through appropriate technique. The tutor opens short discussions to encourage student teachers to think about the previous learning experience and connect it with the current instructional objective. The tutor reviews the prior knowledge, skills and attitudes which have a link with the new concepts to create good foundation and logical sequencings.

2. Development of the new lesson

The development of a lesson that introduces a new concept will go through the following small steps: discovery activities, presentation of student teachers' findings, exploitation, synthesis/summary and exercises/application activities, explained below:

Discovery activity

Step 1

- The tutor discusses convincingly with student teachers to take responsibility of their learning
- He/she distributes the task/activity and gives instructions related to the tasks (working in groups, pairs, or individual to instigate collaborative learning, to discover knowledge to be learned)

Step 2

- The tutor lets the student teachers work collaboratively on the task.
- During this period the tutor refrains to intervene directly on the knowledge
- He/she then monitors how the student teachers are progressing towards the knowledge to be learned and boost those who are still behind (but without communicating to them the knowledge).

Presentation of student teachers' productions

- In this episode, the tutor invites representatives of groups to present the student teachers' productions/findings.
- After three/four or an acceptable number of presentations, the tutor decides to engage the class into exploitation of the student teachers' productions.

Exploitation of student teacher's productions

- The tutor asks the students to evaluate the productions: which ones are correct, incomplete or false
- Then the tutor judges the logic of the student teachers' products, corrects those which are false, completes those which are incomplete, and confirms those which correct.

Institutionalization (summary/conclusion/ and examples)

- The tutor summarises the learned knowledge and gives examples which illustrate the learned content.

Exercises/Application activities

- Exercises of applying processes and products/objects related to learned unit/sub-unit
- Exercises in real life contexts
- Tutor guides student teachers to make the connection of what they learnt to real life situations. At this level, the role of tutor is to monitor the fixation of process and product/object being learned.

3. Assessment

In this step the teacher asks some questions to assess achievement of instructional objective. During assessment activity, learners work individually on the task/activity. The teacher avoids intervening directly. In fact, results from this assessment inform the teacher on next steps for the whole class and individuals. In some cases the teacher can end with a homework assignment

PART II: SAMPLE LESSON PLAN

School Name: ……………………Teacher's name: ………….…………

Term	Date	Subject	Class	Unit Nº	Lesson Nº	Duration	Class size
	… /…/ 2019	CHEMISTRY	SME 3	6	1 of 9	80 min	35

Type of Special Educational Needs to be catered for in this lesson and number of student teachers in each category	Visual impairment (1)
Unit title	pH OF ACIDIC AND ALKALINE SOLUTIONS
Key Unit Competence:	Prepare solutions, measure and calculate their pH, explain the concept of buffer solution, and its applications in manufacturing and biological processes.
Title of the lesson	Degree of ionization in relation to the strength of acids and bases
Instructional Objective	-Differentiate a strong acid and a strong base and a weak acid and a weak base -Define and perform calculations involving degree of ionization (α)
Plan for this Class (location: in / outside)	In the laboratory
Learning Materials (for ALL learners)	Chemicals and lab equipment, student teacher's books; projector and chalks and chalkboard
References	1) Ramsden. E.N (2000), 4th edition. A-level chemistry. Nelson thornes, UK 2) Ritchie, D. G. (2008). *OCR Chemistry A2.* Harlow: Heinemann.

Timing for each step	**Description of teaching and learning activity**		**Generic competences and cross cutting issues to be addressed + a short explanation**
	In groups, student teachers will carry out the practical to compare the speed of two reactions using solutions of same concentration but with different compounds. They will interpret the results and suggest reasons behind the observations made. After that they will work out the exercise given in activity 6.1 and present their answers.		
	Tutor's activities	**Student teachers' activities**	

1.Introduction **10 min**	– Ask students to form groups of four students (Note: putting slow learners with quick learners be remembered). – Give each group the chemicals and apparatus needed. – Distribute worksheets or student teacher's books with the activities to be done. – Give clear instructions on how to carry out the practical.	– Form groups (4 members each) as requested by the tutor – listen carefully to the tutor's instructions – organize themselves in their respective groups – Arrange all the materials and chemicals to be used with care. – make sure all instructions are clear before the practical starts. – Ask for more clarification if necessary.	**Generic competences** **Critical thinking:** student teachers must develop a culture of relating their previous studies to the new concepts. **Cross cutting issues** **Environmental sustainability:** -chemicals to be used are dangerous to the environment. Student teachers must consider disposing them of properly. **Standardisation culture**
2.Development of the lesson			
2.1 Discovery activity **20 min**	– Let student teachers work collaboratively in their groups. – Provide help to the groups in need. – After the practical, ask them to work out the second number of activity 6.1 discuss on the questions and note down the answers	– Start the practical in their respective groups. – Work together and agree on what to note down about the observation made. – Carry out more trials to get consistent results. – Note down the observations made. – Discuss on the observations made to find scientific reasons behind those observations. – After the practical, student teachers will work out the second number of activity 6.1 discuss on the questions and note down the answers.	**Peace and values education** –**Cooperation, respect, love for others** through discussions –**Connection** through social interaction –**Caring** while guiding student teachers –**Attentive listening** through group discussion and –**Responsibility** by leading the group activity

2.2 Presentation of student teachers' productions **20 min**	- Invite two student teachers from each group present and explain the observations made. - Note down some key words while students are presenting.	- Present the observations made by each group. - Suggest possible scientific reasons behind those observations. - Student teachers who will not be presenting should also give their ideas to complement or correct what their colleagues are saying.	cross cutting issues and competences to be addressed are the ones described above

<table>
<tr>
<td>2.3 Exploitation

20 min</td>
<td>Ask the student teachers to comment on the answers given by their colleagues.

Evaluate student teachers' presentations, corrects the wrong points, complete those which are incomplete, and confirm those which are correct.

– Ask some questions to guide slow learners
– Explain how the strengths of weak acids can be quantitatively compared and give examples of the calculations involved.</td>
<td>- Comment on the explanations given by their fellow colleagues from other groups.
- Answer questions asked by the tutor
- Write key points
- Ask questions for more clarification
- Listen carefully to the additional explanations about quantitative comparison of weak acids/bases.

Key observations to be presented:
<table>
<tr><td>Reaction</td><td>Speed</td></tr>
<tr><td>HCl/Na_2CO_3</td><td>Fast</td></tr>
<tr><td>CH_3COOH/Na_2CO_3</td><td>Slow</td></tr>
</table>
Explanations: HCl is a strong acid which is completely ionized when dissolved in water while CH_3COOH is a weak one that ionizes partially. HCl has more free H+ ions in solution than CH_3COOH.

Main explanations to be given by the teacher:
Quantitatively weak acids/bases can be compared using their ionization degree which is the ratio of the number of ionized molecules to the total number of molecules dissolved in water.
It is symbolized by α_a for acids and α_b for bases.

$\alpha = \frac{\text{numberofionizedmolecules}}{\text{totalnumberofmoleculesdissolvedinwater}}$

$\alpha = \frac{\text{concentration of ions formed}}{\text{Original concentration of electrolyte}} \text{x } 100\%$

The greater the degree of ionization, the stronger the acid or base.
$\alpha=0$ for non-electrolytes.
$\alpha=1$ for strong electrolytes.
$\alpha\leq1$ in the case of weak electrolytes.
Example
What is the degree of dissociation of a weak acid in a 0.25M solution, given the concentration of H^+ as 0.001 mol dm^{-3}?
Answer:
Degree of dissociation:
$\alpha = \frac{0.001}{0.25} = 0.004 = 0.4\%$</td>
<td>Cross cutting issues and competences to be addressed are the ones described above.</td>
</tr>
</table>

2.4.Conclusion/ Summary **10 min**	– Give student teachers exercises of calculating the degree of ionization for various weak acids and bases.	– Guided by the tutor student teachers will work out some exercises on the calculation of α by themselves.	– cross cutting issues and competences to be addressed are the ones described above
3. Assessment **5 min**	– Assess the achievement of instructional objectives by giving various exercises. – -Take care of slow learners as student teachers mark each other. – -Ask some of them to write their answers on the board and the others to evaluate those answers. – Ask them to make corrections while marking.	– Student teachers will work out exercises given in application activity 6.1. – They will exchange their work when they are done for marking. – Some student teachers will write their answers and other will confirm or correct them. – They will also make corrections while marking.	– Cross cutting issues and competences to be addressed are the ones described above
Observation on lesson delivery	– The lesson took place very well where each student tried to participate during the exploitation process. One of the reasons is that the lesson attracts the interest of students from their prior knowledge on acids and bases and knowing that these substances are almost in every product we use in our daily life.		

UNIT 1: RADIOACTIVITY

1.1. Key unit competence

Explain the importance and dangers of radioisotopes in everyday life.

1.2. Prerequisite knowledge and skills

Students teacher will learn Radioactivity well if they have understanding on: atomic structure, periodic table of elements), chemical bonding, chemical equations,

1.3. Cross-cutting issues to be addressed

- **Environment and sustainability**

This unit is about nuclear radioactivity which is directly linked to the environment as many radiations are natural and we are continuously exposed to them. As provided in the student's book, not all radiations are harmful but some of them are harmful.

Everything around us is radioactive. Plants can become radioactive when radioactive material enters the soil and is taken up by root systems or when radioactive particles in the air settle on edible portions of the plant. Milk and meat can become contaminated when animals eat grass and other plants that are radioactive. When humans eat radioactive plants or animals, the radioactive substances, such as iodine-131, can settle in particular organs like the thyroid gland. This can increase the risk of thyroid cancer. Children are more vulnerable than adults to exposure to radiation because they are still growing and can absorb more contamination.

Radioactive materials that decay spontaneously produce ionizing radiation, which has sufficient energy to strip away electrons from atoms (creating two charged ions) or to break some chemical bonds. Any living tissue in the human body can be damaged by ionizing radiation. The body attempts to repair the cellular damage, but sometimes the damage is of a nature that cannot be repaired or it is too severe or widespread to be repaired. Also mistakes made in the natural repair process at the cellular level can lead to cancerous cells.

Personal exposure to radiation can be reduced in either of these ways:

- Reduce the time spent near the source of radiation
- Increase the distance from the source of radiation
- Place shielding material between you and the source of radiation

- Avoid eating radiation-contaminated foods once known. Sometimes the government instructs the population from not eating some kinds of food or meat of some animals due to some diseases they can cause. Some of these diseases are related to radiation issues.

This cross-cutting issue can be addressed to students in the introduction of unit 15 and/or while teaching the uses of radioisotopes as well as their health hazards

Financial education

As seen in student's book, one of the main application of radioactivity, especially in nuclear fission and nuclear fusion, is the production of energy.

Nuclear power does not produce polluting combustion gases. So, like renewable energy sources, it could play a key role in helping to reduce global greenhouse gas emissions and in tackling global warming, especially as electricity demand rises in the years ahead. Currently, the perceived problem with nuclear energy from an environmental point of view is how to manage its radioactive waste. Solutions do exist, in particular the technique of burying the waste deep below the ground in engineered facilities, known as geological disposal. The challenge is to convince the public of its safety and reliability.

Radioactive waste is an inevitable by-product of the application activity of ionizing radiation, whether it be in nuclear medicine (for diagnosis and treatment), industrial application (for example, for finding new sources of petroleum or producing plastics), agricultural application (notably for the conservation of foodstuffs), or of course the production of electricity. The radioactive waste produced by the latter represents less than 1% of the total toxic wastes generated in those countries that use nuclear energy to generate electricity, but at the same time this waste has the highest levels of radioactivity.

The long-term solution currently preferred by specialists consists of placing the waste in a deep (500 meters below the surface) and stable geological setting, such as granite, clay, tuff and salt formations that have remained unchanged for millions of years. The aim is to ensure that such wastes will remain undisturbed for the few thousand years needed for their levels of radioactivity to decline to the point where they no longer represent a danger to present on future generations.

As a general rule, the natural security afforded by the chosen geological formation is enhanced by additional precautionary measures. The wastes are immobilized in an insoluble form, in blocks of glass for example, and then placed inside corrosion-resistant containers; spaces between waste packages are filled with highly pure, impermeable clay; and the repository may be strengthened by means of concrete structures. These successive barriers are mutually reinforcing and together ensure that wastes can be contained over the very long term. The waste can be recovered during the initial phase of the repository, and also during subsequent phases, albeit at increased cost. This provides freedom of choice to future generations to change waste management strategies if they wish.

Repositories are designed so that no radioactivity reaches the Earth's surface. Following the precautionary principle, environmental impact assessments spanning 10,000 years analyze worst-case scenarios, including geological and climate changes and inadvertent human intrusion. The assessments maintain that even under those conditions, the impact on the environment and mankind would be less than current regulatory limits, which in turn are lower than natural background radiation.

Cost is an important issue in radioactive waste management as related to sustainable development. In organization for economic co-operation and development (OECD) countries, the costs of dismantling nuclear power plants and of managing long-lived wastes are already included in electricity generating costs and billed to end consumers. Although quite high in absolute terms, these costs represent a small proportion (less than 5%) of the total cost of nuclear power generation.

Deep geological disposal allows present generations to progress without leaving burdens for those of the future, but a main weakness is that although the concept is technically sound, it is rarely socially or politically accepted. The issue is not so much about information provision as understanding the mechanisms that govern the social perceptions of risk.

There are many factors that affect such perceptions, such as:

- Familiarity with the technology
- The degree of uncertainty
- The level of control
- Concern for the consequences
- The degree of credibility of the institutions
- The decision-making process and
- The ideas and values of the community in which people live.

Addressing the public's concern and negotiating acceptable solutions is an important challenge. A decision-making process should be set up step by step, and all the affected groups should be allowed to participate. The role of governments will be crucial in defining this process, and they should act as a source of objective information. They also need to dedicate adequate resources for this purpose, so that public confidence may be won in the scientific solutions being proposed.

Thus, if the effect caused by nuclear radiations could be controlled, the electricity produced by nuclear power would be cheaper compared to that from hydro-electric powers.

This cross-cutting issue can be addressed to students at the end of application of nuclear fission and nuclear fusion sub topics.

- **Standardization culture**

Some materials used at home and in different institutions, especially at hospital, are radioactive or contaminated with radioactive substances. Thus, there must be regular measures to check the standard of any material before use.

The goal of much of radiobiology research is to establish the relationship between radiation dose and the magnitude of the effect of that dose. This is particularly a concern when there is a steep dose-response relationship, when data among different laboratories is to be compared, and when researchers try to repeat experiments.

Concerning the use of radiation that might be present in materials used at home, care should be taken especially by monitoring the hygiene of materials used and food stuffs.

This cross-cutting issue can be addressed to students in the introduction of unit 1 and/or while teaching the uses of radioisotopes as well as their health hazards subtopics just at the same time as when you addressing environment and sustainability cross-cutting issue.

- **Inclusive education**

This unit requires student teachers to carry out a lot of researches to be able to understand first, then share and discuss on things like radioactive emissions, stability and instability of atoms, health hazards of radioactive substances, uses of radioisotopes, and so on. This may be challenging to students with special educational needs especially slow student teachers. However, as teacher you can organize your class and use different strategies to help all student teachers understand well. Some of the strategies to be used are provided below:

- Be patient! If you find that the student teacher takes longer than others to learn or to do an activity, allow more time.
- Do activities together with the student.
- Gradually give the student teacher less help.
- Let the student teacher do the activity with his colleagues and encourage them to help each other.
- Divide the activity into small achievable steps.

This cross-cutting issue can be addressed at the beginning, during the teaching process or at the end of the teaching process of any lesson by providing extra-activities to both slow student teachers and gifted ones. Some activities are provided in the additional activities but you can also prepare more exercises to meet your learning objectives as a teacher.

1.4. Guidance on the introductory activity:

Introductory Activity

1. **The students teachers will be given student teacher books and ask them to observe the photo on the activity 1.1 and asked to describe it, in their groups**

The first photo represents the sun shining over people. Some people are irritated by the sun radiations.

The photo present the patient who has the problems in the skeleton and being administrated by X-ray and the photo of injury has been created on the screen, which means the problem has been demonstrated on the screen by the X-rays and to resolve it becomes more easy even if the problem is inside

The patient has been protected on the other parts of the body especially on sex because they want to isolate them from the penetration of X-rays which could damage the cells of the rest of the body

The last image illustrates doctor putting testoscope on the patient.

2. **Close the class and create the darkness in your class**

Take the flash light(torch) and lights on the wall

After you shall explain how visible right are in the range of having the biggest wavelength and they are in the group of radiation as visible light. Which move at straight line and when they meet the obstacles they never move because they are stopped by that obstacle.

3. **Take your student teachers out on the sunshine, then try to ask them how they are feeling when the sunlight are on their skin, ask them to explain what is the cause of the sensation on their body.**

The sunlight is composed by different radiations of different wavelength, among them we have the ultraviolet, infrared, and the visible light which are reaching our body and feel the small pain

To the above activities you will add the following information.

We live in a sea of radiation, and benefit from many forms of radiation in our everyday lives, including from radio waves, microwaves, visible light and x-rays. Radiation can be harmful, especially when we are exposed to too high doses and/or for too long, for example to x-rays and nuclear radiation.

Different forms of radiation are defined by the energy, i.e. how low or high the energy is, and the type, i.e. whether it is in form of electromagnetic waves or subatomic particles.

Radioactive radiation is high-energy radiation that has many useful application. However, it can also cause damage to materials and to the human body. Whether or not radioactive radiation is dangerous depends on the type of radiation emitted by the radioactive source. The distance to the radioactive source and the duration of exposure to the radiation determine how dangerous it is. The same applies to the sun's rays.

Many forms of radiation are beneficial and essential to our survival. Some types of radiation can be hazardous and therefore pose risks to people. Two examples of high-energy potentially hazardous radiation are x-rays and nuclear radiation emitted by radioactive materials.

1.5. List of lessons/sub-heading

#	Lesson Title	Learning objectives	Periods
	Definition of radioactivity	Explain the concept of radioactivity	1
	Emission of alpha, beta and gamma rays and their properties	Explain the properties of alpha, Beta and Gamma rays	1
	Health hazards of radioactive substances	Explain the properties of alpha, Beta and Gamma rays	1
	Nuclear equations and radioactive decay series	Explain the mechanism of balancing a nuclear reaction	1
	Fission and fusion and their application	Explain half-lives of radioactive radioisotopes.	1
	Comparison between chemical and nuclear reactions	Explain the differences between nuclear reaction and chemical reaction	1
	Uses of some radioisotopes	Explain the application of radioisotopes in medicine, agriculture and industries	1
	End unit assessment		1

Lesson 1: Definition of radioisotopes and radioactivity (1 period)

a) Learning objectives

Explain the concept of radioactivity.

b) Prerequisites/Revision/Introduction:

Students will learn better this lesson if they have knowledge about isotopes of elements which have studied in year one (integrated sciences), atomic structure and chemical reactions and equations, balancing the equation of reaction and law of mass conservation and the subatomic particles (protons, neutrons, electrons and their properties)

c) Teaching resources

Use periodic table of elements, worksheets or books; projectors and/or chalkboard

d) Learning activities

By using different methods of group formation, the student teachers will be grouped in different groups and give them the activity one (1.1), and discuss in their different groups, during that time you will be guiding them in their discussion and manage the time for discussion.

After the given time, you will give the time for presentation where each group will present the findings one after another. Better to ask the following group to add the missing ideas to the previous answers given by their colleagues.

After you will enrich the idea generated by the students by harmonizing them, whereas the students teachers will taking the notes.

Answers to activity 1.1

1. **Each of two or more forms of the same element that contain equal numbers of protons but different numbers of nuetrons in their nuclei, and hence differ in relation atomic mass but not in chemical properties; in particular, a radioactive form of an element.**
2. **Use the formula of A= Z + N**

Atom	A	Z	N
$^{27}_{13}Al$	27	13	14
$^{12}_{6}C$	12	6	6
$^{87}_{38}Sr$	87	38	49

3. $^{1}_{1}\mathrm{H}$, $^{2}_{1}D$, $^{3}_{1}D$, **this is a set of isotopes because they respect the definition**

of isotope of having the same number of protons and different masses and neutrons

$^{27}_{13}\mathrm{Al}, ^{12}_{16}\mathrm{C}, ^{87}_{38}\mathrm{Sr},$,because they dont respect the definition of

protons they have differen masses and ndifferents neutrons.

4. **Each of the lines in which light (and heat) may seem to stream from the sun or any luminous body, or pass through a small opening.**
5. **As the definition indicates, the radiation is from a given source and passes in straight line, you can either see it or not but finally you observe the results of their presence. For example the X-rays are not visible but you can observe their activity on the screen the same for the torch you observe the object after the effect of the visible light.**

Answers to application activity 1.1

1.
   - a) **Radioactive decay** is the process by which an unstable atomic nucleus loses energy (in terms of mass in its rest frame) by emitting radiation, such as an alpha particle, beta particle with neutrino or only a neutrino in the case of electron capture, gamma ray, or electron
   - b) **Daughter nuclide** *is the remaining nuclide left over from radioactive decay.*
   - c) **Transmutation** is *the change of one chemical element into another*
2. Radioisotopes are very unstable and contain high levels of nuclear energy and emit this energy in the form of nuclear radiation i.e, they are naturally radioactive whereas isotopes are not.

The main difference is that isotopes can be either stable or unstable, but Radioisotopes are always unstable.

Lesson 2: Radioactive emission of alpha, beta and gamma rays, their properties and effect of electric and magnetic field on these particles (1period)

a) Learning objectives

Explain the properties of alpha, beta and gamma rays

b) Prerequisites/Revision/Introduction:

Students will learn better this lesson if they have knowledge about the use of periodic table in finding the position of elements when the atomic number is known; mass number and atomic number as discussed in unit one of year 1 and forces that exist between charged particles as discussed in chemical bonding unit

11 year 1, have a knowledge on operation (addition, subtraction, ..) From primary

c) Teaching resources

Use periodic table of elements, worksheets or books; projectors and/or chalkboard.

d) Learning activities

Guidance

Hopefully, student teachers in their respective groups can state the three main particles emitted by radioactive isotopes. In this activity, as a teacher you have to guide them in their respective groups to go through and learn more about their origin, properties and how they can be employed in nuclear equations. Thus, in this point try to make sure that you help each student teacher to do this as something that can make him/her feel proud of the chemistry he/she learnt as the subject of his/her choice.

After presentation in their different groups the tutor will harmonize the answers given by the students

Activity 1.2 Student Teacher's book of Y

1. The three types of the radiation that exist are
    - Alpha rays
    - Beta rays
    - Gamma rays
2. Properties of radiations (see student teacher's book)

Answers to application activity 1.2 Student teacher's book Y3

1. See student teacher's book
2. Both an alpha particle and a helium nucleus have 2 protons and 2 neutrons. However, an alpha particle is emitted from a nucleus during radioactive decay.
3.
    a) ${}^{39}_{19}K$, ${}^{40}_{19}K$ and ${}^{41}_{19}K$

    b) They all have 19 protons and 19 electrons, but they differ in the number of neutrons.
4.

Medical use	Atomic symbol	Mass number	Number of protons	Number of neutrons
Heart imaging	$^{201}_{81}\text{Tl}$	201	81	120
Radiation therapy	$^{60}_{27}\text{Co}$	60	27	33
Abnormal scan	$^{67}_{31}\text{Ga}$	67	31	36
Hyperthyroidism	$^{131}_{53}\text{I}$	131	53	78
Leukaemia treatment	$^{32}_{15}\text{P}$	32	15	17

5. Beta particles are fast moving electrons with a very low mass and so have a high charge to mass density. They are deflected much more than the heavier alpha particles.
6. See student's book

Lesson 3: Nuclear equations and radioactive decay series

a) Learning objectives

- Compare and contrast chemical and nuclear reactions.
- Write and balance nuclear reaction equations.

b) Prerequisites/Revision/Introduction:

Students will learn better this lesson if they have knowledge about chemical equations, atomic and mass numbers.

c) Teaching resources

Use periodic table of elements, worksheets or books; projectors and/or chalkboard.

d) Learning activities

Nuclear equations and radioactive decay series are among simple activities that can be performed successfully by students. What is necessary here for them is to have knowledge on the properties of alpha particle and beta particle as well as their atomic and mass numbers.

Methodological steps:

As a facilitator, you are expected to guide students to learn by doing activity 1.4, as described below:

Answers to activity 1.3

A balanced nuclear equation is one where the sum of the mass numbers (the top number in notation) and the sum of the atomic numbers balance on either side of an equation. Nuclear equation problems will often be given such that one particle is missing

- The following are the expected answers:

a) $^{226}_{88}\mathrm{Ra} \rightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\mathrm{He}$

b) $^{241}_{95}\mathrm{Am} \rightarrow {}^{237}_{93}\mathrm{Np} + {}^{4}_{2}\mathrm{He}$

c) $^{60}_{27}\mathrm{Co} \rightarrow {}^{60}_{28}\mathrm{Ni} + {}^{0}_{-1}\mathrm{e}$

d) $^{118}_{51}\mathrm{Sb} \rightarrow {}^{118}_{50}\mathrm{Sn} + {}^{0}_{+1}\mathrm{e}$

e) $^{4}_{2}\mathrm{He} + {}^{10}_{5}\mathrm{B} \rightarrow {}^{13}_{7}\mathrm{N} + {}^{1}_{0}n$

Answers to application activity 1.3

1. $a) {}^{28}_{13}\mathrm{Al} \rightarrow {}^{28}_{14}Si + {}^{0}_{-1}e$
   b) $^{87}_{36}\mathrm{Kr} \rightarrow {}^{86}_{36}Kr + {}^{0}_{1}n$
   $C) {}^{210}_{83}Bi \rightarrow {}^{206}_{81}Tl + {}^{4}_{2}He$
   d) $^{40}_{18}\mathrm{Ar} + {}^{4}_{2}He \rightarrow {}^{43}_{19}K + {}^{1}_{1}H$
   $e) {}^{238}_{92}U + {}^{1}_{0}n \rightarrow + {}^{239}_{92}U$

2. $^{60}_{27}Co \rightarrow {}^{60}_{28}Ni + {}^{0}_{-1}e$ 3. $+ \rightarrow$

3. $^{66}_{30}Zn + {}^{1}_{1}H \rightarrow + {}^{67}_{31}Ga$

4.

$$\begin{tikzcd}
{}^{232}_{90}\mathrm{Th} \arrow[r, "\beta"] & {}^{232}_{91}\mathrm{Pa} \arrow[r, "\beta"] & {}^{232}_{92}\mathrm{U} \arrow[r, "\alpha"] & {}^{228}_{90}\mathrm{Th} \arrow[r, "\alpha"] & {}^{224}_{88}\mathrm{Ra} \arrow[r, "\alpha"] & {}^{220}_{86}\mathrm{Rn} \arrow[d, "\beta"] \\
{}^{208}_{82}\mathrm{Pb} & {}^{212}_{84}\mathrm{Po} \arrow[l, "\alpha"'] & {}^{216}_{86}\mathrm{Rn} \arrow[l, "\alpha"'] & {}^{216}_{85}\mathrm{At} \arrow[l, "\beta"'] & & {}^{220}_{87}\mathrm{Fr} \arrow[ll, "\alpha"']
\end{tikzcd}$$

Lesson 4: Fission and fusion and their application

a) Learning objectives

- Write and balance nuclear reaction equations.
- Explain the concept of fission and fusion, their differences and uses

b) Prerequisites/Revision/Introduction:

Students will learn better this lesson if they have knowledge about chemical reactions in general, chemical energetics; nuclear equations and decay series.

c) Teaching resources

Use periodic table of elements, worksheets or books; projectors and/or chalkboard.

d) Learning activities

Guidance

- Guide students to explain nuclear fission and fusion as well as their application activitys.
- As a facilitator, you are expected to guide students to learn by doing activity 1.5, as described below:

Answers to Activity 1.4

When the glass is fallen down, it breaks and the different fragments are found around in the surface of falling down.

The reaction used in fabrication of atomic bomb:

Fusion produces neutrons which dissipate energy from the reaction. In weapons, the most important fusion reactionis called the D-T reaction. Using the heat and pressure of fission, hydrogen -2, or deuterium ($^{2}\mathrm{D}$), fuses with hydrogen-3, or tritium ($^{3}\mathrm{T}$) to form helium-4 ($^{4}\mathrm{He}$) plus one neutron (n) and energy

$$^{2}\mathrm{D} + {}^{3}\mathrm{T} \xrightarrow{\qquad} {}^{4}\mathrm{He} + {}^{1}\mathrm{n} + 17.6\mathrm{Mev}$$

1. Fission is the splitting of a heavy, unstable nucleus into two lighter nuclei while fusion is the process where two light nuclei combine together releasing large amount of energy.
2. Refer to student's book

Here, you have to emphasize on loss in mass as both processes take place and this mass is converted into energy. So make sure that, by the end of this lesson, your students are able to apply Einstein's equation to calculate the nuclear energy.

Answers to application 1.4

1. a) Fusion
   b) Both fusion and fission
   c) Fusion

2.

$$^{232}_{92}U + ^{1}_{0}n \longrightarrow ^{94}_{38}Sr + ^{139}_{54}Xe + 3\,^{1}_{0}n$$

1.5. Comparison between nuclear reaction and chemical reaction

a) Learning objectives

Compare and contrast chemical and nuclear reactions.

b) Prerequisite

The student teacher will learn better if they have a prior knowledge on law of mass conservation, balancing a chemical reaction atomic structure, balancing of a chemical reaction

c) Teaching resources

Use periodic table of elements, worksheets or books; projectors and/or chalkboard.

d) Learning activities

Guidance

Ask the student teachers to be in their groups and discuss the activity 1.5 in their student books and each one will contribute on the balancing the equations which are in the same activity after they will present group by group and it will be better if the students will enrich and make a correction of what is wrong for their colleagues.

Answers to activities

$$2H_2 + O_2 \longrightarrow 2H_2O$$

$$Zn + H_2SO_4 \longrightarrow ZnSO_4$$

$$HCl + NH_3 \longrightarrow NH_4Cl$$

Those are chemical reactions because they show the law of mass conservation as the atoms in reactants are the same in product the only difference in number of the same atoms

$${}^{58}_{28}Ni + {}^{1}_{1}H \rightarrow + {}^{55}_{27}Co + {}^{4}_{2}He$$
$${}^{58}_{28}Ni + {}^{1}_{1}H \rightarrow + {}^{55}_{27}Al + {}^{4}_{2}He$$

Those are nuclear reactions because the reactants and products are different and the mass even the atomic numbers have changed

e) Application Activity

1. See student book

2. a) Chemical reaction.
   b) Nuclear reaction
   c) Nuclear reaction
   d) Chemical reaction

Chemical equations are balanced by making the number of atoms of elements present on the reactant side equal to the number of atoms of elements present on the products side.

On the other hand, a nuclear equation is balanced by making the sum of atomic numbers and that of mass numbers of particles present on the left side equal to those present on the right side.

Lesson 6: Uses of some radioisotopes

a) Learning objectives

Explain the applications of radioisotopes in medicine, agriculture and industries

b) Prerequisites/Revision/Introduction:

The student teacher will learn better if they have the knowledge on the atomic structure, radioactive decay, fission and fusion.

c) Teaching resources

Worksheets or books; projectors and/or chalkboard.

d) Learning activities

Guidance

In their group they have to discuss on the activity1.7 and the Student teacher have to think critically to guess some uses of radioactive materials and carry out research to reinforce their prior knowledge.

Answers to learning activities

Task one (this concerns question 1)

- Guide students to answer question number one by asking them randomly.
- The following are the expected answers:

Radioactivity is used in medical examinations (such as X-rays) and nuclear power plants.

Radioactive substances and radiations are also used to sterilize food, prolong its shelf life, and prevent fires in public places.

Answers to application activity 1.6, Student teacher's book Y3

1. - Earth itself is a source of terrestrial radiation.

   - Radioactive materials (including uranium, thorium, and radium) exist naturally in soil and rock.
   - Air contains radon, which is responsible for most of the dose that people receive from natural background sources.

2. The signs and symptoms of acute radiation poisoning are:

- Vomiting, diarrhea, and nausea.
- Loss of appetite.
- Malaise or feeling unwell.
- Headache.
- Rapid heartbeat.

1.6. Summary of the unit

Radioactivity or radioactive decay is the spontaneous process by which an unstable atomic nucleus changes into another more stable atomic nucleus by emitting energy in form of radiation.

Radioactive substances (with unstable nuclei) also known as parent nuclides disintegrate/decay to form substances (with stable nuclei) known as "the daughter nuclides".

The instability in the nucleus of an atom is caused by a great number of protons and neutrons present in it due to the repulsion forces between the protons, hence resulting in transformations that lead to the formation of a stable nucleus by emitting radiations.

The symbols for the main radiations (or particles) emitted by unstable nuclei to become stable are given below:

Alpha particle = ${}^{4}_{2}$He or $({}^{4}_{2}\alpha)$, , beta particle = ${}^{0}_{-1}\beta$ (or ${}^{0}_{-1}$e), gamma radiation $= {}^{0}_{0}\Upsilon$

Proton = ${}^{1}_{1}$p (or ${}^{1}_{1}$H), neutron = ${}^{1}_{0}$n, positron = ${}^{0}_{+1}\beta\left(or\ {}^{0}_{+1}e\right)$

Nuclear equations involve both the parent and daughter nuclides and particles emitted (or used for bombardment of the nucleus). A nuclear equation is balanced when the sum of mass numbers and the sum atomic numbers on the left hand side are equal to the sums of those on the right hand side of the equation.

Unlike chemical equations, nuclear equations involve the atoms of elements present in products which are different from those in reactants.

The following table summarizes the types of radioactive decays and the changes that take place when the decay reaction is presented as a nuclear equation.

Nuclear fission is the splitting of a heavy, unstable nucleus into two lighter nuclei while nuclear fusion is the process where two light nuclei combine together releasing large amounts energy. Both fission and fusion are nuclear reactions that produce energy which can be used in nuclear power plants.

Radioactive isotopes have a variety of application. Generally, they are useful because either we can detect their radioactivity or we can use the energy they release.

Radioactivity plays an important role in medicine, agricultural processes and industry for radioactive dating where the age of an archeological artifact or rock can be determined by referring to the half-life of the rad ioisotope (such us carbon-14 or uranium-238 respectively) present in it.

Besides positive application of radioisotopes, however, it was found that continuous, high exposure to nuclear radiations lead to radiation risks like lung cancer and eventually to death.

1.7. Additional information for tutor

Radioactivity surrounds us

All the energy we get from the sun comes from one comparatively simple reaction: the fusion of two hydrogen nuclei into another, heavier nucleus. This reaction, involving the same forces as those responsible for beta radioactivity, is what has allowed elements other than hydrogen to be generated. Without radioactivity, our planet would have frozen over long ago and life on Earth would be impossible. Radioactive processes in the Earth core slowly release the heat essential for our survival, constantly maintaining the temperate climate we take for granted. All life has developed in a constant shower of radiations, adapting to it and occasionally using it for its own benefit. Radiations are an omnipresent, inescapable feature of our lives. Whether we go on mountain-climbing expeditions, go down to the cellar to get a bottle of wine, or get aboard a plane, we will always be exposed to it.

Apart from the countless natural sources of exposure, the harnessing of radiation by humanity has led to a multitude of application that we use every day. Even though the main artificially generated exposure comes from medical examinations (such as X-rays and gamma rays), we use radioactive substances and radiations to sterilize food, prolong its shelf life, and prevent fires in buildings. We must not forget, however, that all these common sources of radiation, whether natural or artificial, remain virtually harmless. The two main sources of exposure to radiation are natural radioactivity and medicine. A third source is the exposure in case of accidents.

Biological effect

After measuring the activity of a radioisotope, we need to know how much radiation absorbed by the tissues in the body. The rad (radiation absorbed dose) is the unit that measures the amount of radiation absorbed by one gram of material such as body tissue.

The rem (radiation equivalent in humans) measures the biological effects of different kinds of radiation. Alpha particles do not penetrate the skin. But if they enter the body by any other route, they cause a lot of damage even though they travel a short distance in the tissue. High-energy radiation such as beta particles and high-energy protons and neutrons that penetrate the skin and travel into tissue cause more damage. Gamma rays also damage the tissue because they travel a long way through the tissue and create a great deal of ionization.

To determine the equivalent dose or rem dose, the absorbed dose (rads) is multiplied by a factor that adjusts for biological damage caused by a particular form of radiation.

Biological damage (rem) = absorbed dose (rad) factor

Where,

Factor = 1 (for beta and gamma radiation).

Factor = 10 (For high-energy protons and neutrons)

Factor = 20 (for alpha particles)

The measurement for an equivalent dose is often in units of millirems (mrem, 1 rem = 1000 mrem). The SI unit is sievert (Sv). One Sievert is equal to 100 rems.

Table below summarizes some units of activity and the relationship between them.

Measurement	**Common Unit**	**SI Unit**	**Relationship**
Activity	Curie (Ci) = 3.7 disintegration/s	Becquerel (Bq) = 1 disintegration/s	1 Ci = 3.7Bq
Absorbed Dose	rad	Gray (Gy) = 1 J/kg tissue	1 Gy = 100 rad
Biological Damage	rem = rad factor	1 sievert (Sv)	1 Sv = 100 rem

Guidance to skills Lab 3

The student teachers will be given time to make a research on the website given in their book, tutor will take them to the computer laboratory and start the research. After, the student teachers will discuss on their findings in their groups while discussing they will be answering to the proposed question in this lab skills

1. a) By definition, a bomb or missile that uses nuclear energy to cause an expansion, there are two types of nuclear weapons: the fission bomb and thermonuclear bomb, most of nuclear weapons in these days are two stages thermonuclear weapons that uses both fission and fusion.

   b) The use of nuclear weapon in harmful to the environment and the human in general, because when they are used, the radiation are damaging and they remain in the soil and can make mutation which will end up by organ malformation and not good functioning. The plant and the soil in general will be highly affected especially in modifying organs (genetically modified organ) this can at less extent affect the human once eat the fruits of affected plants.

   c) On August 6, 1945, during World War II (1939-1945), an American B-39 bomber dropped the world's first deployed atomic bomb over the Japanese city of Hiroshima. The explosion wiped out 90 percent of the city and immediately killed 80,000 people; tens of thousands more would later die of radiations exposure. Three days later, a second B-29 dropped another A-bomb on Nagasaki, killing an estimated 40,000 people. Japan Emperor Hirohito announced his country's unconditional surrender in World War II in a radio address on August 15, citing the devastating power of " a new and most cruel bomb".

d) As human we have a task of fighting the nuclear weapons because they are highly harmful to us and the environment in general.

e) The environmental impact of nuclear power results form the nuclear fuel cycle operation, and the effect of nuclear accidents.

f) The environmental impact of nuclear power results from the nuclear fuel cycle opearation, and the effects of nuclear accidents

The greenhouse gases emission from nuclear fission power are much smaller than those associated with coal, oil and gas, and the routine health risks are much smaller than those associated with coal. However, there is a «catastrophic risk» potential if containment fails, which in nuclear reactors can be brought about by overheated fuels melting and releasing large quantities of fission products into the environment. This potential risk could wipe out the benefits. The most long-lived radioactive wastes, including spent nuclear fuel, must be contained and isolated from the environment for a long period of time. On the other side, spent nuclear fuel could be reused, yielding even more energy, and reducing the amount of waste to be contained. The public has been made sensitive to these risks and there has been considerable public opposition to nuclear power

Reaction used in fabrication of nuclear bomb (see student book)

Lesson 7: Health hazards of radioactive substances

a) Learning objectives

Develop awareness of the dangers of radioactive substances and nuclear weapons.

b) Prerequisites/Revision/Introduction:

Students will learn better this lesson if they have knowledge about chemical equations, atomic and mass numbers.

c) Teaching resources

Use periodic table of elements, worksheets or books; projectors and/or chalkboard.

d) Learning activities

Guidance

In their group already formed, the student teachers will discuss on the activity which is in their student book, and share idea if among them there are some who have been administrated by the X- ray or who has assisted where it has been done in his or her presence to explain others, after sharing experience, they will present the findings the same time the tutor will be moderating and after presentation he/ she will enrich the ideas of the student teachers

Answers to activities

The role of protecting the other organs while treating with X-rays it is to isolate the rest of the other part from radiations is to shield them to be deteriorated by the X-rays which could kill cells especially reproductive cells (ovum or sperms).

Answers to application activity 1.7

See student teacher's book

1.8. End unit assessment

Answers to End unit 1 assessment questions

I. MULTIPLE CHOICE QUESTIONS. Choose the letter corresponding to the appropriate answer

1C, 2C, 3C, 4B, 5C, 6A , 7D , 8D , 9A , 9B , 10B , 11B , 12C , 13B ,14D

II. Matching: Choose the letter of the correct word for each of the questions below. Each letter will be used only once.

1G, 2J,3B, 4D, 5I (or H), 6H (and J), 7E, 8C, 9A, 10F

III. Short and long answer open questions

1. Radioactivity is the spontaneous emission of particles and electromagnetic radiation from nuclei of unstable atoms.
2. An alpha particle is a collection of two protons and two neutrons and is equivalent to a helium nucleus.
3. $^{244}_{94}Pu \rightarrow + ^{240}_{92}U + ^{4}_{2}He$ Daughter isotope: **^{240}U**
4. $^{212}_{87}Fr \rightarrow + ^{208}_{85}At + ^{4}_{2}He$ Daughter isotope: **^{208}At**
5.

a) $^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e$

b) $^{238}_{92}U \rightarrow ^{4}_{2}He + ^{234}_{90}Th$

c) $^{11}_{6}C \rightarrow ^{11}_{5}B + ^{0}_{+1}e$

d) $^{60}_{27}Co \rightarrow ^{60}_{27}Co + ^{0}_{0}\gamma$

e) $^{195}_{79}Au + ^{0}_{-1}e \rightarrow ^{195}_{78}Pt$

6. a) Give values for a, b, c and d in the following nuclear equations:

i) a = 35, b = 16 ii) c = 4, d = 2

b) Mass number = 230, Atomic number = 90

7. Lead-206

1.9. Additional Activities

1.9.1. Remedial questions

1. Write the isotope symbols for each of the following nuclides:

a) Carbon-14 (Answer: $^{14}_{6}C$)

b) Cobalt-60 (Answer: $^{60}_{27}Co$)

c) Lead-206 (Answer: $^{206}_{82}Pb$)

d) Radium-226 (Answer: $^{226}_{88}Ra$)

e) Uranium-238 (Answer: $^{238}_{92}U$)

f) Californium-251 (Answer: $^{251}_{98}Cf$)

2. Which penetrates matter more deeply: alpha particles or beta particles? Suggest ways to protect yourself against both particles.

Answer: Beta particles penetrate more. A thick wall of inert matter is sufficient to block both Particles.

3. Tin has an atomic number of 50. Write the nuclear equation for the beta particle emission of tin-121. What is the daughter isotope?

Answer: $^{121}_{50}Sn \rightarrow ^{121}_{51}Sb + ^{0}_{-1}e$ **daughter isotope:** ^{121}Sb

1. What are the major types of radioactivity? Write chemical equations demonstrating each type.

Answer

1. The major types of radioactivity are alpha decay, beta decay, and gamma

ray emission; alpha decay with gamma emission: $^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He + \gamma$

beta decay: $^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{14}_{-1}e,$ (answers will vary)

Exercises

1. Define radioactivity.
2. Give an example of a radioactive isotope.
3. How many protons and neutrons are in each isotope?
    a. ^{56}Fe
    b. ^{224}Rn
1. Describe an alpha particle. What nucleus is it equivalent to?
2. Describe a beta particle. What subatomic particle is it equivalent to?
3. Explain what gamma rays are.
4. Explain why it is inappropriate to refer to gamma rays as gamma "particles."
5. Plutonium has an atomic number of 94. Write the chemical equation for the alpha particle emission of ^{244}Pu. What is the daughter isotope?
6. Tin has an atomic number of 50. Write the chemical equation for the beta particle emission of ^{121}Sn. What is the daughter isotope?

Answers

1. Radioactivity is the spontaneous emission of particles and radiation from atomic nuclei.
2. See student teacher's book
3. a)26 protons; 30 neutrons   b) 86 protons; 138 neutrons
4. An alpha particle is a combination of two protons and two neutrons and is equivalent to a helium nucleus.
5. Beta particle is made by the charge of negative one and the mass zero and it is equivalent to electron particle.
6. Gamma rays are high-energy electromagnetic radiation given off in radioactive decay.
7. It is inappropriate to use gamma rays due to its properties like penetration power, ionizing power, which can destroy the material or the body once passed through it.
8. $^{121}_{50}Pu \rightarrow {}^{4}_{2}He + {}^{244}_{92}\mathrm{U},$ $^{244}_{92}Pu \rightarrow {}^{4}_{2}He + {}^{240}_{92}\mathrm{U};$ the daughter isotope is , an atom of uranium
9. $^{121}_{50}Su \rightarrow {}^{0}_{-1}e;$ the daughter isotope is $^{121}_{51}Sb$, an atom of antimony.

1.9.2 Consolidation questions

1. Complete the following nuclear equations. Indicate the symbol, the mass number, and the atomic number of the unknown particle.

a) $^{13}_{7}\text{N} \rightarrow {}^{13}_{6}\text{C} + \_\_\_\_\_$ (**Answer:** $^{0}_{+1}e$)

b) $^{61}_{29}\text{Cu} + {}^{0}_{-1}\text{e} \rightarrow \_\_\_\_\_$ (**Answer:** $^{61}_{28}Ni$)

c) $^{11}_{6}\text{C} \rightarrow {}^{11}_{5}\text{B} + \_\_\_\_\_$ (**Answer:** $^{0}_{+1}e$)

d) $^{21}_{11}\text{Na} \rightarrow \_\_\_\_\_ + {}^{0}_{-1}e$ (**Answer:** $^{21}_{10}Ne$)

2. What are gamma rays?

Answer: *Gamma rays are high-energy electromagnetic radiation given off in radioactive decay.*

1.9.3. Extended activities

1. Define nuclear fission:

Answer: Nuclear fission is the breaking down of large nuclei into smaller nuclei, usually with the release of excess neutrons.

2. Uranium-235 undergoes a series of decays that finally forms lead-207. How many α and β particles are produced in one decay series?

Answer: 7 α and 4 β

3. What units are used to quantify radioactivity?

Answer: The curie, the Becquerel, the rad, the gray, the sievert, and the rem

4. SERIE OF QUESTIONS

1. Define *rad*.
2. Define *rem*.
3. How does a Becquerel differ from a curie?
4. How is the curie defined?
5. A sample of radon gas has an activity of 140.0 mCi. If the half-life of radon is 1,500 y, how long before the activity of the sample is 8.75 mCi?
6. A sample of curium has an activity of 1,600 Bq. If the half-life of curium is 24.0 s, how long before its activity is 25.0 Bq?
7. If a radioactive sample has an activity of 65 µCi, how many disintegrations per second are occurring?
8. If a radioactive sample has an activity of 7.55×10^5 Bq, how many disintegrations per second are occurring?
9. Describe how a radiation exposure in rems is determined.

10. Which contributes more to the rems of exposure—alpha or beta particles? Why?
11. Use Table 11.3.2 to determine which sources of radiation exposure are inescapable and which can be avoided. What percentage of radiation is unavoidable?
12. What percentage of the approximate annual radiation exposure comes from radioactive atoms that are in the body naturally?
13. Explain how a film badge works to detect radiation.
14. Explain how a Geiger counter works to detect radiation.

ANSWERS

1. Known as the radiation absorbed dose, a rad is the absorption of 0.01 J/g of tissue.
3. A Becquerel is smaller and equals 1 decay per second. A curie is 3.7×10^{10} Bq.
5. 6000 y
7. 2.41×10^6 disintegrations per second
9. The radiation exposure is determined by the number of rads times the quality factor of the radiation.
11. At least 16% (terrestrial and cosmic sources) of radioactivity is unavoidable; the rest depends on what else a person is exposed to.
13. A film badge uses film, which is exposed as it is subjected to radiation.

USE OF RADIOACTIVE ELEMENTS

1. Describe some of the different ways that amounts of radioactivity are applied in society.

ANSWERS

Radioactive isotopes are used in dating, as tracers, and in medicine as diagnostic and treatment tools.

OTHER NUMBERS

1. Define *tracer* is and give an example of how tracers work.
2. Name two isotopes that have been used as tracers.
3. Explain how radioactive dating works.
4. Name an isotope that has been used in radioactive dating.
5. The current disintegration rate for carbon-14 is 14.0 Bq. A sample of burnt wood discovered in an archaeological excavation is found to have a carbon-14 decay rate of 3.5 Bq. If the half-life of carbon-14 is 5,700 y, approximately how old is the wood sample?
6. A small asteroid crashes to Earth. After chemical analysis, it is found to contain 1 g of technetium-99 to every 3 g of ruthenium-99, its daughter isotope. If the half-life of technetium-99 is 210,000 y, approximately

how old is the asteroid?
7. What are some of the positive aspects of irradiation of food?
8. What are some of the negative aspects of irradiation of food?
9. Describe how iodine-131 is used to both diagnose and treat thyroid problems.
10. List at least five organs that can be imaged using radioactive isotopes.
11. Which radioactive emissions can be used therapeutically?
12. Which isotope is used in therapeutics primarily for its gamma ray emissions?

ANSWERS

1. A tracer follows the path of a chemical or a physical process. One of the uses of a tracer is following the path of water underground (answers will vary).
2. Radioactive dating works by comparing the amounts of parent and daughter isotopes and calculating back to how long ago all of the material was just the parent isotope.
3. About 11,400 y
4. Increased shelf life (answers will vary)
5. Iodine-131 is preferentially absorbed by the thyroid gland and can be used to measure the gland's activity or destroy bad cells in the gland.
6. Gamma rays, beta particles, or alpha particles

NUCLEAR ENERGY

1. How is nuclear energy produced?
2. What is the difference between fission and fusion?

ANSWERS

1. Nuclear energy is produced by carefully controlling the speed of a fission reaction.
2. In fission, large nuclei break down into small ones; in fusion, small nuclei combine to make larger ones. In both cases, a lot of energy is emitted.

OTHER NUMBERS

1. In the spontaneous fission of uranium-233, the following reaction occurs:

   $^{233}U + {}^{1}n \rightarrow {}^{142}Ce + {}^{82}Se + 10{}^{1}n$

   For every mole of ^{233}U that decays, 0.1355 g of mass is lost. How much energy is given off per mole of ^{233}U reacted?
2. In the spontaneous fission of plutonium-241, the following reaction occurs:

   $^{241}Pu + {}^{1}n \rightarrow {}^{104}Ru + {}^{124}Sn + 14{}^{1}n$

For every mole of ^{241}Pu that decays, 0.1326 g of mass is lost. How much energy is given off per mole of ^{241}Pu reacted?

3. The two rarer isotopes of hydrogen—deuterium and tritium—can also be fused to make helium by the following reaction:

   $^{2}H + ^{3}H \rightarrow ^{4}He + ^{1}n$

   In the course of this reaction, 0.01888 g of mass is lost. How much energy is emitted in the reaction of 1 mol of deuterium and tritium?
4. A process called *helium burning* is thought to occur inside older stars, forming carbon:

   $3^{4}He \rightarrow ^{12}C$

   If the reaction proceeds with 0.00781 g of mass lost on a molar basis, how much energy is given off?
5. Briefly describe how a nuclear reactor generates electricity.
6. Briefly describe the difference between how a nuclear reactor works and how a nuclear bomb works.
7. What is a chain reaction?
8. Why must uranium be enriched to supply nuclear energy?

ANSWERS

1. 1.22×10^{13} J
2. 1.70×10^{12} J
3. A nuclear reactor generates heat, which is used to generate steam that turns a turbine to generate electricity.
4. A chain reaction is an ever-expanding series of processes that, if left unchecked, can cause a runaway reaction and possibly an explosion.

UNIT 2: BENZENE

2.1. Key unit competence:

Relate the chemistry and uses of benzene to its nature and structure

2.2. Prerequisite (knowledge, skills, attitude and values)

Students will learn benzene better if they have understanding on: structures of hydrocarbons (both saturated and unsaturated), their preparation methods, their physical and chemical properties and their uses; covered in previous years.

2.3. Cross-cutting issues to be addressed

- **Peace and Values Education**

Benzene's structure shows that benzene is expected to be a cyclic alkene with three double bonds. It can be also considered to be isomeric with aliphatic alkynes (from isomers of its molecular formula, C_6H_6). However it does not share the majority of its properties with these hydrocarbons. This can be related to relationship in human beings. People share a lot of characters (things) in common but remember that everyone is unique in certain aspects. Some of these aspects are of good quality and can contribute to the development of the country. When a student teacher fails to cope well with his/her friends he/she may forget his/her uniqueness, quality, target, concentration ... and thus fail to contribute to the development of the country

There is a serious issue of peer pressure and bandwagon (ikigage) in youth. When introducing this unit, it would be an opportunity to guide student teachers on making decisions in their relationships. Help student teachers to:

a) Understand that relationship is very important. To be successful in life, they have to work together with others to share their qualities and experiences. But they have to choose good friends who will no mislead them.
b) Understand that in choosing friends they have to be careful and make sure they make good friends who will support them to achieve their future goals.
c) Reflect on their educational goals, the type of friends they have and their characters.
d) Asses if the friends they have are likely to help them achieve their future goals or destroy their future.
e) Make appropriate decisions, especially when it comes to their individual plans where they are not guided by teachers or parents.
f) Maintain the good qualities they have in particular and develop them if possible rather than hiding them in favour of their colleagues bad opinions.
g) To bear in mind that every student teacher has to share whatever he has with the colleagues without any kind of segregation

This can be done in a short whole class discussion about the structure of benzene which prevents it from reacting as alkenes for instance. It may be a good entry point for the chemistry teacher to confront the individual students who need advice on relationship matter.

This can be addressed to students just after the introductory activity and when teaching the stability of benzene.

- **Environment and sustainability**

Benzene is highly toxic and so pollutes environment when introduced into it. Its sources include natural and artificial. Young people should be addressed about this issue so that they can avoid to expose themselves to activities/actions that release benzene into the environment such as: smoking, petroleum stations, ...

This will help them to understand the importance of sustainability as they grow up and become responsible for the world around them.

This cross-cutting issue can be addressed after teaching physical properties, uses and toxicity of benzene.

- **Inclusive education**

This unit requires student teachers to carry out a lot of researches to be able to understand first, then share and discuss on things like structure of benzene, its stability, and so on. This may be challenging to students with special educational needs especially slow student teachers. However, as teacher you can organise your class and use different strategies to help all student teachers understand well. Some of the strategies to be used are provided below:

- Be patient! If you find that the student teacher takes longer than others to learn or to do an activity, allow more time.
- Do activities together with the student.
- Gradually give the student teacher less help.
- Let the student teacher do the activity with his colleagues and encourage them to help each other.
- Divide the activity into small achievable steps.
- Remember to praise and say ‘Well done’ when the student teacher learns something new or makes a strong effort.

2.4. Guidance on the introductory activity

Benzene is a hydrocarbon as it is made up by hydrogen and carbon atoms only. So, to introduce it to the students can be made simple by starting with hydrocarbons as they studied them in senior five. This is a guidance of how you can help your student teachers enter in the unit with open mindset about benzene.

- Put your students in groups of 3-4(or even 5 depending on the size of your class)

- Provide them with books or worksheets with the introductory activity, unit 2 from student teacher's book Y3.
- Give them a limited time to read, analyze, interpret and discuss about the activity. Here they have to cover the whole activity!
- Divide the chalkboard into two or three parts. In the next step you have to start with instruction number 1 (given as question 1) then number 2 will follow.

Instruction number one (or question 1)

- Call five members from different groups (at the same time) to write the five molecular formulae in question 1. Here, each student teacher writes his/her formula.
- Ask other members (randomly) to give their reactions about what their colleagues wrote on the chalkboard (here they can confirm what is written or propose other answers).

The expected answers are the following:

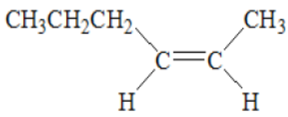
a) C_6H_{14}
b) C_6H_{12}
c) C_6H_{10}
d) C_6H_8
e) C_6H_6

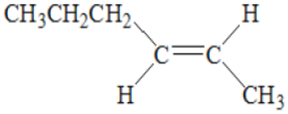
Instruction number one (or question 2 and 3)

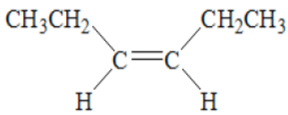
- Ask questions randomly to know your students' understanding about the description given on each question and write the possible structures (not necessarily all, 2 or 3 are enough).
- Ask other students (randomly) to give also their inputs about what their colleagues are suggesting on the chalkboard (here they can confirm what is written or propose other answers). Don't worry if they fail on some points especially those involving benzene's properties and structure! In this case, it is not necessary to give them the right answer because they will understand them and be able to do them through this unit. So, you can leave them with that curiosity!

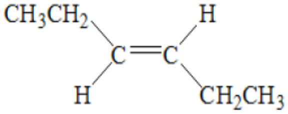
The expected answers are the following:

2. a) C_6H_{12}; C_6H_{10}; $C_6H_{8.}$ Some structures of C_6H_{12} are shown below.



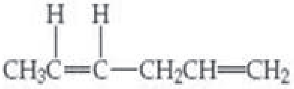




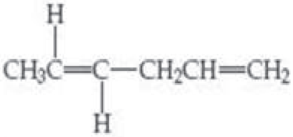


Some structures of C_6H_{10}

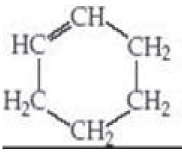
$CH_3CH_2CH_2CH_2C\equiv CH$ $CH_3CH_2CH_2C\equiv CCH_3$

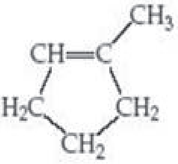


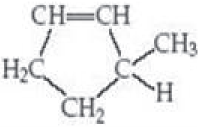
$CH_3\overset{H}{C}=\overset{H}{C}-CH_2CH=CH_2$



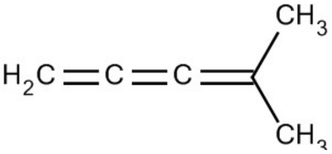
$CH_3\overset{H}{C}=\underset{H}{C}-CH_2CH=CH_2$

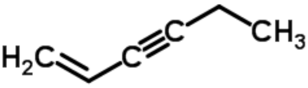


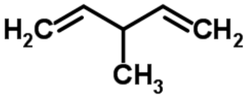




Some structures of C_6H_8

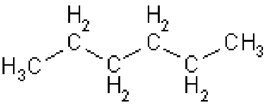


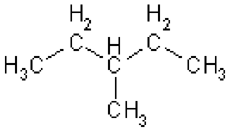


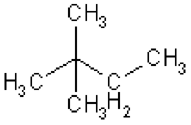


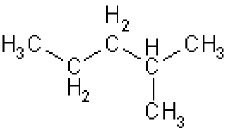
b) C_6H_{14} and structures of C_6H_{12} that are cyclic.

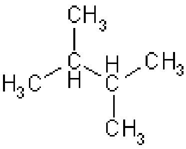
Some structures of C_6H_{14}



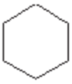


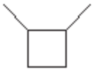
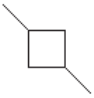
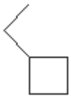
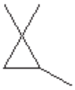
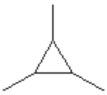






Some cyclic structures of C_6H_{12}

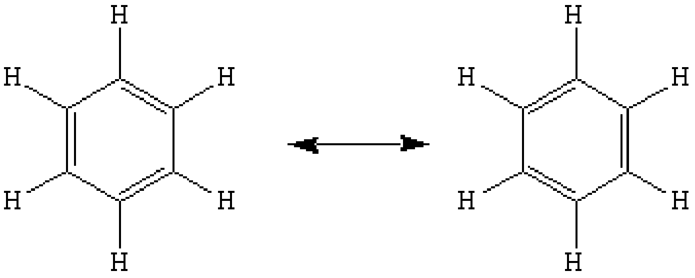




c) C_6H_6

Structures of C_6H_6

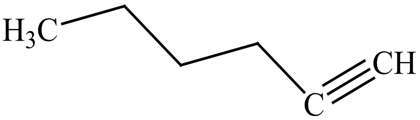


The resonance structures for benzene

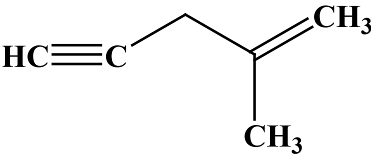
d) As in c) above

e) C_6H_{10} (hex-1-yne + its chain isomers) and C_6H_8 (with a terminal triple bond)

Structure of hex-1-yne:



Structure of C_6H_8



3. Benzene does not decolorise both solutions, due to its stable structure in which pi-electrons are delocalised. Or due to the resonance of its double bonds.

2.5. List of lessons

Unit 2: Benzene (9 periods)

#	Lesson Title	Learning objectives	Periods
	Structure of benzene.	Explain the structure of benzene	1
	Physical properties, uses and toxicity of benzene.	State the physical properties of benzene	1
	Preparation of benzene	Outline the different methods of preparation of benzene.	2
	- π-bond delocalization and Stabilization energy of benzene	Explain the delocalization of electrons in benzene ring and relate them to the stability	1
	Reactions of benzene	Describe the different mechanisms of reactions of benzene such as combustion, electrophilic addition and electrophilic substitution	4
	Nomenclature and positional isomerism in derivatives of benzene.	Explain the different positions on the benzene ring (ortho, meta, para positions)	1
	End unit Assessment		1

Lesson 1: Structure of benzene

a) Learning objectives

State the physical properties of benzene.

b) Prerequisites/Revision/Introduction:

Students will learn better the structure of benzene if they have knowledge on molecular and structural formulae of different hydrocarbons (covered in previous years); bond angles, bond length and resonance (covered in previous years)

c) Teaching resources

Use worksheets or books; projectors and/or chalkboard.

d) Learning activities

Use any methodology and try to form an heterogeneous groups, after you shall distribute the books of year three(Y3), monitor the discussion and tell them to use any other resources which can help them to find the necessary information which could provide the necessary information for better discovering the topic content

- Give them time for research for discussion in their respective groups

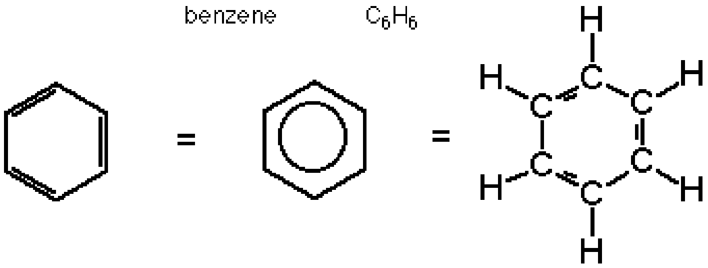
- Call two or 3 (or more depending on your time) groups to present their findings. During the presentation, remember to take notes on some key points (correct ones and wrong ones) that are going to guide you in the next step
- Ask members of other groups to give their comments/ inputs if any.
- Based on student teachers' production, through questioning, guide them to draw important conclusions. Here, you need to focus on resonance in Kekule's structure

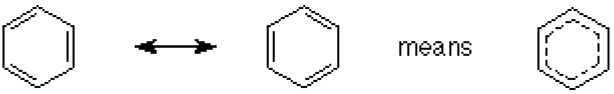
After carrying out research, students should present one or some (or even all) of the following:

- Benzene's structure by drawing its formula for example,
- How it is prepared from ethyne
- And so on..

Activity 2.1, student teacher book S6

- Benzene exist under different structures given as follow





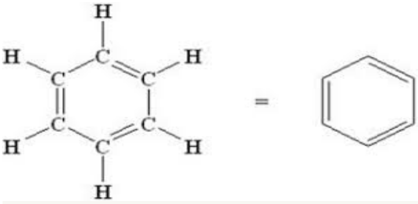
Benzene has been discovered by *Michael FARADAY*, or (*Kékulé) Friedrich August Kékulé Von Stradonitz,*

Answers for application activity 2.1, student teacher's book S6

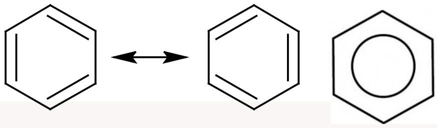
1. This checking can be performed better if it is done in pairs, or given to individual students as a homework.

Answers:

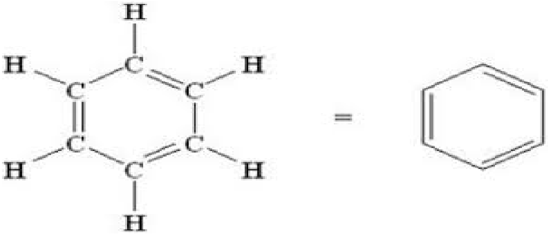
a)



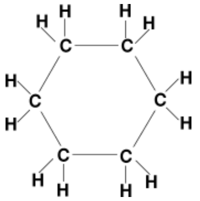
b)



The following structure is a benzene ring. Its chemical formula is $C_6 H_6$:



2. The following structure is a cyclohexane ring. Its chemical formula is C_6H_{12}:



Some major differences in their structure include:

- Benzene is an aromatic compound but cyclohexane is not aromatic.
- Benzene is an unsaturated molecule, but cyclohexane is saturated.
- Carbon atoms in the benzene ring have sp^2 hybridization where carbon atoms in the cyclohexane have sp^3 hybridization.
- Benzene has a planar structure whereas cyclohexane has chair conformations.
- Benzene has alternate double bonds and alternate single bonds while cyclohexane has only single bonds.

Benzene has the chemical formula of C_6H_6 where each carbon atom is bonded to two other Carbon atoms and a single Hydrogen atom. The 4th bond pair of electrons from each Carbon atom is delocalized, creating a delocalized cloud of electrons above and below the plane. Benzene is a hexagonal ring in shape with bond angles of 120 degrees between carbon atoms. All the bond lengths in Benzene are equal. Because of the system of delocalized electrons benzene is also far more energetically stable than it should be; its extra stability is known as its delocalization energy. Because of its increased stability benzene does not readily undergo addition reactions; instead it undergoes substitution reactions whereby a hydrogen atom is replaced by another atom or group of atoms.

Lesson 2: Physical properties, uses and toxicity of benzene

a) Learning objectives

- Appreciate the use of benzene in industries and in daily life. .
- Develop the carefulness while handling toxic chemicals like benzene

b) Prerequisites/Revision/Introduction:

Students will learn better the physical properties, uses and toxicity of benzene if they have knowledge the physical properties, as melting and boiling points, density, state at room temperature, .. and the change in physical properties of different compounds in aliphatic compounds such as alkanes, alkenes, alkynes and how they vary as the molecular mass increase and as the functional groups change

c) Teaching resources

Use worksheets or books; projectors and/or chalkboard.

d) Learning activities

You can start by asking your students questions about the structure of benzene

Methodological Guidance:

Take your student to laboratory, then provide them the possible materials and products even the protocols of carring out the experiment on the activity 2.2, in their groups, they have to respect all the procedures by reminding them the safety rules of laboratory, after you have to conduct them in those experiment and monitoring the application activity of the rules

While carrying out the experiments, you have to tell them to write down the findings and discuss on them after. While presenting in class after lab, you will be harmonizing the answers and enrich others they was not able to find by reminding them how the experiment was.

Activity 2.2, student teacher's book Y3

i) Benzene doesn't react with water, because it is unipolar solvent when you mix it with water it buoyance on it because it is less denser than water

ii) Once you mix benzene with each of the organic solvent, it becomes soluble because it is not polar it will be solubilized in other non-polar solvent.

iii) A highest flame is observed and it highly flammable like other hydrocarbons especially benzene derivatives.

2. According to experiment carried out, benzene can be used as source of energy, burning, a solvent for non-polar substances

Answers for application activity 2.2, student teacher's book Y3

1. Carcinogenic means any chemical known to cause cancer in humans.
2. Cigarette smoke contains benzene. Exposure to benzene vapor causes dizziness, unconsciousness, anaemia or leukemia and eventually cancer. Thus, the main advice here is that everybody should not smoke.
3. See student teacher's book

Lesson 3: Preparation of benzene

a) Learning objectives

Outline the preparations of benzene.

b) Prerequisites/Revision/Introduction:

Students will learn better the chemical reactions of alkanes, especially reforming, polymerizations of alkynes into benzene and preparation methods of other organic chemistry as covered in senior five.

c) Teaching resources

Use worksheets or books; projectors and/or chalkboard, some laboratory equipment.

d) Learning activities

You can start by asking your student teachers questions about the structure of benzene

Methodological steps:

Guide student teachers to do the activity one and guide them to refer to the alkanes in previous year two the activity has to be done in the different groups and give them the time of presentation

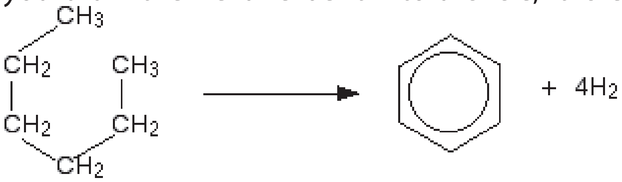
During presentation they have to relate the concept of reforming and discuss on the final product of reforming.

Activity 2.3, student teacher's book Y3

1. Reforming means to do something at the second time to improve its quality. If you take the parts of *reform*, *re*- and *form*, you can see that it means "to

shape again." We often use it to talk about correcting what's wrong in a system, and if you reform something, you make it better and fairer.

2. Reforming takes straight chain hydrocarbons in the C_6 to C_8 range from the gasoline or naphtha fractions and rearranges them into compounds containing benzene rings. Hydrogen is produced as a by-product of the reactions. For example, hexane, C_6H_{14}, loses hydrogen and turns into benzene. As long as you draw the hexane bent into a circle, it is easy to see what is happening.



Answers to application activity 2.3, student teacher's book y3

Step 1: thermal decomposition of calcium carbonate

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

Step 2: heating calcium oxide with coke (at 2000°C) to form calcium carbide

$CaO(s) + 3\ C(s) \rightarrow CaC_2(s) + CO(g)$

Step 3: dissolving calcium carbide in water in presence of acidified copper (II) sulphate to produce acetylene (ethyne)

$CaC_2(s) + 2\ H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(aq)$

Step 4: heating acetylene with iron catalyst

$3\ C_2H_2(g) \rightarrow C_6H_6(l)$

Lesson 4: π-bond delocalization and chemical stability of benzene

a) Learning objectives

Relate the conditions for reactions of benzene to its chemical stability.

b) Prerequisites/Revision/Introduction:

To learn better this lesson the student teacher has to have knowledge on the alkenes, resonances, and alkynes

c) Teaching resources

Use worksheets or books; projectors and/or chalkboard.

d) Learning activities

Guidance

Put your students in groups of 3-4 (or even 5 depending on the size of your class)

Provide them with books or worksheets with the activity 2.4 from student's book, give them time between 10 and 15 minutes to read, analyze, interpret and discuss on the activity in their respective groups, by that time you will be moving around and manage the discussion.

- Divide the chalkboard into two or three parts.
- Call the representatives any 2 or 3 groups (at the same time) to present their findings by writing their answers in the provided parts on the chalkboard (this is the way of gaining time)
- Ask other groups to consolidate by complementing their colleagues who have presented.
- Guide them to draw important conclusions.

Answers to the activity 2.4

1. The energy needed to produce
   a) Six moles of gaseous carbon atoms from C(s): 6 x (+715 kJ) = +4290 kJ
   b) Six moles of gaseous hydrogen atoms from $H_2(g)$: 6 x (+218 kJ) = +1308 kJ
2. The energy released when
   a) Three moles of C-C bonds are formed from gaseous atoms: 3 x (+346) = +1038kJ
   b) Three moles of C=C bonds are formed from gaseous atoms 3 x (+610) = +1830kJ
   c) Six moles of C-H bonds are formed from gaseous atoms. 6 x (+413) = +2478kJ
3. Total enthalpy change in **[1]**: 4290 + 1308 = +5598 kJ

   Total enthalpy change in **[2]**: 1038 + 1830 + 2478 = +5346 kJ

   The formation of benzene involves the following reaction

   $6C(s) + 3H_2(g) \rightarrow C_6H_6(l)$

   Enthalpy change for the reaction = the sum of enthalpy changes in reactants**[1]** – the sum of enthalpy changes in products **[2]**

   Enthalpy change of formation of benzene = +5598 kJ – (+5346 kJ) = +252 kJ
4. 252 – 82 = 170 Kj

   The calculated (theoretical) enthalpy change of benzene is greater than the experimental value by 170 Kj.

5. After searching, the students will come up with some or all of the following points:
   - The delocalization of p-electrons or aromaticity of benzene
   - Resonance of the double bonds in benzene
   - The low reactivity of benzene due to its stability
   - And so on

Answer to application activity 2.4, student teacher book Y3

The results obtained activity 2.4, suggest that real benzene is more stable than Kekule' structure.

Real benzene is more stable than cyclohexa-1,3, 5-triene by 170 kJ. This is due to the resonance of the double bonds in benzene ring.

(consult also student book)

Lesson 5: Reactions of benzene

a) Learning objectives

Illustrate the mechanism of electrophilic substitutions on benzene

b) Prerequisites/Revision/Introduction:

Student teachers will learn better the reactions of benzene if they have knowledge on chemical properties of alkenes, alkanes, halogenoalkanes carbonyl compounds and carboxylic acids covered last year2 and the beginning of this year, they have to must the content of previous lessons especially delocalization of electrons.

c) Teaching resources

Use worksheets or books; projectors and/or chalkboard.

d) Learning activities

Guidance

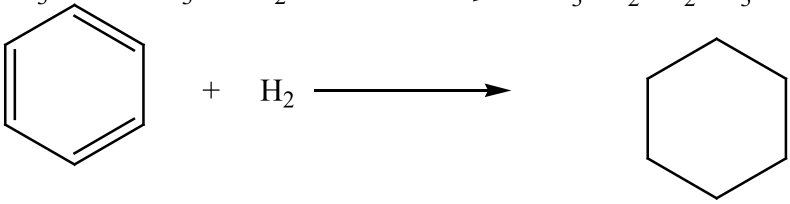
- Group your students in pairs (or groups of 3 or more depending on the size of your classroom) and provide them with resources to be used while carrying out their research.
- Give them time for research (15-20 minutes) for discussion in their respective groups
- Call two or 3 (or more depending on your time) groups to present their findings. During the presentation, remind them to take notes on some key points (correct ones and wrong ones) that are going to guide you in the next step
- Ask members of other groups to give their comments/ inputs if any.

- Based on student teachers' production, through questioning, guide them to draw important conclusions. Here, you need to emphasize on the reason why benzene prefers electrophilic substitution reactions to addition and their mechanism.

Answers to learning activities 2.5

1. $CH_3CHCHCH_3 + H_2 \xrightarrow{Pt} CH_3CH_2CH_2CH_3$

2.



3. $CH_3CH_2\,C(CH_3)CH_2 + HCl \longrightarrow CH_3CH_2CCl(CH_3)CH_3$

4. $C_6H_6 + Cl_2 \xrightarrow{UV} C_6H_6Cl_6$

Answers for application activity 2.5, student teacher's book Y3

a) Refer to student's book

b) Concentrated Nitric acid and concentrated sulphuric acid

c) An electrophile is formed during the nitration of benzene

i) ${}^{+}NO_2$

ii) $H_2SO_4 + HNO_3 \rightarrow HSO_4^- + H_2O + NO_2^+$

iii) See to student's book

Lesson 6: Nomenclature and positional isomerism in derivatives of benzene

a) Learning objectives

Outline the naming mechanism of derivatives of benzene

b) Prerequisites/Revision/Introduction:

Students will learn better the reactions of benzene if they have knowledge on the nomenclature of alkenes, alkanes, halogenoalkanes carbonyl compounds, carboxylic acids and any other organic compounds, they must have knowledge also on the isomerism in hydrocarbons especially positional isomers studies in year two especially for unit 8 and 9

c) Teaching resources

Use worksheets or books; projectors and/or chalkboard, student book of year three, shapes of molecules and molecular models

d) Learning activities

Guidance

- You can start by asking your students questions about the nomenclature of any organic compounds including benzene derivatives
- Put your students in groups of 3-4
- Give your students time between 10 and 15 minutes to read and analyze the content (about the rules of naming aromatic compounds) you have prepared for them on worksheets or in the student teacher's book Y3
- Call two or 3 (or more depending on your time) groups to present their findings.
- During the presentation, remember to take notes on some key points (correct ones and wrong ones) that are going to guide you in the next step
- Ask members of other groups to give their comments/ inputs if any.
- Based on student teachers' production, through questioning, guide them to draw important conclusions. Here, you need to emphasize on the positional isomers in disubstituted benzene derivatives.

After research, the students will come up with some or all of the following points:

- Mono substituted benzene derivatives are named by starting with the substituent's name followed by benzene.
- For di substituted benzene derivatives, the positions of the substituents in relation to one another is revealed since there exhibit positional isomers

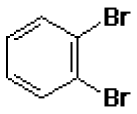
Activity 2.6, in student teacher book Y3

In question 1, in activity 2.6 (a), student teacher's book Y3,

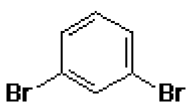
a) $CH_3CH_2CH(CH_3)CH_3$: Methylbutane
b) $ClCH_2CH_2CHOHCH_3$: 4-chlorobutan-2-ol
c) $CH_3CH(C_6H_5)CH_2CH_2CH_3$: 2-phenylpentane
d) $C_6H_5NO_2$: Nitrobenzene
e) C_6H_4ClBr: 1-Bromo-2-chlorobenzene or 1-bromo-3-chlorobenzene or 1-bromo-4-chlorobenzene

Answers to application activity 2.6, student teacher's book Y3

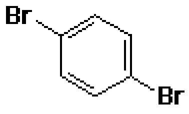
1. The three structural isomers are 1,2-dibromobenzene (o-dibromobenzene); 1,3-dibromobenzene (m-dibromobenzene) and 1,4-dibromobenzene (p-dibromobenzene)



o-dibromobenzene



m-dibromobenzene



p-dibromobenzene

2. Three isomers of nitro phenol (ortho, meta and para)

2.6. Summary of the unit

- Benzene is a colourless volatile liquid with an aromatic (pleasant) smell. It is found in crude oil and is a major part of gasoline. It is used to make plastics, resins, synthetic fibers, rubber, lubricants, dyes, detergents, drugs and pesticides. Benzene is highly toxic and is said to be carcinogen.
- Benzene is obtained on industrial scale by fractional distillation of petroleum oil followed by catalytic reforming.
- The delocalization of pi-electrons in benzene molecule provides it extra stability which is known as 'aromaticity'. Due to aromaticity in the molecule, benzene is more stable compared to aliphatic alkenes and does not show specific addition reactions of alkenes. This stability is explained on the basis of resonance in the molecule.
- To retain its stability, benzene does not undergo electrophilic addition reactions as it is the case for alkenes. Rather, it undergoes electrophilic substitution reactions in presence of a Lewis acid *which acts as a halogen carrier to generate an active electrophile.*
- Benzene derivatives are obtained by replacing one or more hydrogen atoms on benzene ring with other substituent groups. The systematic nomenclature for benzene derivatives involves naming substituent groups and identifying their positions on the ring by numbering the six carbon atoms in one direction. One identifies positional isomers of di-substituted benzene with the prefixes – Ortho, O-substituent groups on adjacent carbons in benzene ring. Meta, m- substituents separated by one carbon atom. Para, p- substituent groups on carbons on opposite sides of ring.

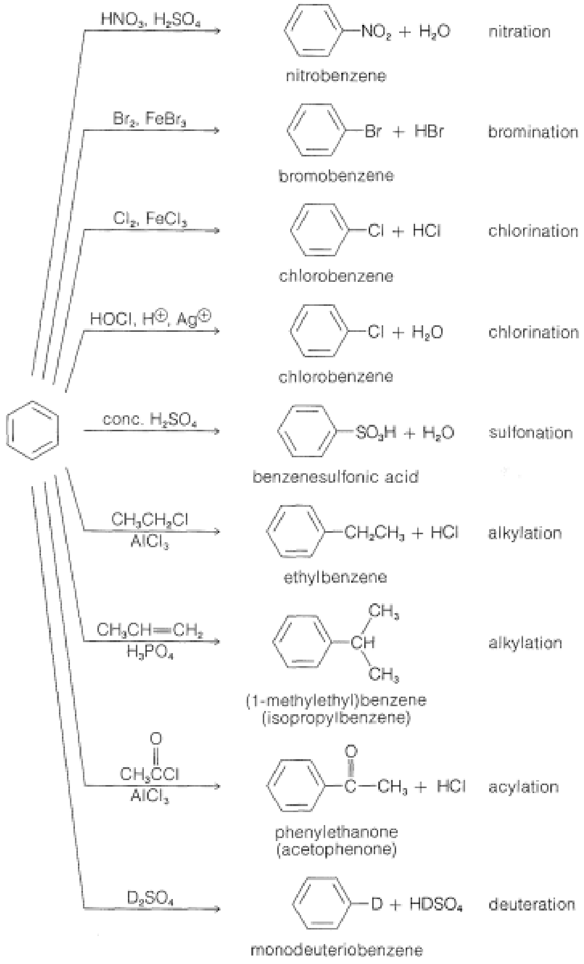
2.7. Additional information for teachers

The principal types of reactions involving aromatic rings are substitution, addition, and oxidation. Of these, the most common type is electrophilic substitution. A summary of the more important substitution reactions of benzene is given in Figure below Many of the reagents used to achieve these substitutions will be familiar to you in connection with electrophilic addition reactions to alkenes (e.g., Cl_{l2}, Br_2, H_2SO_4, and HOCl;. Electrophilic addition to alkenes and electrophilic aromatic substitution are both polar, stepwise processes, and the key step for each is attack of an electrophile at carbon to form a cationic intermediate. We may represent this type of reaction by the following general equations, in which the attacking reagent is represented either formally as a cation, $X^{\ominus}$, or as a neutral but polarized molecule, $X^{\delta\oplus}$ ---$Y^{\delta\ominus}$:

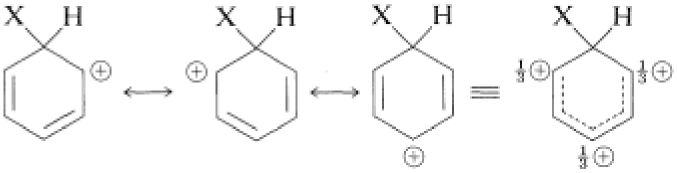
Electrophilic aromatic substitution (first step)

Electrophilic addition to alkenes (first step)

$$H_2C{=}CH_2 + X^{\oplus} \ (\text{or } \overset{\delta\oplus}{X}\cdots\cdots\overset{\delta\ominus}{Y}) \longrightarrow H_2\overset{\oplus}{C}{-}CH_2X \ (+\ Y^{\ominus})$$



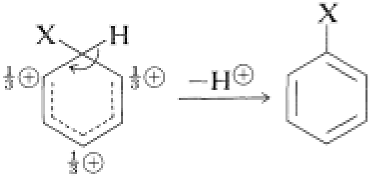
The intermediate shown for aromatic substitution no longer has an aromatic structure; rather, it is a cation with four π electrons delocalized over five carbon nuclei, the sixth carbon being saturated with sp^3-hybrid bonds. It may be formulated in terms of the following contributing structures, which are assumed to contribute essentially equally:



The importance of writing the hybrid structure with the partial charges at these three positions will become evident later. This kind of ion is referred to as a σ *complex* or a *benzene ion*.

The aromatic ring is regenerated from this cationic intermediate by loss of a proton from the sp^3-hybridized carbon. The electron pair of this C–HC–H bond then becomes part of the aromatic π-electron system and a substitution product of benzene, $C_6H_5XC_6H_5X$, is formed.

Electrophilic aromatic substitution (second step)



The gain in stabilization attendant on regeneration of the aromatic ring is sufficiently advantageous that this, rather than combination of the cation with $Y^{\ominus}$, normally is the favoured course of reaction. Herein lies the difference between aromatic substitution and alkene addition. In the case of alkenes there usually is no substantial resonance energy to be gained by loss of a proton from the intermediate, which tends therefore to react by combination with a nucleophilic reagent.

Electrophilic addition to alkenes (second step)

$^{+}CH_2{-}CH_2X + Y^{-} \rightarrow YCH_2{-}CH_2X$

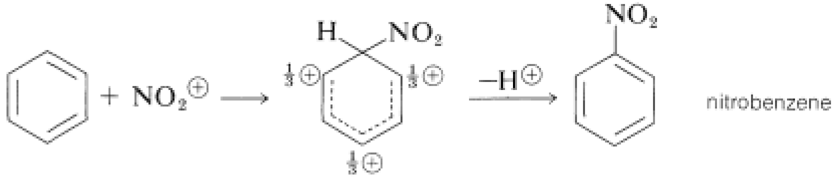
$^{+}CH_2{-}CH_2X + Y^{-} \rightarrow YCH_2{-}CH_2X$

Nature of the Substituting Agent

It is important to realize that in aromatic substitution the actual electrophilic substituting agent, X^+ or $X^{\delta\oplus}-Y^{\delta-}$ is not necessarily the reagent that is added to the reaction mixture. For example, nitration in mixtures of nitric and sulphuric acids is not brought about by attack of the nitric acid molecule on the aromatic compound, but by attack of a more electrophilic species, the nitronium ion, NO_2^+. This ion is formed from nitric acid and sulphuric acid according to the following equation:

$HNO_3 + 2H_2SO_4 \rightleftharpoons NO_2^+ + H_3O^+ + 2HSO_4^-$

The nitronium ion attacks the aromatic ring to give first a nitrobenzenium ion and then an aromatic nitro compound:

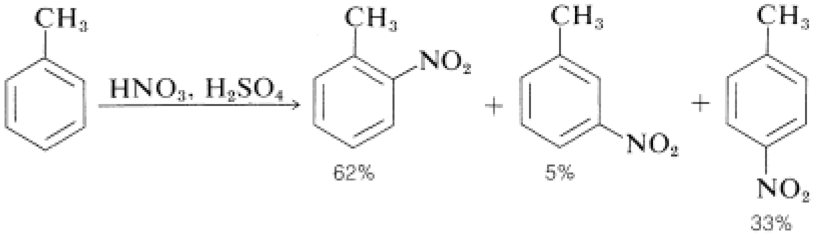


In general, the function of a catalyst (which is so often necessary to promote aromatic substitution) is to generate an electrophilic substituting agent from the given reagents. Thus it is necessary to consider carefully for each substitution reaction what the actual substituting agent may be. This problem does not arise to the same degree in electrophilic additions to alkenes, because alkenes are so much more reactive than arenes that the reagents employed (e.g. Br_2, Cl_2, HCl, HOCl, H_3O^+) themselves are sufficiently electrophilic to react with alkenes without the aid of a catalyst. In fact, conditions that lead to substitution of arenes, such as nitration in mixtures of nitric and sulfuric acid, often will degrade the carbon skeleton of alkenes.

Now we shall consider the individual substitution reactions listed in Figure 22-1 with regard to the nature of the substituting agent and the utility for synthesis of various classes of aromatic compounds.

Nitration

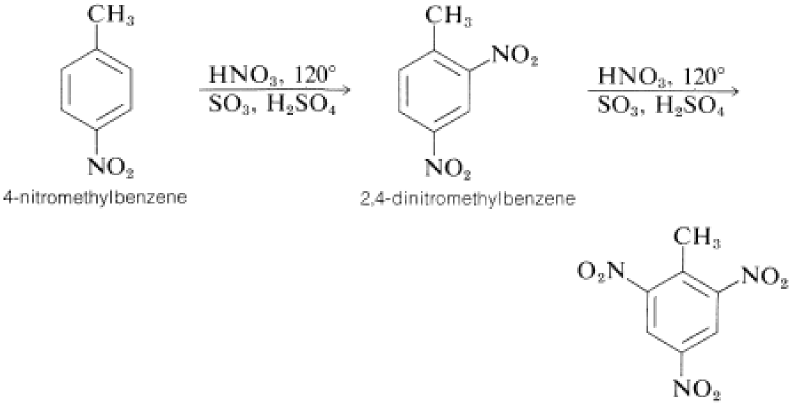
The nitronium ion, NO_2^+, is the active nitrating agent in nitric acid-sulfuric acid mixtures. The nitration of methylbenzene (toluene) is a typical example of a nitration that proceeds well using nitric acid in a 1:2 mixture with sulfuric acid. The nitration product is a mixture of 2-, 3-, and 4-nitromethylbenzenes:



The presence of appreciable amounts of water in the reaction mixture is deleterious because water tends to reverse the reaction by which nitronium ion is formed:

$$NO_2^+ + H_2O \overset{HSO_4^-}{\rightleftharpoons} HNO_3 + H_2SO_4$$

For this reason the potency of a nitric-sulfuric acid mixture can be considerably increased by using fuming nitric and fuming sulfuric acids. With such mixtures nitration of relatively unreactive compounds can be achieved. For example, 4-nitromethylbenzene is far less reactive than methylbenzene, but when heated with an excess of nitric acid in fuming sulfuric acid, it can be converted successively to 2,4-dinitromethylbenzene and to 2,4,6-trinitromethylbenzene (TNT):

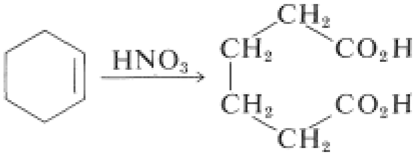


4-nitromethylbenzene

2,4-dinitromethylbenzene

2,4,6-trinitromethylbenzene (TNT)

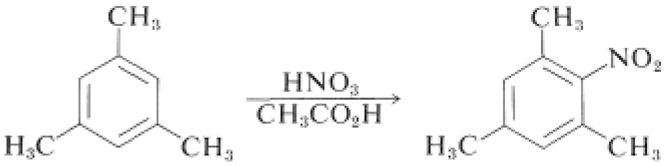
There are several interesting features about the nitration reactions thus far discussed. For instance, the conditions required for nitration of 4-nitromethylbenzene would rapidly oxidize an alkene by cleavage of the double bond:



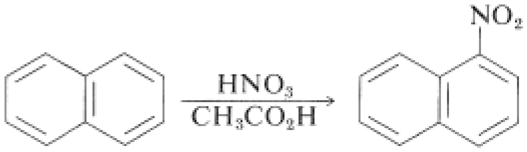
hexanedioic acid
(adipic acid)

Also the mononitration of methylbenzene does not lead to equal amounts of the three possible products. The methyl substituent apparently orients the entering substituent preferentially to the 2 and 4 positions. This aspect of aromatic substitution will be discussed in conjunction with the effect of substituents on the reactivity of aromatic compounds.

Some compounds are sufficiently reactive that they can be nitrated with nitric acid in ethanoic acid. Pertinent examples are 1,3,5-trimethylbenzene and naphthalene:

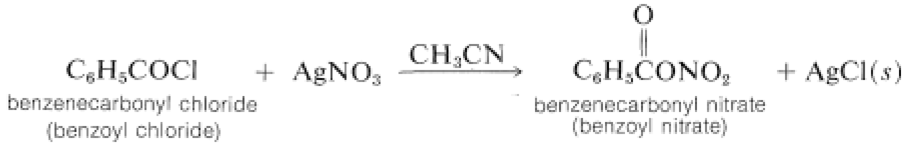


2,4,6-trimethylnitrobenzene

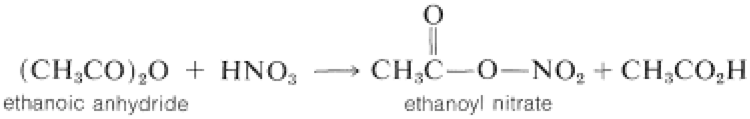


1-nitronaphthalene

Other convenient nitrating reagents are benzoyl nitrate, $C_6H_5COONO_2$, and ethanoyl nitrate, CH_3COONO_2. These reagents provide a source of NO_2^+ and have some advantage over $HNO_3 \cdot H_2SO_4$ mixtures in that they are soluble in organic solvents such as ethane nitrile or nitro methane. Having homogeneous solutions is especially important for kinetic studies of nitration. The reagents usually are prepared in solution as required from the corresponding acyl chloride and silver nitrate or from the acid anhydride and nitric acid. Such reagents are hazardous materials and must be handles with care.

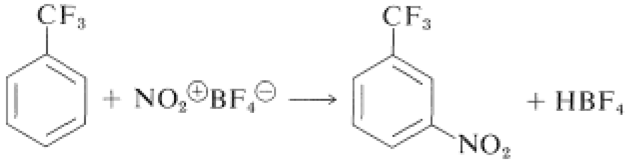


$$\underset{\text{benzenecarbonyl chloride (benzoyl chloride)}}{C_6H_5COCl} + AgNO_3 \xrightarrow{CH_3CN} \underset{\text{benzenecarbonyl nitrate (benzoyl nitrate)}}{C_6H_5\overset{\overset{O}{\|}}{C}ONO_2} + AgCl(s)$$



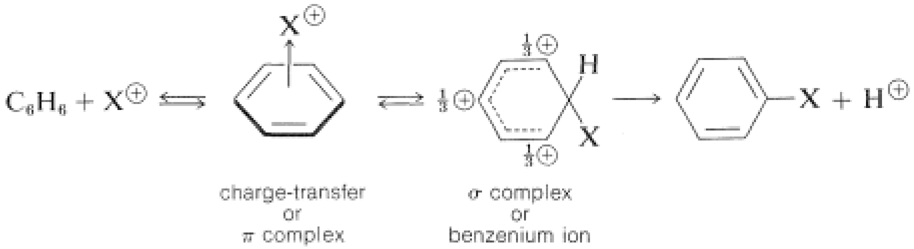
$$\underset{\text{ethanoic anhydride}}{(CH_3CO)_2O} + HNO_3 \longrightarrow \underset{\text{ethanoyl nitrate}}{CH_3\overset{\overset{O}{\|}}{C}-O-NO_2} + CH_3CO_2H$$

Nitronium salts of the type $NO_2^+X^-$ are very powerful nitrating agents. The counterion, X^-, must be non-nucleophilic and usually is fluoroborate, BF_4^- or SbF_4^-:



Halogenation

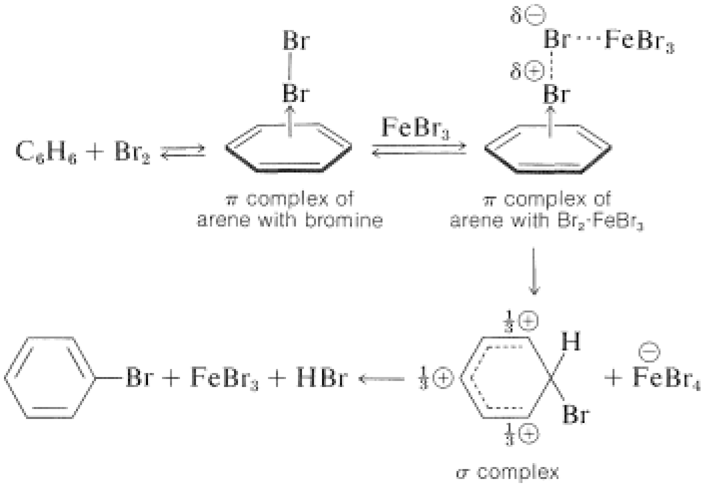
To some degree we have oversimplified electrophilic substitution by neglecting the possible role of the 1:1 charge-transfer complexes that most electrophiles form with arenes



With halogens, especially iodine, complex formation is visually evident from the color of solutions of the halogen in arenes. Although complex formation may assist substitution by bringing the halogen and arene in close proximity, substitution does not necessarily occur. A catalyst usually is required, and the catalysts most frequently used are metal halides that are capable of accepting electrons (i.e., Lewis acids such as $FeBr_3$, $AlCl_3$, and $ZnCl_2$). Their catalytic activity may be attributed to their ability to polarize the halogen-halogen bond in the following way:

$Br^{\delta\oplus}\cdots Br^{\delta\ominus}\cdots FeBr_3$

The positive end of the dipole attacks the aromatic compound while the negative end is complexed with the catalyst. We can represent the reaction sequence as follows, with the slow step being formation of a σσ bond between $Br^{\oplus}$and the aromatic ring:



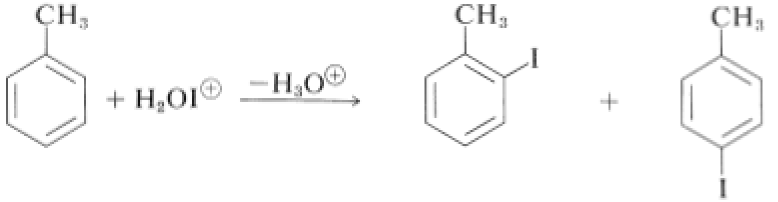
The order of reactivity of the halogens is $F_2>Cl_2>Br_2>I_2$. Fluorine is too reactive to be of practical use for the preparation of aromatic fluorine compounds and indirect methods are necessary. Iodine usually is unreactive. It has been stated that iodination fails because the reaction is reversed as the result of the reducing properties of the hydrogen iodide that is formed:

$C_6H_6+I_2 \rightleftharpoons C_6H_5I+HI$

This view is not correct because, as Kekule himself showed, iodobenzene is not reduced by hydroiodic acid except at rather high temperatures.

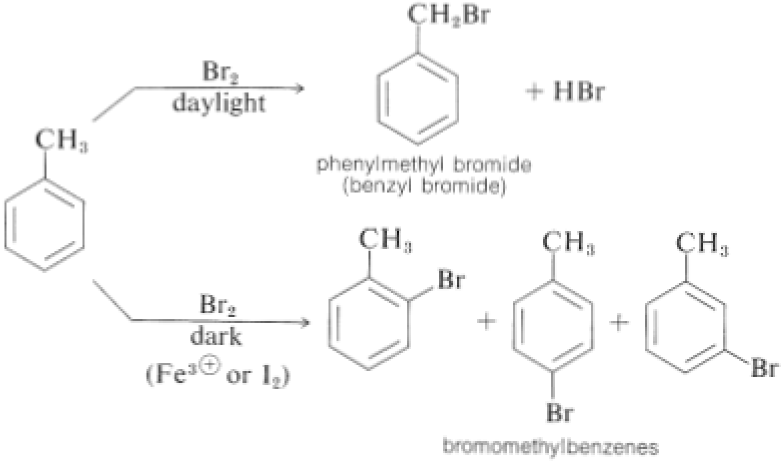
The way to achieve direct iodination in the absence of powerful activating substituent groups is to convert molecular iodine to some more active species (perhaps $H_2OI^{\oplus}$ or $I^{\oplus}$) with an oxidizing agent such as nitric acid or hydrogen peroxide.

With combinations of this kind good yields of iodination products are obtained:



2-iodomethylbenzene (*ortho*-iodotoluene) 4-iodomethylbenzene (*para*-iodotoluene)

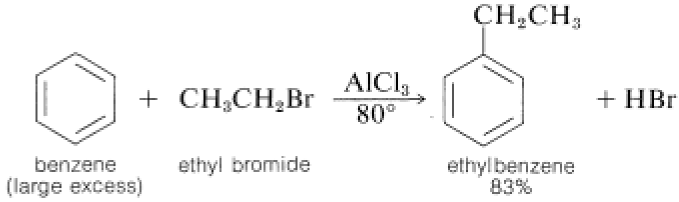
Halogen substitution reactions with chlorine or bromine must be carried out with adequate protection from strong light. If such precautions are not taken, an *alkyl* benzene will react rapidly with halogen by a photochemical process to substitute a hydrogen of the alkyl group rather than of the aromatic ring. The reaction has a light-induced, radical-chain mechanism of the kind discussed for the chlorination of propene). Thus methylbenzene reacts with bromine when illuminated to give phenyl methyl bromide; but when light is excluded and a Lewis acid catalyst is present, substitution occurs to give principally the 2- and 4-bromomethylbenzenes. Much less of the 3-bromomethylbenzene is formed:



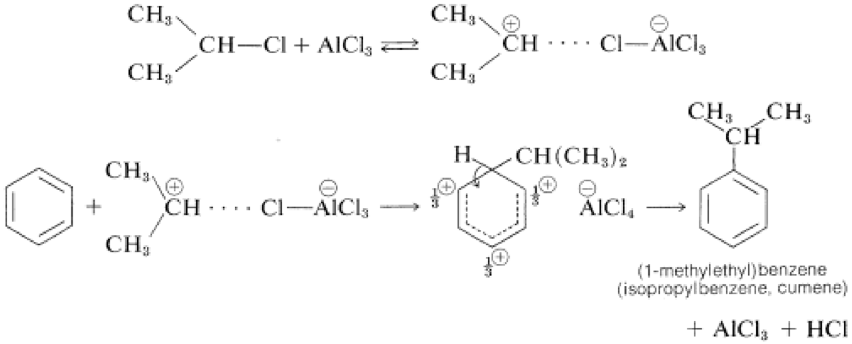
Benzene itself can be induced to *add* halogens on strong irradiation to give polyhalocyclohexanes

Alkylation

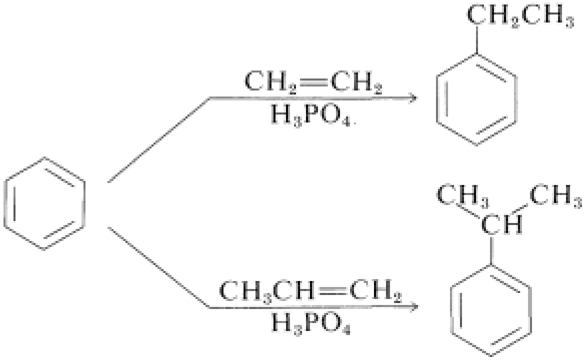
An important method of synthesis of alkyl benzenes utilizes an alkyl halide as the alkylating agent and a metal halide, usually aluminum chloride, as catalyst:



This class of reaction is called Friedel-Crafts alkylation in honor of its discoverers, C. Friedel (a French chemist) and J. M. Crafts (an American chemist). The metal-halide catalyst functions much as it does in halogenation reactions to provide a source of a positive substituting agent, which in this case is a carbocation:



Alkylation is not restricted to alkyl halides; alcohols and alkenes may be used to advantage in the presence of acidic catalysts such as H_3PO_4, H_2SO_4, HF, BF_3, or HF—B_{F3}. Ethyl benzene is made commercially from benzene and ethene using phosphoric acid as the catalyst. Isopropyl benzene is made similarly from benzene and propene:



Guidance to skills lab 2

Ask the student to go and make a further research on benzene and try to show the differences that could exist between benzene and other organic compound, try to reformulate the questions which could exist, you can give them a given time like a week to go to interact either the people like sellers and another which could help them to demonstrate them,.

Tell them to explain how they know it how telling how the packaging is done..

2.8. End unit assessment

Answers to end unit assessment questions

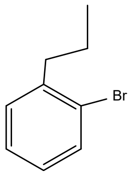
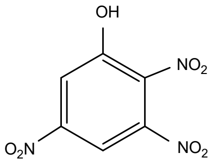
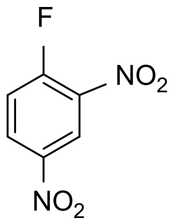
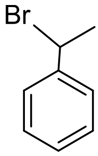
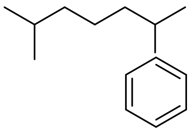
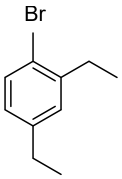
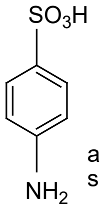
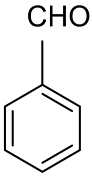
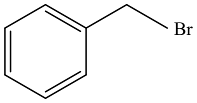
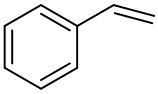
I. MULTIPLE CHOICE QUESTIONS

1. c
2. e
3. a
4. c
5. a
6. d
7. a
8. d

II. OPEN QUESTIONS

1.

a) Chlorobenzene
b) t-Butylbenzene
c) (2-Ethylpentyl)benzene or 2-Ethyl-1-phenylpentane
d) o – Hydroxybenzoic acid
e) 1,2 – benzene dicarboxylic acid or Phthalic acid
f) m - Chlorobenzaldehyde
g) 2 – Chloro -1,4 –dinitrobenzene
h) 4 – Bromo- 1,2- dimethylbenzene
i) 2,6-dibromophenol
j) 4 –Chloro- 2,5 –trinitrotoluene

a) 	b) 	c) 
d) 	e) 	f) 
g)  also called (p-aminobenzene sulfonic acid)	h) 	i) 
j) 		

Benzene is a planar molecule with the shape of regular hexagon

i) Heat of hydrogenation is less than expected

ii) All C – C – C bond angles are 120 °, all six carbon atoms are sp^2 hybridized

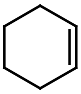
iii) All C – C bonds have the same length (139 pm)

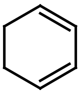
iv) Conjugated with p orbital on each carbon

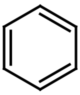
v) Kékulé resonance structures

  a) Cyclohexane ΔHhyd = - 118 kJ/mol (least stable)
  b) 1,3 - Cyclohexadiene Δ Hhyd = 2 x (-118) = - 230 kJ /mol
  c) Benzene ΔHhyd = - 206 kJ/mol (most stable)

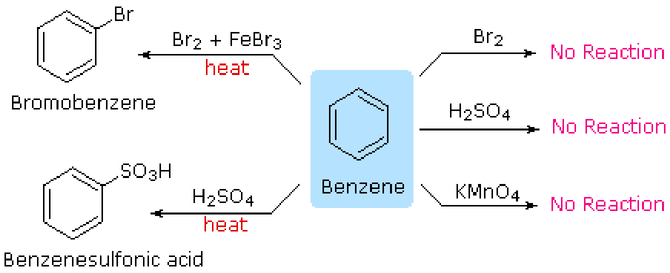
a) b) c)

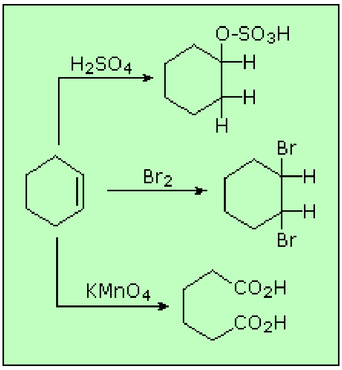






1. The chemical reactivity of benzene contrasts with that of the alkenes in that substitution reactions occur in preference to addition reactions, as illustrated in the following diagram (some comparable reactions of cyclohexene are shown in the green box).





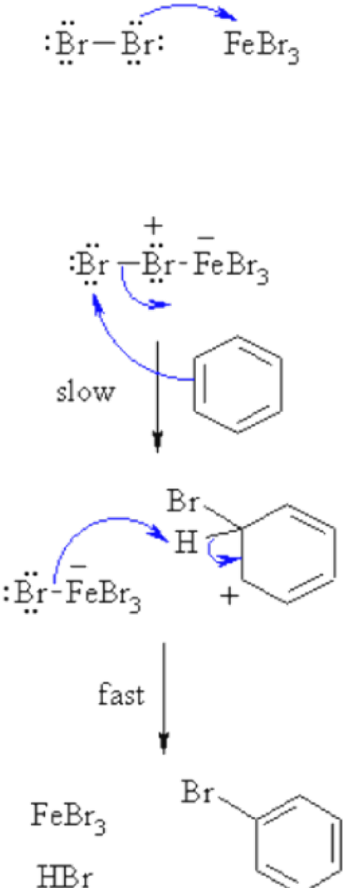
1.

i) FeBr$_3$ (iron (III) bromide) or AlBr$_3$ (aluminium bromide)

ii) Lewis acid

iii) $C_6H_6(l) + Br_2(l) \rightarrow C_6H_5Br(l) + HBr(g)$

iv) Bromobenzene



v)

i) Cyclohexene is a cyclic alkene with one double bond while benzene has three double bonds but which are delocalised

ii) The double bond in cyclohexene is fixed so that it can approach the bromine molecule more readily than that in benzene ring which is delocalised.

1.

a) Refer to nitration in student's book

b) Refer to Student's book

c)

i) Refer to Student's book

ii) A curly arrow is a type of arrow that shows the movement of a pair of electrons from its tail to head (from the electron rich species to an electron deficient species).

iii) Nitronium ion. It acts as an electrophile.

2.9. Additional activities

2.9.1. Remedial activities

1. What is the difference between aromatic and aliphatic compounds?

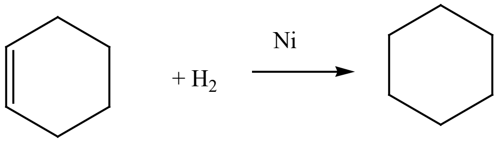
Answer: Aromatic compounds are often strong smelling and contain a ring system of delocalised electrons.

2. What is meant by hydrogenation?

Answer: Hydrogenation refers to the addition of hydrogen to a molecule

3. Write an equation of the hydrogenation of benzene.

Answer:



4. Why is benzene used only for industrial processes?

Answer: Due to its toxicity benzene is not safe for domestic commercial use.

5. For each of the questions below, write down the letter corresponding to the right answer.

i) Friedrich August Kekule's structure of benzene was inspiration of a

a) Chemist

b) Nature

c) Dream

d) Cloud

Answer: C

ii) Chlorobenzene is one of

- a) Halogens
- b) Arenes
- c) Halogenoarenes
- d) All of them

Answer: C

iii) Comparing, Phenol reacts readily then benzene, so it is a

- a) Nucleophile
- b) Electrophile
- c) Protophile
- d) Both a and b

Answer: A

iv) Bromine water does not react with benzene at

- a) High temperature
- b) Low temperature
- c) Room temperature
- d) Constant temperature

Answer: C

v) What is the electrophilic species in the sulphonation of an aromatic compound?

HSO_3^+

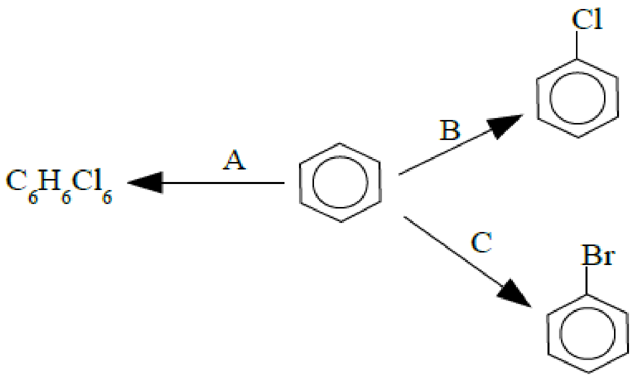
- a) SO_2^+
- b) SO_3
- c) H_2SO_4

Answer: A

2.9.2. Consolidation activities

1.

a) Give the necessary reagents and conditions for each of the following changes:



b) The product from reaction **A** shows geometric isomerism even though it does not contain any carbon-carbon double bonds. Explain briefly why.

c) Name the product from reaction **B.**

Answer:

a) **A:** Bubble chlorine through hot benzene for an hour in the presence of UV light.

B: Bubble chlorine through benzene at room temperature in the presence of either aluminium chloride or iron, but in the absence of UV light.

C: React benzene with bromine at room temperature in the presence of either aluminium bromide or iron, but in the absence of UV light.

(With B and C you don't need to mention both possible catalysts - just choose one of them.)

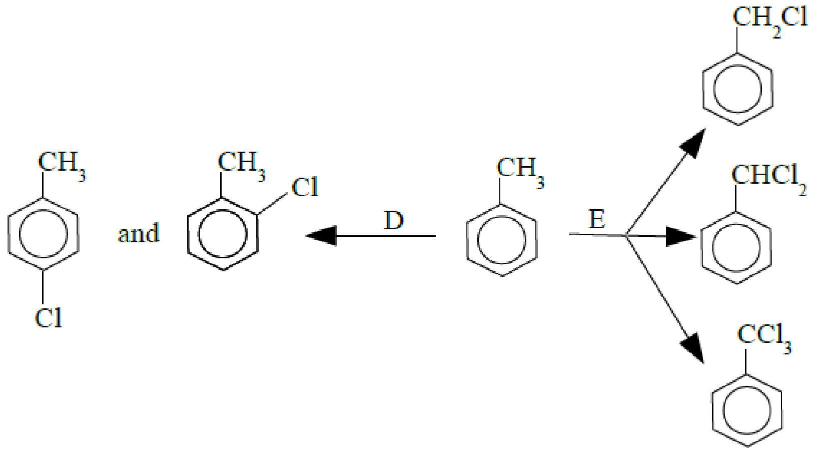
b) The molecule is a ring of carbon atoms, each with a hydrogen and chlorine atom attached. These can lie above or below the ring. If the chlorine atom on, say, carbon 1was below the ring, then the chlorine atom on carbon 2 could lie either above or below the ring – producing geometric isomers.

There are obviously lots of variations on this if you consider all the carbons around the ring.

c) Chlorobenzene

2.

a) Give the necessary reagents and conditions for each of the following changes:



b) Name the products in reaction **D.**

c) In reaction E you normally get a mixture of products, although you can favour the top one or the bottom one by varying the conditions. How would you aim to get mainly the bottom one?

d) Name the three products of reaction **E.**

Answer:

a) D: Bubble chlorine through methylbenzene at room temperature in the presence of either aluminium chloride or iron, but in the absence of UV light.

E: Bubble chlorine through boiling benzene in the presence of UV light.

b) 4-chloromethylbenzene and 2-chloromethylbenzene

c) Use an excess of chlorine.

d) (Chloromethyl)benzene, (dichloromethyl)benzene, (trichloromethyl) benzene.

2.9.3. Extended activities

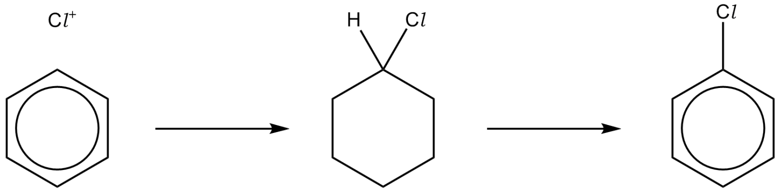
Analyse the following statements and write the letters corresponding to the correct ones:

1. Which aromatic substitution does **not** require a halogen carrier?

A	$C_6H_6 \rightarrow C_6H_5NO_2$
B	$C_6H_6 \rightarrow C_6H_5Cl$
C	$C_6H_6 \rightarrow C_6H_5CH_3$
D	$C_6H_6 \rightarrow C_6H_5COCH_3$

Answer: A

2. The reaction mechanism shown below is incomplete.



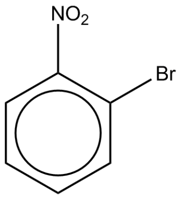
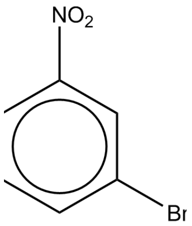
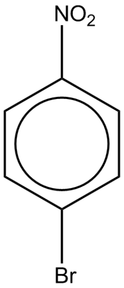
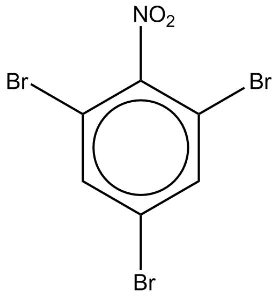
What would be a **correct** addition to this mechanism?

A	A curly arrow from Cl^+ to the benzene ring
B	A curly arrow from the displayed C–H bond, into the ring, in the intermediate
C	An aromatic ring in the C_6 ring in the intermediate
D	HCl as a product in the final step Answer: C

3. Which will **not** result in a reaction?

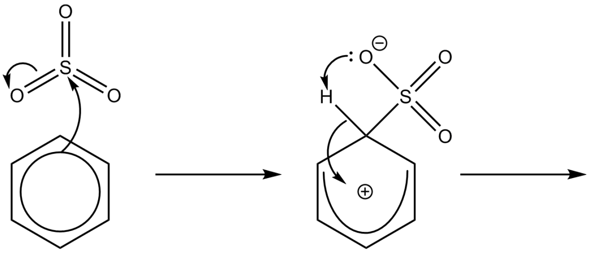
A	$C_6H_5OH + Br_2$	
B	$C_6H_5OH + NaOH$	
C	$C_6H_5OH + Na_2CO_3$	**Answer: C**
D	$C_6H_5OH + HNO_3/H_2SO_4$	

4. Which is the correct product formed from the bromination of nitrobenzene?

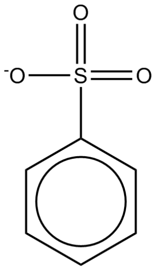
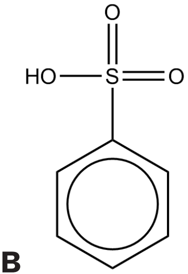
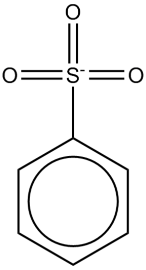
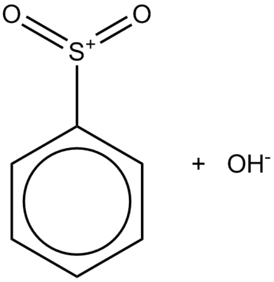
A		**B**	
C		**D**	

Answer: B

5. Sulfonation of benzene involves an electrophilic substitution mechanism.

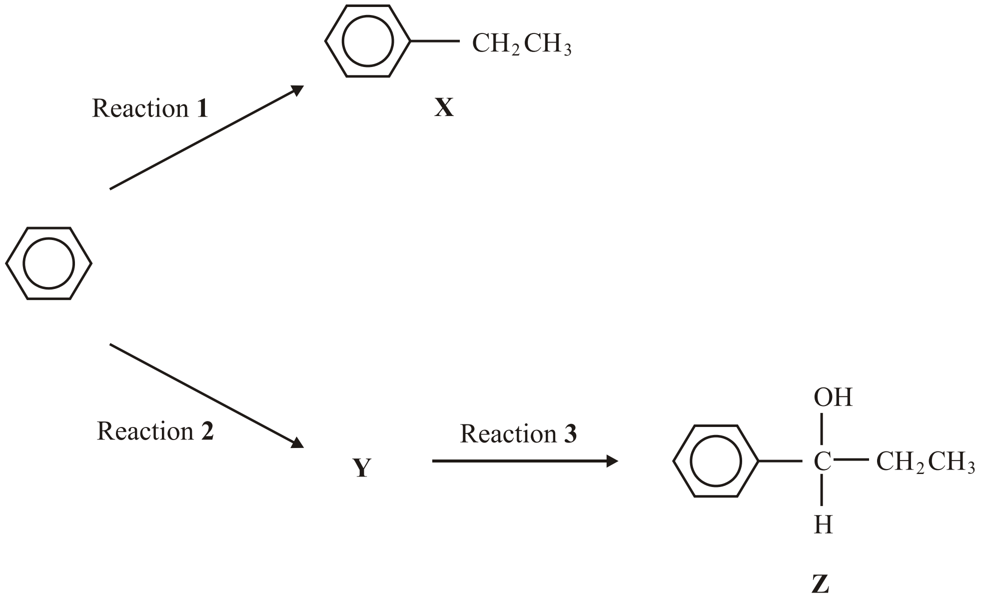


What would be the final product?

 **A**	 **B**
 **C**	 **D**

Answer: B

Two reactions of benzene are shown below.



a) Name **X** and give the reagent and catalyst required for Reaction **1**. Write an equation for the formation of the reactive intermediate involved in this reaction. Name and outline a mechanism for the reaction of this reactive intermediate with benzene to form X.

b) (i) Deduce the structure of Y and give the organic reagent needed for Reaction 2.

iii) Give the reagent(s) needed for Reaction **3**.

ANSWER

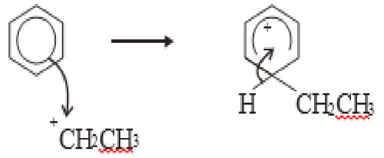
(a) X = Ethyl benzene

Chloroethane or bromoethane *(or ethene and hydrogen chloride / bromide)*

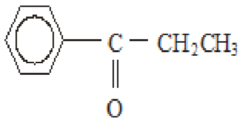
Aluminium chloride/bromide or iron(III) chloride /bromide

$CH_3CH_2Cl + AlCl_3 \rightarrow CH_3CH_2^+ + AlCl_4^-$

Electrophilic substitution



(b) (i)



(ii) CH_3CH_2COCl / propanoyl chloride or $(CH_3CH_2CO)_2O$ / propanoic anhydride

$NaBH_4$ or $LiAlH_4$ or H_2/Ni *(not Sn / Fe with HCl)*

UNIT 3: DERIVATIVES OF BENZENE

3.1. Key unit competence

Relate aromatic ketones, aldehydes, carboxylic acids and amines to their chemical activity.

3.2. Prerequisite knowledge and skills

Student teachers will understand better this unit concerning derivatives of benzene if they know:

The chemical properties, physical properties and nomenclature of benzene (The chemical properties, physical properties and nomenclature of aliphatic compounds

3.3. Cross-cutting issues to be addressed

- **Environment and sustainability**

The growing awareness of the impact of the human race on the environment has led to recognition of the need to ensure our young people understand the importance of sustainability as they grow up and become responsible for the world around them. Hence Environment and Sustainability is a very important cross-cutting issue

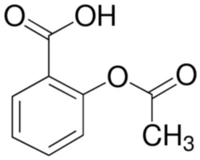
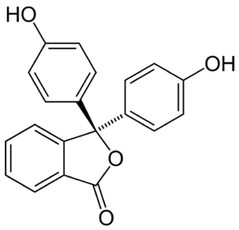
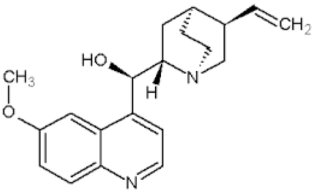
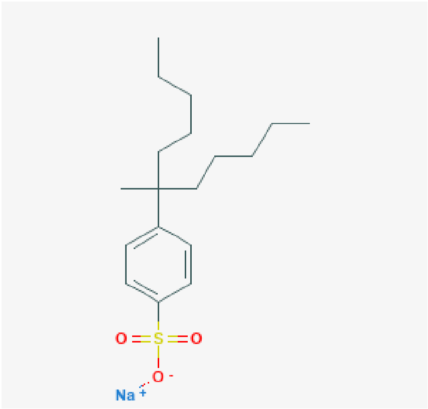
- Student teachers need skills and attitudes that will enable them in their everyday life to address the environment and climate change issue and to have a sustainable livelihood.
- While teaching this unit concerning derivatives of benzene especially their uses, talk about the environment and its sustainability. For instance:
- Detergents like OMO they are very important but they cause water pollution;
- DDT is a derivative of benzene used, especially in the past, for killing insects but nowdays is no longer used because it is harmful to crops;
- Explosives such TNT (Trinitrotoluene) cause air pollution.

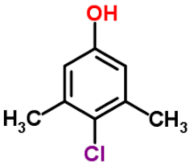
3.4. Guidance on the introductory activity

- Before introducing the lesson one of unit five, you will have to introduce the whole unit. Ask student teachers (in different groups) to attempt the introductory activity from student's book. This activity intends to relate the unit with student teachers' daily life and to capture their attention.
- Give student teachers 30 minutes and ask them to use library or internet (where is possible) in order to conduct this introductory activity very well. Student teachers may not be able to find the right answers but they are invited to predict possible solutions or answers.

- Select some groups (2-4) to share their findings to the whole class.
- After presentation, give your comments showing them how derivatives of benzene are very important in our daily life.
- It is not necessary to give them all answers of this introductory activity because they will study them in this unit. So, you can leave student teachers with the curiosity of knowing the correct answers.

The expected answers of the introductory activity of unit 3

1) Names and uses	**2) Chemical formulae**
Aspirin: is a drug used to reduce pain, fever and inflammation	
Phenolphthalein: is an acid-base indicator	
Quinine: is a drug used in the past to treat malaria	 (-)-Quinine
Detergent: is a liquid or powder used to remove dirt, for example from clothes or dishes.	
DDT: is a chemical substance used, especially in the past, for killing insects that harm crops.	

Dettol: is a chemical substance used for killing bacteria. Is especially used for treating skin problems. Chloroxylenol is the active ingredient in Dettol.	 Chloroxylenol (also known as para-chloro-meta-xylenol)

4. All these substances contain benzene ring in their structures.
5. Dyes, methylorange indicator, explosives like TNT, etc

3.5 List of lessons/Sub-heading:

#	**Lesson Title**	**Learning objectives**	**Periods**
	Effect of substituent groups on the benzene ring.	Explain the effects of substituent groups on the benzene ring.	3
	Phenol.	Describe the reaction of phenol	5
	Aromatic hydrocarbons, carbonyl compounds, carboxylic acids.	Describe aromatic carbonyl compounds and carboxylic acids preparations, reactions, identification and uses	5
	Phenyl amine	Describe the chemical properties of phenyl amines	4
	End unit assessment		2

Lesson 1: Effect of substituent groups on the benzene ring (3 periods)

a) Learning objectives

Explain the effects of substituent groups on the benzene ring.

b) Prerequisites:

Student teacher will understand better this unit if they know the reactivity of benzene ring, concept of resonance and inductive effects. Learnt in previous unit

c) Teaching resources:

- Chemistry textbooks and other relevant chemistry books from the library

- Where possible use internet, molecular models,

d) Learning activities

Guidance

- Ask student teachers to form groups of 2-4 (the number of groups and members will depend on your class size and the number of your resources or materials).
- Give student teachers activity 3.1 (from the student's book)
- As guide or facilitator, move around the class and check if all student teachers are working.
- Ask student teachers to present their findings.
- During the presentation ask some questions that lead to lesson objectives.
- Guide student teachers to make the summary of the lesson themselves. Make sure the following are emphasized on:
- Deactivators and activators substituents,
- Ortho, para-directing substituents and meta-directing substituents.

Make the final conclusion of the lesson. And draw a given conclusion by relating the finding of the student teachers and the lesson while they are taking notes

Answers to Activity 3.1

See the answers in student's book for Effect of Substituent Groups on the Benzene Ring

Application activity 3.1

Answers to application activity 3.1

Lesson 2: Phenols (5periods)

a) Learning objectives

- Test and compare the acidity of phenol with alcohols and carboxylic acids.
- Test for the presence of phenol in a given solution.
- Describe the preparation and reactions of phenol,
- State the uses of phenols.
- Describe the reaction of phenol

b) Prerequisites:

Student teachers will understand better this lesson if they have understanding on the concept of aliphatic alcohols and benzene, reactivities of alkyl groups,

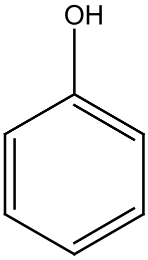
c) Teaching resources:

- Chemistry textbooks
- laboratory equipment (Distilled water, phenol, ethanol, ethanoic acid, test tubes, test tube racks, beakers, litmus papers (blue and red), bromine

water and iron (III) chloride., molecular models)

Answers to Activity 3.2

1. This substance is **Phenol** with the structural formula



2. See student teacher's book
3. See student teacher' book

3.2.1. Sources and preparations of phenol

a) Learning activities

Guidance

- Give student teachers activity   (from the student's book).
- Ask student teachers to carry out this activity in pairs
- Move around the class and check if all student teachers are working.
- Ask student teachers to present their findings.
- Guide student teachers to make the summary of the lesson themselves.

Answers for Activity 3.2.1

a) CH_3-CH_2-N^+NCl^-

b) CH-CH_2-CH^+CH_2 this carbocation is attached to benzene cycle

Application activity

Application activity 3.2.1

See student book

3.2.2. Acidity of phenols

a) Learning activities

Guidance 3.2.2

- Make groups
- Ask students to carry out the activity 3.2.2
- Give time to discuss on it while writing the findings
- Move around helping them to avoid conflicts

- Give time to presentation and harmonize the discussion
- Finally summarize and add missing ideas by enriching the course
- While doing that, the students will be taking notes

Answers for Activity 3.2.2

- In the beaker number one containing phenol the blue litmus paper will turn red because phenol has the behaviour of an acid.
- In the second beaker, the litmus paper remains blue because ethanol is neutral.
- In the third beaker which contains ethanoic acid the blue litmus paper turns red because ethanoic acid is an acidic.

b) Answer to application activity

Answer to Application activity 3.2.2

See student book

3.2.3 Reactions of phenols

a) Learning activities

Guidance

- Make groups
- Ask students to carry out the activity 3.2.3
- Give time to discuss on it while writing don the findings.
- Move around helping them to avoid conflicts
- Give time to presentation and harmonize the discussion
- Finally summarize and add missing ideas by enriching the course
- While doing that, the students will be taking notes

Activity 3.2 3

See student teacher's book

Application activity

Answer to Application activity 3.2.3

Consult student teacher's book and use the mechanism of reaction to make it more clear

3.2.4. Test and uses of phenol

a) Learning activities

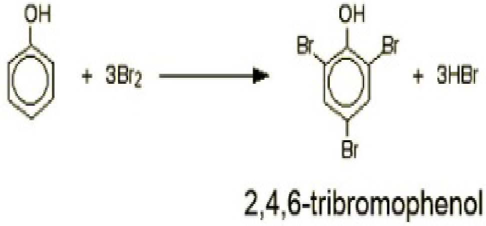
Guidance

- Take your student teachers in laboratory and give them all the necessary chemicals and materials which are needed to carry out the activity 3.2.4

- Form groups and ask them to follow the instructions which described in the student book
- They have to write down the findings and to make sure all laboratory safety rules have been respected.

Answers to activity 3.2.4

1. The addition of bromine water to a solution of phenol in water.
2. The bromine water is decolorized and a white precipitate is formed which smells of antiseptic.
3. The precipitate is 2,4,6- tribromophenol



Notice the multiple substitution around the ring - into all the activated positions.

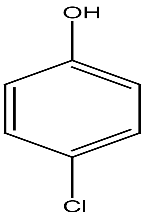
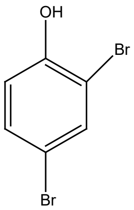
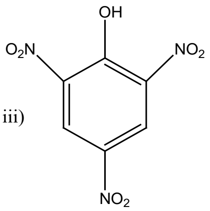
Application activity 3.2.4

Answers to application activity 3.2.4

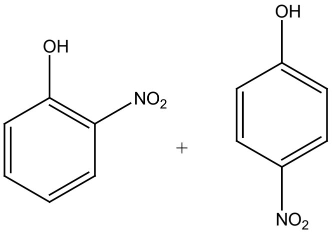
1.
   a) The O-H bond is weaker in phenol than in phenylmethanol. This is because the lone pair of electrons on the oxygen atom of phenol becomes associated with delocalized electrons of the ring. Because of this partial double bond develops between carbon and oxygen with the result that C-O bond is strengthened and the O-H weakened as the electronic density is displaced towards the ring. This thus makes phenol a stronger acid than phenylmethanol.
   b) Phenoxide ion is a weaker base than ethoxide ion because the lone pair of electron on phenoxide ion is not available (it is delocalized) but in ethoxide the lone pair of electrons is available (not delocalised) hence, ethoxide can fix the proton easily.
   c) 4-nitrophenol is less volatile than 2-nitrophenol because in 4-nitrophenol the two function groups are wide part and forms intermolecular hydrogen bonds while in 2-nitrophenol, the two functional groups are close and cause intramolecular hydrogen bonding. The intramolecular forces are easier to break than the intermolecular hydrogen bonds in 4-nitrophenol.

Therefore, 4-nitrophenol has a higher boiling point than 2-nitrophenol.

2.

i) 	ii) 	iii) 
4-chlorophenol 4-chloro-1-hydroxybenzene or p-chlorophenol	2,4-dibromophenol	2,4,6-trinitrophenol

3.



Lesson 3: Aromatic hydrocarbons, carbonyl compounds, carboxylic acids. (5 periods)

3.3.1. Aromatic hydrocarbons

a) Learning objectives

- compare and contrast the reactivity and the properties of Aromatic hydrocarbons, carbonyl compounds, carboxylic acids and amines.
- Structure and nomenclature of aromatic alkanes, alkenes, alcohols, ketones, aldehydes, carboxylic acids and amines. Reactions of alkyl benzene:
- demonstrate the Oxidation of the side chain and Radical substitution on alkyl benzene (chlorination).
- Illustrate Preparations and reactions of aromatic carbonyl compounds and carboxylic acids.

b) Prerequisites:

Student teachers will understand better this lesson if they have understanding on the concept of aliphatic hydrocarbons covered in Y2 (alkanes, alkenes, akyles their properties preparations and their reactivities)

c) Teaching resources:

Internet, Chemistry textbooks and other relevant chemistry books from the library, molecular models,

d) Learning activities

Guidance

As a facilitator, guide student teachers to learn by doing activity 3.3, as described below:

- Ask student teachers to carry out this activity in pairs (or groups of 3 or more depending on the size of your classroom) and provide them with resources to be used while carrying out their research;
- Move around the class and check if all student teachers are working;
- Ask student teachers to present their findings;
- Guide student teachers to make the summary of the lesson themselves; after you have to summarize the content by enriching it by adding the additional information to what the student teachers have given.

Answers for Activity 3.3

See student teacher's book of year two on the chemical properties of hydrocarbons

Application activity 3.3

Answers to application activity 3.3

Apply chemical properties of alkylbenzene in the student teacher's book

3.3.2. Aromatic carbonyl compounds

a) Learning objectives

Describe aromatic carbonyl compounds preparation, reactivity, identification and uses

b) Prerequisites:

Student teachers will understand better this lesson if they have understanding on the concept of aliphatic carbonyl compounds covered previous year II

c) Teaching resources:

- Chemistry textbooks and other relevant chemistry books from the library
- Internet, some chemicals like, benzaldehyde, potassium permanganate, potassium dichromate, benzoic acid, distilled water,

d) Learning activities

Guidance

- Guide student teacher to learn by doing activity 3.4, as described below:
- Ask student teachers to carry out this activity in pairs (or groups of 3 or more depending on the size of your classroom) and provide them with resources to be used while carrying out their research;
- Move around the class and check if all student teachers are working;
- Ask student teachers to present their findings group by group and tell them to enrich the idea of their colleagues
- Guide student teachersto make the summary of the lesson themselves;
- You can intervene by enriching the ideas of the student teachers while they are writing the summaries in their note books

Answers for Activity 3.4

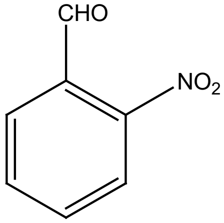
See student book year II on alkyl carbonyl compounds

Application activity

Answers to application activity 3.4

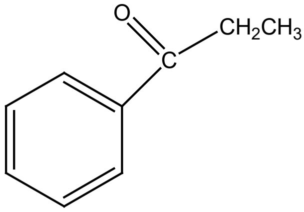
1.

a)



2-nitrobenzaldehyde

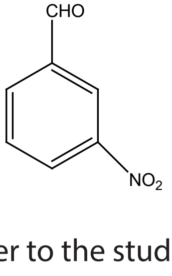
b)



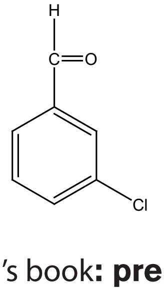
Phenylpropanone

2. See student book on preparation of aldehydes

a)



b)



3. refer to the student's book**: preparation of aldehydes**

3.3.5 Aromatic Carboxylic acids

a) Learning objectives

Describe aromatic carboxylic acids preparations, reactions, identification and uses

b) Prerequisites:

Student teachers will understand better this lesson if they have understanding on the concept of aliphatic carboxylic acids studied in **year II**.

c) Teaching resources:

Internet, Chemistry textbooks and other relevant chemistry books from the library and molecular models

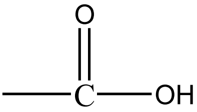
d) Learning activities

Guidance

- As a facilitator, guide student teachers to learn by doing activity 3.5, as described below:
- Ask student teachers to carry out this activity in pairs (or groups of 3 or more depending on the size of your classroom) and provide them with resources to be used while carrying out their research;
- Move around the class and check if all student teachers are working;
- Ask student teachers to present their findings;
- Guide student teachers to make the summary of the lesson themselves;

Answers for Activity 3.5

1. The general formula of carboxylic acid is



$$-\overset{\overset{\displaystyle O}{\|}}{C}-OH$$

2. Apart from the exceptions, they are prepared from oxidation of alcohols and alkenes
3. See studend teacher's book year II to perform the activity 3.5

Application activity

Answers to application activity 3.5

Refer to the student's book: Preparation of carboxylic acid

3.3.6. Aromatic amines

a) Learning objectives

- Describe method of preparation, physical and chemical properties of phenyl amines.
- Test and compare the alkalinity of phenyl amine, ammonia and aliphatic amines.

- Perform experiments on the reactions of phenyl amine.

b) Prerequisites:

Student teachers will understand better this lesson if they have understanding on the concept of aliphatic amines in year II.

c) Teaching resources:

Internet, Chemistry textbooks and other relevant chemistry books from the library

d) Learning activities

Guidance

- As a facilitator, guide student teachers to learn by doing activity 3.6, as described below:
- Ask student teachers to carry out this activity in pairs (or groups of 3 or more depending on the size of your classroom) and provide them with resources to be used while carrying out their research;
- Move around the class and check if all student teachers are working;
- Ask student teachers to present their findings group by group
- Guide student teachers to make the summary of the lesson themselves;
- Make the final conclusion of the lesson and if possible, by enriching the content and the student teachers will be taking notes of the summary.

Answers for Activity 3.6

1. The main functional group of amine is $-NH_2$ ($R-NH_2$)
2. To this question you can use the book of year II on the topic of amines
3. The amine are classified into 3 categories

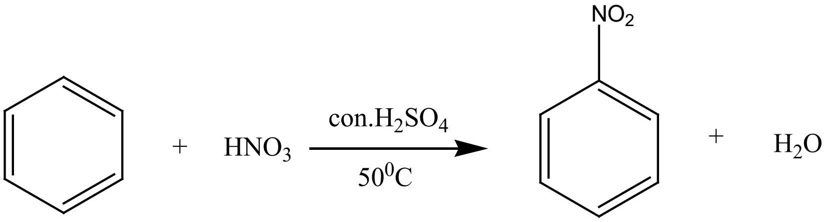
i) Primary amines $R-NH_2$

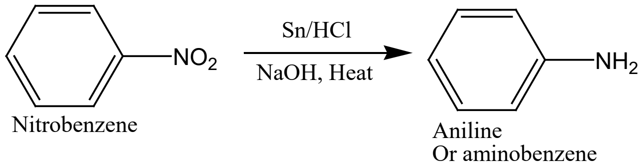
ii) Secondary amines R_2NH

iii) Tertiary amines R_3N

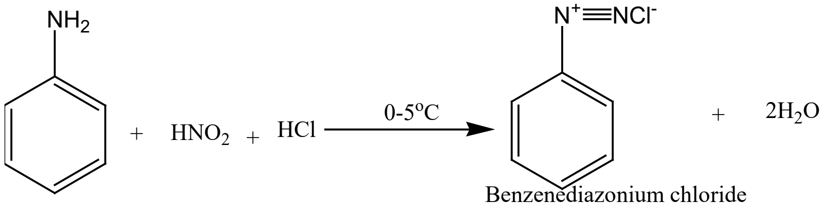
Answers to application activity 3.6

1.





2.



3. See student teacher's book to complete equations

Guidance to skills lab 3

- Encourage the student teachers to have the spirit of making their own products by using the available materials and substances they can find aroud them and be more creative in producing things by applying chemistry principals in their daily life.
- Whithin this line, ask the student to make a further research on detergent preparation and synthesize some detergents at their home. Afterward, request them to share the procedure followed and the results obtained.

3.6. Summary of the unit

Many important chemical compounds are derived from benzene by replacing one or more of its hydrogen atoms with another functional group. Some examples of derivatives of benzene are:

- Phenols: the simplest member is hydroxybenzene or simply called phenol. The presence of hydrogen bonds makes the melting temperatures of phenols higher than those of hydrocarbons of comparable molecular mass. Compared to aliphatic alcohols, phenol (hydroxybenzene) is about one million times more acidic, although it is still considered a weak acid and less acidic than carboxylic acids.
- Alkylbenzenes: the simplest member is methylbenzene (Toluene). An alkyl benzene is simply a benzene ring with an alkyl group attached to it.
- Aromatic carbonyl compounds (aromatic aldehydes and aromatic ketones). These compounds contain carbonyl group attached to the benzene ring. Benzaldehyde is a typical aromatic aldehyde and undergoes chemical reactions involving the side chain and the benzene ring. The simplest aromatic ketone is phenylethanone. The most typical reactions of the carbonyl groups are nucleophilic addition.

- Aromatic carboxylic acids: the simplest member is benzoic acid which is used as food preservative.
- Aromatic amines: the commonly used is phenylamine (aniline or aminobenzene). This aniline is a weaker base than ammonia and aliphatic amines. Aniline and its ring-substituted derivatives react with nitrous acid to form diazonium salts. A large number of benzene derivatives (like dyes can be synthesized from diazonium salts).

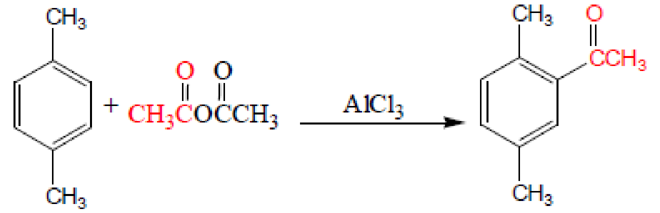
It has been found experimentally that in general ortho-para directing substituents activate the benzene ring and thus enhance the rate of reaction with electrophiles. On the contrary, the meta directing substituents deactivate the ring and retard the rate of reaction as compared to unsubstituted benzene.

3.7. Additional Information for tutor

Multiple Substituent Effects

When a benzene ring bears two or more substituents, both its reactivity and the site of further substitution can usually be predicted from the cumulative effects of its substituents.

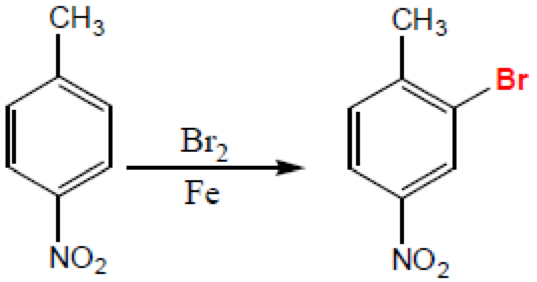
In the simplest cases all the available sites are equivalent and substitution at any one of them gives the same product.



1,4-Dimethylbenzene
(p-xylene)

2,5-Dimethylacetophenone

Often the directing effects of substituents reinforce each other. Bromination of p-nitrotoluene, for example, takes place at the position which is ortho to the ortho, para-directing methyl group and Meta to the meta-directing nitro group.



p-Nitrotoluene 2-Bromo-4-nitrotoluene

In almost all cases, including most of those in which the directing effects of individual substituents oppose each other, *it is the more activating substituent that controls the regioselectivity of electrophilic aromatic substitution…*

When two positions are comparably activated by alkyl groups, substitution usually occurs at the less hindered site.

3.8. End unit assessment Answers

1. Answer: **b, c** and **e**
2. Phenols: **A** and **D**

   Not phenols but alcohols: B and C

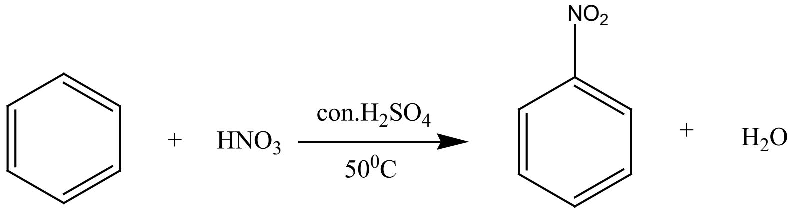
3.
   a) Formation a white precipitate
   b) Because –OH group is an activator, -OH group increases the reactivity of benzene ring.
   c) (See the answer in student's book: uses of phenol)

4. Answers:

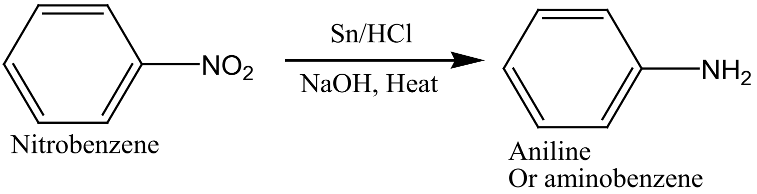
a) 2-bromo-4-nitrobenzoic acid
b) 3-chlorophenylamine
c) 3-chloromethylbenzene
d) Pentachlorophenol
e) 4-aminobenzoic acid

5.

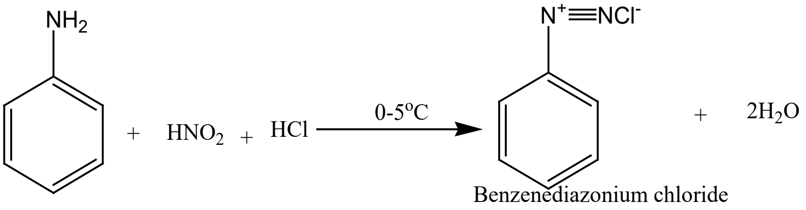
a)



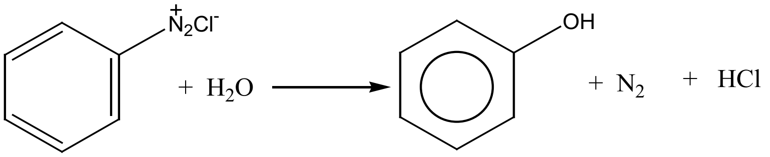
NO2
+ HNO3
con.H2SO4
50⁰C
+ H2O



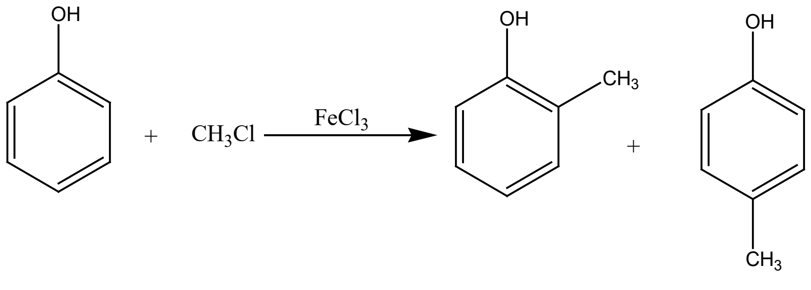
NO2
Sn/HCl
NaOH, Heat
NH2
Nitrobenzene
Aniline
Or aminobenzene



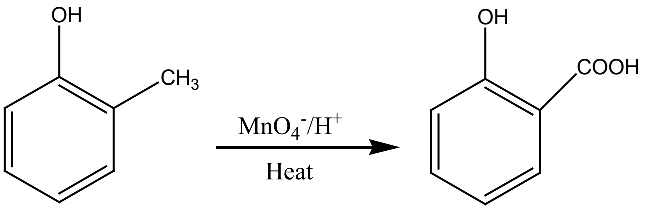
NH2
+ HNO2 + HCl
0-5ºC
N⁺≡NCl⁻
+ 2H2O
Benzenediazonium chloride



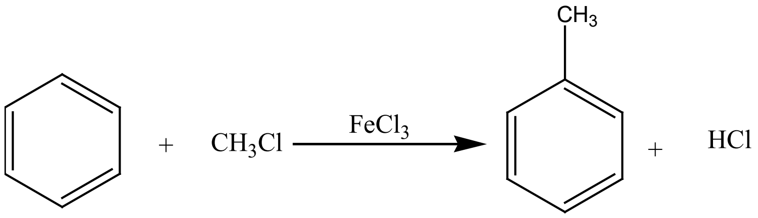
N2Cl⁻
+ H2O
OH
+ N2
+ HCl

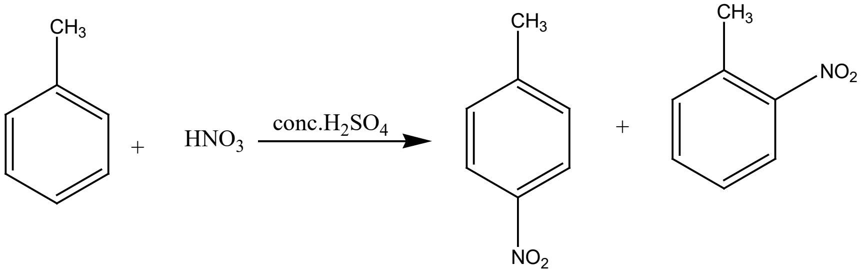


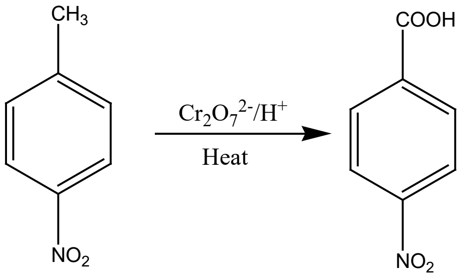
OH
+ CH3Cl
FeCl3
OH
CH3
+
OH
CH3



OH
CH3
MnO4⁻/H⁺
Heat
OH
COOH







[6]

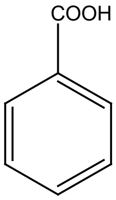
a) Answer:

Step	Reagents	Conditions
I	Cl_2	U.V light
II	$NaOH_{(aq)}$ or $KOH_{(aq)}$	Warm /heat
III	Conc. HNO_3	Conc.H_2SO_4 as catalyst and heat or reflux

b) Answer: Reduction

c) Answer:

B)



Benzoic acid

d) Answer: Step I: Free radical substitution

Step II: Nucleophilic substitution(SN)

[1]

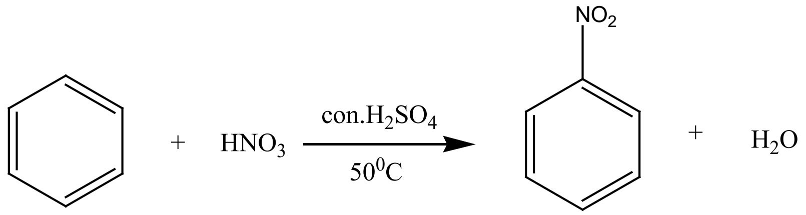
(a) **(i)** Concentrated nitric acid in the presence of H_2SO_4 and Heat.

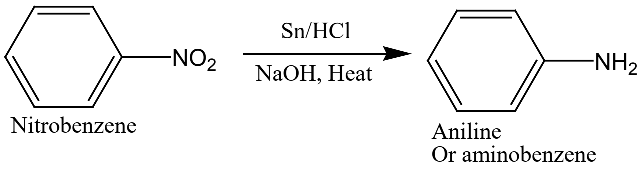
(ii) Electrophilic substitution (nitration). For the mechanism, use student teacher book on nitration of benzene

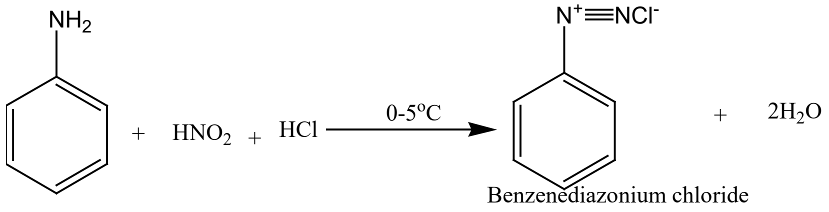
(b) Zn, Sn or Fe can be used together with a mineral acid (HCl or H_2SO_4) in the presence of an alkali.

(c) Use of ammonia in the presence of an alcohol (ethanol) under pressure.

(d) **Answer: K** is a weaker base than ammonia because the lone pair of electron on **K** is not available (it is delocalized) but in ammonia the lone pair of electrons is available (not delocalised) hence, ammonia can fix the proton easily.



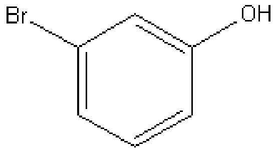




3.9. Additional activities

3.9.1. Remedial Activities:

1. The correct name for the molecule shown below would be:



a) o-bromophenol
b) Hydrobromobenzene
c) m-bromophenol

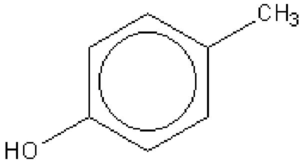
d) p-bromophenol

Answer: c

2. What is another name for p-aminobenzoic acid that would still be considered to be correct?
   a) 4-aminobenzoic acid
   b) 3-aminobenzoic acid
   c) 2-aminobenzoic acid
   d) 1-aminobenzoic acid

Answer: a

3. Which of the following names is correct for this structure?



   a) 4-hydroxytoluene
   b) p-methylphenol
   c) 1-hydroxy-4-methylbenzene
   d) All of the above.

Answer: d

4. Halogenation of benzene requires which of the following catalysts?
   a) FeCl3
   b) H2O
   c) H2SO4
   d) Ni

Answer: a

5. Which of the following processes is useful in the formation of synthetic detergents from aromatic compounds?
   a) Halogenation
   b) Nitration
   c) Sulfonation
   d) More than one answer choice is correct

Answer: c

6. Which of the following is a weak acid?
   a) Aniline
   b) benzene
   c) phenol

d) toluene

Answer: c

7. DDT is no longer used in agriculture because ___________
   a) It is an insecticide
   b) it increases crop yields
   c) it decreases the spread of malaria and typhus
   d) it resists biodegradation

Answer: d

8. Water is not a by-product in which of the following aromatic substitution reactions?
   a) Halogenation
   b) nitration
   c) sulfonation
   d) More than one answer choice is correct

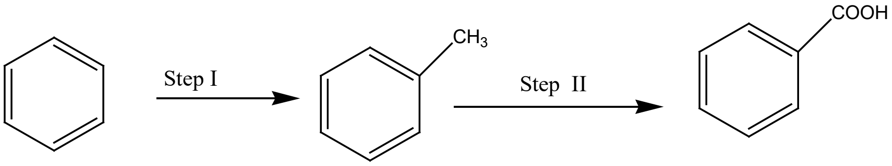
Answer: a

9. Which of the following is not an appropriate name for this compound?
   a) 1,2-dihydroxybenzene
   b) 1,2-benzenediol
   c) m-hydroxyphenol
   d) Catechol

Answer: c

3.9.2. Consolidation activities:

1. Benzoic acid is prepared from benzene as shown below:



a)

i) Give the reagents and conditions for step I

ii) Give the reagents and conditions for step II

b)

i) Give the structure of the organic product formed when methylbenzene and chlorine react in the presence of ultra violet light.

ii) Give the structures of the two isomers formed when methylbenzene reacts with chlorine in the presence of FeCl3.

Answers: See the answers in student's book unit 5.

2. The chart below shows a synthetic route for the preparation of compound Z starting with compound Y:

$$Y \xrightarrow[\text{Heat}]{HNO_3 + D} C_6H_5NO_2 \xrightarrow[\text{Heat}]{E + F} C_6H_5NH_2 \xrightarrow[T<10^0C]{HNO_2 + HCl} Z$$

- State the names of compounds Y, D, E, F and Z.
- Show the reaction mechanism in the formation of compound: C6H5NO2 from compound Y.
- Explain why compound Y undergoes electrophilic substitution more readily than C6H5NO2.
- Which name is given to the reaction which takes place in the production of Z?

Answer:

a) Y: Benzene

D: Concentrated sulphuric acid

E: Sn, Fe or Zn

F: HCl

Z: Benzenediazonium chloride

b) See the answer in student's book unit 4

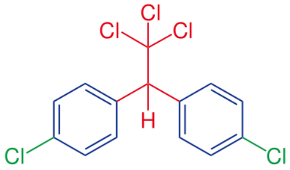
c) The compound C6H5NO2 has the nitro group which acts as deactivators.

d) Diazotisation reaction.

3.9.3. Extended activities:

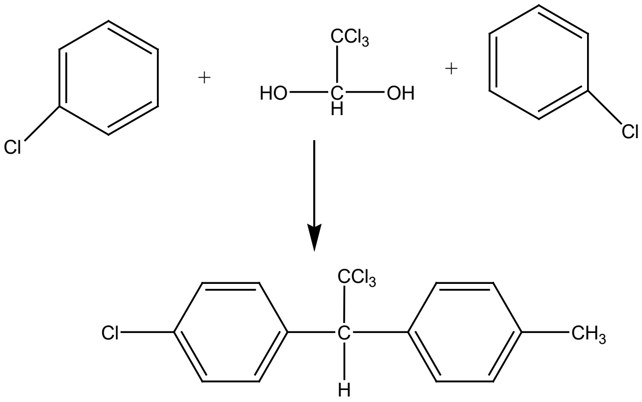
1. How can you prepare the insecticides so known as DDT(Dichloro Diphenyl

Trichloroethane):

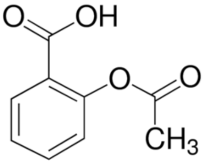


dichlorodiphenyltrichloroethane

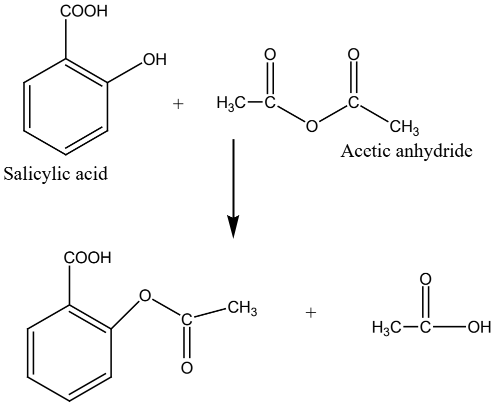
Answer:



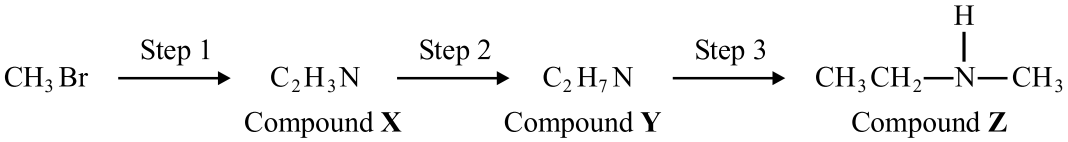
2. How can you prepare Aspirin (Acetylsalicylic acid):



Answer:



a) Compound Z can be formed via compounds X and Y in the three step synthesis shown below.



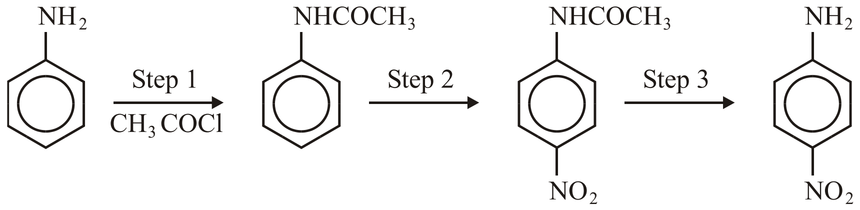
$$CH_3Br \xrightarrow{\text{Step 1}} \underset{\text{Compound }\mathbf{X}}{C_2H_3N} \xrightarrow{\text{Step 2}} \underset{\text{Compound }\mathbf{Y}}{C_2H_7N} \xrightarrow{\text{Step 3}} \underset{\text{Compound }\mathbf{Z}}{CH_3CH_2-\overset{\displaystyle H}{\overset{|}{N}}-CH_3}$$

i) Identify compounds X and Y and give reagents and conditions for Steps 1 and 2.

ii) State the type of compound of which Z is an example.

iii) Compound Z reacts with a large excess of bromomethane to form a solid product. Draw the structure of this product and name the type of mechanism for this reaction.

b) Consider the following reaction sequence which starts from phenylamine.



i) State and explain the difference in base strength between phenylamine and ammonia.

ii) Name and outline a mechanism for the reaction in Step 1 and name the organic product of Step 1.

iii) The mechanism of Step 2 involves attack by an electrophile. Give the reagents used in this step and write an equation showing the formation of the electrophile. Outline a mechanism for the reaction of this electrophile with benzene.

iv) Name the type of linkage which is broken in Step 3 and suggest a suitable reagent for this reaction.

Answer

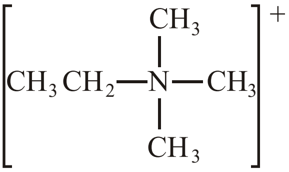
a)

i) X is CH_3CN or ethanenitrile or ethanonitrile or methyl cyanide or cyanomethane or ethyl nitrile or methanecarbonitrile

Y is $CH_3CH_2NH_2$ or ethylamine or aminoethane or ethanamine

Step 1: reagent	KCN not HCN/HCl			
Condition	(aq)/alcohol - only allow condition if reagent			
Step 2: reagent	H_2	$LiAlH_4$ Na	Zn/Fe/Sn	Not $NaBH_4$
Condition	Ni/Pt/Pd	ether	ethanol	HCl

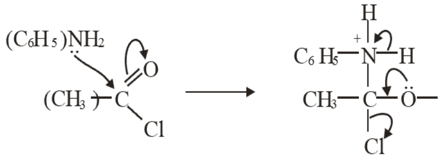
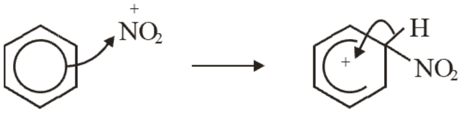
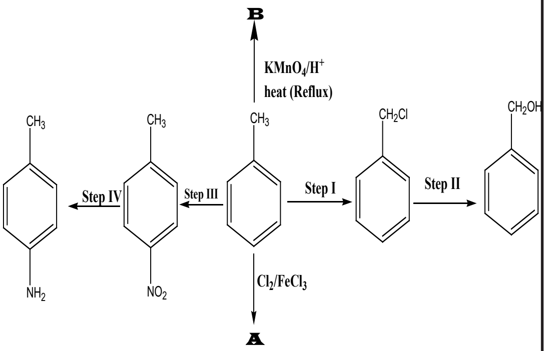
ii) Z is an amine or aminoalkane/secondary

iii) 

$$\left[CH_3CH_2-\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{N}}-CH_3\right]^+$$

(Br–) + can be on N or outside brackets as shown

Nucleophilic substitution

b) i) Phenylamine weaker Lone pair on N (less available)/ delocalised into ring or “explained” ii) Addition – elimination  N-phenyl ethanamide	iii) Conc HNO_3 and conc H_2SO_4 $HNO_3 + 2H_2SO_4 \quad O_2 + H_3O^+ + 2HSO_4^-$  iv) Peptide / amide NaOH(aq), HCl (conc or dil)/ H_2SO_4 (dil)
	a) Give the reagents and conditions in the steps **I, II,III** and **IV** b) What type of reactions are involved in steps **I, II, III** and **IV** c) Give the structures and names of compounds **A** and **B** d) State 2 physical properties and 2 uses of methylbenzene.

Answer

a)

i) $CH_3CH{=}CH_2 + HCl + AlCl_3 \rightarrow (CH_3)_2C{+}H + AlCl_4^-$

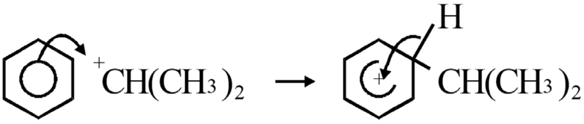
ii) Type of substitution Electrophilic or alkylation

Mechanism

b) $CH_3CH_2CH_2^+$ or primary carbonium ion

Less stable or 1 & 2 inductive effects than $(CH_3)_2CH+$ or secondary

c) $CH_3CHClCH_3$



UNIT 4: POLYMERS AND POLYMERIZATION

4.1. Key unit competence

Relate the types of polymers to their structural properties and uses

4.2. Prerequisite (knowledge, skills, attitude and values)

Students will learn better to relate the types of polymers to their structural properties and uses if they have understanding on: balancing chemical equations; draw the displayed structural formulae of organic compounds and give names using IUPAC system; chemical reactions like esterification and formation of other compounds like amides; reactions of carboxylic acids, amines; nomenclature of inorganic and organic compounds.

4.3. Cross-cutting issues to be addressed

- **Environment and sustainability**

Polymer manufacturing is a very big business. There is great, worldwide demand for synthetic polymers, as well as natural polymers that have been altered to make them more useful. Synthetic polymers can come in a variety of forms, such as common plastics, the nylon of a jacket, or the surface of a non-stick frying pan, but these human-made materials have a detrimental impact on ecosystems. That is why student teachers need to be aware and be responsible for the use and the ways to deal with old polymers in order to protect the environment. Here environment and sustainability cross cutting issue comes in and has to be related to the environment of student teachers but going hand in hand with the national policy on how to protect environment especially they have to avoid using plastic bags in daily life.

Young people should be addressed about this issue so that they can avoid to the disposition of waste materials everywhere. Waste materials should be collected together in areas reserved for them according to their categories. The majority of old materials made of polymers can be recycled to form new ones without polluting environment.

This will help them to understand the importance of sustainability as they grow up and become responsible for the world around them.

- **Inclusive education**

This unit requires student teachers to carry out a lot of researches to be able to understand first, then share and discuss on things like structure of monomers, polymers, and so on. This may be challenging to students with special educational needs especially slow student teachers. However, as teacher you can organise your class and use different strategies to help all student teachers understand well. Some of the strategies to be used are provided below:

- Be patient! If you find that the student teacher take longer than others to learn or to do an activity, allow more time.
- Do activities together with the student.
- Try to moderate the discussion to avoid any kind of conflict
- Let the student teacher do the activity with his colleagues and encourage them to help each other.
- Divide the activity into small achievable steps.
- Remember to praise and say 'well done' when the student teacher learns something new or makes a strong effort.
- The concept of polymerization express how unit can make stronger effort when the monomers are combining together to form a big molecule which interpret the union of the force.

- **Comprehensive sexuality education**

When introduction polymer and polymerization, student teachers should be reminded for that it is similar to the way individual students join to form different peer groups where their group resembles polymer and the individual students would be considered as monomers, their reason of grouping would be considered as the bond. Peer groups among students is sometimes a challenge, because there are some of them who are bonded by drugs or any negative attitude, so individual students have to be carefully from the reason being of the group.

4.4. Guidance on the introductory activity

Introductory activity for unit 4, student teacher's book of Y3.

Polymers and polymerization seem to be new for students but chemical reactions that happen are familiar with the majority of them.

Therefore, the introduction of this unit to students of senior six would be simple. The introductory activity can attract interest of students as it is built on the materials that are around everywhere.

Here is a guide of how this activity can be performed by students guided by the tutor.

- Give them time between 15 and 20 minutes to read, analyze, interpret and discuss about the activity. Here they have to observe and analyze the objects in the pictures and answer the questions asked on them. Let them use books or search from internet if possible, in order to discover what they don't discover directly.

- Call one or two groups to present their findings. You may note some key points at this stage.
- Ask other members (randomly) to give their input. Don't worry if some of them fail to reach the exact results. They get to understand as the unit progresses.

Address your views about their presentations. But it is not necessary to conclude. Just motivate them to create curiosity in them

Answers to introductory activity:

a) 1: Nylon rope, 2: fibbers thread, 3: piece of silk cloth, 4: rubber balloon, 5: plastic materials (including cups), 6: rubber tyres, 7: plastic tubes.

Uses

- **Nylon ropes:** when stretched between two points, clothes are being dried when they are hung on it.
- **Fibber thread:** used to make different things including carpets, curtains, draperies, sheets and pillow cases and wall coverings.
- **Piece of silk cloth:** used to make high-fashion clothes, lingerie and underwear.
- **Rubber balloon:** Balloons are used for decorative purposes or entertaining purposes, while others are used for practical purposes such as meteorology, medical treatment, military defence or transportation.
- **Plastic materials:** Example a cup can be used to carry out liquid substances.
- **Rubber tyres:** It is the outer part of wheel that helps car to move smoothly. When is old, it can be reused of other way.
- **Plastic tubes:** they are used for fluid flow or structural systems through buildings. It is used as insulation or sheathing for electrical or heating assemblies.

b) They are all made by long chain molecules.

c) They have light weight, though, not corrosive, poor conductors of heat and electricity, coloured. They all have long chains or all are made by polymers.

4.5 List of lessons

#	Lesson Title	Learning objectives	Periods

	Definition of monomer, polymer and polymerization.	Define the terms monomer, polymer and polymerization and Describe the formation of polymers.	1
	Types of polymerization:	Describe addition and condensation polymerization	1
	Properties of polymers	Explain the terms thermosetting and thermo softening of plastics.	1
	Uses of polymers and their effect on the environment.	Discuss the advantages and disadvantages of both natural and synthetic polymers and Explain the biodegradability of polymers based on their chemical structure	1
	End unit assessment		1

Lesson 1: Definition of monomer, polymer and polymerization (1 period)

a) Learning objectives

- Define the terms monomer, polymer and polymerization.
- Describe the formation of polymers.

b) Prerequisites/Revision/Introduction:

Students will learn better this lesson if they have knowledge on how to write molecular and to draw the displayed structural formulae of organic compounds, they must have the knowledge on alkenes, alkynes, concept of proteins in biology

c) Teaching resources

Use periodic table of elements, worksheets or books; projectors and/or chalkboard, molecular model

- 500ml 2% milk
- 60ml vinegar
- 100 ml beaker
- 2 beakers of 1L each
- 1 spoon
- 1 strainer
- Aluminium foil
- Thermometer
- Hot plate or Bunsen burner and stand

- Matches if using a Bunsen burner

d) Learning activities

- **Guidance**
- To this kind of activity while introducing monomers and polymers even polymerization, you can use the illustration between the students, whereby you can take two of them then facing each other and holding each other by two hands. You can form like 6 pairs, then after tell the pairs to join each other and form the longue distance formed by many students then from there you can explain the concepts according to the example you started with.
- After this kind of enjoyment in class, tell them to attempt the activity 4.1, discuss on it, and make presentation of the findings, you shall conclude and write the summary while they are taking notes

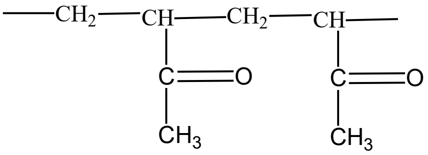
Answers to Activity 4.1, student teacher's book Y3

1. a) The small molecule will constitute the biggest one, this means that the biggest molecules are formed by many simple molecules.

Experimental activity for the preparation of plastic from Milk

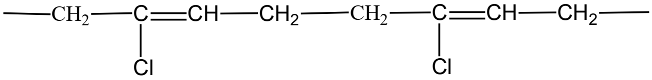
Answers to application activity 4.1

a) Polyvinyl acetate:



$-CH_2-CH(C(=O)CH_3)-CH_2-CH(C(=O)CH_3)-$

b) 2-Chlorobuta-1,3-diene

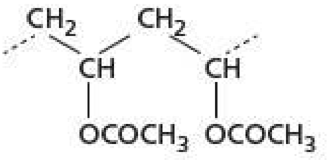


$-CH_2-C(Cl)=CH-CH_2-CH_2-C(Cl)=CH-CH_2-$

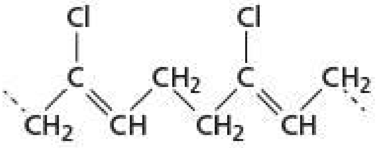
c) $-CH_2CHCl-CH_2CH(CH_3)-$

Or

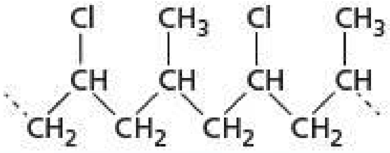
a



b



c



1. a) $CH_2=CH(CN)$

   b) $CH_2=C(CN)-CH=CH(CN)$

Lesson 2: Types of polymerization (1period)

a) Learning objectives

- Use equations to distinguish between condensation and addition polymerization.
- Describe addition and condensation polymerization.

b) Prerequisites/Revision/Introduction:

Students will learn better types of polymerization if they have knowledge on types of chemical reactions; completing and balancing chemical equations covered in senior two and four; additional reactions; condensation reactions covered in senior four.

c) Teaching resources

Use worksheets or books; projectors and/or chalkboard

- **Materials:** glass rod, beakers, funnel, measuring cylinder, dropper and filter paper.
- **Chemicals:** Glacial acetic acid, 40% formaldehyde solution and Phenol, conc. H_2SO_4.

d) Learning activities

Guidance

You can start by asking your students questions about types of chemical reactions. This lesson has two questions in activity 4.2 with a practical. As a facilitator, you are expected to guide student teachers to learn by doing activities from 4.2

Answers to Activity 4.2

1. A and B are polymerization reactions

   A has same type of reactants and one product which means that there is chemical combination of one unit repeating

   B has two different reactants and two chemical products, which means that if two substances are joined together, there is a product formed and water is released.

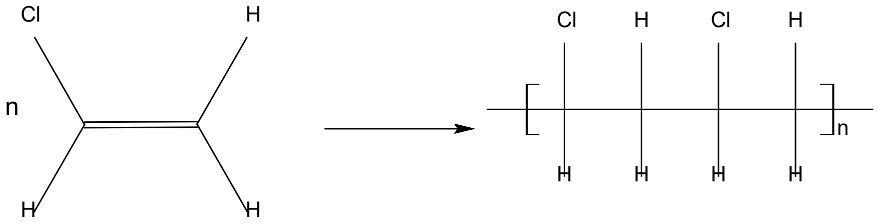
2. Addition polymerization is a process where monomers are linked together to form a polymer, without the loss of atoms from the molecules while condensation polymerization is a process where two or more monomers chemically combine to form a polymer with elimination of simple molecules like water, ammonia, hydrogen chloride, alcohol

Answers to application activity 4.2

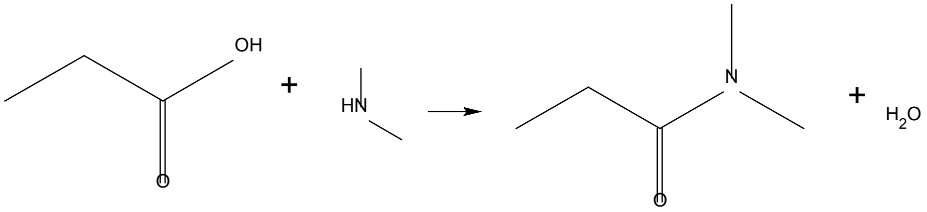
$nH_2N(CH_2)_6NH_2 + nCHCl(CH_2)_4CHCl \rightarrow -(HN(CH_2)_6NH\text{-}CH(CH_2)_4CH)_n- + 2nHCl$

1. Addition polymerization is a process where monomers are linked together to form a polymer, without the loss of atoms from the molecules while condensation polymerization is a process where two or more monomers chemically combine to form a polymer with elimination of simple molecules like water, ammonia, hydrogen chloride, alcohol

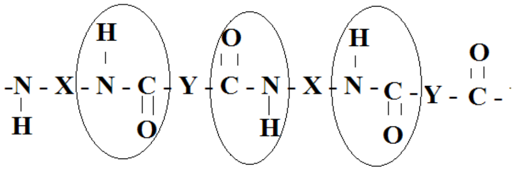
Example of additional polymerization



Example of condensation polymerization



2. a)



$$-\underset{H}{N}-X-\overset{H}{N}-\underset{O}{\overset{}{C}}-Y-\overset{O}{C}-\underset{H}{N}-X-\overset{H}{N}-\underset{O}{C}-Y-\overset{O}{C}-$$

   b) Amide bond

3. a) Condensation polymerization
   b) $HOOC-(CH_2)_4-COOH$ and $H_2N-(CH_2)_6-NH_2$
   c) Proteins such as wool and silk

Lesson 3: Properties of polymers (1 period)

a) Leaning objectives

- Explain the terms thermosetting and thermo softening of plastics.
- Relate the structure and properties of polymers to their uses in plastic and textile industries.

b) Prerequisites/Revision/Introduction:

Students will learn better this lesson if they have knowledge on properties of organic compounds, especially alkenes, alkynes, esters, amides,…

c) Teaching resources

Use clip videos, worksheets or books; projectors and/or chalkboard, molecular models

d) Learning activities

- **Guidance**

- Group them in different groups, then help them to select a leader in every group, distribute the task of doing the activity 4.4, which is in the student teacher's book, manage the discussion the same by moderating the time usage, hence you can limit them over time and start presentation, in that presentation you have to limit them by telling the rest of the groups to enrich and to add the missing ideas from previous group presentations.

- As a facilitator, you are expected to guide student teachers to learn by doing activities 4.3

Answers to activity 4.3

Biodegradable substances are the substances that are fully decomposed into carbon dioxide, methane, water, biomass and inorganic compounds under aerobic or anaerobic conditions and the action of living organisms while

1. Non-biodegradable substances are substances which are resistants' to environmental degradation thus accumulate in form of waste.
2. Something to be degraded, it requires to be in contact with the bacteria under suitable condition (such as water, carbon dioxide, oxygen, etc… which will start to destroy them
3. Non-fertility of the soil, no plant growth, they don't allow water to penetrate in the soil, no productivity,…
4. The solution I can propose, is to recycle them, …

Answers to application activity 4.3

1.
   a) Bio-degradable: Substance or object capable of being decomposed by bacteria or other living organisms and therefore avoiding pollution.
   b) Advantage of biodegradable plastics is that they completely break down and provide required space to dispose other waste materials.
   c) Researchers have worked on developing biodegradable plastics with the hope of protecting environment but the production methods and application of biodegradable plastics could still be detrimental to environmental and human health. Biodegradable plastics behave differently when recycled, and have the potential to negatively influence human health. If the food packaging materials are recycled, their physical properties could change, allowing degraded chemical compounds and external contaminants to enter the food.

      However, when biodegradable plastics decompose, they produce methane gas, a major contributor to global warming. Thus, the biodegradable nature of these plastics poses economic and ecological problems in the current waste management infrastructure

      Finally, the last obstacle to surmount is the proper disposal of biodegradable plastics. In order for biodegradable plastics to be effectively disposed of, the current waste management infrastructure must change, or methods with less economic and environmental costs must be developed

2. A) c

   B) c

   C) c

   D) b

   E) b

   F) c

   G) b

   H) b

   I) a

   J) c

Lesson 4: Uses of polymers and their effect on the environment (1period)

a) Learning objectives

- Develop the sense of responsibility to protect the environment against the hazards of plastics.
- Reduce polymer wastes by reusing, recycling and appropriate disposal.
- Develop observation, research and report writing skills during field visits and survey.

b) Prerequisites/Revision/Introduction:

Students will learn better this lesson if they have knowledge on the use of commonly known polymers, knowledge on biodegradable, and non-biodegradable polymers.

c) Teaching resources

Use clip videos, worksheets or books; projectors and/or chalkboard

d) Learning activities

▪ **Guidance**

- You can improvise and bring materials know in daily life and you ask them their uses and their effects on the environment especially when they are old.
- As a facilitator, you are expected to guide student teachers to learn by doing activities 4.4

Answers to activity 4.4

Like polypropylene, polyvinyl chloride, polystyrene, Teflon, Nylon,...

but when we look at their types, there is rubber, fibres and plastics.

PVC is one of the most widely used polymers in the world. Due to its highly versatile nature, PVC is used extensively in many industries including construction, automotive, electronics, packaging, fashion and design amongst others. During combustion process in produces micro-pollutants as well as acidic gases and solid wastes. This focus is due to chlorine which leads to the production dioxins, emission of HCl and other production of solid hazardous waste because of the presence of heavy metals from the additives used in various formulations.

Many of them are Waste plastic materials on landfill. There are many effects on the land where they are; first of all they do not allow water to penetrate the soil which can cause erosion, secondary they pollute the atmosphere because some of them are degradable on sunlight which can produce chemical substances into the air.

Answers to application activity 4.4

1. Polyester fibres, yarns and ropes are used to make car tire reinforcements, fabrics for conveyor belts, safety belts, coated fabrics and plastic reinforcements with high energy absorption.

   The property of polyesters is that they have high tenacity and durability. They resist for strong and repetitive movements.

2. - They can cause erosion because they do not allow water penetration in the soil
   - They can cause atmospheric air pollution when they are degrading they emit harmful chemical substances in air.
   - The can cause soil pollution through degradation in the soil

4.6. Summary of the unit

Polymerization is the formation of extremely long molecules (polymers) from small molecules called **monomers**. The plastics and rubber are examples of the most common polymers which are commonly used in both everyday life and in medical application. The exact properties of polymers depend on a variety of chemical details and on their specific chemical details.

There are two main types of polymerization reactions: Addition and condensation.

In addition polymerization, the polymer has the same empirical formula as the monomer but a higher molecular mass. An example is the polymerization of chloroethene (vinyl chloride) to form poly(chlorothene), PVC.

For condensation polymerization, monomers join by production of polymer and elimination of small molecules (such as water or ammonia)

Polymers have two classes; natural and synthetic polymers and can be classified into three classes; plastics, rubber and fibres

Polymers have got properties; they are thermosetting plastics and thermo softening properties where on the other side they can be biodegradable or non-biodegradable polymers.

Among the classes, rubber is more used and its vulcanization is needed to improve its quality.

In our daily life, materials made by polymers are used and sometimes have effects on environment.

Polymers are used in a broad range of industries such as textiles, packaging, stationery, plastics, aircraft, construction, rope, toys. When polymers get old, measures should be taken in order to deal with them; that is why polymer management is needed. Three methods could be used; reuse, recycling and disposal.

4.7. Additional information for teachers

More definitions related to polymers

- Oligomer: An oligomer is a molecule that consists of a few monomer units (oligos, for "a few"), in contrast to a polymer that, at least in principle, consists of an unlimited number of monomers.
- Tensile strength: Density, melt viscosity and tensile strength are a few important mechanical properties of a polymer. These are highly influenced by molecular weight of polymers. Tensile strength is increases with molecular mass of the polymer up to 20000.Beyond that the increase is negligible.
- Elasticity: The property by which the polymer undergoes elongation several times under the applied force and regains their original size when the force is released fully is called elasticity.

The elastic property of elastomers is mainly because of their liner and coiled polymer chains.

Guidance to skills lab 4

Help your student teachers to visit the dump which are near them, of you can assist them to do a field work to see the landfill sites and the different wastes especially the plastics see how they affect the plants which grow under them, try to give them the encouragement of making exploration and come to present their findings. Share with your students the different methods which can be adapted in wastes management which could save the environment and you can even raise your idea to the local government together with your students.

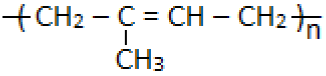
4.8: End unit assessment

ANSWERS TO END UNIT ASSESSMENT QUESTIONS

1. Crosslinking: is a process of where one polymer chain bonds to another while thermosetting is a process of becoming permanently hard and rigid, for some polymers when they are subjected to heat.

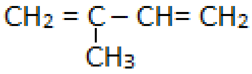
   Thermosetting polymers are suitable for high temperature; they retain their strength and shape even when heated.

2. a) Its inertness comes from the way that they are saturated compounds with single bonds only in their structures.
   b) Their structures make them less reactive which increases their uses because they are chemically stable. They have excellent electrical insulation and very good chemical resistance.
   c) When they are disposed or put in landfill, they do not degrade which is a challenge to environment.
3. a) Carboxylic group and amine
   b) They have the same joining group, amide linkages.
   c) There is hydrogen bond.
4. Examples of synthetic polymers; nylons, Terylene, and polystyrene
5. To strengthen the polymer
   a) Natural addition polymer:
   - Polyisoprene (natural rubber): used in manufacturing tyres, tubes, etc



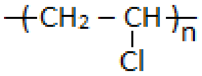
$$\left[CH_2 - \underset{\displaystyle CH_3}{\underset{|}{C}} = CH - CH_2 \right]_n$$

   - Monomer: Isoprene



$$CH_2 = \underset{\displaystyle CH_3}{\underset{|}{C}} - CH = CH_2$$

   - Synthetic addition polymer:
   - Polyvinylchloride (PVC) - uses: pipes, plastic bottles, doors (rigid PVC), rain coats (flexible PVC)



$$\left[CH_2 - \underset{\displaystyle Cl}{\underset{|}{CH}} \right]_n$$

   - Monomer: Chloroethene (vinyl chloride)

$CH_2 = CHCl$

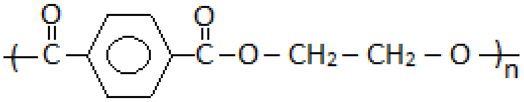
   - Natural condensation polymer:

Polymer: Starch, $(C_6H_{10}O_5)n$ - uses: textile and paper industry, source of ethanol

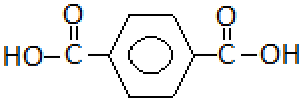
Monomer: Glucose; $C_6H_{12}O_6$

- Synthetic condensation polymer

Polymer: Terylene (polyester) - uses: textile industry (clothing, fishing lines, ropes, bottles…)



Monomers:

Benzene-1,4-dicarboxylic acid 

Ethane-1,2-diol $HOCH_2-CH_2OH$

b)

i) Fillers are solid inert materials added to synthetic polymers or rubber to change their physical properties or simply dilute it for economy (to increase the bulk of a polymer)

ii) Plasticizers are substances added to synthetic polymers to make them flexible, e.g. benzene-1,2-dicarboxylic acid added to thermosetting plastics to make them soft and readily remolded.

c)

i) Vulcanization is a process hardening rubber by heating natural rubber with sulphur or sulphur compounds

ii) By heating natural rubber with sulphur, atoms of sulphur react at both the double bond and at the ethylenic hydrogen such that the sulphur atoms form cross links with the rubber molecules giving the rubber greater elasticity and tensile strength. Formation of cross links also reduces sliding between the rubber molecules

iii) Name the monomer units in natural rubber

iv) SBR, Styrene – butadiene – rubber (the most widely used synthetic rubber). It is produced by copolymerization of butadiene and styrene in a ratio of 3:1 using free radical initiators. Use: tyres production

$$\underset{\text{Butadiene}}{3n\ CH_2{=}CH{-}CH{=}CH_2} + \underset{\text{Styrene}}{n\ CH_2{=}CH{-}C_6H_5} \longrightarrow \underset{\text{SBR}}{-\!\!\!\!+\!(CH_2{-}CH{=}CH{-}CH_2)_3{-}CH_2{-}CH{-}C_6H_5\!+\!\!\!\!-_n}$$

4.9. Additional activities

4.9.1. Remedial Questions

1. Why is Bakelite a thermosetting polymer?

Bakelite being a high cross-linked polymer and cannot be reshaped on heating. Hence, Bakelite is thermosetting polymer.

2. How is vulcanization done?

Vulcanization is carried out by heating raw rubber with sulphur in appropriate ratio and a suitable additive at a temperature range between 373K to 415K. On vulcanization sulphur form cross links at reactive sites of double bonds and thus rubber gets stiffened. In the manufacture of rubber, 5% sulphur is used as a vulcanizing agent.

Question 2

a) Describe linear, branch chained and cross linked polymers.
b) Describe additional and condensation polymers.
c) Describe thermoplastic polymers and thermosetting polymers..

Question 3

Describe the preparation of polyethene polymer and explain its uses.

Question 4

Describe the preparation of Nylon-6,6 and polyester polymers and explain its uses.

Question 4

Describe copolymerization process and copolymers.

Answers

Question 2

a) Linear polymers on Structure: These polymers consist of long and straight chains. The examples of Polymers are high density polythene, polyvinyl chloride, etc. These are represented as:

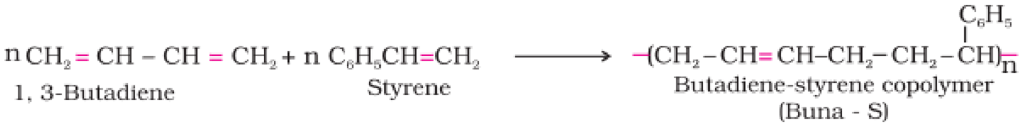
Branched chain polymers: These polymers contain linear chains having some branches, e.g., low density polythene. These are depicted as follows:

Cross linked or Network polymers: These are usually formed from bi-functional and tri-functional monomers and contain strong covalent bonds between various linear polymer chains, e.g. Bakelite, melamine, etc. These polymers are depicted as follows:

b) Addition polymers: The addition polymers are formed by the repeated addition of monomer molecules possessing double or triple bonds, e.g., the formation of polythene from ethene and polypropene from propene. However, the addition polymers formed by the polymerisation of a single monomeric species are known as homopolymers, e.g., polythene.

$$\underset{\text{Ethene}}{n\,CH_2=CH_2} \longrightarrow \underset{\text{Polythene}}{-\!\!\left(CH_2-CH_2\right)\!\!-_n} \text{ Homopolymer}$$

The polymers made by addition polymerization from two different monomers are termed as copolymers, e.g., Buna-S, Buna-N, etc.



$$\underset{\text{1, 3-Butadiene}}{n\,CH_2=CH-CH=CH_2} + \underset{\text{Styrene}}{n\,C_6H_5CH=CH_2} \longrightarrow \underset{\substack{\text{Butadiene-styrene copolymer}\\ \text{(Buna - S)}}}{-\!\!\left(CH_2-CH=CH-CH_2-CH_2-\overset{\overset{\displaystyle C_6H_5}{|}}{C}H\right)\!\!-_n}$$

Condensation polymers: The condensation polymers are formed by repeated condensation reaction between two different bi-functional or tri-functional monomeric units. In these polymerization reactions, the elimination of small molecules such as water, alcohol, hydrogen chloride, etc. take place. The examples are terylene (dacron), nylon 6, 6, nylon 6, etc. For example, nylon 6, 6 is formed by the condensation of hexamethylene diamine with adipic acid.

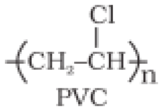
$$n\,H_2N\,(CH_2)_6\,NH_2 + n\,HOOC\,(CH_2)_4\,COOH$$

$$\longrightarrow \underset{\text{Nylon 6, 6}}{-\!\!\left[NH\,(CH_2)_6\,NHCO(CH_2)_4CO\right]\!\!-_n} + n\,H_2O$$

c) **Thermoplastic polymers:** These are the linear or slightly branched long chain molecules capable of repeatedly softening on heating and hardening on cooling.

These polymers possess intermolecular forces of attraction intermediate between elastomers and fibres.

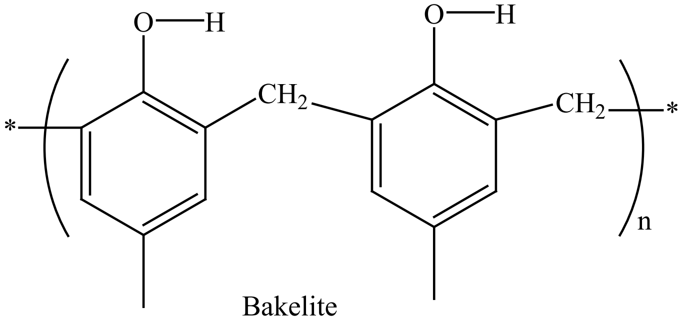
Some common thermoplastics are polythene, polystyrene, polyvinyls, etc.



$-\!\left(\mathrm{CH_2}-\overset{\mathrm{Cl}}{\overset{|}{\mathrm{CH}}}\right)\!\!-_n$

PVC

Thermosetting polymers: These polymers are cross linked or heavily branched molecules, which on heating undergo extensive cross linking in moulds and again become infusible. These cannot be reused. Some common examples are Bakelite, urea-formaldelyde resins, etc.



Bakelite

Question 3

There are two types of polythene as given below:

Low density polythene: It is obtained by the polymerisation of ethene under high pressure of 1000 to 2000 atmospheres at a temperature of 350 K to 570 K in the presence of traces of dioxygen or a peroxide initiator (catalyst). The low density polythene (LDP) obtained through the free radical addition and H-atom abstraction has highly branched structure. Low density polythene is chemically inert and tough but flexible and a poor conductor of electricity. Hence, it is used in the insulation of electricity carrying wires and manufacture of squeeze bottles, toys and flexible pipes.

High density polythene: It is formed when addition polymerization of ethene takes place in a hydrocarbon solvent in the presence of a catalyst such as triethylaluminium and titanium tetrachloride (Ziegler-Natta catalyst) at a temperature of 333 K to 343 K and under a pressure of 6-7 atmospheres. High density polythene (HDP) thus produced, consists of linear molecules and has a high density due to close packing. It is also chemically inert and more tougher and harder. It is used for manufacturing buckets, dustbins, bottles, pipes, etc.

Question 4~1

- Nylon-6,6 is a poly amide and is prepared by the condensation polymerization of hexamethylenediamine with adipic acid under high pressure and at high temperature.

$$n\,HOOC(CH_2)_4COOH + n\,H_2N(CH_2)_6NH_2 \xrightarrow[\text{High pressure}]{553K} \left[\overset{H}{\overset{|}{N}}-(CH_2)_6-\overset{H}{\overset{|}{N}}-\overset{O}{\overset{\|}{C}}(CH_2)_4-\overset{O}{\overset{\|}{C}} \right]_n$$

Nylon 6,6

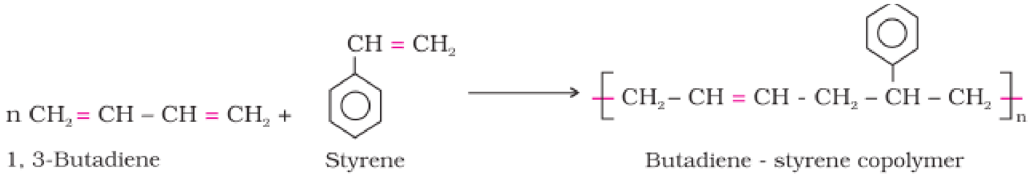
Nylon 6, 6 is used in making sheets, bristles for brushes and in textile industry.

- Polyesters are the polycondensation products of dicarboxylic acids and diols. Dacron or Terylene is the best known example of polyesters. It is manufactured by heating a mixture of ethylene glycol and terephthalic acid at 420 to 460 K in the presence of zinc acetate antimony trioxide catalyst as per the reaction given earlier. Dacron fibre (terylene) is crease resistant and is used in blending with cotton and wool fibres and also as glass reinforcing materials in safety helmets, etc.

Question 4~2

- Copolymerization is a polymerization reaction in which a mixture of more than one monomeric species is allowed to polymerize and form a copolymer. The copolymer can be made not only by chain growth polymerization but by step growth polymerization also.

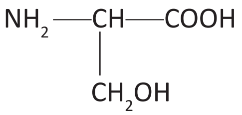
It contains multiple units of each monomer used in the same polymeric chain. For example, a mixture of 1, 3 – butadiene and styrene can form a copolymer.



- Copolymers have properties quite different from homopolymers. For example, butadiene – styrene copolymer is quite tough and is a good substitute for natural rubber. It is used for the manufacture of autotyres, floortiles, footwear components, cable insulation, etc.

4.9.2. Consolidation questions

1. 1. The amino acid “serine” has the structure :



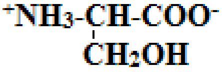
$$NH_2-\underset{\underset{CH_2OH}{|}}{CH}-COOH$$

a) Show the structure of the zwitterion of the above amino acid.

b) What name is given to the polymers formed by amino acids?

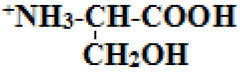
c) Show the structure formed when the above amino acid is dissolved an acidic solution.

Answer:



$$^{+}NH_3\text{-}\underset{CH_2OH}{\underset{|}{CH}}\text{-}COO^{-}$$

a) Condensation polymers

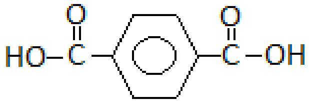
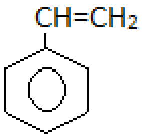


$$^{+}NH_3\text{-}\underset{CH_2OH}{\underset{|}{CH}}\text{-}COOH$$

State the type of polymerization leading to the formation of the polymers given in the table below. In each case, write the name and the structural formula of the monomers.

Polymer	Type of polymerization	Structural formula of the monomers	Name of the monomers
Polyester (Terylene)			
Polyamide (Nylon 6,6)			
Polystyrene			

Answer:

Polymer	Type of polymerization	Structural formula of the monomers	Name of the monomers
Polyester (terylene)	Condensation	 $HOCH_2-CH_2OH$	Benzene-1,4 dioic acid Ethane-1,2-diol
Polyamide (Nylon 6,6)	Condensation	$H_2N\left(CH_2\right)_6NH_2$ $HO_2C\left(CH_2\right)_4CO_2H$	Hexane-1,6 diamine and Hexane-1,4-dioic acid
Polystyrene	Addition		Phenylethene (styrene)

Question 3

a) Describe vulcanization of rubber.

b) Explain biodegradable polymers.

Question 4

a) Write the free radical mechanism for the polymerization of ethene.

b) Explain the terms polymer and monomer.

Question 5

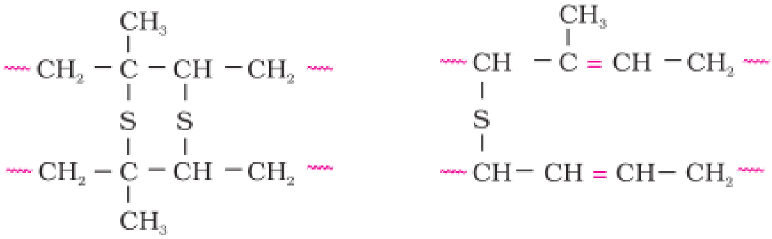
a) Write an equation for the formation of ethyl ethanoate from ethanoyl chloride and ethanol. Name and outline the mechanism for the reaction taking place.

b) Explain why dilute sodium hydroxide will cause holes to appear in clothing made from polymers such as Terylene but a poly(phenylethene) container can be used to store sodium hydroxide.

ANSWERS

Question 3

a) Natural rubber becomes soft at high temperature (>335 K) and brittle at low temperatures (On vulcanisation, sulphur forms cross links at the reactive sites of double bonds and thus the rubber gets stiffened. In the manufacture of tyre rubber, 5% of sulphur is used as a crosslinking agent. The probable structures of vulcanised rubber molecules are depicted below:



b) A large number of polymers are quite resistant to the environmental degradation processes and are thus responsible for the accumulation of polymeric solid waste materials. These solid wastes cause acute environmental problems and remain undegraded for quite a long time. In view of the general awareness and concern for the problems created by the polymeric solid wastes, certain new biodegradable synthetic polymers have been designed and developed.

Question 4

a) Chain initiation step

$$\dot{C}_6H_5 + CH_2{=}CH_2 \longrightarrow C_6H_5-CH_2-\dot{C}H_2$$

Chain propagating step

$$C_6H_5-CH_2-\dot{C}H_2 + CH_2=CH_2 \longrightarrow C_6H_5-CH_2-CH_2-CH_2-\dot{C}H_2$$

b) Chain propagating step

$$\dot{C}_6H_5 + CH_2{=}CH_2 \longrightarrow C_6H_5-CH_2-\dot{C}H_2$$

Chain propagating step

$$C_6H_5-CH_2-\dot{C}H_2 + CH_2=CH_2 \longrightarrow C_6H_5-CH_2-CH_2-CH_2-\dot{C}H_2$$

c) Chain terminating step for termination of the long chain, these free radicals can combine in different ways to form polythene. One mode of termination of chain is shown as under:

$$\begin{matrix} C_6H_5 + CH_2-CH_2 +_n CH_2-\dot{C}H_2 \\ C_6H_5 + CH_2-\overset{+}{\dot{C}}H_2 +_n CH_2-\dot{C}H_2 \end{matrix} \longrightarrow \underset{\text{Polythene}}{C_6H_5 + CH_2-CH_2 +_n CH_2-CH_2-CH_2 + CH_2-CH_2 +_n C_6H_5}$$

d) Polymers are high molecular mass substances consisting of large numbers of repeating structural units. They are also called as macromolecules. Some examples of polymers are polythene, bakelite, rubber, nylon 6, 6, etc.

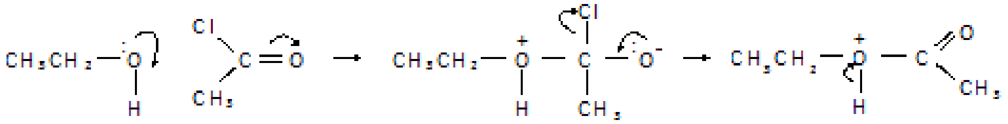
- Monomers are repeating small structural units that are linked to each other by covalent bonds to form a polymer.

Question 5

a) *Equation* $CH_3COCl + CH_3CH_2OH \rightarrow CH_3COOCH_2CH_3 + HCl$

Name of mechanism addition-elimination

Mechanism

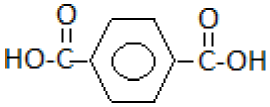


b) Only the polyester is hydrolyzed by alkali.

4.9.3. Extended Questions

1. Terylene is a polymer made from ethane-1,2-diol and benzene-1,4-dicarboxylic acid. The monomers are:

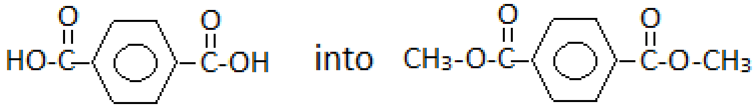
$HOCH_2CH_2OH$ and



a) Give the structure of Terylene showing only one repeat unit

b) What type of polymer is Terylene?

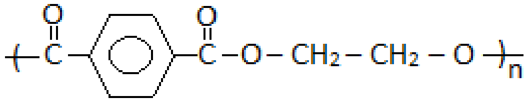
c) How would you convert



State the reagent and condition

Answer:

a)

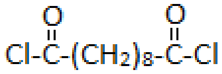


b) Terylene is a condensation polymer (polyester)

c) Add CH_3COOH / conc. H_2SO_4 catalyst, heat

2. a) Give one example and use of a synthetic thermosetting plastic

b) Nylon 6,10 can be formed by reacting-1,6-diamino hexane with decanedioyl dichloride,



$Cl-\overset{O}{\overset{\|}{C}}-(CH_2)_8-\overset{O}{\overset{\|}{C}}-Cl$

3.

i) Write an equation for the formation of nylon 6,10

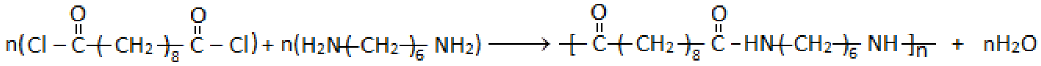
ii) State the type of polymerization involved in the formation of nylon 6,10

iii) State one use of nylon 6,10

Answer:

a) An example and use of a synthetic thermo setting plastic: Bakelite used in making saucepan handle, electrical switches and sockets, etc.

b) i) An equation for the formation of nylon 6,10



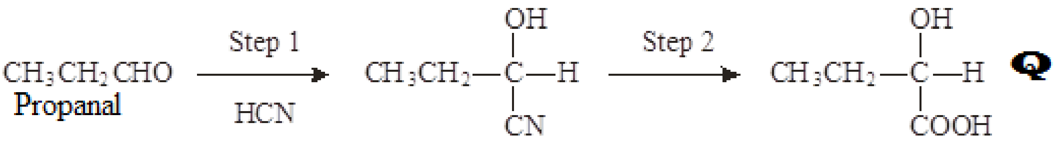
$$n(Cl-\overset{O}{\overset{\|}{C}}-(CH_2)_8-\overset{O}{\overset{\|}{C}}-Cl)+n(H_2N-(CH_2)_6-NH_2)\longrightarrow -[\overset{O}{\overset{\|}{C}}-(CH_2)_8-\overset{O}{\overset{\|}{C}}-HN-(CH_2)_6-NH]_n- \;+\; nH_2O$$

iii) Type of polymerization involved in the formation of nylon 6,10: Condensation polymerization

- Manufacture of surgical gloves
- Manufacture of fishing nets, carpets
- Manufacture of curtains

Question 4

Consider the reaction sequence shown below.



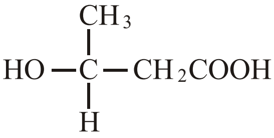
$$CH_3CH_2CHO \xrightarrow[HCN]{\text{Step 1}} CH_3CH_2-\overset{OH}{\underset{CN}{C}}-H \xrightarrow{\text{Step 2}} CH_3CH_2-\overset{OH}{\underset{COOH}{C}}-H \quad \mathbf{Q}$$

a) Name and outline a mechanism for the reaction in Step 1.

b) **(i)** Name compound **Q** formed in Step 2.

(ii) Two stereoisomers are formed by the dehydration of Q. Give the structures of these two isomers and name the type of stereoisomerism shown.

c) An isomer of **Q** which has the structure shown below is polymerized to form the biodegradable polymer known as PHB.

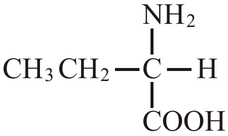


$$HO-\overset{CH_3}{\underset{H}{C}}-CH_2COOH$$

i) Draw the repeating unit of the polymer PHB.

ii) Suggest a reason why the polymer is biodegradable.

d) The amino acid **R** is shown below.



$$CH_3CH_2-\overset{NH_2}{\underset{COOH}{C}}-H$$

R

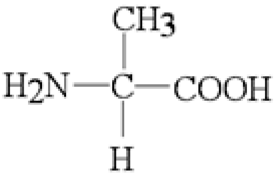
i) Draw the structure of the zwitterion formed by **R**.

ii) Draw the structure of the major organic product formed when an excess of **R** is reacted with bromomethane.

iii) Name the mechanism of the reaction which results in the formation of the product given in part **(ii).**

Question 5

The amino acid *alanine* is shown below.



$$H_2N-\overset{CH_3}{\underset{H}{C}}-COOH$$

Alanine

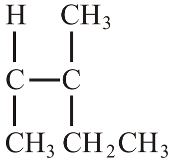
d) A sample of alanine is dissolved in water.

i) Draw the structure of the main alanine species present in this aqueous solution and give the name of this type of species.

ii) Draw the structure of the alanine species formed when an excess of hydrochloric acid is added to the solution.

e) Alanine molecules may be reacted together to form a polypeptide. Give the repeating unit of this polypeptide and name the type of polymerization involved in its formation.

f) The repeating unit of a polyalkene is shown below.



$\overset{H}{\underset{CH_3}{C}}-\overset{CH_3}{\underset{CH_2CH_3}{C}}$

Give the name of the alkene which is used to form this polymer.

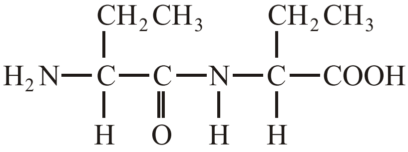
Question 6

a) The compound H2C=CHCN is used in the formation of acrylic polymers.

i) Draw the repeating unit of the polymer formed from this compound.

ii) Name the type of polymerization involved in the formation of this polymer.

b) When the dipeptide shown below is heated under acidic conditions, a single amino acid is produced.

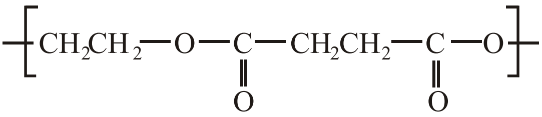


$H_2N-\overset{CH_2CH_3}{\underset{H}{C}}-\underset{O}{\underset{\|}{C}}-\underset{H}{N}-\overset{CH_2CH_3}{\underset{H}{C}}-COOH$

i) Name this amino acid.

ii) Draw the structure of the amino acid species present in the acidic solution.

c) The repeating unit of a polyester is shown below.



$-\!\left[CH_2CH_2-O-\underset{O}{\underset{\|}{C}}-CH_2CH_2-\underset{O}{\underset{\|}{C}}-O\right]\!-$

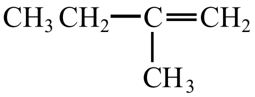
i) Deduce the empirical formula of the repeating unit of this polyester.

ii) Draw the structure of the acid which could be used in the preparation of this polyester and give the name of this acid.

iii) Give **one** reason why the polyester is biodegradable.

Question 7

a) The hydrocarbon **M** has the structure shown below.



$CH_3CH_2-\underset{CH_3}{C}=CH_2$

i) Name hydrocarbon **M**.

ii) Draw the repeating unit of the polymer which can be formed from **M**. State the type of polymerization occurring in this reaction.

iii) The reaction between **M** and benzene in the presence of HCl and $AlCl_3$ is similar to the reaction between ethene and benzene under the same conditions. Name the type of mechanism involved and draw the structure of the major product formed in the reaction between **M** and benzene.

iv) Draw a structural isomer of **M** which shows geometrical isomerism.

b) Draw the repeating unit of the polymer formed by the reaction between butanedioic acid and hexane-1,6-diamine. State the type of polymerization occurring in this reaction and give a name for the linkage between the monomer units in this polymer.

Question 8

a) "Terylene" is a condensation polymer that can be formed from benzene-1,4-dicarboxylic acid and ethane-1,2-diol. Draw graphical formulae to represent:

i) Benzene-1,4-dicarboxylic acid;

ii) Ethane-1,2-diol;

iii) The polymer "Terylene".

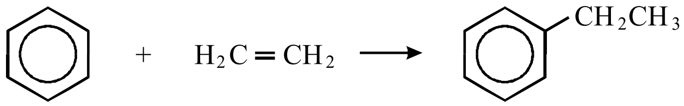
b) Give the name of the type of condensation polymer of which "Terylene" is an example.

c) Outline the difference between the formation of an addition polymer and a condensation polymer.

d) Give the name of **one** addition polymer.

Question 9

Ethylbenzene is made by the reaction shown below.



a) Identify two other substances required as catalysts in this preparation.

b) Write an equation for the reaction of these two substances with ethene to form the reactive intermediate involved in the formation of ethylbenzene.

c) Name and outline a mechanism for the reaction between this reactive intermediate and benzene.

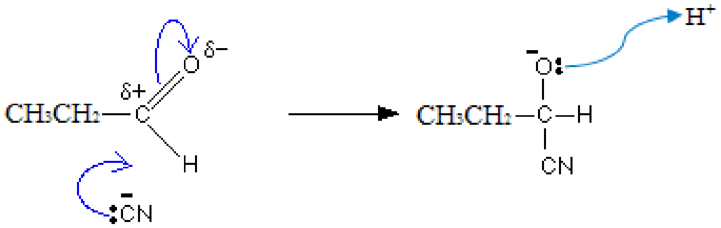
d) Draw the structure of the product formed in a similar reaction between benzene and cyclohexene.

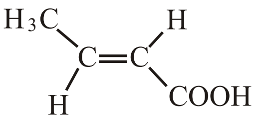
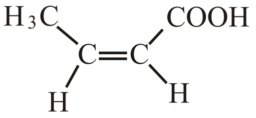
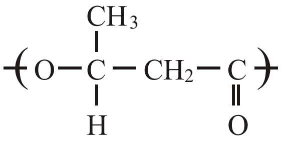
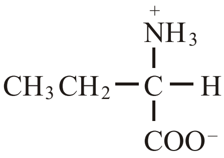
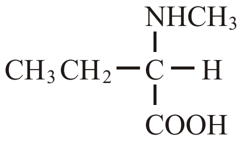
e) Ethylbenzene is used to make phenylethene which can be polymerized to form poly(phenylethene). Name this type of polymerization and draw the structure of the repeating unit in the polymer.

Answers

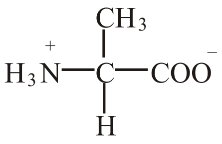
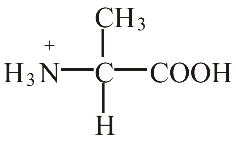
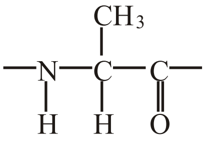
Question 4

a) Nucleophilic addition;

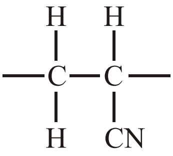
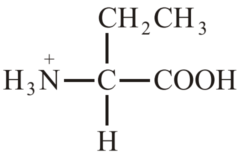


i) 2-hydroxybutanoic acid  ii)  iii) Geometric(al) or cis-trans	i)  $\left(O-\overset{CH_3}{\underset{H}{C}}-CH_2-\underset{\overset{\|}{O}}{C}\right)$ Can be hydrolysed / can be reacted with /attacked by acid/base/nucleophiles /H_2O/OH^-; ii) i)  $CH_3CH_2-\overset{\overset{+}{N}H_3}{\underset{COO^-}{C}}-H$ ii)  $CH_3CH_2-\overset{NHCH_3}{\underset{COOH}{C}}-H$ (or zwitterions product)) **iii) Nucleophilic** substitution;

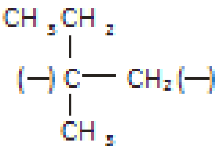
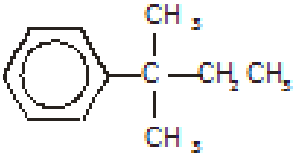
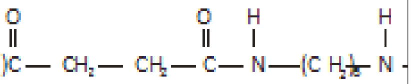
Question 5

i)  $H_3\overset{+}{N}-\overset{CH_3}{\underset{H}{C}}-COO^-$ ii)  $H_3\overset{+}{N}-\overset{CH_3}{\underset{H}{C}}-COOH$	iii)  $-\underset{H}{N}-\overset{CH_3}{\underset{H}{C}}-\underset{\overset{\|}{O}}{C}-$ Condensation or (nucleophilic) addition-elimination 3-methylpent-2-ene

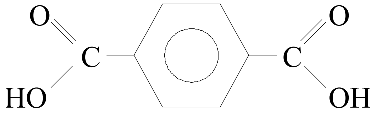
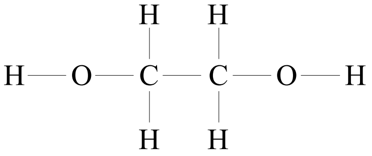
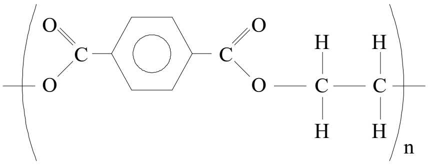
Question 6

a) i)  ii) Addition or radical	b) i) 2-aminobutanoic (acid) ii)  $H_3\overset{+}{N}-\underset{H}{\overset{CH_2CH_3}{C}}-COOH$	c) i) $C_3H_4O_2$ ii)  $HO-\underset{O}{\underset{\|}{C}}-CH_2CH_2-\underset{O}{\underset{\|}{C}}-OH$ Butan-,1,4-dioic acid iii) Can be hydrolyzed / can react with acid or base or water /can react with nucleophiles

Question 7

i) 2-methylbut-1-ene *ii) Repeating unit:*  *Type of polymerization*: Addition or radical iii) Name of mechanism: electrophilic substitution *Major product:* 	iv) $CH_3CH{=}CHCH_2CH_3$ *v) Repeating unit*:  *Type of polymerization*: condensation *Name of linkage*: (poly) peptide or (poly)amide

Question 8

i)  **ii)**  Or $HOCH_2CH_2OH$	**iii)** 

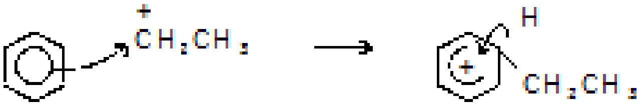
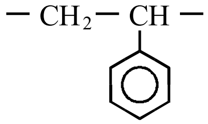
Polyesters

a) *Addition:* joining together (of monomers with double bond) / one product only

Condensation: also involves the elimination of a small molecule (like H_2O, HCl, CH_3OH)

Poly(ethene) / poly(propene)

Question 9

a) *Substance 1*: HCl or HBr *Substance 2*: $AlCl_3$ / $AlBr_3$ / $FeCl_3$ / $FeBr_3$ b) $H_2C{=}CH_2 + HCl + AlCl_3 \rightarrow CH_3CH_2^+ + AlCl_4^-$ c) *Name of mechanism*: Electrophilic substitution *Mechanism:* 	d) *Type of polymerization*: Addition *Repeating* *unit*:  $-CH_2-CH-$

UNIT 5: FACTORS THAT AFFECT THE RATE OF REACTIONS

5.1. Key unit competency:

Explain the factors that affect the rate of chemical reaction and use Arrhenius equation to calculate the ratio of rate constant and activation energy with change in the temperature.

5.2. Prerequisite knowledge and skills

- Learners will understand better this unit if they know
- Chemical equilibrium studied in year two.
- Logarithms studied in mathematics.

5.3. Cross-cutting issues to be addressed

Environment and sustainability

The growing awareness of the impact of humans on the environment has led to the recognition of the need to ensure our young people understand the importance of sustainability as they grow up and become responsible for the world around them. Hence Environment and Sustainability is a very important cross-cutting issue

Learners need skills and attitudes that will enable them in their everyday life to address the environment and climate change issue and to have a sustainable livelihood.

While teaching this unit concerning factors that affect the rate of reaction, talk about the environment and its sustainability. For instance, when you talk about the use of catalysts in contact process and Haber process, tell the student teachers that some gases produced during these processes cause air pollution.

5.4. Guidance on the introductory activity

Before introducing the first lesson of unit 5, you will have to introduce the whole unit. Ask student teachers (in pairs) to attempt the introductory activity from student teacher's book. This activity intends to relate the unit with student teachers' daily life and to capture their attention.

Give them around 10 minutes and ask them to conduct this introductory activity. They may not be able to find the right answers, but they are invited to speak their mind.

Select some groups (2-4) to share their findings to the whole class.

After presentation, give your comments.

The expected answers of the introductory activity for unit 5

1. Reaction A is combustion and reaction B is Oxidation of iron (Rusting).
2. Reaction A: Fast, Reaction B: Slow

3. The slow reaction can be speeded up by using a catalyst, increasing the amount of reactants, … and the fast reaction can be slowed down by decreasing the concentration of reactants, using a retardant (negative catalyst)

5.5. List of lessons/sub-heading

	Lesson title	Learning objectives	Number of periods 7
1	Concept of reaction kinetics	• Explain the concept of reaction kinetics. • Appreciate the importance of reaction kinetics.	2
2	Factors that change the rates of reactions (temperature, concentration, surface area, catalyst, pressure and light).	• Explain the effect of different conditions on the rate of reaction. • Carry out experiments to show how different factors affect the rate of chemical reactions • Predict the effect of changing conditions on the rate of reactions • Appreciate the importance of different conditions on the reaction rates.	4
3	Summative assessment		1

Lesson 1: Concept of chemical kinetic

a) Learning objectives

- Explain the concept of reaction kinetics.
- Appreciate the importance of reaction kinetics.

b) Prerequisites:

Student teachers will understand better this lesson if they know the concept of chemical reactions.

c) Teaching resources:

- Chemistry textbooks and other relevant chemistry books from the library.

- Where possible use internet
- Distilled water, ethanol, lead (II) nitrate, potassium iodide, nails, test tubes, test tube racks, beakers, droppers, stopwatches and match boxes.

d) Learning activities

This lesson contains one activity:

- Ask student teachers to form groups of 2-4 (the number of groups and members will depend on your class size and the number of your resources or materials).
- Give student teachers activity 5.1 (from student teacher's book)
- As a tutor, move around the class and check if all student teachers are working.
- Ask student teachers to present their findings.
- During the presentation ask some questions that lead to lesson objectives.
- Guide student teachers to summarize the lesson themselves.

Possible answers for activity 5.1

1. - in (a) the reaction is combustion
   - in (b) the reaction is precipitation
   - in (c) the reaction is redox (single displacement).

2.
   a) $CH_3CH_2OH + O_2 \rightarrow CO_2 + H_2O$
   b) $Pb(NO_3)_2(aq) + KI(aq) \rightarrow PbI_2(s) + KNO_3(aq)$
   c) $CH_3COOH(l) + Mg(s) \rightarrow (CH_3COO)_2Mg(aq) + H_2(aq)$
   - Give the conclusion of the lesson.
   - After giving conclusion, assess your student teachers using application activity 5.1 (from student teacher's book).Student teachers can do this application activity individually or in pairs. If you do not have enough time in your lesson, give it as individual homework. Make sure you mark the students' work.

Application activity 5.1

Answers for application activity 5.1

1. Refer to the student teacher's textbook for the concept of reaction kinetics.
2. $Rate = -\frac{\Delta[A]}{\Delta t} = -\frac{(0.4-0.5)}{(10-0)}$

   $Rate = 0.01 molL^{-1}\min^{-1}$

   $Rate = 1.66x10^{-4}$

Lesson 2: Factors that change the rates of reactions

a) Learning objectives

- Explain the effect of different conditions on the rate of reaction.
- Carry out experiments to show how different factors affect the rate of chemical reactions
- Predict the effect of changing conditions on the rate of reactions
- Appreciate the importance of different conditions on the reaction rates.

b) Prerequisites:

Student teachers will understand better this lesson if they have understanding on the concept of chemical reaction and thermodynamics.

c) Teaching resources:

- Chemistry textbooks
- Where possible use internet
- Sodium thiosulphate, hydrochloric acid, distilled water, measuring cylinder, stop clock (or stopwatch), conical flask and white paper.
- Hydrogen peroxide, test tubes, wooden splint, manganese (IV) oxide, test tube racks, ammonium iron (II) sulphate crystals or iron (II) sulphate crystals, propane-1,2,3-triol.
- Sodium chloride, silver nitrate, test tubes.

d) Learning activities

This lesson has three activities corresponding to the three sub lessons stated earlier:

- Activity 5.2 (a),
- Activity 5.2 (b) and
- Activity 5.2 (c).
- Activity 5.2 (a)
- Give student teachers activity 5.2 (a) (from the student teacher's book).
- Ask student teachers to carry out this activity in pairs
- Move around the class and check if all student teachers are working.
- Ask them to present their findings.
- Guide by to make a summary of the lesson themselves.

Answers for Activity 5.2 (a)

1. When the reacting mixture is heated, more of the reactants will have the energy necessary to be transformed into products (the activation energy)

than at the lower temperature (room temperature). Higher temperatures cause an increase of reaction rates. More explanations are in the student teacher's book.

Activity 5.2 (b)

- Form groups
- Give student teachers the resources
- Ask student teachers to carry out the activity 5.2 (b) (from the student teacher's book).
- Ask student teachers to present their observations and deductions to the whole class.
- Guide student teachers to make the summary of the lesson themselves.

Possible answers for activity 5.2 (b)

a)

1. The fastest reaction is the in which we use 3cm^3. This is because we use more reacting particles, hence more collisions.
2. $Na_2S_2O_3 + HCl \rightarrow 2NaCl + SO_2 + S + H_2O$

b) The color of the precipitate darkens as time goes on and when the beaker is exposed to light the process of darkening is faster. This is due to light which accelerates some reactions by providing them with the energy they need to tale place.

Activity 5.2 (c)

- Form groups
- Give student teachers the resources
- Ask student teachers to carry out the activity 5.2 (c) (from the student teacher's book).
- Ask student teachers to present their observations and deductions to the whole class.
- Guide student teachers to make the summary of the lesson themselves.

Possible answers for activity 5.2 (c)

- In B1 there is almost no reaction.
- In B2 the reaction takes place and it is too fast.
- In B3 the reaction start faster but after addition of the alcohol the speed of reaction slows down.

Application activities 5.2

Answers to application activities 5.2.a

1. At low temperature, molecules receive less energy and then they move slowly. As they move slowly, the number of collisions per unit time reduces and consequently the rate of reaction decreases.

2. $$\log\frac{K_2}{K_1}=+\frac{Ea}{2.303R}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)$$

$$\left(\log\frac{K_2}{K_1}:\left(\frac{1}{T_1}-\frac{1}{T_2}\right)\right)x2.303R=E_a$$

Ea= 24284.1436J

Since K= $Ae^{-\frac{Ea}{RT}}$

$$1.7x10^{-3}=Ae^{-\frac{24284.14}{8.314x500}}$$

And then, A= 0.585

Answers to application activities 5.2.b

1. Derrick who uses the powder form will get the results first because he has used finely divided $CaCO_3$ which provides a large surface area, hence increases the rate of reaction.
2. Increasing pressure is the same as increasing concentration. The effect of this is to increase the reaction rate because we get more particles per unit volume hence increasing the number of collisions per unit time.

Answers to application activities 5.2.c

1. Give the name and the type of catalyst used in each of the following reactions:
   a) Production of ammonia in the Haber process: catalyzed by Iron and it is heterogenous catalyst.
   b) Hydrogenation of alkenes: catalyzed by nickel or platinum and it is heterogenous catalyst.
2. At lower temperatures reactants get less energy than the activation energy needed for the reaction to take place. As a result the rate of reaction decreases due to low kinetic energy and less collisions. To overcome all this, a catalyst is used as it provides an alternative route which requires less energy. x

5.6. Summary of the unit

Chemical kinetics is a branch of chemistry mainly dealing with the rates of reaction. Chemical kinetics studies not only help us to determine the speed or rate of a chemical reaction but also describe the conditions by which the reaction rates can be altered. The factors such as concentration, temperature, pressure, and catalyst, light and surface area affect the rate of a reaction. This unit deals with factors that affect the rate of chemical reactions. When we say "chemical kinetics", we mean that we are studying the rates of reaction and factors that affect the rates.

A chemical reaction occurs when the molecules of the reactants collide with one another in the reacting environment. The rate at which a reaction occurs depends on the rate of the collision of the molecules, and the collision rate depends on various factors, which can be altered to change the rate of a reaction. The reaction rate can be increased by the action of one or more of the factors:

1. Concentration: The rates of many reactions depend on the concentrations of the reactants. Increasing the concentration of one or more reactants will normally increase the reaction rate.
2. Pressure: When the pressure increases in the gaseous system, the number of collisions between reactants also increases. Consequently, the rate of reaction is increased. At high pressure, the gas particles are closer together which can increase the collision.
3. Temperature: For most chemical reactions, temperature is directly proportional to the rate of the chemical reaction. The increase in temperature increases the energy of the reactant molecules, making them move faster and more susceptible to collisions, thereby increasing the reaction rate.
4. Surface Area of the Reactants: For the same mass, many small particles have a greater surface area than one large particle. The more surface contact between reactants, the higher the rate of reaction. The less surface contact, the lower the reaction rate. The rate of chemical reactions increases by increasing the surface area of reactants. For example, powdered sugar dissolves more quickly in water than a lump of sugar.
5. Catalyst (Positive catalyst): is a substance that increases the rate of a chemical reaction by lowering the activation energy without itself being consumed by the reaction. Catalysts reduce the amount of energy required to break and form bonds during a chemical reaction. When the reaction is complete, catalysts remain chemically unchanged and they can be reused several times.
6. Light: is a form of energy that can affect the rate of a reaction. The rate of some photochemical reactions increases with increase in the intensity of suitable light used. With the increase in the intensity, the number of photons in light also increases. Hence a greater number of reactant molecules gets energy by absorbing more photons and undergo chemical change.

Knowing and controlling the rate of reactions is important in living cells and industry. In the body, chemical reactions must take place at the correct rate to supply your cells with exactly what they need when they need it. The products of chemical reactions costmoney, so it is important to be able to speed up the rate and make them as cheaply as possible.

5.7. Additional Information

THEORIES OF CATALYSIS

Catalysis can be explained using the two theories:

- Intermediate compound formation theory
- Adsorption theory

a) The intermediate compound formation theory

In general, the intermediate compound formation theory applies to homogeneous catalyst reactions. According to this theory, the catalyst forms an intermediate with one of the reactants. But the intermediate compound is unstable so that the intermediate compound combines with other reactant to form the desired product and the catalyst is regenerated.

Example:

$$2NO + O_2 \rightarrow 2NO_2$$

(catalyst) (Intermediate compound)

$$NO_2 + SO_2 \rightarrow SO_3 + NO$$

(product) (catalyst)

b) Adsorption Theory

In general adsorption theory applies to heterogeneous catalytic reactions. The catalyst works by the adsorption of the reacting molecules on its surface.

$$A + B \xrightarrow{catalyst} C + D$$

The adsorption reaction undergoes four types of steps:

i) Adsorption of reactant molecule:

The reactant molecules A and B strike the surface of the catalyst. The reacting molecules are held up by partial chemical bonds.

ii) Formation of intermediate complex:

The reactant molecules adjacent to one another join to form an intermediate complex (A-B). The intermediate complex is unstable.

iii) Decomposition of intermediate complex:

The intermediate complex breaks to form the products C and D. The product molecules hold to the catalyst surface by partial chemical bond.

iv) Release of product:

The product particles are then released from the surface.

Guidance to skills lab 5

This activity controls how student teachers have understood the unit and if they are able to apply concepts to everyday life situations. It should not be done during study hours. The tutor should explain what must be done and let student teachers work on their own. It will be done as a project. The main ideas to appear in each point of this skills lab are described below:

1. Milk processing requires a lot of care to avoid contamination which may result into spoilage of the milk. For this purpose we can use the concept of lowering temperature so as to keep lactobacillus bacteria inactive. This increases the lifespan of the milk.
2. Physical injuries of footballers are treated using cold packs as the coldness from them reduces the speed at the injured part swells. The process going on inside a cold pack is endothermic hence it absorbs heat from the injured part and it lowers the temperature and consequently the swelling speed reduces as well as paining.
3. In the stomach, food is both physically and chemically digested. Chemical digestion is governed by the gastric juice. When someone drinks water right after eating, they dilute the gastric juice and the speed of chemical digestion decreases. Also, when cold water is used, the temperature inside the stomach falls and the body fights to raise it up first before digesting the food. This also delays the start of digestion.

5.8. End unit assessment Answers

Learning and assessment standards:

Collaborate with others to conduct experiments to investigate the factors that affect the rate of chemical reaction, resolving differences and agreeing ways forward.

1. B) reaction kinetics
2. B) reactant molecules collide more frequently and with greater energy per collision

3. C) time
4. A) concentration
5. C) adding a catalyst for the reaction
6. Aluminium powder reacts vigorously because of the particle size (surface area). If aluminium is converted into powder the surface area increases, therefore, increasing the surface area of the metal by converting it into a powder, its reaction rate increases. More small particles get in contact with the acid making the reaction faster.
7. Refer to the student's book, unit 5, lesson 1 on the examples of how the average rate of a reaction is determined.

8. $$Rate = -\tfrac{1}{2}\frac{\Delta[N_2O_5]}{\Delta t} = -\tfrac{1}{2}\left(\frac{(2.08-2.33)molL^{-1}}{184\min}\right)$$

$$Rate = 6.79x10^{-4}molL^{-1}\min^{-1}$$

$$Rate = \left(6.79x10^{-4}molL^{-1}\min^{-1}\right)x\left(60\min/1h\right) = 4.07x10^{-2}molL^{-1}/h$$

$$Rate = \left(6.79x10^{-4}molL^{-1}\min^{-1}\right)/\left(1\min/60s\right) = 1.13x10^{-5}molL^{-1}s^{-1}$$

The rate of production of nitrogen dioxide is:

$$\frac{1}{4}\frac{\Delta\left[NO_2\right]}{\Delta t} = 6.79x10^{-4}mol.dm^{-3}.\min^{-1}x4 = 2.72x10^{-3}mol.dm^{-3}.\min^{-1}\ or$$

$$1.63x10^{-1}mol.dm^{-3}.s^{-1}$$

9. Refer to the student teacher's book, examples of how to calculate activation energy.

10. $$\log\frac{K_2}{K_1} = +\frac{Ea}{2.303R}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)$$

$$\log\frac{K_2}{K_1} = +\frac{190x10^3}{2.303x8.3145}\left(\frac{1}{550}-\frac{1}{781}\right)$$

$$\frac{K_2}{K_1} = 2x10^5$$

It means that, if the temperature increases, the rate constant also increases by a factor of $2x10^{-5}$.

5.9. Additional activities

5.9.1 Remedial Activities:

1. How does the temperature of the reactants affect the reaction rate?
   a) Temperature has no effect on the reaction rate.
   b) Reaction rate decreases with increase in temperature.
   c) It is unpredictable.
   d) Reaction rate increases with increase in temperature.

Answer: D

2. Which of the following is true about the rate of reaction?
   a) The greater the particle size, the greater will be the reaction rate.
   b) Addition of a catalyst decreases the rate of reaction.
   c) Increase in temperature will increase the rate of reaction.
   d) Agitation decreases the rate of reaction.

Answer: C

3. Which of the following will not increase the rate of reaction?
   a) Maintaining constant temperature of the reaction mixture
   b) Addition of a catalyst to the reaction mixture
   c) Addition of more reactants to the reaction mixture
   d) Shaking the vessel containing the reaction mixture

Answer: A

4. Sulphur trioxide reacts with water to form sulphuric acid according to the equation given below.

$SO_3 + H_2O \rightarrow 2H_2SO_4$

At the start of the reaction, there was no acid or $[H^+] = 0$. After 50 seconds, $[H^+] = 7.5 \times 10^{-6}$ M. What is the rate of the reaction?

   a) 1.5×10^{7} M/s
   b) 1.5×10^{-7} M/s
   c) 3.0×10^{-7} M/s
   d) 8.0×10^{5} M/s

Answer: B

5. By use of appropriate examples in each case show what you understand by:
   a) Homogeneous catalysis
   b) Heterogeneous catalysis

Answer: Refer to the student teacher's book.

6. Consider the following reaction: $N_{2(g)} + 3\ H_{2(g)} \rightarrow 2\ NH_{3(g)}$

If the rate of loss of hydrogen gas is -0.03moldm^{-3}s^{-1}, what is the rate of production of ammonia?

Answer: $-\frac{1}{3}\frac{\Delta[H_2]}{\Delta t} = \frac{1}{2}\frac{\Delta[NH_3]}{\Delta t}$

$\frac{\Delta[NH_3]}{\Delta t}$ =($-\frac{1}{3}x$ -0.03x 2) = 0.02moldm-3s-

7. Ethanol (C_2H_5OH), the active ingredient in alcoholic beverages and an octane booster

in gasoline, is produced by the fermentation of glucose. The balanced equation is

$C_6H_{12}O_{6(aq)} \rightarrow 2C_2H_5OH_{(aq)} + 2CO_{2(g)}$

a) How is the rate of formation of ethanol related to the rate of consumption of glucose?

Answer: According to the balanced equation, 2 mol of ethanol are produced for each mole of glucose that reacts. Therefore, the rate of formation of ethanol is twice the rate of consumption of glucose.

b) Write this relationship in terms of $\Delta[C_2H_5OH]/\Delta t$ and $\Delta[C_6H_{12}O_6]/\Delta t$.

Answer: Since the rate of formation of ethanol is $\Delta[C_2H_5OH]/\Delta t$ and the rate of consumption of glucose is $-\Delta[C_6H_{12}O_6]/\Delta t$ (note the minus sign), we can write

$$\frac{\Delta[C_2H_5OH]}{\Delta t} = -2\frac{\Delta[C_6H_{12}O_6]}{\Delta t}$$

5.9.2. Consolidation activities:

1. The following data were obtained for the reaction of methane with oxygen:

$CH_{4(g)} + 2\ O_{2(g)} \rightarrow CO_{2(g)} + 2\ H_2O_{(l)}$

Time(min)	$[CH_4]$ (mol/L)	$[CO_2]$ (mol/L)
0	0.050	0
10	0.030	0.020

20	0.020	?
30	0.015	?

a) How many moles of CO2 are produced for each mole of CH4 that is used up?

Answer: 1mole of CH_4 produces 1mole of CO_2

b) What concentration of CH_4 is used up after 10 minutes?

Answer: 0.020 M

c) What is the concentration of carbon dioxide produced after 20 minutes?

Answer: 0.030M

d) Write an equation for reaction rate in terms of $\Delta[CO_2]$ over a time interval.

Answer: Rate= $\Delta[CO_2]/ \Delta t$

e) What is the reaction rate for the formation of carbon dioxide between 10 and 20 minutes?

Answer: Rate of reaction= $\Delta[CO_2]/ \Delta t = \frac{0.030-0.020}{20-10} = 0.001 moldm^{-3}s^{-1}$

f) What is the average reaction rate between 0 and 30 minutes?

Answer: same method as (e)

g) Write an expression for reaction rate relating $\Delta[O_2]$ to $\Delta[CO_2]$.

Answer: Rate= $\frac{\Delta[CO_2]}{\Delta t} = \frac{-1}{2}\frac{\Delta[O_2]}{\Delta t}$

h) At what rate is O_2 used up between 10 and 20 minutes?

Answer: Rate of consumption of O_2

Rate= $\frac{-1}{2}\frac{\Delta[O_2]}{\Delta t}$, so $\frac{\Delta[O_2]}{\Delta t}$ =Rate x -2= $0.001 moldm^{-3}s^{-1}$x 2 = $0.002 moldm^{-3}s^{-1}$

2. Rate constants for the gas-phase decomposition of hydrogen iodide, $H_{2(g)} + I_{2(g)} \rightarrow 2\,HI_{(g)}$, are listed in the following table:

Temperature 1 in ^{0}C	K_1 in mol.dm^{-3}.s^{-1}	Temperature 1 in ^{0}C	K_1 in mol.dm^{-3}.s^{-1}
283	3.52×10^{-7}	427	1.16×10^{-3}
356	3.02×10^{-5}	508	3.95×10^{-2}
393	2.19×10^{-4}		

a) Calculate Ea from the rate constants at 283 °C and 508 °C.

b) Given the rate constant at 283 °C and the value of *Ea* obtained in part (a), what is the rate constant at 293 °C?

Answer:

a) Substituting the values of k1 = 3.52x10-7 at T1=566K (283 °C) and k2 = 3.95x10-2 at T2=781K (508 °C) into the equation:

$$\ln\left(\frac{k_2}{k_1}\right)=\left(\frac{-Ea}{R}\right)x\left(\frac{1}{T_2}-\frac{1}{T_1}\right)$$

gives, $\ln\left(\frac{3.95x10^{-2}}{3.53x10^{-7}}\right)=\left(\frac{-Ea}{8.314}\right)x\left(\frac{1}{781}-\frac{1}{556}\right)$

$11.628=\left(\frac{-Ea}{8.314}\right)x-5.18x10^{-4}$

Ea = 1.87x10^{5} J/mol = 187 kJ/mol

b) Use the same equation as in part (a), but now the known values are

$$\ln\left(\frac{k_2}{3.52x10^{-7}}\right)=\left(\frac{-1.87\ x10^{-5}}{8.314}\right)x\left(\frac{1}{566}-\frac{1}{556}\right)=0.715$$

c) Taking the antiln of both sides gives

$\frac{k_2}{3.52x10^{-7}}=e^{-0.715}=2.04$

$k_2 = 7.18x10^{-7} moldm^{-3}s^{-1}$

3. The initial concentration of N_2O_5 in the following reaction $N_2O_5(g) \rightarrow 2\ NO_2(g) + 1/2O_2\ (g)$ was 1.24×10^{-2} mol L^{-1} at 318 K. The concentration of N_2O_5 after 60 minutes was 0.20×10^{-2} mol L^{-1}. Calculate the rate of the reaction at 318 K.

4. From the data in the table below, plot a curve of the concentration versus time on a graph and determine:

a) the instantaneous rate of decomposition of N_2O_5 at 250s.

b) the initial rate of decomposition of N_2O_5

Time in seconds	Concentration in mol.dm^{-3}		
	N_2O_5	NO_2	O_2
0	0.0200	0	0
100	0.0169	0.0063	0.0016
200	0.0142	0.0115	0.0029
300	0.0120	0.0160	0.0040
400	0.0101	0.0197	0.0049
500	0.0086	0.0229	0.0057
600	0.0072	0.0256	0.0064
700	0.0061	0.0278	0.0070

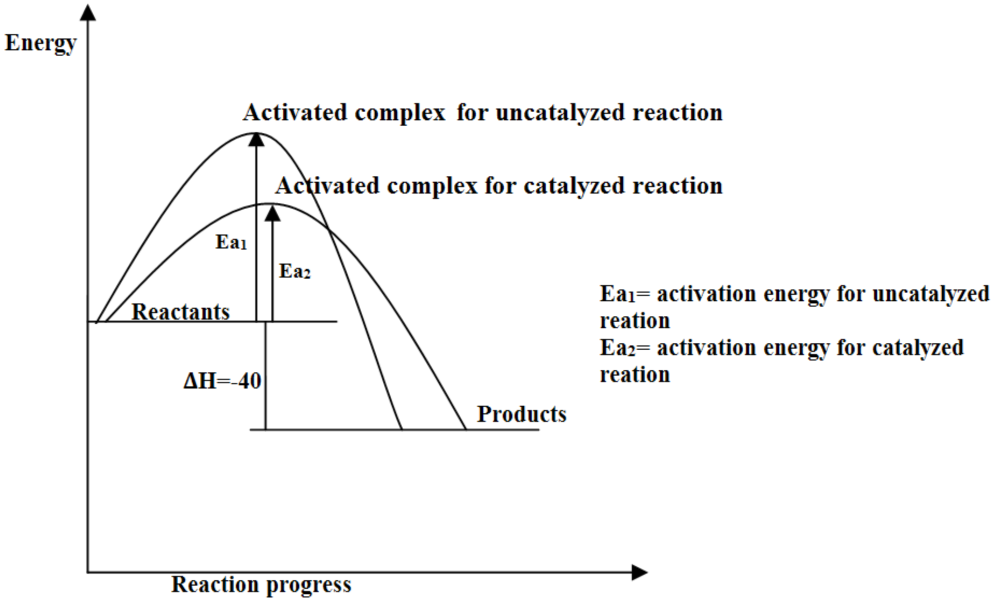
a) Referring to the student teacher's book, draw a graph with time on X axis and concentration on Y axis. On the curve draw a tangent on the point corresponding to 250s and find the value of $\Delta y/\Delta x$.

b) Use the same method for the point on the graph corresponding to 0s, at the starting point.

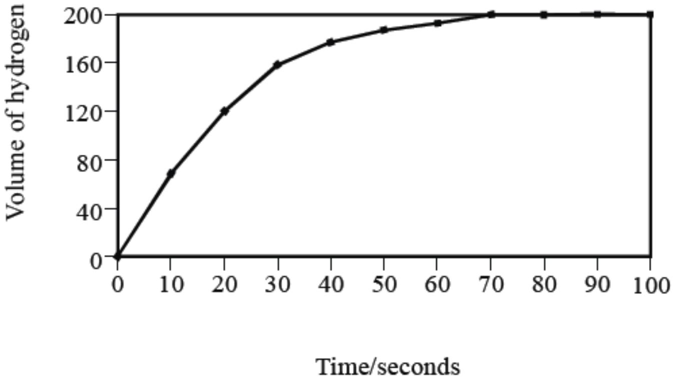
5.9.2 Extended activities:

1. Draw an energy diagram for a reaction where ΔH = -40 kJ, the activation energy of the uncatalyzed reaction is +120 kJ, and the activation energy for a catalyzed reaction is + 80 kJ. Indicate the position of the activated complex for both catalyzed and uncatalyzed reactions.

Answer:



2. The graph below shows the volume of hydrogen produced as 2.00 g of magnesium ribbon reacts with 100 cm^3 of sulphuric acid, concentration 1.00 mol dm^3



a) Explain why the hydrogen is produced at a faster rate at the beginning of the experiment than it is at the end of the experiment.

Answer:

- There is a higher concentration of acid
- There is a greater surface area of magnesium
- There are more collision per second and therefore a faster rate

b) (i) Show by calculation whether the magnesium or the sulphuric acid is in excess.

Answer:

- Amount of magnesium = 2.0/24 = 0.0833 mol
- Amount of sulphuric acid = 0.100 × 1.00 = 0.100 mol
- As they react in a 1/1 ratio
- All the magnesium reacts and the acid is in excess
- Amount of magnesium = amount of hydrogen = 0.0833 mol

(ii) Hence calculate the mass of hydrogen produced.

Mass of hydrogen = 0.0833 × 2.00 g = 0.17 g

c) During the course of the experiment the temperature of the solution rises from 20 °C to 42.5 °C. Taking the specific heat capacity of the solutions as 4.2 J $g^{-1}K^{-1}$, calculate the apparent enthalpy change for this reaction.

Answer: $E = mc\theta = 100 \times 4.2 \times 22.5 = 9.45$ kJ. This is for 2 g ; $\Delta H = 12 \times 9.45 = 113.4$ kJ mol^{-1}

3. Zinc reacts with hydrochloric acid to produce hydrogen gas:

$$Zn_{(s)} + 2HCl_{(aq)} \longrightarrow ZnCl_{2(aq)} + H_{2(g)}$$

Experiments show that the rate of the reaction decreases (i) If zinc powder is replaced by zinc nails and (ii) if the following are added to the reaction mixture: (a) water (b) ice (c) sodium carbonate. Explain all these observations.

Answer:

- Nails have a lower surface area than powder.
- Water dilutes the concentration of the acid, so reducing the number of acid-zinc collisions per second.
- Ice cools the mixture, thereby reducing the reaction rate.
- Sodium carbonate reacts with the acid, so drastically reducing the concentration of hydrogen ions in solution.

UNIT 6: pH OF ACIDIC AND ALKALINE SOLUTIONS

6.1. Key unit competence

Prepare solutions, measure their pH, calculate the pH of acidic and alkaline solutions, explain the concept of buffer solution and discuss their applications in manufacturing industry and biological processes.

6.2. Prerequisite knowledge and skills

Student teacherswill understand this unit: pH of acidic and alkaline solutions, if they possess good laboratory skills, knowledge of the concept of solutes, solvents and solution, acids, bases, pH, salts and their properties, the mole concept and concentration of solutions. It will also be helpful to have knowledge of quantitative chemical equilibrium. These are some of the units covered progressively from senior two to senior five.

6.3. Cross-cutting issues to be addressed

- **Environment and sustainability**

Acids and bases are very common chemicals in the laboratory. They are almost used every day in all classes from senior one to senior six in various experiments. Others occur naturally in the environment. Acids and bases may either be strong or weak and they may be found either dilute or concentrated in the laboratory.

Acidic solutions can burn the skin with just one drop due to a high affinity with water, can damage lungs when inhaled, and corrode metals in different metallic products reducing their quality. Acidic rains destroy off massive numbers of vegetation, kill soil living organisms and dissolve rocks and minerals.

Most salts are used as fertilizers which increase crop production but when applied excessively, they cause ground water contamination, burn crops, increase air pollution (release greenhouse gases), deplete minerals from the soil, acidify the soil and may be washed to water bodies. This leads to rapid growth of algae which utilize oxygen that would be used by fish causing them to suffocate. All these side effects of acids and bases require proper handling and disposal of these substances to conserve our environment.

- **Inclusive education**

This unit involves a lot of research and calculations. To be able to understand it, there must be discussions, experiments and sharing of information among learners. You can organize your class and use different strategies to help all learners understand concepts very well. Some of the strategies to be used are provided in the introductory part of this book.

- **Gender:**

During group activities try to form heterogeneous groups i.e. boys and girls or when student teachers start to present their findings, encourage both boys and girls to present one after the other.

- **Financial education:**

As this unit deals with many acids, bases and salts in modern life, you will draw student teachers' attention on the economic impact of the making common products using that knowledge.

- **Peace and values:**

During group activities, you will encourage student teachers to work together, help each other where it seems to be difficulty, and to respect other's opinions, critiquing but not criticizing their ideas.

6.4. Guidance on the introductory activity:

Introductory activity for unit 6

Student teachers are already familiar with acids and bases. They know the idea of strong acids and bases and weak acids and bases. So, you do not need to over dwell on the acid-base concept. You are supposed to help them identify how we can determine whether an acid or a base is strong or weak. Theoretically they know that but they also need to know that practically. In addition to that, they also possess some knowledge about the pH and its use. The purpose of this activity is to help them recall the concept of acids and bases and pH. If possible you can give this activity as a research work early before you start the unit for them to get enough time for it. If it is not possible, it can be done as a class activity right before you introduce the unit.

Here is a guide of how this activity can be conducted by the student teachers with the tutor's guidance:

- Put your student teachers in groups of 4 or 6 depending on the size of your class.
- Provide them with year three chemistry student teachers'books and guide them on the page where the unit and the introductory activity is.
- Ask them to look at the picture of the activity.
- Give them five minutes to read, analyse and discuss about the activity. Here they must observe and analyse the picture and answer the questions thereafter.
- Invite one representative from each group to present their findings. You may note some key points on the board.
- Ask student teachers at random to give their input considering the quick and slow student teachers in your class. Don't worry if some of them fail to reach the exact results.
- Give them your views about their presentations citing some exact answers suggested below. It is not necessary to conclude here, just motivate them to continue researching on the products in the pictures using the given questions of the introductory activity.

6.5. List of lessons

#	Lesson title	Learning objective(s)	Periods
1	Degree of ionization in relation to strength of acids and bases	– Differentiate between strong acid and strong base, weak acid and weak base – Define and perform calculations involving degree of ionization (α)	2
2	Acid and base dissociation constants (K_a and K_b)	– Define the term K_a and K_b – Write expressions for K_a and K_b of weak acids and weak bases respectively.	2
3	Relationship between K_a and K_b	– Write an expression to show the relationship between K_a and K_b	2
4	Use Ka or pKa and Kb or pKb to explain the strength of the acids and bases.	– Interpret the values of K_a and K_b, pK_a and pK_b in relation to the strength of acids and bases. – Compare the strength of acids and bases of same concentration, using the values of K_a and K_b	2
5	Ionic product of water (K_w)	Define the term pH, K_w and pK_w	2
6	Definition and calculations of pH and pOH of acidic and alkaline solutions.	– Perform calculations involving pH, pOH, K_a, pK_a, K_b pK_b, K_w and pK_w – Relate the values of pH and pOH – Interpret results, draw valid conclusions and report about preparation of solutions with different pH	3
7	Buffer solutions	– Define the term buffer solution. – Derive Henderson-Hasselbalch relation and use it to calculate the pH of buffer solutions.	3
8	Preparation of buffer solutions of different pH	– Prepare different solutions and appropriately use a pH meter to measure their pH	3
9	The working of buffer solutions and their applications.	– Explain how buffers solution control pH. – Explain buffer capacity in relation to buffer range. – Describe the applications of buffer solutions in domains such as biological processes, agriculture, natural systems and industries	3
11	End unit assessment		2

Lesson 1: Degree of ionization in relation to strength of acids and bases

a) Learning objective

Define and perform calculations involving degree of ionization (α)

b) Prerequisites.

- Student teachers will understand better this lesson if they have knowledge about:
- The definitions of an acid and a base from different theories,
- Differences between strong and weak acids and strong and weak bases and,
- Partial and complete ionization of weak and strong electrolytes.

c) Teaching resources

Use worksheets or books, computer, projectors and/or chalkboard, appropriate chemicals such as sodium hydroxide, aqueous ammonia, sulphuric acid and ethanoic acid from the school laboratory.

d) Learning activities

Help student teachers to clearly recall the definitions a weak acid and a weak base. You do not have to explain a lot as these definitions are not new to them. Let them discuss about examples of weak acids and bases and write equations to show their ionization in water. With the help of some examples, do exercises on calculations of the degree of ionization. Use α-values to predict the strength of the acids and bases. You will discuss with them as they note down the summary. End the lesson with a simple discussion about the dangers of acids and bases to humans and the environment. Finally, give them the application activity.

Answers to introductory activity

1.Acidic fruits	Alkaline fruits
Pineapple, orange, tree tomato, passion fruit and lemon.	Aubergine, avocado and green eggplant.

2. Lemon
3. We can measure the pH of the two juices. The one with a lower pH is the more acidic.

Answers to activity 6.1

a) (i) **A Brønsted-Lowry acid** is a proton donor.

(ii) A Lewis base is a lone pair donor.

b) A strong acid dissociate completely while a weak acid dissociates only partially. For a strong acid and a weak acid of the same concentration, the amount of free hydrogen ions in the solutions is far greater in the strong acid solution than in that of the weak acid.

c) $CH_3COOH^+{}_{(aq)}H_2O_{(aq)} \rightleftharpoons CH_3COO^-{}_{(aq)}+H_3O^+{}_{\text{(aq}}$

Acid/base conjugate pairs

Acid Conj. base

$$CH_3COOH_{(aq)} / CH_3COO^-_{(aq)}$$

Base conj. acid

$$H_2O_{(aq)} / H_3O^+_{(aq)}$$

Application activity 6.1

Answers to application activities6.1

1. $\alpha_a = \frac{[H^+]}{[Acid]} = \frac{0.0042}{0.1} = 0.042X100 =$ **<u>4.2%</u>**
2. $\alpha_a = \frac{[H^+]}{[Acid]} = \frac{0.0037}{0.35} = 0.01X100 =$ **<u>1%</u>**
3. Acid A is stronger than B because it has a bigger ionization constant. A bigger value means more H^+ in the solution.
4. The degre of dissociation of ethanamine is $\alpha_b = \frac{[OH-]}{[C2H5NH2]} = \frac{2.04\times10-2\text{ M}}{0.750\text{M}} = 0.027$

Lesson 2: Explanation of acid and base dissociation constants (K_a and K_b)

a) Learning objectives

- Define the term K_a and K_b.
- Write expressions for K_a and K_b of weak acids and weak bases respectively.

b) Prerequisites

Student teachers will understand better this lesson when they have knowledge and skills on ionization of weak electrolytes, writing equations of reactions which are reversible and applying the law of mass action (equilibrium law)

c) Teaching resources

The tutor can use a computer and a projector, chalkboard and a scientific calculator since this lesson involves some calculations.

d) Learning activities

You will group student teachers into pairs (a boy and a girl where applicable), provide them with student teachers's books and guide them on the page where the activity is located. Ask them to discuss, present their findings. You will iron out some issues and they take a summary of the facts.

Answers to activity 6.2

1. $Kc = \dfrac{[PCl_5]}{[PCl_3][Cl_2]}$

2. (a) $CH_3CH_2COOH_{(aq)} + H_2O_{(aq)} \rightleftharpoons CH_3CH_2COO^-_{(aq)} + H_3O^+_{(aq)}$

   (b) $NH_{3(aq)} + H_2O_{(aq)} \rightleftharpoons NH^+_{4(aq)} + H_3O^+_{(aq)}$

Answers to application activity 6.2

1. $\alpha = \sqrt{\dfrac{Ka}{Ca}} = \sqrt{\dfrac{1.3\text{x}10^{-5}}{0.04}} = 0.09$

α **=** 0.09 x 100 = **<u>9%</u>**

2. $\alpha = \sqrt{\dfrac{Ka}{Ca}} = \sqrt{\dfrac{4.39\text{x}10^{-5}}{0.01}} = 0.002$

α **=** 0.002 x 100 = **<u>0.2%</u>**

3. (a) $CH_3NH_2\ (aq) + H_2O\ (l) \rightleftharpoons CH_3NH_3^+\ (aq) + OH^-\ (aq)$

   (b) $K_b = \dfrac{[CH_3NH_3^+][OH^-]}{[CH_3NH_2]}$

   (c) Since the base is partially dissociated, = 0.04M

   $K_b = \dfrac{[OH^-]^2}{[CH_3NH_2]} = \left(\dfrac{0.04^2}{1}\right)$

   K_b = **<u>1.6 x 10^{-3} mol dm^{-3}</u>**

Lesson 3: Relationship between K_a and K_b

a) Learning objectives

Write an expression to show the relationship between K_a and K_b

b) Prerequisites

Student teachers will understand better this relationship using knowledge and skills partial ionization of weak electrolytes, law of mass action (equilibrium law) and expressions for equilibrium constant, K_a and K_b

c) Teaching resources

Use textbooks, worksheets, flip charts and chalkboard.

d) Learning activities

Refer to lesson for the methodological steps to be used.

Answers to activity 6.3

1. (a) $HCO^{-}_{3(aq)} + H_2O_{(l)} \rightleftharpoons CO^{2-}_{3(aq)} + H_3O^{+}_{(aq)}$

(b) $K_a = \dfrac{\left[CO_3^{2-}\right]\left[H_3O^+\right]}{\left[HCO_3^-\right]}$

2. (a) $CO^{2-}_{3(aq)} + H_2O_{(aq)} \rightleftharpoons HCO^{-}_{3(aq)} + OH^{-}_{(aq)}$

$K_b = \dfrac{\left[HCO_3^-\right]\left[OH^-\right]}{\left[CO_3^{2-}\right]}$

Application activity 6.3

Answers to aplication activity

1. (a) $CH_3CH_2NH^{+}_{3(aq)} + H_2O_{(l)} \rightleftharpoons CH_3CH_2NH_{2(aq)} + H_3O^{+}_{(aq)}$

(b) $K_a = \dfrac{\left[CH_3CH_2NH_2\right]\left[H_3O^+\right]}{\left[CH_3CH_2NH_3^+\right]}$

2. (a) $pKw = -\log Kw = -\log 1.14x10^{-15} = 14.94$

(b) $K_b = \dfrac{K_w}{K_a} = \dfrac{1.14x10^{-15}}{1.5x10^{-6}} = 7.6x10^{-10}\,mol.dm^{-3}$

3. $K_a = \dfrac{K_w}{K_b} = \dfrac{1x10^{-14}}{1.6x10^{-5}} = 6.25x10^{-10}\,mol.dm^{-3}$

Lesson 4: Use Ka or pKa and Kb or pKb to explain the strength of the acids and bases.

a) Learning objectives

- Interpret the values of K_a and K_b, pK_a and pK_b in relation to the strength of acids and bases.
- Compare the strength of acids and bases of same concentration, using

the values of K_a and K_b

b) Prerequisites

Students will learn these concepts better if they have knowledge on degree of ionization, factors that influence the strength of acids and bases, ionization constants of acids and bases, calculations of K_a and K_b.

c) Teaching resources

Use textbooks, worksheets, flip charts, chalkboard and a calculator.

d) Learning activities

- The activity reminds learners on expressions of base and acid dissociation constants and introduces them to a related scale measuring acidity or alkalinity of a solution.
- Brainstorm with your student teachers on the prior knowledge of ionization of weak electrolytes and expressions of base or acid ionization constants.
- Your discussions should include term pH is derived from “p” which is a mathematical symbol of negative logarithm, and “H,” the chemical symbol for Hydrogen, then pK_a and pK_b and how to calculate pH, pK_a and pK_b.
- Let student teachers perform the activity in pairs using their prior knowledge and write their ideas on worksheet.
- Have sample group present their work to the class.
- Check student teachers’ responses to views being given and continue involving other student teachers in the discussion with concepts from student teachers’ work and student teachers’s book.
- Comment on student teachers’ responses and give them the summary of expected feedback based on their findings.

Answers to activity 6.4

1. (a) $HCOOH$, CH_3COOH, C_6H_5OH

(b) i. $pKa = -\log Ka$

For phenol $pKa = -\log 1.0\ x\ 10^{-10} = 10$

For ethanoic acid $pKa = -\log 1.8\ x\ 10^{-5} = 4.7$

For methanoic acid $pKa = -\log 1.8\ x\ 10^{-4} = 3.74$

ii. The smaller the pKa, the bigger the Ka and the stronger the acid.

Application activity 6.4

Answers to application activity 6.4

1. (a) For 1M HF, $K_a = 6.3 \times 10^{-4}$ mol dm^{-3}

$pK_a = -\log (6.3 \times 10^{-4})$

$pK_a = 4 - \log(6.3)$

pKa = 3.2

1M HCN, $K_a = 6.2 \times 10^{-10}$ mol dm^{-3}

$pK_a = -\log (6.2 \times 10^{-10})$

$pK_a = 10 - \log(6.2)$

pKa = 9.2

1M $H_2C_2O_4$, $K_a = 5.0 \times 10^{-2}$ mol dm^{-3}

$pK_a = -\log (5.0 \times 10^{-2})$

$pK_a = 2 - \log(5.0)$

pKa = 1.3

1M CH_3COOH, $K_a = 1.25 \times 10^{-3}$ mol dm^{-3}

$pK_a = -\log (1.25 \times 10^{-3})$

$pK_a = 3 - \log(1.25)$

pKa = 2.9

(b) 1M $H_2C_2O_4$ is the strongest acid. It has a large K_a value but a smaller pK_a value. This means that the acid is highly ionized or dissociated in solution.

1M HCN is the weakest acid. It has a smaller Ka value but a larger pKa value. This means that HCN is weakly/less ionized/dissociated in solution.

(c) 1M $H_2C_2O_4$>1M CH_3COOH>1M HF>1M HCN or $H_2C_2O_4$>CH_3COOH>HF>HCN

2. $pK_a + pK_b = 14$

$pK_b = 14 - pK_a = 14 - 7.29$

pKb = 6.71

Lesson 5: Explanation of ionic product of water (K_w)

a) Learning objectives

- Define the terms pH, K_w and pK_w

b) Prerequisites

Student teachers will understand ionic product of water if they have prior information on ionization of water, equilibrium law, and mathematical expression of pH, nature of water.

c) Teaching resources

Use worksheets, flip charts, chalkboard, beaker, water, litmus paper, pH scale and a calculator.

d) Learning activities

Before introducing the lesson with content, let student teachers attempt activity 6.5 from the student teachers's book.

As a facilitator, you are expected to guide student teachers through the following steps:

- Organize your class by putting student teachers into group of 3 or 4 depending on the size of the class.
- Give each group a beaker of water, litmus papers of different colors and a pH meter.
- Ask one student teacher in each group to add litmus papers separately and tell the color change.
- Then tell another one from each group to insert a pH meter and read the pH of water and tell other learners.
- Provide student teachers with student teachers's books and guide them on the page where they can find the activity and discuss the questions.
- Give them enough time to think and discuss about the possible answers.
- Check student teachers responses and ideas, and continue the discussions with a brief brainstorming of the content using student teachers' book.
- Comment on student teachers' responses and give them the summary of expected feedback based on their findings.

Answers to activity 6.5

1. (a) $H_2O_{(l)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + OH^-_{(aq)}$

(b) $Kw = [H_3O^+] [OH^-]$

Application activity 6.5

Answers to application activity. 6.5

1. (a) $K_w = [H^+] [OH^-]$ or $K_w = [H_3O^+] [OH^-]$

   (b) Units are mol^2dm^{-6}

2 From $K_w = [H^+] [OH^-]$

   $[H^+]^2 = 1.471 \times 10^{-14}\ mol^2dm^{-6}$

   $[H^+] = [OH^-] = 1.213 \times 10^{-7}\ moldm^{-3}$

3. (a) Kw increases with temperature.

   (b) The dissociation process of water is endothermic. This is shown by the fact that when temperature increases Kw also increases showing that more water molecules dissociate at a higher temperature. Thus, if temperature favors the dissociation of water the process is endothermic.

Lesson 6: Definition and calculations of pH and pOH of acidic and alkaline solutions

a) Learning objectives

- Perform calculations involving pH, pOH, K_a, pK_a, K_b pK_b, K_w and pK_w
- Relate the values of pH and pOH
- Interpret results, draw valid conclusions and report about preparation of solutions with different pH

b) Prerequisites

Student teachers will understand calculations involving pH and pOH of acidic and alkaline solutions if they have prior information on ionization of acids and alkalis, degree of ionization, acid and base dissociation constant and mathematical expression of pH and pOH, and knowledge about logarithm rules.

c) Teaching resources

Use worksheets, chalkboard and calculators.

d) Learning activities

Refer to lesson 5 for methodological steps on how to conduct the lesson and the activities.

Answers to activity 6.6

1. $pKa = -\log 1.8x10^{-9} = 8.74$

   $pKb = -\log 1.6x10^{-4} = 3.79$

2. pH=-log[H$^+$]

Application activity 6.6

Answers to application activity 6.6

1. pH = - log_{10}[H$^+$]

   4 = - *log10*[H$^+$]

   [H$^+$] = 10^{-4} = 1.0 x 10^{-4} moldm^{-3}

   $CH_3CH_2COOH\ (aq) \rightleftharpoons CH_3CH_2COO^-\ (aq) + H^+\ (aq)$

   $$K_a = \left(\frac{[CH_3CH_2COO^-][H^+]}{[CH_3CH_2COOH]}\right)$$

   $$K_a = \left(\frac{[H^+]^2}{C_a}\right) = \frac{(1.0\,x\,10^{-4})^2}{0.05}$$

   $\underline{K_a = 2.0 \times 10^{-7}\ mol\ dm^{-3}}$

2. $HCOOH\ (aq) \rightleftharpoons HCOO^-\ (aq) + H^+\ (aq)$

   [HCOOH] = [H$^+$] = 0.001 or 1.0 x 10^{-3} mol dm^{-3}

   [H$^+$] = Cα = (1.0 x 10^{-3}) x 0.01

   [H$^+$] = 1.0 x 10^{-5} mol dm^{-3}

   $$\text{Or } K_a = \left(\frac{[H^+]^2}{C_a}\right)$$

$[H^+] = \sqrt{(1.0x10^{-7})x0.001}$

$[H^+] = 1.0 \times 10^{-5}$ mol dm^{-3}

pH = - *log10*$[H^+]$ = - *log10*(1.0×10^{-5})

pH = 5

3. From pOH = 14 – pH = 14 – 6.9

pOH = 7.1

Also pOH = -*log10* $[OH^-]$

7.1 = -*log10* $[OH^-]$

$[OH^-]$ = *log-1* (-7.1)

$[OH^-] = 7.9 \times 10^{-8}$ mol dm^{-3}

From the equation, $NaOH (aq) \longrightarrow Na^+ (aq) + OH^- (aq)$

Mole ratio NaOH: OH^- is 1:1, the molarity of NaOH = **7.9×10^{-8} mol dm^{-3}**

4. From the equation; $KOH (aq) \longrightarrow K^+ (aq) + OH^- (aq)$

1 mole of KOH produces 1 mole of OH^-

$[KOH] = [OH^-] = 2.2 \times 10^{-5}$ mol dm^{-3}

pOH = -*log10* $[OH^-]$ = -*log10* (2.2×10^{-5})

pOH = 4.7

5. From the equation; $NaOH (aq) \longrightarrow Na^+ (aq) + OH^- (aq)$

1 mole of NaOH produced 1 mole of OH^-

$[NaOH] = [OH^-]$ = 0.4 0r 4.0×10^{-1} mol dm^{-3}

pOH = -*log10* $[OH^-]$ = -*log10* (4.0×10^{-1})

pOH = 0.39

pH = pK_w – pOH = 14 – 0.39

pH = 13.61

6. $NH_3 (aq) + H_2O (l) \rightleftharpoons NH_4^+ (aq) + OH^- (aq)$

$$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$$

$$K_b = \frac{\left[OH^-\right]^2}{C_b}$$

$[OH^-] = \sqrt{\left(1.85x10^{-5}\right)x0.005}$

$[OH^-] = 3.04 \times 10^{-4}$ mol dm^{-3}

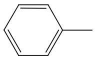
pOH = $-log_{10}$ $[OH^-]$ = $-log10$ (3.04×10^{-4})

pOH = 4 – *log* (3.04)

pOH = 3.5

pH = pK_w – pOH = 14 – 3.5

<u>pH = 10.5</u>

7. ph- NH_3OH (aq) $\rightleftharpoons$ ph- NH_3^+ (aq) + OH^- (aq) where ph- is 

$[OH^-] = C\alpha = 0.01 \times 0.08$

$[OH^-] = 0.0008$ mol dm^{-3}

$$K_b = \left(\frac{\left[ph-NH_3^+\right]\left[OH^-\right]}{\left[ph-NH_3OH\right]}\right)$$

$$K_b = \frac{[OH^-]^2}{C_b} = \frac{(0.0008)^2}{0.01}$$

$K_b = 6.4 \times 10^{-5}$ mol dm^{-3}

Alternatively, you can find K_b from the expression: $K_b = C\alpha^2$

$K_b = 0.01 \times (0.08)^2 = 6.4 \times 10^{-5}$ mol dm^{-3}

Then, pOH = $-log10$ $[OH^-]$ = $-log_{10}$ (8.0×10^{-4})

pOH = 4 – log 8

pOH = 3.1

pH = pK_w – pOH = 14 – 3.1

<u>pH = 10.9</u>

8. From pOH = pK_w – pH = 14 – 10.6

pOH = 3.4

pOH = $-log_{10}$ $[OH^-]$

$[OH^-] = \dfrac{1}{10^{3.4}} = 3.98 \times 10^{-4}$ mol dm^{-3}

$$K_b = \frac{[OH^-]^2}{C_b} = \frac{(3.98x10^{-4})^2}{0.01}$$

$K_b = 1.58 \times 10^{-5}$ mol dm^{-3}

From, $\alpha = \sqrt{\frac{K_b}{C_b}} = \sqrt{\frac{1.58x10^{-5}}{0.01}} = 0.04$

$\alpha = 0.04 \times 100 =$ *4%*

9. pH = - *log10*[H$^+$]

4.35 = - *log10*[H$^+$]

[H$^+$] = 4.47×10^{-5} mol dm^{-3}

From the equation, H_2SO_4 (aq) $\longrightarrow$ 2 H$^+$ (aq) + SO_4^{2-} (aq)

Mole ratio H_2SO_4: is 1:2

Molarity of H_2SO_4 is = $\frac{1x4.47x10^{-5}}{2}$

Molarity = *2.235 x 10-5 mol dm-3*

10. HCl (aq) $\longrightarrow$ H$^+$ (aq) + Cl$^-$ (aq)

[HCl] = [H$^+$] since mole ratio = 1:1, therefore,

[H$^+$] = 0.05 or 5.0×10^{-2} mol dm^{-3}

pH = - *log10*[H$^+$] = - *log10*(5.0×10^{-2})

pH = 1.3

Lesson 7: Buffer solutions and calculations of their pH

a) Learning objectives

- Define the term buffer solution.
- Derive Henderson-Hasselbalch relation and use it to calculate the pH of buffer solutions.

b) Prerequisites

Student teachers will understand better buffer solutions if they have prior knowledge on acids and alkalis, chemical equilibrium, pH and pOH of acidic and alkaline solutions.

c) Teaching resources

Use a computer and a projector, worksheets and textbooks, flip charts and chalkboard, sodium chloride, ammonium chloride, sodium ethanoate, sodium hydroxide and hydrochloric acid, water, beakers, weighing scale, measuring cylinder, stirring rod, and a pH meter.

d) Learning activities

- Organize your class by putting student teachers into group of 3 to 5 depending on the size of the class.
- Let student teachers discuss the activity using their prior knowledge and write their ideas on worksheets.
- Have sample groups to present their ideas/findings to the class.
- Check student teachers' responses and give them a summary of expected feedback based on their findings. This will lead you to discussion of general content.
- Involving all student teachers in the discussion of concepts. Comment on the student teachers' responses.
- Direct the student teachers to the checking up 6.7 at the end of the lessons or give it to them as homework.

Answers to activity 6.7

1. a) $CH_3COONa_{(aq)} + H_2O_{(l)} \rightarrow CH_3COO^-_{(aq)} + Na^+_{(aq)}$

$$CH_3COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COO^-_{(aq)} + H_3O^+_{(aq)}$$

b) $NH_4OH_{(aq)} + H_2O_{(l)} \rightarrow NH^+_{4(aq)} + OH^-_{(aq)}$

2. Expression of the dissociation constants of CH_3COOH and NH_4OH.

$$Ka = \frac{\left[CH_3COO^-\right]\left[H3O^+\right]}{\left[CH_3COOH\right]} \quad Kb = \frac{\left[NH_4^+\right]\left[OH^-\right]}{\left[NH_4OH\right]}$$

3. The relationship between $CH_3CO_2H_2^+$ and CH_3CO_2H.

   The two species form an acid base conjugate pair.

Application activity 6.7

Answers to pplication activity 6.7

1. $pH = pK_a + \log\left(\frac{[Salt]}{[Acic]}\right)$

   $4 = -\log(6.31 \times 10^{-5}) + \log\left(\frac{[Salt]}{[0.012]}\right)$

   $\log[salt] = 2.121$

   $[Salt] = 7.56 \times 10^{-3}$ mol/litre

Thus, mass of sodium benzene carboxylate = concentration x molar mass

$= 7.56 \times 10^{-3} \times 114$

$\underline{= 1.088\ g/litre}$

2. (a) Molar mass of C_6H_5COONa = 144g/mole

$$[Salt] = \left(\frac{7.2}{144}\right) = 0.05\ mol\ dm^{-3}$$

$$pH = pK_a + \log\left(\frac{[Salt]}{[Acid]}\right)$$

$$= -\log(6.25 \times 10^{-5}) + \log\left(\frac{0.05}{0.02}\right)$$

<u>pH = 4.6</u>

(b) On addition of 0.01M NaOH, the added hydroxide ions react with benzoic acid. This decreases [Acid] but increases the [Salt]

New [Acid] = 0.02 – 0.01 mol dm^{-3}

New [Salt] = 0.05 + 0.01 = 0.06 mol dm^{-3}

$$\text{New } pH = -\log(6.25 \times 10^{-5}) + \log\left(\frac{0.06}{0.01}\right)$$

pH = 5 – log 6.25 + log 6

<u>pH = 4.98</u>

pH change = 4.98 – 4.6 = **<u>0.38 units</u>**

3. Concentration of HCl = $\left(\frac{0.1x10}{1000}\right)$ = 0.001 mol dm^{-3}

Concentration of NH_4OH = $\left(\frac{0.05x100}{1000}\right)$ = 0.005 mol dm^{-3}

0.001 moles of HCl reacted with 0.001moles of NH_4OH to form 0.001 moles of NH_4Cl

Moles of unreacted NH_4OH = (0.005 – 0.001) = 0.004 mol dm^{-3}

$$pOH = -\log(1.8 \times 10^{-5}) + \log\left(\frac{0.001}{0.004}\right)$$

pOH = 4.14

From pH = pKw – pOH = 14 – 4.14

pH = 9.86

4. (a) Concentration of $NH_4OH = \left(\frac{80x0.4}{1000}\right)$ = 0.032 mol dm^{-3}

Concentration of $HCl = \left(\frac{100x0.1}{1000}\right)$ = 0.01 mol dm^{-3}

$$NH_4OH\ (aq) + HCl\ (aq) \longrightarrow NH_4Cl\ (aq) + H_2O\ (l)$$

Mole reaction ratio = 1:1, thus moles of NH_4Cl formed = 0.01 moles and moles of ammonia reacted = 0.01 moles.

Moles of ammonia unreacted = 0.032 – 0.01 = 0.022 moles

pOH = -log (1.8 x 10^{-5}) + log $\left(\frac{0.01}{0.022}\right)$ = 5 – log 1.8 + log 0.45

pOH = 4.40

pH = 14 – 4.40

pH = 9.6

(b) Concentration of HCl added = $\left(\frac{0.7x1}{1000}\right)$ 0.0007 mol dm^{-3}

The added hydrogen ions from HCl react with ammonia solution, reducing the concentration of ammonia but increasing the concentration of ammonium chloride.

New $[NH_4OH]$ = 0.022 – 0.0007 = 0.00213 mol dm^{-3}

New $[NH_4Cl]$ = 0.01 + 0.0007 = 0.00107 mol dm^{-3}

pOH = -log (1.8 x 10^{-5}) + log $\left(\frac{0.0107}{0.0213}\right)$ = 5 – log 1.8 + log 0.02347

pOH = 4.44

pH = 14 – 4.44

pH = 9.56

pH change = 9.6 – 9.56 = **0.04 units**

Lesson 8: Preparation of buffer solutions of different pH

a) Learning objectives

- Prepare different solutions and appropriately use a pH meter to

measure their pH
- Explain how buffers solution control pH.
- Explain buffer capacity in relation to buffer range.

b) Prerequisites

Student teacherswill understand better buffer solutions preparation if they have prior knowledge about mole concept and concentration of solutions, pH and pOH of acidic and alkaline buffer solutions,

c) Teaching resources

Use worksheets, textbooks, chalkboard, sodium ethanoate, ethanoic acid, distilled water, beakers, weighing scale, measuring cylinder, Calibrated pH meter, Glass rod, and volumetric flask.

d) Learning activities

As a tutor, you are expected to guide student teachers through the following steps:

- Arrange your class by putting student teachers into group of 3 or 4 depending on the size of the class and the materials/chemicals available in the laboratory.
- First ask them to discuss and record their answers on worksheets.
- Select a member of each group to present their findings
- Make a summary of the expected answers as you sort out some errors that could have been made by the student teachers.
- You can continue the discussion to preparation of buffer solutions of different pH
- Then direct two members of each group to collect the chemicals and apparatus from a safe place previously arranged by the lab attendant or technician.
- Supply student teachers' books to the groups and make sure they are enough to the group. If possible, give each student teacher his/her own copy in the group
- Ask student teachers in each group to follow the experimental procedures in the student teachers' book, perform the experiment and record the results on a worksheet.
- Give them enough time to think and discuss about the possible answers.
- Check student teachers' responses and ideas as the lesson progresses.
- Comment on student teachers' responses and give them a summary of expected feedback based on their findings.

Answers to activity 6.8

Refer to the student teacher's book; unit 6, 6th and 7th lessons.

Application activity 6.8

Answers to application activity 6.8

a) pH: read it on pH meter during the experiment. It is in range (4.8 – 5.2). Learners must state exactly one that is read.

b) Acid] = 0.3 mol dm^{-3}

$$[Salt] = \frac{0.3}{82} = 0.00366 \text{ moles; 82 is molar mass of sodium ethanoate}$$

$$[Salt] = \frac{0.00366x1000}{100} = 0.0366 \text{ mol dm}^{-3}$$

$$pH = pK_a + log\left(\frac{[Salt]}{[Acid]}\right)$$

$$pH = -log\,(1.8 \times 10^{-5}) + \log\left(\frac{0.0366}{0.3}\right)$$

<u>pH = 3.8</u>

Lesson 9: The working of buffer solutions and their applications

a) Learning objectives

- Describe the applications of buffer solutions in domains such as biological processes, agriculture, natural systems and industries.

b) Prerequisites

Student teachers will learn this lesson better if they have knowledge about acidic and basic buffers, reactions of acids and alkalis/bases.

c) Teaching resources

Use a computer, projector, internet, worksheets and buffer solution prepared in the previous lesson.

d) Learning activities

As a tutor, you are expected to guide student teachers to learn by working out activity 6.9 found in the student teacher's book and discuss the content through the following steps:

- Organize your class by putting student teachers into group of 5 or 6 depending on the size of the class.

- Supply student teacher's books to each group and guide them on the page where to find the activity.
- Let them discuss and use reference books or internet to find answers where they find challenges.
- The activity will guide you and your student teachers to enter smoothly the working of buffer solutions and their applications in different fields.
- You will provide student teachers with 1M NaOH and 1M HCl for them to add drops in the buffer solution and note pH changes.
- Choose randomly three representatives from all groups to present their findings.
- Allow some other student teachers to comment about the findings presented by their colleagues.
- Give your feedback highlighting how a given buffer solution works, use equations to clarify your statements.
- Through different small oral questions, help the student teachers to make the conclusions and summaries by themselves.
- To check their understanding, give them the application activity 6.9 in the student teacher's book as an individual homework.
- The feedback will be given in the next session after marking.

Answers to activity 6.9

Refer to student teachers' book; unit 6

Application activity 6.9

Answers to application activity 6.9

1. (a)(i)A Bronsted – Lowry acid is a proton donor.

(ii) $CH_3COOH\ (aq) \rightleftharpoons CH_3COO^-\ (aq) + H+(aq)$

(b) The buffer solution contains a large amount of CH_3COO^- from both the salt and the acid.

When a small amount of the acid is added, the added hydrogen ions are reacted by ethanoate ions to form ethanoic acid. This prevents an increase in concentration of hydrogen ions hence pH remains constant.

$$CH_3COO^-\ (aq) + H^+\ (aq) \rightleftharpoons CH_3COOH\ (aq)$$

When a small amount of the base is added, the added hydroxide ions react with ethanoic acid to form ethanoate ions and water. This prevents an increase in the concentration of hydroxide ions hence pH remains constant.

$$CH_3COOH\,(aq) + OH^-\,(aq) \rightleftharpoons CH_3COO^-\,(aq) + H_2O\,(l)$$

(c) $pH = pK_a + \log\left(\frac{[Salt]}{[Acid]}\right)$

$$pH = -\log(1.75 \times 10^{-3}) + \log\left(\frac{0.25}{0.20}\right)$$

$$pH = 3 - \log 1.75 + \log 1.25$$

$$\underline{pH = 2.85}$$

2. So that the buffer solution will have equal capacity to react with either the acid or base added.

3. This is because the ratio, $[A^-]/[HA]$ does not change very much. This is true as long as

the amount of strong base or acid added is small compared to the amount of conjugate

acid or conjugate base in the buffer. If you add too of much strong acid or base, you will exceed the buffer capacity.

4. Buffer capacity is the amount of added acid or base that can be neutralized by the buffer. It is determined by the concentrations of the conjugate base or conjugate base. Buffer capacity increases as these concentrations increase.

6.6. Summary of the unit

- An acid is a proton donor or any substance which ionizes in aqueous solution to produce hydrogen ions as the only positively charged ions in solution.
- An alkali is substance which ionizes in aqueous solution to produce hydroxide ions as the only negatively charged ions in solution.
- An alkali is part of bases. Bases can be oxides or alkalis (hydroxides). Generally, a base is a proton acceptor or an electron pair donor.
- Acids and alkalis are electrolytes which can ionize partially or completely in water. Those that ionize partially can reach equilibrium and therefore equilibrium law can be applied to get acid or base dissociation constants, K_a or K_b.
- The degree of ionizationis the ratio of the number of ionized molecules to the total number of molecules dissolved in water. It is related to equlibrium constant and concentration of the solution by the expression $\alpha =$
- Acids are given pK_a values: $pK_a = -\log K_a$. The smaller the pK_a value, the stronger the acid. Bases are given pK_b values: $pK_b = -\log K_b$. A stronger base has a smaller pK_b.
- pH is a scale commonly used to measure the degree of acidity or alkalinity

of a solution. Its defined as negative logarithm to base 10 of molar hydrogen ion concentration or $pH = -log_{10} [H^+]$. pOH is the negative logarithm to base 10 of the molar concentration of hydroxide ions in a solution. $pOH = -log_{10} [OH^-]$. $pH = pK_w - pOH$

- A buffer solutionis a solution which resists changes in pH on addition of a small amount of a base or acid.
- The pH of a buffer solution be calculated using the Henderson-Hasselbalch equation given by $pH = pK_a + log$or $pOH = pK_b + log$
- Buffer solutions can be prepared by two methods namely; mixing weak acid and its corresponding salt or weak base and its corresponding salt and the partial neutralization of a base by an acid and viceversa.
- Buffer solutions have many practical applications such as controlling the pH of human blood constant, maintaining pH of soil for survival of microorganisms and proper growth of plants, a stable pH in water bodies ensures survival of aquatic organisms, used in manufacture of cosmetics and alcohols.

6.7. Additional information for tutors

pH of a solution is the negative logarithm to base ten of the molar hydrogen ion concentration. Hydrogen ions do not exist freely in solutions made using water, they are very small and thus have a higxh charge. This means that in water, they are solvated. They only exist as hydrated protons or hydrated hydrogen ions i.e. H_3O^+ and isthe simplest oxonium ion which is specifically called hydroxonium ion or hydronium ion. In chemistryH_3O^+has the same function as a hydrogen ion.

Consider the reaction below:

$$HCl_{(acid)} + H_2O_{(base)} \rightleftharpoons Cl\text{-}_{(base)} + H_3O^+_{(acid)}$$

A conjugate acid is a species produced by addition of a hydrogen ion to a base, such H_3O^+ produced by adding H^+ to H_2O (the base), while a conjugate base is a species formed by removing a proton from an acid. it e.g. Cl^-. Therefore $H_2O/H_3O^+$and HCl/Cl^- are acid-base conjugate pairs.

pH provides a quantitative measure of acidity and alkalinity of a solution. For acidic solutions, $[H^+]$ is greater than $[OH^-]$ and pH is less than 7. For alkaline solutions, $[H^+]$ is less than $[OH^-]$ and pH is greater than 7. For neutral solutions, $[H^+] = [OH^-] = 1.0 \times 10^{-7}$ mol dm^{-3} and pH =7.

Pure water is neutral. Mineral water such as Inyange, Nil, Akandi, Aqua sipi, jibu is alkaline. It contains dissolved ions added as water passes through natural rocks such as limestone. Limestone is chemically known as calcium carbonate which reacts with a few hydrogen ions in water forming calcium hydrogen carbonate. This decreases the concentration of hydrogen ions in water thus the overall pH increases. The pH of mineral water is about 7.0 – 8.0.

pH is obtained using a calculator as follows:

press – (negative sign), log and then [H$^+$] value. E.g: if [H$^+$] =0.001, then pH=-log 0.001= 3

To get [H$^+$] value, press SHIFT, log, – (negative sign) and finally pH value or PRESS 10^{-pH}.

E.g: if the pH is 2, [H$^+$] = 10^{-2}=0.01mol/dm^{-3}

Some necessary logarithm properties to be used in this unit are:

- $\log_{10}\left(\frac{a}{b}\right) = \log_{10}^{a} - \log_{10}^{b}$
- $\log_{10}\left(xy\right) = \log_{10}^{a} + \log_{10}^{y}$
- If $\log_{10}^{x}$ = A, x given by x = 10^{A}

Guidance on skills lab 6

Student teachers have now finished the unit of pH of acidic and alkaline solutions. This is the right time to apply some of the knowledge they acquired from this unit. As a tutor you are expected to guide them on how to perform this skills lab. After providing them with relevant explanations allow them to work on their own. Set a time limit and a plan for the presentation of their findings.

For the 1st activity they are supposed to indentify the plant which grows well in the school farm and the pH of the soil of the farm. If the school does not have a farm they can use another one nearby. Ask them to draw a general conclusion about their findings. (This plant….grows well in soils of pH….)

The 2nd activity is to be done as a research. Tell them to relate enzyme activity to pH change. This is related to biology. They should clearly describe how pH changes affect the working of enzymes and explain how the knowledge of pH and buffer solutions help scientists to set favourable conditions for an optimum enzyme activity.

6.8. End unit assessment

Answers to end unit assessment questions

SECTION A:

1. A

2. D

3. B

4. B

5. C

SECTION B:

6. (a) A weak acid is an electrolyte which is partially ionized in aqueous solutions.

(b) $K_a = \frac{[C_6H_5COO^-][H^+]}{[C_6H_5COOH]}$

$6.4 \times 10^{-5} = \frac{[H^+]}{0.1}$

$[H^+] = \sqrt{(6.4x10^{-5})x0.1}$

$[H^+] = 2.53 \times 10^{-3}$ mol dm^{-3}

pH = $-\log_{10}[H^+]$

$= -\log_{10}(2.53 \times 10^{-3})$

pH = 2.6

7. **$CH_3COOH\ (aq) \rightleftharpoons CH_3COO^-\ (aq) + H^+\ (aq)$**

$K_a = \frac{[CH_3COO^-][H^+]}{[CH_3COOH]} = \frac{[H^+]^2}{C_a}$

$[H^+] = \sqrt{(1.8x10^{-5})x\ o.1}$

$[H^+] = 1.34 \times 10^{-3}$ mol dm^{-3}

pH = $-\log_{10}[H^+]$

pH = $-\log_{10}(1.34 \times 10^{-3})$

pH = 3 – log 1.34

pH = 2.87

8. (a) $CH_3CH_2COOH\ (aq) \rightleftharpoons CH_3CH_2COO^-\ (aq) + H^+\ (aq)$

Or $CH_3CH_2COOH\ (aq) + H_2O\ (l) \rightleftharpoons CH_3CH_2COO^-\ (aq) + H_3O^+\ (aq)$

(b) $K_a =$ or $K_a =$

9. (a) pH = $-\log_{10}[H^+]$

$K_a = \frac{[H+]^2}{C_a}$

$[H^+] = \sqrt{(7.4x10^{-4})x0.23}$

$[H^+] = 1.305 \times 10^{-2}$ mol dm^{-3}

pH = $-\log_{10}[H^+]$

$= -\log_{10}(1.305 \times 10^{-2})$

<u>pH = 1.88</u>

(b) (i) $C_5H_7O_4COO^-$ (aq) + H^+ (aq) $\rightleftharpoons$ $C_5H_7O_4COOH$ (aq)

(ii) $C_5H_7O_4COOH$ (aq) + OH^- (aq) $\rightleftharpoons$ $C_5H_7O_4COO^-$ (aq) + H_2O (l)

(c) $pH = pK_a + \log\left(\frac{[Salt]}{[Acid]}\right)$

$pH = -\log(7.4 \times 10^{-4}) + \log\left(\frac{0.3}{0.2}\right)$

<u>pH = 3.3</u>

(c) K_w is the ionic product of water or the dissociation constant for water

$K_w = [H^+][OH^-]$ or $K_w = [H_3O^+][OH^-]$

Water has a pH of 7 because it is neutral since the concentration of H^+ ions in water is 1.0×10^{-7} mol dm^{-3}

10. NH_4OH (aq) $\rightleftharpoons$ NH_4^+ (aq) + OH^- (aq)

$[OH^-] = C\alpha$

$[OH^-] = 0.01 \times 0.04 = 4.0 \times 10^{-4}$ moldm^{-3}

pOH = $-\log_{10}[OH^-]$

pOH = $-\log_{10}(4.0 \times 10^{-4})$

pOH = 3.39

pH = 14 – pOH

pH = 14 – 3.39

<u>pH = 10.61</u>

(b) $K_b = \frac{[OH^-]^2}{C_b}$

$K_b = \frac{(4.0x10^{-4})^2}{0.01}$

<u>$K_b = 1.6 \times 10^{-5}$ mol dm^{-3}</u>

11. (a) CH_3COOH (aq) + NaOH (aq) $\longrightarrow$ CH_3COONa (aq) + H_2O (l)

At half-way neutralization, $[CH_3COOH] = [CH_3COONa] = 0.05M$

$$\text{pH} = \text{p}K_a + \log\left(\frac{[Salt]}{[Acid]}\right)$$

$$\text{pH} = -\log(1.8 \times 10^{-5}) + \log\left(\frac{0.05}{0.05}\right)$$

$\underline{\text{pH} = 4.7}$

(b) The pH of the resultant solution does not change i.e. remains at 4.7

Explanation

Ethanoic acid is a weak acid which is only partially ionized while sodium ethanoate is a strong electrolyte and is completely ionized in aqueous solution.

$CH_3COOH\ (aq) \rightleftharpoons CH_3COO^-\ (aq) + H^+\ (aq)$

$CH_3COONa\ (aq) \longrightarrow CH_3COO^-\ (aq) + Na^+\ (aq)$

The OH^- ions from the base added combine with hydrogen ions in the solution to form water. However, this increases the ionization of ethanoic acid to re-establish the concentration of hydrogen ions back to normal. Therefore, the pH of the solution remains constant.

12. (a)(i) $CH_3COO^-\ (aq) + HCl\ (aq) \longrightarrow CH_3COOH\ (aq) + Cl^-\ (aq)$

Or $CH_3COO^-\ (aq) + H^+\ (aq) \longrightarrow CH_3COOH\ (aq)$

(ii) $CH_3COOH\ (aq) + NaOH\ (aq) \longrightarrow CH_3COONa\ (aq) + H_2O\ (l)$

Or $CH_3COOH\ (aq) + OH^-\ (aq) \longrightarrow CH_3COO^-\ (aq) + H_2O\ (l)$

(b) $\text{pH} = \text{p}K_a + \log\left(\frac{[Salt]}{[Acid]}\right)$

$4.5 = -\log(1.8 \times 10^{-5}) + \log\left(\frac{0.2}{[Acid]}\right)$

$4.5 = 5 - \log 1.8 + \log 0.2 - \log[\text{Acid}]$

$\log[\text{Acid}] = -0.4543$

$\underline{[\text{Acid}] = 0.35\ \text{moldm}^{-3}}$

13. (a) $K_b = \frac{[NH_4^+][OH^-]}{[NH_4OH]}$

(b) $K_b = \frac{[OH^-]^2}{C_b}$

$[OH^-] = \sqrt{(1.8x10^{-5})} \times 0.1$

$[OH^-] = 1.34 \times 10^{-3}$ mol dm^{-3}

Assumptions

$[NH_4^+] = [OH^-]$; since there is negligible OH^- ions from water and the mole reaction ratio $NH_4^+ : OH^-$ is 1:1

$[NH_4^+] = 0.1M$ since little of NH_4OH has ionized in solution

(c) $K_b = \dfrac{[NH_4^+][OH^-]}{[NH_4OH]}$

$[NH_4^+] = 0.01$ mol dm^{-3}, Since NH_4Cl fully ionizes to NH_4^+ ions in solution

$[NH_4OH] = 0.1$ mol dm^{-3}, poorly ionizes in solution

$K_b = \dfrac{0.01x[OH^-]}{0.1}$

$[OH^-] = \dfrac{(1.8x10^{-5})x0.1}{0.01}$

$[OH^-] = 1.8 \times 10^{-4}$ mol dm^{-3}

Change in $[OH^-] = (1.34 \times 10^{-3}) - (1.8 \times 10^{-4})$

$= 1.16 \times 10^{-3}$ mol dm^{-3}

14. (a) $KOH_{(s)} + H_2O_{(l)} \rightarrow K^+_{(aq)} + OH^-_{(aq)}$

(b) From the equation, $[KOH] = [K^+] = [OH^-]$

$[OH^-] = 2.3 \times 10^{-3}$ mol dm^{-3}

$K_w = [H^+][OH^-]$

$[H^+] = \ = \dfrac{1.0x10^{-14}}{2.3x10^{-3}} = 4.34x10^{-12}$

$[H^+] = 4.34x10^{-12}$ mol dm^{-3}

pH = - $log_{10}[H^+]$

pH = - $log_{10}(4.34x10^{-12})$

pH = 11.36

For answers to (c) and (d), refer to student's book

6.9. Additional activities

6.9.1. Remedial activities

Question 1 What is the pH of a solution containing 0.004M $HClO_4$?	Answer 1 $pH = -\mathit{log}[H^+]$ $= -\mathit{log}(0.004)$ $\underline{pH = 1.4}$
Question 2 Calculate the concentration of Mg^{2+} ions in a solution of $Mg(OH)_2$ whose pH is 10.62	Answer 2 $pOH = 14 - pH = 14 - 10.62$ $pOH = 3.38$ $pOH = -\log[OH^-]$ $[OH^-] = \log^{-1}(3.38)$ $[OH^-] = 4.17 \times 10^{-4}$ mol dm^{-3} $Mg(OH)_{2\,(aq)} \rightleftharpoons Mg^{2+}_{(aq)} + 2\,OH^-_{(aq)}$ Mole ratio $Mg(OH)_2 : OH^- = 1:2$ thus $[Mg(OH)_2] = [Mg^{2+}] = \quad \times 4.17 \times 10^{-4}$ $[Mg^{2+}] = 2.08 \times 10^{-4}$ mol dm^{-3}
Question 3 The K_a of ethanoic acid is 1.8×10^{-5} mol dm^{-3} at room temperature. Calculate the pK_a of the acid.	Answer 3 $pK_a = -\log K_a$ $pK_a = -\log(1.8 \times 10^{-5})$ $pK_a = 4.75$
Question 4 The pH of aqueous ammonium chloride is less than 7 while that of sodium chloride is 7. Explain this observation.	Answer 4 Ammonium chloride is a salt of weak base and strong acid thus undergoes hydrolysis to produce a high concentration of hydrogen ions in solution hence pH is less than 7. $NH_4Cl_{\,(aq)} + H_2O_{\,(l)} \rightleftharpoons NH_4OH_{(aq)} + HCl_{\,(aq)}$ Or $NH_4{}^+{}_{(aq)} + H_2O_{\,(l)} \rightleftharpoons NH_4OH_{(aq)} + H^+_{(aq)}$ In contrast, sodium chloride being a salt of strong base and strong acid, it ionizes in water to form equal concentrations of hydrogen ions and hydroxide ions. Therefore, pH will be 7 (resultant solution is neutral)
6.9.2. Consolidation activities	

Question 1 What volume of NaOH of pH 11.30 is required to neutralize 20 cm^3 of CH_3COOH of pH 2.1 (K_a of CH_3COOH is 1.8×10^{-5} and $K_w = 1 \times 10^{-14}$ mol dm^{-3}	Answer 1 From pH of NaOH, pOH = 14 – 11.30 = 2.70 $[OH^-] = 10^{-2.70}$ $[OH^-] = [NaOH] = 2.0\ x10^{-3}$ mol dm^{-3} For ethanoic acid, $[H^+] = 10^{-2.10}$ $= 7.94 \times 10^{-3} moldm^{-3}$, $[CH_3COOH] = C_a = \frac{[H^+]^2}{K_a} = 3.5M$ Moles of acid = $\left(\frac{3.5x20}{1000}\right)$ = 0.07 moles Moles of NaOH = 0.07 moles, mole ratio 1:1 Volume of NaOH = $\left(\frac{0.07x1000}{2.0x10^{-3}}\right)$ $= 3.5\ x10^4\ cm^3$
Question 2 Explain why the pH of water decreases when it is left standing in air for a long time.	Answer 2 Water absorbs carbon dioxide from the atmosphere which dissolves to form a weak acid called carbonic acid. The acid ionizes partially to produce hydrogen ions responsible for the acidity/reduction in pH $H_2O\ (l) + CO_2\ (g) \rightleftharpoons H_2CO_3\ (aq)$ $H_2CO_3\ (aq) \rightleftharpoons 2H^+\ (aq) + CO_3^{2-}\ (aq)$

Question 3	Answer 3
Given that the pK_a of ammonia at 25 °C is 9.25. Calculate the pH of 0.1M ammonia solution.	$pK_a + pK_b = pK_w$ $pK_b = 14 – 9.25 = 4.75$ $pK_b = - \log K_b$ $K_b = \log^{-1} (4.75) = 1.75 \times 10^{-5}$ mol dm^{-3} $[OH^-] = \sqrt{\left(1.75x10^{-5}\right)x0.1}$ $[OH^-] = 1.33 \times 10^{-3}$ mol dm^{-3} $pOH = - \log [OH^-] = - \log (1.33 \times 10^{-3})$ $pOH = 2.9$ $pH = 14 – 2.9$ $pH = 11.10$

6.9.3. Extended activities

Question 1	Answer 1
(a) Ethanoic acid is a weak acid. (i) Explain what is meant by a weak acid? (ii) Calculate the pH of a 0.05M ethanoic acid solution of K_a 1.8 x 10^{-5} mol dm^{-3}. (b)(i)Explain what is meant by a buffer solution? (ii) Discuss how a buffer solution works. (c) A solution was made by dissolving 7.2g of ethanoic acid and 12.0g of sodium ethanoate to make one litre. To the solution was added 0.8 cm3 of 1M hydrochloric acid. Calculate the pH of the solution. State any assumptions you will make	(a)(i) *Refer to student's book* (ii) $K_a = \frac{[H^+]^2}{C_a}$ $[H^+] = \sqrt{(1.8x10^{-5})x0.05}$ $[H^+]$ = 9.487 x 10^{-3} mol dm^{-3} (b) (i) and (ii), *Refer to student's book* (c) Moles of HCl added = = 8 x 10^{-4} moles Molar mass of CH_3COOH = 60g/mol $[CH_3COOH]$ = 7.2/60 = 0.12 mol dm^{-3} Molar mass of CH_3COONa = 82g/mol $[CH_3COONa]$ = 12/82 = 0.146 mol dm^{-3} Addition of HCl increases $[CH_3COOH]$ and reduces $[CH_3COONa]$ New [Acid] = 0.12 +8 x 10^{-4} = 0.1208 mol dm^{-3} New [Salt] = 0.146 – 8 x 10^{-4} = 0.1452 mol dm^{-3} $pH = pK_a + \log\left(\frac{[Salt]}{[Acid]}\right)$ $pH = -\log(1.8 \times 10^{-5}) + \log\left(\frac{0.1452}{0.1208}\right)$ pH = 4.82
Question 2	Answer 2
Explain why the acid dissociation constant, K_a of bromoethanoic acid is greater than that of ethanoic acid at the same temperature.	Acid dissociation constant is a measure of the strength of acids and depends on the ease with which a proton/hydrogen ion is lost in solution Bromoethanoic acid is a strong acid because of highly electronegative bromine attached to α-carbon which strongly pulls electrons away from α-carbon. The effect is transmitted in the O–H bond weakening it. This facilitates easy release of hydrogen ions in solution. In ethanoic acid, the methyl group has a positive inductive effect which pushes electrons towards the carbonyl carbon. This effect is transmitted to the O – H bond which makes it strong and difficult to release hydrogen ions in solution.

UNIT 7: SOLUBILITY AND SOLUBILITY PRODUCT OF SPARINGLY SOLUBLE SALTS

7.1. Key unit competence

Calculate the solubility product constant of sparingly soluble salts and deduce the applications of common ion effect in the industry.

7.2. Prerequisites

Student teachers will better understand this unit (solubility and solubility)if they have good:

Laboratory skills

- Understanding of the concept of salts and their properties,
- Understanding of the concept of solutes, solvents, solutions and concentration of solutions,
- Understanding of the concept of acids, bases and pH, and
- Understanding of the mole concept and titration.

7.3. Cross-cutting issues to be addressed

- **Environment and sustainability**

When solutes (salts) are dissolved in water (a common solvent), they dissociate into ions. Some ions hydrolyse in water to form either acidic or alkaline solutions which must be disposed of carefully. Acidic solutions can burn the skin completely due to a high affinity for water and corrode metals. Acidic soils do not allow a proper growth of vegetation and they do not support ills soil living organisms. Most salts are used as fertilizers which when applied excessively, they cause ground water contamination, burn crops, increase air pollution and deplete minerals from the soil. Student teachers should therefore be aware of those dangers associated to salts in general to join efforts with other in the process of conserving our environment.

- **Inclusive education**

This unit involves a lot of research and calculations. To be able to understand it, there must be discussions, experiments and sharing of information among learners. You can organize your class and use different strategies to help all learners understand concepts very well.

- **Gender**

During group activities, try to form heterogeneous groups i.e. boys and girls or when learners start to present their findings, encourage both boys and girls to present and challenge each other.

- **Financial education:**

As this unit deals with many salts in modern life, you will draw learners' attention on the economic importance of making salts and common products made using that knowledge of salts.

- **Peace and values**

During group activities, you will encourage learners to work together, help each other where seems to be difficulty, and to respect each other's ideas.

7.4. Guidance on introductory activity

- Put your student teachers in groups of pairs or groups of 4 – 5 depending on the size of your class.
- Provide them with senior six chemistry student teachers' books and guide them on the page where the unit and the introductory activity is.
- Ask them to discuss, provide them with worksheet to note their answers.
- Give them enough time like five minutes to analyze and discuss about the activity.
- Invite one representative from each group to present their findings. You may note some key points on the board and as you draw them towards the introductory content of this unit.

Expected answers to introductory activity

1. Possible cations are those of magnesium and calcium. This is because they are among those present in water, they are mostly the ones which form insoluble precipitates with anions such as sulphate, carbonate,,,
2. Lime scale is an insoluble substance. When water evaporates it leaves behind limescale in the solid form.
3. Mainly limescale is composed by calcium carbonate which is easily dissolved by acids. So using an acidic solution can dissolve the solid and wash it away.

7.5. List of lessons

#	Lesson title	Learning objectives	Periods
1	Definition of solubility and molar solubility	• Define the terms solubility and molar solubility • Calculate solubility and molar solubility of various salts	1

2	Unsaturated, saturated and super saturated solutions.	• Define the terms unsaturated, saturated and super saturated solutions • State and explain the factors that affect solubility of sparingly soluble salts.	1
3	Equations of the dissociation of sparingly soluble salts in water.	• Write the equations of dissociation and Ksp expression for sparingly soluble salts.	1
4	Solubility product Ksp and the relationship between solubility and Ksp	• Explain the meaning of the term solubility product • Derive a relationship between solubility and solubility product	1
5	Calculations involving solubility product	• Perform calculations involving solubility and solubility product	2
6	Definition, calculation and use of ionic product (Q)	• Perform calculations about ionic product of salts. • Use the values of Ksp and Qc to predict if a mixture of solutions will form a precipitate or not.	1
7	Separation of ions by fractional precipitation.	• Explain how fractional precipitation is used in separation of ions.	1
9	Common ion effect, pH, complex ion formation and solubility.	• Explain common ion effect on the solubility of sparingly soluble salts. • Explain the effect of pH on the solubility of sparingly soluble salt. • Relate the common ion effect to the solubility of sparingly soluble salt.	1
9	Applications of solubility product	• Explain the applications of the solubility product and the common ion effect.	1
10	**End unit assessment**		1

Lesson 1: Definition of solubility and molar solubility

a) Learning objectives

- Define the terms solubility and molar solubility
- Calculate solubility and molar solubility of various salts

b) Prerequisites

Student teachers will learn these definitions better if they have knowledge and understanding on the following units: Solutes, solvents and solution, solubility of salts and solubility rules, mole concept and concentration of solutions.

c) Teaching resources

You will use sodium chloride, barium sulphate, silver chloride, water, beakers, stirring rods.

d) Learning activities

Since student teachers have already studied some of these definitions from the previous classes, you will not directly be involved in their discussion because they already know. Guide them through the following steps.

Methodological steps

- Put your student teachers in groups of pairs or groups of 4 – 5 depending on the size of your class.
- Guide student teachers on clearly defining a solute, solvent, solution, solubility and molar solubility.
- Let them discuss and give examples of where possible.
- You will keep checking on each group and guide them as they note down their summaries.
- End the lesson with a short discussion about the dangers of acids salts to humans and the environment.
- Finally, give them the application activity to prove their understanding.

Answers to activity 7. 1

1. Calculate the molarity of a solution made by dissolving 4g of sodium hydroxide in distilled water to make 250ml of solution. Determine its mass concentration.

A solution of sodium hydrogen carbonate has a molarity of 0.5mol.dm^{-3}. what mass of sodium hydrogen carbonate must be dissolved to make 2dm^{3} of this solution

2. **Molar concentration** (also called molarity) is a measure of the concentration of a chemical species, in particular of a solute in a solution, in terms of amount

of substance (in mole) per unit volume of solution (L). While

Mass concentration is defined as the mass of a constituent divided by the volume of the mixture.

Mass concentration is

3. Molar concentration is the amount of solute in moles dissolved in one liter of solution whereas mass concentration is the mass of a solute dissolved in one liter of solution.

$$Molarity = \frac{n}{V} = \frac{\frac{m}{Mm}}{V} = \frac{\frac{4g}{40gmol^{-1}}}{0.25dm^{3}} = 0.4moldm^{-3}$$

4. $Molarity = \dfrac{\frac{m}{Mm}}{V}$

$$m = MxMmxV = 0.5moldm^{-3}x84gmol^{-1}x2dm^{3} = 84g$$

Application activity 7.1

Expected answers to application activity 7.1

1. Solubility increases when temperature increases and vice versa.
2. Soluble: $CaCl_2$, $CuSO_4$, NH_3

   Insoluble: $PbCr_2O_7$, CaC_2O_4 and LiI.
3. Solubility of gases decreases as temperature increases.
4. Dissolution of salts in water is endothermic as increasing temperature makes more salt dissolution.

Lesson 2: Unsaturated, saturated and super saturated solutions

a) Learning objectives

- Define the terms unsaturated, saturated and super saturated solutions
- State and explain the factors that affect solubility of sparingly soluble salts.

b) Prerequisites

Student teachers will learn these definitions better if they have knowledge on solutes, solvents and solution, solubility of salts and solubility rules.

c) Teaching resources

Use a weighing scale, beakers, distilled water, sodium chloride or sugar crystals and a heat source.

d) Learning activities

Since this lesson is more of a practical than theory, give materials to use and guide them through the steps below.

Methodological steps

- Organize your class by putting student teachers into group of 3 or 4 depending on the size of the class.
- Give each group a beaker of water, salt and a weighing scale and a stirring rod.
- Ask a student teacher in each group to add a given amount of salt into water and dissolve.
- Another student teacher from each group can continue adding more salt and dissolving as they note down their observations.
- Provide each group with student teacher's books and guide them on the page where they will find the learning activity of the lesson.
- Give them enough time to think and discuss about the possible answers relating them to simple experiment above.
- Comment on student teachers' responses and give them the summary of expected feedback based on their findings.

Expected answers to activity 7.2

1. The salt dissolves completely.
2. Some of the additional salt does not dissolve. The solution gets saturated and excess salt remains undissolved.
3. At a higher temperature more salt would dissolve, but when the resulting solution is cooled down the excess solute will precipitate out from solution.

Application activity 7.2

Expected answers for application activity 7.2

1. Refer to the student teacher's book for these definitions. Topic 7.2
2. This solution is unsaturated as at this temperature the maximum KCl that can completely dissolve to make a saturated solution is approximately 50g but here we are only dissolving 10g.
3. Below 60^0C a precipitate starts to form.
4. At 20^0C KI is the most soluble.
5. Approximately 50g of KNO_3 should be added. This is because at 50^0C the mass of saturation is 80g and at 70^0C it is $\approx$130g.

Lesson 3: Equations of the dissociation of sparingly soluble salts in water

a) Learning objectives

Write the equations of dissociation for sparingly soluble salts

b) Prerequisites

Student teachers will better understand this unit if they have knowledge on balancing chemical equations, chemical equilibrium and molar solubility.

c) Teaching resources

Use a computer, projector, internet and chalkboard.

d) Learning activities

Methodological steps

You will group student teachers into pairs (a boy and a girl where applicable), provide them with student teacher's books and guide them on the page where to find the activity. Ask them to discuss, present their findings. You will iron out some issues and they take a summary of the facts.

Answers to activity 7.3

1. $BaSO_{4(s)} \rightleftharpoons Ba^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)}$
2. $AgI(s) \rightleftharpoons Ag^{+}(s) + I^{-}(aq)$
3. $Ag_2CO_{3(s)} \rightleftharpoons 2Ag_{(aq)}^{+} + CO^{2-}{}_{3}$
4. $Ca_3(PO_4)_{2((s)} \rightleftharpoons 3Ca_{(aq)}^{2+} + 2PO_4^{3-}{}_{(aq)}$

Application activity 7.3

Answers for application activity 7.3

1. (a) $CaCO_{3((s)} \rightleftharpoons Ca_{(aq)}^{2+} + CO_3^{2-}{}_{(aq)}$
   (b) $Fe(OH)_{3(aq)} \rightleftharpoons Fe^{3+}_{(aq)} + 3OH^{-}_{(aq)}$
   (c) $AgI(s) \rightleftharpoons Ag^{+}(aq) + I^{-}(aq)$
2. (a) $PbCr_2O_7$
   (b) $Al(OH)_3$

Lesson 4: Solubility product Ksp, and its relationship with solubility

a) Learning objectives

- Explain the meaning of the term solubility product
- Derive a relationship between solubility and solubility product

b) Prerequisites

Student teachers will understand it better if they have knowledge on balancing equations, chemical equilibrium and molar solubility.

c) Teaching resources

Use a computer, projector, internet and chalkboard.

d) Learning activities

For learning activities and methodological steps, refer to lesson 3 above.

Expected answers to activity 7.4

1. (a) $AgCl_{(s)} \rightleftharpoons Ag_{(aq)}^{+} + Cl^{-}_{(aq)}$

   (b) $Ca_3(PO_4)_{2((s)} \rightleftharpoons 3Ca_{(aq)}^{2+} + 2PO_4{}^{3-}{}_{(aq)}$

2. $CH_3COOH_{(aq)} + H_2O \rightleftharpoons CH_3COO^{-}_{(aq)} + H_3O^{+}_{(aq)}$

$$Ka = \frac{\left[CH_3COO^-\right]\left[H_3O^+\right]}{\left[CH_3COOH\right]}$$

3. (a) $Ksp = \left[Ag^+\right]\left[Cl^-\right]$

   (b) $Ksp = \left[Ca^{+2}\right]^3\left[PO_4^{3-}\right]^2$

Application activity 7.4

Expected answers application activity 7.4

1. (a) AgI **Ksp = $[Ag^+]\ [I^-]$**

   (b) $CaSO_4$ **Ksp = $[Ca^{2+}]\ [SO_4{}^{2-}]$**

   (c) Ag_2CO_3 **Ksp = $[Ag^+]^2[CO_3{}^{2-}]$**

   (d) Li_3PO_4 **Ksp = $[Li^+]^3\ [PO_4{}^{3-}]$**

2. (a) Ksp= $[A^{y+}]^x[B^{x-}]^y$

(b) Ksp=$[xS]^x[yS]^y=(xyS^2)^{xy}$

Lesson 5: Calculations involving solubility product

a) Learning objectives

Perform calculations involving solubility and solubility product

b) Prerequisites

Student teachers will understand it better if they have knowledge on balancing equations, chemical equilibrium, molar solubility and solubility product, indices in mathematics.

c) Teaching resources

Use a computer, projector, internet and chalkboard, worksheets and calculators.

d) Learning activities

You will group student teachers into pairs (a boy and a girl where applicable), provide them with student teacher's books and guide them on the page where the activity is located. Ask them to discuss, present their findings. You will iron out some issues and they take a summary of the facts.

Expected answers to activity 7.5

1. (a) Ksp = $[Pb^{2+}]\,[SO_4^{2-}]$

(b) Ksp = $[Pb^{2+}]\,[I^-]^{\,2}$

2. $XB_{2(s)} \leftrightarrow X^{2+}_{(aq)} + 2B^-_{(aq)}$

I: 0.05 0 0

C: -0.0002 + 0.0002 + (0.0002x2)

E: 0.0498 0.0002 0.0004

Equilibrium amount of $B^-$is 0.0004

Application activity 7.5

Expected answers application activity7. 5

1. $Sr_3(AsO_4)_2\,(s) \rightleftharpoons 3\,Sr^{2+}\,(aq) + 2\,AsO_4^{2-}\,(aq)$

s 3s 2s

Where, s = moles of $Sr_3(AsO_4)_2$ that dissolved.

Ksp = $[Sr^{2+}]^3\,[AsO_4^{3-}]^2 = 4.29\text{x}10^{-19.}$

$(3s)^3\,(2s)^2 = 4.29\text{x}10^{-19.}$

$(27s^3)\ (4s^2) = 4.29x10^{-19}$

$$s = 5\sqrt{\frac{4.29x10^{-19}}{108}}$$

$s = 8.31x10^{-5}$

2. $Ag_2CO_3\ (s) \rightleftharpoons 2Ag^+\ (aq) + CO_3^{2-}\ (aq)$

   $[Ag^+]^2 = 2\ (1.27 \times 10^{-4}) = 2.54 \times 10^{-4}$ M

   $[CO_3^{2-}] = 1.27 \times 10^{-4}$ M

   $Ksp = [Ag^+]^2 [CO_3^{2-}] = (2.54 \times 10^{-4})^2 [1.27 \times 10^{-4})$

   $Ksp = 8.2x10^{-12}$

3. (a) $Mg(OH)_2\ (s) \rightleftharpoons Mg^{2+}\ (aq) + 2OH^-\ (aq)$

   S S 2S

   $[Mg^{2+}]\ [OH^-] = 1.8 \times 10^{-11}$

   $(S)\ (2S)^2 = 1.8x10^{-11.}$

   $(S)(4S^2) = 1.8 \times 10^{-11.}$

   $4S^3 = 1.8 \times 10^{-11}$

   Molar solubility, $S = 1.65 \times 10^{-4}$

   (b) pOH = 14 – PH = 14 – 11.22 = 2.78

   $[OH^-] = 10^{-2.78} = 1.66 \times 10^{-3}$ M

   Let x be mol dm^{-3} of $Mg(OH)_2$ that dissolved (Molar solubility)

   $[Mg^{2+}]\ [OH^-]^2 = 1.8 \times 10^{-11}$.

   $(x)(1.66 \times 10^{-3} + 2x)2 = 1.8 \times 10^{-11}$

   Assuming that 2x is negligible compared to 1.66×10^{-3}.

   $(x)(1.66 \times 10^{-3}) = 1.8 \times 10^{-11}$

   $(x)(2.7556 \times 10^{-6}) = 1.8 \times 10^{-11}$

   $$x = \frac{1,8x10^{-11}}{2.7556x10^{-6}}$$

   $x = 6.53x10^{-6}$ M

4. pH=7.8 so pOH=14-7.8= 6.2

   $[OH^-]=10^{-6.2}=6.3x10^{-7}moldm^{-3}$

   $2OH^-$ correspond to $1B^+$ so, $[B^{2+}]=6.3x10^{-7}moldm^{-3}:2=3.15x10^{-7}moldm^{-3}$

   $Ksp=[B^{2+}]\ [OH^-]\ ^2=3.15x10^{-7}\ x\ (6.3x10^{-7})^2=1.25x10^{-19}$

Lesson 6: Definition, calculation and use of ionic product (Q)

a) Learning objectives

- Perform calculations about ionic product of salts.
- Use the values of Ksp and Q to predict if a mixture of solutions will form a precipitate or not.

b) Prerequisites

Student teachers will understand if they have knowledge on solubility/molar concentration, solubility product, quantitative chemical equilibrium and various types of solutions.

c) Teaching resources

Use a computer, projector, internet, chalkboard and worksheets

d) Learning activities

Before introducing this lesson, let student teachers first attempt the activity from the student teacher's book.

As a facilitator, you are expected to guide student teachers through the following steps:

Methodological steps

- Organize your class by putting student teachers into group of 3 - 4 depending on the size of the class.
- Provide them with student teacher's books and guide them on the page where they can find the activity and discuss the questions.
- Give them enough time to think, refer to notes and discuss about the possible answers.
- Check student teachers' responses and ideas and continue the discussions with a brief brainstorming on the content using student teacher's book.
- Comment on their responses and give them the summary of expected feedback.

Expected answers to activity 7.6

a) Solubility equation is $BaSO_{4(s)} \rightleftharpoons Ba^{2+}{}_{(aq)} + SO_4{}^{2-}{}_{(aq)}$

b) Solubility expression is Ksp = [Ba^{2+}] [SO$_4{}^{2-}$]

c) Solubilty of BaSO$_4$= 0.002563gdm^{-3}= 0.002563:233= 0.000011moldm^{-3}

Since 1 mole of BaSO4 produces 1 mole both Ba^{2+} and SO$_4{}^{2-}$

[Ba^{2+}] =[SO$_4{}^{2-}$]= solubility of BaSO$_4$ =0.000011moldm-3

Ksp =[Ba^{2+}] =[SO$_4{}^{2-}$] = 0.000011 X 0.000011 = 1.21 X 10^{-10} mol^{2}dm^{-6}

Application activity 7.6

Answers for application activity 7.6

1. At 298K, the molar solubility of AgCl in water is:

   (0.00188 g/L):143.5g/mol=1.31x10^{-5}moldm^{-3}

   K$_{sp}$ (AgCl) = [Ag$^+$][Cl$^-$] = (1.31 x 10^{-5}) ^{2}= 1.7 x lO^{-10}

2. When mixed, the total volume gets doubled and hence the effective concentration of the ions would be half of the initial concentration, i.e., in solution

   [Mg^{2+}] =(0.01/2)=0.005 mol/L

   [C$_2$O$_4{}^{2-}$] = (0.02/2) = 0.01 mol/L

   Q=[Mg^{2+}] [C$_2$O$_4{}^{2-}$] = 0.005 x 0.01 = 5 x 10^{-5}

   The K$_{sp}$ value for MgC$_2$O$_4$ at 18°C is 8.57 x 10^{-5}. Since, the ionic product Q is smaller than the K$_{sp}$, precipitation does not take place.

3. Total volume after mixing = 25.0 + 35.0 = 60.0 mL = 60.0 x 10^{-3} L

   New [Ag$^+$] after mixing = M x V ÷ total V

   = (7.9 x 10^{-7} x 35.0 x 10^{-3}) ÷ (60.0 x 10^{-3}) = 4.6 x 10^{-7}M

   New [I$^-$] after mixing = M x V ÷ total V

   = (1.4 x 10^{-9} x 25.0 x 10^{-3}) ÷ (60.0 x 10^{-3}) = 5.8 x 10^{-10} M

   Q= [Ag$^+$][I$^-$] = 5.8 x 10^{-10} x 4.6 x 10^{-7} = 2.7 x 10^{-16}

   Q (2.7 x 10^{-16}) is greater than K$_{sp}$ (8.6 x 10^{-17}) so a precipitate will form.

Lesson 7: Separation of ions by fractional precipitation

a) Learning objectives

- Explain how fractional precipitation is used in separation of ions.
- Explain common ion effect on the solubility of sparingly soluble salts.

b) Prerequisites

Learners will understand if they have knowledge on solubility of salts and solubility rules, identification of ions or qualitative analysis.

c) Teaching resources

Use a computer, projector, internet, chalkboard and worksheets

d) Learning activities

For methodological steps of the lesson, refer to lesson 6 above

Expected answers to activity 7.7

Concentrations of each species after mixing

$$\left[OH^-\right]=\frac{4.2\times10^{-3}\,mol.dm^{-3}}{2}=2.1\times10^{-3}\,mol.dm^{-3}$$

$$\left[Mg^{2+}\right]=\left[Ca^{2+}\right]=\left[Sr^{2+}\right]=\left[Ba^{2+}\right]=\frac{0.10\times mol.dm^{-3}}{2}=0.05mol.dm^{-3}$$

$$Q=\left[Mg^{2+}\right]\left[OH^-\right]^2=(0.05)(2.1\times10^{-3})^2=2.205x10^{-7}$$

Only magnesium will precipitate because it has a smaller Ksp than Q.

Application activity 7.7

Answers for application activity 7. 7

1. In the resulting solution, [Ca2^{+}] = 0.0035M and [$C_2O_4^{2-}$] = 1 x 10^{-6} M

   Q= [Ca^{2+}][$C_2O_4^{2-}$] = 0.0035 x 10^{-7} = 3.5 x 10^{-10}

   This is less than the solubility product of calcium oxalate. Thus, precipitation of calcium oxalate does not occur.

2. When mixed, the total volume gets doubled and hence the effective concentrations of the ions would be half of the initial concentration, i.e., in solution

$[Mg^{2+}] = (0.01/2) = 0.005$ mol/L

$[C_2O_4^{2-}] = (0.02/2) = 0.01$ mol/L

$Q = [Mg^{2+}][C_2O_4^{2-}] = 0.005 \times 0.01 = 5 \times 10^{-5}$

Q is smaller than K_{sp} ; precipitation does not take place.

3. $Ksp = \left[Sr^{2+}\right]\left[SO_4^{2-}\right] = 2.5x10^{-7}$

$$\left[SO_4^{2-}\right] = \frac{Ksp}{\left[Sr^{2+}\right]} = \frac{2.5x10^{-7}}{0.1} = 2.5x10^{-6} \text{ moldm}^{-3}$$

The minimum concentration is $2.5x10^{-6}$ moldm^{-3}

Lesson 8: Impact of Common ion, pH change and complex ion formation on solubility.

a) Learning objectives

Explain the effect of pH, common ion and complex ion formation on the solubility of sparingly soluble salt.

b) Prerequisites

Student teachers will learn this lesson better if they know and understand the following: Solutes and solvents, solubility of salts, solubility rules and solubility product, chemical and ionic equilibria, mole concept, pH of acidic and alkaline solutions and concentration of solutions.

c) Teaching resources

Use iodine and potassium iodide, beakers and distilled water.

d) Learning activities

Remind your learners about solubility, molar solubility through question and answer approach, and guide them into the activity.

Methodological steps

- Put your learners in groups of pairs or groups of 4 – 5 depending on the size of your class.
- Guide learners on clearly defining solubility, molar solubility and common ion effect. Give them enough time to discuss.
- You will keep checking on each group and guide them as they note down their summaries.
- Finally, give them the checking up activity to prove their understanding.

Expected answers to activity 7.8

1. When sodium hydroxide is added aluminium hydroxide precipitates but because it is amphoteric it reacts with excess sodium hydroxide and dissolves.
2. Decreasing pH means increasing the concentration of H^+ ions in the solution. As H^+ ions increase in the solution equilibrium position shifts to the left side.

Application activity 7.8

Answers for application activity 7.8

1. a) Adding ammonia solution would increase the solubility of silver oxalate because hydroxide ions would combine with silver ions and precipitate them out decreasing their concentration in the solution hence shifting the equilibrium position to the right.

   b) Adding a common ion, the oxalate ion would decrease the solubility of silver oxalate as equilibrium position shifts to the left.

2. a) $Sr(OH)_2(s) \rightleftharpoons Sr^{2+}{}_{(aq)} + 2OH^-{}_{(aq)}$

   b) $Ksp = \left[Sr^{2+}\right]\left[OH^-\right]^2$

   c) i) The solubility of strontium hydroxide decreased

      ii) OH^- is a common ion. It makes equilibrium position shift to the left.

Lesson 9: Applications of solubility product

a) Learning objectives

Explain the applications of solubility product

b) Prerequisites

Students will understand the applications if they have knowledge on solubility of salts, ionic product and solubility product.

c) Teaching resources

Use worksheets, flip charts, chalkboard, computer and internet.

d) Learning activities

Having studied solubility and solubility product, their applications are so simple from the previous discussions. As a facilitator, you are expected to guide learners to learn through these steps.

Methodological steps

Organize your class by putting students into pairs, a boy and a girl where applicable.

- Let them discuss the activity and the applications of solubility product using reference books or internet to find answers where they find challenges.
- Choose randomly a representative from each group to present their findings.
- Allow some other students to comment about the findings presented by their colleagues.
- Through different small oral questions, help the students to make the conclusions and summaries themselves.

Expected answers to activity 7.9

1. a) Use ammonia solution. A precipitate forms for Calcium ions but not for magnesium ions.

   b) Use sodium hydroxide. Cu^{2+} forms a blue precipitate but Fe^{3+} forms a brown precipitate.

   c) Silver nitrate is used. White precipitate for chloride ions and yellow precipitate for iodide ions.

2. An acid-base indicator is a substance used to show whether a solution is acidic, basic or neutral by changing its colour. $KMnO_4$ changes its colour from purple to colourless at the end point.

Application activity

Expected answers to application activity7. 9

1. $$S = \sqrt[2+3]{\frac{1x10^{-97}}{2^2 x 3^3}} = 3.686x10^{-22} moldm^{-3}$$

   =Fe^{3+} ions: Cu^{2+} and CrO_4^{2-}: F^- ions

7.6. Summary of the unit

Solubility is the amount of solid/solute either in moles or grams that dissolves in a given amount of the solvent at equilibrium producing ions in solution. Usually, it is defined as the number of grams or number of moles of the solid/solute that will dissolve in 100g of water at a given temperature. It is fundamentally expressed in molar (mol/dm^{-3} of solution).

Molar solubility can be expressed as the number of moles of a solute that can be dissolved per liter of solution before the solution becomes saturated.

A saturated solution is one which contains the maximum amount of dissolved solid at a particular temperature. If the quantity of a substance in a solution is less than that required to get the equilibrium with the solid, the solution is said to be “unsaturated”. A super saturated solution contains more solute than a saturated solution.

A sparingly soluble solute is one which slightly dissolves in a given solvent. It partly dissociates into component ions. The equation for this solubility is reversible.

The solubility product is the equilibrium constant expressed in terms of concentrations of the ions produced from a sparingly soluble solid in contact with a saturated solution. The equilibrium constant for the system is given the symbol Ksp. The concentrations of various ions are simply raised to the power of the stoichiometric number in the equation.

Solubility products are only constant at a particular temperature which is usually 298K.

The ionic product (Q) of salt is the product of the concentrations of the ions in solution raised to the same power as in solubility product expression. Ionic product describes concentrations that are not necessarily equilibrium concentrations.

Ksp is applicable to saturated solutions only, whereas ion product is applicable to all types of solutions of any concentration.

Homogenous mixtures appear in one phase while heterogeneous mixtures are in more than one phase. Sparingly soluble salts form heterogeneous mixtures involving formation of precipitates. Homogenous matures do not form precipitates.

Ions can be separated from each other basing on the solubility of their salts in water. This is done by using a reagent that forms a precipitate with one or a few of the ions in solution (fractional precipitation)

Common ion effect is the precipitation of a sparingly soluble salt from its saturation by adding a soluble compound containing one of the ions contained by the sparingly soluble salt.

7.7. Additional information for teachers

A sparingly soluble salt is one which dissolves up to a certain point beyond which no more of it dissolves. At this point, the equilibrium is established between the unionized solid and the ions produced. For example;

$MX(s) \rightleftharpoons M^+(aq) + X^-(aq)$; this is the solubility equation.

$$K = \frac{[M^+][X^-]}{[MX]}$$

Because the solid is too much, its solubility is taken to be a constant.

Ksp = $[M^+]$ $[X^-]$; this is the expression of solubility product.

The idea of solubility product, Ksp can be used to show conditions under which an electrolyte will dissolve to form a solution or precipitate from the solution.

When the ionic product is equal to the solubility product, the solution is saturated and will not dissolve any more solutes.

If the ionic product tends to exceed the solubility product, the solution is super saturated i.e. it contains excess dissolved solute, but this cannot take place because solubility product is a constant at constant temperature, instead the excess solid will precipitate out of the solution

Ostwald's Dilution Law applies to sparingly soluble salts binary weak electrolytes.

When a sparingly soluble salt is dissolved in water, it partially ionizes so that equilibrium is established between the ions and the undissolved molecules.

For example;

$$AB\ (s) \rightleftharpoons A^{n+}\ (aq) + B^{n-}\ (aq)$$

If α is the degree of ionization of this electrolyte and 'C' is the concentration of the electrolyte in mol dm^{-3}, then, the concentrations at equilibrium becomes;

$$AB\ (s) \rightleftharpoons A^{n+}\ (aq) + B^{n-}\ (aq)$$

$C(1 - \alpha)$ $c\alpha$ $C\alpha$

Applying the equilibrium law to the concentrations at equilibrium,

$$K = \frac{(C.\,C)}{C-C} = \frac{C^2\alpha^2}{C(1-\alpha)} = \frac{C^2}{1-a}$$

For a weak acid, $\alpha$is too small such that 1-α ≈ 1

Therefore, $K = C\alpha^2$

$$\alpha^2 = \frac{K}{C}$$

$$\alpha = \sqrt{\frac{K}{C}}$$

Ostwald's dilution law states that "for a weak binary electrolyte, the degree of ionization is inversely proportional to the square root of the concentration or directly proportional to the reciprocal of the square root of concentration"

Ostwald's dilution law does not apply to strong electrolytes as they are completely ionized.

Under what conditions will ionic product tend to exceed solubility product such that precipitation of salts takes place

i) By evaporation: Evaporation tends to increase the concentration of ions.

ii) By addition of a common ion. This also increases the concentration of ions.

A good example of common ion effect is the salting out of soap.

Here, concentrated solution of sodium chloride (brine) is added to a saturated solution of soap ($C_{17}H_{35}COONa$), and considering soap in solution,

$$C_{17}H_{35}COONa\ (s) \rightleftharpoons C_{17}H_{35}COO^{-}\ (aq) + Na^{+}\ (aq)$$

When sodium chloride is added, the concentration of sodium ions increases and becomes excess. The excess react with the$C_{17}H_{35}COO^{-}$ to precipitate out soap to upper layers ($C_{17}H_{35}COONa$) so as to keep Ksp constant.

Addition of a solution of a soluble salt which does not contain a common ion increases the solubility for example, addition of a solution of silver nitrate to a saturated solution of lead (II) chloride. Silver ions from silver nitrate react with chloride ions from lead (II) chloride at equilibrium to form an insoluble silver chloride. This reaction reduces the concentration of chloride ions in the equilibrium and in order to restore Ksp, more $PbCl_2$ ionizes or dissolves.

This explains why; Barium sulphate dissolves more rapidly in lead (II) nitrate than in water. Lead (II) iodide is more soluble in silver nitrate than in water.

Guidance to Skills Lab 7

This activity checks how student teachers have mastered the unit and if they are able to apply concepts to everyday life situations. It should not be done during study hours. The tutor should explain what must be done and let student teachers work on their own. It is will be done as a project. The main ideas to appear in each point of this skills lab are described below:

1. Kidney stones are formed by sparingly soluble salts of calcium mainly. Drinking a lot of water decreases the concentration of dissolved ions in the urine and then favors the dissolution of more solid kidney stone.
2. Hard water contains ions such as Ca^{2+} and Mg^{2+} which form sparingly soluble salts with soap. The precipitate which forms is the one we call scum. On the other hand, soft water does not contain those cations.

7.8. End unit assessment

Expected answers to end unit assessment

1. c 2.b 3.c 4.c 5.a 6.e
2. The answer is NO. This is because they do not have the similar solubility product expressions.
3. i) $Ksp = [Hg_2^{2+}] [Cl^-]^2$

   ii) $Ksp = [Sr^{2+}]^3 [AsO_4^{3-}]^2$

4. M_3X_4 (s) ⇆ $3 M^{4+}$ (aq) + $4 X^{3-}$ (aq)

s 3s 4s

Where, s is solubility of M_3X_4 (s)mol/dm^3

$Ksp = [M^{4+}]^3 [X^{3-}]^4 = 8.2 \times 10^{-24}$

$(3s)^3 (4s)^4 = 8.2 \times 10^{-24}$

$(27s^3) (256s^4) = 8.2 \times 10^{-24}$

$6912 s^7 = 8.2 \times 10^{-24}$

$S = 1.42 \times 10^{-4}$

5. The common ion effect refers to the shifting of equilibrium system caused by a common ion in the system from a source other than the system itself.

Le chatelier's principle predicts this effect.

Example; if you were to add some Cl^- ions or Ag^+ ion to a saturated solution of AgCl.

$AgCl (s) \rightleftharpoons Ag^+ (aq) + Cl^- (aq)$

Adding a common ion to the system increases the concentration of the Cl^- and silver ions the system will shift to the left to undo this stress.

6. $Ba(IO_3)_2 (s) \rightleftharpoons Ba^{2+} (aq) + 2 IO_3^- (aq)$

s s **2s**

Where; s = mol of $Ba(IO_3)_2$ that dissolved.

$[Ba^{2+}] [IO_3^-]^2 = 1.5 \times 10^{-9}$

$(S)(2S)^2 = 1.5 \times 10^{-9}$

$(S)(4S^2) = 1.5 \times 10^{-9}$

$4S^3 = 1.5 \times 10^{-9}$ $S = 7.2 \times 10^{-4}$ M

Molar solubility = 7.2×10^{-4} mol/dm^3

7. Refer to the answer of question 5 above.

7.9. Additional activities

7.9.1. Remedial activity

Questions

1. The chromate that is the most soluble in water at 25oC on a molar basis is:

(a) Ag_2CrO_4

(b) $BaCrO_4$

(c) $PbCrO_4$

(d) impossible to determine

(e) none of these

2. What is the pH of a saturated solution of $Mg(OH)_2$?

(a) 3.5

(b) 10.1

(c) 10.9

(d) 10.5

(e) 9.2

3. (a) Explain what is meant by common ion effect.

(b)(i) State how the solubility product of a sparingly soluble salt may be determined.

(ii) State how the solubility of a soluble salt can be affected by adding a common ion

(c) State one application of solubility product

4. The solubility of calcium phosphate $Ca_3(PO_4)_2$ is 0.0011g per 100g of water at 250C.

a) Calculate the solubility product of calcium phosphate.(Ca=40, P=31, O=16)

b) What would be the effect of adding a solution of sodium phosphate to a saturated solution of calcium phosphate?

5. a) What is meant by the term acid according to the Bronsted – Lawry theory of acids and bases?

b) Identify two substances acting as acids in the following reaction:

$CH_3NH_2 + H_2O \quad CH_3NH_3^+ + OH^-$

(c) Write an expression for the solubility product (Ksp) of calcium hydroxide.

(d) A 20.0cm^3 sample of saturated, aqueous calcium hydroxide required 18.2 cm^3 of

0.050 mol dm^{-3} hydrochloric acid for neutralization. Calculate:

i) The concentration of OH^- in the saturated solution.

ii) A value for the solubility product of calcium hydroxide, stating the units.

(e) Explain why calcium hydroxide is more soluble in water than in aqueous potassium hydroxide.

Answers

1.a

2.d

3. (a) Common ion effect is the precipitation of a sparingly soluble ionic compound from a saturated solution, by addition of another soluble compound containing a similar ion.

(b)(i) - By titration or volumetric analysis

- By conductivity measurements

- By ion exchange

(ii) Addition of a common ion reduces the solubility of a sparingly soluble salt.

(c) - Purification of common salt or sodium chloride

- Purification or salting out of soap
- Predicting precipitation of salts in qualitative analysis.
- Selective separation of sulphides

4. (a) $Ca_3(PO_4)_2 \rightleftharpoons 3Ca^{2+} + 2PO_4^{3-}$, let the solubility of Ca^{2+} be x:

$$\quad 3x \qquad 2x$$

$Ksp = [Ca^{2+}]^3[PO_4^{3-}]^2$

$= (3x)^3(2x)^2 = 108\ x^5$

Solubility of $Ca_3(PO_4)_2$ in g/l

1 g = 1cm³ = 1 ml

$$1000cm^3 \rightarrow \frac{0.0011x1000}{100} = 0.011g/l$$

$$\text{Solubility of } Ca_3(PO_4)_2 \text{ in moles } dm^{-3} = \frac{concentrationing / l}{Rmming / l}$$

Rmm of $Ca_3(PO_4)_2 = 40 \times 3 + (31+16) \times 2 = 310$

Hence , solubility of $Ca_3(PO_4)_2$ in moles dm^{-3} = = 3.55×10^{-5} mol dm^{-3}

Solubility of Ca^{2+} which is x is 3.55×10^{-5} $moldm^{-3}$

$Ksp = 108\ x^5 = 108\ (3.55 \times 10^{-5})^5 = 6.08 \times 10^{-21}\ mol^{-5}dm^{-15}$

(b) The solubility of $Ca_3(PO_4)_2$ decreases because of common ion effect. Addition of sodium phosphate increases the concentration of phosphate ions in equilibrium. So to restore Ksp, the excess phosphate ions from Na_3PO_4 react with Ca^{2+}.

$3Ca^{2+} + 2PO_4^{3-} \rightarrow Ca_3(PO_4)_2$

This decreases the solubility of calcium phosphate.

5. (a) Acid is proton donor according to Bronsted-Lowry theory of acids and bases.

(b) H_2O and $CH_3NH_3^+$ are acting as acids.

(c) $Ksp = [Ca^{2+}][OH^-]^2$

(d) (i) $Ca(OH)_2\,(aq) + 2HCl(aq) \rightleftharpoons CaCl_2(aq) + 2H_2O(l)$

1000cm^3 contain 0.050 moles of HCl

18.2 cm^3 contain $\frac{0.050x18.2}{1000}$ = 0.00091 moles of HCl

2 moles of HCl → 1 mole of $Ca(OH)_2$

0.00091 moles of HCl → $\frac{1x0.00091}{2}$ of $Ca(OH)_2$ = 0.000455mol of $Ca(OH)_2$

20 cm^3 contain 0.000455 mol of $Ca(OH)_2$

1000cm^3 contain $\frac{0.000455x1000}{20.0}$ = 0.02275 M of $Ca(OH)_2$

But one moe of $Ca(OH)_2$ is produced by 2 moles of OH^-

Thus concentration of OH^- = 2 x 0.02275 moldm^{-3} = 0.0455 moldm^{-3}

ii) $[Ca^{2+}]$ = 0.02moldm^{-3}

$[OH^-]$ = 0.0455 moldm^{-3}

$Ksp = [Ca^{2+}][OH^-]^2$

Ksp = (0.02275 moldm^{-3}) (0.0455moldm^{-3}) = 4.7 x 10^{-5} mol^{3}dm^{-9}

(e) Calcium hydroxide is less soluble in aqueous potassium hydroxide due to the common ion effect of OH^- which reduces the solubility of calcium hydroxide.

7.9.2. Consolidation activities

Section A

1. The solubility of silver sulfate in water at 100°C is approximately 1.4 g per 100 mL. What is the solubility product of this salt at 100°C?

(a) 5.7 x 10^{-8}

(b) 3.5 x 10^{-7}

(c) 8.3 x 10^{-6}

(d) 4.1 x 10^{-5}

(e) 3.6 x 10^{-4}

2. What is the molar solubility, s, of $Ba_3(PO_4)_2$ in terms of K_{sp}?

   (a) $s = K_{sp}{}^{1/2}$

   (b) $s = K_{sp}{}^{1/5}$

   (c) $s = [K_{sp}/27]^{1/5}$

   (d) $s = [K_{sp}/108]^{1/5}$

   (e) $s = [K_{sp}/4]^{5}$

3. For $Cu(OH)_2$, $K_{sp} = 1.6 \times 10^{-19}$. What is the molar solubility of $Cu(OH)_2$?

   (a) 3.4×10^{-7} M

   (b) 6.4×10^{-7} M

   (c) 2.7×10^{-11} M

   (d) 5.1×10^{-10} M

   (e) 1.7×10^{-10} M

4. The molar solubility of $PbCl_2$ in 0.20 M $Pb(NO_3)_2$ solution is:

   (a) 1.7×10^{-4} M

   (b) 9.2×10^{-3} M

   (c) 1.7×10^{-5} M

   (d) 4.6×10^{-3} M

   (e) 8.5×10^{-5} M

Section A

1.e 2.d 3.a 4.d

Section B

1. Explain the following observations:

(a) When solution of sodium sulphate is added to a saturated solution of lead (II) sulphate, a precipitate of lead (II) sulphate was formed.

(b) Iodine is much more soluble in potassium iodide than in water.

2. Barium sulphate is sparingly soluble in water.

(a) (i) Write an equation for the solubility of barium sulphate in water.

(ii) Write the expression for the solubility product of barium sulphate.

(b) A saturated solution of barium sulphate contains 1.1×10^{-5} moles per litre of the salt. Calculate the solubility product of barium sulphate.

Answers

1. (a) Addition of sodium sulphate increases the concentration of sulphate ions in solution. Therefore, the excess sulphate ions combine with lead ions to form insoluble lead (II) sulphate which precipitates.

(b)The molecules of iodine are non-polar whereas those of water are polar. Therefore, since the two interactions are completely different, iodine will be insoluble in water.

However, iodine is more soluble in potassium iodide due to formation of a soluble complex, potassium triiodide.

$$KI\ (aq) + I_2\ (s) \rightleftharpoons KI_3\ (aq)$$

Formation of this soluble complex offsets the equilibrium and this causes iodine to dissolve so as to re-establish the position of the equilibrium.

2. (a)(i) $BaSO_4\ (s) + aq \rightleftharpoons Ba^{2+}\ (aq) + SO_4^{2-}\ (aq)$

(ii) $Ksp = [Ba^{2+}]\ [SO_4^{2-}]$

(b) Solubility, $S = 1.1 \times 10^{-5}$ mol dm^{-3}

$Ksp = [Ba^{2+}]\ [SO_4^{2-}]$

$Ksp = (1.1 \times 10^{-5})\ (1.1 \times 10^{-5})$

$Ksp = 1.21 \times 10^{-10} mol^2\ dm^{-6}$

7.9.3. Extended activities

Section A

1. Which solid will precipitate first if an aqueous solution of Na_2CrO_4 at 25°C is slowly added to an aqueous solution containing 0.001 M $Pb(NO_3)_2$ and 0.100 M $Ba(NO_3)_2$ at 25°C?

   (a) $BaCrO_4(s)$

   (b) $NaNO_3(s)$

   (c) $PbCrO_4(s)$

   (d) $Pb(NO_3)_2(s)$

   (e) none of these

2. At what pH will $Cu(OH)_2$ start to precipitate from a solution with $[Cu^{2+}] = 0.0015$ M?

   (a) 9.0

   (b) 8.0

(c) 6.0

(d) 9.4

(e) 4.6

3. When equal volumes of the solutions indicated are mixed, precipitation should occur only for:

   (a) 2×10^{-3} M Mg^{2+} + 2×10^{-3} M OH^-

   (b) 2×10^{-1} M Ba^{2+} + 2×10^{-3} M F^-

   (c) 2×10^{-3} M Ca^{2+} + 2×10^{-2} M OH^-

   (d) 2×10^{-3} M Ca^{2+} + 2×10^{-3} M OH^-

   (e) 2×10^{-4} M Pb^{2+} + 2×10^{-5} M SO_4^{2-}

4. A swimming pool was sufficiently alkaline so that CO_2 absorbed from the air produced in the pool a solution which was 2×10^{-4} M in CO_3^{2-} M. If the pool water was originally 4×10^{-3} M in Mg^{2+}, 6×10^{-4} M in Ca^{2+} and 8×10^{-7} M in Fe^{2+}, then a precipitate should form of:

   (a) only $MgCO_3$

   (b) only $CaCO_3$

   (c) only $FeCO_3$

   (d) only $CaCO_3$ and $FeCO_3$

   (e) $MgCO_3$, $CaCO_3$ and $FeCO_3$

Section B

1. (a) (i) Describe an experiment which can be carried out to determine the solubility product of calcium iodate, $Ca(IO_3)_2$.

   (ii) The solubility product of calcium iodate is 1.69×10^{-9} mol/l at 25 ^{0}C. Calculate the concentration of iodide ions in a solution of calcium iodate at 25 ^{0}C.

   (iii) State three factors that can affect the solubility product.

   (b) Triphosphate ions form a soluble complex with calcium ions. State what would happen when triphosphate ions are added to a saturated solution of calcium iodate and give a reason for your answer.

2. The solubility product Ksp, of zinc hydroxide is 4.5×10^{-17} at 25 ^{0}C

   (a) Write an expression for the solubility product of zinc hydroxide.

   (b) Determine the concentration in moles per litre of zinc and hydroxide ions in a Saturated solution of zinc hydroxide at 25 ^{0}C.

(c) State how the solubility of zinc hydroxide would change if its saturated solution is treated separately with:

(i) Aqueous zinc sulphate

(ii) Ammonia

(d) Briefly explain your answers in (c).

Answers

Section A

1.c 2.c 3.a 4.d

Section B

1. (a) (i) **Determination of solubility product of calcium iodate in water**

- A known volume of distilled water is placed in a bottle and a large excess of calcium iodate is added.
- The bottle is then stoppered and left to stand for several hours, while shaking occasionally so as to attain equilibrium.
- After equilibrium has been attained, aliquots (known volume) of the clear saturated solution are pipetted into a conical flask containing potassium iodide with sulphuric acid.

$$IO_3^- (aq) + 5I^- (aq) + 6H^+ (aq) \longrightarrow 3I_2 (aq) + 3H_2O (l)$$

- The iodine liberated is then titrated with a standard thiosulphate solution using starch indicator.

$$2S_2O_3^{2-} (aq) + I_2 (aq) \longrightarrow S_4O_6^{2-} (aq) + 2I^- (aq)$$

- Titrate until when the solution turns blue (end point)
- Repeat the titration and note the average volume of the thiosulphate solution used.
- The concentration of the iodate ions is calculated from the average volume of the thiosulphate using the equations above.
- Since 1 mole of calcium iodate dissociates to give 1 mole of calcium ions for every 2 moles of iodate ions, then $[Ca^{2+}]$ = half of $[IO_3^-]$,
- $Ksp = [Ca^{2+}] [IO_3^-]^2$

(ii) The solubility, s of a sparingly soluble salt, $Ca(IO_3)_2$ is related to its ionic concentration.

$$Ca(IO_3)_2(s) + aq. \rightleftharpoons Ca^{2+}(aq) + 2IO_3^-(aq)$$

If the solubility or concentration of salt is s and Ksp is 1.69×10^{-9} mol/l

$$Ksp = [Ca^{2+}] [IO_3^-]^2$$

$$1.69 \times 10^{-9} = s . (2s)^2$$

$1.69 \times 10^{-9} = 4s^3$

$$S = \sqrt[3]{\frac{1.69 \times 10^{-9}}{4}}$$

$S = 7.504 \times 10^{-4}$ mol/l

(iii) - Change in temperature

- Addition of a common ion salt
- Complex ion formation

(b) Solubility of calcium iodate increases

Reason:

Formation of a complex reduces the concentration of calcium ions in the solution, and this disturbs the equilibrium so that more calcium iodate dissolves to maintain the equilibrium constant.

Or Formation of a complex reduces the concentration of calcium ions to such a low level, that the solubility product of calcium iodate is no longer exceeded, hence a solution results.

2. (a) $K_{sp} = [Zn^{2+}][OH^-]^2$

(b) Let the concentration in mol/l of Zn^{2+} be X and that of OH^- be 2X

$K_{sp} = [Zn^{2+}][OH^-]^2$

$4.5 \times 10^{-17} = X.(2X)^2$

$4.5 \times 10^{-17} = 4X^3$

$$X = \sqrt[3]{\frac{4.5 \times 10^{-17}}{4}}$$

$X = 2.24 \times 10^{-6}$

$[Zn^{2+}] = 2.24 \times 10^{-6}$ mol/l

$[OH^-] = 2(2.24 \times 10^{-6}) = 4.8 \times 10^{-6}$ mol/l

(c) (i) Solubility of zinc hydroxide decreases.

(ii) Solubility of zinc hydroxide increases.

(d) Addition of zinc sulphate increases the concentration of the zinc ions in solution.

This consequently causes zinc hydroxide to precipitate due to common ion effect hence decreasing the solubility.

Addition of ammonia causes formation of a complex with zinc ions. This decreases the concentration of zinc ions in the solution, so that more zinc hydroxide dissolves to restore the equilibrium.

UNIT 8: REDUCTION AND OXIDATION REACTIONS

8.1 Key unit competence:

Explain the concept of reduction and oxidation and balance equations for redox reactions

8.2. Prerequisite (knowledge, skills, attitudes and values)

Student teachers will learn better reduction and oxidation reactions if they have understanding on: The types of reactions, Electrolysis and applications. The tutor will help student teachers to recap the concepts above.

8.3. Cross-cutting issues to be addressed:

a) Inclusive education:

This unit involves a number of formulae of substances, the writing of formulae and chemical reactions. This may be challenging to student teachers with special educational needs especially student teachers with visual impairment or visual difficulties.

However, the teacher can make some arrangements like the following:

- Grouping student teachers
- Student teachers with special educational needs are grouped with others and assigned roles basing on individual student teacher's abilities.
- If a teacher has student teachers with visual difficulties, when writing on the blackboard, write in large, clear writing, especially when it comes to formulae and chemical reactions. Read out what you are writing, for the benefit of those who are not able to see the blackboard clearly.
- If student teachers are sharing textbooks, try to arrange for those with visual difficulties to have their own copies, as far as this is possible.
- Give extra time for them to write summary notes or write down observations after experiments.
- Every important point is written and spoken.
- Remember to repeat the main points of the lessons.
- For student teachers with **hearing difficulties**, the teacher has to encourage them to sit closer to the front of the classroom. Stop every so often while teaching to ask student teachers whether they have understood, or if they need you to repeat a point. Encourage student teachers not to be afraid to ask questions.
- When teaching, speak clearly and ensure that all the student teachers can hear your voice. Avoid speaking hurriedly as this will make it difficult for student teachers with hearing difficulties to make sense of what you are saying.

Student teachers with mobility difficulties:

- These include student teachers in crutches, wheelchairs, or with walking difficulties.
- Encourage other student teachers to look out for and help their classmates. Ask their follow student teachers to help them with their notes, if their conditions hinder them from writing well.

Student teachers with reading difficulties:

- Student teachers with this kind of difficulties struggle to make sense of words or understand written work and take longer to read than other student teachers.
- Encourage them to pay careful attention during class time and participate for example by asking questions, answering questions, so that they can make the most of what they hear and observe. Instead of repeating word for word what is in the textbook, simplify the concepts to ease their understanding, so that when they have already understood.

b) Gender

During group activities try to form heterogeneous groups (with boys and girls) or when student teachers start to present their findings encourage both (boys and girls) to present.

c) Financial education

Electrochemical processes affect largely the economy of many nations as well electrolysis and electrochemical cells find many application in the daily life.

In addition, the problem of corrosion is one of the main causes of financial loss of money. Therefore the student teachers should be aware of this issue.

d) Peace and values education

During group activities, the teacher will encourage student teachers to help each other's and to respect opinions of colleagues.

e) Environment and sustainability

The attention of the student teachers is drawn on the necessity of to not throw chemicals anywhere but rather to put them in appropriate containers.

8.4. Guidance on introductory activity

Before introducing the first lesson (definition of electrochemistry and its relationship with redox reactions) of this unit, let student teachers attempt the introductory activity.

- For this activity, the teacher forms groups of five student teachers that are as heterogeneous as possible.

- The teacher makes sure that each student from each group performs an activity.
- The teacher provides a clear sheet for reporting. On this, there is among others the title of experiment, the observations and deductions.
- The teacher asks randomly representative of two or three groups to present their findings.
- After presentation, the teacher decides to engage the class into exploitation of the student teachers' findings.
- After presentation the teacher asks the student teachers to judge findings from different groups and harmonise their work.
- The teacher summarises their findings and introduce the new unit.

Answers to introductory activity

1. Title: Corrosion of iron
2. $2Fe + 2O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4OH^-$
3. Presence of oxygen from air and water/moisture
4. The corrosion process is not reversible. Once iron is damaged by the corrosion process, it cannot be turned back to the original
5. There are several methods for protecting metals from corrosion (iron from rusting). Some of these methods are being discussed as follows:

a) **Barrier Protection**. In this method, a barrier film is introduced between iron and atmospheric oxygen and moisture. Barrier protection can be achieved by any of and following methods:

i) Painting the surface;

ii) Coating the surface with a thin film of oil or grease;

iii) Electroplating iron with some non-corrosive metal such as nickel, chromium, copper, etc;

iv) Lamination with plastics

All these methods do not involve any oxidation or reduction. Hence, these are called non-redox methods. However, in this type of protection, if scratches or cracks appear in the protective layer then surface of iron may get exposed. In this region, moisture and oxygen may come into contact with iron and rusting starts. This rusting extends beneath the protective layer and eventually peels off the protective layer.

b) **Sacrificial Protection**. In this method, surface of iron is covered with a layer of more active metal like zinc. This active metal loses electrons in preference to iron and hence, prevents the rusting of iron. However, the covering metal gets consumed in due course of time, but so long as it is present, even the nearly uncovered surfaces of iron do not get rusted. In this way, scratches in the protective layer of this type are not harmful. This type of protection is called sacrificial protection.

Zinc metal is generally used for protecting iron and the process is called galvanization. Galvanized iron sheets maintain their shine due to the formation of a thin protective layer of basic zinc carbonate, $ZnCO_3.Zn(OH)_2$ due to the reaction between zinc, oxygen, $C0_2$ and moisture in air. .

Zinc, magnesium and aluminium powders dissolved in paints can also be applied as protective layers. The well known aluminium paint contains aluminium powder suspended in varnish.

c) **Electrical Protection**. This is also a case of sacrificial protection. In this method, the exposed surface of iron is protected by connecting it to some more active metal such as magnesium. The other metals which can be used for this purpose are aluminium, zinc, etc. The more active metal acts as anode and loses electrons in preference to iron. The iron surface, acts as cathode. This method, therefore, is also called cathodic protection of iron.

8.5. List of lessons/sub-heading

#	Lesson title	Learning objectives	Periods
Lesson 1	• Definition of electrochemistry and its relationship with redox reactions • Definition of electrochemistry • Definition of reduction and oxidation reaction • Relationship between electrochemistry and redox reactions	Explain the redox reactions in terms of electron transfer and changes in oxidation state (number).	2
Lesson 2	• Determination of the oxidation numbers of elements in the compounds. • Rules used to determine oxidation number of elements.	Work out the oxidation numbers of elements in the compounds	2

Lesson 3	• Reduction half reaction and oxidation half reaction • Disproportionation reactions	Explain the concept of disproportionation	2
Lesson 4	• Oxidising and reducing agents.	Differentiate the reducing agent from the oxidising agent in a redox reaction	2
Lesson 5	• Balancing oxidation reduction reactions • in acidic medium • in basic medium	Apply half-reaction method to balance redox reactions Deduce balanced equations for redox reactions from relevant half equations	2 2
Lesson 6	• Reactivity series of metals	Perform simple displacement reactions to order elements in terms of oxidising or reducing ability	2
	End unit assessment		1

Lesson 1: Definition of electrochemistry and its relationship with redox reactions (2 periods)

a) Learning objectives

Explain the redox eactions in terms of electron transfer and changes in oxidation state

b) Prerequisites/ Revision/ Introduction

Student teachers will learn better the relationship between electrochemistry and redox reactions if they have good understanding on types of reactions (Senior 2), electrolysis and its application (Senior 3)

c) Teaching resources

- Chalkboard/ smart board Chalks, manila paper and flip charts
- Charts illustrating some reduction and oxidation reactions

d) Learning activities

Guidance

Before introducing the lesson, the tutor has to introduce the whole unit. Let then student teachers attempt activity 8.1 which leads student teachers to the first lesson of the unit.

As a facilitator, the tutor is expected to guide student teachers through the following steps:

- Ask student teachers carefully to attempt the questions.
- Each student records his or her answers.
- Ask 2 or 3 groups to share their findings to the whole class.
- Allow the rest of the class evaluate the findings of the presenters.
- Based on the student-teachers' finding write a summary about solutions and standard solutions.

Answers to activity 8.1

1. **Chemistry**, study of the structure, the composition and properties of the matter.

   Electricity, flow of electrons over a wire due to the presence and flow of electric charge.

   Electrochemistry, party of chemistry that deal with of the interchange between electrical and chemical energies

Types of reactions

Chemical reactions are classified as: addition/synthesis, decomposition, displacement, double displacement reactions, etc.

2. **a) Oxidation reaction:** process in which a chemical species gains oxygen atoms or loss hydrogen atoms. In terms of transfer of electrons, oxidation may be defined as reaction in which a chemical species donates electrons to another one.

   In terms of oxidation number, oxidation is process in which the oxidation of element of a substance is increased.

   b) Reduction reaction: process in which a chemical species gains hydrogen atoms or loss oxygen atoms.

   In terms of transfer of electrons, reduction may be defined as reaction in which a chemical species gains electrons to another one.

   In terms of oxidation number, oxidation is process in which the oxidation of element of a substance decreases.

Application activities

Expected answers to application activity 8.1

i) $H_2O(l) \rightarrow H_2(g) + O_2(g)$, hydrogen is reduced and oxygen is oxidised.

ii) $N_2(g) + H_2(g) \rightarrow NH_3(g)$, hydrogen is oxidised and nitrogen is reduced.

iii) $H_2C{=}CH_2(g) + H_2(g) \rightarrow CH_3CH_3(g)$, hydrogen is oxidised and ethene is reduced.

iv) $K(s) + ½ Br_2 \rightarrow KBr(s)$, Potassium is oxidised and bromine is reduced.

v) $Fe(s) + S(s) \rightarrow FeS(s)$, iron is oxidised and sulphur is reduced.

vi) $KBr(l) \rightarrow K(s) + ½ Br_2(g)$, potassium is reduced and bromine is oxidised.

Lesson 2: Oxidation numbers of elements in the compounds (2 periods)

a) Learning objective:

- Work out the oxidation numbers of elements in the compounds

b) Prerequisites/ Revision/ Introduction

Student teachers will learn concept of oxidation number if they have good understanding on electrolysis and its applications (Senior 3)

c) Teaching resources

Chalkboard/ smart board, chalks/flipcharts, markers

d) Learning activities

Guidance

Learning activity 8.2 is suggested in student teacher's book. However the tutor is free to add more.

- Form groups of 4 student teachers. The number of groups and members will depend on your class size.
- In the groups student teachers attempt activity 8.2, discuss and record their answers.
- Each group representative presents their answers to the whole class.
- Allow the other student teachers to evaluate the ideas of the presenters.
- Make a summary of the lesson (short notes) and assess your lesson. Let student teachers do checking up 8.2 Let student teachers do the application activity 8.2.

Answers to activity 8.2

1. A redox reaction is recognized by the change in oxidation number of some elements.

2. a) Valence: number of electrons that an atom can involve in a chemical bond.

   b) Electronegativity is the ability of an atom to attract electrons to itself. In redox reactions are transferred or assumed to be are transferred to the more electronegative atom..

3. See student book

Application activity 8.2

Answers application activity 8. 2

1) a) +1, -1, +1, -1

   b) +6, +6, +4, +2, +6, +10/2

   c) +2, +4, -1, -1/3, +1, +3

   d) + 4, +2, +8/3

   e) +2, +3, +3

   f) -1, +1, +5, +1

   g) +4, +4, +4, + 14/4

2) a) Na_3N

   b)HNO_3

3) $K_2\underline{Cr}_2O_7$ (+6), $Na_2\underline{C}_2O_4$(+3), $\underline{K}MnO_4$ (+7) , $\underline{Mn}SO_4$ (+2), $\underline{C}O_2$(+4), $\underline{Cr}Cl_3$(+3),
   $H\underline{N}O_3$(+5), $\underline{S}O_3$(+6)

Lesson 3: Oxidation – reduction half-equations and concept of disproportionation reaction (2 periods)

a) Learnig objective

Explain the concept of disproportionation

b) Prerequisites/ Revision/ Introduction

The student teachers will learn better the concepts of oxidation – reduction half-equations and concept of disproportionation reaction if they have a good understanding of electrolysis (Senior3) redox reactions Chemistry TTC Year II, Unit 8, Lesson1)

c) Teaching resources

Chalkboard/ smart board, chalks/flipcharts, markers

Copper sulphate solution, zinc metal, beakers,

d) Learning activities

Guidance

- The tutor form groups of 4 student teachers. The number of groups and members will depend on your class size.
- Avail the required materials and chemicals before the day before.
- In the groups student teachers attempt activity 8.3, discuss and record their answers.
- Each group record their findings.
- The tutor asks randomly two groups to present their findings.
- Allow the other student teachers to evaluate the ideas of the presenters.
- Make a summary of the lesson (short notes) and assess your lesson. Let student teachers do checking up 8.3
- Let student teachers do the application activity 8.3.

Answers to activity 8.3

1) Ionic bonding

b) Ionisation of sodium

Formation of chloride ion

c) $K(g) \rightarrow K^+(g) + e^-$ **Oxidation**

$F(g) + e^- \rightarrow F^-(g)$ **Reduction**

2) $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ **Reduction**

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ **Oxidation**

$Cu^{2+}(aq) + Zn(s) \rightarrow Cu(s) + Zn^{2+}(aq)$ **Overall**

Answers to application activities 8.3

a) $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$ **Oxidation**

b) $Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$ **Reduction**

a) $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ **Oxidation**

b) $2NO_3^-(aq) + 2e^- \rightarrow 2NO_2(aq)$ **Reduction**

a) $Cu(s) \rightarrow Cu^{2+}(aq) + 2e^-$ **Oxidation**

b) $2Ag^+(aq) + 2e^- \rightarrow 2Ag(s)$ **Reduction**

$2S_2O_3^{2-}(aq) \rightarrow S_4O_6^{2-}(aq) + 2e^-$ **Oxidation**

$I_2(aq) + 2e^- \rightarrow 2I^-(aq)$ **Reduction**

Lesson 4: Oxidizing and reducing agents (2 periods)

a) Learning objective

Differentiate the reducing agent from the oxidising agent in a redox reaction

b) Prerequisites/ Revision/ Introduction

The student teachers will learn better the concepts of oxidation – reduction half-equations and concept of disproportionation reaction if they have a good understanding of electrolysis(Senior 3) redox reactions Chemistry TTC Year II, Unit 8, Lesson1)

c) Teaching resources

Chalkboard / smart board, chalks, flip chart, periodic tables of elements

d) Learning activities

Guidance

- Before introducing the lesson, let student teachers therefore attempt activity 8.4 which leads student teachers to the fourth lesson of the unit
- As facilitator you are expected to guide student teachers through the following steps:
- form groups of four and let the student teachers perform the activity 8.4
- Let some groups present their work to the class and allow the rest of the class to evaluate the work of their colleagues
- Comment on student teachers' responses written in their note books, and give them the summary of expected feedback based on their findings.

Answers to activity 8.4

1. Reactions that is expected to occur are a) and b)
2. a) $2Cu^{2+}{}_{(aq)} + I^{-}{}_{(aq)} \rightarrow 2CuI(s) + I_{2(aq)}$

   b) (+2) (-1) (+1) (0)
3. Cu^{2+} is reduced

   I^{-} is oxidised

Application activities

For each of the following reactions, identify which species has been oxidized and which has been reduced.

$2I^{-} + Br_2 \rightarrow I_2 + 2Br^{-}$ **I^{-}, reducing agent, Br_2, oxidising agent**

$2HI + H_2SO_4 \rightarrow H_2S + 4H_2O + I_2$ **I-, reducing agent, $SO_4{}^{2-}$, oxidising agent**

$SO_2 + 2H_2O + 2Cu^{2+} + 2Cl^- \rightarrow H_2SO_4 + 2H^+ + 2CuCl$ **SO_2, reducing agent,Cu^{2+}, oxidising agent**

$Cr_2O_7^{2-} + 8H^+ + 3SO_3^{2-} \rightarrow 2Cr^{3+} + 4H_2O + 3SO_4^{2-}$ **SO_3^{2-}, reducing agent, $Cr_2O_7^{2-}$, oxidising agent**

$5Fe^{2+} + MnO_4^- + 8H^+ \rightarrow 5Fe^{3+} + Mn^{2+} + 4H_2O$ **Fe^{2+}, reducing agent, MnO_4^-, oxidising agent**

In the following reactions, indicate whether the underlined species is acting as an oxidising agent or a reducing agent.

$\underline{\mathbf{Fe_2O_3}} + 3CO \rightarrow 2Fe + 3CO_2$, **oxidising agent**

$2\underline{\mathbf{Ca}} + O_2 \rightarrow 2CaO$ **Reducing agent**

$Zn + \underline{\mathbf{Fe^{2+}}} \rightarrow Zn^{2+} + Fe$ **oxidising agent**

Lesson 5.1: Balancing of equations of redox reactions in acidic medium (2 periods)

a) Learning objectives

Apply half-reaction method to balance redox reactions

b) Prerequisites/ Revision/ Introduction

The student teachers will learn better this unit on the balancing of chemical equations (Senior 1), half-equations of reduction and oxidation reactions (Chemistry SME Year, unit 8)

c) Teaching resources

Materials and chemical required for activity 8.5

Guidance

- Before the practical
- Try to copy this activity on a worksheet and make copies equal to the number of groups that you will form according to your class size.
- Try to make the required materials available before your student teachers enter (go) in the laboratory.
- Prepare all chemicals needed to perform this practical activity.
- Make sure you understand well the content (theory) about the practical to be performed so as to help student teachers link it with their observations

During practicals

- Form groups of 2-4.
- Give them worksheet and ask them to read instructions.

- Ask them to read the procedure written on the worksheet and verify if all chemicals and apparatus are available and well prepared.
- Provide each group with a reporting sheet.
- Let student teachers perform the experiment as described in the procedure.
- Move around to ensure that all student teachers are actively engaged.
- Every group records their observations and make an interpretation.
- Call upon randomly four groups to share their results
- Let the class evaluate the findings of their colleagues and point out the key ideas about the balancing of redox reactions.
- Write a short summary about the balancing of redox reactions.

Answers to activity 8.5.

1. a) Iron atoms react with dilute sulphuric acid to form iron(II) sulphate and hydrogen

   Gas: $Fe_{(s)} + H_2SO_{4(aq)} \rightarrow FeSO_{4(aq)} + H_{2(g)}$

2. a) Iron atoms are oxidized to form iron(II) ions

   $Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^-$

   b) Hydrogen ions in the acid are reduced and form hydrogen gas

   $2H^+_{(aq)} + 2e^- \rightarrow H_2$

   c) Redox reaction:

   $Fe_{(s)} + 2H^+_{(aq)} \rightarrow H_{2(g)} + Fe^{2+}_{(aq)}$ or

   $Fe_{(s)} + 2H_3O^+_{(aq)} \rightarrow H_{2(g)} + 2H_2O_{(l)} + Fe^{2+}_{(aq)}$

3. Sodium hydroxide solution or ammonia solution are added to the salt solution so that insoluble hydroxides of $Fe(OH)_2$ and $Fe(OH)_3$ form. Iron(II) hydroxide appears s green precipitate which turns brown at the top.

   $Fe^{2+}_{(aq)} + 2OH^-_{(aq)} \rightarrow Fe(OH)_{2(s)}$

   (green solid)

   Iron(III) hydroxide appears as a reddish brown solid

   $Fe^{2+}_{(aq)} + 3OH^-_{(aq)} \rightarrow Fe(OH)_{3(s)}$

4. It will oxidise iron(II) ions to iron(III) ions.

Application activity

Answers to application activity 8.5.a)

1. $Cr_2O_7^{2-} + I^- \rightarrow Cr^{3+} + IO_3^-$ (acidic solution)

$\mathbf{Cr_2O_7^{2-} + 8H^+ + I^- \rightarrow 2Cr^{3+} + 4H_2O + IO_3^-}$

2. $MnO_4^- + CH_3OH \rightarrow Mn^{2+} + HCO_2H$ (acidic solution)

   $12H^+ + 4MnO_4^- + 5CH_3OH \rightarrow 4Mn^{2+} + 11H_2O + 5HCO_2H$

3. $As + ClO_3^- \rightarrow H_3AsO_3 + HClO$ (acidic solution)

   $6H_2O + 4As + 3H^+ + 3ClO_3^- \rightarrow 4H_3AsO_3 + 3HCl$

   $2ClO_2 + H_2O_2 + 2OH^- \rightarrow 2ClO_2^- + O_2 + 2H_2O$

Lesson 5.2: Balancing of equations of redox reactions in basic medium (2periods)

a) Learning objective

Deduce balanced equations for redox reactions from relevant half equations

b) Prerequisites/ Revision/ Introduction

The student teachers will learn better this unit on the balancing of chemical equations (Senior 1), half-equations of reduction and oxidation reactions (Chemistry SME Year, unit 8)

c) Teaching resources

Smart board, chalk board/flip charts, chalks, markers

d) Learning activities

- **Guidance**

- Learning activity 8.5.b) is suggested in student teacher's book. However the tutor is free to add more.
- Form groups of 3-4 student teachers. The number of groups and members will depend on your class size.
- In the groups student teachers attempt activity 8.5.b), discuss and record their answers.
- Ask randomly 4 groups to present their findings.
- Allow the other student teachers to evaluate the ideas of the presenters.
- Make a summary of the lesson (short notes) and assess your lesson. Let student teachers do checking up 8.2 Let student teachers do the application activity 8.5.b)

Answers to activity 8.5.b)

See student teacher's book

Answers to Application activities 8.5.b)

$CN^- + MnO_4^- \rightarrow CNO^- + MnO_2$

$\mathbf{3CN^- + H_2O + 2MnO_4^- \rightarrow 3CNO^- + 2MnO_2 + 2OH^-}$

$H_2O_2 + ClO_2 \rightarrow ClO_2^- + O_2$

$H_2O_2 + 2ClO_2 + 2OH^- \rightarrow 2ClO_2^- + O_2 + 2H_2O$

Lesson 6: Reactivity series of metals (1 period)

a) Learning objective

Perform simple displacement reactions to order elements in terms of oxidising or reducing ability

b) Prerequisites/ Revision/ Introduction

The student teachers will learn better this unit on the balancing of chemical equations (Senior 1), half-equations of reduction and oxidation reactions (Chemistry SME Year ,unit 8)

c) Teaching resources

Materials and chemical required for activity 8.6

d) Learning activities

- **Guidance**

Before the practical

- Try to copy this activity on a worksheet and make copies equal to the number of groups that you will form according to your class size.
- Try to make the required materials available before your student teachers enter (go) in the laboratory.
- Prepare all chemicals needed to perform this practical activity.
- Make sure you understand well the content (theory) about the practical to be performed so as to help student teachers link it with their observations

During practicals

- Form groups of 2-4.
- Give them worksheet and ask them to read instructions.
- Ask them to read the procedure written on the worksheet and verify if all chemicals and apparatus are available and well prepared.
- Provide each group with a reporting sheet.
- Let student teachers perform the experiment as described in the procedure.
- Move around to ensure that all student teachers are actively engaged.
- Every group records their observations and make an interpretation.
- Call upon randomly four groups to share their results
- Let the class evaluate the findings of their colleagues and point out the key ideas about the balancing of redox reactions.

- Write a short summary about the balancing of redox reactions.

Answers to activity 8.6

1) to 4) after doing experiment

5) Except copper, others react

6) Copper as it is a durable, non reactive metal to water and acids, good conductor of heat – suitable to make saucepans. The others are too reactive especially sodium and magnesium. Sodium will react in air or with water. Magnesium will react with acid.

7) Since Magnesium is a more reactive metal than copper, it will displace the copper in the copper sulphate, forming magnesium sulphate the copper metal. Magnesium + Copper Sulphate →Magnesium Sulphate + Copper

$Mg(s) + CuSO_4(aq)\ MgSO_4(aq) + Cu(s)$

Application activity

Answers to application activity 8.6

1. Complete the following word equations for each reaction.
   a) zinc + lead nitrate solution → **zinc nitrate + lead**
   b) iron + zinc sulphate solution →**no reaction**
   As iron is lower than zinc in the metal reactivity series; therefore, it can't displace zinc that is stronger reducing agent from zinc sulphate.
   c) lead + copper nitrate solution →**lead nitrate + copper**
   d) magnesium + zinc chloride solution →**magnesium chloride + zinc**
   e) copper + sodium chloride solution →**no reaction**
   f) zinc + iron sulphate solution →**zinc sulphate + iron**
   g) gold + silver nitrate solution →**no reaction**
   h) calcium + magnesium nitrate solution →**calcium nitrate + magnesium**
2. Least reactive X, then Y and Z (Most reactive)
3. a)Yes b)No c)Yes d) Yes
4. a) (i) magnesium is put into silver nitrate solution. Magnesium will react with the silver nitrate

   solution. The corresponding chemical equation is as follow:

   $Mg(s) + 2AgNO_3(aq) \rightarrow Mg(NO_3)(aq) + 2Ag(s)$

   (ii) No reaction, because copper is a stronger reducing agent than silver.

   b) $Ca(s) + Pb^{2+}(aq) \rightarrow Ca^{2+}(aq) + Pb(s)$

5. Based on the activity series, what is the outcome (if any) of each of the following reactions?
   a) $Mn(s) + NiCl_2(aq) \rightarrow Ni(s) + MnCl_2(aq)$
   b) $Cu(s) + Cr(CH_3COO)_3(aq) \rightarrow$ no reaction
   c) $Cr(s) + NiSO_4(aq) \rightarrow Ni(s) + CrSO_4(aq)$
   d) $Pt(s) + HBr(aq) \rightarrow$ No reaction
   e) $H_2(g) + CuCl_2(aq) \rightarrow Cu(s) + 2HCl(aq)$

8.6 Summary of the Unit

Electrochemistry is the study of the relationship between electoral energy and chemical reactions. The oxidation–reduction reaction that occurs during an electrochemical process consists of two half-reactions, one representing the oxidation process and one the reduction process. The sum of the half-reactions gives the overall chemical reaction.

Oxidation–reduction reactions, or **redox reactions**, are processes in which one or more electrons are transferred between reaction partners.

An **oxidation** is the loss of one or more electrons; a **reduction** is the gain of one or more electrons.

The overall redox reaction is balanced when the number of electrons lost by the reducing agent equals the number of electrons gained by the reducing agent. An electric current is produced from the flow of electrons from the reducing agent to the oxidising agent.

Redox reactions can be identified by assigning to each atom in a substance an **oxidation number**, which provides a measure of whether the atom is neutral, electron rich, or electron-deficient. Comparing the oxidation numbers of an atom before and after reaction shows whether the atom has gained or lost electrons.

Oxidations and reductions must occur together. A chemical species that loses one or more electrons is oxidized whereas a chemical species that gains electron(s) is reduced.

The substance that causes a reduction by giving up electrons is called a **reducing agent**. The substance that causes an oxidation by accepting electrons is called an **oxidizing agent**.

A list of metals arranged in order of decreasing ease of oxidation is called *activity series*. The activity series can be used to predict the products of reactions between metals and either metal salts or acids.

Redox reactions can be balanced using the **half-reaction method**, which divides a reaction into oxidation and reduction parts and focuses on equalizing the transfer of electrons between the parts.

8.7. Additional information for teachers

Balancing equations of redox reactions using oxidation number change method

Equations of redox reactions may also be balanced using the oxidation number change method. The following steps are followed.

1. Determine the oxidation numbers of the species being oxidized and reduced (and make sure there is the same number of atoms on each side).
2. Balance the changes in oxidation numbers by multiplying by the appropriate coefficient.
3. Balance charges with: a. H^+ in acidic solution. b. OH^- in basic solution.
4. Balance H (and O!) with H_2O.

Example 1:

Given the skeletal equation $H_3PO_2 + Cr_2O_7^{2-} \rightarrow H_3PO_4 + Cr^{3+}$ (in acidic medium),

Step 1: Phosphorus is being oxidized (from +1 to +5) and chromium is being reduced (from +6 to +3). Therefore, put a 2 in front of the Cr^{3+} to have the same number of chromium atoms on both sides of the equation:

$$\overset{+1}{H_3PO_2} + \overset{+6}{Cr_2O_7} \rightarrow \overset{+5}{H_3PO_4} + \overset{+3}{Cr^{3-}}$$

Step 2: Phosphorus is going up 4 in oxidation number and chromium is going down 6 (down 3 each but there are two chromium atoms).

$$\underset{\underset{4}{\downarrow}}{\overset{+1}{H_3PO_2}} + \underset{\underset{6}{\uparrow}}{\overset{+6}{Cr_2O_7}} \rightarrow \overset{+5}{H_3PO_4} + \overset{+3}{Cr^{3+}}$$

We need to multiply all the phosphorus species by 3 and the chromium species by 2 to get the same number going up as going down (up 12, down 12):

$$\mathbf{3}H_3PO_2 + \mathbf{2}Cr_2O_7^{2-} \rightarrow \mathbf{3}H_3PO_4 + 4Cr^{3+}$$

Step 3: Now balance charges with H^+. Note that the net charge is -4 on the left hand side of the equation, and +12 on the right. Therefore add 16 H^+ to the left hand side of the equation (to get a net charge of +12):

$$\mathbf{3}H_3PO_2 + \mathbf{2}Cr_2O_7^{2-} + \mathbf{16H^+} \rightarrow \mathbf{3}H_3PO_4 + 4Cr^{3+}$$

Step 4: Finally balance H or O with H_2O. In this case, add 8 water molecules to the right side of the equation (25 H and 20 O on each side):

$\mathbf{3}H_3PO_2 + \mathbf{2}Cr_2O_7^{2-} + \mathbf{16H^+} \rightarrow \mathbf{3}H_3PO_4 + 4Cr^{3+} + \mathbf{8H_2O}$

Example 2:

Given the skeletal equation: $MnO_4^- + C_2O_4^{2-} \rightarrow MnO_2 + CO_2$ (in basic solution)

Step 1: Manganese is being reduced (+7 to +4) and carbon is being oxidized (+3 to +4). Put a 2 in front of the CO_2 to have the same number of carbons on both sides of the equation:

$$\overset{+7}{MnO_4^-} + \overset{+3}{C_2O_4^{2-}} \longrightarrow \overset{+4}{MnO_2} + \mathbf{2}\overset{+4}{CO_2}$$

Step 2: Manganese is going down 3 in oxidation number and carbon is going up 2 (up 1 each, but there are 2 carbons):

$$\underset{\underset{3}{\downarrow}}{\overset{+7}{MnO_4^-}} + \underset{\underset{2}{\uparrow}}{\overset{+3}{C_2O_4^{2-}}} \longrightarrow \overset{+4}{MnO_2} + \mathbf{2}\overset{+4}{CO_2}$$

Multiply all the manganese species by 2 and the carbon species by 3 to get the same number going up as down:

$\mathbf{2}MnO_4^- + \mathbf{3}C_2O_4^{2-} \rightarrow \mathbf{2}MnO_2 + \mathbf{6}\,CO_2$

Step 3: Now balance charges with OH-. Notice that the net charge on the left hand side of the equation is -8, but zero on the right. Therefore add 8 OH to the right:

$\mathbf{2}MnO_4^- + \mathbf{3}C_2O_4^{2-} \rightarrow \mathbf{2}MnO_2 + \mathbf{6}CO_2 + \mathbf{8OH^-}$

Lastly, we balance H or O with H_2O. Add 4 waters to the left (8 H's and 24 O's on each side).

$\mathbf{2}MnO_4^- + \mathbf{3}\,C_2O_4^{2-} + \mathbf{4H_2O} \rightarrow \mathbf{2}MnO_2 + \mathbf{6}\,CO_2 + \mathbf{8OH^-}$

GUIDANCE ON SKILLS LAB 8

- This is a research activity that can be carried out during extra time lessons.
- Student teachers should be allowed to use ICT lab during these extra time under the supervision of their chemistry teacher.
- The task can be in groups of two student teachers.
- The tutor has to monitor the progress of this research.
- After the required time the tutor evaluate the work done and communicate a feedback to the student teachers. This required time should a result of an agreement between the student teachers and the tutor based on their availability.

Expected answers to skills lab

- During the extraction of metals oxides are reduced or some metal salts undergoe electrolysis.
- Antioxidants are added to food in order to prevent their spoilage and therefore the loss of money.
- Production of substances such as sulphuric acid or nitric acid involves redox reactions. (Refer to the contact process or the Haber process for chemical equations).
- Water treatment and making of bleaches involve disproportionation reaction.
- All these processes help to get money but many health/environmental issues are associated with their manufacture.
- The student teachers should detail these ideas.

8.8. Answers to end unit assessment 8

1. B(gold is highly nonreactive in such way it cannot be oxidized by O_2 to form gold oxide)
2. B, 3.D, 4.D, 5.B
6. Metals corrode because they oxidize easily. Referencing Table 178.2, most metals are strong reducing agents. This means that the reverse reactions are oxidation half-reactions, indicating that they oxidize fairly easily. Another key point is that the O_2 (which is a reactant in corrosion processes) is an oxidizing agent. This means that when O_2 is coupled with most metals, the reaction will be spontaneous, so corrosion occurs.

   The noble metals (Ag, Au, and Pt) all are potentially non reactive: Therefore, O_2 is not capable of oxidizing these metals under standard conditions.

7. $Au + HNO_3 + HCl \rightarrow AuCl_4^- + NO$

   Only deal with ions that are reacting (omit H^+): $Au + NO_3^- + Cl^- \rightarrow AuCl_4^- + NO$

   The balanced half-reactions are:

   $Au + 4\,Cl^- \rightarrow AuCl_4^- + 3\,e^-$ $3\,e^- + 4\,H^+ + NO_3^- \rightarrow NO + 2\,H_2O$

   Adding the two balanced half-reactions:

   $Au(s) + 4\,Cl^-(aq) + 4\,H^+(aq) + NO_3^-(aq) \rightarrow AuCl_4^-(aq) + NO(g) + 2\,H_2O(l)$

8. a) Oxidizing agents (species reduced) are on the left side of the preceding reduction half- reactions. Of the species available, Ag^+ would be the best oxidizing agent since it is located at lower level of reactivity series.

b) Reducing agents (species oxidized) are on the right side of the reduction half-reactions. Of the species available, Zn would be the best reducing agent since it is located at high level of the reactivity series of the metals

c. $SO_4^{2-} + 4\,H^+ + 2\,e^- \rightarrow H_2SO_3 + H_2O$; SO_4^{2-} can oxidize Pb and Zn

d. Al can reduce Ag^+ and Zn^{2+}

9. a) $2(6\,e^- + 14\,H^+ + Cr_2O_7^{2-} \rightarrow 2\,Cr^{3+} + 7\,H_2O)$

$3\,H_2O + C_2H_5OH \rightarrow 2\,CO_2 + 12\,H^+ + 12\,e^-$

b) $16\,H^+ + 2\,Cr_2O_7^{2-} + C_2H_5OH \rightarrow 4\,Cr^{3+} + 2\,CO_2 + 11\,H_2O$

10. Aluminium has the ability to form a durable oxide coating over its surface. Once the HCl dissolves this oxide coating, Al is exposed to H^+ and is easily oxidized to Al^{3+}, i.e., the Al foil disappears after the oxide coating is dissolved.

11. Only statement c is true. The attached metals that are more easily oxidized than iron are called sacrificial metals. For statement a, corrosion is a spontaneous process, like the ones harnessed to make galvanic cells. For statement b, corrosion of steel is the oxidation of iron coupled with the reduction of oxygen.

12.The substances where nitrogen can exhibit oxidation states from -3 to +5 are listed in the following table.

Substance	N_2	N_2O	N_2H_2	NO	N_2H_4	N_2O_3	NH_3	NO_2	N_2O_5
O.N of nitrogen	0	+1	-1	+2	-2	+3	-3	+4	+5

13. The reaction is: $3Cl_2 + 6NaOH_{(conc.,hot)} \rightarrow 5NaCl_{(aq)} + NaClO_{3(aq)} + 3H_2O_{(l)}$

This is a disproportionation reaction where the O.N of Cl_2 changes from zero to -1 and zero to +5, the answer is B.

14. **Oxidation half equation**: An equation showing only the oxidation part of a redox reaction, balanced with respect to both atoms and charge. The charge balance is achieved by adding the required number of electrons to the right hand side of the equation.

Reduction half equation: An equation showing only the reduction part of a redox reaction, balanced with respect to both atoms and charge. The charge balance is achieved by adding the required number of electrons to the left hand side of the equation.

Oxidizing agent or **oxidant** is any species that **cause** oxidation of other chemical species and thus is itself reduced. For example the oxidizing agent O_2 is reduced to O^{2-} when it oxidizes a metal such as Zn to Zn^{2+}.

Reducing agent or **reductant is** any species that **causes the** reduction of another chemical species and thus is itself themselves oxidized. For. the reducing agent H_2S is oxidized to S when it reduces Fe^{3+} to Fe^{2+}.

15. a) $Fe^{3+} + e^- \rightarrow Fe^{2+}$ (reduction)

$2I^- \rightarrow I_2 + 2e^-$ (oxidation)

$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$

b) $Sn^{2+} \rightarrow Sn^{4+} + 2e^-$ (oxidation)

$Fe^{3+} + e- \rightarrow Fe^{2+}$ (reduction)

$Sn^{2+} + 2Fe^{3+} \rightarrow Sn^{4+} + 2Fe^{2+}$

c) $Ag^+ + e^- \rightarrow Ag$ (reduction)

$Cu \rightarrow Cu^{2+} + 2e^-$ (oxidation)

$Cu + 2Ag^+ \rightarrow Cu^{2+} + 2Ag$

d) $2H^+ + 2e^- \rightarrow H_2$ (reduction)

$Al \rightarrow Al^{3+} + 3e^-$ (oxidation)

$6H^+ + 2Al \rightarrow 3H_2 + 2Al^{3+}$

e) $Fe^{3+} + e- \rightarrow Fe^{2+}$ (reduction)

$H_2S \rightarrow S + 2H^+ + 2e-$ (oxidation)

$H_2S + 2Fe^{3+} \rightarrow 2H^+ + S + 2Fe^{2+}$

16. a) not redox (no atom changes its oxidation state).

b) not redox (no atom changes its oxidation state).

c) redox reaction Mg, the element (O.N. = 0) is oxidised to Mg^{2+} which has O.N. = +2.

The H^+ ion (O.N. = +1) is reduced to the element, H_2, which has O.N. = 0.

d) not redox (no atom changes its oxidation state).

(e) redox reaction.

Cu is oxidised from O.N. = 0 in the element to O.N. = +2 in CuS.

S is reduced from O.N. = 0 in the element to O.N. = -2 in CuS.

17.These are the displacement reactions based on the reactivity series of the metals

	$Mg(NO_3)_2$	$FeSO_4$	$Cu(NO_3)_2$	$Pb(NO_3)_2$	$Zn(NO_3)_2$
Mg	No reaction	dark crystals of iron on the magnesium ribbon	Brown dark layer of copper on the magnesium strip	Dark crystals of lead on the magnesium ribbon	Dark crystals of zinc on the magnesium ribbon
Fe	No reaction	No reaction	Brown dark layer of copper on the magnesium strip	Theoretically reacts - but doubt if you see anything	No reaction
Cu	No reaction	No reaction	No reaction	No reaction	No reaction
Pb	No reaction	No reaction	Brown-dark layer of copper on the lead strip	No reaction	No reaction
Zn	Dark crystals of zinc on the magnesium ribbon	No reaction	No reaction	No reaction	No reaction

18. The oxidation number of S in both SO_2 and SO_3^{2-} is +4. Oxygen atoms in both species all have O.N=-2. As there has been no change in the oxidation number of any atom, this is not a redox reaction.

19. a) Reducing agent: Cl^- Oxidizing agent: MnO_2

Atom oxidized: Cl as Cl^- (O.N. = -1) to Cl in Cl_2 (O.N. = 0).

Atom reduced: Mn in MnO_2 (O.N. = +4) to Mn as Mn^{2+} (O.N. = +2).

b) Reducing agent: SO_2 Oxidizing agent: NO_3^-

Atom oxidized: S in SO_2 (O.N. = +4) to S in SO_4^{2-}S (O.N. = +6).

Atom reduced: N in NO_3^- (O.N. = +5) to N in NO (O.N. = +2).

c) Reducing agent: Ag Oxidizing agent: H_2S

Atom oxidized: Ag as the element (O.N. = 0) to Ag^+ in Ag_2S (O.N. = +1).

Atom reduced: H in H_2S (O.N. = +1) to H in H_2 (O.N. = 0).

d) Reducing agent: H_2S Oxidizing agent: NO_3^-

Atom oxidized: S in H_2S (O.N. = -2) to S as the element (O.N. = 0).

Atom reduced: N in NO_3^- (O.N. = +V) to N in NO_2 (O.N. = +4).

e) Reducing agent: Fe^{2+} Oxidizing agent: MnO_4^-

Atom oxidized: Fe as Fe^{2+} (O.N. = +2) to Fe as Fe^{3+} (O.N. = +3).

Atom reduced: Mn in MnO_4^- (O.N. = +7) to Mn as Mn^{2+} (O.N. = +2).

f) Reducing agent: Fe^{2+} Oxidizing agent: $Cr_2O_7^{2-}$

Atom oxidized: Fe as Fe^{2+} (O.N. = +2) to Fe as Fe^{3+} (O.N. = +3).

Atom reduced: Cr in $Cr_2O_7^{2-}$ (O.N. = +6) to Cr as Cr^{3+} (O.N. = +3).

g) Reducing agent: Br^- Oxidizing agent: Cl_2

Atom oxidized: Br as Br^- (O.N. = -1) to Br as the element Br_2 (O.N. = 0).

Atom reduced: Cl as the element Cl_2 (O.N. = 0) to Cl as Cl^- (O.N. = -1).

h) Reducing agent: H_2 Oxidizing agent: CuO

Atom oxidized: H as the element H_2 (O.N. = 0) to H in H_2O (O.N. = +1).

Atom reduced: Cu in CuO (O.N. = +2) to Cu as the element (O.N. = 0).

i) Reducing agent: Sn^{2+} Oxidizing agent: H_3AsO_4

Atom oxidized: Sn as Sn^{2+} (O.N. = +2) to Sn as Sn^{4+} (O.N. = +4).

Atom reduced: As in H_3AsO_4 (O.N. = +V) to As in H_3AsO_3 (O.N. = +3).

j) Reducing agent: Pb Oxidizing agent: PbO_2

Atom oxidized: Pb as the element (O.N. = 0) to Pb as Pb^{2+} (O.N. = +2).

Atom reduced: Pb in PbO_2 (O.N. = +4) to Pb^{2+} (O.N. = +2).

(This example shows that two different oxidation states of the same element can lead to both oxidation and reduction of the one type of atom; this reaction is the basis for the lead acid battery).

20. a). copper , iron, zinc, magnesium,

b) $Mg + Cu^{2+} \rightarrow Mg^{2+} + Cu$

$Mg + Fe^{2+} \rightarrow Mg^{2+} + Fe$

$Mg + Zn^{2+} \rightarrow Mg^{2+} + Zn$

$Fe + Cu^{2+} \rightarrow Fe^{2+} + Cu$

$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$

$Zn + Fe^{2+} \rightarrow Zn^{2+} + Fe$

The reactions are redox reactions because the oxidation states of the reactants change.

c) i) copper + chromium sulfate → no reaction

ii) magnesium + chromium sulfate → magnesium sulfate + chromium

iii) chromium + copper sulfate → copper + chromium sulfate

d) Add chromium to solutions of zinc ions and iron ions. Add iron and zinc metal powders to chromium ion solutions. Observe what happens.

8.9 Additional activities

8.9.1. Remedial activities

1. Consider the elements: Cs, Ne, I and F
   a) Identify the element that exhibits only negative oxidation state.
   b) Identify the element that exhibits only positive oxidation state.
   c) Identify the element that exhibits both positive and negative oxidation states.
   d) Identify the element which exhibits neither the negative nor does the positive oxidation state.

Solution

a) F exhibits only negative oxidation state of -1.
b) Cs exhibits positive oxidation state of +1.
c) I exhibits both positive and negative oxidation stat It exhibits oxidation states of – 1, + 1, + 3, + 5, and + 7.
d) The oxidation state of Ne is zero. It exhibits neither negative nor positive oxidation states.

2. Specify which of the following equations represent oxidation–reduction reactions, and indicate the oxidizing agent, the reducing agent, the species being oxidized, and the species being reduced.
   a) $CH_4(g) + H_2O(g) \rightarrow CO(g) + 3H_2(g)$
   b) $2AgNO_3(aq) + Cu(s) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$
   c) $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$
   d) $2H^+(aq) + 2CrO_4^{2-}(aq) \rightarrow Cr_2O_7^{2-}(aq) + H_2O(l)$

Solution:

The species oxidized shows an increase in oxidation numbers and is called the reducing agent. The species reduced shows a decrease in oxidation numbers and is called the oxidizing agent. The pertinent oxidation numbers are listed by the substance oxidized and the substance reduced.

			Substance	Substance
Redox?	Ox. Agent	Red. Agent	Oxidized	Reduced
a. Yes	H_2O	CH_4	CH_4 (C, −4 → +2)	H_2O (H, +1 → 0)
b. Yes	$AgNO_3$	Cu	Cu (0 → +2)	$AgNO_3$ (Ag, +1 → 0)
c. Yes	HCl	Zn	Zn (0 → +2)	HCl (H, +1 → 0)
No; there is no change in any of the oxidation numbers.				

3. The Ostwald process for the commercial production of nitric acid involves the following three steps:

$4NH_{3(g)} + 5O_{2(g)} \rightarrow 4NO_{(g)} + 6H_2O_{(g)}$

$2NO_{(g)} + O_{2(g)} \rightarrow 2NO_{2(g)}$

$3NO_{2(g)} + H_2O_{(l)} \rightarrow 2HNO_{3\,(aq)} + NO_{(g)}$

a) Which reactions in the Ostwald process are oxidation–reduction reactions?

b) Identify each oxidizing agent and reducing agent.

Solution:

a) $4\ NH_3(g) + 5\ O_2(g) \rightarrow 4\ NO(g) + 6\ H_2O(g)$

−3 +1 0 +2 −2 +1 −2 oxidation numbers

$2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$

+2 −2 0 +4 −2

$3\ NO_2(g) + H_2O(l) \rightarrow 2\ HNO_3(aq) + NO(g)$

+4 −2 +1 −2 +1 +5 −2 +2 −2

All three reactions are oxidation-reduction reactions since there is a change in oxidation numbers of some of the elements in each reaction.

b) $4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$ O_2 is the oxidizing agent and NH_3 is the reducing agent.

$2\ NO + O_2 \rightarrow 2\ NO_2$; O_2 is the oxidizing agent and NO is the reducing agent.

$3\ NO_2 + H_2O \rightarrow 2\ HNO_3 + NO$; NO_2 is both the oxidizing and reducing agent.

8.9.2. Consolidation activities

4. Balance the following oxidation–reduction reactions that occur in acidic solution using the half-reaction method.

a) $Cu(s) + NO_3^{\,-}(aq) \rightarrow Cu^{2+}(aq) + NO(g)$

b) $Cr_2O_7^{\,2-}(aq) + Cl^{-}(aq) \rightarrow Cr^{3+}(aq) + Cl_2(g)$

c) $Pb(s) + PbO_2(s) + H_2SO_4(aq) \rightarrow PbSO_4(s)$

d) $Mn^{2+}(aq) + NaBiO_3(s) \rightarrow Bi^{3+}(aq) + MnO_4^{\,-}(aq)$

e) $H_3AsO_4(aq) + Zn(s) \rightarrow AsH_3(g) + Zn^{2+}(aq)$

Solution:

a) $(Cu \rightarrow Cu^{2+} + 2\,e^{-}) \times 3$ $\qquad$ $NO_3^{-} \rightarrow NO + 2\,H_2O$

$(3\,e^{-} + 4\,H^{+} + NO_3^{-} \rightarrow NO + 2\,H_2O) \times 2$

Adding the two balanced half-reactions so that electrons cancel:

$$\begin{array}{r} 3\,Cu \rightarrow 3\,Cu^{2+} + 6\,e^{-} \\ 6\,e^{-} + 8\,H^{+} + 2\,NO_3^{-} \rightarrow 2\,NO + 4\,H_2O \\ \hline \end{array}$$

$3\,Cu(s) + 8\,H^{+}(aq) + 2\,NO_3^{-}(aq) \rightarrow 3\,Cu^{2+}(aq) + 2\,NO(g) + 4\,H_2O(l)$

b) $(2\,Cl^{-} \rightarrow Cl_2 + 2\,e^{-}) \times 3$ $\qquad$ $Cr_2O_7^{2-} \rightarrow 2\,Cr^{3+} + 7\,H_2O$

$6\,e^{-} + 14\,H^{+} + Cr_2O_7^{2-} \rightarrow 2\,Cr^{3+} + 7\,H_2O$

Add the two half-reactions with six electrons transferred:

$$\begin{array}{r} 6\,Cl^{-} \rightarrow 3\,Cl_2 + 6\,e^{-} \\ 6\,e^{-} + 14\,H^{+} + Cr_2O_7^{2-} \rightarrow 2\,Cr^{3+} + 7\,H_2O \\ \hline \end{array}$$

$14\,H^{+}(aq) + Cr_2O_7^{2-}(aq) + 6\,Cl^{-}(aq) \rightarrow 3\,Cl_2(g) + 2\,Cr^{3+}(aq) + 7\,H_2O(l)$

c) $Pb \rightarrow PbSO_4$ $\qquad$ $PbO_2 \rightarrow PbSO_4$

$Pb + H_2SO_4 \rightarrow PbSO_4 + 2\,H^{+}$ $\qquad$ $PbO_2 + H_2SO_4 \rightarrow PbSO_4 + 2\,H_2O$

$Pb + H_2SO_4 \rightarrow PbSO_4 + 2\,H^{+} + 2\,e^{-}$ $\qquad$ $2\,e^{-} + 2\,H^{+} + PbO_2 + H_2SO_4 \rightarrow PbSO_4 + 2\,H_2O$

Add the two half-reactions with two electrons transferred:

$$2\,e^- + 2\,H^+ + PbO_2 + H_2SO_4 \rightarrow PbSO_4 + 2\,H_2O$$

$$Pb + H_2SO_4 \rightarrow PbSO_4 + 2\,H^+ + 2\,e^-$$

$$Pb(s) + 2\,H_2SO_4(aq) + PbO_2(s) \rightarrow 2\,PbSO_4(s) + 2\,H_2O(l)$$

This is the reaction that occurs in an automobile lead-storage battery.

d) $Mn^{2+} \rightarrow MnO_4^-$

$$(4\,H_2O + Mn^{2+} \rightarrow MnO_4^- + 8\,H^+ + 5\,e^-) \times 2$$

$$NaBiO_3 \rightarrow Bi^{3+} + Na^+$$

$$NaBiO_3 \rightarrow Bi^{3+} + Na^+$$

$$6\,H^+ + NaBiO_3 \rightarrow Bi^{3+} + Na^+ + 3\,H_2O$$

$$(2\,e^- + 6\,H^+ + NaBiO_3 \rightarrow Bi^{3+} + Na^+ + 3\,H_2O) \times 5$$

$$8\,H_2O + 2\,Mn^{2+} \rightarrow 2\,MnO_4^- + 16\,H^+ + 10\,e^-$$

$$10\,e^- + 30\,H^+ + 5\,NaBiO_3 \rightarrow 5\,Bi^{3+} + 5\,Na^+ + 15\,H_2O$$

$$8\,H_2O + 30\,H^+ + 2\,Mn^{2+} + 5\,NaBiO_3 \rightarrow 2\,MnO_4^- + 5\,Bi^{3+} + 5\,Na^+ + 15\,H_2O + 16\,H^+$$

Simplifying:

$$14\,H^+(aq) + 2\,Mn^{2+}(aq) + 5\,NaBiO_3(s) \rightarrow 2\,MnO_4^-(aq) + 5\,Bi^{3+}(aq) + 5\,Na^+(aq) + 7\,H_2O(l)$$

e) $H_3AsO_4 \rightarrow AsH_3$ $(Zn \rightarrow Zn^{2+} + 2\,e^-) \times 4$

$$H_3AsO_4 \rightarrow AsH_3 + 4\,H_2O$$

$$8\,e^- + 8\,H^+ + H_3AsO_4 \rightarrow AsH_3 + 4\,H_2O$$

$$8\,e^- + 8\,H^+ + H_3AsO_4 \rightarrow AsH_3 + 4\,H_2O$$

$$4\,Zn \rightarrow 4\,Zn^{2+} + 8\,e^-$$

$$8\,H^+(aq) + H_3AsO_4(aq) + 4\,Zn(s) \rightarrow 4\,Zn^{2+}(aq) + AsH_3(g) + 4\,H_2O(l)$$

5. Balance the following oxidation–reduction reactions that occur in basic solution.

a) $Al\,(s) + MnO_4^-(aq) \rightarrow MnO_2\,(s) + Al\,(OH)_4^-(aq)$

b) $Cl_2\,(g) \rightarrow Cl^-(aq) + OCl_2(aq)$

c) $NO_2^-(aq) + Al(s) \rightarrow NH_3(g) + AlO_2^-(aq)$

Solution:

a) $Al \rightarrow Al(OH)_4^-$ $MnO_4^- \rightarrow MnO_2$

$4\,H_2O + Al \rightarrow Al(OH)_4^- + 4\,H^+$ $3\,e^- + 4\,H^+ + MnO_4^- \rightarrow MnO_2 + 2\,H_2O$

$4\,H_2O + Al \rightarrow Al(OH)_4^- + 4\,H^+ + 3\,e^-$

$4\,H_2O + Al \rightarrow Al(OH)_4^- + 4\,H^+ + 3\,e^-$

$3\,e^- + 4\,H^+ + MnO_4^- \rightarrow MnO_2 + 2\,H_2O$

$2\,H_2O(l) + Al(s) + MnO_4^-(aq) \rightarrow Al(OH)_4^-(aq) + MnO_2(s)$

H^+ doesn't appear in the final balanced reaction, so we are done.

b) $Cl_2 \rightarrow Cl^-$ $Cl_2 \rightarrow OCl^-$

$2\,e^- + Cl_2 \rightarrow 2\,Cl^-$ $2\,H_2O + Cl_2 \rightarrow 2\,OCl^- + 4\,H^+ + 2\,e^-$

$2\,e^- + Cl_2 \rightarrow 2\,Cl^-$

$2\,H_2O + Cl_2 \rightarrow 2\,OCl^- + 4\,H^+ + 2\,e^-$

$2\,H_2O + 2\,Cl_2 \rightarrow 2\,Cl^- + 2\,OCl^- + 4\,H^+$

Now convert to a basic solution. Add $4OH^-$ to both sides of the equation. The $4OH^-$ will react with the $4H^+$ on the product side to give $4H_2O$. After this step, cancel identical species on both sides ($2H_2O$). Applying these steps gives:

$4OH^- + 2Cl_2 \rightarrow 2Cl^- + 2OCl^- + 2H_2O$, which can be further simplified to:

$2OH^-(aq) + Cl_2(g) \rightarrow Cl^-(aq) + OCl^-(aq) + H_2O(l)$

c)$NO_2^- \rightarrow NH_3$ $Al \rightarrow AlO_2^-$

$6\,e^- + 7\,H^+ + NO_2^- \rightarrow NH_3 + 2\,H_2O$ $(2\,H_2O + Al \rightarrow AlO_2^- + 4\,H^+ + 3\,e^-) \times 2$

Common factor is a transfer of 6 e^-.

$6e^- + 7\,H^+ + NO_2^- \rightarrow NH_3 + 2\,H_2O$

$4\,H_2O + 2\,Al \rightarrow 2\,AlO_2^- + 8\,H^+ + 6\,e^-$

$OH^- + 2\,H_2O + NO_2^- + 2\,Al \rightarrow NH_3 + 2\,AlO_2^- + H^+ + OH^-$

Reducing gives $OH^-(aq) + H_2O(l) + NO_2^-(aq) + 2\,Al(s) \rightarrow NH_3(g) + 2\,AlO_2^-(aq)$.

6) Chlorine gas was first prepared in 1774 by C. W. Scheele by oxidizing sodium chloride with manganese(IV) oxide. The reaction is :

$NaCl\ (aq) + H_2SO_4\ (aq) + MnO_2\ (s) \rightarrow Na_2SO_4\ (aq) + MnCl_2\ (aq) + H_2O(\ l\ ) + Cl_2\ (g)$

Balance this equation.

Solution:

$NaCl + H_2SO_4 + MnO_2 \rightarrow Na_2SO_4 + MnCl_2 + Cl_2 + H_2O$

We could balance this reaction by the half-reaction method, which is generally the preferred method. However, sometimes a redox reaction is not so complicated and thus balancing by inspection is a possibility. Let's try inspection here. To balance Cl^-, we need 4 NaCl:

$4\ NaCl + H_2SO_4 + MnO_2 \rightarrow Na_2SO_4 + MnCl_2 + Cl_2 + H_2O$

Balance the Na^+ and SO_4^{2-} ions next:

$4\ NaCl + 2\ H_2SO_4 + MnO_2 \rightarrow 2\ Na_2SO_4 + MnCl_2 + Cl_2 + H_2O$

On the left side: 4 H and 10 O; on the right side: 8 O not counting H_2O

We need 2 H_2O on the right side to balance H and O:

$4\ NaCl(aq) + 2\ H_2SO_4(aq) + MnO_2(s) \rightarrow 2\ Na_2SO_4(aq) + MnCl_2(aq) + Cl_2(g) + 2\ H_2O(l)$

8.9.3. Extended activities

7) Sulphur dioxide (SO_2) is a chemical of major industrial significance.

a) SO_2 gas can be produced in a reaction between concentrated sulphuric acid and nickel metal. A containing Ni^{2+} ions is also formed. Write balanced equations for the

   i) oxidation reaction

   ii) reduction reaction

   iii) overall reaction, showing the states of all reactants and products.

b) SO_2 can also be produced in a chemical reaction between zinc sulphite ($ZnSO_3$) and hydrochloric acid according to the equation

$ZnSO_3(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + SO_2(g) + H_2O(l)$

   i) Is this reaction also a redox reaction? Explain your answer.

   ii) Which one of the following is least likely to be a product of a redox reaction between sulphuric acid and zinc metal?

A. H_2

B. H_2S

C. SO_2

D. SO_3

Solution:

a) i) $Ni_{(s)} \rightarrow Ni^{2+}_{(aq)} + 2e$

ii) $H_2SO_{4(aq)} + 2H^+_{(aq)} + 2e^- \rightarrow SO_{2(g)} + 2H_2O_{(l)}$

iii) $Ni_{(s)} + H_2SO_{4(aq)} + 2H^+_{(aq)} \rightarrow Ni^{2+}_{(aq)} + SO_{2(g)} + 2H_2O_{(l)}$

b) i) No, there is no change in oxidation numbers (or nothing is oxidized or reduced)

ii) In a redox reaction between zinc metal and sulphuric acid, zinc metal would be the reductant(and be oxidized) and sulphuric acid would be the source of the oxidant(which will be reduced). In dilute sulphuric acid, the oxidant is H^+, which is reduced to H_2 according to

$2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)}$

In concentrated sulphuric acid solution the oxidant is $H_2SO_{4(l)}$. When H_2SO_4 is reacting as an oxidant, and hence being reduced, the O.N of sulphur, which is +6), must decrease: the O.N of S in the suggested products are H_2S-(-), SO_2-(+4); SO_3–(+6). Hence SO_3 is unlikely to be a product of the reaction.

8) a) Turn the following processes into redox reactions by writing out half-equations and combining them:

i) $PbO_2 \rightarrow Pb^{2+}$, $Cl^- \rightarrow Cl_2$

ii) $S_2O_3^{2-} \rightarrow S_4O_6^{2-}$, $I_2 \rightarrow 2I^-$

iii) $IO_3^- \rightarrow I_2$, $I^- \rightarrow I_2$

iv) $ClO^- \rightarrow ClO_3^-$, $ClO^- \rightarrow Cl^-$

v) $H_2SO_4 \rightarrow SO_2$, $Br^- \rightarrow Br_2$

vi) $H_2SO_4 \rightarrow S$, $I^- \rightarrow I_2$

vii) $H_2SO_4 \rightarrow H_2S$, $I^- \rightarrow I_2$

viii) $ClO^- \rightarrow Cl^-$, $I^- \rightarrow I_2$

ix) $PbO_2 \rightarrow Pb^{2+}$, $SO_3^{2-} \rightarrow SO_4^{2-}$

b) Identify the oxidising and reducing agents in the equations in question 2.

c) Identify any disproportionation reactions in question 2.

Solution:

i) $PbO_2 + 4H^+ + 2e^- \rightarrow Pb^{2+} + 2H_2O$

$2Cl^- \rightarrow Cl_2 + 2e^-$

$PbO_2 + 4H^+ + 2Cl^- \rightarrow Pb^{2+} + 2Cl^- + 2H_2O$

ii) $2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2e^-$

$I_2 + 2e^- \rightarrow 2I^-$

$2S_2O_3^{2-} + I_2 \rightarrow S_4O_6^{2-} + 2I^-$

iii) $2IO_3^- + 12H^+ + 10e^- \rightarrow I_2 + 6H_2O$

$2I^- \rightarrow I_2 + 2e^-$

$IO_3^- + 6H^+ + 5I^- \rightarrow 3I_2 + 3H_2O$

iv) $ClO^- + 2H_2O \rightarrow ClO_3^- + 4H^+ + 4e^-$

$ClO^- + 2H^+ + 2e^- \rightarrow Cl^- + H_2O$

$3ClO^- \rightarrow 2Cl^- + ClO_3^-$

v) $H_2SO_4 + 2H^+ + 2e^- \rightarrow SO_2 + 2H_2O$

$2Br^- \rightarrow Br_2 + 2e^-$

$H_2SO_4 + 2H^+ + 2Br^- \rightarrow SO_2 + Br_2 + 2H_2O$

vi) $H_2SO_4 + 6H^+ + 6e^- \rightarrow S + 4H_2O$

$2I^- \rightarrow I_2 + 2e^-$

$H_2SO_4 + 6H^+ + 6I^- \rightarrow S + 3I_2 + 4H_2O$

vii) $H_2SO_4 + 8H^+ + 8e^- \rightarrow H_2S + 4H_2O$

$2I^- \rightarrow I_2 + 2e^-$

$H_2SO_4 + 8H^+ + 8I^- \rightarrow H_2S + 4I_2 + 4H_2O$

viii) $ClO^- + 2H^+ + 2e^- \rightarrow Cl^- + H_2O$

$2I^- \rightarrow I_2 + 2e^-$

$ClO^- + 2H^+ + 2I^- \rightarrow Cl^- + H_2O + I_2$

ix) $PbO_2 + 4H^+ + 2e^- \rightarrow Pb^{2+} + 2H_2O$

$SO_3^{2-} + H_2O \rightarrow SO_4^{2-} + 2H^+ + 2e^-$

$PbO_2 + 2H^+ + SO_3^{2-} \rightarrow Pb^{2+} + SO_4^{2-} + H_2O$

Oxidising and reducing agents

Equation	**Oxidising agent**	**Reducing agent**
(i)	PbO_2	Cl^-
(ii)	I_2	$S_2O_3^{2-}$
(iii)	IO_3^-	I^-
(iv)	ClO^-	ClO^-
(v)	H_2SO_4	Br^-
(vi)	H_2SO_4	I^-
(vii)	H_2SO_4	I^-
(viii)	ClO^-	I^-
(ix)	PbO_2	SO_3^{2-}

c) Only reaction (iv) is a disproportionation reaction

9) While sulphur dioxide and hydrogen peroxide can act as oxidizing as well as reducing agents in their reactions, ozone and nitric acid act only as oxidants. Why?

Solution: In sulphur dioxide (SO_2), the oxidation number (O.N.) of S is +4 and the range of the O.N. that S can have is from +6 to -2.

Therefore, SO_2 can act as an oxidising as well as a reducing agent.

In hydrogen peroxide (H_2O_2), the O.N. of O is -1 and the range of the O.N. that O can have is from 0 to -2. O can sometimes also attain the oxidation numbers -1 and +2. Hence, H_2O_2 can act as an oxidising as well as a reducing agent.

In ozone (O_3), the O.N. of O is zero and the range of the O.N. that O can have is from 0 to -2. Therefore, the O.N. of O can only decrease in this case. Hence, O_3 acts only as an oxidant.

In nitric acid (HNO_3), the O.N. of N is +5 and the range of the O.N. that N can have is from +5 to -3. Therefore, the O.N. of N can only decrease in this case. Hence, HNO_3 acts only as an oxidant.

10) Balance the following equations by the half-reaction method.

a) $Fe_{(s)} + HCl_{(aq)} \rightarrow HFeCl_{4(aq)} + H_{2(g)}$

b) $IO^-_{3\,(aq)} + I^-_{(aq)} \rightarrow I^-_{3\,(aq)}$ (in Acid medium)

c) $Cr(NCS)_6{}^{4-}{}_{(aq)} + Ce^{4+}{}_{(aq)} \rightarrow Cr^{3+}{}_{(aq)} + Ce^{3+}{}_{(aq)} + NO^-_{3\,(aq)} + CO_{2\,(g)} + SO_4{}^{2-}{}_{(aq)}$ (Acid medium)

d) $CrI_3\,(s) + Cl_2\,(g) \rightarrow CrO_4^{2-}(aq) + IO_4^-(aq) + Cl^-(aq)$(Base medium)

e) $Fe(CN)_6{}^{4-}{}_{(aq)} + Ce^{4+}{}_{(aq)} \rightarrow Ce(OH)_{3(s)} + Fe(OH)_{3(s)} + CO_3{}^{2-}{}_{(aq)} + NO^-_{3\,(aq)}$(Base medium)

Solution

HCl(aq) dissociates to $H^+(aq) + Cl^-(aq)$. For simplicity, let's use H^+ and Cl^- separately.

$H^+ \rightarrow H_2$

$Fe \rightarrow HFeCl_4$

$(2\,H^+ + 2\,e^- \rightarrow H_2) \times 3$

$(H^+ + 4\,Cl^- + Fe \rightarrow HFeCl_4 + 3\,e^-) \times 2$

$6\,H^+ + 6\,e^- \rightarrow 3\,H_2$

$2\,H^+ + 8\,Cl^- + 2\,Fe \rightarrow 2\,HFeCl_4 + 6\,e^-$

$8\,H^+ + 8\,Cl^- + 2\,Fe \rightarrow 2\,HFeCl_4 + 3\,H_2$

or **$8\,HCl(aq) + 2\,Fe(s) \rightarrow 2\,HFeCl_4(aq) + 3\,H_2(g)$**

b) $IO_3^- \rightarrow I_3^-$ $\qquad$ $I^- \rightarrow I_3^-$

$3\,IO_3^- \rightarrow I_3^-$ $\qquad$ $(3\,I^- \rightarrow I_3^- + 2\,e^-) \times 8$

$3\,IO_3^- \rightarrow I_3^- + 9\,H_2O$

$16\,e^- + 18\,H^+ + 3\,IO_3^- \rightarrow I_3^- + 9\,H_2O$

$16\,e^- + 18\,H^+ + 3\,IO_3^- \rightarrow I_3^- + 9\,H_2O$

$24\,I^- \rightarrow 8\,I_3^- + 16\,e^-$

$8\,H^+ + 24\,I^- + 3\,IO_3^- \rightarrow 9\,I_3^- + 9\,H_2O$

Reducing: **$6\,H^+(aq) + 8\,I^-(aq) + IO_3^-(aq) \rightarrow 3\,I_3^-(aq) + 3\,H_2O(l)$**

c) $(Ce^{4+} + e^- \rightarrow Ce^{3+}) \times 97 Cr(NCS)_6^{4-} \rightarrow Cr^{3+} + NO_3^- + CO_2 + SO_4^{2-}$

$54\,H_2O + Cr(NCS)_6^{4-} \rightarrow Cr^{3+} + 6\,NO_3^- + 6\,CO_2 + 6\,SO_4^{2-} + 108\,H^+$

$54\,H_2O + Cr(NCS)_6^{4-} \rightarrow Cr^{3+} + 6\,NO_3^- + 6\,CO_2 + 6\,SO_4^{2-} + 108\,H^+$

Charge on left $= -4$. Charge on right $= +3 + 6(-1) + 6(-2) + 108(+1) = +93$. Add 97 e^- to the product side, and then add the two balanced half-reactions with a common factor of 97 e^- transferred.

$54\,H_2O + Cr(NCS)_6^{4-} \rightarrow Cr^{3+} + 6\,NO_3^- + 6\,CO_2 + 6\,SO_4^{2-} + 108\,H^+ + 97\,e-$

$97\,e- + 97\,Ce^{4+} \rightarrow 97\,Ce^{3+}$

$97\,Ce^{4+}(aq) + 54\,H_2O(l) + Cr(NCS)_6^{4-}(aq) \rightarrow 97\,Ce^{3+}(aq) + Cr^{3+}(aq) + 6\,NO_3^-(aq)$

$+ 6\,CO_2(g) + 6\,SO_4^{2-}(aq) + 108\,H^+(aq)$

This is very complicated. A check of the net charge is a good check to see if the equation is balanced. Left: Charge = 97(+4) −4 = +384. Right: Charge = 97(+3) + 3 + 6(−1) + 6(−2) + 108(+1) = +384.

d) $CrI_3 \rightarrow CrO_4^{2-} + IO_4^-$

$Cl_2 \rightarrow Cl^-$

$(16\ H_2O + CrI_3 \rightarrow CrO_4^{2-} + 3\ IO_4^- + 32\ H^+ + 27\ e^-) \times 2$

$(2\ e^- + Cl_2 \rightarrow 2\ Cl^-) \times 27$

Common factor is a transfer of 54 e^-.

$54\ e^- + 27\ Cl_2 \rightarrow 54\ Cl^-$

$32\ H_2O + 2\ CrI_3 \rightarrow 2\ CrO_4^{2-} + 6\ IO_4^- + 64\ H^+ + 54\ e^-$

$32\ H_2O + 2\ CrI_3 + 27\ Cl_2 \rightarrow 54\ Cl^- + 2\ CrO_4^{2-} + 6\ IO_4^- + 64\ H^+$

Add 64 OH^- to both sides and convert 64 H^+ into 64 H_2O.

$64\ OH^- + 32\ H_2O + 2\ CrI_3 + 27\ Cl_2 \rightarrow 54\ Cl^- + 2\ CrO_4^{2-} + 6\ IO_4^- + 64\ H_2O$

Reducing gives:

$64\ OH^-(aq) + 2\ CrI_3(s) + 27\ Cl_2(g) \rightarrow 54\ Cl^-(aq) + 2\ CrO_4^{2-}\ (aq) + 6\ IO_4^-(aq) + 32\ H2O(l)$

e) $Ce^{4+} \rightarrow Ce(OH)_3$

$(e^- + 3\ H_2O + Ce^{4+} \rightarrow Ce(OH)_3 + 3\ H^+) \times 61$

$Fe(CN)_6^{4-} \rightarrow Fe(OH)_3 + CO_3^{2-} + NO_3^-$

$Fe(CN)_6^{4-} \rightarrow Fe(OH)_3 + 6\ CO_3^{2-} + 6\ NO_3^-$

There are 39 extra O atoms on right. Add 39 H_2O to left; then add 75 H^+ to right to balance H^+.

$39\ H_2O + Fe(CN)_6^{4-} \rightarrow Fe(OH)_3 + 6\ CO_3^{2-} + 6\ NO_3^- + 75\ H^+$

Net charge = 4–

Net charge = 57+

Add 61 e^- to the product side, and then add the two balanced half-reactions with a common factor of 61 e^- transferred.

$39\ H_2O + Fe(CN)_6^{4-} \rightarrow Fe(OH)_3 + 6\ CO_3^- + 6\ NO_3^- + 75\ H^+ + 61\ e^-$

$61\ e^- + 183\ H_2O + 61\ Ce^{4+} \rightarrow 61\ Ce(OH)_3 + 183\ H^+$

$222\ H_2O + Fe(CN)_6^{4-} + 61\ Ce^{4+} \rightarrow 61\ Ce(OH)_3 + Fe(OH)_3 + 6\ CO_3^{2-} + 6\ NO_3^- + 258\ H^+$

Adding 258 OH^- to each side and then reducing gives:

$258\ OH^-(aq) + Fe(CN)_6^{4-}(aq) + 61\ Ce^{4+}(aq) \rightarrow 61\ Ce(OH)_3(s) + Fe(OH)_3(s) + 6\ CO_3^{2-}(aq) + 6\ NO_3^-(aq)$

$+ 36\ H_2O(l)$

UNIT 9: ELECTROCHEMICAL CELLS AND APPLICATIONS

9.1. Key unit competence

Explain the working of electrochemical cells and their industrial applications

9.2. Prerequisite (knowledge, skills, attitudes and values)

Student teachers will learn better the concept of electrochemical cells and applications if they have understanding on the following topics:

- Electrolysis and applications (Senior 3),
- Oxidation-reduction reactions (Chemistry SME, Year 3, Unit 8).
- The tutor will help student teachers to recap the concepts above.

9.3. Cross-cutting issues to be addressed:

a) Inclusive education:

This unit involves a number of formulae of substances, the writing of formulae and chemical reactions. This may be challenging to student teachers with special educational needs especially student teachers with visual impairment or visual difficulties.

However, the teacher can make some arrangements like the following:

Grouping student teachers

- Student teachers with special educational needs are grouped with others and assigned roles basing on individual student's abilities.
- If a teacher has student teachers with visual difficulties, when writing on the blackboard, write in large, clear writing, especially when it comes to formulae and chemical reactions. Read out what you are writing, for the benefit of those who are not able to see the blackboard clearly.
- If student teachers are sharing textbooks, try to arrange for those with visual difficulties to have their own copies, as far as this is possible.
- Give extra time for them to write summary notes or write down observations after experiments.
- Every important point is written and spoken.
- Remember to repeat the main points of the lessons.
- For student teachers with **hearing difficulties**, the teacher has to encourage them to sit closer to the front of the classroom. Stop every so often while teaching to ask student teachers whether they have understood, or if they need you to repeat a point. Encourage student teachers not to be afraid to ask questions.
- When teaching, speak clearly and ensure that all the student teachers can hear your voice. Avoid speaking hurriedly as this will make it difficult for student teachers with hearing difficulties to make sense of what you are saying.

- Student teachers with mobility difficulties:
- These include student teachers in crutches, wheelchairs, or with walking difficulties.
- Encourage other student teachers to look out for and help their classmates. Ask their follow student teachers to help them with their notes, if their conditions hinder them from writing well.
- Student teachers with reading difficulties:
- Student teachers with this kind of difficulties struggle to make sense of words or understand written work and take longer to read than other student teachers.
- Encourage them to pay careful attention during class time and participate for example by asking questions, answering questions, so that they can make the most of what they hear and observe. Instead of repeating word for word what is in the textbook, simplify the concepts to ease their understanding, so that when they have already understood.

b) Gender

During group activities try to form heterogeneous groups (with boys and girls) or when student teachers start to present their findings encourage both (boys and girls) to present.

c) Financial education

Electrochemical cells find many applications in many activities. They are used every day in electronic devices (laptop computers, clocks, radios, remote controls, calculators, vehicles, etc) to produce electrical energy needed. It is in this way that the student teachers should be aware that he can make money from these cells and/or batteries as they are needed by a great number of users. A particular attention should always be put on the comparison between the cost and the quality of electrochemical cells to be purchased..

d) Peace and values education

During group activities, the teacher will encourage student teachers to help each others and to respect opinions of colleagues.

e) Environment and sustainability

Electrochemical cells poorly used may have many harmful effects, and for human beings and for the environment in general. For example, some components of the electrochemical cells contain poisonous chemicals like mercury (Hg), lead (Pb), etc; and several which are disposable are the main environmental pollutants.

f) Standardisation culture

Every student teacher who can learn electrochemical cells and its applications must be informed the way to use the standard ones. Student teachers should always not use or advice people to not use expired electrochemical cells that are rather a public danger

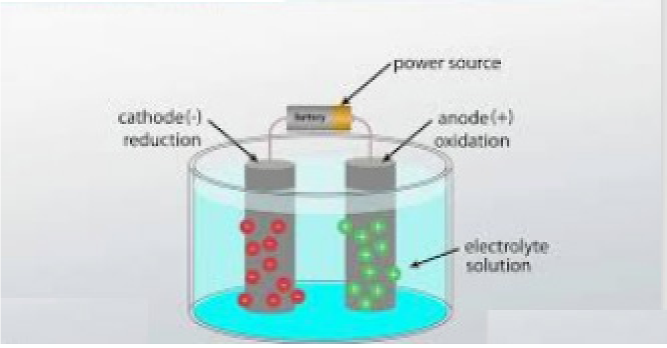
9.4. Guidance on introductory activity

Before introducing the first lesson (Definition and description of an electrochemical cell) of this unit, let student teachers attempt the introductory activity 9.

- Allow the student teachers to carefully and attentively analyse because they have questions required to be answered using their observations.
- Put your student teachers in groups of four (4)
- Give them time between 15 and 20 minutes to answer discussion questions provided.
- Randomly, choose four (4) groups to present their findings.
- Allow some student teachers evaluate the ideas of the presenters.
- Take this time to draw the conclusion (by asking some short questions about the observation and the answers provided to the discussion questions) which is in line with the objectives of the unit.

Expected answers to discussion questions

1. Picture (a) represents batteries whereas picture (b) represent an electrolytic cell.
2. Batteries produce electric current from chemical reaction. In an electrolytic cell a chemical reaction is caused by an electric current. In both cases, redox reactions are involved.
3. Refer to student teacher's book
4. Label of the picture (b).



9.5. List of lessons/sub-heading

Unit 9	**Objectives**	**Content**	**Number of periods**
Lesson 1	• Define and description the term electrochemical • Construct a simple galvanic cell. • Record the results of a measurement accurately using a voltmeter	Definition and description of an electrochemical cell	2
Lesson 2	• Describe the standard hydrogen electrode.	Standard hydrogen electrode	2
Lesson 3	• Explain the working of galvanic cells using the fully labelled diagram • Calculate standard cell potentials from standard electrode potentials of two half cells • Apply the principles of redox processes to energy storage devices	Cell reactions and e.m.f. of the galvanic cells	2
Lesson 4	• Properly use electrolytic cell to carry out electroplating of graphite by copper	Corrosion and its effects on metallic objects	1
Lesson 5	• Describe industrial applications of electrochemical cells • Appreciate contributions of electrochemistry to the social and economic development of the society	Applications of electrochemical cells	1
Lesson 6	• Compare galvanic cell with electrolytic cell	Comparison between galvanic cell and electrolytic cell.	1
		End unit assessment	1

Lesson 1: Definition and description of an electrochemical cell (2 periods)

a) Learning objectives

- Define and description the term electrochemical
- Construct a simple galvanic cell.
- Record the results of a measurement accurately using a voltmeter

b) Prerequisites/ Revision/ Introduction

For a better understanding of the electrochemical cells, it requires acknowledge about the oxidation and reduction reactions that must be studied in unit 8; electrolytic cell as studied in electrolysis (Senior 3)

c) Teaching resources

The resources like a projector, chalkboard, smart board, worksheets, etc may be used in teaching/learning this lesson.

d) Learning activities

- **Guidance**

Before introducing the lesson, let student teachers attempt activities 9.1.1 and 9.1.2 that introduce the lesson 1 of the unit.

As facilitator you are expected to guide student teachers through the following steps:

- form groups of four and let the student teachers perform the activity 8.4
- Let some groups present their work to the class and allow the rest of the class to evaluate the work of their colleagues
- Comment on student teachers' responses written in their note books, and give them the summary of expected feedback based on their findings.

Before the practical

- Try to copy this activity on a worksheet and make copies equal to the number of groups that you will form according to your class size.
- Try to make the required materials available before your student teachers enter (go) in the laboratory.
- Prepare all chemicals needed to perform this practical activity.
- Make sure you understa nd well the content (theory) about the practical to be performed so as to help student teachers link it with their observations

During practicals

- Form groups of 3-4.
- Give them worksheet and ask them to read instructions.
- Ask them to read the procedure written on the worksheet and verify if all chemicals and apparatus are available and well prepared.
- Provide each group with a reporting sheet.
- Let student teachers perform the experiment as described in the procedure.
- Move around to ensure that all student teachers are actively engaged.
- Every group records their observations and make an interpretation.

- Call upon randomly four groups to share their results
- Let the class evaluate the findings of their colleagues and point out the key ideas about the balancing of redox reactions.
- Write a short summary about the electrochemical cells..

Answers to activity 9.1

An oxidising agent is a chemical species that causes the oxidation of another substance by accepting electrons from it.

A reducing agent is a chemical species that causes the reduction of another substance by giving it electrons.

Copper (II) ions act as oxidising agent whereas zinc acts as a reducing agent.

$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ oxidation

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$ reduction

Overall ionic equation: $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$

Galvanic cell

Oxidation in the zinc compartment and reduction in the copper compartment.

Application activity 9.1

1. An electrochemical cell is a device which is capable of either producing electrical energy from chemical reactions or causes chemical reactions to take place through the introduction of electrical energy.
2. A simple electrochemical cell can be made by connecting together **two half cells** with different electrode potentials.

One half cell **releases electrons (oxidation at the anode).**

The other half cell **gains electrons (reduction at the cathode).**

In an electrochemical cell, *the electrons flow* from the negative terminal (anode) to the positive terminal (cathode) and the *current flows in the opposite direction* i.e. from cathode to anode.

3. The salt bridge is used to prevent the potential difference that arises between the two solutions when they are in contact with each other. This potential difference is called *the liquid junction potential.*
   - It completes the electrical circuit by connecting the electrolytes in the two half cells.
   - It prevents the diffusion of solutions from one half-cell to the other.
   - It maintains the electrical neutrality of the solutions in the two half cells.

Lesson 2: Standard hydrogen electrode (2 periods)

a) Learning objective

Describe the standard hydrogen electrode.

b) Prerequisites/ Revision/ Introduction

The student teachers will learn better the concept of **Standard Hydrogen Electrode** if they have a good understanding of Current electricity (Senior 1, Unit 12), redox reactions (Chemistry SME, year 3, Unit 8).

c) Teaching resources

Smart board /chalk board, chalkboard, flip charts, text books.

d) Learning activities

▪ **Guidance**

- Let student teachers to discuss in groups for 10 minutes of two the activity 9.2
- Ask randomly five groups to present their findings;
- Allow the rest of the class to evaluate the ideas presented by their colleagues.
- Ask student teachers thee key points about the standard Hydrogen Electrode.
- Answers to activity 9.2
- Potential difference or voltage, difference in charge between two points in an electrical circuit.
- Measure of the potential difference is measured using a voltmeter
- Units of the potential difference are volts.

See student book

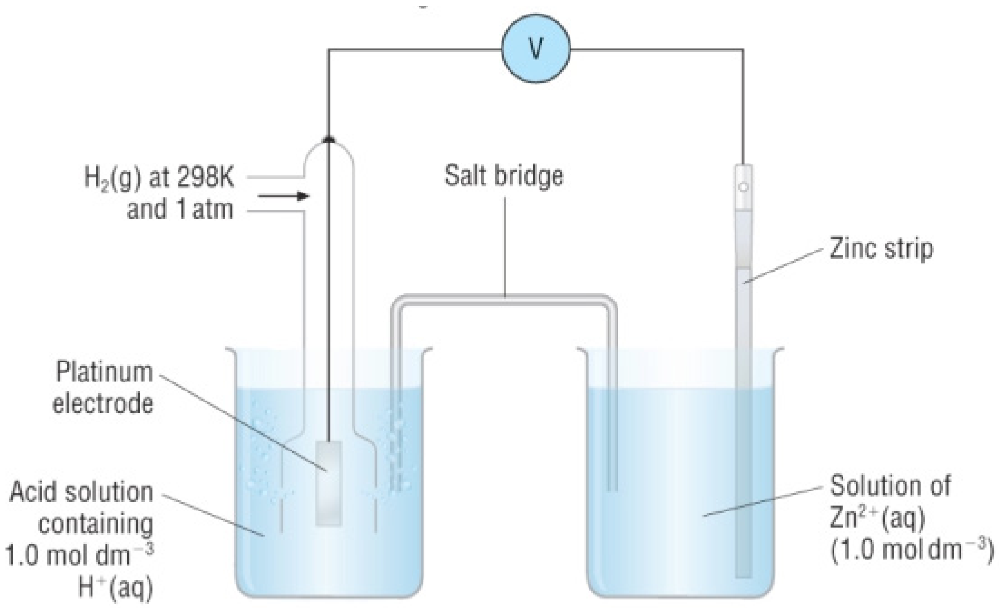
Application activities 9.2

Answers to application activities

1. Standard electrode potential is the potential measured with respect to a standard hydrogen electrode (SHE) at 25 ^{o}C with 1 M concentration of each ion in solution and 1 atm of pressure of each gas involved.
2. Yes, it is possible to use another. In fact, the hydrogen electrode is not a convenient reference electrode to use in measurements because maintaining a stream of hydrogen at 1 atm takes careful management. Thus, secondary standards are employed, such as the saturated calomel electrode.
3. Answers

a) True
b) False

4. With the aid of a diagram, explain how the standard electrode potential of zinc is measured.



A = Hydrogen at 1 atm, B = Inner glass tube, C = 1M HCl, D = Platinum

Lesson 3: Cell reactions and e.m.f. of the galvanic cells (2 periods)

a) Prerequisites/ Revision/ Introduction

The student teachers will learn better the concept of **Standard Hydrogen Electrode** if they have a good understanding of Current electricity (Senior 1, Unit 12), redox reactions (Chemistry SME, year 3, Unit 8).

b) Teaching resources

Smart board /chalk board, chalkboard, flip charts, text books.

c) Learning activities

- **Guidance**

- Let student teachers to discuss in groups for 10 minutes of two the activity 9.3
- Ask randomly five groups to present their findings;
- Allow the rest of the class to evaluate the ideas presented by their colleagues.
- Ask student teachers thee key points about the electromotive force (e.m.f).

Answers to activity 9.3

See student book

Answers to application activities 9.3

1.

a) To remove the oxide layer on the aluminium

b) An appropriate method for delivering H_2 gas over a Pt electrode

Need H_2 gas and Pt electrode labelled (allow gas delivered directly below the electrode).

The Pt electrode must clearly be in contact with a solution of a named acid

c) The carbonate ion reacts with the acid (in the SHE) / reaction between carbonate and Al^{3+}

OR H^+ / Al^{3+} concentrations change / cell e.m.f. altered.

2.

a) Pressure: 101.3 kPa (1.013 x 105Pa)

Temperature: 25°C (298K)

b) Salt bridge

c) Anode

Mg is a stronger reducing agent than H_2 and (Mg) will be oxidised.

Mg undergoes an oxidation reaction in this setup

d) $Mg(s) \mid Mg^{2+}(1\ mol\ dm^{-3}) \parallel H^+(1\ mol\ dm^{-3}) \mid H_2(g) \mid Pt(s)$

$Mg(s) \mid Mg^{2+}(aq) \parallel H^+(aq) \mid H_2(g) \mid Pt(s)$

e) $E^0_{cell} = E^0_{cathode} - E^0_{anode}$

$= 0.00 - E^0_{anode} = 0.00-2.36$

$= -2.36V$

f) $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$

3.

a) Temperature= 25^0C (298K)

Concentration (of electrolytes)= 1 $mol.dm^{-3}$

b) Emf / potential difference

c) i) (Half-cell) A

ii) (Half-cell) B

d) Combination AB

e) i) Magnesium (Mg)

It is oxidised (loses electrons), increases in oxidation number (stronger reducing agent).

ii) = $E^0_{cell} = E^0_{cathode} - E^0_{anode}$

= -0.13 –(-2.36) =-2.23

iii) Increases

Use equilibrium shifts to work out answer.

iv) Allow for the migration of positive ions to the cathode half-cell.

Allows for the migration of negative ions to the anode half-cell

4.

a) increase

The reaction is exothermic. Energy (heat) is released $\Delta H < 0$

b) Aluminium is a stronger reducing agent than copper and will reduce the copper (II) ions to copper.

c) $2\,Al(s) + 3\,Cu^{2+}(aq) \longrightarrow 2\,Al^{3+}(aq) + 3\,Cu(s)$

5.

a) Al (Aluminium)

b) $Al(s)\ |\ Al^{3+}(1\ mol\ dm^{-3})\ ||\ Cu^{2+}(1\ mol\ dm^{-3})\ |\ Cu(s)$

c) $E^0_{cell} = E^0_{cathode} - E^0_{anode}$

= -0. 34 –(-1.66) =-2.23

= 2.00V

d) The salt bridge is now removed.

Zero Volts (0 V)

The circuit is open.

6.

a) $Fe \longrightarrow Fe^{2+} + 2e-$

Oxygen

= 0.84 V ; Because E° cell is positive, the reaction is spontaneous

Lesson 4: Corrosion and its effects on metallic objects (1 period)

a) Prerequisites/ Revision/ Introduction

For better understanding corrosion as an electrochemical process and its effects on metallic objects, it is required to know the reduction and oxidation reactions (Chemistry SME Year3 Unit 7), electrochemical cell description as must be studied previously in this unit and electrolysis and electrolytic cells, the half-reactions at electrodes and the processes like electroplating, galvanising or anodisation studied in Senior 3

b) Teaching resources

Video player, a projector, computer machine, chalkboard, worksheets, flip chart paper, etc

c) Learning activities

- **Guidance**

- Put your student teachers in groups of four.
- Provide them with the **activity 9.4** (you can use the chalkboard, books, and worksheets or even use the projector).
- Give them time between 15 and 25 minutes to answer the questions of this activity.
- Invite 3 groups chosen randomly to present their findings.
- Allow some student teachers to comment about the findings presented by their colleagues.
- Take this time to give additional information (missing in what found by all groups) and use some questions to draw the conclusion.
- Give them the **application activity 9.4** in pairs to be completed in 10 min and collect worksheets to be corrected, once you return in the class with corrected copies, remember to give feedback.

Answers to activity 9.4

This is known as *corrosion*.

We know that metals are highly reactive elements due to less number of valence electrons therefore they tend to lose electrons during chemical reactions. Corrosion is also a chemical reaction in which metal reactions with atmospheric moisture and oxygen gas to form metallic oxides. That is the reason, metals corrode quickly.

Some effect of corrosion on metallic objects:

- Loss of efficiency
- Contamination of product
- Damage of metallic equipment
- Inability to use metallic materials
- Loss of valuable materials such as blockage of pipes, mechanical damage of underground water pipes, etc.

d) Answers to application activities 9.4

1. $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$
2. $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$
3. The presence of salt (or any electrolyte) in the water accelerates the reaction because it increases the conductivity of water, effectively increasing the concentration of ions in the water and so increasing the rate of oxidation (corrosion) of the metal.
4. Magnesium and Zinc. Magnesium and zinc are often used as sacrificial metals. They are more reactive than iron and lose their electrons in preference to iron. Although tin is used to coat steel cans, it does not act as a sacrificial metal.

Lesson 5: Applications of electrochemical cell (1 period)

a) Prerequisites/ Revision/ Introduction

Understanding the working and applications of electrochemical cell, you should know better the functioning of an electrochemical cell (as studied in the previous lessons of this unit) and redox reactions at electrodes.

b) Teaching resources

Computer, video player, a projector, chalkboard/ smart board, worksheets, flip chart paper, books, etc

c) Learning activities

- **Guidance**

- Before studying this lesson, give **activity 9.5** as homework in groups of 6 to be submitted and presented in the beginning of this lesson.
- Let the student teachers be in their respective groups (those used in working the homework).
- Randomly invite the representative of each group to present their findings
- Allow the rest of the class evaluate the ideas of the presenters.
- Allow the student teachers to summarise the key points
- After this, add the main information missing and correct the common mistakes made.
- Let the student teachers do the application activity 9.5

Answers to activity 9.5

1. Generation of electricity
2. Use the Student's Book to answer this question.
3. Cells ('batteries') can be classified as:

PRIMARY CELLS (or non-rechargeable); they are discarded, after they run down when all the chemicals are used up i.e. no more chemical potential energy available

SECONDARY CELLS (oe rechargeable); they can be recharged after they have run down i.e. the discharge reactions producing the electricity are reversed to build up the store of chemical potential energy.

Fuel cells, which must be continuously fed of chemicals e.g. fuel plus oxidant to maintain the chemistry producing the electrical current. Fuel cells used to generate an electric current do not need to be electrically recharged.

They produce electricity directly from gaseous or liquid fuels such as hydrogen or hydrocarbons with only safe waste products of water or carbon dioxide.

Answers to application activities 9.5

1. Secondary because it can be recharged by passing direct current through them and can be used again and again.

$Pb + PbO_2 + 2\ H_2SO_4 \rightarrow 2\ PbSO_4 + 2\ H_2O$

Or $Pb + PbO_2 + 2\ HSO_4^- + 2H^+ \rightarrow 2\ PbSO_4 + 2\ H_2O$

= 2.06 V

Emf of cell battery = 6 x 2.06 = 12.36 V

- Environmental risks Acid used as electrolyte can contaminate groundwater
- Plastic casings are non-degradable and can pollute the environment.
- Lead (in electrodes) is a heavy metal and can harm crops / plants.

2.

$O_2\ (g) + 2\ H_2O(l) + 4\ e^- \rightarrow 4\ OH^-(aq)$

(i) $2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$

(ii) EMF = 0.88 + 0.40 = 1.23 V

(iii) From the hydrogen half-cell to the oxygen half-cell.

As a catalyst

c) Water produced during the cell reaction can be consumed by an astronaut. The cell can supply electricity indefinitely as long as the supply of hydrogen and oxygen is not discontinued.

3.

$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ / $H_2 \rightarrow 2H^+ + 2e^-$

Or $O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$ / $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$ (Any order)

Hydrogen (electrode) produces electrons and Oxygen (electrode) accepts electrons/Electrons flow to the oxygen electrode

Hydrogen / The fuel / Reactants are supplied continuously.

Hydrogen-oxygen fuel cell can produce drinking water of potable quality because the residual product discharged by the hydrogen-oxygen cell is water which is in its pure form.

i) In the fuel cell, a greater proportion of the energy available from the hydrogen–oxygen reaction is converted into useful energy/Less energy wasted / More efficient

ii) Hydrogen is flammable / H^+ corrosive / OH^- corrosive / Hydrogen explosive

4.

a) Primary cells

b) Equation 2

- This is a reduction equation
- Reduction takes place (at the cathode)

c) ANY ONE:

- The cell reaction reaches equilibrium.
- The rates of the forward and reverse reactions become equal.
- Substances reach their equilibrium concentrations.

5.

a) Secondary cells

b) Equation II $NiO_2(s) + 2\ H_2O(l) + 2e- \rightarrow Ni(OH)_2(s) + 2\ OH^-(aq)$ Reduction (takes place at cathode). Electrons gained (at cathode)

$NiO_2(s) + Cd(s) + 2\ H_2O(l) \rightarrow Ni(OH)_2(s) + Cd(OH)_2(s)$

6.

Electrolyte is a paste/not a liquid

The acid in the battery attacks (reacts with) the zinc, causing it to corrode faster than the alkaline-based battery.

Rechargeable batteries can be re-used and less is manufactured/transported - less greenhouse gases emitted OR More primary batteries need to be manufactured as they cannot be re-used and transportation / manufacturing leads to emission of greenhouse gases.

7.

The build-up of $H_{2(g)}$ in the cell could cause the cell to burst or explode if ignited.

In a zinc-carbon cell, such as the one above, half-reaction (iii) and the half-reaction that takes place in the Zn/Zn2+ half-cell, produce an emf of 1.5 V under standard conditions.

$Zn \rightarrow Zn^{2+} + 2e^-$

$Zn(s) + 2\ NH_4^+(aq) + 2\ MnO_2(s) \rightarrow Zn^{2+}(aq) + Mn_2O_3(s) + 2\ NH_3(g) + H_2O(l)$

NH_4^+ is an acid and reacts with the zinc casing.

Can be reused as an electrode in other situations.

Lesson 6: Comparison between galvanic cell and electrolytic cell (1 period)

a) Prerequisites/ Revision/ Introduction

For comparing electrochemical cell and electrolytic cell, student teachers have to master the concept of electrolysis studied in senior 3 and the functioning of electrochemical cells dealt with in this unit

b) Teaching resources

- Chalkboard, worksheets, flip chart paper,
- All materials and chemicals require for activity 9.6

c) Learning activities

- **Guidance**
- This lesson must be started in the laboratory in order to be able to work out the learning activity proposed.
- Put your student teachers in groups of 4.
- Provide them with the activity 9.6 (you can use the chalkboard, books, and worksheets or even use the projector).

- Give them time between 15 and 25 minutes to read, analyze, work out the experiment, interpret, discuss and answer questions about the activity.
- Ask 3 groups to present their findings and submit this work to be corrected.
- Allow some student teachers to comment about the findings of their colleagues presented.
- Take this time to use some questions in order to draw the conclusion which is in line with the objectives of the unit (using the answers being provided by student teachers).
- Give them the checking up 9.6 as homework and collect worksheets to be corrected, once you return in the class with corrected copies, remember to give feedback.

Answers for activity 9.6

1. Carbon (graphite) electrode is coated with copper metal.

   $Cu^{2+}(aq) + 2\ e- \rightarrow Cu(s)$

   $4OH^{-}\ (aq) \rightarrow O_2 + H_2O(aq) + 4e-$

   Graphite electroplating/separation of copper

2. Galvanic cell is a device which converts chemical energy into electrical energy.

   Electrolytic cell is a device which converts electrical energy into chemical energy.

3. See the Student's Book

Answers to application activities 9.6

1. See the Student' Book
2. (a)
3. (a)
4. (b)
5. Electrolytic cells

i) A

ii) B

(i) Remains the same.

The rate of oxidation of copper at the anode is equal to the rate of reduction of copper(II) ions at the cathode.

(ii) Cu → $Cu^{2+} + 2e^-$

(i) It contains precious metals (valuable, expensive metals.)

(ii) Consumes large amount of electricity (energy).

Depletes coal resources/Contributes to global warming/Habitats destroyed in mining of coal/Contributes to acid rain.

6. a) DC

   b) Free ions needed to conduct electricity.

      (i) Cathode: $Cu^{2+} + 2e- \rightarrow Cu$

      (ii) $Cu \rightarrow Cu^{2+} + 2e-$

i) Pt is a weaker reducing agent than Cu and will not be oxidized/Cu is a stronger reducing agent than Pt and will be oxidised. The platinum will not react at all, and will just be left over at the end.

ii) Remains the same

The rate at which Cu is oxidised at the anode equals the rate at which Cu^{2+}(aq) is reduced at the cathode.

9.6.Summary of the Unit

An electrochemical cell is a device which is capable of either producing electrical energy from chemical reactions or causes chemical reactions to take place through the introduction of electrical energy. There are two types of electrochemical cells: galvanic (voltaic) and electrolytic cells.

Oxidation-reduction (or redox) reactions take place in electrochemical cells where spontaneous reactions occur in galvanic (voltaic) cells; non-spontaneous reactions occur in electrolytic cells. Oxidation occurs at the **anode** and reduction occurs at the **cathode.**

The anode of an electrolytic cell is positive whereas the cathode is negative. In a galvanic cell, the anode is negatively charged and the cathode is its positive terminal.

In both galvanic and electrolytic cells, oxidation takes place at the anode and electrons flow from the anode to the cathode. In a galvanic cell, each electrode is immersed in an electrolyte containing its own ions (in the separate containers) and these form a half cell. A simple electrochemical cell can be made by connecting together two half cells with different electrode potentials. The oxidation occurs at one half-cell and reduction at another.

Standard Hydrogen Electrode (SHE) is used to measure “standard electrode potential” but other electrodes may be used as a *standard.*

Electromotive force is also known as cell voltage or cell potential, *and it is measured in volts. Conveniently*, an electrochemical cell can be represented by writing a cell notation than by making a drawing.

If the standard cell potential is positive, the reaction is spontaneous; if it is zero, a redox reaction is at equilibrium and if the $\mathbf{E^0}$ is negative, the reaction is not spontaneous.

The importance of electrochemical cells or galvanic cells lies in their ability to provide us with a portable source of electrical energy. Quite often, we use the term “battery” to represent the arrangement of two or more galvanic cells connected in series. The galvanic cells can be broadly classified into three categories, namely primary cells, secondary cells and fuel cells.

Primary cells are the type of cells that become dead over a period of time and the chemical reaction stops. They cannot be recharged or used again. Some common examples are dry cell, mercury cell, etc.

Secondary cells are the type of cells that can be recharged by passing direct current through them and can be used again and again. These are the types of batteries found in devices such as smart phones, electronic tablets, and automobiles. Some examples are lead-storage battery, nickel-cadmium storage cell, etc.

Fuel cells work like batteries but they do not run down or need recharging. They produce electricity and heat as long as fuel is supplied. In a hydrogen fuel cell, a catalyst at the anode separates hydrogen molecules into protons and electrons, which take different paths to the cathode.

Electrolytic and voltaic cells are very similar as but also they have striking differences between them.

9.7. Additional information for teachers

Nernst Equation

The Nernst Equation enables one to determine electromotive forces (emf) of many processes, for instance the resting potential of cell membranes. We can then deduce the biological standard potentials which are important in studying biological process such as action potential during a spike of a neuron in response to a stimulus.

The Nernst Equation is derived from the e.m.f and the Gibbs energy **under**

non-standard conditions.

$E^o = E^o_{reduction} - E^o_{oxidation}$

When **Eo** is positive, the reaction is spontaneous. When $\mathbf{E^o}$ is negative, the reaction is not spontaneous. Since the change in Gibbs free energy ΔG, is also related to spontaneity of a reaction, therefore, ΔG and **E** are related.

Specifically,

$\Delta G = -\mathbf{nFE}$

where, **n** is the number of electrons transferred in the reaction, **F** is the Faraday constant (96500 C/mol) and **E** is potential difference. Under standard conditions, this equation is then

$\Delta G^o = -\mathbf{nFE^o}$

Since,

$\Delta G = \Delta G^o + \mathbf{RTlnQ}$(1)

Substituting $\Delta G = -\mathbf{nFE}$ and $\Delta G^o = -\mathbf{nFE^o}$ into equation (1), we have:

$- nFE = - nFE^o + RTlnQ$

Divide both sides of the equation above by $-\mathbf{nF}$, we have

$\mathbf{E = E^o - RTn/FlnQ}$(2)

Equation (2) can be rewritten in the form of log base 10:

$\mathbf{E = E^o - 2.303RT/nFlogQ}$ (3)

At standard temperature T = 298K, the **2.303RTF** equals .0592 V, so equation (3) turns into:

$E = E^o - .0592V/nlogQ$

The equation above indicates that the electrical potential of a cell depends upon the reaction quotient **Q** of the reaction. As the redox reaction proceeds, reactants are consumed, thus concentration of reactants decreases.

Conversely, the products concentration increases due to the increased in products formation. As this happens, cell potential gradually decreases until the reaction is atequilibrium, at which ΔG =0.

Example

For the Zn-Cu reaction:

$Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s) = 1.10V$

Initially, $[Cu^{2+}] = [Zn^{2+}] = 1M$ at standard $T = 298K$. as the reaction proceeds, the concentration of **Cu^{2+}** decreases as the concentration of Zn^{2+}increases. After one minute, $[Cu^{2+}] = 0.05M$ while $[Zn^{2+}] = 5.0M$. Calculate the cell potential.

Answer:

According to Nernst, the cell potential is:

$E = E^o - \log Q$

$E = E^o - \log$

$E = 1.04V$

The initial cell potential is E = 1.10V. After one minute, the potential drops to 1.04V. As the reaction continue to progress, more Cu^{2+} will be consumed and more Zn^{2+} will be generated. As a result, the cell potential continues to decrease until it drops down to 0. At that moment the concentration of the reactants and products stops changing. The system has reached the equilibrium.

At equilibrium, the reaction quotient **$Q = Keq$**. Also, at equilibrium, $\Delta G = 0$ and $\Delta G =$ **$-nFE$**, so **$E = 0$**. Therefore, substituting **$Q = Keq$** and **$E = 0$** into the Nernst equation, we have:

$0 = E^o - RTnFlnKeq$

At standard conditions, the equation above simplifies into:

$0 = E^o - 0.0592nlogKeq$

This equation can be rearranged into:

$\log K_{eq} = nE^o 0.0592$

The equation above indicates that the equilibrium constant **Keq is proportional to the standard potential** of the reaction. Specifically, when:

$K>1$, $Eo>0$, reaction favours products formation.

$K<1$, $Eo<0$, reaction favours reactants formation.

This result fits Le Chatelier Principle that states that when a system at equilibrium experiences a change, the system will minimize that change by shifting the equilibrium in the opposite direction.

The reaction will proceed spontaneously if $\Delta G < 0$, and if ΔG is negative, then E_{cell} must be positive.

If the concentrations of reactants increase relative to those of products, the cell reaction becomes more spontaneous and the emf increases. If the concentrations of products increase relative to reactants, the emf decreases. As voltaic cell operates, reactants are converted into products and this increases the value of Q and causes the emf to decrease.

The concentration cell is a voltaic cell with a non-zero emf can be constructed using the same species in both the anode and cathode compartments as long as the concentrations are different. Metal corrosion causes metal destruction and the most common corrosion process is the rusting of iron which is an electrochemical process.

GUIDANCE ON SKILLS LAB 9

- This is a research activity that can be carried out during extra time lessons.
- Student teachers should be allowed to use ICT lab during these extra time under the supervision of their chemistry teacher.
- The task can be in groups of two student teachers.
- The tutor has to monitor the progress of this research.
- After the required time the tutor evaluate the work done and communicate a feedback to the student teachers. This required time should a result of an agreement between the student teachers and the tutor based on their availability.

Expected answers to skills lab 9

Electrochemical cells present some advantages over fossil fuels. Among them, we can highlight the following.

- Electrochemical cells do not release greenhouses or toxic gases in the environments
- Hydrogen fuel is safer than nuclear power plant or fossil plant as it does not release radioactive substances.
- Methanol fuel is interesting as methanol can easily be converted into hydrogen on-board vehicle. It is abundant, biodegradable and is liquid at room temperature.
- Microbial fuels cells help to get energy from wastes products. That is the technology uses the biochemical activities of microorganisms as a resource to obtain hydrogen that may be used to generate electricity.

However, the following are some of the many problems that may be faced when using electrochemical cells as sources of energy.

- Some cells are expensive and /or contain toxic metals such as mercury, lead, cadmium and so on.
- Hydrogen is not easy to handle as it flammable and requires very low temperature for liquefaction.
- Cost for transporting hydrogen is very high.
- Hydrogen fuel is very expensive.
- Methanol fuel cell has health issues as methanol is toxic and corrosive. It burns with non luminous flame and it is produced from fossil fuels.

The student teacher should add to these ideas and develop them.

Most of these technologies are still under studies in order to make them affordable,

9.8. Answers to End unit assessment 9

MULTIPLE CHOICE QUESTIONS

1. d) To convert chemical energy to electrical energy
2. d) The electrode where reduction takes place and electrons are gained.
3. e) All voltaic (galvanic) cells involve the use of electricity to initiate non-spontaneous chemical reactions.
4. c) Reduction occurs at the zinc electrode as the cell operates.
5. b) Au, 1.94 V
6. c) 1.44 V
7. e) 0.080 V
8. b) -145 kJ
9. e) ~10^{-72}
10. c) only I

OPEN QUESTIONS

Question 1

a) a) *Hint:* Electrons move from Zn to Ag.
b) Ag is the cathode.
c) Cell will stop functioning.
d) When $E_{Cell} = 0$.
e) Concentration of Zn^{2+} ions will increase and concentration of Ag^{+} ions will decrease

When $E_{cell} = 0$ equilibrium is reached and concentration of Zn^{2+} ions and Ag^{+} ions will not change.

Question 2

a) a) *Cell e.m.f.*: 1.93 V

b) *Half equation*: Mg $\longrightarrow$ $Mg^{2+} + 2e^{-}$ or use $\rightleftharpoons$

c) *Change in e.m.f.*: increases

Explanation: Equilibrium displaced to Mg^{2+} or to the left

d) *Cell e.m.f.* : –0.84 (V)

Explanation: Fe is giving electrons or forming Fe^{2+} or reaction goes in the reverse direction.

Question 3

a) i) *Name:* (standard) hydrogen (electrode) / hydrogen half cell

Role: reference electrode / electrode to which others are compared

ii) 0.00(V) / 0 / zero

b) i) emf = –0. 14 –(–0.25) = + 0.11 V

ii) Electrode D / Sn^{2+} /Sn /tin / right hand electrode

iii) Ni + Sn^{2+} // Ni^{2+} + Sn

c) i) e.m.f = –0.44 – (–0.14) = –0.30 (V) / emf for cell is – ve +ve e.m.f for feasible reaction / tin is a weaker reducing agent thus the reaction would not occur

ii) Manganese will decrease in size / disappear / eaten away / dissolves / solution turns (pale) pink Effervescence / bubbles (of colourless gas) / fizzing not gas given off.

Reaction likely to occur is $Mn + 2H^{+} \longrightarrow Mn^{2+} + H_2$ +ve e.m.f. / +1.18 V / Mn is strong reducing agent / has large – ve E°

Question 4

Write the Nernst Equation for 25°C:

$E = E^{o} - 0.0592/n \times \log Q$

Calculate E° for the cell:

Write the expression for Q:

$Q = [Sn^{2+}]/[Ag^{+}]^{2}$

(concentrations of solids = 1)

Write the Nernst Equation for this example:

$E = E^{o} - 0.0592/n \times \log([Sn^{2+}]/[Ag^{+}]^{2})$

Substitute the values:

$E^o = +0.66V$

n = 2 (2 moles of electrons transferred during the redox reaction)

$[Sn^{2+}] = 0.15$ M

$[Ag^+] = 1.7$ M

$E = +0.66 - 0.0592/2 \times \log([0.15]/[1.7]^2)$

Anode: $Sn_{(s)} \rightarrow Sn^{2+}_{(aq)} + 2e$ $E^0 = -0.14V$	
Cathode : $2 \times [e^- + Ag^+_{(aq)} \rightarrow Ag_{(s)}]$ Cell: $Sn_{(s)} + 2Ag^+_{(aq)} \rightarrow Sn^{2+} + 2Ag_{(s)}$	$E^o = +0.80V$ $E^o = +0.66V$
Calculate Q: $E = +0.66 - 0.0592/2 \times \log[0.0519]$ Calculate logQ: $E = +0.66 - 0.0592/2 \times -1.285$	Calculate E: $E = +0.66 - 0.0592/2 \times -1.285$ **E = +0.70V** $E > E^o$, and positive, so the cell reaction has a greater tendency to take place at these concentrations.

Question 5

a) $H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$ / $H_2 \rightarrow 2H^+ + 2e^-$

$O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$ / $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

b) Hydrogen (electrode) produces electrons

Oxygen (electrode) accepts electrons

c) Hydrogen / the fuel / reactants supplied continuously / fed in

d) i) In the fuel cell, a greater proportion of the energy available from the hydrogen–oxygen reaction is converted into useful energy

ii) Hydrogen is flammable / H^+ corrosive / OH^- corrosive / hydrogen explosive

Question 6

a) Pressure: 101.3 kPa (1.013 x 105 Pa) and Temperature: 25 °C (298 K)

b) Salt Bridge

c) Anode, Mg is a stronger reducing agent than H_2 and therefore (Mg) will be oxidised.

d) $Mg(s) \mid Mg^{2+}(1\ mol{\cdot}dm^{-3}) \parallel H^+(1\ mol{\cdot}dm^{-3}) \mid H_2(g) \mid Pt(s)$

e) $E^{\theta}cell = E^{\theta}_{cathode} - E^{\theta}_{anode}$

$2.36 = 0.00 - (E^{\theta}_{anode})$

$E^{\theta}_{anode} = -2{,}36$ V

f) $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$

Question 7

a) The process in which electrons are lost by a substance.

b) Reduction

c) $Ag^+(aq) + e^- \rightarrow Ag(s)$

d) Silver (Ag)

e) The rate of oxidation (of Ag from the electrode) equals the rate of reduction of Ag^+ from the electrolyte.

Question 8

a) Platinum electrode Hydrogen gas $H^+(aq)$ or HCl or H_2SO_4

298 K, 100 kPa or 1 atm or 1 bar 1 M $[H^+]$

b) i) 1.61 V

ii) Positive

c) i) 1.36 V Left to right

ii) $Ce^{4+} + e^- \longrightarrow Ce^{3+}$ $V^{3+} + H_2O \longrightarrow VO^{2+} + 2H^+ + e^-$

or reversed or $V^{3+} + 2H_2O \longrightarrow VO^{2+} + 4H^+ + 2e^-$

d) $Ce^{4+} + V^{3+} + H_2O \longrightarrow VO^{2+} + 2H^+ + Ce^{3+}$

or $2Ce^{4+} + V^{3+} + 2H_2O \longrightarrow VO^{2+} + 4H^+ + 2Ce^{3+}$

e) VO_2^+ and VO^{2+}

9.9. Additional activities

9.9.1. Remedial activities

1. Voltage is the measure of ______.

a) The amount of charge per unit of work

b) The number of joules per electron

c) The number of coulombs per joule

d) The amount of work done per group of charge

e) The amount of work per unit energy

2. What is the reduction potential for the half-reaction at 25° C: $Al^{3+} + 3e^- \rightarrow Al$, if $[Al^{3+}] = 0.10$ M and $E^o = -1.66$ V ?

a) -1.84 V
b) -1.60 V
c) -1.68 V
d) -1.66 V
e) -1.72 V

3. In the standard notation for a voltaic cell, the double vertical line "||" represents:
   a) A phase boundary
   b) Gas electrode
   c) A wire (metal) connection
   d) A salt bridge
   e) A standard hydrogen electrode

4. The following questions are about this cell: $Al|Al^{3+}||Pb^{2+}|Pb$
   a) Identify the anode and the cathode.
   b) Write the balanced overall reaction.
   c) Which electrode is inert, Al or Pb?

Answer:

a) Al is on the left so it is the anode. Pb is the cathode
b) $2\,Al + 3\,Pb^{2+} \rightarrow 2\,Al^{3+} + 2\,Pb$
c) Pb because it is not a reactant in the equation.

5. Use the data in the table below, where appropriate, to answer the questions that follow.

	Standard electrode potentials $E^{\ominus}$/V
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$2BrO_3^-(aq) + 12H^+(aq) + 10e^- \rightarrow Br_2(aq) + 6H_2O(l)$	+1.52
$O_3(g) + 2H^+(aq) + 2e^- \rightarrow O_2(g) + H_2O(l)$	+2.08
$F_2O(g) + 2H^+(aq) + 4e^- \rightarrow 2F^-(aq) + H_2O(l)$	+2.15

Each of the above can be reversed under suitable conditions.

a) i) Identify the most powerful reducing agent in the table.
   ii) Identify the most powerful oxidising agent in the table.

iii) Identify all species in the table which can be oxidised in acidic solution by $BrO_3^-{}_{(aq)}$.

b) The cell represented below was set up.

$Pt|Fe^{2+}(aq), Fe^{3+}(aq) || BrO_3^-(aq), Br_2(aq)|Pt$

i) Deduce the e.m.f. of this cell.

ii) Write a half-equation for the reaction occurring at the negative electrode when current is taken from this cell.

iii) Deduce what change in the concentration of $Fe^{3+}(aq)$ would cause an increase in the e.m.f. of the cell. Explain your answer.

Answer:

a) i) Fe^{2+}

ii) F_2O

iii) Fe^{2+}/Cl^-

b) i) e.m.f. = E(RHS) – E(LHS)

$= 1.52 - 0.77 = 0.75\ V$

ii) $Fe^{2+} \rightarrow Fe^{3+} + e^-$

iii) Decrease

Equilibrium (or reaction) shifts to right.

Electrode potential (for Fe^{3+}/Fe^{2+}) less positive (or decreases)

9.9.2. Consolidation activities

1. The following cell has an EMF of +0.46 V.

$Cu \mid Cu^{2+} \mid\mid Ag^+ \mid Ag$

Which statement is correct about the operation of the cell?

a) Metallic copper is oxidised by Ag^+ ions.

b) The silver electrode has a negative polarity.

c) The silver electrode gradually dissolves to form Ag^+ ions.

d) Electrons flow from the silver electrode to the copper electrode via an external circuit.

2. In an electrolytic cell the electrode at which the electrons enter the solution is called the ______; the chemical change that occurs at this electrode is called ________.

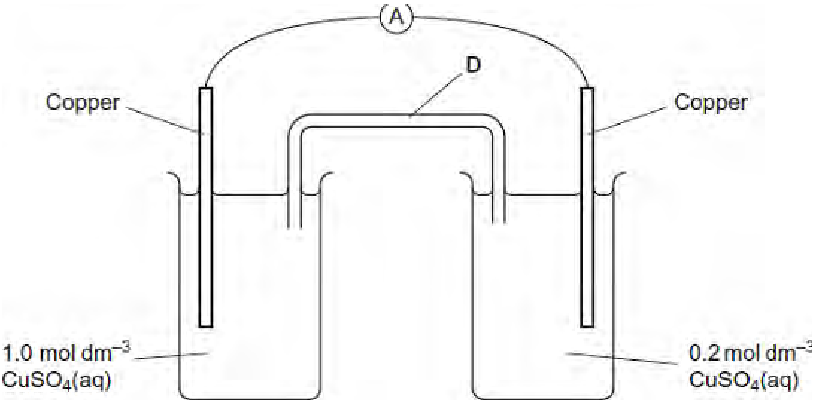
a) Anode, oxidation

b) Anode, reduction
c) Cathode, oxidation
d) Cathode, reduction
e) Cannot tell unless we know the species being oxidized and reduced.

3. In voltaic cells, such as those diagrammed in your book, the salt bridge ________ .

   a) is not necessary in order for the cell to work
   b) acts as a mechanism to allow mechanical mixing of the solutions
   c) allows charge balance to be maintained in the cell
   d) is tightly plugged with firm agar gel through which ions cannot pass
   e) drives free electrons from one half-cell to the other

4. An electrochemical cell is shown in the diagram. In this cell, the amount of copper in the electrodes is much greater than the amount of copper ions in the copper sulphate solutions.



   a) Explain how the salt bridge D provides an electrical connection between the two electrodes.
   b) Suggest why potassium chloride would not be a suitable salt for the salt bridge in this cell.
   c) In the external circuit of this cell, the electrons flow through the ammeter from right to left.
      i) Suggest why the electrons move in this direction.
      ii) Explain why the current in the external circuit of this cell falls to zero after the cell has operated for some time.
   d) The simplified electrode reactions in a rechargeable lithium cell are

Electrode B $Li^+ + e^- \longrightarrow Li$

Electrode B is the negative electrode.

The e.m.f. of this cell is 2.90 V.

i) Use this information to calculate a value for the electrode potential of electrode B.

ii) Write an equation for the overall reaction that occurs when this lithium cell is being recharged.

iii) Suggest why the recharging of a lithium cell may lead to release of carbon dioxide into the atmosphere.

Answer:

a) It has mobile ions / ions can move through it / free ions.

b) Chloride ions react with copper ions / Cu^{2+} **or** $[CuCl_4]^{2-}$ formed

c) i) The Cu^{2+} ions / $CuSO_4$ in the left-hand electrode more concentrated.

So the reaction of Cu^{2+} with 2e– will occur (in preference at) left-hand electrode / $Cu \rightarrow Cu^{2+}$ + electrons at right-hand electrode

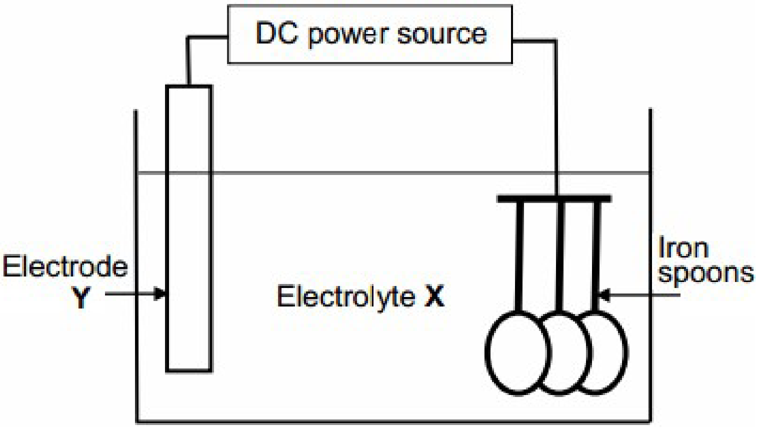
ii) (Eventually) the copper ions / $CuSO_4$ in each electrode will be at the same concentration

d) i) –3.05 (V)

ii) $LiMnO_2 \rightarrow Li + MnO_2$

iii) Electricity for recharging the cell may come from power stations burning (fossil) fuel (of carbon-containing) fuels.

7) The simplified diagram below shows an electrolytic cell used at an electroplating company to coat iron spoons with silver.



a) Write down the energy conversion that takes place in this cell.

b) Direct current (DC) is used in this process. Give a reason why alternating current (AC) is not used.

c) Which type of reaction (oxidation or reduction) takes place at the spoons?

d) Write down the:

   i) Equation for the half-reaction that takes place at electrode **Y**

   ii) Name or formula of electrolyte **X**

e) Give a reason why the concentration of electrolyte X remains constant during electroplating.

f) Apart from the income generated, write down one major reason why the company electroplates the spoons.

g) Write down the two major expenses for the company during the process.

Answer:

a) Electrical energy to chemical energy.

b) The polarity of the electrodes must remain constant during plating.

c) Reduction

d) i) $Ag(s) \rightarrow Ag^+ + e^-$

   ii) Silver nitrate /AgNO3 OR Silver ethanoate (silver acetate) /CH3COOAg

e) Rate of oxidation is equal to the rate of reduction.

f) Protection Protects it from rusting (corrosion) or Appearance/Improve appearance of spoons.

g)
   - Cost of electricity
   - Cost of silver

9.9.3. Extended activities

1. As the cell given below operates, the strip of silver gains mass (only silver) and the concentration of silver ions in the solution around the silver strip decreases, while the strip of lead loses mass and the concentration of lead ions increases in the solution around the lead strip. Which of the following represents the reaction that occurs at the negative electrode in the above cell? $Pb / Pb(NO_3)_2$ (1.0 M) || $AgNO_3$ (1.0 M) / Ag

   a) $Pb^{2+} + 2e^- \rightarrow Pb$

   b) $Pb \rightarrow Pb2+ + 2e-$

   c) $Ag^+ + e^- \rightarrow Ag$

   d) $Ag \rightarrow Ag^+ + e^-$

   e) none of the above

2. Calculate the potential (in volts) for the voltaic (or galvanic) cell indicated at 25°C.

Ga / Ga^{3+} (10^{-6} M) || Ag^+ (10^{-4} M) / Ag

a) 1.29 V b) 0.97 V c) 1.45 V	a) 1.21 V b) 1.37 V

3. Use the data below, where appropriate, to answer the questions which follow.

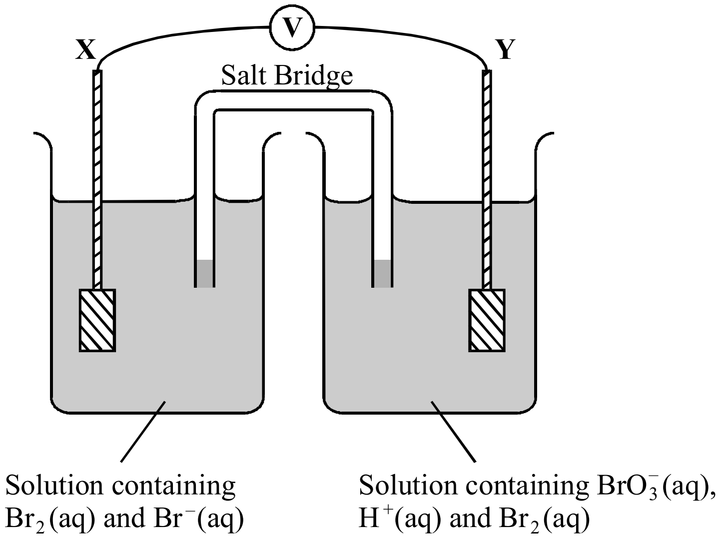
Standard electrode potentials	$E^\ominus$/V
$2\,H^+(aq) + 2\,e^- \longrightarrow H_2(g)$	0.00
$Br_2(aq) + 2\,e^- \longrightarrow 2\,Br^-(aq)$	+1.09
$2BrO_3^-(aq) + 12\,H^+(aq) + 10\,e^- \longrightarrow Br_2(aq) + 6\,H_2O(l)$	+1.52

Each of the above can be reversed under suitable conditions.

a) State the hydrogen ion concentration and the hydrogen gas pressure when, at 298 K, the potential of the hydrogen electrode is 0.00 V.

b) The electrode potential of a hydrogen electrode changes when the hydrogen ion concentration is reduced. Explain, using Le Chatelier's principle, why this change occurs and state how the electrode potential of the hydrogen electrode changes.

c) A diagram of a cell using platinum electrodes X and Y is shown below.



i) Use the data above to calculate the e.m.f. of the above cell under standard conditions.

ii) Write a half-equation for the reaction occurring at electrode X and an overall equation for the cell reaction which occurs when electrodes X and Y are connected.

Answer:

a) Hydrogen ion concentration: 1.00 mol dm^{-3}

Hydrogen gas pressure: 100 kPa

b) Explanation of change: Equilibrium displaced to left to reduce constraint

Change in electrode potential: Becomes negative or decreases/more negative

c) i) 0.43V

ii) *Half-equation*: $2Br^{-} \longrightarrow Br_2 + 2e^{-}$

Overall equation: $2BrO_3^{-} + 10Br^{-} + 12H^{+} \longrightarrow 6Br_2 + 6H_2O$
or $BrO_3^{-} + 5Br^{-} + 6H^{+} \longrightarrow 3Br_2 + 3H_2O$

4. The table below shows some values for standard electrode potentials. These data should be used, where appropriate, to answer the questions that follow concerning the chemistry of copper and iron.

Electrode reaction	$E^{\ominus}$/V
$Fe^{2+}(aq) + 2e^{-} \rightleftharpoons Fe(s)$	– 0.44
$2H^{+}(aq) + 2e^{-} \rightleftharpoons H_2(g)$	0.00
$Cu^{2+}(aq) + 2e^{-} \rightleftharpoons Cu(s)$	+ 0.34
$O_2(g) + 2H_2O(l) + 4e^{-} \rightleftharpoons 4OH^{-}(aq)$	+ 0.40
$NO_3^{-}(aq) + 4H^{+}(aq) + 3e^{-} \rightleftharpoons NO(g) + 2H_2O(l)$	+ 0.96

a) Write an equation to show the reaction that occurs when iron is added to a solution of a copper (II) salt.

b) A similar overall reaction to that shown in (a) would occur if an electrochemical cell was set up between copper and iron electrodes.

i) Write down the cell diagram to represent the overall reaction in the cell.

ii) Calculate the e.m.f. of the cell.

c) i) Use the standard electrode potential data given to explain why copper reacts with dilute nitric acid but has no reaction with dilute hydrochloric acid.

ii) Write an equation for the reaction between copper and dilute nitric acid.

d) Although iron is a widely used metal, it has a major disadvantage in that it readily corrodes in the presence of oxygen and water. The corrosion is an electrochemical process which occurs on the surface of the iron.

i) Use the standard electrode potential data given to write an equation for the overall reaction that occurs in the electrochemical cell set up between iron, oxygen and water.

ii) State, with a reason, whether the iron acts as the anode or cathode of the cell.

iii) Predict and explain whether or not you would expect a similar corrosion reaction to occur with copper in the presence of oxygen and water.

Answer:

a) $Fe + Cu^{2+} \longrightarrow Cu + Fe^{2+}$

b) i) $Fe(s) \mid Fe^{2+}(aq) \parallel Cu^{2+}(aq) \mid Cu(s)$

ii) e.m.f. = + 0.34 – (–0.44) = + 0.78 V

c) i) e.m.f for cell must be positive for reaction to occur / be feasible / spontaneous or ΔG must be negative)

$Cu(s) + 2H^+ \longrightarrow$ products. e.m.f = – 0.34V will not happen / sensible comparison of the magnitude of $E^\ominus$ for the electrodes, eg 'Cu electrode more positive than hydrogen electrode will not work'

$Cu(s) + NO_3^- + 4H^+ \longrightarrow$ products

e.m.f = + 0.96 – 0.34 = + 0.62V can occur / similar sensible comparison

ii) $3Cu + 2NO_3^- + 8H^+ \longrightarrow 3Cu^{2+} + 2NO + 4H_2O$

d) i) $2Fe + O_2 + 2H_2O \longrightarrow 2Fe^{2+} + 4OH^-$ or $2Fe(OH)_2$

ii) Anode because Fe loses e^- (negative pole) / oxidation occurs
iii) e.m.f. = + 0.06 V or reference to $E^\ominus$ for electrodes

Reasoned argument, e.g. positive should occur / difference so small that reaction unlikely

UNIT 10: ENERGY CHANGES AND ENERGY PROFILE DIAGRAMS

10.1. Key unit competence

Explain the concept of energy changes and energy profile diagrams for the exothermic and endothermic processes.

10.2. Prerequisite (knowledge, skills, attitudes and values)

Student teachers will learn better the concept of energy changes and energy profile diagrams if they have understanding on the following topics:

Categories of chemical reactions (Chemistry senior 2, Unit 5)

Work, Power and Energy(i) (Physics senior 1, Unit 6)

Work, Power and Energy. (II) (Physics senior 2, Unit 8)

Thermodynamics (Physics SME Year 2)

The tutor will help student teachers to recap the concepts above.

10.3. Cross-cutting issues to be addressed:

a) Inclusive education:

This unit involves a number of formulae of substances, the writing of formulae and chemical reactions. This may be challenging to student teachers with special educational needs especially student teachers with visual impairment or visual difficulties.

However, the teacher can make some arrangements like the following:

- Grouping student teachers
- Student teachers with special educational needs are grouped with others and assigned roles basing on individual student's abilities.
- If a tutor has student teachers with visual difficulties, when writing on the blackboard, write in large, clear writing, especially when it comes to formulae and chemical reactions. Read out what you are writing, for the benefit of those who are not able to see the blackboard clearly.
- If student teachers are sharing textbooks, try to arrange for those with visual difficulties to have their own copies, as far as this is possible.
- Give extra time for them to write summary notes or write down observations after experiments.
- Every important point is written and spoken.
- Remember to repeat the main points of the lessons.

- For student teachers with **hearing difficulties**, the teacher has to encourage them to sit closer to the front of the classroom. Stop every so often while teaching to ask student teachers whether they have understood, or if they need you to repeat a point. Encourage student teachers not to be afraid to ask questions.
- When teaching, speak clearly and ensure that all the student teachers can hear your voice. Avoid speaking hurriedly as this will make it difficult for student teachers with hearing difficulties to make sense of what you are saying.
- Student teachers with mobility difficulties:
- These include student teachers in crutches, wheelchairs, or with walking difficulties.
- Encourage other student teachers to look out for and help their classmates. Ask their follow student teachers to help them with their notes, if their conditions hinder them from writing well.
- Student teachers with reading difficulties:
- Student teachers with this kind of difficulties struggle to make sense of words or understand written work and take longer to read than other student teachers.
- Encourage them to pay careful attention during class time and participate for example by asking questions, answering questions, so that they can make the most of what they hear and observe. Instead of repeating word for word what is in the textbook, simplify the concepts to ease their understanding, so that when they have already understood.

b) Gender

During group activities try to form heterogeneous groups (with boys and girls) or when student teachers start to present their findings encourage both (boys and girls) to present.

c) Financial education

The concept of enthalpy change has many applications as it allows knowing the amount of energy absorbed or released during a chemical process. This helps student teachers to be aware of the cost in terms energy required for a given process of the fuel that can supply it (that energy).

A particular attention should always be put on the comparison between the cost and the quality of the fuel or the galvanic cells to be purchased as an important part of the energy we depend on is derived from chemical reactions.

d) Peace and values education

During group activities, the tutor will encourage student teachers to help each other's and to respect opinions of colleagues.

e) Environment and sustainability

Part of the energy we need is obtained from the combustion of fuels. This combustion is most of time source of the green house effect and various pollutants that are emitted in the air.

In addition, electrochemical cells poorly used may have many harmful effects, and for human beings and for the environment in general. For example, some components of the electrochemical cells contain poisonous chemicals like mercury (Hg), lead (Pb), etc; and several which are disposable are the main environmental pollutants.

f) Standardisation culture

Every student teacher who can learn the concept of energy changes should always seek for fuels of good qualities, that is, contain no pollutants.

10.4. Guidance on introductory activity 10

- Before introducing the first lesson (Types of systems) of this unit, let student teachers attempt the introductory activity 10.
- For this activity, the tutor forms groups of five student teachers that are as heterogeneous as possible.
- The teacher makes sure that each student teacher from each group performs an activity.
- The tutor provides a clear sheet for reporting. On this, there is among others the title of experiment, the observations and deductions.
- The tutor asks randomly representative of three or four groups to present their findings.
- After presentation, the teacher decides to engage the class into exploitation of the student teachers' findings.
- After presentation the tutor asks the student teachers to judge findings from different groups and harmonise their work.
- The teacher summarises their findings and introduce the new unit.

Answers to introductory activity

1. The energy used for the flight of airplanes, the functioning of vehicle's engines or some machines used in factories, launching of spacecrafts, Bunsen burner, energy used by our bodies is derived from of fuels.

2. The main chemical reactions that are involved in the processes described in the introductory activity are combustion reactions.
3. The energy used may be determined by many ways such as the use of the bond dissociation energy, enthalpy of formation (See details in the lesson).

10.5. List of lessons/sub-headings

	Objectives	Content	Number of periods
Lesson 1	• Differentiate between the types of systems	Types of systems	1
Lesson 2	• Derive the relationship between heat energy and temperature.	Heat energy and temperature	1
Lesson 3	• Explain the differences between exothermic and endothermic reactions using profile energy diagrams.	Energy profile diagrams of different chemical reactions	1
Lesson 4	• Define heat of reaction, standard enthalpy change of combustion, enthalpy of neutralization, enthalpy of solution, enthalpy of hydration and lattice enthalpy	Definition of standard enthalpy of reactions (enthalpy change of combustion, enthalpy change of neutralization, enthalpy change of solution, enthalpy of hydration and lattice enthalpy	1
Lesson 5	• Describe an experimental procedure in determination of heat of combustion. • Carry out practical activities to determine enthalpy change of combustion of ethanol • Develop practical experimental skills about enthalpy changes of reactions, interpreting results and drawing valid conclusions. • Calculate the enthalpy change of combustion from experimental data	Experimental determination of the standard enthalpy of change of combustion,	2

Lesson 6	• Carry out practical activities to determine enthalpy change of neutralization. • Develop practical experimental skills about enthalpy changes of reactions, interpreting results and drawing valid conclusions. • Calculate the enthalpy change of neutralization from experimental data	Experimental determination of the standard enthalpy change of neutralization	2
Lesson 7	• Carry out practical activities to determine enthalpy change of dissolution • Calculate the enthalpy change of dissolution from experimental data • Develop practical experimental skills about enthalpy changes of reactions, interpreting results and drawing valid conclusions.	Experimental determination of the standard enthalpy change of dissolution	1
		End unit assessment	1

Lesson 1: Types of systems (1 period)

a) Prerequisites/ Revision/ Introduction

The student teachers will better learn this concept if they have a good understanding of the following.

- Heat and temperature (Physics senior 1, Unit 9)
- Conservation of mechanical energy in isolated systems (Physics senior 2, Unit 9)
- Heat transfer and quantity (Physics senior 3, Unit 5)
- Laws of thermodynamics (Physics senior 3, Unit 6)

b) Teaching resources

Laboratory equipments (See Activity 10.1)

c) Learning activities

- **Guidance**

The lesson 1 intends to make student teachers familiar with the experimental methods for finding the standard enthalpy of combustion reactions.

- Form groups and let students attempt the activity 10.1.

- Provide to each group all the requirements for this experiment. These must be availed before the lesson.
- Provide student teachers with the procedure (this could be provided in advance) and well explained it.
- Provide each group with a reporting sheet.
- Let student teachers perform the experiment as described in the procedure.
- Move around to make sure that the safety precautions are respected.
- Every group records their observations and make an interpretation.
- Call upon randomly four groups to share their findings.
- Let the class analyse the ideas of their colleagues and point out the key ideas about Experimental methods for finding the standard enthalpy of combustion reactions.

Note: the activity should take not too much time as the concept of open and closed system has been dealt with in senior 3.

Answers to activity 10.1

Experiment A

1. The process absorbs energy.
2. The mass of the crucible and its content decreases. This because on heating magnesium carbonate releases in the air carbon dioxide.

Experiment B

1. The temperature in the conical flask was increased and the conical flask became warm.
2. The mass of the conical flask did change appreciably because no substances are released in the air.
3. Nothing should be recorded on the outer walls of the thermos flask because it is insulated.

Answers to application activities 10.1

1. Ocean: open, aquarium: closed, a greenhouse: closed.
2. The final mass will be 2g. Remember, a closed system does not allow for mass exchange.
3. The final temperature will be 30^{o}C. Remember, an isolated system does not allow energy transfer.
4. A stationary pencil has potential energy and a falling pencil has kinetic energy.
5. The first law of thermodynamics is based on an isolated system because the first law of thermodynamics says that the internal energy of an isolated

system stays constant. This can only be said for an isolated system because it is the only system that does not allow energy transfer. The second law of thermodynamics states that the entropy of an isolated system increases.

Lesson 2: Heat energy and temperature (1 period)

a) Prerequisites/ Revision/ Introduction

Student teachers will get a better understanding of the content of this lesson if they refer to the heat transfer and quantity (Unit 5 senior 3).

Let students discuss in pairs, how amount of heat exchanged may by calculated using data from calorimeter measurements.

b) Teaching resources

- Weighing balance
- Thermometer
- Insulated plastic beaker (calorimeter)
- Measuring cylinder
- Sodium hydroxide pellets
- Distilled water

c) Learning activities

- **Guidance**

- The lesson 2 relates temperature and heat.
- Form groups and let students attempt the activity 10.2.
- Provide each group with all the requirements for this experiment. These must be availed before the lesson.
- Provide student teachers with the procedure (this could be provided in advance) and explain it.
- Provide each group with a reporting sheet.
- Let student teachers perform the experiment as described in the procedure.
- Move around to make sure that all student teachers participate.
- Every group records their observations and make an interpretation.
- Call upon randomly three groups to share their results.
- Let the class harmonise the ideas. The latter will summarize the relationship between temperature and heat.

Answers to activity 10.2

Refer to the student book

Assess the lesson by allowing them to do the Application activity 10.2.

Answers to application activities 10.2

Answers to multiple choice and short questions

1. a) S
   b) P
2. A
3. B .
4. Hotter, colder

Answers to open questions

Temperature rise, $\Delta T = 56^oC - 20^oC = 36^oC$

$q = m \times C \times \Delta T$

$q = 250g \times 4.18Jg^{-1o}C^{-1} \times 36^oC$

$q = 37{,}620J = 37.62kJmol^{-1}$

Temperature rise, $\Delta T = 60^oC - 25^oC = 35^oC$

$q = m \times C \times \Delta T$

$$C = \frac{q}{mx\Delta T} = \frac{204.75J}{15g\ x35^o C} = 0.39\ J\ g^{-1\ o}C^{-1}$$

Lesson 3: Definition of standard enthalpy of reactions (1period)

a) Prerequisites/ Revision/ Introduction

The student teachers will learn better this concept if they have a good understanding on the following.

- Types of chemical reactions (Senior 2)
- Types of systems (Chemistry SME, Year 3, Unit 10)

b) Teaching resources

Chalkboard/smart board, chalks, flip chart, textbooks

c) Learning activities

- **Guidance**
- Form groups of four.
- Provide them with the activity 10.3 (you can use the chalkboard, books, and worksheets or even use the projector).
- Give them time between 5 and 10 minutes to answer the questions of this activity.
- Invite 3 groups chosen randomly to present their findings.

- Allow some student teachers to comment about the findings presented by their colleagues.
- Take this time to give additional information (missing in what found by all groups) and use some questions to draw the conclusion.
- Let the student student teachers to do the application activity 10.3

Answers to activity 10.3

Thermodynamic system, Part of the universe which is under study.

There are three types of systems: open, closed and isolated.

The main types of reactions are:

Displacement, combustion, addition, neutralisation, double displacement, decomposition and so on

Answers to application activities 10.3

1.
   a) $6C(s) + 7H_2(g) \rightarrow C_6H_{14}(l)$
   b) $H_2(g) + N_2(g) + O_2(g) \rightarrow HNO_3(l)$
   c) $(s) + 2H_2(g) + O_2(g) \rightarrow CH_3OH(l)$
   d) $K(s) + Br_2(g) \rightarrow KBr(s)$
   e) $4C(s) + 4H_2(g) + O_2(g) \rightarrow CH_3CH_2CH_2CO_2H(l)$
2. b), c) in b) two moles are formed. In c) when the reactants is a compound.
3. a) $H_2(g) + O_2(g) \rightarrow H_2O(l)$

   b) $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

   c) $S(s) + O_2(g) \rightarrow SO_2(g)$

   d) $CH_3CH_2CH_2OH(l) + O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$
4. a) $K(s) \rightarrow K(g)$

   b) $N_2(g) \rightarrow N(g)$

   c) $I_2(g) \rightarrow I(g)$

Lesson 4: Energy profile diagrams of different chemical reactions (1 period)

a) Prerequisites/ Revision/ Introduction

The student teachers will learn better this concept if they have a good understanding on the following.

- Work, Power and Energy(i) (Physics senior 1, Unit 6)
- Work, Power and Energy. (II) (Physics senior 2, Unit 8)

b) Teaching resources

Chalkboard/smart board, chalks, flip chart, textbooks

c) Learning activities

- **Guidance**

- Form groups of four.
- Provide them with the activity 10.4 (you can use the chalkboard, books, and worksheets or even use the projector).
- Give them time between 5 and 10 minutes to answer the questions of this activity.
- Invite 3 groups chosen randomly to present their findings.
- Allow some student teachers to comment about the findings presented by their colleagues.
- Take this time to give additional information (missing in what found by all groups) and use some questions to draw the conclusion.
- Let the student student teachers to do the application activity 10.4

Answers to activity 10.4

In points A, B and C the moving car has kinetic energy.

In the diagram above the car starts with maximum kinetic energy in point A. As it moves uphill, its kinetic energy decreases while its potential energy increases and becomes maximum at point B. As the car moves downhill, its potential energy decreases while its kinetic energy increases and becomes maximum at point C.

The points corresponding to maximum stability are A and C because they are the ones corresponding to minimum potential energy.

d) Answers for application activities 10.4

The compound AX and the element M are in gaseous and solid states, respectively.

What effect would grinding M into a fine powder have o the above graph?

The activation energy of a reaction is the minimum energy required to start that reaction.

E (Reactants) = 52 kJ

E (Products) = 16 kJ

Ea (Forward) = (80-52) kJ = +28 kJ

Ea (Reverse) = (52-16) kJ = +64 kJ

ΔH (Forward) = (16-52) kJ = -36 kJ

ΔH (Reverse) = (52-16) kJ = +36 kJ

a. The forward reaction is exothermic

b. The reverse reaction is endothermic

Activated complex is AXM

The stronger chemical bond is MX.

Reason: It has lower energy (more stable). It takes more energy (+64 J) to break M-X bond than to break A-X bond (+28 kJ).

The chemical species whose particles move the fastest are A+MX.

Reason: Since these species have minimum potential energy, they have maximum kinetic energy and therefore the highest speed.

The chemical species whose particles move the slowest are AX+M.

Reason: Since these species have maximum potential energy, they have minimum kinetic energy and therefore the lowest speed.

Lesson 5: Experimental determination of the standard enthalpy of change of combustion (2 periods)

a) Prerequisites/ Revision/ Introduction

For a better understanding of this lesson, student teachers will refer to: Categories of chemical reactions (unit 5, senior 2), Energy changes and energy profile diagrams for chemical reactions (unit 10, SME, Year3))

Form groups and ask student teachers to brainstorm about the different types of chemical reactions and let them to make a recall.

b) Teaching resources

- spirit burner (containing ethanol)
- thermometer
- copper can
- measuring cylinder
- retort stand and accessories
- balance

- breeze shield

c) Learning activities

- **Guidance**

The lesson 3 intends to make student teachers familiar with the experimental methods for finding the standard enthalpy of combustion reactions.

- Form groups and let students attempt the activity 10.5.
- Provide to each group all the requirements for this experiment. These must be availed before the lesson.
- Provide student teachers with the procedure (this could be provided in advance) and well explained it.
- Provide each group with a reporting sheet.
- Let student teachers perform the experiment as described in the procedure.
- Move around to make sure that the safety precautions are respected.
- Every group records their observations and make an interpretation.
- Call upon randomly four groups to share their findings.

Let the class analyse the ideas of their colleagues and point out the key ideas about Experimental methods for finding the standard enthalpy of combustion reactions.

Answers to activity 10.5

Refer to the student book

Assess the student teachers' understating by allowing them do the checking up 10.5.

Answers to application activities 10.5

$C_6H1_4(l) + 19/2O_2(g) \rightarrow 6CO_2(g) + 7H_2O(l)$

$\Delta T = 25^oC$

q = 100g x 4.18g/mol.^{o}C x 25^{o}C = 10450J

Number of moles = 0.18 g/86 g mol^{-1} = 0.0021mol

Molar enthalpy = 10450/0.0021 mol = 497,619.05 J = 497.62 kJ

$C_6H_6 + 15/2O_2 \rightarrow 6CO_2 + 3H_2O$

Moles of C_6H_6 = 30g/(78g〖mol〗^(-1)) = 0.85mol

0.85mol produces 0.85mol x 3270kJmol^{-1} = 12,589.5kJ

b) When 3270kJ are produced, 6 moles of CO_2 are produced.

8800kJ are produced (6 moles x 8800kJ)/3270 = 16.147mol

Mass of CO_2 = 16.147mol x 44g/mol = 710.5g

Lesson 6: Experimental determination of the standard enthalpy change of neutralization (2periods)

a) Prerequisites/ Revision/ Introduction

For a better understanding of this lesson, student teachers will refer to solutions and titrations (Chemistry SME Year 1 unit 4)

b) Teaching resources

- 2 plastic beakers
- 50 mL of 1 M HCl
- 50 mL of 1 M NaOH
- Thermometer
- Electronic balance
- Weigh boats

c) Learning activities

- **Guidance**

- Form groups and let students attempt activity 10.6
- Provide each group with all the requirements for this experiment. These must be available before the lesson.
- Provide to the student teachers the procedure (this could be provided in advance) and explained.
- Provide for each group a reporting sheet.
- Let student teachers perform the experiment as described in the procedure.
- Move around to ensure that all student teachers are involved.
- Every group records their observations and make an interpretation.
- Call upon randomly four groups to share their results.
- Let the class evaluate the findings of their colleagues and point out the key ideas about the experimental methods for finding the standard enthalpy of neutralisation reactions. From learner’s ideas, write a short summary.
- Let the student teachers do the application activity 10.6

Answers to activity 10.6

Refer to the student's book.

d) Answers to application activities 10.6

Equation of the reaction: $HX(aq) + NaOH(aq) \rightarrow NaX(aq) + H_2O(l)$

Heat energy released, $q = m \times C \times \Delta T = 70g \times 4.18J/g^{o}C \times 5^{o}C = 1463J$

Number of moles reacted = $1moldm^{-3} \times 30 \times 10^{-3}dm^{3} = 0.03mol$

Molar enthalpy of neutralisation = = 48,766.67J =48.767kJ

$Mm(NaHCO_3) = 23+1+12+3 \times 16 = 84g/mol$

Moles of reacted = = $3.417 \times 10^{-2}mol$

Heat energy exchanged, $q= m \times C \times \Delta T = 3.71 \times 4.18 \times (-8.5) = -131.82J$

Heat energy exchanged par mol = = 3798.85J = -3.79885kJ

The enthalpy change of the reaction, $\Delta Hr = +3.79885kJmol^{-1}$

Lesson 7: Experimental determination of the standard enthalpy change of dissolution (1 period)

a) Prerequisites/ Revision/ Introduction

For a better understanding of this lesson, student teachers will refer to solubility (Chemistry SME Year 3 , unit 8)

b) Teaching resources

- spirit burner (containing ethanol)
- thermometer
- beaker
- measuring cylinder
- balance

c) Learning activities

▪ **Guidance**

- Form groups and let students attempt activity 10.7
- Provide each group with all the requirements for this experiment. These must be available before the lesson.
- Provide to the student teachers the procedure (this could be provided in advance) and explained.
- Provide for each group a reporting sheet.

- Let student teachers perform the experiment as described in the procedure.
- Move around to ensure that all student teachers are involved.
- Every group records their observations and make an interpretation.
- Call upon randomly four groups to share their results.
- Let the class evaluate the findings of their colleagues and point out the key ideas about the experimental methods for finding the standard enthalpy of neutralisation reactions. From learner's ideas, write a short summary.
- Let the student teachers do the application activity 10.7

Answer to activity 10.7

Refer to the student book

Answers to application activity 10.7

1. Number of moles of KI = 12.78g : 166g/mol = 0.77mol
2. Heat exchanged, q = m x c x ΔT
3. q = 25g x 4.18$Jg^{-1}K^{-1}$ x 13.7K = 1431.65J
4. Molar enthalpy of dissolution of KI
5. 0.77moles of KI absorbs 1431.65j
6. One mole of KI absorbs = 1431.65J : 0.077mol = 18592.86kJ/mol
7. Enthalpy of dissolution of KI, ΔHdis(KI) = + 18.92kJmol-1

10.6. Summary of the Unit

The transfer of heat energy from to or chemical reactions plays a vital role in modern society and in living beings. The heat energy change at constant pressure is called **enthalpy change** noted ΔH. The standard enthalpy change for a chemical reaction is the amount of heat exchanged under standard conditions.

The conditions for standard enthalpy changes are: temperature T = 298K, a pressure P equals to one atmosphere, substances in their most stable state under these conditions, concentrations of 1 mol dm^{-3}.

Among the most important enthalpy changes, we distinguish the enthalpy of formation, the enthalpy of combustion, and the lattice enthalpy.

Enthalpy changes values can be determined experimentally by measuring the temperature rise of a known volume of water that is heated by the reaction of a known amount of the reactants.

It takes 4.18 joules of heat energy to increase the temperature of one gram of water by one degree. This value is called" specific heat capacity of water".

10.7. Additional information for teachers

Enthalpy changes of reactions may also be estimated using calorimetry measurements. They may also be determined by applying the Hess’s law or law of Constant Heat Summation.

Remember that the enthalpy (heat of reaction) is a state function. This means that a change in enthalpy does not depend on how the change was made, but only on the initial state and final state of the system; it is independent of the pathway.

In 1840, the Russian chemist Germain Henri Hess, a professor at the University of St. Petersburg, discovered from his thermochemical studies that the enthalpy change is a state function. The result from his experiment was known as Hess’s law or Law of Constant Heat Summation. This law state that “the heat evolved or absorbed in a chemical process is the same whether the process takes place in one or in several steps”.

In other words, no matter how you go from a given set of reactants to a set of products, the enthalpy change for the overall chemical reaction is the same whether the reaction takes place in one step or in *a series of steps.*

The enthalpy change is independent of the pathway of the process and the number of intermediate steps in the process as long as the initial and final conditions are the same’.

Hess’s law can be illustrated by the following reaction:

$A + 2B \rightarrow AB_2$

The reaction can be decomposed into two steps. The two steps and the overall process are represented by the following thermochemical equations.

$$
\begin{array}{lcl}
A + B \longrightarrow AB & & \Delta H_1 \\
AB + B \longrightarrow AB_2 & & \Delta H_2 \\
\hline
A + 2B \longrightarrow AB_2 & & \Delta H_{rxn} = \Delta H_1 + \Delta H_2
\end{array}
$$

The two processes can be represented in a thermochemical cycle. This diagram is known as the *Hess’s principle* (See figure below).

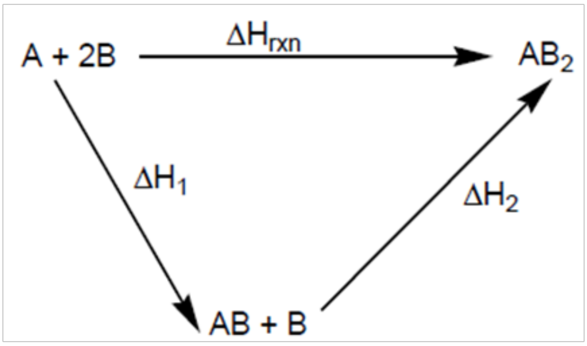


Illustration of the Hess's principle

Hess's law tells us that the enthalpy change of reaction for the direct route is the same as for the indirect route. It does not matter how many steps there are in the indirect route. We can still use Hess's law.

We can use Hess's law to calculate enthalpy changes that cannot be found by experiments using calorimetry. For example, the enthalpy change of formation of propanone cannot be found by direct experiment because hydrogen, carbon and oxygen do not react under standard conditions.

Example:

Calculate a value for the standard enthalpy of formation of propanone,

$CH_3COCH_3(l)$, given the following standard enthalpy changes of combustion:

	ΔHc/kJ mol^{-1}
C(s)	–394
$H_2(g)$	–286
$CH_3COCH_3(l)$	–1821

Answer:

Write the main equation for the enthalpy change to be calculated and then write equations for the standard enthalpy changes given.

Main equation:

$3C(s) + 3H_2(g) + ½O_2(g) \rightarrow CH_3COCH_3(l)$

Equations for given enthalpy changes of combustion:

$C(s) + O_2(g) \rightarrow CO_2(g)$ –394 kJ mol^{-1}
(1)

$H_2(g) + ½\ O_2(g) \rightarrow H_2O(l)$ –286 kJ mol^{-1}

(2)

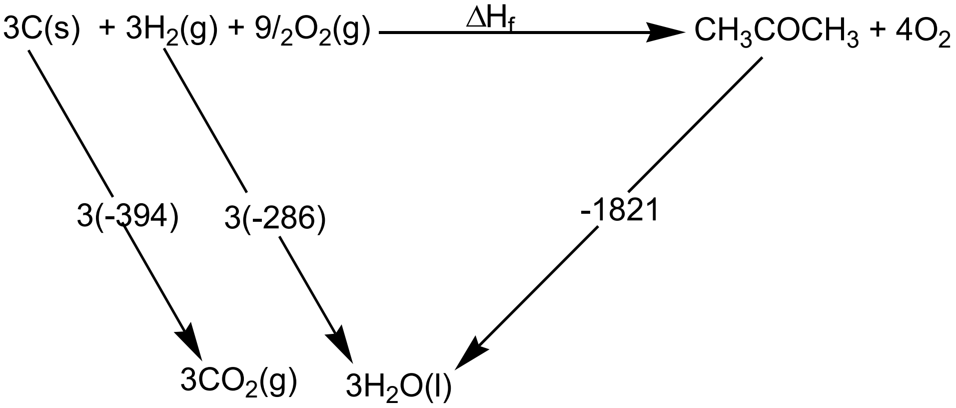
$CH_3COCH_3(l) + 4O_2(g) \rightarrow 3CO_2(g) + 3H_2O(l)$ −1821 kJ mol^{-1} (3)

The substances which do not appear in the main equation but do appear in these equations for the given enthalpy changes are $CO_2(g)$ and $H_2O(l)$.

These are these link substances which allow to draw a Hess's Law diagram.

Below the main equation put $3CO_2(g)$ and $3H_2O(l)$.

Draw arrows for the enthalpy changes given to you in the question in the direction of the change. Write values on the arrows and remember to multiply by the number of moles of substance burned.



Hess's Law Diagram

A value for the standard enthalpy of formation of propanone (main equation) can be calculated by going from the reactants to $CO_2(g)$ and $H_2O(l)$ and then reversing the combustion of propanone.

$\Delta H_f\,(C_3H_6O(l)) = +3(-394) + 3(-286) - (-1821)$

$= -1182 - 858 + 1821 = -219$ kJ mol^{-1}

Note: the enthalpy change may be calculated by adding equations above corresponding to the different combustion so that the main equation is obtained and then adding the enthalpy change values multiplied by appropriate coefficient and if necessary reverse some of them.

Main equation:

$3C(s) + 3H_2(g) + ½\ O_2(g) \rightarrow CH_3COCH_3(l)$

Equation corresponding to the different combustions
3 moles of C(s) react in the main equation so the first equation is multiplied by 3

3 moles of $H_2(g)$ react in the main equation so the second equation is multiplied by 3

1 mole of propanone is formed in the main equation so the third equation should be reversed.

$3C(s) + 3O_2(g) \rightarrow 3CO_2(g)$	3(–394)
$3H_2(g) + 1/2O_2(g) \rightarrow 3H_2O(l)$	3(–286)
$3CO_2(g) + 3H_2O(l) \rightarrow CH_3COCH_3(l) + 4O_2(g)$	+1821
$3C(s) + 3H_2(g) + 1/2O_2(g) \rightarrow CH_3COCH_3(l)$	**–219 kJ mol^{-1}**

GUIDANCE ON SKILL LAB 10

This is a research activity that can be carried out during extra time lessons.

Student teachers should be allowed to use ICT lab during these extra time under the supervision of their chemistry teacher.

The task can be in groups of two student teachers.

The tutor has to monitor the progress of this research.

After the required time the tutor evaluate the work done and communicate a feedback to the student teachers. This required time should a result of an agreement between the student teachers and the tutor based on their availability.

Expected answers to skills lab questions

The statements are not enough relevant because of the following.

1. The use of biofuels in car engines and burning wood to produce electricity seems to be an alternative to fossil fuels. However, dedicating land for producing biofuels in not enough judicious because too much land is used to generate a very small amount of fuel.
2. There is a dangerous completion for land for food and for biofuels. While photosynthesis converting carbon dioxide and water in carbohydrates using the sun’s rays, it is an inefficient way to turn solar radiation into non-food energy that people can use.
3. The combustion of biofuels may not reduce appreciably the emission of greenhouse gases in the atmosphere. Burning biomass, whether directly as wood or in the form of ethanol or biodiesel, emits carbon dioxide just like burning fossil fuels.

10.8. Answers to end unit assessment questions

1. a) Enthalpy change, heat energy exchange at constant pressure.

   b) Standard enthalpy change of reaction, heat energy exchanged (absorbed or released)

   during a chemical reaction under standard conditions.

   For example if we consider the reaction: $2C_2H_6(g) + 7O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)$ ΔH -3120 kJ mol-1 -3120 kJ mol^{-1} represents the enthalpy of the reaction.

   c) The standard enthalpy of combustion is the heat released when one mole of a substance

   undergoes a complete combustion in excess oxygen under standard conditions. Therefore

   3120kJmol-1 does not represent the standard enthalpy of combustion of ethane because

   two moles are involved in the reaction

2. a) $\Delta T = 3.2$

   Moles = $50 \times 10^{-3}dm^{-3} \times 0.5moldm^{-3} = 2.5 \times 10^{-2}mol$

   $q = m \times Cs \times \Delta T = 100g \times 4.15Jg^{-1o}C^{-1} = 1337.04J = 1.3376kJ$

   b) $\Delta H = \frac{1.3376kJ}{2.5 \times 10^{-2}mol} = 53.50kJmol^{-1}$

3. Amount of heat used = - 2202kJ x 0.015mol = -33.03kJ or 33,030J

   $q = m \times Cs \times \Delta T$

   33,030J = 200g x 4.18Jg-1 x ΔT

   $\Delta T = \frac{33,030J}{200g \times 4.18Jg^{-1}K^{-1}} = 39.51K$

4. $\Delta T = 28.2^oC - 21.5^oC = 6.7^oC$

   $q = m \times Cs \times \Delta T$ = 50g x 4.18Jg-1$^oC^{-1}$ x 6.7^oC = 1400.3J

   Moles = $25 \times 10^{-3}dm^{-3} \times 1moldm^{-3} = 25 \times 10^{-3}mol$

   $\Delta H = \frac{1400,3J}{25 \times 10^{-3}mol}$ = 56,012J or 56.012kJ

5. a) Excess zinc was used to make sure that all the copper sulphate reacted

   b) $q = m \times Cs \times \Delta T = 25 \times 4.18 \times 21 = 2195.5J$

   c) Moles of $CuSO_4$ used = $25 \times 10^{-3}dm^3 \times 0.5moldm^3 = 0.0125mol$

d) Molar enthalpy = $\frac{2195.5J}{0.0125mol}$ = -175560J = -175.56kJ

e) Source of error: heat loss

Proposals for reducing that error: Use of a lid on the calorimeter

wrap the calorimeter

a) Endothermic reaction

b) Activation energy for the forward reaction, 80 kJ

c) Activation energy for the reverse reaction, 30 kJ

d) +50kJ

e) Exothermic

f) X_2Y_2

g) X_2Y_2

h) $X_2 + Y_2$

i) XY

j) X_2Y_2

k) -50kJ

l)Reverse reaction

m) Activated complex, chemical species in which bonds are being broken and formed at the same time

n) $X_2 + Y_2$

The reaction will proceed faster

10.9. Additional activities

10.9.1. Remedial activities

1. Multiple choice questions

a) Which statement about enthalpy is true?

b) Heat is given off to the surroundings in endothermic reactions.

c) Some substances have a negative specific heat capacity.

d) Specific heat capacity is the same for all liquids.

e) The sign of ΔH is always negative in exothermic reactions.

2. What happens to the value of ΔH for a thermochemical reaction if the reaction is reversed?

a) ΔH has the same numerical value, and the sign changes.

b) ΔH has the same numerical value, and the sign remains the same.

c) ΔH is the reciprocal of the original value, and the sign changes.

d) ΔH is the reciprocal of the original value, and the sign remains the same.

3. Which is an exothermic process?

a) Ice melting	c. Water evaporating
b) Water boiling	d. Water vapour condensing

4. Which statement is true for the combustion of ethanol?

$C_2H_5OH\ (l) + 3O_2(g) \rightarrow 2CO_2\ (g) + 3H_2O(l) \qquad \Delta H = -1370\ kJ$

a) The enthalpy change would be the same is gaseous water were produced.

b) The potential energy of the products is less than the potential energy of the reactants.

c) The products of the reaction occupy a larger volume than the reactants.

d) The reaction is endothermic.

5. Which statement correctly describes an endothermic chemical reaction?

a) The products have higher potential energy than the reactants, and the ΔH is negative.

b) The products have higher potential energy than the reactants, and the ΔH is positive.

c) The products have lower potential energy than the reactants, and the ΔH is negative.

d) The products have lower potential energy than the reactants, and the ΔH is positive.

6. Using the data below, what is the order of changes that occur when ethanol is heated from 25.0°C to 85.0°C?

Boiling point of ethanol: 78.5°C, Melting point of ethanol: -117.3°C

a) Phase change, temperature change

b) Phase change, temperature change, phase change

c) Temperature change, phase change

d) Temperature change, phase change, temperature change

7. Which process results in the greatest endothermic change for 10.0g of H_2O?

a) Condensation

b) Melting

c) Solidification

d) Vaporization

8. The following decomposition reaction may occur in an air bag.

$2NaN_3(s) \rightarrow 3N_2(g) + 2Na(s) \qquad \Delta H = -43.5\ kJ$

What is the heat of formation, ΔH_f, for NaN_3?

a. -43.5 kJ b. -21.8 kJ c. 21.8 kJ d. 43.5 kJ

9. What is the ΔH value for an exothermic energy change?

a) Always negative
b) Always positive
c) Could be positive or negative
d) Depends on the potential energy of the reactants

10. How much heat is required to vapourize 15.8 g $CH_3OH(l)$ at its boiling point? ($\Delta H_{vap} = 38.0$ kJ/mol)

a) 2.41 kJ b. 18.8 kJ c. 77.0 kJ d. 600. kJ

11. Which of the following statements is true?

a) In an endothermic process heat is transferred from the surroundings to the system.
b) In an exothermic process heat is transferred from the surroundings to the system.
c) The surroundings will feel cooler in an exothermic process.
d) The surroundings will feel warmer in an endothermic process.

12. The enthalpy change for the following reaction is -184.6 kJ.

$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$

What is the standard enthalpy of formation, ΔH_f, for HCl(g)?

a) -369.2 kJ b. -184.6 kJ c. -92.3 kJ d. +92.3 kJ

13. Which of the following processes is exothermic?

a) Ether evaporating
b) Ice melting
c) Steam condensing
d) Water decomposing

14. What quantity of heat is evolved with 5.550 mol $H_2O(l)$ is formed from the combustion of $H_2(g)$ and $O_2(g)$?

$H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l) \quad \Delta H = -285.8\ kJ$

a) 51.44 kJ b. 285.8 kJ c. 1586 kJ d. 2297 kJ

15. As energy is added to a substance, the temperature remains constant. How may the substance be changing?

a) From a gas to a solid
b) From a liquid to a gas
c) From a liquid to a solid
d) In the amount of kinetic energy

2. Open questions

When 50cm^3 of 0.10M sodium hydroxide is added t0 50cm^3 of 0.10M hydrochloric acid, the temperature of the mixture increases by 11.6K. Calculate the heat change of the reaction that occurs.

Data: Specific heat capacity of the solution 4.18Jg^{-1}K^{-1}.

Density of the solution =1.18gcm$^{-3.}$

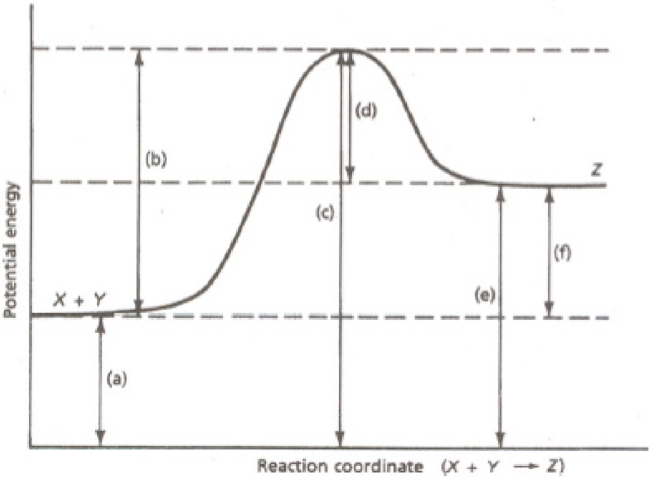
Answers

1. (1)d (2) a (3) d (4) b (5) b (6) a (7) d (8) c (9) a (10) b (11) a (12) c (13) c (14)b 15.b

2. Q = m x C x T =118 x 4.18 x 11.6 = 5721.584J = 5.722kJ

10.9.2. Consolidation activities

1. Answer the questions by referring to the diagram of the potential energy of a reaction below.



1. Which of the letters (a)-(f) in the diagram represents the potential energy of the products?
2. Which letter indicates the potential energy of the activated complex?
3. Which letter indicates the potential energy of the reactants?
4. Which letter indicates the activation energy?

5. Which letter indicates the heat of reaction?
6. Is the reaction exothermic or endothermic?
7. Which letter indicates the activation energy of the reverse reaction?
8. Which letter indicates the heat of reaction of the reverse reaction?
9. Is the reverse reaction exothermic or endothermic?
10. If a catalyst were added, which lettered quantities, if any, would change?
11. Would the activation energy increase, decrease, or remain unchanged?
12. Would the heat of reaction increase, decrease, or remain unchanged?

Answers

1. (1) e (2) c (3) a (4) b (5) f (6) endo (7) d (8) f (9) exo (10) b,c,d (11) decrease (12) unchanged

2. 100cm^3 of 1M sodium hydroxide solution and 100cm^3 of 1M ethanoic acid were mixed in a calorimeter. All three were at the same temperature. The rise in temperature was 5.9K. Calculate the standard enthalpy of neutralisation. Assume that no heat passes to the calorimeter.

Answer

$q = m \times C \times T\Delta$

$q = 100g \times 4.18J/g.K \times 5.9K = 4{,}932.4J$

Moles of NaOH = $100 \times 10^{-3} dm^3 \times 1 mol dm^{-3} = 0.1 mol$

Molar enthalpy of neutralisation = $\frac{4{,}932.4J}{0.1mol}$ = 49,324J = 49.324kJmol^{-1}

3. Calculate the enthalpy change for the reaction:

$CH_2{=}CH_2(g) + H_2O(g) \rightarrow CH_3CH_2OH(g)$

Given the following average bond enthalpies in kJmol^{-1}:

C-C : 348; C=C: 612; C-H: 412; O-H: 463; C-O 360

Answer

Bonds broken	ΔH	Bonds formed	ΔH
1 x C=C	1 x 612	1 x C-C	1 x 348
1 x H-O	1 x 463	1 x C-H	1 x 412
		1 x C-O	1 x 360

Total	1075		1120

ΔH_r = 1075 – 1120= -45kJmol^{-1}

10.9.3. Extended activities

1. a) Given the definition of the standard enthalpy of formation for a substance, write an equation

for the reaction for the formation of KBr, $C_6H_{12}O_6$, HNO_3.

b) Calculate the enthalpy of each of the following reactions using the data provided

(i) $SiCl_4(l) + 2H_2O(l) \rightarrow SiO_2(s) + 4HCl(aq)$

(ii) $4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$

$\Delta H_f(SiCl_4)$ = - 640kJ/mol

$\Delta H_f(2H_2O(l))$ = -286kJ/mol

$\Delta H_f(SiO_2)$ = -911kJ

$\Delta H_f(HCl)$ = -167kJ/mol

$\Delta H_f(NH_3)$ = -96kJ/mol

$\Delta H_f(NO)$ = -90.4kJ

$\Delta H_f(2H_2O(g))$ = - 242kJ

Answers

1.

a) $K(s) + Br(l) \rightarrow KBr(s)$

b) $6C(s) + 6H_2(g) + 3O_2(g) \rightarrow C_6H_{12}O_6(s)$

c) $H_2(g) + N_2(g) + O_2(g) \rightarrow HNO_3(l)$

(i) $\Delta Hr = \Delta H_f(SiO_2) + 4 \times \Delta H_f(HCl) – 2 \times \Delta H_f(2H_2O(l)) - \Delta H_f(SiCl_4)$

$\Delta Hr = -911 + 4 \times (-167) – 2 \times (-286) - (-640) = -367kJmol^{-1}$

(ii) $\Delta Hr = 4 \times \Delta H_f(NO) + 6 \times \Delta H_f(2H_2O(g)) -4 \times \Delta H_f(NH_3)$

$\Delta Hr = 4 \times (-90.4) + 6 \times (-284) -4 \times (-96) = - 1636.6\ kJmol^{-1}$

2. In an experiment to determine the enthalpy of neutralization of an acid, HX, a student placed

50cm^3 of 1M NaOH in a polystyrene cup and recorded the temperature every minute for three minutes. At the fourth minute the student added 50cm^3 of a 1M HX. The student stirred the mixture and recorded the temperature at the fifth minute and every minute for the next five minutes. The results are shown in the table below:

Time	1	2	3	4	5	6	7	8	9	10
Temperature/ °C	19.0	19.0	19.0	-	25.1	24.5	23.7	23.5	23.1	22.7

The equation of the reaction is: $HX\ (aq) + NaOH\ (aq) \rightarrow NaX\ (aq) + H_2O(l)$

Explain why the mixture was stirred at regular intervals.

Plot a cooling curve from the data in the table.

From your cooling curve, calculate the theoretical temperature rise at the fourth minute.

Calculate the heat energy released in the reaction.

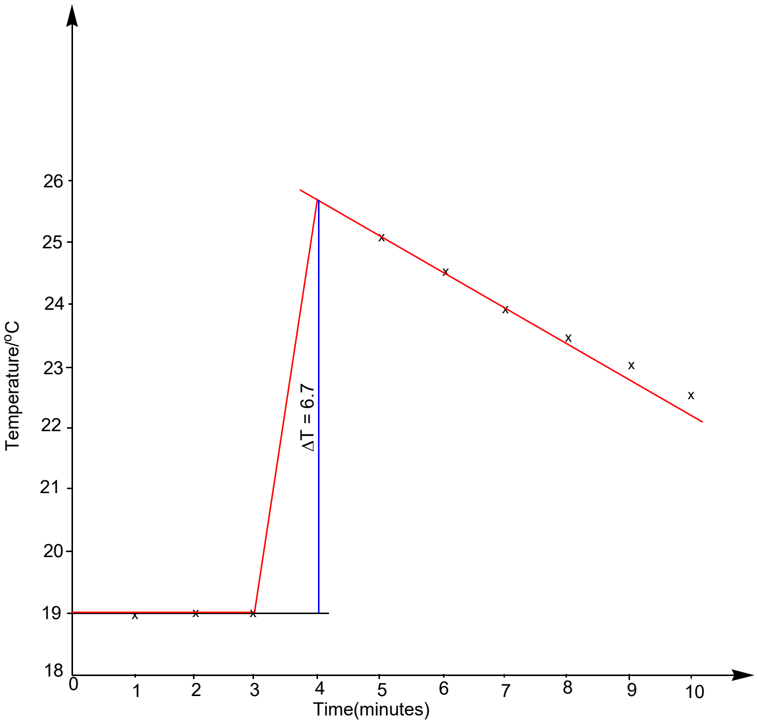
Calculate the moles of acid, HX, neutralized in the reaction.

Hence calculate the enthalpy of neutralization per mole of acid

Solution

a) The mixture was stirred at regular intervals to make uniform the temperature throughout the solution

b) Cooling curve



c) From the cooling curve, T =6.7°C.

d) Heat energy is released, $q = m \times Cs \times \Delta T = 100 \times 4.18 \times 6.7 = 2800.6J$

e) Moles of the acid reacted = $50 \times 10^{-3}dm^3 \times 1moldm^3 = 0.05mol$

f) Molar enthalpy = = -56012J = -56.012kJ

REFERENCES

Andrady A. L. and Neal M. A. (2009). Applications and societal benefits of plastics. Phil. Trans. R. Soc. B 364, 1977–1984

Bahl, A. (2010). *Advanced Organic Chemistry.* S Chand & Company Limited.

Briggs, J. (2002). *Level Course in Chemisrty* (Illustrated, reprint ed.). Pearson Education South Asia.

C., P., & H., P. (2014). *Combridge International AS and A level Chemistry.* London: HODDER Education.

Chang, R. (2005). *Chemistry* (eighth ed.). McGraw-Hill.

Harwood, William S., F. G. Herring, Jeffry D. Madura, and Ralph H. Petrucci. General Chemistry Principles and Modern Applications, 9th edition. New Jersey: Prentice Hall, 2007.

H., R., & L., I. (2011). *Combridge IGCSE Chemistry Workbook* (Third edition ed.). NewYork: Combridge university press.

Holman, G. H. (2000). *Chemistry in Context 5th Edition.* United Kingdom: Nelson Thornes.

Huhes, P. C. (2002). *Chemistry for advanced level.* London: JOHN MURRAY.

Hopewell, J., Dvorak, R., and Kosior, E. (2009). Plastics recycling: challenges and opportunities. Philos Trans R Soc Lond B Biol Sci; 364(1526): 2115–2126. doi: 10.1098/rstb.2008.0311.

Jain, S., & Shailesh, K. *Chemistry Volume-I For Class XII.* S.Chand Publishing.

Kasangandjo, L. (2013). *Advanced level Chemistry Students' Book for S6.* England: Pearson.

Keith, J., & Sue, A. &. (2000). *Spotlight Science: Teacher Support Pack* (Illustrated, revised ed.). Nelson Thornes.

Lister, T., & Renshaw. (1995). *Understanding Chemistry for Advanced Level* (second ed.). Stanley Thornes.

Lister, T., & Renshaw, J. (2000). *New Understanding Chemistry for Advanced Level* (Illustrated ed.). Nelson Thornes.

Lwishi, K. (2013). *Pearson Advanced level Chemistry Student's Book for S6.* Harlow: PEARSON.

Moore, J. T. (2012). *Chemisrty II For Dummies.* John Wiley & Sons.

Negi, A., & Anand, S. (1985). *Textbook of Physical Chemistry* (Illustrated, reprint ed.). New Age International.

NCERT. (2007). *Chemistry Part II Textbook for Class XII.* National Council of e.

Obonyo, S.; Mukama, D. (2013). *Chemistry for Rwanda Secondary Schools Advanced level Senior 6.* Kampala: Fountain.

Pavia, D. L. (2005). *Introduction to organic Laboratory Techniques: A Small Scale Approach* (Illustrated ed.). Cengage Learning.

Peter, C., & H., P. (2014). *Cambridge International AS and A level Chemistry.* London: HODDER Education.

Prakashan. (2006). Medical entrance examination student in India. *Competition Science Vision* , *8*, 1537.

Ramsden, E. (2000). *A level Chemistry* (Fourth Edition Ed.). United Kingdom: Nelson Thornes.

Ramsden, E. (1995). *Calculations for A-Level Chemistry* (Illustrated ed.). Nelson Thornes.

Ritchie, D. G. (2008). *OCR Chemistry A2.* Harlow: Heinemann.

Satya Prakashh, G. T. (1999). *Advanced Inorganic Chemistry.* New Delhi: S. Chand & Company Ltd.

Sinha, N. (2007). *Handbook of Food Products Manufacturing* (Vol. 2). John Wiley and Sons.

Soffar, H. (2017, June 19). *Thermosets*, *Uses*, *features*, *Advantages and disadvantages.* Retrieved March 23, 2018, from htttp.online-sciences.com

Stellman, J. M. (1998). Encyclopedia of Occupatioanal Health. *3* Sarda, V., & Handa, A. &. *Chemistry.* Saraswati House Pvt Ltd.

Thompson, R.C., Moore, C.J., vom Saal, F.S. and Swan, S.H. (2009). Plastics, the environment and human health: current consensus and future trends.Biol Sci., 364(1526): 2153–2166.