CHEMISTRY

Senior 4

Teacher's Guide

Kigali, January 2019

FOREWORD

Dear teacher,

Rwanda Education Board is honoured to present Senior 4 Chemistry teacher'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 learners 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 teachers' pedagogical approaches, the assessment strategies and the instructional materials available. We paid special attention to the activities that facilitate the learning process in which learners can develop ideas and make new discoveries during concrete activities carried out individually or with peers. With the help of the teachers, learners 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 teacher. 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 learner where concepts are mainly introduced by an activity, situation or scenario that helps the learner to construct knowledge, develop skills and acquire positive attitudes and values.

In addition, such active learning engages learners 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 learners considering the importance of social constructivism suggesting that learning occurs more effectively when the learner works collaboratively with more knowledgeable and experienced people.
- Engage learners through active learning methods such as inquiry methods, group discussions, research, investigative activities and group and individual work activities.
- Provide supervised opportunities for learners 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 learners' contributions in the class activities.
- Guide learners 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 teacher`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 the teaching guidance for each concept given in the student book.

Even though this teacher`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 teacher`s guide, particularly REB staff who organized the whole process from 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 teachers 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. NDAYAMBAJE Irénée
Director General of Rwanda Education Board

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Joan MURUNGI,
Head of Curriculum, Teaching and Learning Resources Department

CONTENTS

UNIT 1: STRUCTURE OF AN ATOM AND MASS SPECTRUM

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1.1. Key unit competency

The learner should be able to interpret simple mass spectra and use them to calculate the relative atomic mass (R.A.M) of different elements.

1.2. Prerequisite knowledge and skills

Components of an atom and their properties, definition of an atomic number, mass number and isotopes as they learnt them from senior one chemistry unit 5.

1.3. Cross-cutting issues to be addressed

- **Gender inequality**

General need of people to complement one each over without conflict in order to be peaceful.

The nature of atoms can be related to relationship in human beings. There is a serious issue of misunderstanding of gender equality in our society. When introducing this unit, it would be an opportunity to guide learners on understanding the importance of gender equality and how the issues related to gender inequality may be addressed.

Help learners to:

a) Understand that complementarities are very important. Atom constituents such as protons and neutrons coexist in the atomic nuclei for playing the specific role. There are no conflicts between protons and neutrons in the nucleus of the atom even though their masses are quite equal. Students should know that female and male are both human beings and no one should say that he/she is more indispensable than another.

b) Understand that gender equality plays a big role in the development of the country.

c) Understand that female needs male and vice-versa in different ways for their future achievement.

d)Underline the necessity of cooperation and working in mixed group rather than working in single group)

You can do this in a short whole class discussion. This may be an opportunity for you as chemistry teacher to confront the individual students who need advise on relationship matter.

- **Inclusive education**

This unit involves a number of activities on the properties and discovery of atoms, and calculations involving mass spectrometer; the activities require reading and writing. This may be challenging to students with special educational needs especially children with visual impairment. However, the teacher can make some arrangements like:

- Grouping students. Students with special educational needs are grouped with others and assigned roles basing on individual student's abilities.
- Providing procedure earlier before the activity so that students get familiar with them. They can be written on the chalkboard or printed depending on available resources. If you have children with low vision remember to print in appropriate fonts or in Braille.
- Every important point is written and spoken. The written points help students with hearing impairment and speaking aloud helps students with visual impairment
- Remember to repeat the main points of the lessons.

1.4. Guidance on introductory activity

Before introducing the first lesson **(outline of the discovery of the atom constituents and their properties)** of this unit, let learners attempt the introductory activity.

Expected answers for the introductory activity

1. Diagram A Red: 7 spheres, Blue: 7 spheres
   Diagram B Red: 10 spheres, Blue: 11 spheres
   Diagram C Red: 7 spheres, Blue: 8 spheres
2. In common, all 3 diagrams have red and blue spheres
3. a)Blue spheres represent the number of neutrons
   b)Red spheres represent the number of protons

Explanation: in the nucleus of an atom, the number of neutrons may be equal or greater than the number of protons, so the number of blue spheres is higher in B and C

4. Symbols A: $^{14}_{7}N$,B: $^{21}_{10}Ne$, C: $^{15}_{7}N$ (note: A and C are isotopes of nitrogen)
5. Yes there are. The missing particles are called electrons
6. When the atom is broken down three smallest particles are obtained: protons, neutrons and electrons

1.5. List of lessons

Heading	Lesson title	Learning objectives	No of periods
1.1. Outline of the discovery of the atom constituents and their properties	Discovery of the atom constituents and their properties	• Outline the discovery of the sub-atomic particles. • Compare the properties of sub-atomic particles.	2
1.2. Concept of atomic number, mass number, and isotopic mass	Concept of atomic number, mass number, and isotopic mass	• To compare the isotopes of an element • To assess the relationship between number of protons and the number of electrons • To calculate mass number knowing the number of protons and number of neutrons	2
1.3.Calculation of relative atomic mass of elements with isotopes	Calculation of relative atomic mass of elements with isotopes	• To understand the meaning of relative atomic mass and relative abundances • Calculate the relative atomic mass of an element, given isotopic masses and abundances.	2
1.4. Description and functioning of the mass spectrometer	Description and functioning of the mass spectrometer	Draw and label the mass spectrometer. Explain the fundamental processes that occur in the functioning of a mass spectrometer.	4
1.5 Interpretation of mass spectra	Interpretation of mass spectra	Interpret different mass spectra.	2
1.6. Uses of the mass spectrometer and involving calculation	Uses of the mass spectrometer and involving calculation	State the uses of the mass spectrometer. Calculate the relative atomic mass of an element, given mass spectrum.	4
Assessment			2

Lesson 1: Discovery of the atom constituents and their properties

This is the first lesson of unit 1. It is a single lesson, but it also covers the introduction of the whole unit, it has two periods (80 minutes).

a) Prerequisites/Revision/Introduction

Students will learn better the discovery of the atom constituents and their properties if they have understanding on: main components of an atom and their properties (S 1 chemistry: unit 5)

b) Teaching resources

Use the illustrations in the students' book

c) Learning activities

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt the introductory activity first then learning activity1.1 which leads students to the first lesson of the unit.

- Form groups of 3 to 5 learners and ask them to choose a group leader
- Provide the activity 1.1 from the student book (when the books are not enough, he/she can write the activity on the chalkboard) to the learners in their groups and ask every group to discuss questions 1 – 5, and provide answers.
- Let learners to work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to present the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 1.1. Learners should do the checking up activity in any method you wish to use

Expected answers for activity 1.1

1. True. The answer to this question lies in the number and the arrangement of the electrons. The electrons constitute most of the atomic volume and thus are the parts that "intermingle" when atoms combine to form molecules. Therefore, the number of electrons possessed by a given atom greatly affects its ability to interact with other atoms. As a result, the atoms of different elements, which have different numbers of protons and electrons, show different chemical behavior.

2. J. J. Thomson's study of cathode-ray tubes led him to postulate the existence of negatively charged particles that we now call electrons.

Thomson also postulated that atoms must contain positive charge in order for the atom to be electrically neutral.

Ernest Rutherford and his alpha bombardment of metal foil experiments led him to postulate the nuclear atom with a tiny dense center of positive charge (the nucleus) with electrons moving about the nucleus at relatively large distances away; the distance is so large that an atom is mostly empty space.

3. The atom is composed of a tiny dense nucleus containing most of the mass of the atom. The nucleus itself is composed of neutrons and protons. Neutrons have a mass slightly larger than that of a proton and have no charge. Protons, on the other hand, have a 1+ relative charge as compared to the 1– charged electrons; the electrons move about the nucleus at relatively large distances. The volume of space that the electrons move about is so large, as compared to the nucleus, that we say an atom is mostly empty space.

4. Protons in an atom determine the identity of the atom .The number and arrangement of electrons in an atom determine how the atom will react with other atoms, i.e., the electrons determine the chemical properties of an atom. The number of neutrons present determines the isotope identity and the mass number. Neutrons bind protons together inside the nucleus.

d) Checking up 1.1

Expected answers for checking up 1.1

1. $5.93 \times 10^{-18}\text{C} \times \dfrac{1 electon\ charge}{1.602\ x\ 10^{-19}C}$

=37 negative (electron) charges on the oil drop

2. False. Hydrogen contains only 2 (1 proton and 1 electron)

3.

Particle	a) Relative masse	b) Relative charge
Neutron(n)	1.0087 a.m.u	0
Proton(p or P+)	1.0073 a.m.u	+1
Electron(e-)	0.00054858 a.m.u	-1

4.

	Carbon	Calcium	Chlorine	Chromium
Protons	6	20	17	24
Electrons	6	20	17	24

Lesson 2: Concept of atomic number, mass number, and isotopic mass

Concept of atomic number, mass number, and isotopic mass is the second lesson of the unit. Students are expected to compare the isotopes of an element, to assess the relationship between number of protons and the number of electrons, and to calculate mass number knowing the number of protons and number of neutrons

a) Prerequisites/Revision/Introduction:

Students will learn better a concept of atomic number, mass number, and isotopic mass if they have understanding on: Definition of atomic number, mass number and isotope (S1 chemistry: unit 5)

b) Teaching resources:

- The Periodic Table of Chemical Elements
- Charts illustrating isotopes of some elements.

c) Learning activities

Learning activity 1.2 is suggested in students' book. However you are free to add more.

- Form groups of 3 to 5 learners and ask them to choose a group leader
- Provide the activity 1.2 from the student book (when the books are not enough, you can write the activity on the chalkboard) to the learners in their groups and ask every group to do questions 1 – 8, and provide their answers.
- Let learners to work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to present the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 1.2. Learners should do the checking up activity in any methodology you wish to use.

Expected answers for activity 1.2

1. In common, sodium isotopes have the same number of protons and electrons, and they differ in the number of neutrons.
2. Isotopes are atoms of the same element with same atomic number but different

mass numbers.

3. Mass number is determined by the addition of the number of protons and the number of neutrons.

4. Atomic number provides information regarding the number of protons in the atomic nucleus.

5. In the atom the number of protons are equal to the number of electrons.

6. Protons and neutrons are located in the nucleus of an atom; electrons are distributed within the sphere surrounding the nucleus

7. This is because in the centre/nucleus is where the two heaviest subatomic particles located.

8. This is because both isotopes have the same number of proton in the nucleus and hence the same number of electrons which are responsible for chemical reaction.

9.i) wrong

ii) Correct

iii) Wrong

iv) Correct

v) Wrong

d) Checking up 1.2.

Expected answers for checking up 1.2

1. (a): For: $^{35}_{17}Cl$:Atomic number =17. There are therefore 17 protons per nucleus.

Mass number = 35. There are therefore 35 protons plus neutrons or, because we know that there are 17 protons, there are 18 neutrons. Because no charge is indicated, there must be equal numbers of protons and electrons, or 17 electrons.

For: $^{35}_{17}Cl$: There are 17 protons, 20 neutrons, and 17 electrons per atom. **These are isotopes of the same element Cl.** Both have 17 protons, but they differ in their numbers of neutrons: one has 18 neutrons and the other has 20.

(b) For: $^{63}_{29}Cu$: Atomic number = 29. There are 29 protons per nucleus. Mass number = 63. There are 29 protons plus 34 neutrons.

Because no charge is indicated, there must be equal numbers of protons and electrons, or 29 electrons.

For: $^{65}_{29}Cu$:There are 29 protons, 36 neutrons, and 29 electrons per atom. **These are isotopes.** Both have 29 protons, but they differ in their numbers of neutrons: one isotope has 34 neutrons and the other has 36.

2. a) $a)\ ^{9}_{4}Be$ b) $^{51}_{23}V$ c) $^{124}_{54}Xe$ d) $^{69}_{31}Ga$

3. a)Protons, Electrons b) Atomic number c) Mass number d) Isotope e) Neutron

Lesson 3: Calculation of relative atomic mass of elements with isotopes

a) Prerequisites/Revision/Introduction:

Before beginning this lesson, learners should be able to recall the definition of isotopes and give some examples.

b) Teaching resources

- The Periodic Table of Chemical Elements
- Charts illustrating isotopes of some elements and their relative abundances.

c) Learning activities

- Learning activity 1.3 is suggested in students' book. However the teacher is free to add more.
- Form groups of 3-5 students. The number of groups and members will depend on your class size.
- In the groups students attempt activity 1.4, discuss and record their answers.
- Each group representative presents their answers to the whole class.
- During the presentation ask some questions that lead to lesson conclusion such as calculating the relative atomic mass of an element, given isotopic masses and abundances.
- Make a summary of the lesson (short notes) and assess your lesson. Let students do checking up 1.3. Learners should do the checking up activity in any method you wish to use.

Expected answers for Activity 1.3

1. Isotope of argon which is the most abundant in nature is argon-40.

Explanation: A relative atomic mass of Argon from the periodic table is equal to 39.948, this value must be closer to the isotopic mass of the most abundant isotopes i.e. argon-40

(the atomic weight of an element is always closer to the mass of the most abundant isotope or isotopes)

2. Applying the formula of RAM we can calculate that of X

$(0.7215\times 84.9118\text{amu}) + (10.2785\times 86.9092\text{amu}) = 61.263\text{amu} + 29.209\text{amu} = 85.467\text{amu}$

From the periodic table, X is Rubidium (Rb)

3. $[10x + 11(100-x)]/100 = 10.8$

$10x + 1100 - 11x = 1080$

$x = 1100 - 1080 = 20\%$

d) Checking up 1.3

Expected answers for checking up 1.3

1. Atomic weight = 0.7899(23.98504 amu) + 0.1000(24.98584 amu) + 0.1101(25.98259 amu)

= 18.946 amu + 2.4986 amu + 2.8607 amu

= 24.30 amu (to 2 decimal places)

2. Let x = fraction of 69Ga. Then (1 - x) = fraction of 71Ga.

$$x\,(68.9257\text{ amu}) + (1 - x)\,(70.9249\text{ amu}) = 69.72\text{ amu}$$

$$68.9257x + 70.9249 - 70.9249x = 69.72$$

$$-1.9992x = -1.20$$

$$x = 0.600$$

x = 0.600 = fraction of 69Ga, hence the % abundance of 69Ga is 60.0%

(1 - x) = 0.400 = fraction of 71Ga , hence % abundance of 71Ga is 40.0%

Lesson 4: Description and functioning of the mass spectrometer

a) Prerequisites/Revision/Introduction

Make sure that learners understood well the previous lessons. You can give learners some quick revision questions.

b) Teaching resources

Student books, books from library and internet resources

c) Learning activities

- This is a guided research activity. Students are asked to do research on functioning of mass spectrometer and answer questions in activity 1.4. You may help learners by giving them a list of important reference books available in the school library and the internet websites for relevant information.
- Give to learners clear instructions keeping in mind that in addition to subject matter skills and knowledge, this lesson also tends to develop research skills (report writing and referencing), lifelong learning skills, and communication (reading, writing and speaking skills) in English.
- The lesson starts with answering the activity 1.4 questions.
- On each question you will have to first give learners time to share their answers then agree on what is right.
- Make sure that learners are able to explain the function of each spectrometer part in their own words.
- Summarise the lesson and verify learners' notes.
- Assess the lesson using checking up 1.4.

d) Expected answers for activity 1.4

1. Cfr student's book.

2. d) Ion transducer.

3. d) Injection system.

e) Checking up 1.4

Expected answers for Checking up 1.4

1. The words are filled in the passage as follows: Vaporization, ionization, velocity, acceleration, deflection, detector, mass spectrum

2.B **3**.D **4**.C **5**.D **6**.C

Lesson 5: Interpretation of mass spectra

a) Prerequisites/Revision/Introduction:

Introduce the lesson by allowing learners to do the activity 1.5 in the groups or any other appropriate method chosen. This activity is diagnostic i.e. intended to check on the previous information about isotopes and description of mass spectrometer. Learners will be asked to read learning activity in student's book and answer them.

b) Teaching resources

Chemistry student book

c) Learning activities 1.5

- After organizing the learners in their respective groups, let them work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to present the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 1.5. Learners should do the checking up activity in any method you wish to use.

Expected answers for activity 1.5

a) m/z is the mass/charge ratio - the mass of the ion divided by its charge.

b) Zirconium has 5 isotopes with relative isotopic masses of 90, 91, 92, 94 and 96.

The most abundant one is Zr-90, followed by Zr-94 and Zr-92 which have similar abundances.

Then Zr-91, and the least abundant is Zr-96

c) You would find a similar set of peaks but at exactly half the m/z values. The heights of the peaks are likely to be much less than the corresponding ones with 1+ ions, because a 2+ ion is less likely to form than a 1+ ion.

e) Checking up 1.5

Expected answers for Checking up 1.5

a) Three isotopes

b) 24, 25, 26

c) 79, 10, 11

Lesson 6: Uses of the mass spectrometer and calculations of RAM with mass spectrum

a) Prerequisites/Revision/Introduction

All previous lessons have to be understood

b) Teaching resources

Student's chemistry book and other relevant books from the school library

c) Learning activities 1.6

- Introduce the lesson by allowing learners to do the learning activity 1.6 in their respective groups. Let them work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to present the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 1.6. Learners should do the checking up activity in any method you wish to use.

Expected answers for activity 1.6

a) Atomic mass

b) RAM= (54x5.84) + (56x91.68)+(57x2.17)+(58x0.31)/5.84+91.68+2.17+0.31

= 315.36 + 5134 + 123.69+ 17.0.31/100

= 55.91

d) Checking up 1.6

Expected answers for Checking up 1.6

1. C, Mass spectrometer is not used to confirm the presence of O-H and C=O in organic compounds. You use infra red spectroscopy for this.

2. a) Isotopes are atoms of the same element (and so with the same number of protons), but with different masses due to having different numbers of neutrons.

b) The relative atomic mass of an element is the weighted average of the masses of the isotopes on a scale on which a carbon-12 atom has a mass of exactly 12 units.

c) Because you only have 1+ ions, the m/z value tells you the relative isotopic masses of 100 typical atoms, the total mass = (0.56 x 84) + (9.86 x 86) + (7.00 x 87) + (82.58 x 88) = 8771.04

Relative atomic mass = 8771.04/100 = 87.7 (to 1 decimal place)

3. a) Chlorine goes into the mass spectrometer as molecules; Cl_2 Ionisation of these gives the lines at 70/72/74. But the Cl_2^+ ions are not very stable and some of them split to give a Cl^+ ion and a chlorine atom. The Cl^+ ions give the lines at 35/37.

b)

m/z	Caused by
35	$^{35}Cl^+$ ions
37	$^{37}Cl^+$ ions
70	Cl_2^+ molecular ions containing two ^{35}Cl atoms
72	Cl_2^+ molecular ions containing one ^{35}Cl and one ^{37}Cl atom
74	Cl_2^+ molecular ions containing two ^{37}Cl atoms

c) ^{35}Cl is approximately 3 times more abundant than ^{37}Cl.

d) 9 : 6 : 1

e) There is no way of predicting what proportion of the Cl_2^+ molecular ions will split up to give Cl^+ ions and a chlorine atom

1.6. Unit Summary

- The nucleus contains protons (positively charged) and neutrons.
- The atomic number (proton number) is equal to the number of protons in

the atom's nucleus.

- The number of protons, positively charged, is equal to the number of electrons, negatively charged; hence the atom is neutral.
- The mass number is the total number of protons and neutrons in the nucleus.
- The mass of an atom is practically concentrated in the nucleus, the mass of electrons is negligible.
- Ions do not have the same number of electrons as protons, and so have an overall charge.
- Isotopes are atoms having the same number of protons but different numbers of neutrons.
- The relative atomic mass is the weighted mean mass of an atom relative to ^{12}C , so that carbon is exactly 12 on this scale.
- The average relative atomic mass is equal to the sum of each isotope's mass for an element times its relative abundance.
- The relative formula mass of a compound is equal to the sum of the individual relative atomic masses.
- A mass spectrometer will separate ions of different mass and charge in a gaseous sample of ions. The instrument allows the researcher to determine the accurate mass of each ion, whether the ions are composed of individual atoms, molecules, or molecular fragments.

1.7. End unit assessment

Assessment is an important part of teaching and learning. At the unit level, the teacher needs to know how well the key unit competence was achieved. End of unit assessment questions were suggested and two periods are reserved.

Expected Answers for "end unit assessment"

Multiple choice questions:

1. D, Explanation: mass of proton is almost 1836times that of the electron

2.

A. **False.** Neutrons have no charge; therefore, all particles in a nucleus are not charged.

B. **False**. The atom is best described as having a tiny dense nucleus containing most of the mass of the atom with the electrons moving about the nucleus at relatively large distances away; so much so that an atom is mostly empty space.

C**. False**. The mass of the nucleus makes up most of the mass of the entire atom.

D. **True.**

E. **False.** The number of protons in a neutral atom must equal the number of electrons.

3.

A. The atom is not an indivisible particle but is instead composed of other smaller particles, called electrons, neutrons, and protons.

B. The two hydride samples contain different isotopes of either hydrogen and/or lithium. Although the compounds are composed of different isotopes, their properties are similar because different isotopes of the same element have similar properties (except, of course, their mass).

4. **B, Explanation:** In mass spectrometer, the sample which is to be analysed is bombarded with electrons. As a result, ions are produced.

5. **D, Explanation:** Mass spectrometer separates ions on the basis of mass to charge ratio. Most of the ions are singly charged. Hence, the mass to charge ratio is equal to the mass.

6. **C, Explanation:** In mass spectrometer, the ions are sorted out by accelerating them through electric and magnetic field. A record of number of different kinds of ions is called mass spectrum.

7. **C, Explanation:** The procedure for mass spectroscopy starts with converting the sample into gaseous state. This is done by chemical processes.

8. **D, Explanation:** Positive ions of specific mass pass through the slit and reach the collecting plate. These ions are measured.

9. **A, Explanation:** Impurities of masses different from the one being analysed does not interfere with the result in mass spectroscopy. This is a major advantage of this technique.

10. **A, Explanation:** The sample gas is introduced into the highly evacuated spectrometer tube and it is ionised by electron beam. The sample has to be in gaseous state

Short and long answer open questions

11. Proton, neutron, and electron. Proton has positive charge, neutron has no charge, and electron has negative charge and it is the least massive of the three. Particles that constitute nucleus are protons and neutrons.

12. $$RAM = \frac{(6.015121 \times 7.50) + (7.016003 \times 92.50)}{100} = 6.94093685$$

Writing the answer with two decimal places we prove that the RAM of lithium is 6.94

13. a) The hot metal coil releases electrons which are attracted to the electron trap which is positively charged. On their way, they hit atoms or molecules in the sample, and knock one or more electrons off to give positive ions. Those ions are repelled by another positively charged plate on the left out of the slit on the right-hand side.

b) (i) Mass and charge. The heavier the ion, the less it is deflected. The higher the positive charge, the more it is deflected.

(ii) Assuming that all of the ion streams have the same charge, then this must have the heaviest ions. To be more general about it, the least deflected ion stream will be the one with the highest mass/charge ratio.

(iii) You would need to increase the magnetic field.

c) To avoid the possibility of the ions hitting, and being deflected by, air molecules.

d) The detector is made of metal connected to a wire. When an ion hits the metal, an electron jumps off the metal to neutralise the ion. Electrons flow from the wire to replace those removed from the detector, and this flow is seen as an electric current which can be amplified and recorded. The greater the number of ions arriving, the greater the current.

14. a) RAM = [(113X) + 115(100-X)]/100 = 114.5

X = 25% for Indium-113

100- X = 75% for Indium-115

b) i)Magnesium exists as three isotopes hence it gives 3 peaks, one peak for each isotope

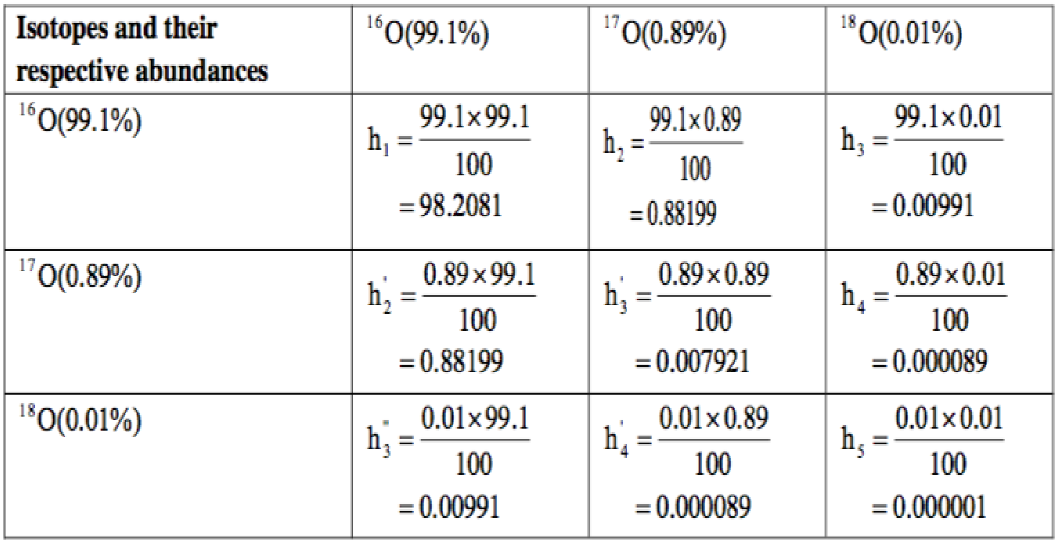
ii) Relative abundance for each isotopes

m/z	**24**	**25**	**26**
Abundance	1/1.266 = 78.98%	0.127/1.266 =10.04%	0.139/1.266 =10.98%

1.266 is the sum of relative intensities

RAM of magnesium=[(24×78.98)+(25×10.4)+(26×10.98)]/100=24.41

15. Let us organize the given information in the following table.



Isotopes and their respective abundances	$^{16}O(99.1\%)$	$^{17}O(0.89\%)$	$^{18}O(0.01\%)$
$^{16}O(99.1\%)$	$h_1 = \frac{99.1\times 99.1}{100} = 98.2081$	$h_2 = \frac{99.1\times 0.89}{100} = 0.88199$	$h_3 = \frac{99.1\times 0.01}{100} = 0.00991$
$^{17}O(0.89\%)$	$h_2^{'} = \frac{0.89\times 99.1}{100} = 0.88199$	$h_3^{'} = \frac{0.89\times 0.89}{100} = 0.007921$	$h_4 = \frac{0.89\times 0.01}{100} = 0.000089$
$^{18}O(0.01\%)$	$h_3^{'} = \frac{0.01\times 99.1}{100} = 0.00991$	$h_4^{'} = \frac{0.01\times 0.89}{100} = 0.000089$	$h_5 = \frac{0.01\times 0.01}{100} = 0.000001$

We can conclude the following:

a. There will be 5 molecular ions' peaks and 3 atomic ions' peaks observed on the screen of the mass spectrometer

1) $(^{16}O\text{-}^{16}O)^{+}$ or $^{16}O_2^{+}$ at $\frac{m}{z} = 32$

2) $(^{16}O\text{-}^{17}O)^{+}$ and $(^{17}O\text{-}^{16}O)^{+}$ which overlap to form one peak at $\frac{m}{z} = 33$

3) $(^{16}O\text{-}^{18}O)^{+}$,$(^{17}O\text{-}^{17}O)^{+}$ or $^{17}O_2^{+}$ and $(^{18}O\text{-}^{16}O)^{+}$ which overlap to form one peak at $\frac{m}{z} = 34$

4) $(^{17}O\text{-}^{18}O)^{+}$ and $(^{18}O\text{-}^{17}O)^{+}$ which overlap to form one peak at $\frac{m}{z} = 35$

5) $(^{18}O\text{-}^{18}O)^{+}$ or $^{18}O_2^{+}$ at $\frac{m}{z} = 36$

1st peak=98.20
2nd peak=0.88x2=1.76
3rd peak= (0.01x2) + 0.008=0.028
4th peak=0.0001x2=0.0002
5th peak=0.000001

1.8. Additional Information

The History of the Atom

1. Timeline: 400 BC

Scientist: Democritus (Greek Philosopher)

Democritus was a Greek philosopher who was the first person to use the term **atom** (atomos: meaning indivisible). He thought that if you take a piece of matter and divide it and continue to divide it you will eventually come to a point where you could not divide it any more. This **fundamental** or **basic** unit was what Democritus called an atom.

He called this the **theory of the universe:**

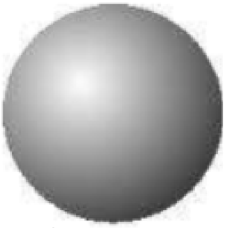
- All matter consists of atoms, which are bits of matter too small to be seen.
- There is an empty space between atoms
- Atoms are completely solid
- Atoms have no internal structure
- Each atom (of a different substance) is different in size, weight and shape.

2. Timeline: 1800's

Scientist: John Dalton

John Dalton was the first to adapt Democritus' theory into the first modern atomic model.

John Dalton’s Atomic Model:



1. All matter consists of tiny particles called atoms
2. Atoms are indestructible and unchangeable
3. Elements are characterized by the weight of their atoms
4. When elements react, it is their atoms that have combined to form new compounds

3. Timeline: 1890’s

Scientist: J.J Thomson

J.J Thomson was a physicist who is credited for discovering the **electron**. He used his research on **cathode ray** tube technology in this discovery.

1. Nearly empty tube (Air has been sucked out)
2. An electric charge is passed through the tube. Travels from cathode to anode
3. The charge is invisible, so to see where it traveled a fluorescent screen is placed at back of tube. Where the beam hits, a dot will appear on the screen. You could also use a fluorescent gas and the whole tube will light up.
4. This beam will always travel straight if not interfered with.
5. The deflection coils each have a specific charge. One is positive and the other is negative.
6. Thomson showed (as in the diagram above) that the charge would deflect away from the negative coil. He then stated that this charge was thus a negative charge. J.J Thomson was an excellent physicist and thus did not stop when he had found this negative charge. Through a series of clever experiments he was able to predict the mass of this charge.

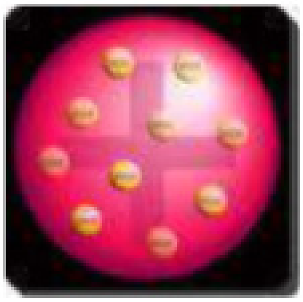
Scientific Interpretation at its Best

He then found out that this charge was 1000 times lighter that a hydrogen atom. He made a bold statement saying that this negative charge must be inside an atom. This negative charge (he called corpuscles) later became known as the electron.

Thomson’s Atomic Model

Using what he had discovered, Thomson predicted what an atom should look like.

These are the key points to Thomson's Atomic Model:



1. Because of its design this model is known as the plum pudding model
2. Each atom is a sphere filled with positively charged 'fluid'. This resembles the sticky jam part of a pudding.
3. Corpuscles (later called electrons), are the negatively charged particles suspended in this 'fluid'. This resembles the plums in the pudding.
4. He did not predict the movement of these electrons

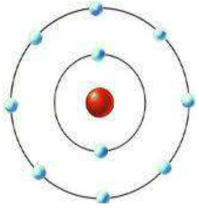
4. Timeline: 1910's

Scientist: Ernest Rutherford

Ernest Rutherford was not convinced about the model of the atom proposed by Thomson. He thus set up his now famous Gold Foil Experiment.

1. He fired alpha particles (positively charged) at a gold foil.
2. He measured the deflection as the particles came out the other side.
3. Most of the particles did not deflect at all. Every now and then a particle would deflect all the way back.
4. He said that there must be a positive centre of the foil. He called this centre the nucleus.

Rutherford's Atomic Model



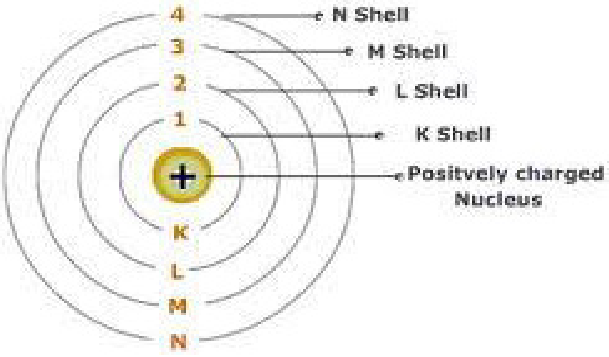
1. The nucleus of the atom is a dense mass of positively charged particles.
2. The electrons orbit the nucleus
3. A problem raised was: Why are the negatively charged particles not attracted by the positively charged nucleus
4. Rutherford stated that the atom was like a mini solar system and that the electrons orbited the nucleus in a wide orbit. That is why it is known as the planetary model.

5.Timeline: 1910's

Scientist: Niels Bohr

Niels Bohr agreed with the planetary model of the atom, but also knew that it had a few flaws. Using his knowledge of energy and quantum physics he was able to perfect Rutherford's model. He was able to answer why the electrons did not collapse into the nucleus.

Bohr's Atomic Model



1. Electrons orbit the nucleus in orbits that have a set size and energy.

2. The lower the energy of the electron, the lower the orbit.

3. This means that as electrons fill up the orbitals, they will fill the lower energy level first.

4. If that energy level is fill (or at capacity), a new energy level will begin.

5. Radiation is when an electron moves from one level to another.

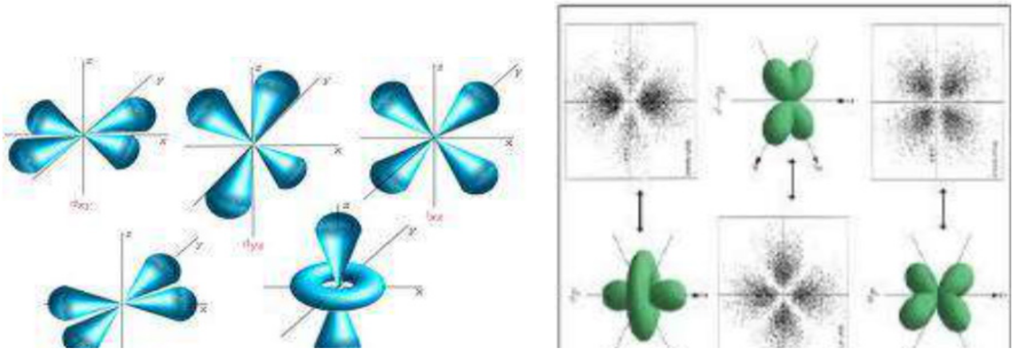
Problems with this theory: Electrons do not travel on a specific orbit or path.

6. Timeline: 1920's

Scientist: Erwin Schrödinger

Erwin Schrödinger was a revolutionary physicist who used Heisenberg's uncertainty principle to come up with the atomic model that we still use today.

Schrödinger's Atomic Model (The Cloud Model)



1. An electron does not travel in an exact orbit
2. We can predict where it will probably be
3. We cannot say for certain where it is, but only where it ought to be.
4. The type of probability orbit is dependent on the energy level described by Bohr

1.9. Additional activities

1.9.1. Remedial activity

1. Atomic Structure Puzzle

Across

2. A charged atom is called an _______

4. Atoms with the same number of protons and electrons but a different number of neutrons

6. Neutral atoms have a ________ charge

8. I do not have a charge

9. If an electron is added to a neutral atom,
the atom becomes ________ charged

10. Number of protons plus neutrons

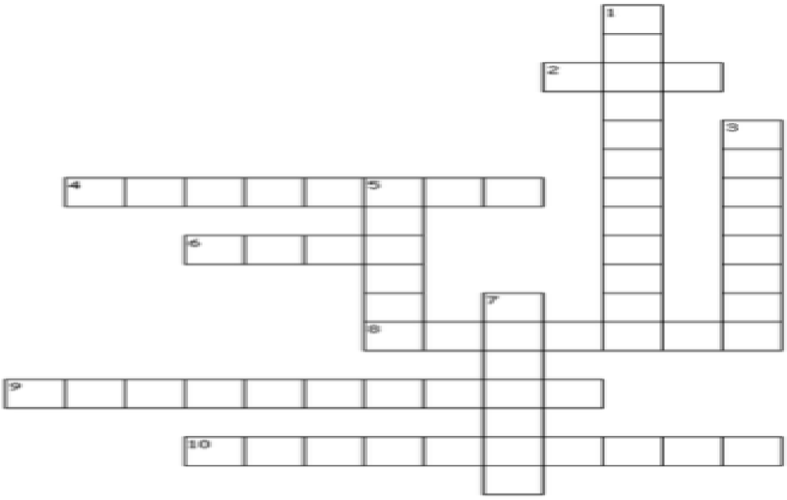
Down

1. Number of protons

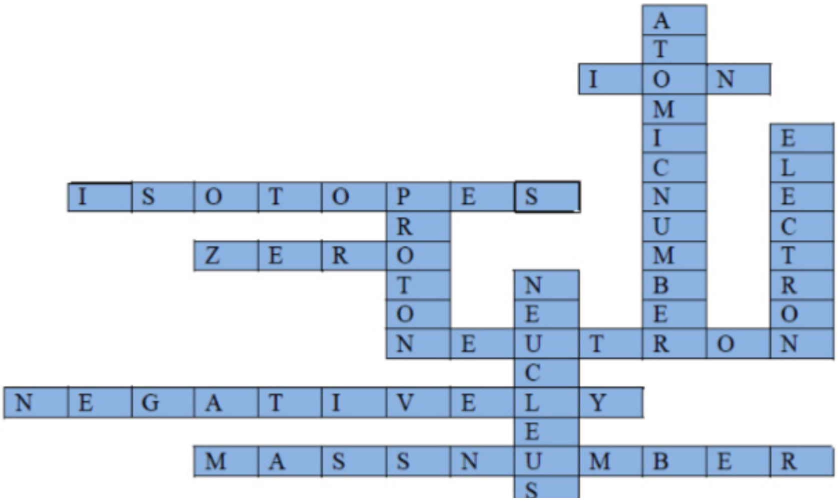
3. I move around the nucleus

5. My charge is positive

7. I am in the centre of the atom. I contain protons and neutrons



Answer



2. Which of the following is (are) correct?

a) $^{40}Ca^{2+}$ contains 20 protons and 18 electrons.

b) Rutherford created the cathode-ray tube and was the founder of the charge-to-mass ratio of an electron.

c) An electron is heavier than a proton.

d) The nucleus contains protons, neutrons, and electrons.

Answer:

3. The listed atomic weight of gallium is 69.723 amu. Gallium has two stable isotopes, both of which are used in nuclear medicine. These two stable isotopes have the following masses: ^{69}Ga, 68.925580; ^{71}Ga, 70.9247005. Calculate the percent of each isotope in naturally occurring gallium.

Answer:

$$69.723 = \frac{(68.92558 \times X) + 70.924700(100 - X}{100}$$

$$6972.3 = 68.92558X + 7092.4700 - 70.924700$$

$$1.99912X = 120.17$$

$$X = \frac{120.17}{1.99912}$$

$$\Rightarrow X = 60.13$$

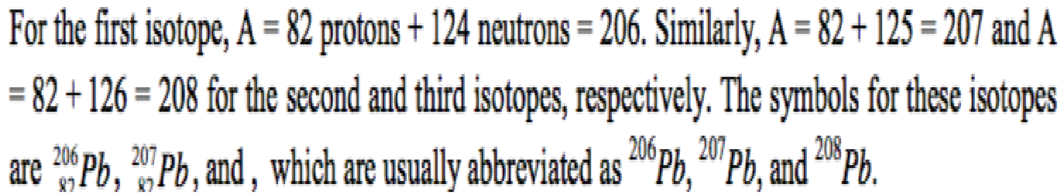
$$100 - 60.13 = 39.87$$

The percent of ^{69}Ga is 60.13%; and that of ^{71}Ga is 39.87%

An element with three stable isotopes has 82 protons. The separate isotopes contain 124, 125, and 126 neutrons. Identify the element and write symbols for the isotopes.

Answer:

The element with 82 protons (atomic number of 82) is lead: Pb.



For the first isotope, A = 82 protons + 124 neutrons = 206. Similarly, A = 82 + 125 = 207 and A = 82 + 126 = 208 for the second and third isotopes, respectively. The symbols for these isotopes are $^{206}_{82}Pb$, $^{207}_{82}Pb$, and , which are usually abbreviated as ^{206}Pb, ^{207}Pb, and ^{208}Pb.

5. The separation of ions in a mass spectrometer depends on

a) Only the charge on the ions

b) Only the mass of the ions

c) The mass and the charge of the ions

d) Only the velocity of the ions

Answer: (C)

6. When injected into a mass spectrometer a compound gave a number of ion peaks. Two peaks,one of which was the molecular ion, had m/z values of 58 and 43. Which of the molecular fragments below might have been lost from the original molecule?

A. CH3

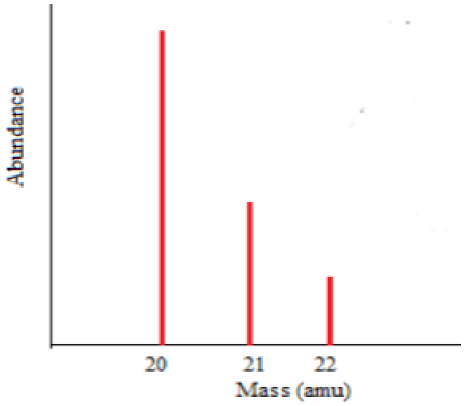
B. OH

C. C2H5

D. CHO

Answer: (a)

According to the mass spectrum below, the relative atomic mass of the element shown is best expressed as



(a)20.0

(b)Between 20.0 and 21.0

(c)21.0

(d)Between 21.0 and 22.0

Answer: (b)

1.9.2. Consolidation activity

8. One of the oxides of tantalum is tantalum (V) oxide,Ta_2O_5If the charge on the metal remained constant and then sulfur was substituted for oxygen,

a) How would the formula change?

b) Calculate the difference in the total number of protons between Ta_2O_5 and its sulfur analog?

Answer:

Sulfur is in the same group as oxygen, and its most common ion is .S^{2-} Therefore, the formula of the sulfur analogue would be .Ta_2S_5

Total number of protons in :Ta_2O_5

Ta, Z = 73, so 73 protons x 2 = 146 protons; O, Z = 8, so 8 protons x 5 = 40 protons

Total protons = 186 protons

Total number of protons in :Ta_2S_5

Ta, Z = 73, so 73 protons x 2 = 146 protons; S, Z = 16, so 16 protons 5 = 80 protons

Total protons = 226 protons

Proton difference between Ta_2s_5 andTa_2S_5 : 226 protons – 186 protons =

40 protons

9. A binary ionic compound is known to contain a cation with 51 protons and 48 electrons. The anion contains one-third the number of protons as the cation. The number of electrons in the anion is equal to the number of protons plus 1. Suggest the formula of this compound and the name of this compound.

Answer:

The cation has 51 protons and 48 electrons. The number of protons corresponds to the atomic number. Thus this is element 51, antimony.

There are 3 fewer electrons than protons. Therefore, the charge on the cation is 3+.

The anion has one-third the number of protons of the cation, which corresponds to 17 protons; this is element 17, chlorine. The number of electrons in this anion of chlorine is 17 + 1 = 18 electrons. The anion must have a charge of 1–.

The formula of the compound formed between Sb^{3+} and Cl^- is $SbCl_3$. The name of the compound is antimony (III) chloride. The Roman numeral is used to indicate the charge on Sb because the predicted charge is not obvious from the periodic table.

10. The mass spectrum of a hypothetical monatomic element A contains a peak at mass number 14 and another at mass number 16.

a)Sketch the mass spectrum assuming the peak at mass number 14 is three times the height of the peak at 16.

b)How many isotopes are present? Why?

c)Determine the relative abundances of the isotopes?

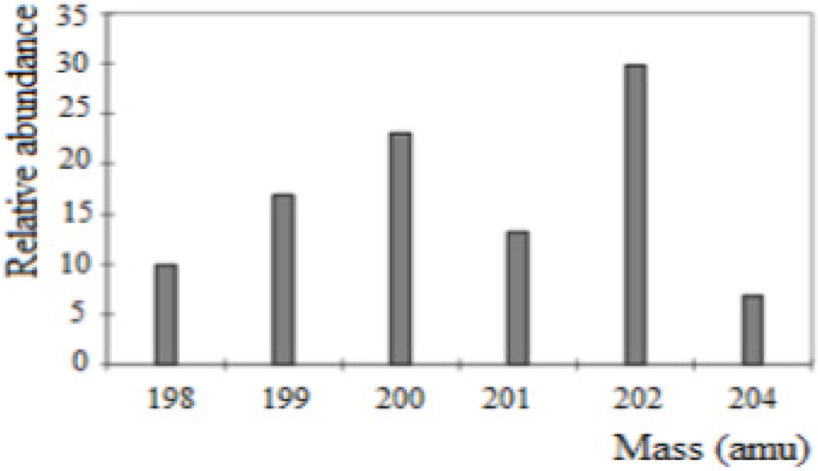
Answer:

a) Label of the vertical axis: relative abundance

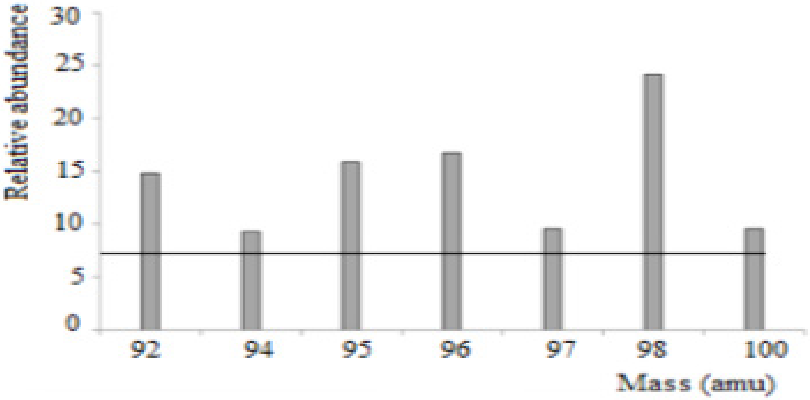
Label of the horizontal axis: mass (amu) or m/z

Then plot the height of the peaks as indicated in the question

11. The figures below represent the mass spectrum of mercury and Molybdenum respectively.



Mass spectrum of mercury



Mass spectrum of Molybdenum.

a)Calculate the atomic masses of mercury, and molybdenum from your data.

b) Compare your results to the actual atomic weights of these elements found on the periodic table. Calculate the percent difference for each.

$$\% \text{ difference} = \frac{|\text{experiment al} - \text{theoretica l}|}{\text{theoretica l}} \times 100$$

a) **Answer:**

$$\text{RAM of Hg} = \frac{(180\times10)+(199\times17)+(200\times24)+(201\times13)+(202\times30)+(204\times7)}{100} = 200.84$$

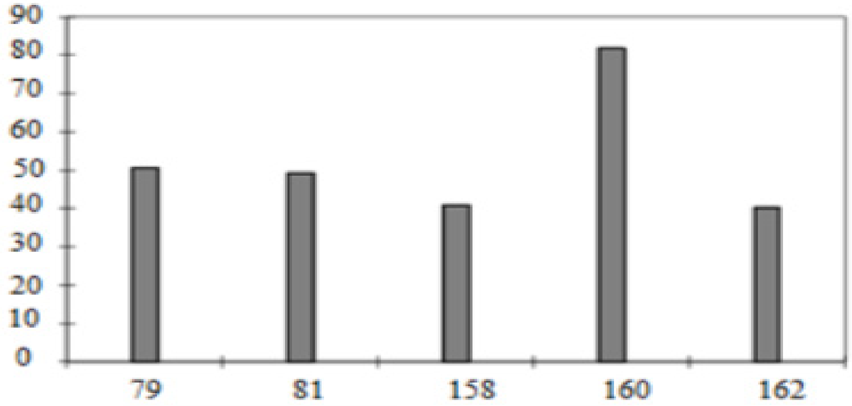
$$\text{RAM of Mo} = \frac{(92\times15)+(94\times9.90)+(95\times15.09)+(96\times15.20)+(97\times9.99)+(98\times28)+(100\times10)}{100} = 99.16$$

b)

$$\% \text{ difference(Hg)} = \frac{|200.59 - 200.84|}{200.84} \times 100 = 0.125\%$$

$$\% \text{ difference(Mo)} = \frac{|95.94 - 99.16|}{99.16} \times 100 = 3.25\%$$

12. The figure below represents the mass spectrum of Br2



Explain why the mass spectrum of Br_2 contains 5 peaks. Explain why the 3 last peaks have the heights approximately in the ratio 1:2:1? What are the origins of these signals?

Answer: there are 2 isotopes of Bromine (^{79}Br and ^{81}Br), the peak at 79 is for $^{79}Br^+$ and that at 81 is for are those of $81Br^+$.

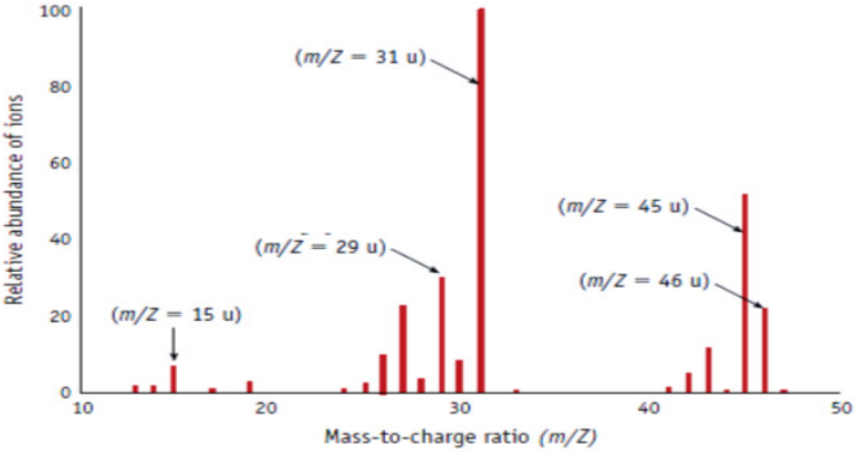
Other peaks formed due to the Br_2^+: the peak at 158 is for $(^{79}Br^{79}Br)^+$, the peak at 160 is for $(^{79}Br^{81}Br)^+$ or($^{81}Br^{79}Br)^+$, the peak at 162 is for $(^{81}Br^{81}Br)^+$. The height of 3 last peaks is approximately in the ratio 1:2:1 because at 160 two peaks overlap due to the two molecular ions with same m/z i.e $(^{79}Br^{81}Br\ )^+$ or $(^{81}Br^{79}Br)^+$.

When bromine is passed into the ionization chamber, an electron is knocked off the molecule to give a **molecular ion**, Br^+_2. After the fragmentation of Br^+_2, the Br ions will pass through the machine and will give lines at 79 and 81. The unfragmented Br^+_2 ions will also record lines at 158, 160, and 162.

1.9.3. Extended activity

13. The mass spectrum of ethanol (CH_3CH_2OH) contains 1 prominent peak for a "parent"

ion and other 4 peaks for "fragment" ions. (The figure of the mass spectrum of ethanol is shown below)



a) Write the formula of the parent ion

b) Write the formula of the fragment ions which correspond to each mass-to-charge ratio as they were shown on the figure

Answer:

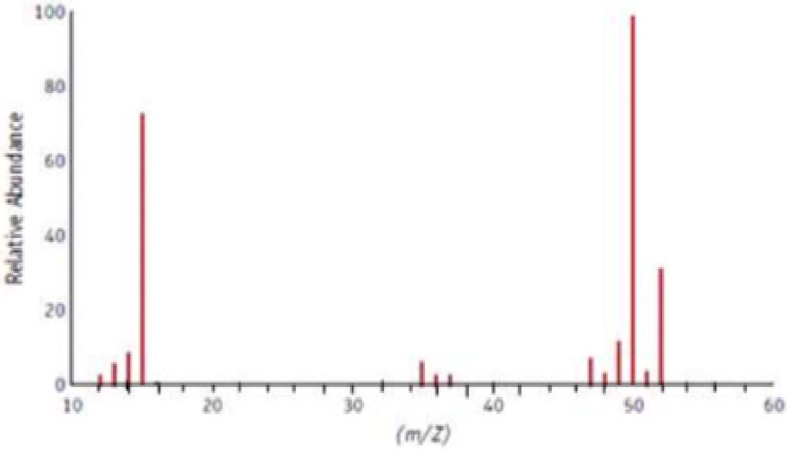
a)The parent ion is the heaviest ion observed and its m/z confirms the formula of the molecule. Therefore the formula of the "parent" ion is ($CH_3CH_2OH^+$) and it appear at m/z of 46

b) The formula for "fragment" ions are $CH_3CH_2O^+$ at 45, CH_2OH^+ at 31, $C_2H_5^+$ at 29, and CH_3^+ at 15

14. The mass spectrum of CH_3Cl is illustrated here. You know that carbon has two stable isotopes, ^{12}C and ^{13}C with relative abundances of 98.9% and 1.1%, respectively, and chlorine has two isotopes, ^{35}Cl and ^{37}Cl with abundances of 75.77% and 24.23%, respectively.

a) What molecular species give rise to the lines at m/Z of 50 and 52? Why is the line at 52 about 1/3 the height of the line at 50?

b) What species might be responsible for the line at m/Z = 51?



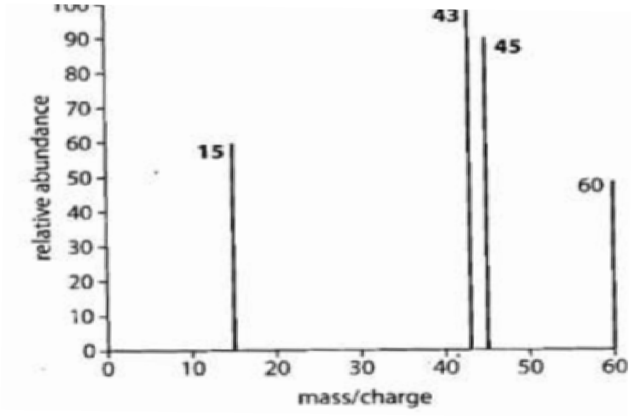
Answer:

m/Z = 50 is ${}^{12}C^{1}H_{3}\ {}^{35}Cl$+; m/Z = 52 is ${}^{12}C^{1}H_{3}{}^{37}Cl^{+}$

The height of the line at m/Z = 52 is about 1/3 the height of the line at m/Z = 50 because the abundance of ${}^{37}Cl$ is about 1/3 that of ${}^{35}Cl$.

${}^{13}C^{1}H_{3}{}^{35}Cl^{+}$ (a small portion of this peak is also due to ${}^{12}C^{2}H^{1}H_{2}{}^{35}Cl^{+}$)

15. A molecule with an empirical formula CH_2O has the simplified mass spectrum below. Deduce the molecular formula and possible structure of the compound.



Answer:

Empirical formula = CH_2O; molecular formula = CnH_2nOn

We can see that the parent ion has a relative mass of 60.

Mr = n(12.01) + 2n(1.01) + n(16.00) = 30.03n

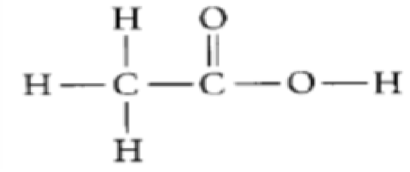
n = 60 ÷ 30.03 = 2

Molecular formula = $C_2H_4O_2$

From the spectrum we can identify the following peaks:

Peaks	Explanation
15 (60–45)	Presence of CH_3^+- loss of COOH from molecule
43 (60–17)	Presence of $C_2H_3O^+$ - loss of OH from molecule
45 (60–15)	Presence of $COOH^+$ - loss of CH_3 from molecule

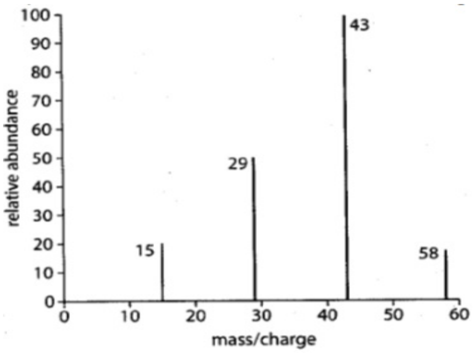
The structure consistent with this fragmentation pattern is:



16. The simplified mass spectrum of a compound with empirical formula C_2H_5 is shown below.

a) Explain which ions give rise to the peaks shown.

b) Deduce the molecular structure of the compound.



Answer:

a) Empirical formula = C_2H_5; molecular formula = $C_{2n}H_{5n}$

We can see that the parent ion has a relative mass of 58.

$Mr = 2n(12.01) + 5n(1.01) = 24.07n$

$n = 58 \div 27.07 = 2$

Molecular formula = C_4H_{10}

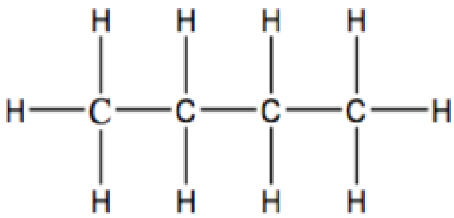
From the spectrum we can identify the following peaks:

Peaks	Explanation
15 (58–43)	Presence of $[CH_3]^+$ - loss of $CH_3CH_2CH_2$ from molecule

29 (58−29)	Presence of $[CH_3CH_2]^+$ - loss of CH_3CH_2 from molecule
43 (58−15)	Presence of $[CH_3CH_2CH_2]^+$ - loss of CH_3 from molecule
58 (58−0)	Presence of $[CH_3CH_2C_{H2}CH_3]^+$ parent ion

molecular structure of the compound is $CH_3 - CH_2{-}CH_2{-}CH_3$

or



17. The existence of isotopes in magnesium can be shown using a mass spectrometer. The operation of mass spectrometer can be described in terms of five main stages. The first is evaporation and the last is detection

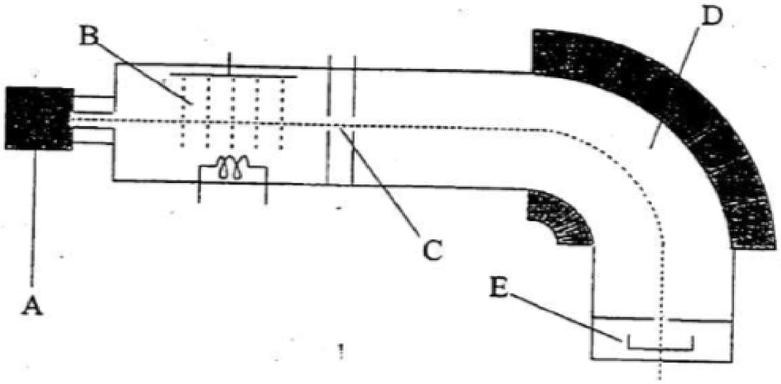
a) After evaporation, the magnesium is then ionized. Outline how it is ionised

b) State the names, in the correct order, of the other two stages, and in each case state the technique used

c) The relative abundances of the three isotopes of magnesium are as follows:

$^{24}Mg=78.6\%$, $^{25}Mg=10.1\%$, $^{26}Mg=11.3\%$

Below is a diagram of a simple mass spectrometer.



Calculate the relative atomic mass of magnesium using the values, giving your answer to three decimal places

Answer:

(a)In the ionization chamber, the beam of high-energy electrons is emitted from a filament that is heated to several thousand degrees Celsius. In normal operation, the emitted electrons have energy of about 70 electronvolts (eV). These high-energy electrons strike the stream of molecules which has been admitted from the sample system and ionize the molecules in the stream by removing electrons from them; the molecules are thus converted to positive ions.

(b) Acceleration: Electric field – attracts ions towards it until all have the same kinetic energy

a) State which of the sections below corresponds to which lettered part of the spectrometer.

Section	Letter
Accelerating potential	
Gaseous sample	
Electron bombardment ionisation	
Detector	
Magnetic field to deflect ions	

b) Why must the inside of the mass spectrometer be kept at a high vacuum

c) The spectrometer is setup so that ion X^+ is focused on the detector. The settings are left uncharged and an ion with a mass less than that of X^+ travels through the magnetic field. State and explain whether this ion will be deflected more than, or less than, X^+.

Answer

a)

Section	Letter
Accelerating potential	C
Gaseous sample	A
Electron bombardment ionisation	B
Detector	E
Magnetic field to deflect ions	D

b) Most of the sample molecules are not ionized at all but are continuously drawn off by vacuum pumps which are connected to the ionization chamber.

c) This ion which has the mass less than that of X^+ will deflect more than X^+.

Reason: The greater the mass-to-charge (m/e) ratio of the ion, the larger the radius of the curved path.

20. The separation of ions in a mass spectrometer depends on

A. Only the charge on the ions

B. Only the mass of the ions

C. The mass and the charge of the ions

D. Only the velocity of the ions

Answer: (C)

21. When injected into a mass spectrometer a compound gave a number of ion peaks.

UNIT 2: ELECTRONIC CONFIGURATION OF ATOMS AND IONS

2

Two peaks,one of which was the molecular ion, had m/z values of 58 and 43. Which of the molecular fragments below might have been lost from the original molecule?

A. CH_3

B. OH

C. C_2H_5

D. CHO

Answer: (A)

2.1. Key unit competence

The learner should able to relate Bohr's atomic model with atomic spectrum of Hydrogen, write electronic configuration of atoms and ions using s, p, d and f atomic orbitals and interpret graphical information related to ionization energy of elements.

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

- Rutherford's nuclear model
- The composition of an atom and the dot/cross diagrams of at least the first 20 elements.

2.3. Cross-cutting issues to be addressed

Inclusive education

Provide great print and speak aloud every important point for learners with low vision.

Write every important point for learners with hearing impairment.

2.4. Guidance on Introductory Activity

- Establish a relationship between the unit and learners' daily life so as to capture their attention.
- Assess learners' prior knowledge of the learners in Physics which is fundamental to the understanding of Quantization concept and hence to the modern atomic models.

2.5. List of lessons/sub-heading

Heading	Lesson title	Learning objectives	No of periods
Electronic configuration of atoms and ions.	Bohr's atomic model and concept of energy levels	Describe the existence of energy levels in atoms bond together. Explain the stability of atoms using the concept of quantization of energy. Explain the achievements and limitations of Bohr's atomic model.	2
	Hydrogen spectrum and spectral lines	Explain the evidence of energy levels using the data from emission spectra. Describe Hydrogen spectral lines and spectral line series.	2

	Atomic spectra	Explain the types of spectra Explain the nature of light.	2
	Quantum Numbers	Explain the quantum theory of the atom using the quantum numbers. Determine the number and shapes of orbitals.	2
	Electronic configuration of atoms and ions	Explain the Rules governing the electronic configuration. Describe the methods of writing electronic configuration for atoms and ions. Explain the relationship between the electronic configuration and the stability of the atoms.	4
	Relationship between ionization energy, energy levels and factors influencing ionization energy	Interpret the graphs of first ionisation energy against the atomic number. Derive the electronic configuration of an element using data on successive ionization energies. Describe the factors which influence the first ionisation energy.	4
End unit assessment			2

Lesson 1: Bohr’s atomic model and concept of energy levels

This is the first lesson of unit 2 and two periods have been allocated to it. It is exclusively intended to raise the curiosity of learners and relate the lesson to daily life processes. You are advised to spend a reasonable time on this introductory activity.

a) Prerequisites/Revision/Introduction:

For learners to learn better the **Bohr’s atomic model and concept of energy levels** they need to have prerequisites on the electronic configuration of elements using dot-and-cross diagrams.

b) Teaching resources:

Use **Figure 2.1** in the students' book for lesson 1 or draw them on a manila paper.

Use the Leaner's text book, Learning videos and/or printed images depending on the availability of each.

c) Learning activities :

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do introductory activity and thereafter proceed to activity 2.1 which is specific to lesson 1.

- As you enter the class, greet students inform them on the activity taking place.
- Ask learners to sit in groups of 4 to 5 students and chose a group leader.
- Ask students to observe the figure 2.1 in the student book and discuss the related questions.
- Monitor the progress of the group discussion and assist those who are still struggling, avoid communicating to them while helping them. Only give them a hint to discover for themselves
- Invites group leaders to present their findings.
- Think and share if the pairs were used.
- Have the learners to evaluate the findings.
- Integrate the cross-cutting issues indicated in the lesson and real life experiences.
- Summarise the learned knowledge and gives examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements

Expected answers for Activity 2.1

1. On the image above there are a man climbing up a hill and a lady moving up steps.

2. They perform a uniformly ascending motion.

3. The potential energy of the gentleman walking up ramp increases in uniform and continuous manner while the potential energy of the lady walking up steps increases in stepwise and discrete/quantized manner. The potential energy of the gentleman walking up ramp has a continuous range of values whereas the potential energy of the lady walking up steps has a discontinuous range of values.

d) Checking up 2.1

Expected answers for Checking up 2.1

1. Two more examples that can be used to illustrate the concept of quantization include:

- The gravitational potential energies of textbooks in shelves in a library.
- The pitches of overtones of a given fundamental note on a piano keyboard.

2. The main weakness of Rutherford's nuclear atom consists in its inability to account

for the stability of atoms. The Rutherford model of a nuclear atom does not show the arrangement of electrons outside the atomic nucleus. According to classical physics, a stationary, negatively charged particle would be pulled into the positively charged nucleus. Therefore, electrons cannot have fixed position around the nucleus. This perspective suggests that the electrons in an atom must be in motion like the planets orbiting the sun. However, in accordance with the laws of classical theory of electromagnetism, orbiting electrons should be constantly accelerating and should radiate energy. By losing energy, the electrons would be drawn closer and closer to the nucleus and soon spiral into it. In reality atoms are stable in contradiction with the expectations of classical physics.

Lesson 2: Hydrogen spectrum and spectral lines

This is the second lesson under **Electronic configuration of atoms and ions**. It is planned to be taught in two periods. Students are expected to be able explain the evidence of energy levels using the data from emission spectra and to describe Hydrogen spectral lines and spectral line series.

a) Prerequisites/Revision/Introduction:

Refer to lesson 1 above and use the concept of quantization of energy and radius to meet the above expectations.

b) Teaching resources:

- The Periodic Table of Chemical Elements
- Charts illustrating Hydrogen spectral lines and spectral line series.
- Manila papers, flipcharts and YouTube videos with computers and projectors if applicable.

c) Learning activities

Refer to Learning activity 2. 2 which was suggested in the student's book

- Welcome the learners to the new lesson.
- Form working groups of 4 to 5 learners depending on the size of your class.
- Assign the groups with tasks that can include group discussion or research.
- In the groups learners discuss, attempt activity 2.2 and record their answers.
- Each group representative presents the answers of his/her group to his/her classmates.
- During the presentation ask some questions that lead to lesson conclusion.

d) Checking up 2.2

Expected answer for checking up 2.2

1. In Hydrogen spectral lines, infinity level means very far away from the hydrogen atom. An electron that supposedly belongs to such energy level in a hydrogen atom is

not part of this atom.

2. $Data: n_i = 5; n_f = 2$

   $Unknown: E = ?; v = ?; \lambda = ?$

$Solution:$

$$E = -hCR_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

i. $E = -2.179\times10^{-18} J\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$

$$= -2.179\times10^{-18} J\left(\frac{1}{2^2} - \frac{1}{5^2}\right) = -\frac{2.179\times10^{-18} J\times21}{100} J = -4.58\times10^{-19} J$$

The obtained energy has a negative sign. It means that a photon is emitted. The negative sign is associated with forces of attraction.

ii. $v = \frac{E}{h} = \frac{4.5759\times10^{-19} J}{6.626\times10^{-34} J.s} = 6.9059\times10^{14} Hz$

iii. $\lambda = \frac{c}{v} = \frac{3\times10^{8} ms^{-1}}{6.9059\times10^{14} Hz} = 4.344\times10^{-7} m$

Lesson 3: Atomic spectra

This is the third lesson under electronic configuration of atoms and ions. It is planned to be taught in two periods. Students are expected to be able to explain the types of atomic spectra and explain the nature of light.

a) Prerequisites/Revision/Introduction:

Refer to lesson 1 and 2 above and use the concept of quantization of energy and radius to meet the above expectations.

b) Teaching resources:

- Glass prisms
- Lamp torches
- Charts illustrating different types of atomic spectra.
- Manila papers, flipcharts and YouTube videos with computers and projectors if applicable.

c) Learning activity

Refer to Learning activity 2.3 which is suggested in the student's book

- Welcome the class to the new lesson.
- Form working groups of 4 to 5 learners depending on the size of your class.
- Assign the groups with tasks that can include group discussion or research.
- In the groups learners discuss, attempt activity 2.3 and record their answers.
- Each group representative presents the answers of his/her group to his/her classmates.

Expected answer for activity 2.3

(a) The rainbow is shown by the above photo.

(b) Refraction of light through water droplets in atmosphere.

(c) Refraction of light can be also produced by other media such as water, glass, dew, ...

(d) Light has wave properties since refraction is a characteristic of waves.

(e) In the advertising sign posts the observed colours are due to the electronic transitions.

When electrons are excited they absorb energy and jump from their fundamental energy state to excited energy states. The absorbed energy is released in form of electromagnetic radiation when electrons fall back to their ground state.

d) Checking up 2.3

Expected answers for checking up 2.3

1. When a metal is heated, electrons are excited from lower energy levels to higher ones. When they come back to their ground energy level they emit energy in form of light.

2. No. The only observable rays are these from emission rays.

3. For the same element, the spectral rays depend on the energy emitted. When electrons are highly excited, the absorbed energy is high then the emitted energy will be high also.

Lesson 4: Quantum Numbers

This is the fourth lesson under **Electronic configuration of atoms and ions**. It is planned to be taught in two periods. Students are expected to be able to explain the types of atomic spectra and explain the nature of light.

a) Prerequisites/Revision/Introduction:

Refer to lesson 1above and use the concept of energy levels so as to meet the above expectations. A particular attention must be put on the concept of orbital.

b) Teaching resources:

- Charts illustrating different types and shapes of orbitals.
- Manila papers, flipcharts and YouTube videos with computers and projectors if applicable.

c) Learning activity

Refer to Learning activity 2.4 which is suggested in the student's book.

- Welcome the class to the new lesson.
- Form working groups, of 4 to 5 learners depending on the size of your class.
- Assign the groups with tasks that can include group discussion or research.
- In the group learners discuss, attempt activity 2.4 and record their answers.
- Each group leader presents the answers of his/her group to his/her classmates.

Expected answers for activity 2.4

a) AL(Z=13):$1s^22s^22p^63s^239^1$

b) As the highest value of the principal quantum number is 3, there are 3 energy levels, namely K, L and M containing 2, 8 and 3 electrons, respectively.

c) The other name given to the quantum shells is **Energy levels**.

d) In order to obtain the exact number of electrons in each energy level/quantum shell I added up the electrons in all subshells within each energy level.

d) Checking up 2.4

Expected answers for checking up 2.4

a. For n=3 l lies in the range $0 \le n \le (n-1)$ cannot be higher than 2.

d. ms is $m_s = +\frac{1}{2}$ or $m_s = -\frac{1}{2}$ and cannot take any other value.

e. l cannot have negative values.

f. The value of ml should lie in the range $-l \le m_l \le +l$. No value outside this range is acceptable.

Lesson 5: Electronic configuration of atoms and ions

This is the fifth lesson under Electronic configuration of atoms and ions. It is planned to be taught in four periods. Students are expected to be able to explain and apply the Rules governing the electronic configuration (Aufbau principle, Pauli's exclusion Principle and Hund's rule), to use different methods of writing electronic configuration for atoms and ions and account for the relationship between the electronic configuration and the stability of the atoms.

a) Prerequisites

Refer to lesson 4 above and use the concept of quantum numbers and orbitals so as to meet the above expectations.

b) Teaching resources:

- Student Book

c) Learning activities

Refer to Learning activity 2.5 which is suggested in the student's book.

- Welcome the class to the new lesson.
- Form working groups of 4 to 5 learners depending on the size of your class.
- Assign the groups with tasks that can include group discussion or research.
- In the groups learners discuss, attempt activity 2.5 and record their answers.
- Monitor the progress of the group work and assist slow learners. Only give them a hint to discover for themselves
- Each group representative presents the answers of his/her group to his/her classmates.
- Ask learners to compare their answers.
- Have the learners to evaluate the findings.
- Integrate the cross-cutting issues indicated in the lesson and real life experiences.
- Summarise the learned knowledge and gives examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements.

Expected answers for activity 2.5

1. K: 2.8.8.1, Ne: 2.8, Al^{3+}:2.8, Cl: 2.8.7, O^{2-}:2.8.8

2. a. K belongs to group 1 since it has 1 valence electrons and to period 4 because it has 4 shells.

Cl belongs to group VII since it has 7 valence electrons and to period 3 because it has 3 shells.

b. Ne, Al^{3+} and O^{2-} have stale electronic configuration because they achieve the octet rule.

d)Checking up 2.5

Expected answers for checking up 2.5 a

1. $Cu^{+}(Z=29):1s^{2}2s^{2}2p^{6}3s^{2}3p^{6}3d^{10}$

   $Cu^{2+}(Z=29):1s^{2}2s^{2}2p^{6}3s^{2}3p^{6}3d^{9}$

   Cu^{+} is more stable than Cu^{2+} since Cu^{+} has a totally filled 3d-orital whereas Cu^{2+} has neither full nor half-filled 3d-orbital.

2. $Fe^{2+}(Z=26):1s^{2}2s^{2}2p^{6}3s^{2}3p^{6}3d^{6}$

   $Fe^{3+}(Z=26):1s^{2}2s^{2}2p^{6}3s^{2}3p^{6}3d^{5}$

   Fe^{3+} is more stable than Fe^{2+} since Fe^{3+} has a half-filled 3d-orital whereas Fe^{2+} has neither full nor half-filled 3d-orbital.

Expected answer for checking up 2.5 b

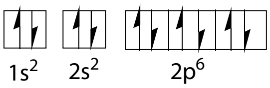
S(Z=16): $1s^{2}2s^{2}2p^{6}2s^{2}2p^{4}$

P^{3+} Z=15) : 1s22s22p62s22p4

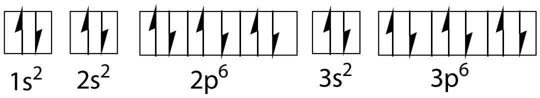
Mg^{2+}(Z= 12): $1s^{2}2s^{2}2p^{6}2s^{2}$

Expected answer for checking up 2.5 c

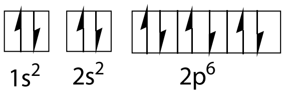
N^{3-}(Z=7):



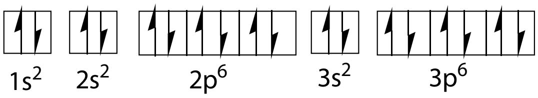
Ti^{4+}(Z=22):



Mg^{2+}(Z=12):



Ar (Z=18):



N^{3-} and Mg^{2+} are isoelectronic as it is the case for Ti^{4+} and Ar since each has 10 and 18 electrons, respectively.

Expected answers for checking up 2.5 d

$Ge(Z=32):[Ar]3d^{10}4s^{2}4p^{2}$

$S(Z=16):[Ne]3s^{2}3p^{4}$

$Co(Z=27):[Ar]3d^{7}$

$Br^{-}(Z=35):[Ar]3d^{10}4s^{2}4p^{6}$

$Sr(Z=38):[Kr]5s^{2}$

Lesson 6: Relationship between ionization energy, energy levels and factors influencing ionisation energy

This is the sixth lesson under Electronic configuration of atoms and ions. It is planned to be taught in four periods. Students are expected to be able to explain and apply the Rules governing the electronic configuration (Aufbau principle, Pauli's exclusion Principle and Hund's rule), to use different methods of writing electronic configuration for atoms and ions and account for the relationship between the electronic configuration and the stability of the atoms.

a) Prerequisites

Refer to lesson 4 above and use the concept of quantum numbers and orbitals so as to meet the above expectations.

b) Teaching resources:

- Student's Book

c) Learning activity

Refer to Learning activity 2.6 which is suggested in the student's book.

- Welcome the class to the new lesson.
- Form working groups of 4 to 5 learners depending on the size of your class.
- Assign the groups with tasks that can include group discussion or research.
- In the groups learners discuss, attempt activity 2.6 and record their answers.
- Monitor the progress of the group work and assist slow learners. Only give them a hint to discover for themselves
- Each group representative presents the answers of his/her group to his/her classmates.
- Ask learners to compare their answers.
- Have the learners to evaluate the findings.
- Integrate the cross-cutting issues indicated in the lesson and real life experiences.
- Summarise the learned knowledge and give examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements.

Expected answers for Activity 2.6

1. The electronic structure of the given chemical species:

Na(Z =11):$1s^2\ 2s^2\ 2p^6\ 3s^1$

Mg(Z =12):$1s^2 2s^2 2p^6 3s^2$

Mg^{2+}(Z =12):$1s^2 2s^2 2p^6$

Al(Z =13):$1s^2 2s^2 2p^6 3s^2 3p^1$

Al^{3+}(Z =13):$1s^22s^22p^6$

O^{2-}(Z =16):$1s^22s^22p^63s^23p^6$

2. The common feature possessed by the ions in (1) is the full valence shell.

Ions achieve a full valence shell as noble gases in order to become stable.

3. Aluminium atom lost 3 electrons when it changed to Aluminium ion.

4. The group and period of Aluminium, Sodium and Oxygen are shown in the following table.

Element	Group	Period
Aluminium	III	3
Sodium	I	3
Oxygen	VI or 16	2

d) Checking up 2.6

Expected answers for Checking up 2.6

The unknown element is most likely to belong to the family of Alkaline earth metals (Group II).

In fact the largest gap is between the second and third ionisation energy (the 3rd I.E is almost 8 times higher than 2rd I.E).This means that the third electron is removed from an inner shell which is subject to a stronger nuclear attraction. The element has 2 valence electrons which require quite close energy values since they are at the same shell.

2.6. Summary of the unit

For example: In this unit, we explore Bohr's atomic model and found that an atom is stable in its ground state. An electron can absorb energy when it passes from a lower energy level to a higher energy level. Conversely, it can emit energy when it transits from a higher energy level to a lower energy level.

Niels Bohr was the scientist to make the very first attempt to account for the atomic line spectral and overcome the limits of classical Physics. He introduced the concept of quantization of energy to account for the line spectra of hydrogen and hydrogen-like species. The energy of an electron on a given energy level can be calculated using the Balmer-Rydberg relation

$$E_n = -2.179\times10^{-18}\,J\left(\frac{Z^2}{n^2}\right).$$

The wavelength of the photon associated with an electronic transition from an energy level n_i to another energy level n_f is given by Balmer's equation

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

The frequency and the energy of a photon are related by Plank's equation

$$\Delta E = nh\nu = n\frac{hc}{\lambda} \quad \text{with } n=1,2,3,\ldots$$

A set of 4 quantum numbers is used to describe the orbital.

The principal quantum number, **l** (l=0,1,2...n-1) describes the energy levels, the azimuthal quantum number or angular momentum quantum number **l** (l = 0, 2,...,n - l) the shapes of the orbitals, the magnetic quantum number m_l (m_l = -l,-l +1,...,0,1,2,3,+l) the possible spatial orientations of the orbitals and the spin quantum number represents one of the two possible values for the electron spin. Electrons fill orbitals from the lowest energy to the highest energy orbital ensuring that the energy of the atom is at a minimum. The filling of orbitals with electrons is governed by Pauli's exclusion principle and Hund's rule. These combined rules form the Aufbau principle.

The electronic structure gives information on the position of an element in the periodic table and helps to explain the shape of the curve of ionisation energy

2.7. End unit assessment

Answers for the end unit assessment questions

1.(b) is the correct ground-state electron configuration of molybdenum.

In (a) the orbital 3f does not exist.

In (c) the proposed electronic structure [Kr] $4d^5 5s^2$ corresponds to another element (Technetium: Z=43) next to Molybdenum (Z=42).

In (d), Hund's rule is violated since electrons pair up in 4d-orbital before 5s-orbital is full.

$\text{Data}: \lambda = 660nm = 660\times10^{-9}m = 6.60\times10^{-7}m$, $\quad\text{Unknown}: \nu = ?$ und state and that of

$$\nu = \frac{c}{\lambda} = \frac{3\times10^{8}ms^{-1}}{6.60\times10^{-7}m} = 4.54\times10^{14}Hz$$

4. 1p, 3f and 2d are the incorrect orbital designations.

The wavelength of an electromagnetic radiation is calculated using the expression

$$\lambda = \frac{c}{\nu}$$

a) $\lambda(CD\ laser) = \dfrac{3\times10^{8}ms^{-1}}{3.85\times10^{14}Hz} = 7.79\times10^{-7}m$

b) $\lambda(DVD\ laser) = \dfrac{3\times10^{8}ms^{-1}}{4.62\times10^{14}Hz} = 6.49\times10^{-7}m$

$$\lambda(Blu-ray\ laser) = \frac{3\times10^{8}ms^{-1}}{7.41\times10^{14}Hz} = 4.05\times10^{-7}m$$

6. a) There are 3 subshells in the n=3 level.

b) The subshells in the n=3 level are s, p and d.

c) There are 7 orbitals with n=4 and l=3

d) There are 1 orbital with n=3 and l=2 and ml=-2

e) There are 16 orbitals in the level n=4

7. given that λ/4=1.17nm

λ= 1.17nm x 4 = 4.68nm

8. a) The wave a has the longer wavelength since there are 5 crests in the given distance.

b)There are 4 wavelength units in wave a and 8 wavelength units in wave b. Therefore, we have

$$4\lambda_a = 1.6\times10^{-3}m$$

$$\Rightarrow \lambda_a = \frac{1.6\times10^{-3}m}{4} = 4\times10^{-4}m$$

$$8\lambda_b = 1.6\times10^{-3}m$$

$$\Rightarrow \lambda_b = \frac{1.6\times10^{-3}m}{8} \Rightarrow \lambda_b = 2\times10^{-4}m$$

c) Wave b has higher frequency and photon energy.

d)The frequency and energy for waves a and b are calculated hereafter.

(i) Wave a

$$\nu_a = \frac{c}{\lambda_a} = \frac{3\times10^8 ms^{-1}}{4\times10^{-4}m} = 7.5\times10^{11}Hz$$

The photon energy is calculated using the expression

$$E_a = h\nu_a = 6.626\times10^{-34}J.s\times7.5\times10^{11}Hz = 4.969\times10^{-22}J$$

(ii) Wave b

$$\nu_b = \frac{c}{\lambda_b} = \frac{3\times10^8 ms^{-1}}{2\times10^{-4}m} = 1.5\times10^{12}Hz$$

The photon energy is calculated using the expression

$$E_b = h\nu_b = 6.626\times10^{-34}J.s\times1.5\times10^{12}Hz = 9.939\times10^{-22}J$$

The wave b is the one which has a higher speed since it performs a higher number of cycles per unit time (twice faster than wave a).

e) The type of electromagnetic radiation that is illustrated is visible light. (Refer to the electromagnetic spectrum in Student's book, Figure 2.2).

9. Increasing energy order

a) $5p < 5d5p < 5d$

b) $3p < 4s3p < 4s$

c) $4d < 6s4d < 6s$

10. a) 3d

b) 4p

c) 6d

d) 6s

11. a) 3s

b) 3d

c) 6s

d) 4f

12. Electronic configuration B is correct.

The configuration C violates Pauli's exclusion principle because it has an orbital containing electrons with parallel spins.

The configuration A, C and D violate Hund's rule because in A and C the electrons form pairs before each orbital of 2p-subshell contains at least one electron. In configuration D the electrons do not have parallel spins.

13. The ionisation energy increases smoothly from the first to the fourth ionisation number and it has relatively low values. This is the case because the four electrons belong to the same outermost shell. The gradual increases is due to the increase in effective nuclear charge as more and more electrons are removed.

The graph shows a steep increase in ionisation energy because the fifth electron is removed from an inner shell where it is experiences a stronger attraction towards the nucleus.

The ionisation energy increases smoothly from the fifth to the sixth ionisation energy. This means that the fifth and sixth electrons belong to the same energy level. The gradual increase is due to the increase in effective nuclear charge as more and more electrons are removed.14. a) The first ionisation energy is the energy required to remove one electron from each atom of a mole of gaseous atoms.

b) The factors influencing the first ionisation energy include:

(i) Size of atom: As the distance between the nucleus and valence shell electrons increases, the force of attraction between nucleus and valence electron decreases. Therefore, the valence electrons are loosely held to the nucleus and lower energy is required to remove them, i.e Ionisation energy decreases with increase in atomic size vice versa.

(ii) Nuclear charge: As the nuclear charge increases, the force of attraction between nucleus and valence electrons increases and hence makes it is difficult to remove an electron from the valence shell. The stronger the nuclear charge, the higher the Ionisation energy.

(iii) Screening effect or Shielding effect: The electrons present in inner shells between nucleus and valence shell reduce the attraction between nucleus and the outermost electrons. This shielding effect increases with the increasing number of inner electrons. The strong the Shielding effect makes it easier to remove an electron and hence lowers the ionisation energy.

(iv) Penetration effect: The extent to which electrons in degenerate orbitals are close to the atomic nucleus varies in the order s > p > d > f. Hence s-electrons experience stronger attraction from the nucleus than the electrons p, d and f-electrons. Thus Ionisation energy to remove an electron from a given energy level decreases in the order s > p > d > f.

(v) Electronic Configuration: Electronic Configuration plays a crucial role in determining the value of Ionisation energy. Atoms having stable configuration show the least tendency to lose electron and hence have high value of I. E.

c) The element W belongs to group IV or 14. In fact the largest energy gap exists between the 4th and 5th Ionisation energy. This means the first four electrons that are removed are on the same energy level which is the outermost shell. The fifth electron belongs to an inner shell where it is more attracted by the nucleus and thus require significantly high energy to get removed.

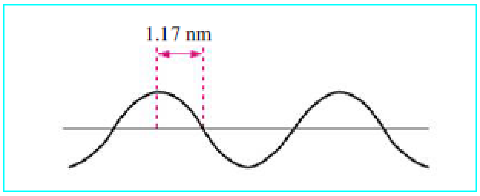
2.8 Additional activities

2.8.1. Remedial Activities

1. What are the seven colours making the white light spectrum? Rank them in ascending order of their wavelengths.

Answer. Violet, Indigo, Blue, Green, Yellow, Orange, Red.

2. A hypothetical electromagnetic wave is pictured here. What is the wavelength of this radiation?



Solution:

The distance shown in the diagram corresponds to $\frac{1}{4}$ of the distance between two successive crests. Therefore, λ = 4 x1.17nm = 4.68nm = 4.68 x 10^{-9} m

3. What is the frequency (in 1/s) of light with wavelength equal to 5 x 10^{-6} cm?

a. 6 x 10^{15} b. 6 x 10^{14} c. 1.5 x10^{15} d. 1.5x10^{3}

Answer a.

4. What is the wavelength of photons of light of frequency = 1150 kilocycles/sec

a. 26 m b. 3.4 x 10^{11} m c. 261 m d. 3.4 x 10^{14} m

Answer c.

5. What is the wavelength of a wave having a frequency of 3.76 x 1014 s^{-1}?

Answer. $\lambda = \frac{c}{\nu} = \frac{3.00 \times 10^{8} ms^{-1}}{3.76 \times 10^{14} s} = 7.98 \times 10^{-7} m$

6. What is the frequency of a wave carrying energy of 8.35 x 10^{-18} J?

Answer. $.v = \frac{E}{h} = \frac{8.35\times10^{-18}J}{6.626\times10^{-34}J.s} = 1.26\times10^{16}Hz$

7. What is meant by first ionization energy?

Answer. First ionization energy is the energy required to remove the first electron from a gaseous atom.

8. Explain the jump in ionization energy related to the valence electrons of the element?

Answer: The jump occurs after the valence electrons have been removed.

2.8.2. Consolidation activities

1. What electron transition in a hydrogen atom, ending in the orbit n=2 will produce light of wavelength 1090 nm?

Solution

Data: λ =1090nm=1.090x10^{-6}m, n_f =3

Unknown: $n_i = ?$

Solution: The wavelength of the radiation is calculated using Balmer's relation.

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right) \quad \text{Rearranging the equation yields}$$

$$n_i = \sqrt{\frac{n_f^2 R_H \lambda}{R_H \lambda - n_f^2}}$$

$$n_f = \sqrt{\frac{3^2 \times 1.097\times10^7 m^{-1} \times 1.090\times10^{-6} m}{1.097\times10^7 m^{-1} \times 1.090\times10^{-6} m - 3^2}} = \sqrt{\frac{98.73}{89.73}} = \sqrt{1.100} = 1$$

The electron transition corresponding to λ =1090nm in hydrogen atom is from n=3 to n=1.

2. The number of electrons a single d orbital can hold is

a. 10 b. 6 c. 2 d. 14

Answer: a

3. How many d electrons can the second energy level hold?

a. 0 b. 2 c. 6 d. 10

Answer: a

4. What is the total number of orbitals containing electrons in a nitrogen atom?

a. 5 b. 3 c. 4 d. 6

Answer: b

5. Of the orbitals shown, the one with the lowest energy is

a. 2s b. 3s c. 3d d. 2p

Answer: a

6.The maximum number of electrons that can occupy a 3p sublevel is

a. 1 b. 2 c. 3 d. 6

Answer: d

7. The electron configuration of an atom is $1s^2 2s^2 2p^6 3s^2 3p^3$. The atomic number of the atom is

a. 15 b. 11 c. 5 d. 3

Answer: a

8. The electron configuration of an atom is $1s^2 2s^2 2p^6 3s^2 3p^6$. The number of unpaired electrons in this atom is

a. 2 b. 3 c. 5 d. no correct answer given

Answer: d

9. The electron configuration of an atom is $1s^2 2s^2 2p^6 3s^2 3p^6$. The number of orbitals occupied by electrons is

a. 5 b. 9 c. 11 d. 15

Answer: b

10. The maximum number of electrons in the 4d sublevel is

a. 2 b. 6 c. 8 d. 10

Answer: d

11. According to the Aufbau principle, which orbital is filled immediately before each of the following?

a. 3p

b. 4p

c. 4f

d. 5d

Solution

Orbital	The orbital that is filled immediately

a. 3p	3s
b. 4p	3d
c. 4f	6s
d. 5d	4f

2.8.3. Extended activities

Suggestion of Questions and Answers for gifted and talented students.

I. Which of the following are permissible sets of quantum numbers for an electron in a hydrogen atom:

a) $n = 2; l = 1; m_l = 1$ **Permissible 2p**

b) $n = 1; l = 0; m_l = -1$ **Not permitted**

c) $n = 4; l = 2; m_l = -2$ **Permissible 4d**

d) $n = 3; l = 3; m_l = 0$ **Not permitted**

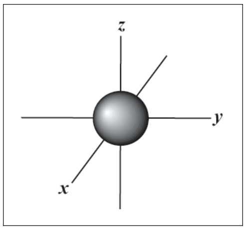
II. Sketch the shape AND orientation of the following types of orbitals:

a) s

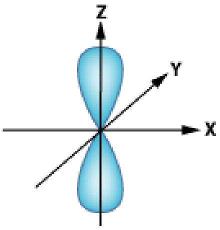
b) p_z

Answer

s orbital



p_z orbital



III. An energetically excited hydrogen atom has its electron in a 5f subshell. The electron drops down to the 3d subshell, releasing a photon in the process.

a) Give the n and l quantum numbers for both subshells and give the range of possible miquantum numbers.

b) Find the wavelength of light is emitted by the process in metres and micrometres.

c) The hydrogen atom now has a single electron in the 3d subshell. What is the energy in kJ/mol required to remove this electron?

Solution

a) For 5f, n=5 and l=3

For 3d, n=3 and l=2

b)Data:n_i =5,n_f =3

R_H =1.097x107m

h=6.6262x10^{-34}J.s

$$\frac{1}{\lambda}=R_H\left(\frac{1}{n_f^2}-\frac{1}{n_i^2}\right)=R_H\left(\frac{1}{3^2}-\frac{1}{5^2}\right)=\frac{16R_H}{225}$$

$$\lambda=\frac{225}{16R_H}=\frac{225}{16\times1.097\times10^{7}m^{-1}}=1.28\times10^{-6}m=1.28\mu m$$

$$c)\ E=hc=h\frac{c}{\lambda}=6.626\times10^{-34}J.s\times\frac{3\times10^{8}ms^{-1}}{1.28\times10^{-6}m}=1.552\times10^{-19}J$$

The energy in kilojoule per mole is given as

$$IE=\frac{E\times N_A}{1000}=\frac{1.552\times10^{-19}\times6.022\times10^{23}}{1\times10^{3}}kJmol^{-1}=93.4kJmol^{-1}$$

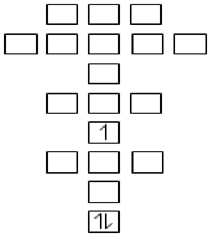
(N_A=6.022 x 10^{23} is the Avogadro number) It expresses quantity of matter in terms of the number of particles contained in one mole.

IV. Atomic Hotels

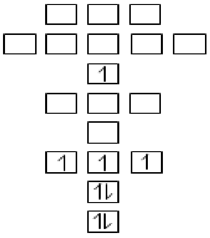
Group roles: A Leader; B Recorder; C Reporter

1. The Atomic Hotel is a special hotel designed for electrons. The hotel has a strict policy called the Aufbau principle that states "ground" floors must be filled first and in order. It costs more to get rooms on higher floors. In the atomic world energy is money. Therefore "excited" electrons get rooms on higher floors, thus the exception to hotel policy.

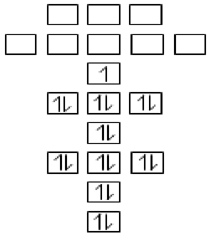
Looking back through the old guest logs, the following layouts can be sketched. Determine which electrons had more "money". Highlight those electrons as excited.



May 23,
A

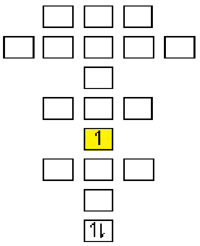


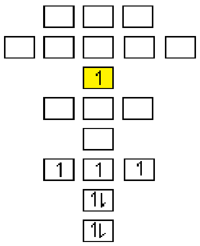
June 19,
B

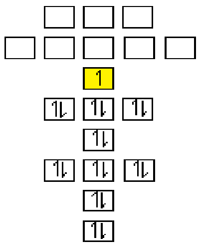


September 10,
C

Solution:

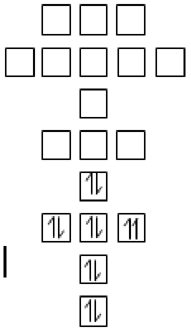

May 23,
A

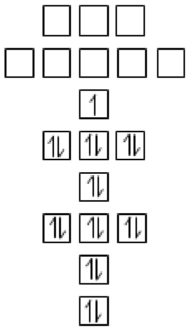

June 19,
B

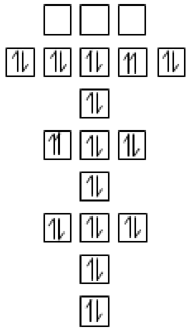

September 10,
C

2. Another policy that the hotel enforces is called the Pauli Exclusion Principle. It was determined in 1925 that electrons can occupy the same room, but only if they have opposite spins so they do not interfere with one another.

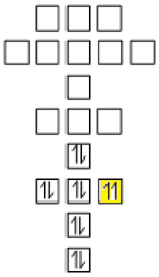
Copy the diagram below and highlight the electrons below which did not follow the Pauli Exclusion Principle.

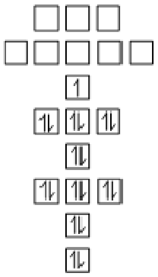

April 2,
A

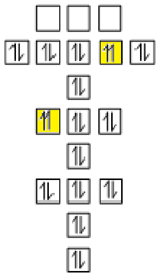

December 1,
B


July 4,
C

Solution:

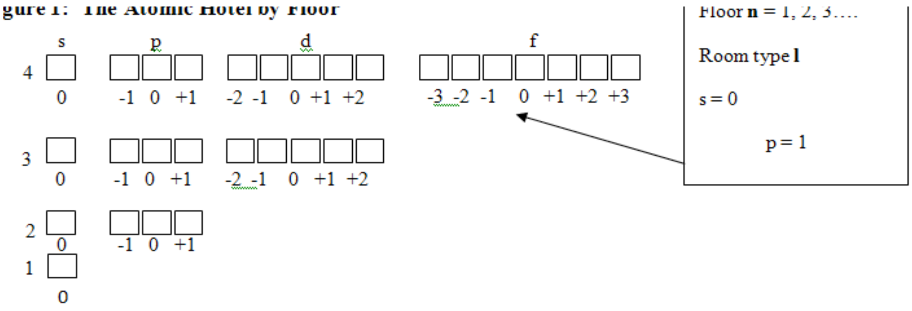

April 2,
A


December 1,
B

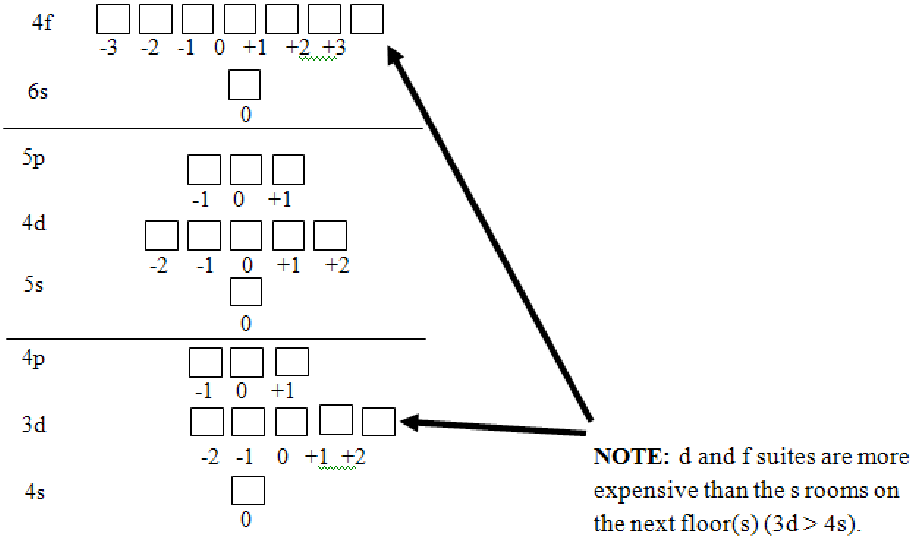

July 4,
C

3. The Pauli Exclusion Principle serves to identify each electron. Four numbers (n, l, ml, and ms) are assigned to each guest in the hotel. The number n, is the principle quantum number which corresponds to the "floor" the electron is on. The letter l describes the room layout or the "floor area" in which the electron is staying (s = 0, p = 1, d = 2, etc.). There is only one s type room on each floor; there are three p type rooms on each floor from the second up; there are five d type rooms on each floor starting with the third floor and going up; and there are seven f type rooms on each floor starting with the fourth floor and moving upwards. The letter ml describes the specific room (most analogous to a room number.) Figure 1 shows a diagram of the hotel rooms available by floor.

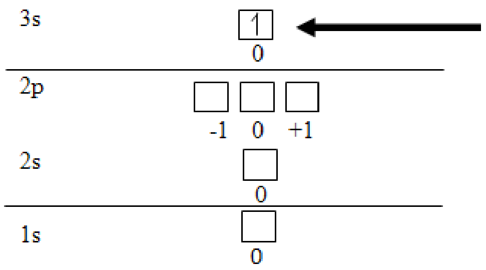
Figure 1 The atomic Hotel by Floor



The preferred hotel diagram is one which shows the hotel rooms by cost (which, as stated in part I is the also the order in which the rooms are filled. Generally, the most inexpensive rooms are on the first floor, with prices increasing with floor. Note that d rooms are more expensive than the s or p rooms on the next floor. Electrons can pair up in a single room, therefore, the hotel has to have a way of identifying each one separately. This is done with ms, the spin quantum number which is +½ or -½.

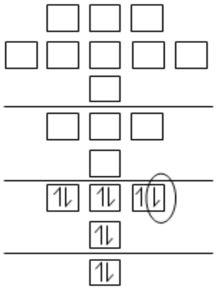


NOTE: d and f suites are more expensive than the s rooms on the next floor(s) (3d > 4s).



Example: an electron with the numbers 3, 0, 0, ½ is staying on the 3rd floor, in section s, in room #0, and is in + ½ spin state.

Using the above pattern, identify the circled electrons using the four quantum numbers.

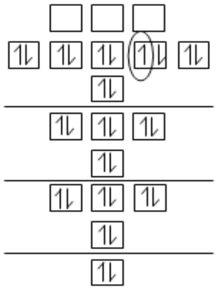


March 9, 1992

— — — —

n l m_l m_s

A

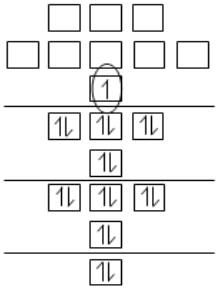


August 22, 1994

— — — —

n l m_l m_s

B



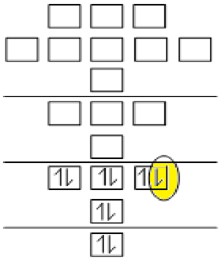
January 17, 1980

— — — —

n l m_l m_s

C

Answer

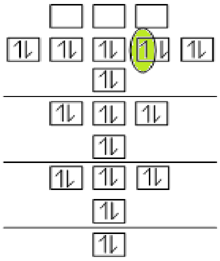


March 9, 1992

— — — —

n l m_l m_s

A

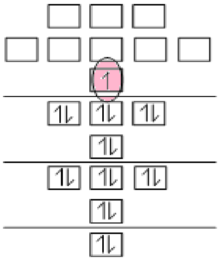


August 22, 1994

— — — —

n l m_l m_s

B



January 17, 1980

— — — —

n l m_l m_s

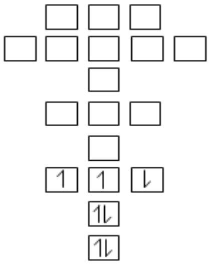
C

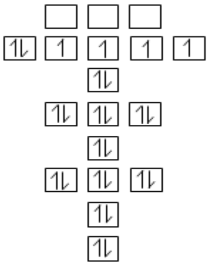
In A: The electron is in Floor: 2nd floor Section: p Room: +1 Spin state: $-\frac{1}{2}$	**In B:** The electron is in Floor: 2nd floor Section: p Room: +1 Spin state: $-\frac{1}{2}$	**In C:** The electron is in Floor: 4th floor Section: s Room: 0 Spin state: $+\frac{1}{2}$

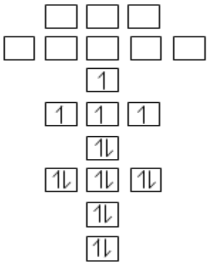
4. There is one more policy that helps the hotel run smoothly and keep customers

happy. Hund's Rule states that if electrons are being placed in the same section of a floor (rooms that cost the same) then each one gets their own room and has the same spin until the floor is half-filled. If any more electrons want to stay in that same section, then they must pair up with another electron and assume the opposite spin. This does not necessarily apply to electrons that have purchased more expensive rooms.

In the diagrams below identify the areas in which Hund's Rule was broken. Describe how the rule is being broken in each case.

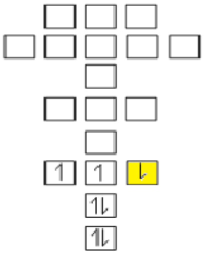

February 12, 1997


November 26, 1995

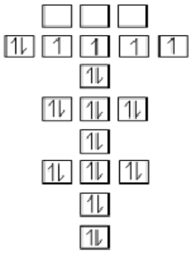

July 10, 1983

Answer

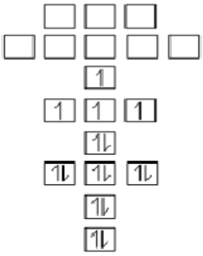
A **B** **C**


February 12, 1997

A


November 26, 1995

B


July 10, 1983

C

The electron in yellow room should have an up spin until the floor is half-filled, i.e with 3 electrons.

5. Observations:

a. How many "rooms" are there in an "s" suite of a floor?

Answer: 2 rooms

b. How many "rooms" are there in a "p" suite of a floor?

c. Answer: 3 rooms

d. How many "rooms" are there in a "d" suite of a floor?

Answer: 10 rooms

e. How many electrons can stay on the first floor?

Answer: 2 electrons

f. How many electrons can stay on the second floor?

Answer: 8 electrons

g. Describe how the rooms in each section are numbered.

Answer: Electrons in each section are numbered using m_l.

h. In diagram C (Section 4 above), describe why the electron could go into the 4s orbital instead of the 3p.

Answer: The electrons with more money (excited) could occupy more expensive rooms (orbitals with higher energy).

i. Why might section 3d fall between section 4s and 4p?

Answer: section 3d might fall between section 4s and 4p its cost is higher than that of 4s and lower than that of 4p.

j. Write out the electron configurations for each of the following elements: B, N, F and Na. Then identify the atoms whose atomic hotels were drawn in 1C, 2B, 3A, 3B, 3C, and 4B.

B(Z =5):$1s^2 2s^2 2p^1$

N(Z =7):$1s^2 2s^2 2p^3$

F(Z =9):$1s^2 2s^2 2p^5$

Na(Z =11):$1s^2 2s^2 2p^6 3s^1$

Counting the number of electrons allows to get the atomic number of each labelled element and determine it. Therefore,

1C is Potassium (Z=19), 2B is Potassium (Z=19), 3A is Oxygen (Z=10), 3B is Zinc (Z=30), 3C is Potassium (Z=19), 4B is Cobalt (Z=27)

UNIT 3: FORMATION OF IONIC AND METALLIC BONDS

3

3.1. Key unit competence

Describe how properties of ionic compounds and metals are related to the nature of their bonding

3.2. Prerequisite knowledge and skills

Students will learn better the formation of ionic and metallic bond if they have understanding on: The symbols of elements and compounds, concept of bonding, the arrangement of elements in the periodic table and electronic configuration of at least the first 20 elements.

3.3. Cross-cutting issues to be addressed

- **Comprehensive Sexuality Education**

There is General need of people to associate in order to be stronger, more productive, etc.

The bonding character in atoms can be related to relationship in human beings. There is a serious issue of peer pressure and bandwagon (ikigare) in youth. When introducing this unit, it would be an opportunity to guide learners on making informed decisions in their relationships. Help learners to:

e) Understand that relationship is very important. As atoms bond to gain stability so human beings also need to bond (relate) due to different reasons. Students should know that some relationship is natural (biological) e.g we do not choose family members but we can choose our friends.

f) 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.

g) Reflect on their educational goals, the type of friends they have and their characters.

h) Assess if the friends they have are likely to help them achieve their future goals or destroy their future.

i) Make appropriate decisions.

j) Be aware that elders (parents, school staffs) are willing to give guidance and advise them on this issue.

k) Understand that the attraction between girls and boys is normal (like there is strong force of attraction between opposite charges which leads to formation of strong bonds). However, self control is very crucial to avoid undesirable consequences like contracting disease e.g HIV/AIDS, STIs, unwanted pregnancies , etc.

l) Underlining the necessity of cooperation and working in group rather than working in isolated way

This can be done in a short whole class discussion but point c to f can be given to students as an assignment to be done during their free time. This may be a good entry point for the chemistry teacher to confront the individual students who need advise on relationship matter.

3.4. Guidance on introductory activity

Before introducing the first lesson of this unit (Stability of atoms and why they bond together), let learners attempt activity 3.1. This activity intends to:

- Relate the unit with learners' daily life to capture their attention.
- Assess learners understanding of the concept of bonding.

3.5. List of lessons

Heading	Lesson title	objectives	No of periods
3. 1 Ionic bonding	Stability of atoms and why they bond together.	Explain why atoms bond together. Explain the mechanisms by which atoms of different elements attain stability.	1
	Formation of ionic bond	Explain the formation of ionic bonds using different examples. Represent ionic bonding by dot-and-cross diagrams.	1
	Physical properties of ionic compounds	Describe the properties of ionic compounds. Perform experiments to show properties of ionic compounds Assemble experimental set up appropriately and carefully Make correct observations on the properties of ionic compound	2
	Lattice energy	State the factors that influence the magnitude of lattice energy. Relate the lattice structure of metals to their physical properties.	1

3.2 Metallic bonding	Formation of metallic bonds and Physical properties of metals	Describe the formation of metallic bonds. State the physical properties of metals and forces of attraction that hold atoms of metal.	1
3.3 End unit assessment			1

Lesson 1: Stability of atoms and why they bond together

This is the first lesson of unit 3 and is a single lesson. That is to say it has only one period (40 minutes).The first lesson also covers the introduction of the whole unit.

a) prerequisites/Revision/Introduction:

Students will learn better the stability of atoms and why they bond if they have understanding on: The concept of bonding, the arrangement of elements in the periodic table and electronic configuration of at least the first 20 elements.

b) Teaching resources:

- -Use the illustrations in the learners or draw them on a manila paper.
- -Periodic table of chemical elements

c) Learning activities:

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt activity 3.1 first then 3.2 which leads students to the first lesson of the unit.

- Learners carefully observe the pictures then **individually** answer the questions in introductory activity then
- Let learners in pairs answer questions 1-6 of activity 3.1.
- Select some learners (2-4) to share their answers to the whole class, the class discusses on the presentation as you record the main points on the chalkboard or flipchart.
- During the discussions guide learners to relate bonding in atoms to relationship in human beings to integrate the cross-cutting issue (CSE) as guided in point 3 above.
- Complete each questions and make general corrections to the whole class.
- From electronic configuration of some atoms e.g sodium and chlorine illustrate instability of atoms, Show that they gain stability by losing and gaining an electron hence forming bonds.
- Make a summary of the lesson (short notes) and assess your lesson. Let

students do checking up 1.

- Remember to even say whatever you write so that learners with visual and impairment and hearing impairment benefits.

Answers to activity 3.1: refer to student's book

d) Checking up 3.1

Expected answers for checking up 3.1

1. Symbol: Cu, No. of electrons: … , Shorthand electronic configuration: [Ar]4s1 3d10. The filled d-sublevel is a stable configuration. Electrons tend to leave the 4s to d-sublevel. By so doing, the overall and final configuration of copper is more stable.

2.

#	Atom	Atomic No.	Ion symbol	Noble gas	No. of electrons. (e-)	shorthand E.C of ion formed
a	Br	35	Br^-	Kr	36	[Ar] 4s23d10 4p6
b	Mg	12	Mg^{2+}	Ne	10	[He] 2s22p6
c	S	16	$S2^-$	Ar	18	[Ne] 3s23p6
d	Al	13	Al^{3+}	Ne	10	[He] 2s1 2p6

Lesson 2: Formation of ionic bond

Formation of ionic bond is the second lesson of the unit. Students are expected to be able to explain the formation of ionic bond using cross and dots diagram.

a) Prerequisites/Revision/Introduction:

- The same as for the unit.

b) Teaching resources:

- The Periodic Table of Chemical Elements
- Charts illustrating formation of ionic bonds.
- Where possible use manila papers, flipcharts and you-tube videos with computers and projectors.

c) Learning activities

Learning activity 3.2 is suggested in learner's book. However, the teacher is free to add more.

- Form groups of 3-6 students. The number of groups and members will depend on your class size.
- In the groups students attempt activity 3.2, discuss and record their answers.
- Each group representative presents their answers to the whole class.

- During the presentation ask some questions that lead to lesson conclusion like: write the chemical formula of the compound and state the type of bond formed and reasons for their answers.
- Ask students to individually complete the table below:

#	Compound	Chemical formula	Cross-dot diagram	Type of bond formed	Reasons
1	Sodium chloride				
2	Magnesium oxide				
3	Magnesium chloride				
4	Sodium peroxide				
5	Sodium sulphide				

- Guide students to make the summary of the lesson themselves. Make sure the following are emphasized on:
- Ionic bond is formed when there is transfer of electrons from one atom to another. It occurs between metals and non-metals.
- Metals lose electrons while non-metals gain them to form positively charged and negatively charged ions respectively. The attraction between positive and negative ions leads to the formation of ionic bond.
- The resulting compounds are called ionic compounds.
- Make the final conclusion of the lesson.

d) Checking up 3.2

Expected answers for checking up 3.2

1. a) Na, Cl, Mg, I, O, Ca, Al

b) cfr student's book

d) NaCl; MgI_2; Na_2O; $CaCl_2$; $AlCl_3$

e) cfr Student's book

2. a) cfr student's book

b) Sodium and chloride ions are held together by electrostatic attraction forces between oppositely charged ions (Na^+ and Cl^-) resulting from a transfer of an electron from sodium atom to chlorine atom.

c) The melting point is affected by the strength of ionic bond. The ionic bond in magnesium oxide is stronger than that in sodium chloride, due to high charge of magnesium oxide that results in stronger electrostatic attraction compared to the weaker attraction in sodium chloride.

Lesson 3: Physical properties of ionic compounds

a) Prerequisites/Revision/Introduction

Before beginning this lesson, learners should be able to recall some of the properties of ionic compounds studied in senior two. The teacher may ask oral questions to name and explain some of the physical properties of ionic compounds. If the learners are able to mention some, then he can proceed. If not he can ask some probing questions to give them a hint like, what happens when you add table (sodium chloride) salt into water and stir vigorously?

b) Teaching resources

Activity 3.3	Materials
(a)	Flip chart papers written on procedure to investigate the melting point of ionic compound, aluminium sheet, retort stand, Crystals of sugar and sodium chloride, a pair of scissors and a source of heat.
(b)	Sodium chloride and distilled water, copper (II) sulfate solution, ethanol, sugar solution, , solid sodium chloride, crocodile clips and battery bulb
(c)	Solid sodium chloride, sodium chlorine, magnesium chloride , copper sulphate, calcium carbonate, copper carbonate , sodium sulphate, distilled water, test tubes, test tube rack, stirring rod and forceps.
(d)	Hammer or any hard object used to hitting the crystals of salt, a piece of cloth or paper.

c) Learning activities

Learners should carry out the experiments in activity 3.4 (a), (c) and (d). They should also do the study questions from each of the experiments performed in activity 3.4, Learners should do the checking up activity in any method you wish to use.

Answers to activity 3.3(a, b,c): refer to the student's book

d) Checking up 3.3

1. In the first beaker, distilled water does not conduct a current because water is a molecular compound. In the second beaker, solid sodium chloride also does not conduct a current. Despite being ionic and thus composed of charges particles, the solid crystal lattice does not allow the ions to move between the electrodes. Mobile charged particles are required for the circuit to be complete and the light bulb to light up. In the third beaker, the NaCl has been dissolved into the distilled water. Now the crystal lattice has been broken apart and the individual positive and negative ions can move.

2.Ionic crystals are hard because the positive and negative ions are strongly attracted to each other and difficult to separate, however, when pressure is applied to an ionic crystal then ion of like charge may be forced closer to each other. The electrostatic repulsion can be enough to split the crystal, which is why ionic solids also are brittle.

Due to strong electrostatic forces of attraction existing among the ions, they have high melting and boiling point.

3.When ionic compounds are dissolved in water the dissociated ions are free to conduct electric charge through the solution. Molten ionic compounds (molten salts) also conduct electricity.

Lesson 4: Lattice energy

a) Prerequisites/Revision/Introduction

The previous lessons therefore, make sure they were well understood.Give learners some quick revision questions.

b) Teaching resources

- Textbooks and internet resources

c) Learning activities

- Students are asked to do research on lattice energy and answer questions in activity 3.4. The teacher may help learners by giving them a list of important reference books available in the school library.
- Research work (activity 3.4) is done prior to the lesson time and date.
- Prepare it before and give to learners clear instructions keeping in mind that In addition to subject matter skills and knowledge, this lesson also tends to develop research skills (report writing and referencing), lifelong learning skills, and communication (reading, writing and speaking skills) in English as a medium of instruction.
- Make sure that learners are able to explain what lattice energy is in their own words and can relate the lattice structure in metals to their properties.
- Learners brainstorm on the questions in activity 3.5: Find out factors that affect lattice energy, which has the larger lattice energy, NaCl or CsI? Summarise the lesson and verify learners' notes.
- The magnitude of a substance's lattice energy is affected both by the charges on its constituent ions and by the sizes of those ions. The higher the charges on the ions and the smaller the sizes of the ions, the larger the lattice energy.
- In this case, all four ions— Na^+ ,Cs^+, Cl^- and I^- are singly charged, so they differ only in size. Because Na^+ is smaller than Cs^+ and is smaller than Cl^- , the distance between ions is smaller in NaCl than in CsI. Thus, NaCl has the larger lattice energy.

d) Checking up 3.4

Expected answers for checking up 3.4

1. Lattice energy: The difference in energy between the expected experimental value for the energy of the ionic solid and the actual value observed. More specifically, this is the energy gap between the energy of the separate gaseous ions and the energy of the ionic solid.

2. (a) MgO. It has ions with the largest charge.

(b) $MgCl_2$

3. $AlCl_3$. According to the periodic trends, as the radius of the ion increases, lattice energy decreases.

4. 1) **Ionic radius** –the bigger the ionic radius, the less negative the lattice energy because the oppositely charged ions attract less strongly.

2) Ion charge – the higher the charge, the more negative the lattice energy because the ions attract ions of opposite charge more strongly.

Lesson 5: Metallic bonding (formation and properties of metals)

a) Prerequisites/Revision/Introduction

The teacher will introduce the lesson by allowing learners to do the introductory activity in groups or any other appropriate method chosen. This activity is diagnostic i.e. intended to check on the previous information about metallic bonding. Learners will be asked to look at the picture in learner's book and answer the questions below it.

b) Teaching resources

Activity 3.6	Materials
a	Metal spoon, a plastic spoon, water and source of heat
b	Wires, nails, hammer, piece of cloth.
c	Aluminium wire/sheet, copper wire, wood, plastic material, silver wire, battery/ dry cells, resistor, LED bulb and crocodile clips.
d	sodium mental, knife, aluminium sheet, forceps

d) Learning activity

- Let learners do the activity (experiment to investigate **thermal conductivity of metals, malleability and ductility**, electric conductivity, **lustrous/shiny** as indicated in learner's book.
- The lesson also targets practical/experimental skills (manipulation, observation, recording and interpretation, making inferences, generalisation and conclusion)
- After experiments learners will have do study questions that will help them to make conclusions.
- Experiments on melting and boiling points: a teacher may provide the table indicated in the learner's book and ask learners to answer the activity 3.6 or ask the learners to use their book and check on the table provided if available.
- Let learners do the activity 3.7 about the factors that affect the strength of a metallic bond in groups and allow them to make presentations.

d) Checking up 3.6

Expected answers for checking up 3.6

1. (a) Silver and Stainless steel

(b)Polystyrene and air

(c) Polystyrene is a poor conductor of heat and hence good insulator o it does not lose heat easily.

(d) Wood is a poor conductor of heat and the little heat supplied inside take longer to disappear.

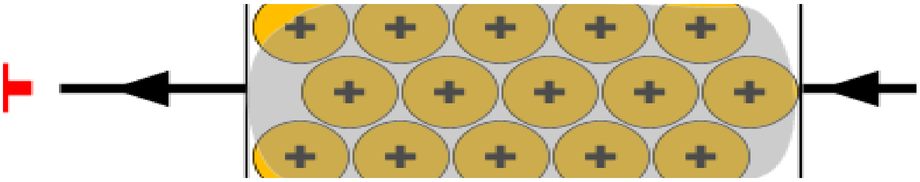
(e) Igloos are normally built from compressed snow, which is sawn into blocks, and then these blocks are stacked around a hole, which is dug out after the blocks have been set. Solid ice is a poor insulator, when compared to compressed snow. The snow has many more air pockets per cubic foot, and is also lighter. Also, igloos do not have flat bottoms. The inside of the igloo is tiered, or terraced, the uppermost level being where the people sleep, the middle is where the fire is and the work takes place, and the bottom level actually is a "cold sump". The principle is that all the coldest air from inside the igloo runs downward off the terraces and collects in the bottom, thus allowing the upper portions to stay warmer.

2. (a) electronic structure: Sodium has one outer electron which it can delocalize to form the metallic bond; magnesium has two. So with magnesium there will be a higher electron density in the bond. Magnesium also has an extra proton. There will therefore be stronger attractions between the nuclei and the delocalized electrons, making the bond harder to break, and so more energy is needed to melt or boil the magnesium.

Packing: Each magnesium atom is in close contact with 12 others, whereas sodium only has 8 near-neighbours. This creates more bonding in the magnesium.

Atomic radii: Magnesium atoms are smaller than sodium atoms because of the extra proton in the magnesium. Magnesium nuclei are therefore closer to the bonding electrons, strengthening the bond.

(b) For a substance to conduct electricity it must have mobile ions or electrons.Because the electron cloud is mobile, electrons are free to move throughout its structure. Electrons attracted to the positive end are replaced by those entering from the negative end.



Mobile electron cloud allows the conduction of electricity.

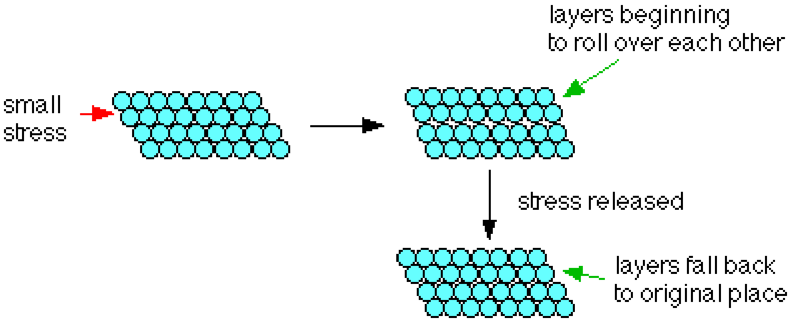
(c) This due to the presence of delocalized electrons that vibrate in fixed positions when heat energy is applied to one end of the metal hence allowing it to be conducted from one point to another.

3(a) **Malleable:** can be hammered into sheets

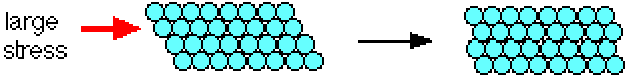
Ductile: can be drawn into rods and wires

(b)Metals are described as malleable (can be beaten into sheets) and ductile (can be pulled out into wires). This is because of the ability of the atoms to roll over each other into new positions without breaking the metallic bond.

If a small stress is put onto the metal, the layers of atoms will start to roll over each other. If the stress is released again, they will fall back to their original positions. Under these circumstances, the metal is said to be elastic.



If a larger stress is put on, the atoms roll over each other into a new position, and the metal is permanently changed.



(c) Heating a piece of metal tends to shake the atoms into a more regular arrangement with fewer grain boundaries (breaks in the regular pattern). The grain boundaries stop the layers of atoms from rolling over each other easily, and so removing them make the metal softer.

Hitting the metal breaks up the regular structure again, producing lots of small crystal grains, and so increasing the number of grain boundaries. That makes it more difficult for the layers of atoms to roll over each other, and so hardens the metal.

a) Copper and zinc atoms aren’t the same size. A structure containing both of them will be much more irr≠egular than one containing identically sized atoms. This will make it more difficult for the layers to slide over each other, and so the alloy is harder than the individual metals.

3.6. Unit summary

Onic bonding: This is a force of attraction that joins two oppositely charged ions together in a crystal lattice. It is formed when one atom mainly a metal transfers electron(s) to another atom mainly non metal to form an ionic compound.

Ionic compounds also exhibit the following properties:

Physical state: The ionic compounds can exists as solid only as the constituent particles are closely packed due to strong electrostatic forces of attraction.

They're hard and brittle: Ionic crystals are hard because the positive and negative ions are strongly attracted to each other and difficult to separate, however, when pressure is applied to ionic crystal then ions of like charge may be forced closer to each other.

Crystal structure: In ionic compounds the constituent particles occupying the lattice points are the positive and negative ions which are arranged in a regular pattern in three dimensional space.

High melting and boiling point: Due to strong electrostatic forces of attraction existing among the ions, they have high melting and boiling point.

Electrical conductivity: The ionic compounds are good conductors of electricity in molten or aqueous solution. However, they do not conduct in crystalline state where the ions are not free to move.

They have higher enthalpies of fusion and vaporization than molecular compounds: Just as ionic compounds have high melting and boiling points, they usually have enthalpies of fusion and vaporization that can be 10 to 100 times higher than those of most molecular compounds.

Vapour pressure The ionic compounds have very low vapor pressure.

Solubility: The ionic compounds are soluble in water and in other polar solvents. They are insoluble or very less soluble in non-polar solvents. This is caused by the ionic bonds being polar in nature.

Metallic bonding

Metallic bonds are formed when the valence electrons from the s and p orbitals of the interacting metal atoms delocalize. That is to say, instead of orbiting their respective metal atoms, they form a "sea" of electrons that surrounds the positively charged atomic nuclei of the interacting metal ions.

Metallic properties

Metallic lustre: The bright lustre of metals is due to presence of delocalised mobile electrons. When light falls on the surface of the metal, the loosely held electrons absorb photons of lights. Electrical conductivity: The presence of mobile electrons causes electrical conductivity of a metal. When a potential difference is applied across the metal sheet, the free mobile electrons in the metallic crystal start moving towards the positive electrode.

Thermal conductivity: When a part of the metal is heated, the kinetic energy of the electrons in that region increases.

Malleability and ductility: Metals can be beaten into sheets (malleability) and drawn into wires (ductility). Metallic bonds are non-directional in nature.

High tensile strength: Metals have high tensile strength. Metals can resist stretching without breaking. A strong electrostatic attraction between the positively charged kernels and the mobile electrons surrounding them is the reason for tensile strength.

Hardness of metals: The hardness of metals is due to the strength of the metallic bond. In general, the strength of a metallic bond depends upon:

The greater the number of valence electrons for delocalisation the stronger is the metallic bond. Smaller the size of the kernel of metal atom, greater is the attraction for the delocalised electrons. Consequently, stronger is the metallic bond.

Opaqueness: The light that falls on metals is either reflected or completely absorbed by the delocalised electrons. Because of this, no light is able to pass through metals and they are termed as opaque.

Melting and boiling points: Metals have metallic bond strengths, which is intermediate to that of covalent and ionic bonds. Therefore in general, metals have boiling and melting points in between to that of covalent and ionic compounds.

3.7. End unit assessment

Assessment is an important part of teaching and learning. At the unit level, the teacher needs to know how well the key unit competence was achieved. End of unit assessment questions were suggested and one period reserved.

Expected Answers for end unit assessment

The order of filling : positive ions, free electrons, attractive force, high melting points, high density, metal, non metal, free electrons, great malleability, free electrons, good conductivity, metal, non metal, positive ion, negative ion, attraction, regular crystal shape, high melting point, conduct electricity, electrolysis, electrodes, positive ions, negative ions, non metals

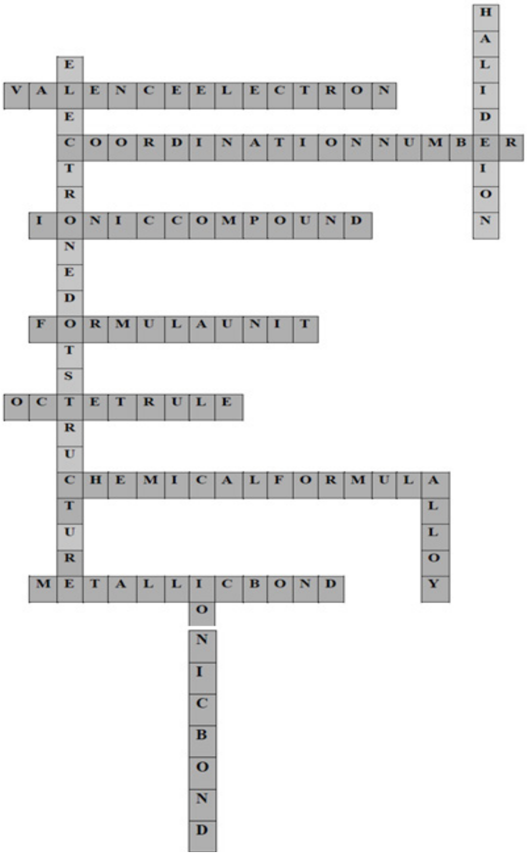
Multiple choice answers

1-A,	8-B,	15-A
8-B,	2-C,	16-D,
2-C,	9-B,	17-C,
9-B,	3 –B,	18-C,
3 –B, 10-B, 4-D, 11-C,	10-B,	19-C,
5-D,	4-D,	20-B,
12-C,	11-C,	21-C
6-C,	5-D,	
13-A,	12-C,	
7-D,	6-C,	
	13-A,	
	7-D,	
	14-B,	

22) This is due to a bigger size of bromide ion (Br-) than chloride ion (Cl-)

b) This is due to the big size and large charge of magnesium compared to that of sodium.

2. The Puzzle



3. For a solid to dissolve in a solvent, you have to break up the solid lattice. This needs energy. This can only happen if that energy can be recovered when new forces are set up between the particles in the solid and the solvent molecules.

There are strong forces set up between the very polar water molecules and both sodium ions and chloride ions. But there aren't any strong forces set up between the ions and a non-polar solvent like hexane. That means that there is nothing to help to break up the strong ionic lattice.
To add on that, It is the lone pairs on the oxygen atoms in the water molecules which are strongly attracted to the sodium ions. Water molecules attach to chloride ions via hydrogen bonds.

3.8. Additional information

Polarization (covalency character in ionic compound)

Ionic bonds can be polarised by the cations strongly attracting the outer shell electrons of the anion.

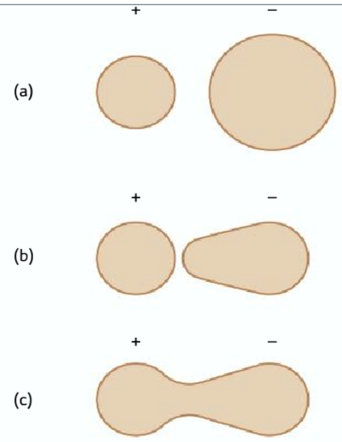


fig. 1.4.13 The distortion of an ionic bond. Distortion is favoured if the (positive) cation is small with a large charge, and the (negative) anion is large.

The ions' charge density: Depends on the size of the ions and its charge. Smaller the ionic radius and/or the greater the charge – the greater the charge density.

For an anion, the larger the radius, the more easily it is polarized. When difference in electronegativity of the ions in a crystal lattice is high, the ionic model works well. When difference in electronegativity is low, the bonding in the crystal has got high covalent character.

Well theoretical model assumes all ions are spherical and separate giving evenly distributed electron charge across the ion. Polarizing the bond, and distorting the ion, and increased covalent character; decreases lattice energy values.

3.9. Additional activities

1. Sodium chloride and magnesium oxide have exactly the same structure. Their melting and boiling points are:

Melting point /K	NaCl	MgO
	1074	3125
	1686	3873

Explain why the values for magnesium oxide are much higher than those for s**odium chloride.**

Answer: Melting and boiling points depend on the attractions between the ions. In MgO, 2+ magnesium ions are attracting 2- oxide ions. These attractions will be much stronger than those between 1+sodium and 1- chloride ions.

Explain why ionic compounds such as sodium chloride have brittle crystals.

Answer:A small shock to the crystal brings ions of the same charge alongside each other. The repulsions will shatter the crystal. (You could do this perfectly well with simple diagrams.)

2. Molten sodium chloride undergoes electrolysis. Electrolysis is a chemical change

produced by passing an electric current through a molten substance or a solution in water.

a) Explain (including an electrode equation) what happens at the cathode (the negative electrode).

Answer:

a) Positive sodium ions are attracted to the negatively charged cathode. When they get there, they are neutralised when electrons from the electrode jump on to the ion. Neutral sodium atoms are formed, which come together as a drop of molten sodium metal.

$Na^+ + e^- \longrightarrow Na(s)$

b) Explain (including an electrode equation) what happens at the anode (the positive electrode).

b) Negative chloride ions are attracted to the positively charged anode. When they get there, they release electrons to the electrode, and form chlorine atoms. These immediately pair up to give chlorine gas,

$Cl_2 + 2e- \longrightarrow 2CL^-$

c) Explain why this enables an electric current to flow around the external circuit.

Answer: c) Electrons are being removed from the cathode, leaving a space on the cathode. Electrons are being added to the anode. The power source can move electrons through the external circuit from the anode to the cathode to replace those being removed. Movement of electrons is an electric current.

1.Why doesn't solid sodium chloride conduct electricity?

Answer: d) This only works if ions are free to move in the sodium chloride. In solid sodium chloride, they are locked into a rigid lattice and aren't free to move.

Define the terms

a) Lattice dissociation enthalpy

Answer: Lattice dissociation enthalpy is the enthalpy change needed to convert 1 mole of solid crystal into its scattered gaseous ions.

b) Lattice formation enthalpy.

Answer: Lattice formation enthalpy is the enthalpy change when 1 mole of solid crystal is formed from its scattered gaseous ions.

3.NaCl, NaBr and MgO all have the same crystal structure.

a) Explain why the lattice dissociation enthalpy of NaBr is a bit less than that of NaCl.

Answer: Lattice dissociation enthalpy is a measure of the forces of attractions between the positive and negative ions. Bromide ions are bigger than chloride ions, and so the distance between the centres of the positive and negative ions in the lattice is greater in NaBr. Increasing distance weakens the forces of attraction between them, and hence the lattice enthalpy.

b) Explain why the lattice dissociation enthalpy of MgO is about 5 times greater than that of NaCl

Answer: There are two factors at work here. Magnesium ions are smaller than sodium ions, and oxide ions are smaller than chloride ions. That means that the distance between the positive and negative ions is quite a lot less in MgO than in NaCl, and so the forces of attraction will be greater in MgO.

But the main factor is the charge on the ions. In MgO, both positive and negative ions carry two charges. In NaCl, they only carry one. The strength of the attractions is much greater in MgO than in NaCl.

In fact, the strength of the attractions is proportional to the charges on the ions. If you double the charges on both positive and negative ions, the strength of the attractions will go up 4 times. The question says that the MgO lattice enthalpy is about 5 times greater than that of NaCl. The extra is due to the shorter distance between the ions in MgO.

5. The table (using figures for lattice energies from gives experimental and theoretical values for the silver halides.(The values are listed as lattice dissociation energies. Don't worry about the difference between lattice energy and lattice enthalpy. All I am asking you to do is to compare the values, and you can do that OK without worrying about the exact difference between the two terms.)

b) For AgF, the experimental and theoretical values are very close. What does that show?

Answer: a)the theoretical value is based on assuming the substance has purely ionic bonding. If this agrees with the experimental value (as it does to within 1.5% for AgF), then you can assume that AgF is almost purely ionic.

b) For AgI, there is a much greater difference between the two values. What does that suggest?

Answer: b) If there is a greater discrepancy (about 9% for AgI), then the bonding can't be entirely ionic, and must have covalent nature as well.

c) Why do you think the difference between the two values increases as you go from AgF to AgI

In terms of these energy changes, explain why magnesium forms a chloride with the formula MgCl2 and not MgCl or MgCl3

c) As you go from AgF to AgI, the electronegativity of the halogen is falling. That means that the electronegativity difference between the silver and the halogen will be greatest with AgF, and least with AgI. The greater the difference, the more purely ionic the bonding will be. The fluorine will have the greatest tendency to pull bonding electrons to its end of the bond, and so form ions. Iodine doesn't have as strong a tendency, and so the bonding isn't so purely ionic.

4.Explain why metals are malleable and ductile but ionic-crystalline compounds are not.

The metallic bond is the same in all directions throughout the metallic structure allowing the atoms to slide past each other. This sliding is why metals are ductile and malleable. Ionic compound must break bonds to slide past one another, which causes the ionic material to split and crack.

5.Explain why metal surfaces are shiny.

Metals are shiny or have luster due to the many available orbitals, which can absorb and give off a wide spectrum of light.

6.Describe the electron-sea model of metallic bonding. Explain why metals are good electrical conductors.

In the electron-sea model of bonding the valence electrons are free to move in the large number of vacant orbitals. These empty overlapping orbitals (the “p”, “d” and “f” orbitals) allow the electrons to delocalize with the ability to move freely from one atom to the next. Metals are such good conductors due to the freedom with which the valence electron can move.

7.Why do metals have high density compared to non-metals or plastics?

Most common metals like aluminium, copper, and iron are denser than plastic or wood. The atoms that make up metals are generally heavier than the atoms in plastic and wood and they are packed closer together. The difference in density between different metals is usually based on the size and the mass of the atoms but the arrangement of the atoms in most metals is mostly the same.

: UNITY 4: COVALENT BOND AND MOLECULAR STRUCTURE

4

4.1. Key unit competence

To demonstrate how the nature of the bonding is related to the properties of covalent compounds and molecular structures.

4.2. Prerequisite knowledge and skills

Before learning this unit, students should have a prior knowledge ionic bonding as seen in the previous unit 3. This will help them relate the information about formation of why atoms bond to achieve the stability. Learners also should be helped to recall the formation of covalent bonds also seen in senior two unit1 in ordinary level chemistry. It is also important for students to recall how electronic configuration of different elements is written.

4.3. Cross-cutting issues to be addressed

Comprehensive Sexuality Education

Refer to the unit 3 teacher guide. However, you can still emphasise this cross-cutting issue though mentioned in the previous unit 3.

Peace values education

It is very important to note that like atoms of non metals share their electrons to complete their octet, likewise people need each other in many perspectives irrespective of their race, economic, political and social status for the success of human race.

Inclusive education

This unit involves number of structures that require drawing. It is therefore imperative to note that learners with visual impairment are helped by drawing big enough pictures or find them spaces near the chalk board.

4.4. Guidance on Introductory activity

Before introducing the first lesson of this unit (Overlap of atomic orbitals to form covalent bonds), let learners attempt introductory activity. This activity intends to:

- Relate the unit with learners' real daily life to capture their attention and enhance their curiosity towards the unit.
- Assess learners understanding of the concept of covalent bonding by using the activity 4.1

4.5. List of lessons

Unit No	Lesson title	Objectives	No of periods
4.1	Overlap of atomic orbitals to form covalent bonds	Define octet rule as applied to covalent compounds. Explain the formation of covalent bonds and describe the properties of covalent compounds. Describe how the properties of covalent compounds depend on their bonding.	3
4.2	Lewis structures	Explain the rules of writing proper Lewis structures Draw different Lewis structures State the difference between Lewis structures from other structures. Apply octet rule to draw Lewis structures of different compounds. Make structures of molecules using models. Write structures of some compounds that do not obey octet rule.	3
4.3	Dative covalent bonding, properties and resonance structures	Explain the formation of dative covalent bonds in different molecules. Compare the formation of dative covalent to normal covalent bonding.	3
4.4	Valence bond theory	Describe the concept of valence bond theory.	2

4.5	Types of hybridization of atomic orbitals	Relate the shapes of molecules to the type of hybridization. Differentiate sigma from pi bonds in terms of orbital overlap and formation.	2
4.6	VSEPR(Valence shell electron pair repulsion theory)	Explain the VSEPR theory. Apply the VSEPR theory to predict the shapes of different molecules/ions.	5
4.7	Polarity of covalent bonds.	Predict whether the bonding between specified elements will be primarily covalent or ionic.	2
4.8	Simple and giant covalent structures	Relate the structure of simple and giant molecular covalent compounds to their properties. Describe simple and giant covalent molecular structures.	3
4.9	Intermolecular forces of attraction	Describe the origin of inter-molecular forces. Describe the effect of inter and intra molecular forces on the physical properties of certain molecules. Describe the effect of hydrogen bonding in the biological molecules. Relate the physical properties to type of inter and intra molecular forces in molecules. Compare inter and intra molecular forces of attraction in different molecules.	3
5.0	End unit assessment		2

Lesson 1: Overlap of atomic orbital to form covalent bonds

This is the first lesson of unit 4 and is made up of suggested three periods. The first lesson also covers the introduction of the whole unit (introductory activity). You are advised not to spend a lot of time on this introductory activity. This is only intended to raise the curiosity of learners and relate the lesson to real/daily life.

a) Prerequisites/Revision/Introduction

Students will learn better the overlap of atomic orbitals to form covalent bonds if they have understanding on: The concept of bonding and the stability of atoms as the sole reason why covalent bonding take place, the arrangement of elements in the periodic table and writing the electronic configuration of elements, (refer to unit 2).

b) Teaching resources:

- Periodic table of elements
- Use the illustrations in the students' book for lesson 1 or draw them on a manila paper.
- Use downloaded videos from youtube if the internet is not sufficient.
- Other relevant chemistry text books if available in the library.

c) Learning activities:

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do introductory activity and thereafter proceed to activity 4.1 which is specific to lesson 1.

- Form groups of 4-5 depending on the size of the class.
- Distribute the introductory activity and estimate the time for it.
- Let the learners proceed and do activity 4.1 of lesson 1.
- Allows the learners to work together in groups.
- Invite group leaders to present their findings.
- Instead of groups you can also use "**pair-think and share**".
- In this step you can guide the learners to evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- You summarise the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated in step 2.
- Integrate crosscutting and real life experiences by linking them with the lesson learned.

Expected answers to the introductory activity

a) **Metal-non metal group**: NaCl, MgO

Non metal-non metal group: H_2O, N_2, Diamond, CH_4, SiO_2, and ethanol

b) **Solids**: NaCl, MgO, Diamond, SiO_2

Liquids: H_2O, ethanol

Gases: N_2, NH_3 and CH_4

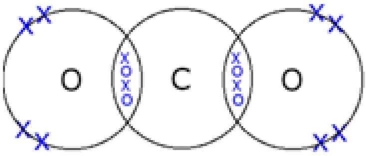
c) Alcohol, NH_3, NaCl, and MgO

d) Activity 4.1

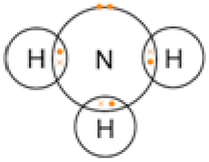
Answers to activity 4.1: refer to the student's book.

e) Expected Answers for Checking up 4.1

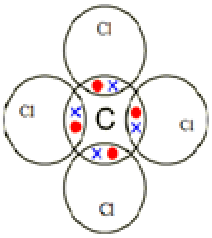
1.



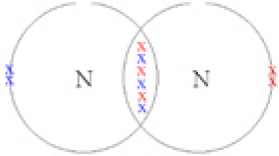
CO_2



NH_3



CCl_4



$N\equiv N$

2.

Property	Covalent molecules	Ionic compounds
Formation	A covalent bond is formed between two non-metals that have similar electronegativities. Neither atom is "strong" enough to attract electrons from the other. For stabilization, they share their some valence electrons.	An ionic bond is formed between a metal and a non-metal. Non-metals can get electrons very easily from the metal. The non-metal becomes an anion and a metal becomes an a cation. These two opposite ions attract each other and form the ionic bond

Polarity	Low	High
Shape	Definite shape	No definite shape
What is it?	Covalent bonding is a form of chemical bonding between two non metallic atoms which is characterized by the sharing of pairs of electrons between atoms and other covalent bonds.	Ionic bond, also known as electrovalent bond is a type of bond formed from the electrostatic attraction between oppositely charged ions in a chemical compound. These kinds of bonds occur mainly between a metallic and a non metallic atom.
Melting point	Low	High
Occurs between	Two non-metals Note: it is possible between metal and non- metal. Remember polarization	One metal and one non-metal Remember :Polarization
Boiling point	Low	High
State at room temperature	Liquid or gaseous Note: few are solids	Solid
Examples	Methane (CH_4), Hydrochloric acid (HCl), water (H_2O)	Sodium chloride (NaCl), Sulphuric acid (H_2SO_4)

Lesson 2: Lewis structures

This is the second lesson under covalent bonding formation it consists of three periods. Students are expected to explain how Lewis structures are drawn and muster the rules followed to write Lewis structures through practicing as many examples of molecules as possible.

a) Prerequisites/Revision/Introduction

Refer to lesson 1 above but mainly here the concept of valence electrons and electronic configuration is much more needed.

b) Teaching resources

- The Periodic Table of Chemical Elements
- Charts illustrating formation of Lewis structures and rules may be pinned in class for some time for students to familiarize with them and practice.
- Where possible use manila papers, flipcharts and youtube videos with computers and projectors. (If there is no internet you can download and keep the videos on memory sticks)

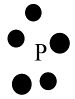
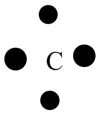
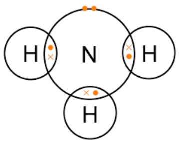
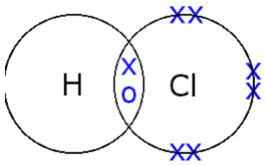
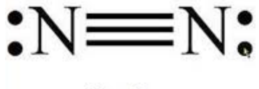
c) Learning activities

- The teacher form groups of 3-4. the number of groups and members will depend on your class size.
- In the groups learners do activity 4.2 indicated in learner's book, discuss

and record their answers.

- Allow the learners to concentrate and use their time appropriately.
- learners do the activity 4.2.1 (this includes the exceptions of the octet rule) to avoid confusion
- During the presentation ask some questions that lead to discovery of new concepts. Use learners examples to guide them discover some of the rules that were applied to draw correct Lewis structures and some exceptions octet rule
- The teacher summarises the learned knowledge and gives examples which illustrate the learned content.
- Your purpose here to confirm the correct information, correct the ambiguity among the findings presented.
- Emphasise about rules of writing the Lewis structures and give some examples among the exceptions of the octet rule.

Here is some of the expected answer for the Activity 4.2 (a)

#	Compound /element	Chemical formula	Lewis structure
1	phosphorous	P	
	Carbon	C	
	Chlorine	Cl_2	
2(i)	Ammonia	NH_3	
(ii)	Hydrogen chloride	HCl	
(iii)	Nitrogen molecule	N_2	

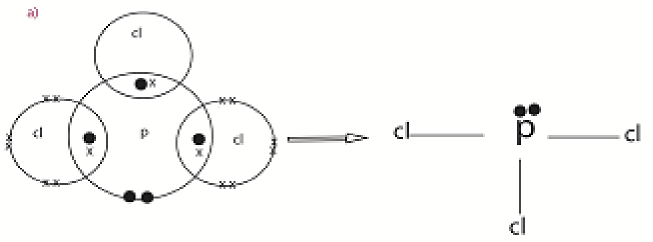
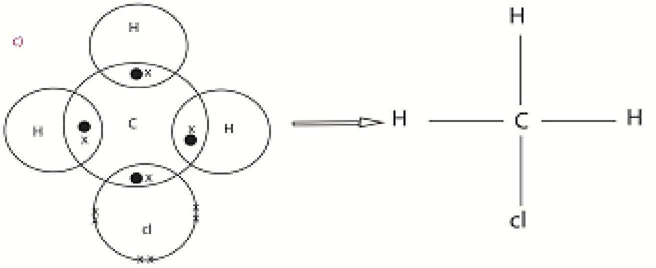
3. No more single electron (all electrons are paired)

4. Lewis structures

d) Checking up 4. 2(a)

Expected answers for checking up 4.2(a)

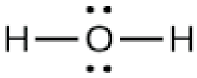
1. Refers to the student book for the answers.
2.

a	
b	
c	

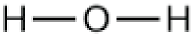
d	

3. Refer to student book

4.



A



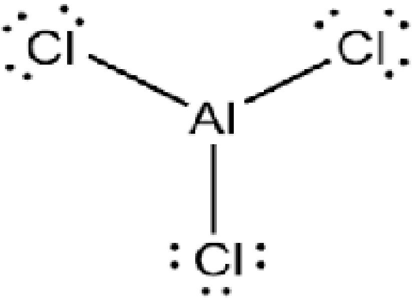
B

A and B are different in a way that one has lone pairs (unused electrons) , Lewis structure and the other one do not have.

Refer to student book

Activity 4.2 (b)

Expected answers for activity 4.2 (b)



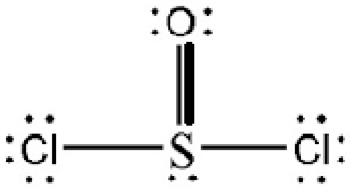
$AlCl_3$

6 electrons

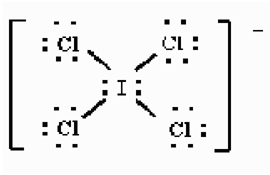
No. aluminium is surrounded by 6 electrons instead of 8 electrons to obey the octet rule.

Checking up 4.2.(b)

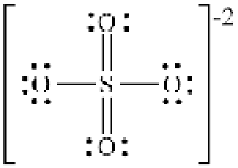
Expected answers



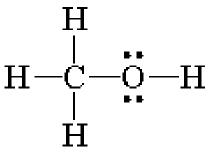
a



b

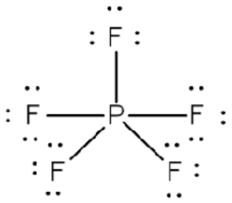


c



d

e



f

The number of electron surround the central are less in BeCl$_2$ and more than eight in PCl5 and they are confirmable with what they have.

Lesson 3: coordinate or dative covalent bonding, properties and resonance structures

This lesson consists of three periods, during these you can split the lesson according to the nature of your students. It is about formation of dative covalent bond, properties and resonance structures.

a) Prerequisites

Before beginning this lesson, you can ask a few questions about the formation of covalent bonds either orally or set a simple exercise for revision. You can also use the activity 4.3. This activity is only intended to remind learners and link the information with the previous lesson and other lessons learnt in S.2 chemistry unit 1.

b) Teaching resources

- You can use a periodic table
- You can use flip charts, videos downloaded from you tube (if internet is available) ,
- Learners' text books or other relevant chemistry books can be used if available.

c) Learning activities

- Form groups or pairs of learner and distribute the activity 4.3 in learners' book.
- Remember to give learners activity 4.3.1 for resonance structures.
- Allow the learners to work in their respective groups.
- You can invite the representatives of groups to presents their findings.

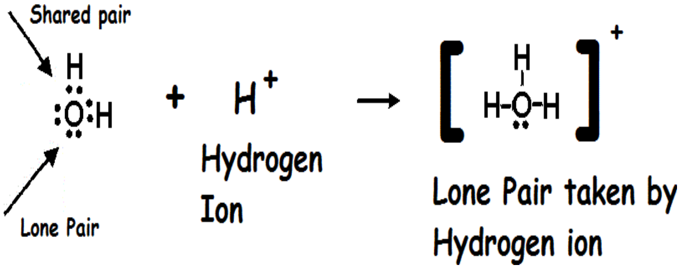
- Learner evaluates their findings through discussion with the assistance of the teacher to correct, the incomplete or false
- You can use the examples given by the learners to link the lesson to the content being learned.
- You summarise the learned knowledge and gives examples which illustrate the learned content.
- Emphasise on the difference between covalent bond formation and co-ordinate bond.

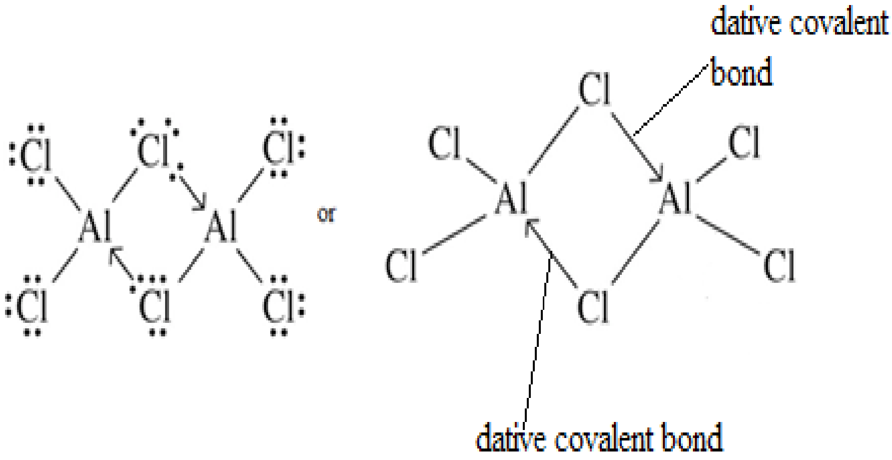
d) Activity 4.3

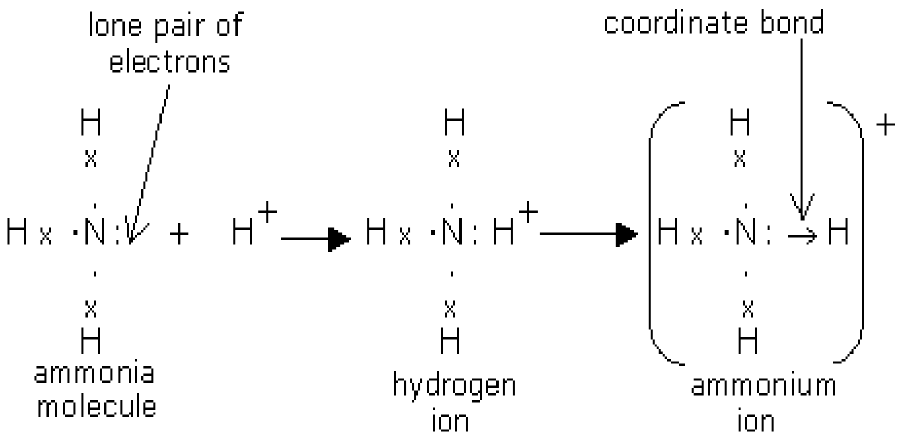
Expected answers for activity 4.3

1. Refer to the student’s book (unit 2)

2. Refer to student’s book



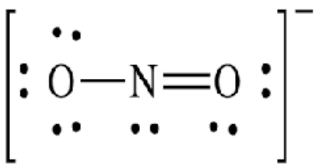




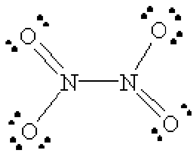
d) Checking up 4.3

Expected Answers

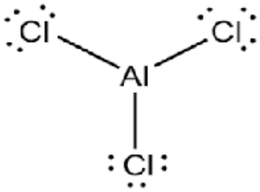
1. For (a) and (b) Refer to student book page.....
2. Refer to students' book page for (a) and (b).
3. Refer to students book page for (a) and (b)
4.



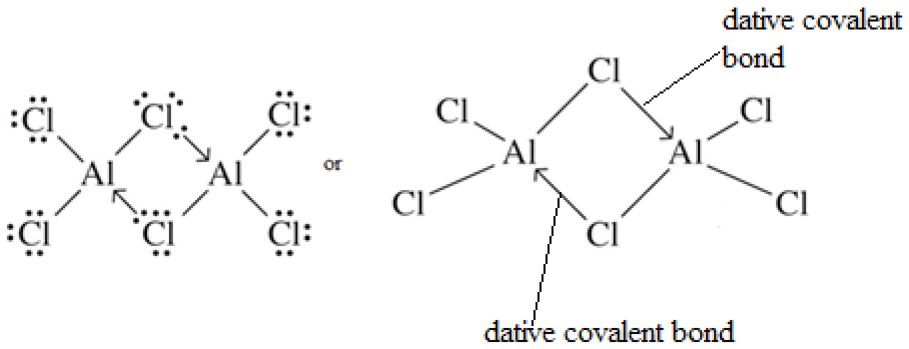
NO_2



N_2O_4



$AlCl_3$



5. Refer to student's book
6. Refer to student's book
7. Iron is an important component of haemoglobin, the substance in red blood cells that carries oxygen from your lungs to transport it throughout your body. Haemoglobin

represents about two-thirds of the body's iron. If you don't have enough iron, your body can't make enough healthy oxygen-carrying red blood cells.

Iron is necessary for haemoglobin production. Insufficient amount of iron causes iron deficiency (anaemia). "a red protein responsible for transporting oxygen in the blood of vertebrates. Its molecule comprises four subunits, each containing an iron atom bound to a haem group.

Lesson 4: Valence bond theory (VBT)

a) Prerequisites/Revision/Introduction

The previous lessons can be used here, make sure it was well understood. The activity indicated in 4.4 can be used to introduce the lesson.

b) Teaching resources

- Periodic table of elements
- Textbooks and internet resources
- Balloons to represent the p-orbitals.
- Downloaded videos from you tube.

c) Learning activities

- Learners are asked to do research or read it from learner's book on valence bond theory and try to answer questions in activity 4.4 in learner's book.
- The teacher may guide the learners by giving them a list of important reference books available in the school library. If the internet is available you can give exact URL for proper researching.
- You can allow presentations of the summarised work
- Correct the mistakes and eliminate false or unnecessary information.
- Give the summary of the lesson and other examples(description of valence bond theory must be emphasised)

d) Activity 4.4

Expected answers

Refer to student's book

e) Checking up 4.4

Expected Answers

Refer to learner's book for all the answers of checking up 4.4

Lesson 5: Types of hybridization

a)Prerequisites/Revision/Introduction:

This activity is diagnostic intended to test the previous knowledge obtained from Lewis structures and valence bond theory

You can distribute the learner's book and ask them to read and make a summary on types of hybridization.

b) Teaching resources

- Periodic table of elements,
- Flip charts and internet for videos where applicable, a teacher may also use balloons to illustrate the orbital arrangement during hybridisation.
- A teacher can use atomic models if available to illustrate the shapes of different molecules according to VSEPR theory.

c) Learning activities:

- Form pairs of learners depending on their learning capacities.
- You can distributes the activity 4.5 indicated in learners book
- Allow the learners to work in their respective groups or pair
- Learners present their research and summarised findings to the whole class.
- Remove the ambiguity of some information given during presentation and confirm and link it with learned content.
- Summarise the lesson by adding more examples and answer some questions from learners. Make sure all the three types of hybridisation are clearly explained.

d) Checking up 4.5

Expected Answers

1. The intermixing of two or more pure atomic orbitals of an atom with almost same energy to give same number of identical and degenerate new type of orbitals is known as hybridization. The new orbitals formed are also known as hybrid orbitals.
2. The hybrid orbitals participate in the σ bond formation with other atoms.
3. Refer to learner's book for the answers.
4. Refer to learner's book for the answers.
5. Refer to learner's book for the answers.
6. Refer to learner's book for the answers.
7. Refer to learner's book for the answers.
8. Refer to learner's book for the answers.

Prediction of sp, sp^2, sp^3 Hybridization states

We know, hybridization is nothing but the mixing of orbital's in different ratio to form some newly synthesized orbitals called hybrid orbitals. The mixing pattern is as follows: s + p (1:1) - sp hybrid orbital; s + p (1:2) - sp^2 hybrid orbital; s + p (1:3) - sp^3 hybrid orbital

Formula used for the determination of sp, sp^2 and sp^3 hybridization states:

Power on the Hybridization state of the central atom = (Total number of σ bonds around each central atom -1)

All single (-) bonds are σ bond, in double bond (=) there is one σ and 1π, in triple bond($\equiv$) there is one σ and 2π. In addition to these each lone pair (LP) and Co-ordinate bond can be treated as one σ bond subsequently.

For example:

a) In NH_3: central atom N is surrounded by three single bonds i.e. three sigma (σ) bonds and one lone pair (LP) . So, in NH_3 there are 3 bond pairs (BPs) + 1 lone pair (LP) around central atom N. Therefore, in this case power of the hybridization state of N = 4-1 = 3 i.e. hybridization state = sp^3.

b) In H_2O: central atom O is surrounded by two O-H single bonds i.e. two sigma (σ) bonds and two lone pairs. So, altogether in H_2O bonds (2 bond pairs + 2 lone pairs) around central atom O, So, in this case power of the hybridization state of O = 4-1 =3 i.e. hybridization state of O in H_2O = sp^3.

c) In H_3BO_3:- B has 3σ bonds (3BPs but no LPs) and oxygen has 4σ bonds (2BPs & 2LPs) so, in this case power of the hybridization state of B = 3-1 = 2 i.e. B is sp^2 hybridized in H3BO3. On the other hand, power of the hybridization state of O = 4-1= 3 i.e. hybridization state of O in H3BO3 is sp^3.

d) In I-Cl: I and Cl both have 4σ bonds and 3LPs, so, in this case power of the hybridization state of both I and Cl = 4 - 1 = 3 i.e. hybridization state of I and Cl both are sp^3.

e) In $CH_2=CH_2$: each carbon is attached with 2 C-H single bonds (2 σ bonds) and one C=C bond (1σ bond), so, altogether there are 3 sigma bonds. So, in this case, power of the hybridization state of both C = 3-1 = 2 i.e. hybridization state of both C's are sp^2.

Prediction of sp^3d, sp^3d^2, and sp^3d^3 Hybridization States

In case of sp^3d, sp^3d2 and sp^3d^3 hybridization state there is a common term sp3 for which 4 sigma bonds are responsible. So, in addition to 4 sigma bonds, for each additional sigma, added one d orbital gradually as follows:-

5σ bonds = 4σ bonds + 1 additional σ bond = sp^3d hybridization

6σ bonds = 4σ bonds + 2 additional σ bonds = sp^3d^2 hybridization

7σ bonds = 4σ bonds + 3 additional σ bonds = sp^3d^3 hybridization

For example

a) IF4+: I has 7 electrons in its outermost shell, so, in this case, subtract one e- from 7 i.e.

7– 1 = 6. So, out of 6 electrons, 4 electrons form 4 I-F bonds i.e. 4 sigma bonds and there is one lone pair (LP). So, altogether there are 5 σ bonds. So, 5σ bonds = 4 σ bonds + 1 additional σ bond = sp3d hybridization

b) IF7: 7 I-F single bonds i.e. 7σ bonds = 4σ bonds + 3 additional σ bonds = sp^3d^3 hybridization.

c) ICl_2^-: I has 7 e-s in its outermost shell, so, in this case, add one e- with 7(overall charge on the compound) i.e. 7+1= 8. So, out of 08 electrons, 2 electrons form 2 I-Cl bonds i.e. 2 sigma bonds and there is 3 LPs. So, altogether there are 5σ bonds. So, 5σ bonds = 4 σ bonds + 1 additional σ bond = sp3d hybridization.

d) XeF4: Xe, an inert gas, consider 8 e-s in its outermost shell, 4 of which form 4 Xe-F sigma bonds and there is two LPs, i.e. altogether there is 6 σ bonds = 4 σ bonds + 2 additional σ bonds = sp^3d^2 hybridization.

In case of determination of the hybridization state by using the above method, one must have a clear idea about the outermost electrons of different family members in the periodic table as follows:

Family	Outermost electrons
Nitrogen family	5
Oxygen family	6
Halogen family	7
Inert gas family	8

In case of cationic species you must remove requisite electron / electrons from the outermost orbit of the central atom and in case of anionic species you must add requisite electron with the outermost electrons of the central atom. Examples have been explored in here below.

Table 1: Total number of σ bonds and Hybridization State

Total number of sigma (σ) bonds	Nature of Hybridization State	Examples
2	sp	BeCl2, HgCl2,C2H2,CO2,CO,CdCl2, ZnCl2 etc.
3	sp^2	BCl3, AlCl3,C2H4,C6H6,SO2,SO3,HNO3, H2CO3,SnCl2, PbCl2 etc.
4	sp^3	NH_4^+, BF_4^-, H2SO4, HClO4,PCl3, NCl3, AsCl3, HClO3,ICl2,OF2,HClO2,SCl2,HClO, ICl, XeO3 etc.
5	sp^3d	PCl5, SbCl5, SF4, ClF3, BrF3, XeF2, ICl_2^- etc.
6	sp^3d^2	SF6, $AlF6^{3-}$, $SiF6^{2-}$, $PF6^-$, IF5, BrF5, XeOF4, XeF4, BrF_4^-, ICl_4^- etc.
7	sp^3d^3	IF7, XeF6 etc.

6. The atomic orbitals of same atom with almost same energy can only participate in the hybridization.

The full filled or half filled or even empty orbitals can undergo hybridization provided they have almost equal energy.

7. The shapes of hybrid orbitals are identical. Usually they have one big lobe associated with a small lobe on the other side.

The hybrid orbitals are degenerate i.e., they are associated with same energy

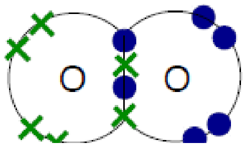
8. The intermixing or hybridization of atomic orbitals is a mathematical concept based on quantum mechanics. During this process, the wave functions, Ψ of atomic orbitals of same atom are combined to give new wave functions corresponding to hybrid orbitals.

9. The hybrid orbitals are oriented in space so as to minimize repulsions between them. This explains why the atomic orbitals undergo hybridization before bond formation.

The reason for hybridization is to minimize the repulsions between the bonds that are going to be formed by the atoms by using hybrid orbitals. Remember that the hybridization is the process that occurs before bond formation.

10. The bond angles in the molecule are equal to or almost equal to the angles between the hybrid orbitals forming the σ bonds. The shape of the molecule is determined by the type of hybridization, number of bonds formed by them and the number of lone pairs

12 a)



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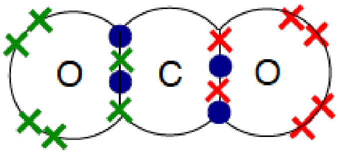
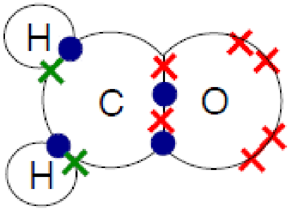
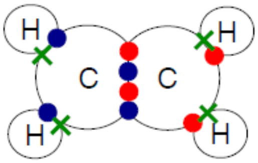


c)

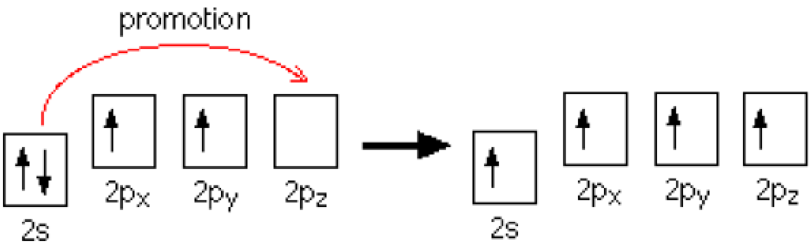


d)

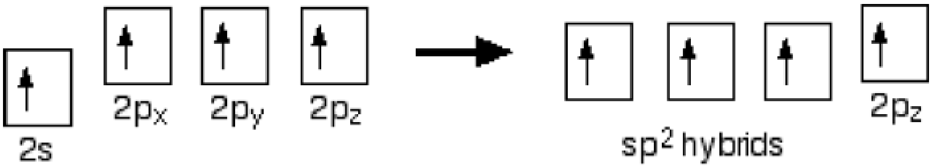


2. a) $1s^2\ 2s^2\ 2p_x^1\ 2p_y^1$

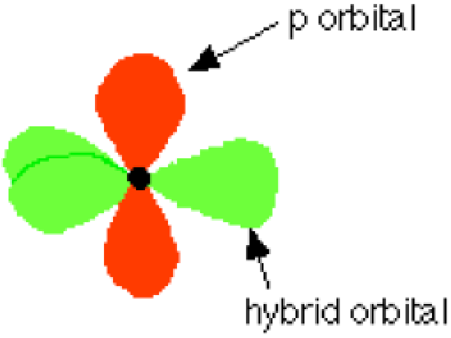
b)



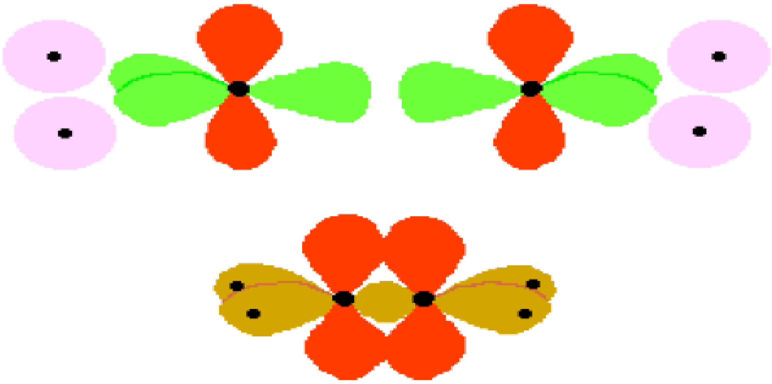
c) Hybridization rearranges the electrons into new orbitals ready for bonding. In this case, the 2sorbital and two of the 2p orbitals are rearranged to make three sp2 hybrids. The other 2p orbital isn't changed at this point.



These orbitals are arranged with the three sp² hybrid orbitals in a plane and the p orbital at right angles to them.

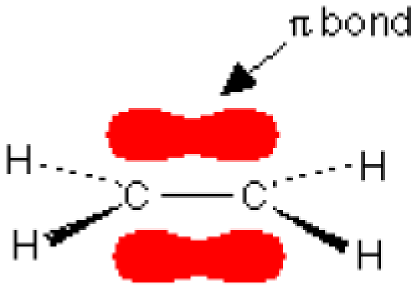


d) A sigma bond is formed when two atomic orbitals overlap end-to-end. Sigma bonds are just simple single covalent bonds. Each of the three sp2 hybrid orbitals overlaps with the 1s orbital from one of the hydrogen atoms to give:



The diagram shows five sigma bonds in brown. The p orbitals are still sticking up at right angles to these. The black dots show the various nuclei.

e) A pi bond is formed by a sideways overlap between touching atomic orbitals – in this case, between the two unhybridised p orbitals. They overlap to give a molecular orbital which has parts above and below the plane of the rest of the molecule.



The sigma bonds are shown by ordinary lines joining the atoms. A simple line shows a bond in the plane of the paper (or screen). A dotted line shows a bond going back into the paper away from you. A wedge shows the bond coming out towards you.

Lesson 6: Valence Shell Electron Pair Repulsion (V.S.E.P.R) Theory

This lesson consists of five periods and therefore teachers should use this opportunity to take students through by giving enough examples and many activities some of which may not be necessarily indicated in learner's book.

a) Prerequisites/Revision/Introduction:

All the above previous lessons can be used but most especially learners should remember electronic configuration and valence electron concept.

b) Teaching resources

Balloons, strings, scissors, flip charts, internet or videos of VSEPR, periodic table of chemical elements.

c) Learning activities

- Learners will do the activity 5.6.(number 1 and 2 must be done individually.
- Number 3 will be done in groups of 3-4 learners.
- Give learners appropriate time to accomplish the activity number 3.
- Allow presentations individually for number 1&2 and then group representative for number 3.
- Guide the learners to evaluate their work by commenting on each other's presentations.
- Confirm the correctly presented information about the molecular structures; remove the wrong ones and link examples to the learned content.
- Learners may be given enough exercises to make sure they can familiarise with geometric shapes.
- Summarise all the content including some of the examples added.

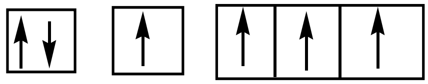
d) Checking up 4.6

Expected answers

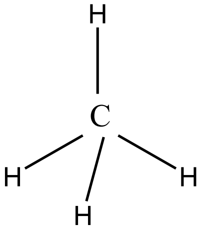
1. (i) tetrahedral (ii) octahedral (iii) tetrahedral (iv) Trigonal planar (v) v-shape (vi) tetrahedral (vii) Trigonal pyramidal

2. Electronic configuration of carbon atom: $1s^2 2s^2 sp^2$

In the excited state the orbital picture of carbon atom



Hence, carbon atom undergoes SP^3 hybridisation in CH_4 molecule and takes a tetrahedral shape.



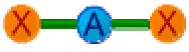
For a square planar shape, the hybridization of the central atom has to be dsp^2. However, an atom of carbon does not have a d-orbitals to undergo dsp^2 hybridisation. Hence, the structure of CH4 cannot be square planar.

Moreover, with a bond angle of 90°C in square planar, the stability of CH_4 will be very less of repulsion existing between the bond pairs. Hence VSEPR theory also supports a tetrahedral structure for CH_4.

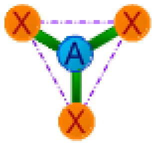
3. The shape of the molecular affects its physical properties since it makes the molecule polar or non polar.

4.(i) tetrahedral (109.5°) (ii) v-shape (104.5°) (iii) Trigonal pyramidal(107°) (iv) linear(180°) (v)octahedral (90°) (vi) seesaw (<90°)

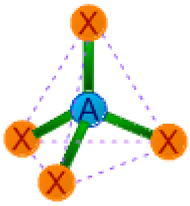
5. linear



triagonal planar

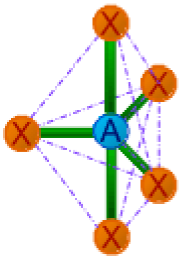


tetrahedral

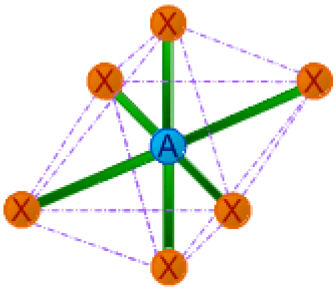


tetrahedral

Trigonal bipyramid



octahedral



b. CH_3-CH=CH_2 (sp^3, sp^2, sp^3)
c. CH_3-CH_2OH (sp^3, Sp^3)
d. CH_3-CHO (sp^3, sp^2)
e. CH_3-COOH (sp^3, sp^2)

Lesson7: Polarity of covalent bonds

a) Prerequisites/Revision/Introduction

Before beginning this lesson, you have to make sure that learners understood how to draw different shapes of molecules using VSEPR theory.

b) Teaching resources

- Periodic table of chemical elements (make sure it contains electronegative values)
- Flip charts or manila papers.

c) Learning activities

- Discovery activity
- Distribute the periodic that contains electronegative values.
- Let the learners pair think and share on activity 4.7
- Ask the learners to do number 1 of activity 4.7 in pairs or groups
- Allow them to continue with the activity.
- Learners present the findings of the activity 4.7.
- Guide the learners by helping them to evaluate their findings by commenting and making contributions or subtractions or criticising each other.
- Summarise by confirming or eliminating the false information and link their examples to the learned content. You can give more examples if necessary.
- Make sure learners are able to explain the purpose of difference in electronegativity

d) Checking up 4. 7

Expected answers

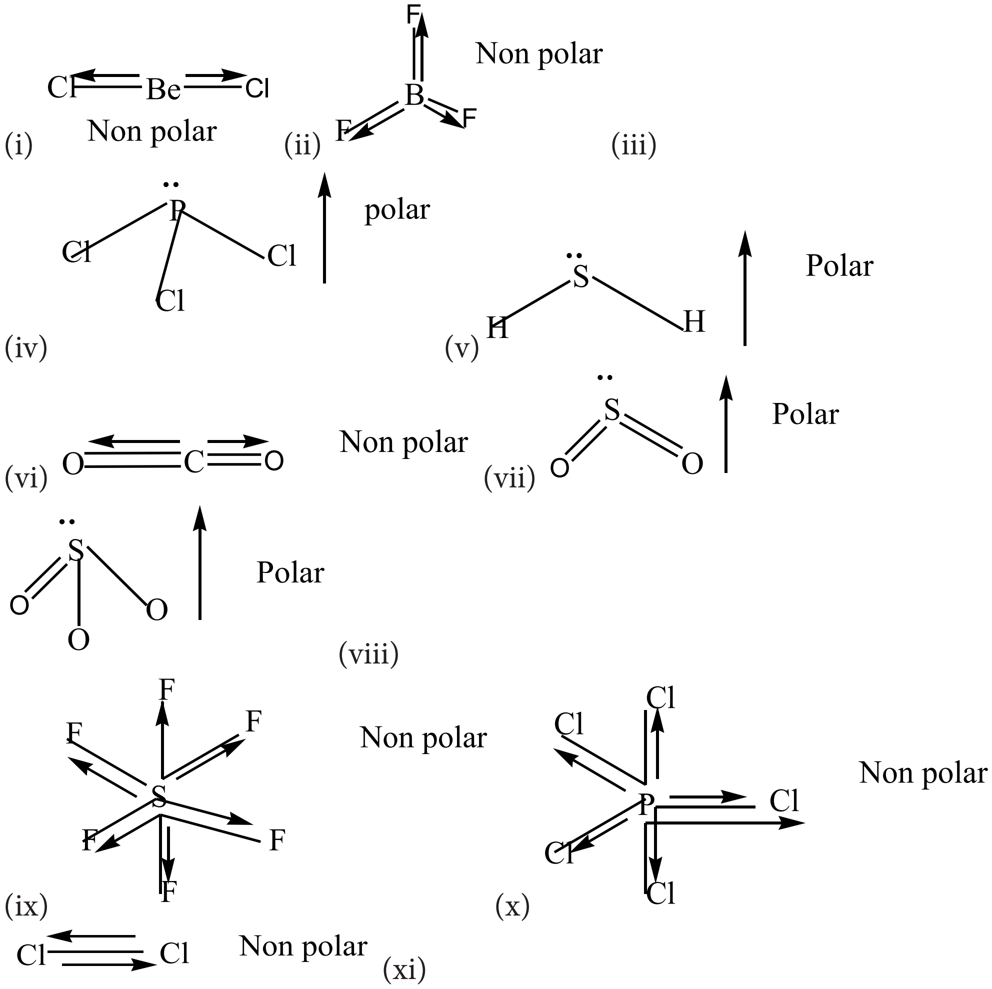
1.(a) (i) (i)$BeCl_2$ (polar bonds) (ii) BF_3 (polar bonds) (iii) CH_4 (non polar bonds (iv) PCl_3 (polar bonds) (v) H_2S (polar bonds) (vi) CO_2(polar bonds) (vii) SO_2 (polar bond) (viii) SO_3 (polar bonds) (ix) SF_6 (polar bonds) (x) PCl_5 (polar bonds) (xi) Cl_2 (non polar)

(b) $BeCl_2$, BF_3, SF_6, PCl_5, CO_2, these molecules have symmetrical shapes.

(c) Water has lone pairs which affect the physical properties of water such as high boiling point, surface tension, high specific heat capacity e. t. c.

(d) both are polar molecules

e)



Lesson 8: Simple and giant covalent structures

a) Prerequisites/Revision/Introduction:

Remember this is almost similar to the unit 1 of senior 2 ordinary level and learners should recall the uses and physical properties of graphite, diamond and silicon dioxide.

b) Teaching resources

- Graphite, diamond and silicon dioxide models if available.
- videos showing the structures of diamond, graphite and silicon dioxide can be used

c) Learning activities

- Form groups and distribute activity 4.8 to respective groups.
- Allow the learners to do the work in their groups.
- Let learner's representative from the group present their findings of the activity 4.8.

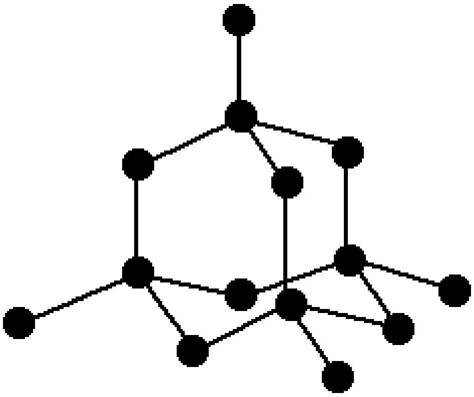
- Allow the learners to evaluate their findings by commenting, criticising and making observations on each other's finding.
- Give summary of learned content. This may not take much of your time because the same content was seen unit 1 of chemistry senior 2.
- Give the home work if necessary.

d) Checking up 4.8

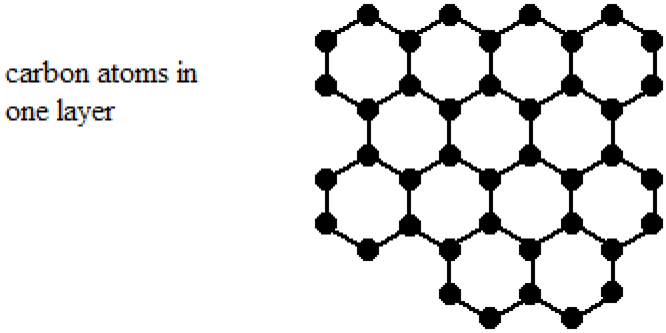
Expected Answers

1. Giant doesn't just mean very large. It applies to a structure which has a huge, but variable number of atoms (or ions) depending on the size of the crystal. This is different from a large molecule where the number of atoms is fixed for a particular molecule

2. a



This is probably the bare minimum that you should draw, but don't try to be too clever and draw any more than this. Any other lines which you have included to join up any other atoms make your diagram wrong.



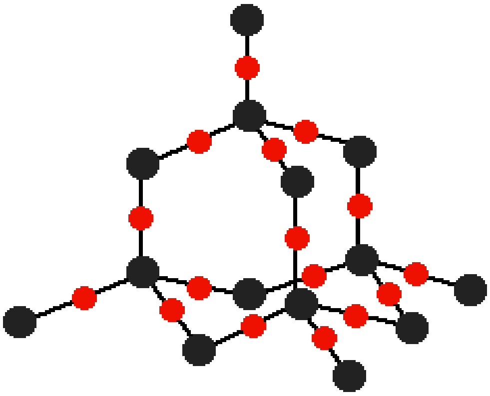
3. a) In diamond, you have to break very strong C-C covalent bonds in 3-dimensions in order to split the crystal. In graphite, although there are very strong C-C bonds within the sheets, the sheets can slide over each other.

b) There is a large amount of empty space between the sheets in graphite, whereas the atoms are all close together in diamond.

c) To melt both substances you have to break C-C bonds – it isn't enough just to separate the sheets in graphite. This takes lots of energy.

d) In graphite, an electron from each carbon atom is delocalized and is free to move around in the sheet. In diamond, all the electrons are tied to particular bonds and aren't free to move.

e) In both diamond and graphite the structure involves strong C-C bonds. Breaking these structures up could only happen if there were strong interactions between solvent molecules and carbon atoms. There are no interactions which are strong enough.



Draw a diamond structure and then draw an oxygen atom halfway along each bond. In chemistry at this level, a diagram like this should be perfectly acceptable.

b) (i) To destroy the structure, you have to break strong Si-O bonds in 3-dimensions.

(ii) It needs a lot of energy to break these strong covalent bonds.

(iii) There are no mobile delocalized electrons. All the electrons are tied to particular bonds.

(iv) There are no possible attractions which could occur between solvent molecules and the silicon or oxygen atoms which could overcome the covalent bonds in the giant structure.

Lesson 9: Intermolecular forces

a) Prerequisites/Revision/Introduction:

Before introducing this lesson, you should make sure learners understood the concept of polar and non polar bonds, simple calculations of electronegative difference. This can be achieved by giving simple exercise on polarity of the bonds using activity 4.9 in learner's book.

b) Teaching resources

Periodic table of elements (make sure it contains electronegative values/ numbers),

c) Learning activities

In groups of 4 to 6, leaner's do activity 4.9.

Let one of the learners read some of the findings, this may be oral or you can move around while marking their exercise books.

Remember to make corrections of some misconceptions and link the findings with the learned.

d) Activity 4.9

Expected answers to the activity 4.9

i) and ii) ice floats over water and the bottle full of water breaks on freezing because hydrogen bonds expand and become rigid on cooling.

iii) water molecules are held together by strong intermolecular forces while hydrogen sulfide molecules are held together by weak intemolecular forces. Hence breaking down water molecules requires high energy than breaking down hydrogen sulfide molecules.

Trichloromethane < ethanol < aluminium fluoride.

Checking up 4.9

Expected answers

1. Liquid water contains associations of water molecules. In ice, the arrangement of molecules is similar, but the regularity extends throughout the whole structure. The structure spaces the molecules further apart than they are in liquid water. This is why, when water freezes, it expands by 9%, and why ice is less dense than water at 0°C

2. Hydrogen bonding in alcohols needs high energy to break thus high melting and boiling temperature than alkanes of the same molecular mass with weak intermolecular forces of attraction.

3. Strong hydrogen bonding increases the boiling point of water much higher than that in hydrogen sulphide.

4. Strong hydrogen bonds make the water molecules hold one another to make layer-like structure which enables some insects to walk on the surface.

5. HCl < HBr < HI ; This is due to increase in intermolecular forces (van der waals forces) that increases as the size of the molecule increases (molecular mass)

6. n- Pentane > 2-methylbutane > 2, 2-dimethylpropane; this is the order of increasing intermolecular forces which increases the boiling points.

7. Refer to learner's book

8.6 Unit Summary

Covalent bonding is the sharing of electron pair(s) between nuclei of atoms.

The covalent bond and ionic bond are both very strong chemical bonds.

A covalent bond is formed by the overlapping of two half-filled valence atomic orbitals of two different atoms

The electrons on in the overlapping orbitals get paired and confirmed between the nuclei of two atoms.

The electron density between two bonded atoms increases due to overlapping. This confirms stability to the molecule.

A dative covalent bond is one formed in which both electrons are donated from the same atom.

The covalent bond formed by sidewise overlapping of atomic orbitals is called π- bond.

The covalent bond formed due to overlapping of atomic orbital along the inter nucleus axis is called σ-bond. It is a stronger bond and cylindrically symmetrical.

The shape of a molecule is determined by the repulsion between bonded electrons and non-bonded electrons (lone pairs).

Lone electron pairs repel more than bonded pairs of electrons and give rise to distorted shapes.

By reducing the number of bonded electron pairs and lone pairs of electrons, the shape of a molecule may be predicted.

Type of hybridization of atomic orbital sp ,sp^2,sp^3, sp^3d, sp^3d^3

BF_3 is Trigonal planar; CH_4 and NH_4^+ are tetrahedral; SF_6 is octahedral; H_2O is non-linear (V-shaped/bent); CO_2 is linear and ammonia, NH_3, as pyramidal

An intermolecular force exists between molecules and may include hydrogen bonding, dipole-dipole or van der Waals' forces.

Electronegativity is the ability of an atom in a covalent bond to attract a bonded pair of electrons towards itself.

Hydrogen bonding arises in molecules in which a hydrogen atom is bonded to either an N or O atom.

Water molecules, and other substances consisting of hydrogen bonding, have anomalous properties as a result.

4.7 End unit assessment

Assessment is an important part of teaching and learning. At the unit level, the teacher needs to know how well the key unit competence was achieved. End of unit assessment questions were suggested and one period reserved.

PART1: Multiple choice questions.

1).

1	A	6	B	11	A
2	A	7	B	12	D
3	D	8	D	13	B
4	C	9	C	14	D
5	A	10	D	15	C

PART 2: Filling in questions

16.

(2) Top of Form

2. 1a. A **covalent bond** is formed by two atoms sharing one or more pairs of electrons

to make a **strong bond** between the two atoms in a molecule.

1b. However, between small molecules, only a weak force holds them together in the bulk liquid or solid.

1c.This results in small covalent molecules having low **melting points** and **soft crystals** if solid. 1d. Small covalent molecules have no f**ree electrons** and so have a l**ow electrical conductivity.**

2. 2a.The Group 7 **non-metals** collectively known as the **halogens** form diatomic molecules of two atoms.

2b.The **intermolecular forces** between the molecules are weak giving them relatively low melting points and boiling points.

2c.This also explains why they are gases, liquids or solids with **low melting points**.

2d. As you go down Group 7 the melting boiling points and boiling points **increase** because the molecules get **bigger** and the intermolecular forces **increase**.

3. 3a. In giant covalent structures the forces between all the atoms are **strong** forming **hard crystals** like diamond or silica.

3b. In the atomic giant structure metals there are free electrons which allow **high electrical conductivity**

17. **PART3: complete the table below using a mark sign (√)**

Physical Attribute	Covalent Compound	Ionic Compound	Metal
a. Usually gases or liquids at room temperature	√		
b. Usually a solid or solid crystals at room temperature		√	
c. Low melting and boiling points	√		
d. High melting and boiling points		√	

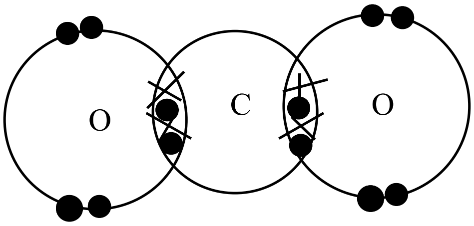
e. Dissolves easily in water		√	
f. Poor conductor of electricity in any form	√		
g. Good conduct or of heat and electricity			√

Bottom of Form

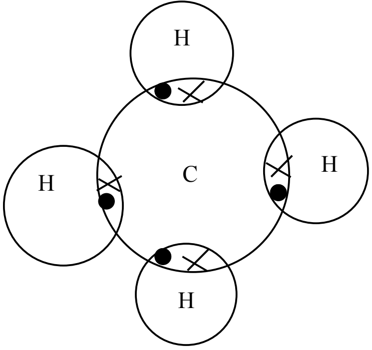
PART4: SHORT AND LONG ANSWER QUESTIONS

18.

(a) In covalent the electrons are shared between the bonding atoms, in ionic the electrons are transferred between the bonding atoms whereas in metallic bonding the electrons drift away from the metal atom and form a cloud between the cations.



(b) CO_2 CH_4



(c).The bond between C-O is stronger than the one between C-H because in the former a double bond is formed which is shorter and stronger than in C-H single bond.

19. (a) X: $1s^2 2s^2 2p^6 3s^2$, Y: $1s^2 2s^2 2p^5$ Z: $1s^2 2s^2 2p^6 3s^2 3p^5$

((b) Formula formed between PCl_3 or PCl_5

20. During this process the hydrogen–hydrogen bonds will break and the molecules will fall apart into hydrogen atoms. It is believed the electrons in this

solid will flow freely; meaning atomic hydrogen should behave like a metal and conduct electricity.

21. X forms a giant ionic structure with strong electrostatic forces.

22. Sulphur-Oxygen are identical due resonance structure formation.

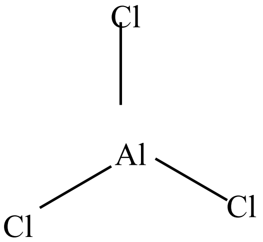
23. Neon and Argon exist as simple mono atomic molecules with weak forces of attraction, water has hydrogen bonding , sodium chloride is giant ionic crystal structure while carbon exist as a giant atomic covalent compound.

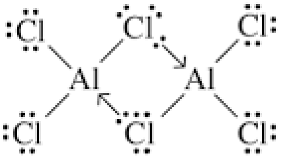
24. Nitrogen in period 2 cannot expand its octet whereas phosphorous in period 3 can expand its octet to accommodate more than 8 electrons in the outer shell.

(a) N: $1s^2 2s^2 2p^5$ P: $1s^2 2s^2 2p^6 3s^2 3p^5$

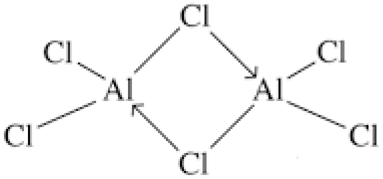
(b) Refer to student's book page 113 for the diagram (Trigonal pyramidal)

25. (a)





Or



(b) To determine the geometry of chloromethane, CH_3Cl
Hybridize carbon, overlap each hydrogen 1s orbital with carbon sp3 orbitals
Overlap one chlorine 3p orbital with one carbon sp^3 orbital
Note, we do not have to "hybridize" chlorine orbitals since chlorine has only one bond.

(c) (i)NCl_3:Trigonal pyramidal(Nitrogen and chlorine have almost identical electronegativities, and so the N-Cl bond is essentially **non polar**. Even so, the one common compound that contains N-Cl bonds, **NCl_3**, is still slightly **polar** because of the lone pair of electrons on the nitrogen atom.

(ii) BCl_3 : Trigonal planar

(iii) CO_2: (linear)

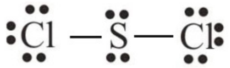
(d) CO_2: Exists as a simple molecular structure with weak intermolecular forces of attraction

SiO_2: Exists as a giant molecular structure with strong covalent bonds.

26. (a) $1s^2 2s^2 2p^6 3s^2 3p^4$

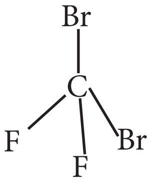
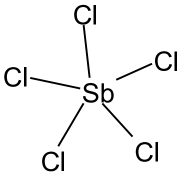
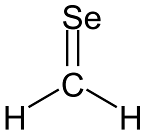
(b)

(i)



(ii) v-shape /bent

27.

Molecule	Structural Formula	Geometry name	Polar/Nonpolar
CF_2Br_2		tetrahedral	Polar
$SbCl_5$		Trigonal bipyramidal	Non-polar
P_2	$P\equiv P$	Linear	Non-polar
CH_2Se		Trigonal Planar	Polar

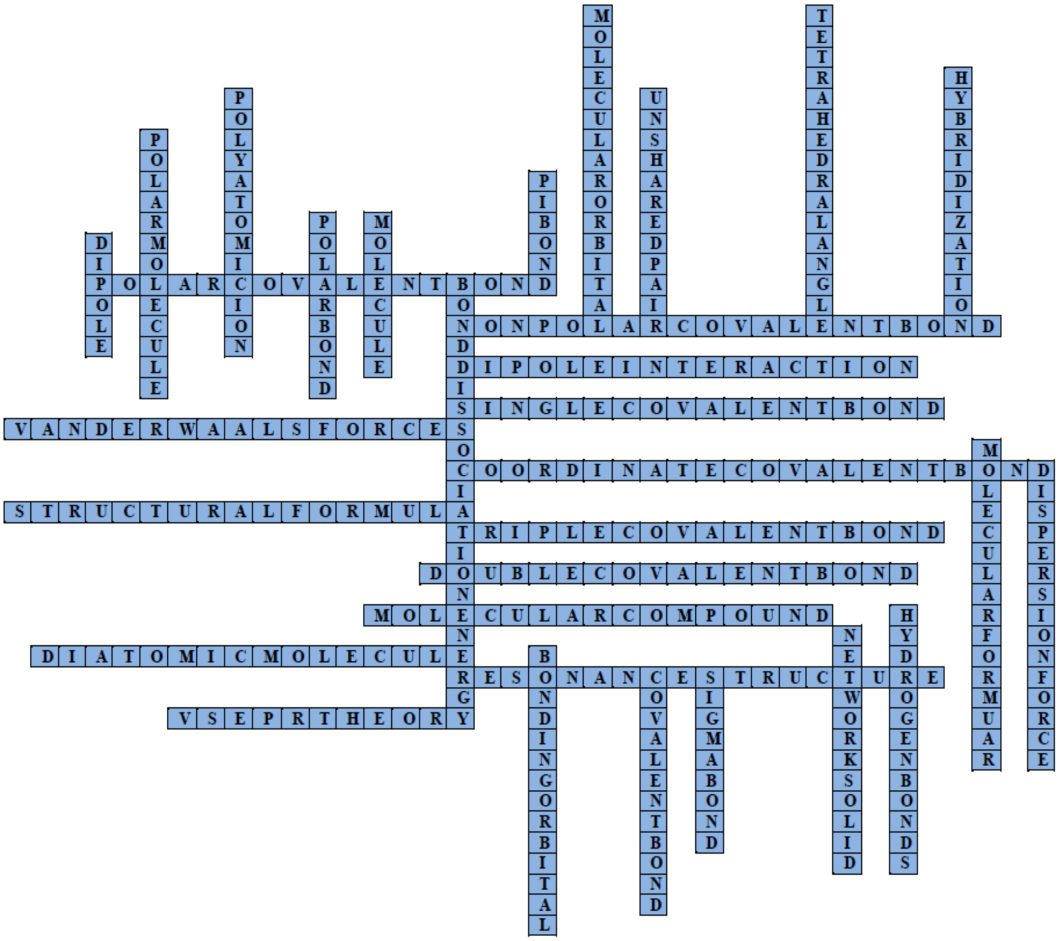
PART4: MATCHING TYPE QUESTIONS:

K	A 3-D, repeating pattern of + and – ions, formed by ionic compound
A	Tendency for an atom to attract electrons when chemically bonded to another atom
B	A sharing of electrons
P	Atoms will gain or lose enough electrons in order to become isoelectronic with a noble gas
Q	A transfer of electrons
R	A chemical formula that is arranged in the smallest whole number ratio
D	The term that means dissolved in water
F	A chemical formula that describes the makeup of a single molecule
J	The shape (geometry) that is always an exception to the octet rule

M	A bond where electrons are shared unequally between atoms
L	One of the shapes (geometries) that will always be polar
H	A bond where electrons are shared equally between atoms

PART 5: CROSSWORD PUZZLE

29.

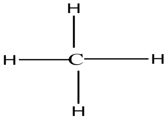
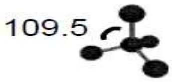


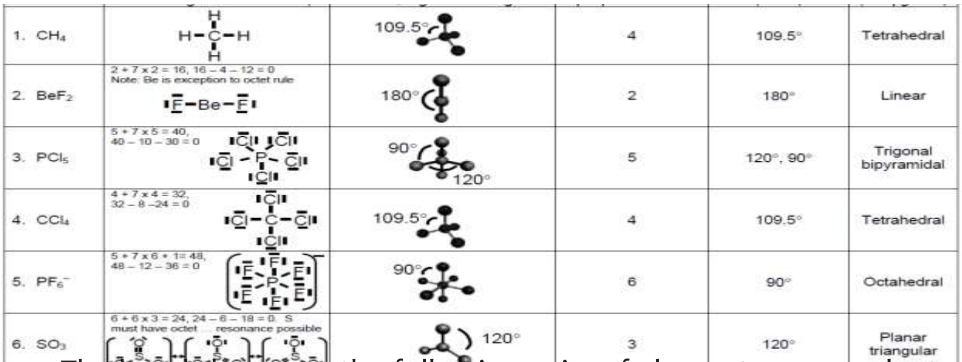
4.8. Additional activities

4.8.1. Remedial activity

1. Collect the following equipment: 6 small white Styrofoam balls, one large coloured ball, and 6 toothpicks. Complete the chart. Note: when building molecules use a large coloured Styrofoam ball as the central atom, small white balls as peripheral atoms, and toothpicks to represent bonds. If the molecule has resonance structures, draw these in the “Lewis structure” box (B), but build only one resonance structure for the “Build

molecule” box (C). The bond angle for a tetrahedral molecule is 109.5°. Other bond angles can be calculated by correctly dividing the 360 degrees of a circle (look at your structure).

A. Molecule	Show your working here	B. Lewis structure (use rules for drawing Lewis structures)	C. Build molecule sketch, & give bond angles	D. Number of peripheral atoms	E. Bond angles (list all)	F. Name
CH_4			 109.5	4	109.5°	Tetrahedral
BeF_2						
PCl_5						
CCl_4						
PF_6^-						
SO_3						



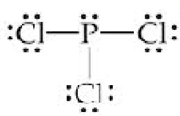
1. CH_4	H–C–H	109.5°	4	109.5°	Tetrahedral
2. BeF_2	2 + 7 x 2 = 16, 16 – 4 – 12 = 0 Note: Be is exception to octet rule	180°	2	180°	Linear
3. PCl_5	5 + 7 x 5 = 40, 40 – 10 – 30 = 0	90°, 120°	5	120°, 90°	Trigonal bipyramidal
4. CCl_4	4 + 7 x 4 = 32, 32 – 8 –24 = 0	109.5°	4	109.5°	Tetrahedral
5. PF_6^-	5 + 7 x 6 + 1= 48, 48 – 12 – 36 = 0	90°	6	90°	Octahedral
6. SO_3	6 + 6 x 3 = 24, 24 – 6 – 18 = 0. S must have octet … resonance possible	120°	3	120°	Planar triangular

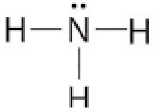
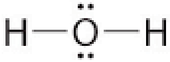
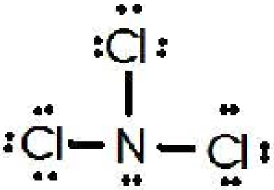
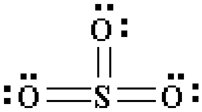
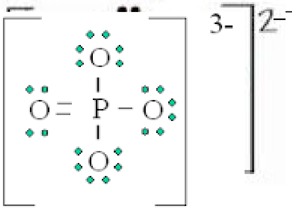
2. a. The bonds between the following pairs of elements are covalent. Arrange them according to polarity, naming the most polar bond first.

(a) H—Cl (b) H—C (c) H—F (d) H—O (e) H—H (f) S—Cl

b. Using the table of electronegativities from your Periodic table, calculate the EN difference for the atoms that are bonded in the following molecules. Then tell whether the bond is non-polar covalent, polar covalent, or ionic. Tell which atom has the greater share of the bonding electrons. In your drawing, show which atom is partially positive or partially negative if it is a polar covalent bond.

Answers

Molecule	EN Difference	Type of Bond	Atom with greater EN	Lewis Structure
PCl3		polar		

NH3		polar		
H2O		polar		
H2O2		polar		H-Ö̤-Ö̤-H
HCN		Non polar		
NI_3		polar		
SO3		Non polar		
(SO4)$^{2-}$		Non polar		
(PO4)$^{3-}$		Non polar		

4.8.2. Consolidation activity

1. Use the periodic table containing the electronegativity value to answer the following questions.

a) List these bonds in order of increasing polarity:

H-F, F-F, C-Cl, C-Br, C-O, N-H

b) By writing δ+ and δ- as appropriate above each of the atoms in the bond, show the polarity of the following bonds:

C-O, C-Cl, C-Br, C-N, C-C, N-H, H-Br, O-H

Answer

(a) F-F (electronegativity difference = 0)

C-Br (electronegativity difference = 0.3)

C-Cl (electronegativity difference = 0.5)

N-H (electronegativity difference = 0.9)

C-O (electronegativity difference = 1.0)

H-F (electronegativity difference = 1.9)

(b)

$\overset{\delta+}{C} - \overset{\delta-}{O}$ $\overset{\delta+}{C} - \overset{\delta-}{Cl}$ $\overset{\delta+}{C} - \overset{\delta-}{Br}$ $\overset{\delta+}{C} - \overset{\delta-}{N}$ $\overset{\delta+}{H} - \overset{\delta-}{Br}$

$\overset{\delta-}{N} - \overset{\delta+}{H}$ $C - C$

Question

1. a) Part of the attractions between hydrogen chloride molecules, HCl, are due to van der Waals dipole-dipole interactions. Using hydrogen chloride as your example, explain how these arise.

b) In chlorine gas, Cl_2, there are no permanent dipole-dipole interactions. Explain why these are absent in chlorine.

c) Instead, the attractions between chlorine molecules consist entirely of van der Waals dispersion forces (also known as London forces). Explain briefly the origin of these attractions.

2. The stronger the intermolecular attractions, the greater the boiling point of a molecular substance.

Explain the trend in boiling points of the halogens

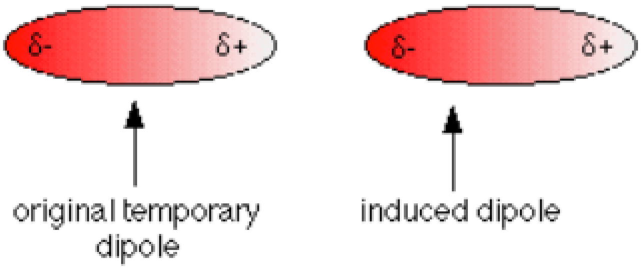
	F_2	Cl_2	Br_2	I_2
boiling point (K)	85	238	332	457

Answer

1. a) Chlorine is more electronegative than hydrogen and so the bond between the two is polar. The chlorine end will be slightly negative, and the hydrogen end slightly positive. The molecules have permanent dipoles. The positive end of one molecule will attract the negative end of another one close to it.

b) The chlorine-chlorine bond is non-polar because the atoms at either end have the same electronegativity.

c) The electrons moving around in the molecule will cause temporary fluctuating dipoles. If one end of a chlorine molecule is temporarily positive, this will induce a dipole in a nearby molecule, and these attract each other



2. The increasing boiling points mean that the intermolecular attractions are getting stronger as you go down the group. These attractions are van der Waals dispersion forces, and depend on setting up temporary fluctuating dipoles. The more electrons you have in a molecule, and the longer the molecule, the bigger the dipoles that can be formed, and the stronger the attractions. As you go from fluorine to iodine, there are more and more electrons and bigger molecules.

1. What is a co-ordinate (or dative covalent) bond?

2. Carbon monoxide can be represented as:

Redraw this using a dots-and-crosses diagram to make clear the difference between the bond shown by the arrow and those shown by the ordinary lines.

3. a) The ammonium ion, NH_4^+, and the hydroxonium ion, H_3O^+, contain ordinary covalent bonds and co-ordinate bonds. Draw dots-and-crosses diagrams to show the bonding in both of these ions, making clear which sort of bond is which.

b) Draw a dots-and-crosses diagram for the ion H_2F^+.

4. a) Aluminium chloride sublimes (turns directly from a solid to a gas) at about 180°C.Measurements of its relative molecular mass show that its formula is Al_2Cl_6 in the vapour at that temperature. Draw a dots-and-crosses diagram (showing outer electrons only) to show how the aluminium chloride is bonded in Al_2Cl_6.

b) Ammonia, NH_3, and boron trifluoride, BF_3, combine to make a compound $NH_3.BF_3$. Draw a dots-and-crosses diagram (showing outer electrons only) to show the bonding in this new compound.

5. Most metal ions in solution react with water to give what are called hydrated ions. For example, magnesium ions in solution exist as [Mg(H2O)6] $^{2+}$. The water molecules attach to the magnesium ions via co-ordinate bonds.

a) Explain what it is about water that enables it to form co-ordinate bonds.

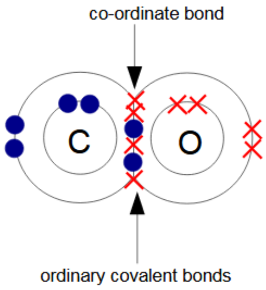
b) The electronic structure of magnesium is $1s^2\ 2s^2\ 2p^6\ 3s^2$. What is the electronic structure of a magnesium ion, Mg^{2+}?

c) Explain briefly which orbitals are used in the magnesium ion for attaching the water molecules too.

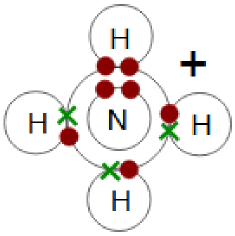
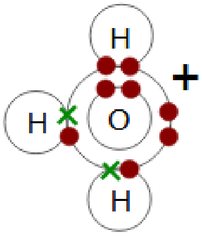
d) Beryllium is in the same group as magnesium, but unlike the rest of Group 2 forms a hydrated ion with only four water molecules attached. Can you think of a reason (or perhaps two reasons) why that might be?

Answer

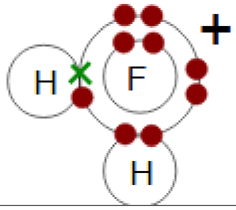
1. This is a covalent bond (a pair of shared electrons) in which both electrons came from the same atom

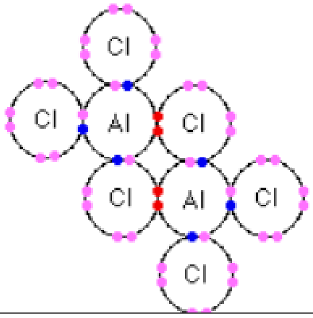
2.  	The question didn't allow you to just draw the outer electrons! In that case, if you don't put all the electrons in, you risk losing a mark. You have to read the question carefully

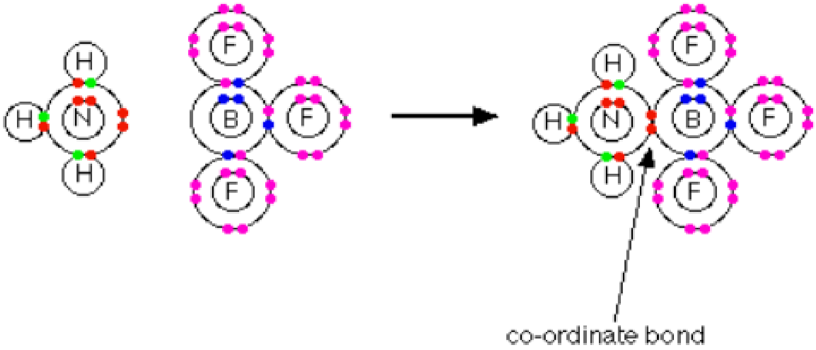
3.

  	In the diagrams below, the bonds consisting of two red dots are the co-ordinate bonds. The ordinary covalent bonds have a dot and a cross

In the first diagram, it doesn't matter which bond you show as the co-ordinate one. It doesn't matter where you attach the three hydrogens around the oxygen in the second diagram, as long as you show one co-ordinate and two simple covalent bonds.

 	Again, it doesn't matter where you attach the two hydrogens around the fluorine, or which bond you show as the co-ordinate one.

	it doesn't matter if you haven't colour-coded everything as long as it is obvious that the two bonds drawn here with red electrons are different from the other bonds.



b)

You only need the structure of the product, and you don't need to point out the co-ordinate bond, but it must be clear that both electrons in the bond are coming from the nitrogen. You don't need to draw the inner electrons.

5. a) The lone pairs of electrons on the oxygen atom.

   b) $1s^2 2s^2 2p^6$

   c) If it is going to form six co-ordinate bonds, it will need six empty orbitals on the magnesium ion.

   These will be hybridised versions of the 3s, the three 3p orbitals and two of the 3d orbitals.

   d) There are two things which you might have thought of.

One is that the beryllium ion is going to be very small (its electronic structure is just $1s^2$), and so it may be impossible to fit six water molecules around it. But in fact that possibility can never arise anyway.

The main reason is that beryllium doesn't have enough orbitals of the right energy. There aren't any 2d orbitals – only the 2s and the three 2p orbitals, and it uses a hybridized version of these to join to the four water molecules. To fit six water molecules around it would need it to use 3-level orbitals as well. There is too big an energy gap between the 2- and 3-level orbitals for this to work.

The table below gives Pauling Values for Electronegativity:

H 2.1																	He ….
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne ….
Na 0.9	Mg 1.2											Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar ….
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr ….
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe ….
Cs 0.7	Ba 0.9	La-Lu 1.1-1.2	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2	Rn ….
Fr 0.7	Ra 0.9	Ac-Lr 1.1-															

4.8.3. Extended activities

1. This question is about the shape of the molecule $SiCl_4$.
    - (a) How many electrons are there in the outer level of a silicon atom?
    - (b) How many electrons are there in the outer level after it has bonded with the four chlorine atoms?
    - (c) How many pairs of electrons is this?
    - (d) How many of the electron pairs are bond pairs and how many lone pairs?
    - e) Draw a diagram to show the shape of a molecule of SiCl4.

2. The molecules BF3 and NF3 have similar formulae, but completely different shapes. Draw diagrams to show the shapes of the two molecules, and explain carefully why they are different.

3. In the molecules CH4, NH3 and H2O, the bond angles are as follows:

H-C-H	H-N-H	H-O-H
109.5°	107°	104.5°

All of these molecules have four pairs of electrons arranged around the central atom in a tetrahedral arrangement. Explain why the bond angles are different.

4. Work out the shapes, including the bond angles, of the following:

a) PH_4^+ (b) PF_5 (c) PF_6^- (d) XeF_4 (e) BrF_3.

Answer

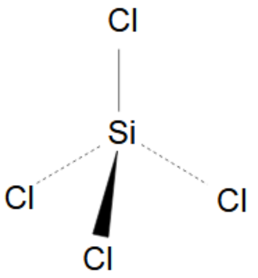
1(a) Silicon is in Group 4 of the Periodic Table, and so has 4 outer electrons. There is no need to work out the whole electronic structure.

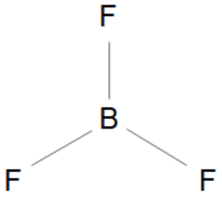
(b) Since we are talking about single covalent bonds, each chlorine is going to contribute 1 electron to each bond. That gives a total of 8 electrons.

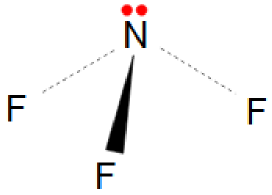
(c) 4

(d) There are 4 pairs of electrons and 4 bonds. So there are 4 bond pairs and no lone pairs.

(e) The bonds will take up a tetrahedral arrangement to minimize repulsion.







The boron has only 3 electrons in its outer level, and is forming 3 bonds with fluorine. There are therefore only three bond pairs and no lone pairs. The bond pairs arrange themselves in a Trigonal planar way.

In NF_3 there are also three bond pairs, but the nitrogen has a lone pair as well. The four pairs of electrons arrange themselves tetrahedrally, but the description of the shape only takes account of the atoms. NF_3 is pyramidal.

3. In methane, the four bond pairs get as far apart as possible in a tetrahedral arrangement. All the Repulsions are identical, and the bond angle is that found in a pure tetrahedron.

In ammonia, one of the electron pairs is a lone pair. The repulsion between a lone pair and a bond pair is greater than between two bond pairs, and that squeezes the bond pairs very slightly closer together. In water, with two lone pairs, that effect is even greater.

4.(a) PH_4^+ :Phosphorus has 5 electrons in its bonding level.

The four bonds to the hydrogens add another 4 electrons to that bonding level, making 9.

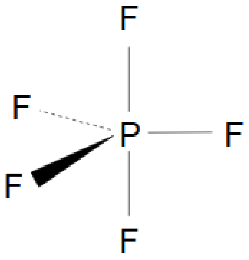
The single positive charge reduces that by 1 – giving 8 electrons in 4 pairs.

These must all be bonding pairs because of the four bonds to hydrogens.

The shape will be tetrahedral with a bond angle of 109.5°.

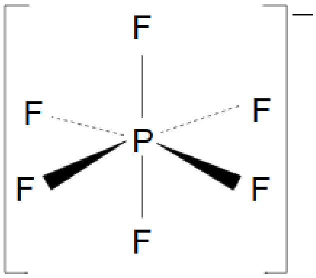
(b) PF_6^-: Phosphorus has 5 electrons in its bonding level.

The five bonds to the fluorines add another 5 electrons to that bonding level, making 10 – in 5 pairs. These must all be bonding pairs because of the five bonds to fluorines. The shape will be a trigonal bipyramid with bond angles of 120° and 90°.



(c) PF_6^- : Phosphorus has 5 electrons in its bonding level.

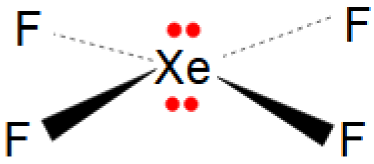
The six bonds to the fluorines add another 6 electrons to that bonding level, making 11.The negative charge adds another electron; making 12 – in 6 pairs. These must all be bonding pairs because of the six bonds to fluorines. The shape will be octahedral with bond angles of 90°.



d) The molecule XeF_4 Xenon has 8 electrons in its bonding level.
The four bonds to the fluorines add another 4 electrons to that bonding level, making 12 – in 6 pairs. These are only four fluorines and therefore 4 covalent bonds. That means that there must be 2 lone pairs as well. The pairs will arrange themselves in an octahedral shape.

Lone pair-lone pair repulsions are greater than lone pair-bond pair repulsions and bond pair-bond pair repulsions, so the lone pairs will get as far apart as possible at 180°.

That leads to a square planar structure for the atoms with bond angles of 90°. Any other arrangement would have lone pairs at 90° to each other, and there would be more repulsion.

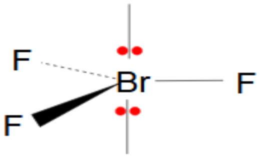


5. BrF_3: Bromine has 7 electrons in its bonding level.

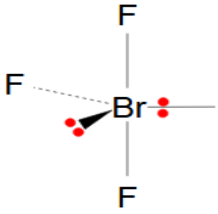
The three bonds with the fluorines add another 3 electrons to that bonding level, making 10 – in 5 pairs. These are only three fluorines and therefore 3 covalent bonds. That means that there must be 2 lone pairs as well. The pairs will arrange themselves in a trigonal bipyramid.

The problem is now to work out where the two lone pairs are.

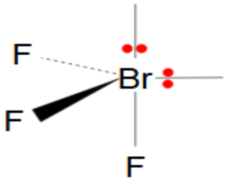
The possible structures are:



1



2



3

Count the various repulsions in each structure, remembering that you can ignore any repulsion where the angle is greater than 90°:

The least repulsions are in structure 2. The molecule is T-shaped.

structure	lone pair-lone pair	lone pair-bond pair	bond pair-bond pair
1	0	6	0
2	0	4	2
3	1	3	2

The least repulsions are in structure 2. The molecule is T-shaped.

UNIT 5: VARIATION IN TRENDS OF THE PHYSICAL PROPERTIES

5

5.1. Key unit competence

Use atomic structure and electronic configuration to explain the trends in the physical properties of elements.

5.2 Prerequisite knowledge and skills

Students will learn better how to locate and classify an element in the periodic table based on the electronic configuration, differentiate the major parts of the periodic table, explain the variation of physical properties of elements in the periodic table.

5.3 Cross-cutting issues to be addressed

Inclusive education

This unit involves the use of the periodic table to locate elements based on their properties. This may be challenging to students with special educational needs especially students with visual impairment. However, the teacher can make some arrangements like:

- Grouping students. Students with special educational needs are grouped with others and assigned roles basing on individual student's abilities.
- Every important point is written and spoken. The written points helps students with hearing impairment and speaking aloud helps students with visual impairment
- Remember to repeat the main points of the lessons.

5.4 Guidance on introductory activity

Before introducing the first lesson of this unit, let learners should attempt introductory activity. This activity intends to:

Assess the understanding of learners of the evolution of the modern periodic table.

5.5 List of lessons

#	Lesson title	Objectives	No of periods

1	Introduction to the unit Historical background of the periodic table	Explain the law of triads and octaves Explain the organization of elements into the modern periodic table Discuss the contributions of scientists in the development of the periodic table	2
2	Mendeleev’s table and the modern periodic table	Explain the arrangement of elements in the Modern periodic table	1
3	Location of Elements in Periodic Table	Locate elements in the periodic table	2
4	Classification of elements into s, p, d and f-blocks	Classify the elements into blocks (s, p, d and f) Characterize elements of each block of the periodic table.	3
5.	Variation of the physical properties down the group and across the period	Explain the factors that influence the physical properties in the periodic table and how they vary across the period and down in a group	4
			3
5.6. End unit assessment			2

Lesson 1: Historical background of the periodic table

This is the first lesson of unit 5 and is divided into two periods. The first lesson also covers the introduction of the whole unit (introductory activity). You are advised not to spend a lot of time on this introductory activity. This is only intended to raise the curiosity of learners to understand the important dated and names of scientists who participated in the creation of the periodic table.

a) Prerequisites/Revision/Introduction

Students will learn better the **historical background of the periodic table** if they have understanding on: the difference of Mendeleev’s table and the modern periodic table, the arrangement of elements in the periodic table and writing the electronic configuration of elements, (refer to unit 2).

b) Teaching resources

- Periodic table of elements
- Use the illustrations in the students' book for lesson 1 or draw them on a manila paper.
- Other relevant chemistry text books if available in the library.

c) Learning activities

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt the introductory activity and thereafter proceed to activity 5.1 which leads students to the first lesson of the unit.

- Form groups of 3-4 depending on the size of the class.
- Distribute the introductory activity and estimate the time for it.
- Let the learners proceed and do activity 5.1 of lesson 1.
- Allows the learners to work together in groups.
- Invite group leaders to present their findings.
- Instead of groups you can also use **"pair-think and share".**
- In this step you can guide the learners to evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- You summarise the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated in step 2.
- Integrate crosscutting and real life experiences by linking them with the lesson learned.

Expected Answers for the introductory activity

If at your school there is a library where books are classified according to different subjects; this can be a basic to understand why elements are classified in the periodic table. The elements in the periodic table can be classified into corresponding groups and periods. The elements can be classified based on their atomic numbers but also based on their chemical/physical properties.

After observing a periodic table, you may found that a modern periodic table comprised 18 groups and 7 periods. The electronic configuration of elements indicates the location of element is its corresponding group and period. The Period of an element is equal to the highest energy level of electrons or principal quantum number. The number of electrons in the last orbital shows the group of element.

Answers to activity 5.1 Learner's book.

1. Mendeleev Dmitri, the Russian chemist and inventor is best known as the father for the discovery of the periodic table. Through his observations of different known elements during his period of time, Mendeleev classified many elements into a table of rows and columns based on each element's atomic weight. His table was the starts of the periodic table as we know today.

2. The difference between laws of triads and octaves:

Law of triads: According to Dobereiner, elements were arranged in increasing order of their atomic mass. He arranged all the known elements in groups of three each. These groups are called triads. In each triad, elements are arranged in increasing order of their atomic mass. The atomic mass of the middle element is equal to the average atomic mass of both the terminal elements. These triads are also termed as Dobereiner triads. If these elements were classified in order of their atomic masses, the average of the molar mass of the first and third elements in the triad was the molar mass of the second element.

Example:

The halogens, chlorine, bromine, and iodine, have atomic masses ≈ 35 g/mole, ≈ 80 g/mole, and ≈ 127 g/mole, respectively.

If we take the average of the masses of chlorine and iodine we get:

(35 g/mole + 127 g/mole)/2 = 81 g/mole, which is very close to bromine's atomic mass of 80 g/mole.

Law of octaves: According to the law of octave, when elements are placed in increasing order of their atomic mass, every eight element shows similarity with the preceding eighth element in their physical and chemical properties."In Newland's periodic table, each row of elements consists of a total of seven elements and the eight element falls under the first element. In the first column Lithium is the first element and sodium is the eighth element. Similarly, the eighth element after sodium is potassium. Hence from Newland's law of octaves, the elements Li, Na and K must have similar chemical and physical properties, and they do. Law of triad and octave had limitations at the time, reason why researches continues till the modern periodic table was made.

Expected Answers for checking up 5.1

1. Groups and periods are two techniques used to classify elements in the periodic table. Periods are horizontal rows (across) the periodic table, while groups are vertical columns (down) the table. Elements in a group share a common number of valence electrons. Elements belonging to a group typically share several common properties. Elements in a period share a highest unexcited electron energy level. There are more elements in some periods than others because the number of elements is determined by the number of electrons allowed in each energy sublevel. In a modern periodic table, there are 18 groups and 7 periods.
2. All the elements of Group 1 or group 17 has the same number of electrons in their outermost shell. Group 1 elements are alkaline metals while group 17 elements are non-metals but both are known as representative's elements of the periodic table.

Examples: Group 1: H ($1s^1$), Na; ($1s^2 2s^2 2p^6 3s^1$)
Group 17: F ($1s^2 2s^2 2p^5$)

Lesson 2: Comparison of Mendeleev's table and modern periodic table

This is the second lesson under Variation in trends of the physical properties, it consists of one period. Students are expected to explain the similarities and the differences between Mendeleev's table and the modern periodic table.

a) Prerequisites/Revision/Introduction:

Refer to lesson 1 above on the historical background of the periodic table.

b) Teaching resources:

- The Periodic Table of Chemical Elements
- Where possible use manila papers, flipcharts and youtube videos with computers and projectors. (If there is no internet you can download and keep the videos on memory sticks)

c) Learning activities

- The teacher form groups of 3-4. The number of groups and members will depend on your class size.
- In the groups learners do activity 5.2 indicated in learner's book, discuss and record their answers.
- Allow the learners to concentrate and use their time appropriately.
- During the presentation ask some questions that lead to discovery of new elements. Use learners' examples to guide them.
- The teacher summarises the learned knowledge and gives examples which illustrate the learned content.
- Your purpose here to confirm the correct information, correct the ambiguity among the findings presented.
- Emphasise about the numbering of groups presently in the periodic table.

Expected answers for Activity 5.2

In Mendeleev's table and modern periodic table, there are some similarities and differences that can be presented below.

Similarities

- In Mendeleev's Periodic Table and the Modern Periodic Table, the elements were arranged noticing similar chemical and physical properties between them.
- In Mendeleev's Periodic Table and the Modern Periodic Table, both elements are arranged in groups or families and periods.

Differences

- Mendeleev put the elements into vertical lines, instead of horizontally like as it is seen today.
- Mendeleev's periodic table was based on atomic mass and the modern periodic table is organized by atomic number.

- Mendeleev was able to predict where several undiscovered elements would fall in the table, and left room for them.
- In Mendeleev's periodic table noble gases were not placed (as they were not discovered at that time) while in Modern periodic table noble gases are put in a separate group named as group-18.

Expected Answers for checking up 5.2

1. Mendeleev realized that the physical and chemical properties of elements were related to their atomic mass in a 'periodic' way, and arranged them so that groups of elements with similar properties fell into vertical columns in his table. This method of arranging elements meant there were gaps in his horizontal rows or 'periods'… ..
2. Compared to Mendeleev's table which contained 66 elements, the modern periodic table contains 118 elements.
3. The modern periodic table includes 18 groups and 7 periods.

Lesson 3: Location of elements in the periodic table based on the electronic configuration

This lesson consists of two periods, during these you can split the lesson according to the nature of your students. It is about the location of elements in groups and periods of the periodic table.

a) Prerequisites

Before beginning this lesson, you can ask a few questions about the periodic table either orally or set a simple exercise for revision. You can also use the activity 5.3. This activity is only intended to remind learners and link the information with the previous lesson and other lessons learnt in S.2 chemistry unit 2.

b) Teaching resources

- A periodic table
- Manila papers, flip charts,
- Learners' text books or other relevant chemistry books can be used if available.

c) Learning activities

- Form groups or pairs of learner and distribute the activity 5.3 in learners' book.
- Allow the learners to work in their respective groups.
- You can invite the representatives of groups to present their findings.
- Learner evaluates their findings through discussion with the assistance of the teacher to correct and complete the learner's answers.
- You can use the examples given by the learners to link the lesson to the content being learned.
- You summarises the learned knowledge and gives examples which illustrate the learned content.
- Emphasise on the difference between modern periodic table and the Mendeleev's

table.

Expected Answers for Activity 5.3

1.a. The electronic configuration of the element $_{25}Mn$ is: 2, 8, 8, 7 or $1s^22s^22p^63s^23p^6\mathbf{4}s^23d^5$

The electronic configuration of the element $_{11}Na$ is: 2, 8, 1 or $1s^22s^22p^6\mathbf{3}s^1$

b. Information about the element 25Mn:

- For the element $_{25}$Mn, the value **4** is the highest energy level of electrons or principal quantum number. Thus the period of Mn is 4. Since the last sub shell is s and d, the element bromine (Mn) is located in group 7 of the modern periodic table.
- This element has the electron configuration **ns** and **(n-1)d**, thus, it informs us that the element is located in group of element corresponding to transition metals.

c. X belong to 7th group and Y belongs to 1st group

X belongs to 4th period and Y belongs to 3rd period.

2. An element with 1.5 atomic number and located between hydrogen and helium does not exist. The atomic number is equal to the number of protons and equal to the number of electrons. It is not possible of existence of half proton or electron.

Expected answers for checking up 5.3

1.a. X is located in Group 1 of the periodic table, it is an alkaline metal: The answer is True

b. Y is in p block: True

c. z is an halogen: True, it is located in group 17.

d. U is lanthanide: False because it is located in d-block while the lanthanides are located in f-block.

e. T is noble gas: True because T is located in group 18 which include the noble gases.

2. The main body of the periodic table is a 18 × 7 grid. It comprises 18 columns and 7 periods. The period relates to the principal energy level. The Group of an element is equal to the number of outermost or valence electrons of element or number of electrons in the highest energy level of elements.

3. There are four distinct rectangular areas or blocks in the periodic table such as s-block, p-block, d-block and f-block.

a. Examples: Na and H are located in s-block

Al and Cl are located in p-block

Mn and Cu are located in d-block

Ce and U are located in f-block

b. Na and H are located in group 1, Na in period 3 and H in period 1

Al is located in group 13, and period 3.

Cl is located in group 17 and period 3

Mn is located in group 7 and period 4

Cu is located in group 11 and period 4

Lesson 4: Classification of Elements into Blocks (s, p, d, f-block)

a) Prerequisites

Refer to previous lessons in the unit.

b) Teaching resources

Periodic table of elements

c) Learning activities

Form pairs and provide activity 5.3 from learner's book.

Ask learners to answer the questions in the activity 5.3.

Learners use think- pair and share method and then the you can ask some learners to present to the whole class.

From the answers presented the should guide the learners to classify elements into blocks using the last filled orbitals according to Aufbau's principle.

Expected answers for Activity 5.4

1. Refer to leaner's book

2. Based on their characteristics, the elements Al (z=13), K (z= 19), Ca (z =20) and Fe (z=26) are classified:

Al has 3 electrons in the last shell, its last orbital is$3s^2 3p^1$, Al is classified in group 13 (p-bock); 3 is its highest level meaning that it is found period is 3.

K has 1 electron in the last shell, its last orbital is $4s^1$ (1) shows that K is classified in group 1 (s-bock); 4 is its highest level meaning that it is found period is 4.

Ca has 2 electrons in the last shell, its last orbital is $4s^2$ (2) shows that Ca is classified in group 2 (s-bock); 4 is its highest level meaning that it is found period is 4.

Fe has 8 electrons in the last shell, its last orbitals is $4s^2 3d^6$ $(2+6 = 8)$) shows that Fe is classified in group 8 (d-bock); 4 is its highest level meaning that it is found period is 4.

Expected Answers for checking up 5.4

1. The Transition metal shows complex compound. They form large no. of complex compound due to presence of partially filled d- orbital and their tendency to show variable oxidation state. It means that d-block elements have a good tendency to form complex compounds.
2. Since d block elements are placed in middle of s and p and their properties are also between the properties of s and p so they are called as transition elements.

   The elements in groups 3 through 12 are called the transition metals. Sometimes this block of elements is referred to as the d block. They are called d block elements because the electrons being added in this block of elements are being added to the d orbitals.
3. The f-block elements are called inner- transition elements because of their placement in the periodic table due to their electronic configuration. Atoms fill

f-orbitals that are in principal energy levels that are lower than the outermost electrons. The inner-transition elements are two series of elements known as the lanthanides and a series of Actinides.

Lesson 5: Characteristics of different blocks of the periodic table

a) Prerequisites

Refer to previous lessons in the unit.

b) Teaching resources

Periodic table of elements

c) Learning activities

Expected Answers for Activity 5.5

1. Many factors can influence the physical properties of elements in the periodic table such as:

   Atomic radius, electronegativity, density, ionization energy, melting and boiling point, metallic character,…

   Let us discuss the first three

Atomic radius of elements decreases as we move from left to right in periodic table. This is explained by the number of outer electrons and protons which increase while there is no change in the energy level. The results increase the attracting forces making the radius smaller.

Electronegativity is a measure of an atom's attraction for the shared pair of electrons in a bond. The charge in the nucleus increases across a period. The electronegativity of atoms is affected by both the atomic number and its size.

The density of a substance is its mass per unit volume, usually in g/cm^3. The density is a basic physical property of a homogeneous substance; it is an intensive property, which means it depends only on the substance's composition and does not vary with size or amount.

Trends

Atomic radius of elements decreases as we move from left to right in periodic table. This is explained by the number of outer electrons and protons which increase while there is no change in the energy level. In the same group, as we go down, **the atomic radius** of elements increases. This is due to the energy level which increases when you move down in group of the periodic table, the attraction of electrons by protons decrease and atomic radius increases.

In a period, the **electronegativity** increases from left to right. If the valence shell of an atom is less than half full, it requires less energy to lose an electron than to gain one. **In a group**, the electronegativity decreases from top to bottom. This is due to the atomic number which increases down in a group, and thus there is an increased distance between the valence electrons and nucleus, or a greater atomic radius.

The trends **in density** of elements can be observed in groups and periods of the periodic table. In general in any period of the table, the density first increases from group 1 to a maximum in the centre of the period, and then decreases again towards group 18.

Going down a group gives an overall increase in density. The variation of density with atomic number.

Expected Answers for checking up 5.5

(1) Li

(2) Kr

(3) less

(4) Increases

(5) Increases

(6) increases

(7) increases

(8) remain the same

(9) smaller

(10) Ne

(11) K

(12) larger

(13) energy levels

(14) decrease

(15) nuclear charge

Lesson 6: Variation of Physical Properties down The Group and Across the Period

a) Prerequisites/Revision/Introduction:

Refer to the previous lessons

b) Teaching resources:

Periodic table of Chemical elements.

c) Learning activities

- Provide activity 5.6 as research on the day before the lesson.
- Learners will present their findings.
- Make corrections from the presented work and provide explanations on variation trends such as electronegativity, ionic radius, atomic radius, ionisation energy e.t.c .

Expected Answer for end of unit assessment

1.

T							G
E	J	A	R	K	B	Q	P
	F	O	H	M	V	D	
N	I	U	S	C	W	L	Y

2. Refer to learner's book

3. a) Nitrogen has three electrons in 2p subshell it means the 2p subshell is half filled resulting in a stable configuration. Oxygen has four electrons in 2p subshell, it is unstable.

c) Noble gases have completely filled energy level, they are stable.

a) Alkali metals are highly reactive.

b) The additional of 10d-orbital offer a poor screening effect for outer electrons from the increase of nuclear charge of Gallium. This is why atomic radius of Gallium(135pm) is smaller than that of Aluminium(143pm)

5.6. Additional activities

5.6.1. Remedial activities

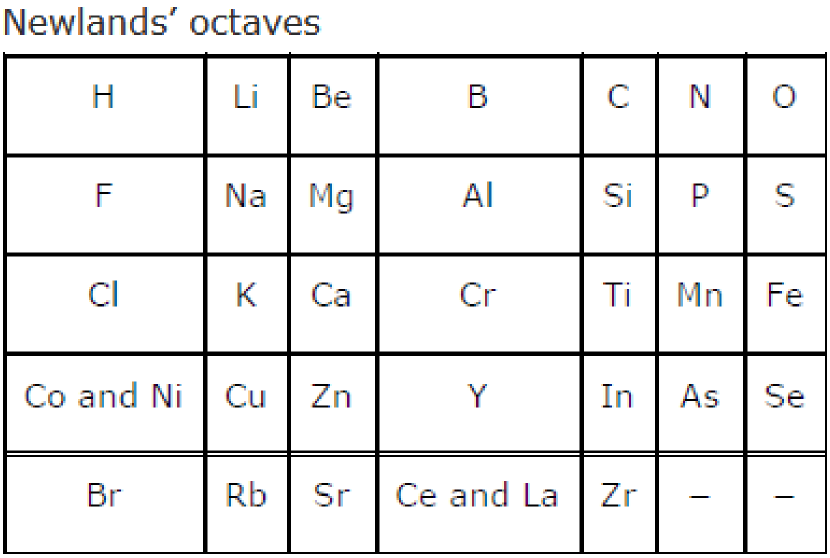
1. Did Doberiener's triads also exist in the columns octaves? Compare and find out.

Answer: only one triad of Dobereiner's triads exists in the columns of Newlands octaves. The triad formed by the elements Li, Na and K of Dobereiner's triads also occurred in the columns of Newlands' octaves. Dobereiner's triads

Li Ca Cl

Na Sr Br

K Ba I



Newlands' octaves

H	Li	Be	B	C	N	O
F	Na	Mg	Al	Si	P	S
Cl	K	Ca	Cr	Ti	Mn	Fe
Co and Ni	Cu	Zn	Y	In	As	Se
Br	Rb	Sr	Ce and La	Zr	–	–

2. What were the limitations of the Dobereiner's Classification?

Answer: all known elements could not be classified into groups of triads on the basis of their properties

3. What were the limitations of Newland's classification?

Answer: Limitations of Newland's classification

- Newlands assumed that only 56 elements existed in nature and no more elements would be further discovered in the nearer future. But later on several new elements were discovered, whose properties couldn't be defined as per the Law of Octaves.
- In order to fit elements into law of octaves Newlands not only adjusted two elements in the same slot but also adjusted some unlike elements under the same note.
- Cobalt and nickel are in the same slot and are positioned in the same column with fluorine, chlorine and bromine possessing different properties than these elements.
- Iron possessing similar properties as cobalt and nickel, is placed far away from these elements
- Thus, Newlands' Law of Octaves can be obeyed well by the lighter elements only.

4. Besides gallium, which other elements have since been discovered that were left by Medeleev in his periodic table? (any two)

Answer: scandium and Germanium

5. What were the criteria used by Mendeleev in creating his periodic table?

Answer: Mendeleev's periodic table was based on the observation that the properties of elements are periodic function of their atomic masses. This means that elements are arranged in the increasing order of their atomic masses, then their properties get repeated after regular intervals

6. How could the modern periodic table remove various anomalies of Mendeleev's periodic table?

Answer: Mendeleev was unable to give fixed position to hydrogen and isotopes in the periodic table. in Mendeleev's periodic table , the increasing manner of atomic mass of the elements is not always regular from one to its next. It was believed that more fundamental property than atomic mass could explain periodic properties in a better manner.

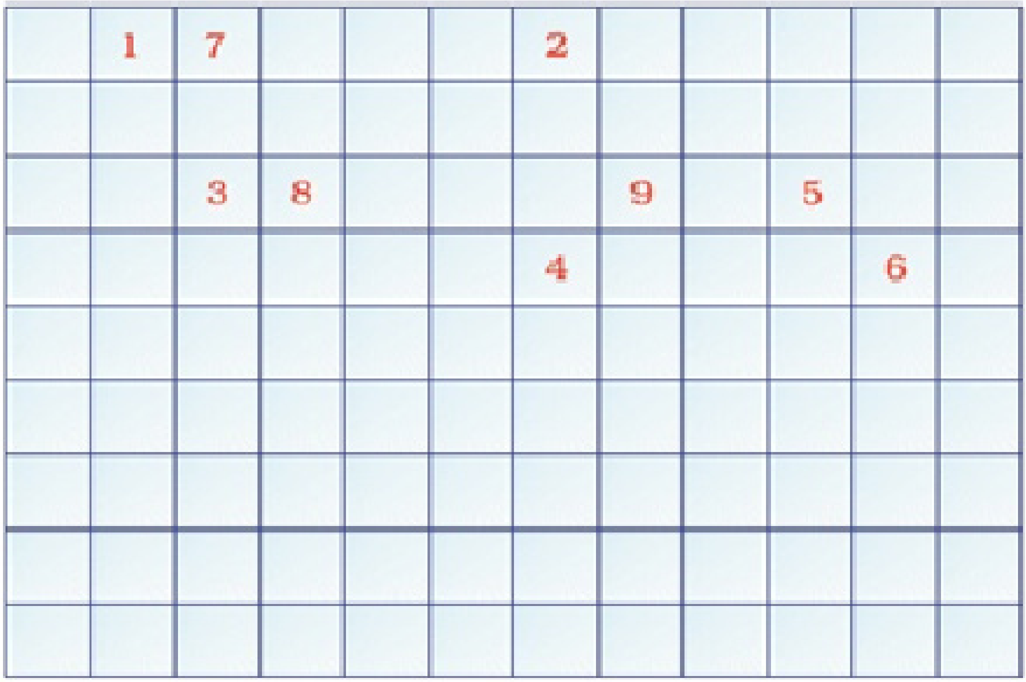
It was Henry Moseley who demonstrated that atomic number of an element could explain periodic properties in a better way than atomic mass of an element and arranged the elements in increasing order of their atomic numbers. Then it was found that the various anomalies of Mendeleev's periodic table were removed by the modern periodic table.

7. Compare and contrast the arrangement of elements in Mendeleev's periodic table and the modern periodic table.

Concept	Mendeleev	Modern
Definition	Mendeleev's periodic table was created on the basis of periodic functions of the elements, leaving room for future findings of the missing elements at that time	The modern periodic table is the one used at the moment, as a collective improvement of the works of so many chemists and scientists in an effort to order the chemical elements to resemble the similarities in their properties
Basis of Ordering	Mendeleev's periodic table orders the elements based on their atomic weight	Modern periodic table orders the elements based on their atomic number.
Gaps for Missing Elements	Mendeleev's periodic table had gaps for the missing elements at that time.	Modern periodic table has no concept as such.
Number of Columns and Rows	Mendeleev's periodic table has 8 vertical columns called groups and 12 horizontal rows called periods.	Modern periodic table has 18 columns called groups and 7 rows called periods.

Characteristics of Grouped Elements	Mendeleev's periodic table has elements with dissimilar properties in the same group sometimes.	Modern periodic table's elements have similar properties repeated at regular intervals.
Existence of Isotopes	Mendeleev periodic table doesn't support the fact of the existence of isotopes.	Modern periodic table supports this fact as the classification is based upon the atomic number, rather than the atomic weight of the element.
Defining atomic Structure	Mendeleev periodic table doesn't support the concept of the atomic structure.	Modern periodic table supports this fact by grouping the elements in such a manner that their electronic configuration can be deduced easily.

7. Complete the following cross word puzzle



Across

An element with atomic number 12

(3) Metal used in making cans and member of group 14

(4) A lustrous non-metal which has 7 electrons in its outer shell

Down:

(2) highly reactive and soft metal which imparts yellow clour when subjected to flame and is kept in kerosene.

(5) the first element of the second period.

(6) An element which is used in making fluorescent bulbs and is second member of group 18 in the modern periodic table.

(7) a radiactive element whih is the last member of halogen family.

(8) a metal which is an important constituent of steel and forms rust when exposed to moist air.

(9) the first metalloid in modern periodic table whose fibres are used in making bullet-proff vests

10. Mendeleev predicted the existence of certain elements not known at that time and named two of them as Eka-silicon and Eka-aluminium.

(a) name the elements which have taken the place of these elements

(b) mention the group and the period of these elements in the modern periodic table.

(c) classify these elements as metals , non-metals or metalloid.

(d) how many valence electrons are present in each one of them?

11. explain the following statements

(a) electropositive nature of the element(s) increases down the group and decrease across the period.

(b) electronegativity of the elements decreases own the group and increases across the period.

(c) atomic size increases down the group and decreases across the period.

(d) metallic character inccreases down the group and decreases across the period.

12. on the basis of the above trends explained in number (11) of the periodic table , answer the following about the elelments with atomic number 3 to 9

13. With reference to number 11

(a) name the mos electronegative element among them

(b) name the most electropositive element.

(c) name the element with the smallest size.

(d) name the element which i a metalloid

(e) Name the element which shows maximum valency.

5.6.2. Extended activities

1 .Explain ‘Dobereiner’s Triads and its drawback.

Answer: Dobereiner classified elements into groups of three where the atomic weight of the middle element was approximately the average of the atomic weights of the other two Example: A triad of lithium (Atomic weight = 7), Sodium (Atomic weight = 23), Potassium (Atomic weight = 39)

$$\text{Mean of Li and K} = \frac{7 + 39}{2} = \frac{46}{2} = 23$$

This is the atomic weight of the middle element, sodium.

The two drawbacks of Dobereiner's triads are:

1) A large number of elements could not be grouped into triads. For e. g. , iron, manganese, nickel, cobalt, zinc and copper are similar elements but cannot be placed in the triads.

2) It was also observed that dissimilar elements were being grouped into triads.

2. State Newland's 'Law of Octaves'.

Answer: When elements are arranged in ascending order of their atomic weights, every eighth element had similar physical and chemical properties and resembled the first element just like the eighth note of an octave of music resembles the first.

3. State Mendeleev's Periodic Law.

Answer: Mendeleev's Periodic Law states that the physical and chemical properties of elements are periodic function of their atomic weights.

4. State the Modern Periodic Law.

Answer: The Modern Periodic Law states that the physical and chemical properties of elements are a periodic function of their atomic numbers.

5. What is meant by periodicity? What is the cause of periodicity?

Answer: The recurrence of characteristic properties of elements, arranged in the periodic table at regular intervals, is called periodicity. Elements having similar electronic configuration have similar properties. Thus the cause of periodicity is the repetition of similar electronic configuration.

6. In the periodic table what is

1) period?

2) group?

Answer:

1) The seven horizontal rows of the periodic table are called periods.

2) The vertical columns starting from top to bottom are called groups. There are eighteen such groups in the periodic table.

7. What are normal elements and noble gases?

Answer:

The elements of group IA, IIA, IIIA, IVA, VA, VIA and VIIA are called the normal elements. These are also called typical or representative elements. Their outer most shells are incompletely filled.

Elements in the zero group are called noble gases. They have their outer most shells completely filled and hence are totally non-reactive due to their stable configuration. Examples of noble gases are helium, neon, argon, xenon, krypton and radon.

8. What is the major difference between Mendeleev's classification of elements and Moseley's classification?

Answer:

Mendeleev's classification of elements was on the basis of increasing atomic weights while Moseley's classification was on the basis of increasing atomic numbers.

9. Name three elements which were not known during the preparation of Mendeleev's Periodic Table but were more or less correctly predicted by him.

Answer:

The three elements that were correctly predicted by Mendeleev's Periodic Table are Scandium, Gallium and Germanium.

10. On what basis is Potassium (z = 19) placed in 4th period and 1st group?

Answer:

The electronic configuration of potassium is: 2.8.8.1. It has four shells so it belongs to the 4th period. The 4th period has elements with the 4^{th} shell being filled. K has 1 electron in its valence shell; hence it is placed in group IA. Group IA has elements with 1 electron in the valence shell. K is like other alkali metals of group I with similar properties.

5.6.3. Consolidation activities

1. Which physical and chemical properties of the elements were used by Mendeleev in creating his periodic table? List two observations which posed a challenge of Mendeleev's periodic law.

Answer: The creation of Mendeleev's periodic table was based upon certain physical and chemical properties.

Physical properties: The atomic masses of the elements were taken into account and the elements were arranged in order of increasing atomic masses. The influences of their physical properties such as melting points, boiling points, density, etc. are related to atomic masses.

Chemical properties: The distribution of the elements into different groups was linked with formation of hydrides by combining with hydrogen and formation of oxides by combining with oxygen. This is linked with the valency of the elements.

The two main observations which posed challenge to Mendeleev's periodic table are as follows:

(i) Position of isotopes: Since the isotopes of an element differ in their atomic masses, they must be assigned separate slots or positions in the periodic table.

(ii) Anomalous positions of some elements: In the Mendeleev's periodic table, certain elements with higher atomic masses precede or placed before the elements with lower atomic masses. For example, the element Ar (Atomic mass = 39.9) is placed before the element K (Atomic mass = 39.1).

2. using the part of the periodic table given below, answer the questions that follow.

Group Period	I	II	III	IV	V	VI	VII	Zero
1	H							He
2	Li	Be	B	C	N	O	F	Ne
3	Na	Mg	Al	Si	P	S	Cl	Ar
4	K	Ca						

(i) Na has physical properties similar to which elements and why?

(ii) Write the electronic configuration of N and P

(iii) State one property common to fluorine and chlorine

Answer: (i) Na has physical properties similar to Li and K. All the three elements have one electron each in the valence of their atoms. These are known as alkali metals.

(ii)Electronic configuration of N(z=7)=2,5

Electronic configuration of P (z = 15) = 2, 8, 5

(iii) Both the elements have seven electrons in the valence shells as their atoms

Fluorine (Z = 9)= 2,7

Chlorine (z = 17) = 2, 8, 7

3. On the basis of quantum numbers, justify that the sixth period of the periodic table shold have 32 elements.

Answer: The sixth period of the periodic table must have elements whose electrnic configuration starts from 6s and continue filing 4f, 5d and 6p orbitals. As the electron enters 7s orbital such element will come under 7th period.

The number of electrons that can be accommodated in 6s, 4f, 5d and 6p orbitals are 2, 14, 10 and 6 respectively whose total is 32. Hence the sixth period of the periodic table should have 32 elements

4. How does atomic radius vary in period and in group? Explain the variation.

Answer: Variation of atomic size down the group: The atomic radius increases as you we go from top to bottom in the group.

Reason: as we go down the group electrons are added in a new shell. At the same time the nuclear charge increases down the group. Though the effect of increase in nuclear charge is to reduce the atomic radius, this effect is offset by the effect of new shell and as a result, the atomic radius increases down the group.

Along the period: the atomic radius decreases along the period

Reason: along the period, electrons are added on the same shell while the nuclear charge increases. As a result of increase in nuclear charge, atomic radius decreases.

5. What are the various factors due to which the ionization enthalpy of the main group

elements tends to decrease down a group?

Answer: (i) There is an increase in the number of main energy shells (n) in moving from one element to the other.

(ii) There is also an increase in magnitude of the screening effect due effect due to the gradual increase in number of inner shells. The valence electrons are shielded from the nuclear attraction.

6.Aline and Calixte are the students of Class X. Aline is very much organized and maintained whereas Calixte is an unorganized student and always faces a lot of problems in handling life situations.

(a) How does organization help in daily life?

(b) How can you relate the above fact with the unit 'Classification of Elements'?

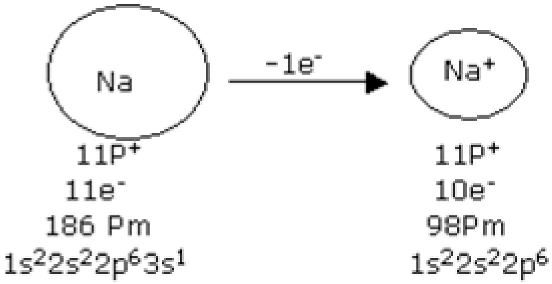
(c)How classifications of elements help us studying them properly?

7. Explain why cations are smaller and anions larger than their corresponding parent atoms?

Answer: Cationic radius is smaller than that of the parent atom:

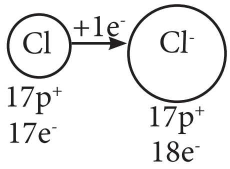
Reason: cations are formed by loss of one or more electrons from the parent atom. As a result the number of electrons is decreased while the number of protons remains the same. The number of positive charges becomes greater than the negative charges which results in greater attraction (increase in effective nuclear charge per electron).

The greater the nuclear attraction (electrostatic force of attraction between the nucleus and the outer electrons), lesser will be the atomic radius. For example.



The third shell does not have electrons in the case of Na^+ ion. Anionic radius is larger than that of parent atom.

Reason: anions are formed by the gain of one or more electrons by the gain of one or more electrons by the gaseous atom. Here nuclear charge remains the same whereas the number of electrons increases by one or more. The nuclear attraction is decreased as the number of protons is smaller than that of electrons. i.e. the effective nuclear charge per electron decreases in the case of anions and hence the electrons are less tightly bound by the nucleus which results in increased size of the ion.



TERM TWO

School Name:....................................Teacher’sname: ....

Term	Date	Subject	Class	Unit	Lesson Number	Duration	Class size
I	30/03/2018	Chemistry	S4	6	7	40	42

Type of Special Educational Needs to be catered in this lesson and number of learners in each category	…………………………………………… …………………………………………… …………………………………………… ……………………….
Topic area:	The periodic table
Sub-topic area:	Periodicity of properties of elements
Key Unit competency:	To be able to: compare and contrast the chemical properties of the Group 13 elements and their compounds in relation to their position in the Periodic table
Plan for this Class	**classroom : 7 groups of 5 students each**
Learning Objectives **(inclusive to reflect needs of whole class)**	-Having different salt solutions and nichrome wire, learners will be able to: -Carry out the flame tests for the presence of Group 1 metal cations in solution -Identify the colours of the flame of salts containing Na^+,K^+
Materials	Clean water, samples of salt containing solutions, Bunsen burner, nichrome wire,

References	-Chemistry A'L. Competence- based Syllabus; -Ramsden, E. 2000. In A-Level chemistry Fouth eddition. Nelson Thorns Ltd. -Ramsden, E. N. 2000. Advanced Level Chemistry (4th ed.). Cheltenham, United Kingdom: Nelson Thornes Ltd.

<table>
<tr>
<td rowspan="2">Timing for each step</td>
<td colspan="2">Description of teaching and learning Activity
The teacher provides the required materials for the flame test and organizes learners into 6 groups. The teacher gives instructions to carry out the experiment, while learners, in their respective group, perform the experiment on flame test, observe, discuss and make report of the results.</td>
<td rowspan="3">Competences and Cross-Cutting Issues to be addressed:
1. Generic competences
- Communication
- Critical thinking
- Cooperation
2. Cross-cutting issues
- Gender education:
while learners form mixed groups of girls and boys,and shoow respect for each other
Inclusive educational:
learners with disabilities are integrated in learning process and participate actively as possible as</td>
</tr>
<tr>
<td>Teacher’s activities</td>
<td>Learners’ activities</td>
</tr>
<tr>
<td>Introduction:
10 min
(approx. 10%)</td>
<td>The teacher will ask the following questions:
-What type of ions are present in drinking water as listed on a water bottle of AKANDI natural mineral water.
What type of group 1 ions present in drinking water
-The teacher asks question to help learners to discover the lesson of the day and communicate the objectives of the lesson: the characteristics of drinking water and pure water and pure wate</td>
<td>Learners observe the label of “AKANDI mineral water” and answer the questions by listing the mineral composition.
Learners predict that today’s lesson: present ions in solution and their identification test</td>
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Timing for each step	**Description of teaching and learning Activity**		**Competences and Cross-Cutting Issues to be addressed:**
	The teacher provides the required materials for the flame test and organizes learners into 6 groups. The teacher gives instructions to carry out the experiment, while learners, in their respective group, perform the experiment on flame test, observe, discuss and make report of the results.		**1. Generic competences** - Communication - Critical thinking - Cooperation **2. Cross cutting issues** **- Gender education:** while learners form mixed groups of girls and boys,and shoow respect for each other **Inclusive educationl:** learners with disabilities are integrated in learning process and participate actively as possible as
	Teacher's activities	**Learners' activities**	
Introduction: **10 min** (approx. 10%)	The teacher will ask the following questions: -What type of ions are present in drinking water as listed on a water bottle of AKANDI natural mineral water. What type of group 1 ions present in drinking water -The teacher ask question to help learners to discover the lesson of the day and communicate the objectives of the lesson: the characteristics of drinking water and pure water and pure wate	Learners observe the label of "AKANDI mineral water" and answer the questions by listing the mineral composition. Learners predict that today's lesson: present ions in solution and their identification test	

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<tr>
<td>Development of the lesson
25 min
(approx. 75%)</td>
<td>-Divide students in groups and provide them different solutions containing Group 1 metal cations
- give the following instructions:
Performing flame test of ions as described in student’s book (lesson 6,activity 6.6)
The teacher monitors students engaged in activities
The teacher asks to different groups to explain why the samples have different colors on flame of a Bunsen burner
Teacher asks students to state some cause of the flame.
Teacher guides learner to interpret the observations.</td>
<td>Students work in groups of six each and they and observe the samples of water provided, (listening, discussing, making their own notes…)
Each group discusses different observations, fill in the working sheet and choose a group representative to report the findings to the class
<table>
<tr><th>Sample</th><th>Flame color</th><th>Deductions</th></tr>
<tr><td>A</td><td></td><td></td></tr>
<tr><td>B</td><td></td><td></td></tr>
<tr><td>C</td><td></td><td></td></tr>
</table>
Probable Students’ response:
Colors are due to the presence of different mineral salts in the sample</td>
<td>- Financial education: focusing on being care while buying item and advised to pay after checking standards
- Standardization culture:
carefullness in buying item and check for standards before using them</td>
</tr>
</table>

Conclusion **10 min (approx 15%)**	Teacher summarizes the lesson and asks oral and written questions: Teacher recalls and integrates cross-cutting issues financial education and standardization culture: buying any item requires observation of labels to check the expiration date, the composition of the substance and standards Assessment Individually, learners carry checking up 6.6 in learners book	Learners follow the summary and ask questions where they do not understand for clarifications. Learners answer oral questions and do assessment individually	
Teacher self-evaluation	Learners have understood what the concept of flame test . Learners have understood what cause of flame in solutions: Excited electrons by flame. Learners can identify different types of cations present in solution on the basis of flame test.		

UNIT 6: TRENDS IN CHEMICAL PROPERTIES OF GROUP 1 ELEMENTS AND THEIR COMPOUNDS

6

6.1 Key unit competency

To be able to compare and contrast the chemical properties of the Group 1 elements and their compounds in relation to their position in the Periodic Table.

6.2 Prerequisite knowledge and skills

Components of an atom and their properties, definition of an atomic number, mass number and electronic structure, chemical reactions ,trend in physical properties of elements in periodic table ,handling laboratory equipments, safety rules and regulations in laboratory.

6.3 Cross-cutting issues to be addressed

Gender equality

General need of people to complement one each over without conflict in order to be peaceful.

The nature of atoms can be related to relationship in human beings. There is a serious issue of misunderstanding of gender equality in our society. When introducing this unit, it would be an opportunity to guide learners on understanding the importance of gender equality and how the issues related to gender inequality may be addressed.

Help learners to:

a) Understand that complementarities are very important. Atoms react to form bond between them. Metals lose their electrons to get stable .the lost electrons are gained by nonmetals. There are complementarities between metals and non metals to give stable compounds. Students should know that female and male are both human beings and one need each other to establish good relationship and no one should say that he/she is more indispensable than another.

b) Understand that gender equality plays a big role in the development of the country.

c) Understand that female needs male and vice-versa in different ways for their future achievement.

d) Underline the necessity of cooperation and working in mixed group rather than working in single group)

You can do this in a short whole class discussion. This may be an opportunity for you as chemistry teacher to confront the individual students who need advise on relationship matter.

Environment and sustainability

We live in environment where human beings have an significant impact ,both positive and negative. The demand for survival requires hard working without thinking on direct impact of our action. Handling chemical requires taking into consideration their different effect on the environment .This unit is an opportunity to guide learners on understanding the impact of air , water and soil pollution. This issue should be addressed especially considering the different uses of chemicals and different ways of waste management mainly chemical wastes.

- Help learner to work in healthy environment
- Learners perform experiment by keeping the classroom environment clean before and
- after the experiment.
- Learner are skilled on the ways of waste management
- Learner are also skilled on the rational use of chemical by avoiding or reducing all
- means of pollution

Inclusive education

This unit involves a number of activities that involves practical work; observation, use of sense organ, reading and writing. This may be challenging to students with special educational needs especially children with physical impairment, hearing impairment, visual impairment. However, the teacher can make some arrangements like:

- Grouping students. Students with special educational needs are grouped with others and assigned roles basing on individual students abilities.
- Providing procedure earlier before the activity so that students get familiar with them. They can be written on the chalkboard or printed depending on available resources. If you have children with low vision remember to print in appropriate fonts or in Braille.
- Every important point is written and spoken. The written points helps students with hearing impairment and speaking aloud helps students with visual impairment
- Remember to repeat the main points of the lessons
- Remember to allow learners with disabilities to get helped with their colleagues without disabilities

d) Underlining the necessity of cooperation and working in mixed group rather than working in single group)

You can do this in a short whole class discussion. This may be an opportunity for you as chemistry teacher to confront the individual students who need advise on relationship matter.

Environment and sustainability

We live in environment where human beings have an significant impact ,both positive and negative. The demand for survival requires hard working without thinking on direct impact of our action. Handling chemical requires taking into consideration their different effect on the environment .This unit is an opportunity to guide learners on understanding the impact of air , water and soil pollution. This issue should be addressed especially considering the different uses of chemicals and different ways of waste management mainly chemical wastes.

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- Every important point is written and spoken. The written points helps students with hearing impairment and speaking aloud helps students with visual impairment .
- Remember to repeat the main points of the lessons.
- Remember to allow learners with disabilities to get helped with their colleagues without disabilities

Financial education

As any field that involves some kind of expenses, the teacher should focus on the rational use of chemical while performing experiment, strategies that should put into action to minimize the cost of manufactured products, so as to enhance the competition with products from various factories

6.4 Guidance on introductory activity

Before introducing the first lesson (outline of the properties the first group elements by examining them in a table of physical properties and relating them to general trend in the group) of this unit, let learners attempt the introductory activity.

6.5 List of lessons

Heading	Lesson title	Learning objectives	No of periods
6.1 Occurrence and physicalProperties of Group 1 Elements: physical state, Metallic character, physical Appearance and melting point.	Occurrence and physical Properties of Group 1 Elements: physical state, Metallic character, physical appearance and melting point.	Describe and explain the physical properties of Group 1 elements in terms of metallic character and strength of metallic bond.	2
6.2 Reactivity of Group 1 elements with: oxygen (formation of monoxides, peroxides and superoxides), water and the halogens.	Reactivity of Group 1 elements with: oxygen (formation of monoxides, peroxides and superoxides), water and the halogens.	-Describe and explain the reactivity of the Group 1 elements with oxygen, water and the halogens -Compare the reactivity of Group 1 elements. -Develop care when dealing with extremely reactive Group 1 element.	2

6.3 Properties of Group 1 oxides and hydroxides.	Properties of Group 1 oxides and hydroxides.	-State and explain the properties of Group 1 oxides and Hydroxides. -Perform experiments to test the alkalinity of Group 1 hydroxides.	2
6.4 Effect of heat on Group 1 carbonates and nitrates.	Effect of heat on Group 1 carbonates and nitrates.	Interpret the trends in the thermal decomposition of Group 1 carbonates and nitrates.	2
6.5 Solubility of Group 1 compounds.	Solubility of Group 1 compounds.	Explain the trends in the solubility of Group 1 compounds	1
6.6 Flame tests for Na^+, K^+.	Flame tests for Na^+, K^+.	Carry out the flame tests for the presence of Group 1 metal cations in solution.	1

6.7 Uses of Group 1 elements and their compounds e.g. manufacture of soaps, detergents and bleaching agents (sodium hydroxide, potassium hydroxide), Manufacture of lithium batteries, common table salt, production of photoelectric cells , baking powder, etc.	Uses of Group 1 elements and their compounds e.g. manufacture of soaps, detergents and bleaching agents (sodium hydroxide, potassium hydroxide), Manufacture of lithium batteries, common table salt, Production of photoelectric cells , baking powder, etc.	State the uses of Group 1 elements and their compounds.	2
Assessment			2

Lesson 1: Occurrence and physical properties of Group 1elements

This is the first lesson of unit 6 and is divided into two periods.The first lesson also covers the introduction of the whole unit (introductory activity). You are advised not to spend a lot of time on this introductory activity. This is only intended to raise the curiosity of learners to group I elements

a) Introduction

Students will learn better the physical properties of group 1 elements if they have understanding on: the variation in trends of physical properties of elements in periodic table, the arrangement of elements in the periodic table and writing the electronic configuration of elements, (refer to unit 5).

b) Teaching resources

- Periodic table of elements.

-Use the table of physical properties of group 1 elements in the student's book for lesson 1 illustrations drawn on a manila paper.

-Other relevant chemistry text books if available in the library.

c) Learning activities

With the aid of previous lesson (unit 5) learners are tasked to read deeply on the variation in trends of physical properties. This can be a basic to understand how is the trend in chemical properties of group 1 elements in comparison to their physical properties

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt the introductory activity and thereafter proceed to activity 6.1 which leads students to the first lesson of the unit.

- Form groups of 3-4 depending on the size of the class.
- Distribute the introductory activity and estimate the time for it.
- Let the learners proceed and do activity 6.1 of lesson 1.
- Allows the learners to work together in groups.
- Invite group leaders to present their findings.
- Instead of groups you can also use —pair-think and sharel.
- In this step you can guide the learners to evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- You summarise the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated in step 2.
- Integrate crosscutting and real life experiences by linking them with the lesson learned.

Expected answers for the introductory activity

Answers to activity 6.1 a) Learner‘s book.

a) The energy required to remove the most loosely held electron from an atom is called first ionization energy.

b) Ionization energies that decreases down the group as the atomic radius increases. The outermost electron is far away from the nucleus and less attracted by it. So it becomes easier to remove the electron as the screening effect of inner shells is increased.

On descending a group both the nuclear charge and screening effect increase but the increase in screening effect as a result of an extra shell of electrons added outweighs that of the nuclear charge. Therefore, effective nuclear charge decreases so that electrons are less strongly held down the group and is easy to remove.

c) The melting point decreases down group 1 elements as the atomic radius increases. It decreases down the group due the increase in atomic size which decreases close packing points also follow the same trend. The smaller atoms on the top are compactly together. The lesser the forces of attraction and hence the melting point decreases from the top to the bottom in group 1 of a periodic table.

Answers to activity 6.1 b) Learner‘s book.

a) Group 1 elements show relatively weak metallic bonding as only one electron is available from each atom to contribute to the delocalized sea of electrons in metallic bond. Also they have a big atomic radius and the attraction of nucleus toward the valence electron is weak.

b) The atomic radius of Na is greater than the corresponding ion Na^+: as the outer electron is removed the occupied outermost shell is removed also. The positive nuclear charge exerts strong attraction to the remaining negative outer shell hence reducing the size of positive ion.

c) The shining appearance of metals disappears after a certain period of time because of the formation of an oxide layer on the metal.

d) checking up

Expected answers to checking up 6.1

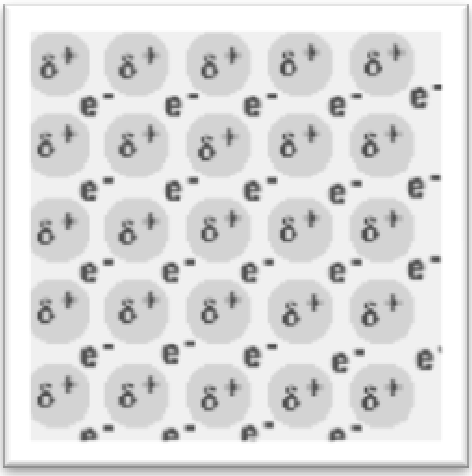
1. The ionization energy decreases as the atomic radius increases down the group as. This is due to the following factors:

-**The distance of the outermost electron from the nucleus:** as the distance increases, the attraction of the positive nucleus for the negative electron will decrease. Consequently the ionization energy will decrease.

-**The screening effect of inner electrons:** the outermost electrons are repelled by all the other electrons in the atom besides being attracted by the positive nucleus. Consequently it becomes easy to remove them.

2. Yes there is a relationship between atomic radius and melting point in group 1 elements. As the atomic radius increases down the group 1 elements the melting point decreases. This is caused by decreasing metallic bonding down the group i. e the metallic bonding gets weaker down the group as atomic radius increases. The boiling point decreases down the group due the increase in atomic size which decreases close packing points.

3. The good electrical conductivity is due to metallic bonding in which a sea of electrons is free to move as illustrated below:



Where e- : free electrons, +: positive cations

4. X is potassium since the values of melting point; atomic radius and ionization energy are in the middle of the values of Y and Z

Y is lithium because of the smallest value of atomic radius and the biggest values of ionization energy and melting point.

Z corresponds to caesium because of its big size (atomic radius) and the lowest values of melting point and ionization energy.

Lesson 2: Reactivity of group 1 elements

a) Introduction

Students will learn better the reactivity of group 1 elements if they have understanding on: the variation in trends of physical properties of elements in periodic table, the arrangement of elements in the periodic table and writing the electronic configuration of elements, (refer to unit 5).

b) Teaching resources

- Periodic table of elements

-Use the table of physical properties of group 1 elements in the student's book for lesson 1 illustrations drawn on a manila paper.

-Other relevant chemistry text books if available in the library

c) Learning activities

With the aid of previous lesson (unit 5) learners are tasked to read deeply on the variation in trends of physical properties. This can be a basic to understand how is the trend in chemical properties of group 1 elements in comparison to their physical properties such as atomic radius and reactivity.

- Form groups of 3-4 depending on the size of the class.
- Distribute the activity 6.2.a and 6.2.b and estimate the time for it.
- Let the learners proceed and do activity 6.2.a and b of lesson 2 :learners observe the pictures in learners book and make comments
- Allows the learners to work together in groups.
- In this step you can guide the learners to evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- Invite group leaders to present their findings.
- You summarise the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated
- Integrate crosscutting and real life experiences by linking them with the lesson learned.

Expected answer to activity 6.2.a

Description of the scenario

1. As the hen mother cannot protect the chicks that are far from her ,the attraction between the nucleus and the valence electron decreases with increasing distance between the nucleus and the valence electron. With decreasing attraction between the nucleus and the valence electron, it becomes more easy to remove

valence electron and the distance increases or as the radius and the volume of the atom increase.

2. In the other case, people who are far from the fire cannot warm themselves. This resembles to the interactions between the nucleus and the valence electron

Expected answer to activity 6.2.b

a. Order of increasing reactivity in group 1 elements

Li (Z=3), Na (Z=11), K (Z=19), Rb (Z=37) Cs (Z=55).As the atomic number increases the number of shells that are filled with electron increases also, resulting in increase of atomic radius down the group .So the reactivity will increase accordingly i. e the ability to lose electrons in group 1 increases as the atomic number increases.

b. The electronic structure of the species below:

Na^+ (number of electrons=10):$1s^2\ 2s^2\ 2p^6$ (Na metal has lost one electron; stable structure similar to neighbouring noble gas Ne)

Na^{2+} (number of electrons=9):$1s^2\ 2s^2\ 2p^5$ (Na metal has lost 2 electrons; unstable structure)

Na^- (number of electrons=12):$1s^2 2s^2 2p^6 3s^2$ (Na metal gained one electron; unstable structure)

Lesson 3: Properties of oxides and hydroxides

a) Introduction

Students will learn better the properties of group 1 oxides and hydroxides if they have understanding on: the variation in trends of physical properties of elements in periodic table, the arrangement of elements in the periodic table and writing the electronic configuration of elements, (refer to unit 5), the chemical reactions as they have learnt it in senior 2 &3 O'level.

b) Teaching resources

- Periodic table of elements

-Use the table of physical and chemical properties of group 1 elements in the student's book for lesson 1&2

-Other relevant chemistry text books if available in the library.

c) Learning activities

With the aid of previous lesson (unit 5) learners are tasked to read deeply on the variation in trends of physical properties. This can be a basic to understand how is the trend in chemical properties of group 1 elements in comparison to their physical properties such as atomic radius and reactivity.

- Form groups of 3-4 depending on the size of the class.
- Give the instructions on the experiment and distribute the tasks for each member of the group.

- Let the learners proceed and do experiment in activity 6.2.1, 6.2.2.
- Learners are given a homework to do activity 6.2.3
- Allows the learners to work together in groups.
- In this step you can guide the learners to perform the experiment, evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- Invite group leaders to present their findings.
- You summarise the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated
- Integrate crosscutting and real life experiences by linking them with the lesson learned.

Expected answers to activity 6.2.1

Answer to task on the experiment

a) $4M(s) + O_2(g) \longrightarrow 2M_2O(s)$ M=Li, Na

b) The products formed are oxides: they are named as: metal oxide (Ex: lithium oxide,…)

c) Metallic oxides of group 1 elements dissolve in water giving an alkaline solution MOH(aq). The alkaline solution turns red litmus paper to blue while blue litmus paper remains unchanged.

d) $M_2O(s) + H_2O(l) \longrightarrow 2MOH(aq)$ where M=Li,Na,K,Rb,Cs

Expected answers to activity 6.2.2

1. Sodium is easy to cut because of the weak metallic bonding which results in its softness

2. When sodium is placed on water in a beaker it reacts vigorously, fizzing (a hissing sound is heard) and skating about on the water surface, a colourless gas is evolved

3. Sodium reacts with water by forming an alkaline solution that turns red litmus paper blue, and does not change the colour of blue litmus paper.

$$2Na(s) + 2H_2O(l) \rightarrow 2NaOH_{(aq)} + H_{2(g)}$$

Expected answer to activity 6.2.3

a) Cl (Z=17) :$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5$

Br (Z=35):$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^5$

I (Z=53) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^5$

b) Valency electrons

Cl (Z=17) : $3s^2\ 3p^5$

Br (Z=35): $4s^2\ 4p^5$

I (Z=53): $5s^2\ 5p^5$

c) Molecular equations when

Sodium reacts with bromine: $2Na(s) + Br_2(l) \longrightarrow 2NaBr(s)$
Potassium reacts with iodine $2K(s) + I_2(S) \longrightarrow 2KI(s)$
Lithium reacts with chlorine $2Li(s) + Cl_2 \longrightarrow 2LiCl(s)$

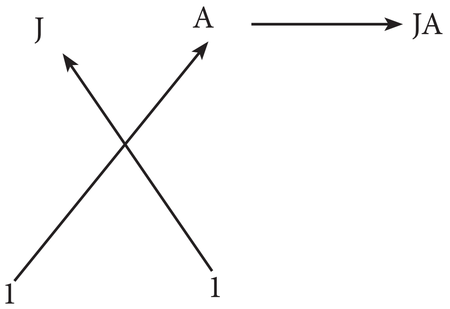
d) Expected answers to checking up 6.2

a) J (Z=19) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$ 4s1(Valence=1)

A (Z=35)1s2 2s2 2p6 3s2 3p6 $4s^2\ 3d^{10}\ 4p^5$(Valence=1)

b) (i) oxides of J:J_2O(normal oxide) and J_2O_2(peroxide)

(ii)Formula of a compound formed between J and A:



Valences

(iii)The expected bond between J and A ionic bond. This occurs between an element of group 1 J(metal) and an element of group 17 an halogen(a non metal).

c) $J(s)+H_2O(l) \longrightarrow JOH(aq)+H_2(g)$

d) -the colourless solution should be tested using litmus paper: red litmus paper turns blue while blue litmus paper remains unchanged (this is an alkaline solution of JOH)

-The colourless gas should be tested using a burning splint where a pop sound is heard.

Expected answers to checking up 6.3

1 .a) $K(s)+H_2O(l) \longrightarrow KOH(aq)+H_2(g)$
b) $K_2O(s) +H_2O(l) \longrightarrow 2KOH(aq)$
2. $LiOH(s) \longrightarrow$ heat $\longrightarrow Li_2O(s) +H_2O(g)$

i) The white powder a is Li2O

ii) The colourless gas Y that condenses to colourless liquid is H2O .This is tested using

-white $CuSO_4$ which turns to blue in presence of water.

3. Group 1 elements form ionic bonding because they lose easily the outermost shell electron.

Lesson 4: Effect of heat on carbonates and nitrates

a) Introduction

Students will learn better the effect of heat on carbonates and nitrates if they have understanding on: the variation in trends of physical properties of elements in periodic table, the arrangement of elements in the periodic table and writing the electronic configuration of elements, (refer to unit 5), the chemical reactions as they have learnt it in senior 2 &3 O'level, the safety rules and regulations learnt in senior 1 O'level.

b) Teaching resources

- Periodic table of elements.

-Use the table of physical and chemical properties of group 1 elements in the student's book for lesson 1&2.

-Other relevant chemistry text books if available in the library.

c) Learning activities

With the aid of previous lesson (unit 5) learners are tasked to read deeply on the variation in trends of physical properties. This can be a basic to understand how is the trend in chemical properties of group 1 elements in comparison to their physical properties such as atomic radius and reactivity.

- Form groups of 3-4 depending on the size of the class.
- Give the instructions on the experiment and distribute the tasks for each member of the group
- Let the learners proceed and do activity 6.4, and proceed on the experiments as described in 6.4.1&6.4.2.
- Allows the learners to work together in groups.
- You can guide the learners to perform the experiment, evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- Invite group leaders to present their findings.
- Summarize the content give examples which illustrate the learned content.
- Integrate crosscutting of environment and sustainability and real life experiences by focusing on the effect of heat on environment such as bush burning, pollutant gases released while burning.
- Let learners the time to work on checking up 6.4 and give homework on it if possible

Expected answers of activity 6.4

a) In the experiment the learners discover that only lithium carbonate decomposes while other carbonates of group 1 do not.

b) $Li_2CO_3(s) \longrightarrow Li2(s)CO_2(g)$

c) $2KNO_3(s) \longrightarrow 2KNO_{2s}+O_2(g)$

$$2liNo_3(g) \longrightarrow Li_2O(s)+2NO_2(g)+\frac{1}{2}O_2(g)$$
$$2NaNo_3(s) \longrightarrow 2NaNO_2(s)+O_2(g)$$

Expected answers for checking up 6.4.1

Learners perform the experiment on heating nitrates and proceed on the test of the gases evolved. The observations are as followed:

a) On heating potassium nitrate releases only oxygen which relights a glowing splint but does not action on litmus paper. This is a proof for the release of oxygen only.

-While on heating lithium nitrate the gases that are evolved turns blue litmus paper to red and the glowing splint is relighted. This is a proof for release of an acidic oxide NO_2 which turns blue litmus paper to red, and also the release of oxygen which relights a glowing splint.

a) $2KNO_3(s) \longrightarrow 2KnO_2(s)+O_2(g)$

$2LiNO_3(g) \longrightarrow Li_2O(g)+2No_2(g)$

b) i) $LiNO_3(s)$

ii) Nitrogen dioxide, NO_2, brown colour.

Expected answer to activity 6.4.2

Learners perform the experiment on thermal decomposition of carbonates.

Lithium carbonate and calcium carbonate decompose while sodium and potassium carbonate do not.

By testing the evolved gas this one turns colourless lime water to white (milky mixture) confirming the release of carbon dioxide.

The gas also turns damp blue litmus paper to red.

Expected answers for checking up 6.4.2

a) $Li_2CO_3(s) \longrightarrow Li_2O(s)+CO_2(g)$

b) By testing the evolved gas this one turns colourless lime water to white (milky mixture)

The gas also turns damp blue litmus paper to red

Lesson 5: Solubility of group 1 elements

a) Introduction

Students will learn better the solubility of group1 compounds if they have understanding on: the variation in trends of physical properties of elements in periodic table, the arrangement of elements in the periodic table and writing the electronic configuration of elements, (refer to unit 5),the solubility rules as learnt in senior 2 O'level.

b) Teaching resources

- Periodic table of elements.

-Use the table of physical and chemical properties of group 1 elements in the student's book for lesson 1&2

-Other relevant chemistry text books if available in the library.

c) Learning activities

With the aid of previous lesson (unit 5) learners are tasked to read deeply on the variation in trends of physical properties. This can be a basic to understand how is the trend in chemical properties of group 1 elements in comparison to their physical properties such as atomic radius and reactivity.

- Form groups of 3-4 depending on the size of the class.
- Give the instructions and distribute the tasks for each member of the group.
- Let the learners proceed and do activity 6.5.
- Allows the learners to work together in groups.
- Guide the learners to do the activity 6.5, evaluate their findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- Invite group leaders to present their findings.
- Give examples which illustrate the learned content and summarize the content. Give also other necessary examples that are not indicated in the content.
- Integrate crosscutting and real life experiences focus on strength in chemical bonding to reinforce peace and values.
- Let learners the time to work on checking up 6.5 and give homework on it if possible

Expected answers to activity 6.5

a) i) Group 1 elements form ionic compounds because they lose easily their single outermost electron

b) Properties of ionic compounds:

-Good electrical conductivity in aqueous solution and in molten state

-Solubility in polar solvent (water)

-High melting and boiling points

-They are brittle

c) Because it's smallest size lithium forms covalent compounds. The teacher should have knowledge on the polarizing power of lithium but it is not necessary to focus on this to learner.

d) The abnormal behaviour of lithium results from its small size forming covalent compounds that are not soluble in water.

d) Expected answers for checking up 6.5

a) LiCl; NaCl; KCl; RbCl; CsCl. The solubility of chlorides increases down the group(from the top to the bottom)

b) Cs_2SO_4, Rb_2SO_4, K_2SO_4, Na_2SO_4, Li_2SO_4, The solubility of sulphates decreases down the group (from the top to the bottom).

Lesson 6: Flame test on Na^+ and K^+

a) Introduction

Students will learn better the flame test if they have understanding on: the variation in trends of physical properties of elements in periodic table, the arrangement of elements in the periodic table and writing the electronic configuration of elements, (refer to unit 5), the concept of energy absorption and energy emission learnt in previous unit of senior 4, the safety rules and regulations learnt in senior 1 O'level.

b) Teaching resources

- Periodic table of elements.

-Use the table of physical and chemical properties of group 1 elements in the student's book for lesson 1&2.

-Other relevant chemistry text books if available in the library.

c) Learning activities

With the aid of previous lesson (unit 5) learners are tasked to read deeply on the variation in trends of physical properties. This can be a basic to understand how is the trend in chemical properties of group 1 elements in comparison to their physical properties such as atomic radius and reactivity.

- Form groups of 3-4 depending on the size of the class.
- Give the instructions on the experiment and distribute the tasks for each member of the group.
- Let the learners proceed and do activity 6.6, and proceed on the experiments as described in 6.6 activity .Allow the learners to work together in groups.
- Monitor the learners' activity during the experiment; evaluate their findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- Invite group leaders to present their findings.
- Harmonize the learned knowledge and give examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated
- Integrate crosscutting and real life experiences such as inclusive education where learners with different types of disabilities (slow learners, physical impairment learners …) are helped by their colleagues to participate).
- Let learners the time to work on checking up 6.6 and give homework on it if possible.

Expected answers to activity 6.6

The learners perform the experiment on flame test. They observe that

- Lithium carbonate gives a deep red colour.
- Potassium sulphate gives a violet colour.
- Sodium sulphate gives a yellow colour.

d) Expected answers to checking up 6.6

a) Solution of CsCl gives a blue colour.

KCl gives a violet/ lilac colour.

b) Solution of NaCl a yellow colour.

LiCl a deep red colour.

Element	Flame colour
Lithium	Deep red
Sodium	Yellow
Potassium	Lilac/violet
Rubidium	Red
Caesium	Blue

Lesson 7: Uses of group 1 elements and their compounds

a) Introduction

Students will learn better this lesson if they have understanding on: the physical properties and chemical properties of group 1 elements in periodic table so as to relate them to their use.

b) Teaching resources

- Periodic table of elements

-Use the table of physical and chemical properties of group 1 elements in the student's book for lesson 1&2

-Other relevant chemistry text books if available in the library.

c) Learning activities

With the aid of previous lessons and previous units learners are tasked to read deeply on the variation in trends of physical properties and chemical properties of group 1 elements. This can be a basic to understand their uses.

- Form groups of 3-4 depending on the size of the class.
- Give the instructions and distribute the tasks for each member of the

group.

- Let the learners proceed and do activity 6.5 Allow the learners to work together in groups to share information supplied from various resources
- You can guide the learners to do research in library, on internet…, evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- Invite group leaders to present their findings.
- Harmonize the learned knowledge and give examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated
- Integrate crosscutting and real life experience such as environment and sustainability by avoiding for example use of fuel containing lead (where sodium was used in alloys with lead to produce additives to fuel under form of PbEt4 and PbMe2) that are actually seen as pollutants to environment
- Let learners the time to work on checking up 6.7 and give homework on it if possible

Expected answers to activity 6.7

After the research in library and from internet learners presentation of their findings to the whole class about the use of group 1 elements and some of their compounds

-Lithium: Used for making alloys especially with aluminium to make the parts of the aircraft which are light and strong.

-Due to its size and electropositivity (opposite of electronegativity), lithium is used in both primary and secondary lithium batteries. Lithium is used in light weight electrical batteries of the type found in clock sand watches, heart pacemakers (a small piece of electronic equipment connected to someone’s heart to help the heart muscles move regularly).

-Otherwise its compound, Li_2CO_3, is used to toughen glass.

-Sodium: Globally, about 60% of Na was used to form alloys with lead, which was used to produce $PbEt_4$ and $PbMe_2$ used as anti-knock additive in Petrol. But nowadays it has been banned because it is a pollutant for the atmosphere?

-Caustic soda, NaOH, and soda ash, Na_2CO_3 are the most important alkali used in industries. Both find applications in paper making, alumina, soap, and rayon. Na2CO_3 (soda ash) is used in water treatment.

-NaOCl is used as bleaching agent and disinfectant.

-NaCl is used in seasoning food, preparing hydrogen chloride gas, manufacture of soap, manufacture of sodium, chlorine, sodium hydroxide and sodium carbonate.

-Molten sodium is used as a coolant in nuclear reactor. Its high thermal conductivity and low melting temperature and the fact that its boiling temperature is much higher than that of water make sodium suitable for this purpose.

-Sodium wire is used in electrical circuits for special applications. It is very flexible and has a high electrical conductivity. The wire is coated with plastics to exclude moisture.

-Sodium vapor lamps are used for street lighting; the yellow light is characteristic of sodium emission.

-Sodium amalgam (alloy with mercury) and sodium tetrahydridoborate, NaBH4, are used as reducing agents.

-Sodium cyanide is used in the extraction of silver and gold.

d) Expected answers to checking up 6.7

1) -Caustic soda, NaOH, and soda ash, Na_2CO_3 are the most important alkali used in industries. Both find applications in paper making, alumina, soap, and rayon. Na_2CO_3 (soda ash) is used in water treatment.

-NaOCl is used as bleaching agent and disinfectant.

-NaCl is used in seasoning food, preparing hydrogen chloride gas, manufacture of soap, manufacture of sodium, chlorine, sodium hydroxide and sodium carbonate.

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-Sodium vapor lamps are used for street lighting; the yellow light is characteristic of sodium emission.

-Sodium amalgam (alloy with mercury) and sodium tetrahydroborate, NaBH4, are used as reducing agents.

-Sodium cyanide is used in the extraction of silver and gold.

2) Because sodium is highly reactive with water and air

6.6 Summary of the unity

Group I elements:

- Are characterised by valence electronic structure ns
- Are good reducing agents. Their reducing power increases the top to the bottom down the group.
- Lithium behaves differently from other element in this group because of its small size which results in its polarizing power.
- Form ionic compounds with non metals.
- Are produced by electrolysis of corresponding molten salts.
- React with water to produce hydrogen gas and an alkaline solution
- React with oxygen to form monoxides, peroxides and superoxide. Lithium forms only monoxide.
- Form various compounds such as: oxides, hydroxides, carbonates, halides, nitrates, sulfates.

- Thermal decomposition of Lithium carbonate and lithium nitrate differs from that of the rest of the group due to small size of lithium.
- Flame test is used as identification test for group 1 elements.

6.7 Additional information for teachers

I. Solubility of compounds in water

When a salt dissolves in water two types of energy are involved:

1. The ions must be separated from the ionic lattice: this requires lattice dissociation energy (endothermic process).

2. The separated ions interact with the molecules of the water. Because water molecules are polar the charged ions are attracted to the end of molecules of water.(exothermic process)The energy released(hydration energy) as these attractive forces come into play is compensation for the energy required to dissociate the lattice.

For an ionic solid:

Energy of dissolution=Energy of lattice dissociation +energy of hydration

On balance the energy of dissolution may be positive or negative. A negative value favours dissolution.

6.8 Expected answer to end unit assessment

1 a)LiCl, NaCl, KCl, RbCl, CsCl. The solubility of chlorides increases down the group (from the top to the bottom)

b) Proceed to flame test: the suspected ion will show the following colour

Element	Flame colour
Lithium	Deep red
Sodium	Yellow
Potassium	Lilac/violet
Rubidium	Red
Caesium	Blue

2. a) When sodium is placed on water in a beaker it reacts vigorously, fizzing (a hissing sound is heard) and skating about on the water surface, a colourless gas is evolved.

b) $Na(s)+H_2O(l) \qquad NaOH(aq)+H_2(g)$

c) -the colourless solution should be tested using litmus paper: red litmus paper turns blue while blue litmus paper remains unchanged(this is an alkaline solution of NaOH)

-The colourless gas should be tested using a burning splint where a pop sound is heard.

3. a) A soluble compound which does not decompose on heat:K_2CO_3

b) A soluble compound which may decompose on heat releasing a gas that relights a glowing splint: KNO_3

c) A soluble compound which decomposes on heat releasing brown fumes and a colorless gas that support combustion. $LiNO_3$

d) A slightly soluble compound which decomposes on heat and releases a colorless gas that turns lime water milky.Li_2CO_3

4. a) Because of its small size Li forms :

-covalent compounds

-slightly soluble compounds Li_2CO_3, LiOH

-High melting point compared to other group members

b)

i) Atomic radius: in group 1 element atomic radius increases down the group as the number of filled shells with electrons increases as you pass from one period to another.

ii) Ionization energy: it decreases down the group as the atomic radius increases .Bigger atoms tend to electrons easily.

iii) Reducing properties: increases down the group as the atomic radius increases. Bigger atoms lose electrons easily.

iv) Reactivity with water: Increases down the group as the reducing properties increase. Bigger atoms are more reactive.

v) Electronegativity: Decreases down the group because bigger atoms are less attractive to electrons because of the screening effect exerted by the increasing number of shells

c) The first ionization energy is small because it is easier to remove one single electron from the outermost shell electrons. The second ionization energy becomes bigger because the electron is removed from a stable cation Na^+

d) Na^+ (number of electrons = 10):$1s^2\ 2s^2\ 2p^6$ (Na metal has lost one electron; stable structure similar to neighboring noble gas Ne)

Na^{2+} (number of electrons = 9):$1s^2\ 2s^2\ 2p^5$ (Na metal has lost 2 electrons; unstable structure)

e) The first group elements react by losing electrons .Easier is losing outermost electron easy is the reactivity.

6.9 Additional activities

6.9.1. Remedial activities

1. Explain the origin of the name alkali metal for group 1 element Illustrate your answer

using reaction of sodium with water.

2. Why does group 1 element form ionic compounds?

3. Potassium oxide is an basic oxide. What does it mean?

4. Write the equation of reaction between potassium with:

a) Oxygen

b) Chlorine

c) Water

5. Write the electronic structure of (Z=19) that of the ion K^+

Answers:

1. The name alkali comes from the ability of group 1 element to form strong alkaline solution when they react with water.

$$2Na(s) + 2H_2O\ (l) \longrightarrow 2NaOH(aq) + H_2(g)$$

2. Group 1 element form ionic compounds because they lose easily their single outermost electrons.

3. Potassium is a basic oxide because it reacts with water to form a basic solution.

4.a) $K(s)+O_2(g) \longrightarrow KO_2(s)$

b) $2K(s)+Cl_2(g) \longrightarrow 2KCl(s)$

c) $2K(s)+2H_2O(l) \longrightarrow 2KOH\ (aq) + H_2(g)$

5. K(Z=19)$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s1$that of the ion K^+: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6$

6.9.2. Consolidation activities

1. a) The statement below are about white solid compound containing an s-block element. For each statement say what conclusions can be drawn at that stage:

   i) The compound reacted with water to give a colorless gas and an alkaline solution.

   ii) The gas gives pop sound when tested with a small lighted wax candle.

   iii) A flame test on the solution gives a lilac flame.

b) Write the equation for the reaction.

2. a) This question concerns a white solid compound of an s-block metal. For each statement say what conclusions you can draw at that stage

   i) On heating it produced a brown gas and a white powder.

   ii) The resulting white solid was soluble to give an alkaline solution.

   iii) A flame test on the original solid gave a deep red color.

b) Write the equation for the reactions in(i) and in (ii)

Answers:

1.a) i. Alkali metal is suspected

ii) Hydrogen gas confirmed by pop sound with burning candle

iii) K is confirmed by the lilac flame color .

b)2 $K(s) + 2H_2O(l) \longrightarrow 2KOH(aq) + H_2(g)$.

2.a) i)Brown NO_2 gas is suspected resulting from decomposition of a nitrate

ii) An alkali oxide that dissolves in water is suspected

iii) Lithium ion are confirmed by the deep red flame test color

b i) $2LiNO_3(s) \longrightarrow Li_2O(s) + 2NO_2(g) + 1/2\ O_2(g)$.

ii) $Li_2O(s) + H_2O(l) \longrightarrow 2LiOH(aq)$.

6.9.3. Extended activities

An s-block element A is a starting point of a series of reaction that are described in the following lines.

The element A reacts with water to produce a solution of substance B and a colorless gas C. When A is burnt in chlorine gas, the substance D is obtained.

The aqueous solution of the substance D conducts electricity and gives a yellow color on a Bunsen flame.

On the other side A burns in oxygen gas giving 2 types of oxides E and F.

The oxide E gives a solution of substance B, while the oxide F reacts with water producing a solution of substance B and the release of a gas a colorless gas G.

The substance B reacts with an acidic solution of nitric acid to give a salt solution H of nitrate of A which decomposes on heat to produce a salt I and the colourless gas G.

a) Identify substance A to I

b) Write the equations of reactions that lead to substance B in the description above.

c) Explain what happens when A is burnt in oxygen to form E and F

d) Write the equation of reaction between F and water.

e) Describe the chemical tests to differentiate the gases C and G

f) Write the equation of thermal decomposition of substance H

Answers:

a) The key of the statement is located on the confirmatory yellow flame test which indicates the presence of Na^+

So D is a salt that contains sodium ions. The beginning point A is Na .So the series of reactions contain sodium in the following stages.

Stage 1:A: Na, B:NaOH,C:H_2, D:NaCl,

Stage 2: E: Na_2O, F: Na_2O_2, substance B: NaOH, Colourless gas G is O_2

Stage 3:H: $NaNO_3$ I: $NaNO_2$ G:O_2

b) $Na(s) + H_2O(l) \longrightarrow NaOH(aq) + H_2(g)$

c) Normal oxide of sodium and sodium peroxide are formed because of the vigorous reactivity of Na

d) Na2O2 $(s) + H_2O\ (l) \longrightarrow 2NaOH(aq) + O_2(g)$

e) C is hydrogen and tested by a burning splint. The pop sound is heard.

G is oxygen and tested using a glowing splint that is relighted.

f) $2NaNO_3(s) \longrightarrow 2\ NaNO_2(s) + O_2(g)$

UNIT 7: TRENDS IN CHEMICAL PROPERTIES OF GROUP 2 ELEMENTS AND THEIR COMPOUNDS

7

7.1 Key unit competency

The learner should be able to compare and contrast the properties of the group 2 elements and their compounds in relation to their position in the periodic table.

7.2 Prerequisite knowledge and skills.

Students learnt from the previous units

- -Trends in chemical properties of group1 elements and their compounds
- -Factors influencing the ionization energy.

7.3 Cross-cutting issues addressed:

Environmental sustainability:

The exploitation of limestone for the manufacture of slaked lime and cement can be the cause of destroying the textile of the land. Therefore, the erosion can occur easily.

Inclusive education

This unit involves a number of activities like experiments on the chemical properties of group 15 elements and their compounds. The activities require assembling of apparatus, writing, reading and observation of the results. This may be challenging to students with special educational needs especially children with visual impairment difficulties. However, the teacher can make some arrangements like:

Grouping students: Students with special educational needs are grouped with others and assigned roles basing on individual student's abilities.

- Providing procedure earlier before the experiment so that students get familiar with them. They can be written on the board or printed depending on available resources. If you have children with low vision remember to print in appropriate fonts.
- Give extra time for them to write summary notes or write down observations after experiments.
- Every important point is written and spoken. The written points helps students with hearing impairment and speaking aloud helps students with visual impairment
- Remember to repeat the main points of the lessons.

For learners with hearing difficulties:

Teacher has to encourage them to sit closer to the front of the classroom. While teaching, avoid asking learners whether they have understood, or if they need you to repeat a point. Encourage learners not to be afraid to ask questions. When teaching, speak clearly and ensure that all the learners can hear your voice. Avoid speaking hurriedly as this will make it difficult for learners with hearing difficulties to make sense of what you are saying.

Learners with mobility difficulties:

- These include learners in crutches, wheelchairs, or with walking difficulties. Encourage other learners to look out for and help their classmates. Ask their follow learners to help them with their notes, if their conditions hinder them from writing well.

Learners with reading difficulties:

Learners with this kind of difficulties struggle to make sense of words or understand written work and take longer to read than other learners. 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.

Gender:

During group activities try to form heterogeneous groups (with boys and girls) or when students start to present their findings encourage both (boys and girls) to present.

Financial education

As the unit deals with the importance of group 16 elements and their compounds in modern life, the teacher will draw the learner's attention on the economical impact of the making of common items made using knowledge of chemistry.

Peace and values education

During group activities, the teacher will encourage learners to help each other's and to respect opinions of colleagues.

7.4 Guidance on introductory activity

To study the trends in chemical properties of group 2 elements, it is necessary to explore all points related to the alkaline earth metals as they are found in this introductory activity.

Expected answers for the introductory activity

Substance	Element	Occurrence
Chalk	Calcium	Chalkstone rock
Slaked lime	Calcium	Limestone rock
Limestone	Calcium	Limestone rock

Medicine plaster/ Plaster of paris	Calicium	Gypsum
Malox drug	Magnesium	Magnesium hydroxide

7.5 List of the lessons

Heading	Lesson title	Learning objectives	Number of periods = 19
7.1	Occurrence and physical properties of group2 elements	-Describe the physical properties of group 2 elements. -Describe the properties of group 2 oxides and hydroxides.	3
7.2	Reactivity of group 2 elements with oxygen, water, halogens and dilute acids.	-Perform experiments to compare and contrast the reactivity of group2 elements. -Write balanced equations of the reactions of group2 elements, different elements and the compounds.	3
7.3	Properties of group 2 compounds	-Illustrate practically the trends in solubility and thermal decomposition of group 2 compounds. -Test the alkaline character of group 2 hydroxides -Explain the trends in the thermal decomposition of group 2 carbonates and nitrates. -Explain the trends in the solubility of group2 compounds	5
7.4	Anomalous properties of beryllium compounds	-Be aware that the compounds of beryllium are different from the compounds of the other group elements.	2

7.5	Identification test of Ba2+ ions in aqueous solutions.	- Perform chemical test for the presence of group2 cations in solution.	2
7.6	Uses of group 2 elements	-Develop the attitude of sustainable exploitation of natural resources . -Stimulate the culture of entrepreneurship in the area of chemistry. -Suggest preventive measures for environmental and health issues associated with the manufacture of the cement.	2
7.7	End unit assessment		2

Lesson 1: Occurrence and physical properties of group2 elements

a)Introduction

Students have studied the electronic configuration, occurrence of group 1 elements and that knowledge will help them to understand more the occurrence and properties of group 2 elements.

b)Teaching resources

Use of the illustrations (example: a photo of limestone) found in the student’s book.

c)Learning activities

- The students form groups composed by 5 students maximum.
- The activity 7.1 is given to engage students
- Guided by the teacher, students present their findings

Expected answers for activity 7.1

In our nearest area we can find

- Pieces of chalk.
- Slaked lime for decoration of houses.
- Cement as building material.
- Limestone found in some region of our country.

d)Application activities (Checking up 7.1)

1.As you go down the group, electronegativity decreases.

Explanation:

- Be has the small atomic radius while Barium has the big one
- The outermost shell of Be is not far from the nucleus.
- It is easier for beryllium to form covalent compound than barium.

Therefore, as you go down the group2, the nuclear attraction decreases and ability to form a negatively charged ion decreases. The best reducing agent Ba

2.i)**Atomic radius:** It increases as you go down the group because; each element below has more number of shells.

ii)**Ionization energy**: Ionization energy is inversely proportional to the metallic character. As you go down, the ease of losing electron increases. Therefore, the energy required to remove electron will be low as you go down group and ionization energy decreases.

iii)**Electropositivity:** This is the ability of an atom to form a positively charged ion. As you go down, the outer electron will be far from the nucleus and it can be removed easily. Therefore, electropositivity increases downward.

Lesson 2: Reactivity of group 2 elements

a)Introduction

Students have studied the occurrence of group 2 elements and that knowledge will help them to identify their compounds and the corresponding reactivity.

b)Teaching resources

- Tables which are found in the student's book can describe well the compounds of group2 elements. There are some equations to explain the reactivity with water, acids, oxygen and alkalis.
- The teacher can use videos to explain the concept.
- In this lesson, the students can carry out the experiment about the reaction

c)Learning activities

- The students form groups composed by 5 students maximum.
- The activity 7.2 is given to engage students
- Guided by the teacher, students present their findings

Expected answers for activity 7.2

Task 1

- For the first beaker, magnesium ribbon cannot react with cold water. When the blue or red litmus papers are used, there is no observable change.

Mg (s) + cold water → no reaction and observable change.

- For the second beaker, sodium reacts violently with water to yield the alkaline solution and hydrogen gas.

$Na(S) + H_2O(l) \rightarrow NaOH(aq) + H_2(g)$

The solution in the second beaker will turn red litmus paper into blue.

Task 2

- When magnesium react with steam, it yield the white powder which is solid Mg(OH)2

$Mg(s) + H2O(g) \rightarrow Mg(OH)2(s) + H2(g)$

Experiment:

When magnesium ribbon is put in aqueous hydrochloric acid, there is production of hydrogen gas and a colourless solution of magnesium chloride.

Equation: $Mg(s) + 2HCl(aq) \rightarrow MgCl2(aq) + H2(g)$

Checking up 7.2

1.Reactions of group 2 elements

$Be(s) + H2O(l) \rightarrow$ no reaction

$3Be(s) + N_2(g) \rightarrow Be_3N_2(s)$

$Be(s) + 2HCl(aq) \rightarrow BeCl_2(aq) + H_2(g)$

$Mg(s) + H2O(g) \rightarrow Mg(OH)_2(s) + H_2(g)$

$3Mg(s) + N_2(g) \rightarrow Mg_3N_2(s)$

$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

$Ca(s) + H_2O \rightarrow Ca(OH)_2(aq) + H_2(g)$

$3Ca(s) + N_2(g) \rightarrow Ca3N_2(s)$

$Ca(s) + 2HCl(aq)CaCl_2(aq) + H_2(g)$

Radium is radioactive element, is not considered, beryllium reacts difficultly.

2.Beryllium reacts difficultly with the reagents above, because it has the small atomic size. The metallic character is low.

Lesson 3: Properties of group2 compounds

a)Introduction

At this point, students use the previous knowledge related to:

- Ionic character
- Covalent character
- Trend in atomic and ionic radius.
- Trend in first ionization energy.

b)Teaching resources

The teacher uses different books, especially the content found in the student's book. Other resources such as internet are recommended.

c)Learning activities

Students provide different ideas about the planned activities.

All answers from students (wrong and correct) are collected and answered through a brainstorming.

Expected answers for activity 7.3

Answers 7.3.1 (a)

In beaker number 1.Calcium chloride is an ionic compound. All ionic compounds are soluble in polar solvent such as water.

In beaker number 2.Calcium chloride does not dissolve in non polar solvents such as paraffin.

Answers 7.3.1 (b)

- Burning magnesium ribbon, the ash produced is MgO

$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$

The ash is soluble in water to produce the alkaline solution.

$MgO(s) + H_2O\ (l) \rightarrow Mg(OH)_2(s)$

When phenolphthalein is introduced, the solution becomes pink to justify the alkaline

Answers.7.3.2

When you heat a salt of group 2 elements, some are decomposed to produce the gas

$2Ca(NO3)_2(aq) \rightarrow 2CaO(s) + 4NO_2(g) + O2(g)$

$CaCO3(aq) \rightarrow CaO(s) + CO_2(g)$

CaSO4 resists to the thermal decomposition

Na2CO3 resists to the thermal decomposition

When the wet blue litmus paper is used:

- -Nitrates produce nitrogen dioxide which turn blue litmus red. Hence, the gas is acidic.
- -Carbonates produce carbon dioxide which turns blue litmus red. Hence, the gas is acidic.

Answers 7.3.3

Test tube	Compound	Observation
1	Magnesium hydroxide	White precipitate
2	Magnesium sulphate	Slight soluble
3	Calcium hydroxide	White precipitate
4	Calcium sulphate	Slight soluble
5	Strontium hydroxide	Slight soluble
6	Strontium sulphate	Sparingly soluble
7	Barium hydroxide	Slight soluble

8	Barium sulphate	White precipitate

Comments:

Sulphate of group 2 elements

Their solubility decreases down the group due to little decrease in lattice energy down the group.

BeSO4 and MgSO4 are soluble

CaSO4 is slightly soluble

SrSO4 and BaSO4 are insoluble.

Hydroxides of group 2 elements

Their solubility increases down the group due to increase in ionic character of the hydroxides and rapid decrease in lattice energy as the group is descended.

Be(OH)2 and Mg(OH)2 are insoluble

$Ca(OH)_2$ and Sr(OH)2 are slightly soluble, and $Ba(OH)_2$ is fairly soluble

d)Application activities (Checking up 7.3)

Checking up 7.3.1

1) Factors which causes group 2 elements to dissolve:

- Ionic size
- Covalent character of their compounds
- Position of the element in the periodic table.

2) It is an oxide which dissolves in water to form an alkaline solution.

3) $CaO(s) + H_2O(l) \rightarrow Ca(OH_{)2}(s)$

Expected answers to checking up 7.3.2

1.A: Na_2CO_3

B: $CaCO_3$

For explanation refer to student's book.

2.$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$

Expected answers to checking up 7.3.3

1. Use any soluble sulphate. The reaction between sulphate ions ($SO4^{2-}$) and barium ions (Ba2+) forms a white precipitate of a barium sulphate.

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(9)$

2. Pour the 2 samples in water. $Be(OH)_2$ is insoluble and $Ba(OH)_2$ is soluble in water.

Lesson 4: Anomalous properties of beryllium compounds

a)Introduction

Students have studied:

- The general properties of group 1 and group 2 compounds.
- The anomalous properties of lithium compounds in group 1 elements.

b)Teaching resources

Use of the illustrations found on internet. Considering equations found in the student' book.

c)Learning activities

- The students form groups composed by 5 students maximum.
- The activity 7.4 is given to engage students and to use their critical thinking.
- Guided by the teacher, students present their findings.
- **Expected answers for activity 7.4**

1.-Beryllium is in group 2, but it reacts with alkalis as it is done for aluminium. They are not in the same group, but they have the diagonal relationship.

Anomalous properties of beryllium

- 2 Size of atom: This causes the compounds of this element to exhibit the covalent character. The compounds of beryllium are hydrolyzed to produce the acidic medium. Therefore, the element can react with alkalis while other group 2 elements cannot.
- The hardness of the metal: Compared to other group metals, beryllium cannot react with water. This is caused by the hardness of the element.

d)Application activities (Checking up 7.4)

Compound	Reagents or solvent	Observation &Equations (if any)
Be(OH)2	HCl	$Be(OH)_2(s) + 2HCl(aq) \longrightarrow BeCl_2(s)) + 2H_2O(l)$
Be(OH)2	NaOH	$Be(OH)_2(s) + NaOH(aq) \longrightarrow Be(OH)_4^{2-}(aq)$
BeCl2	Non polar solvent	Soluble

Lesson 5: Identification test for Ba^{2+} ions in aqueous solutions

a)Introduction

Students have studied:

- Identification of group1 and group 2 ions
- The flame test for group 1 and group2 elements.
- Solubility and thermal stability of compounds of group 1 and 2 elements.

b)Teaching resources

Use of the illustrations found on internet. Considering equations found in the student's book.

c)Learning activities

- To provide a table of ion identification to students
- Formation of groups of 5 students
- Students exchange ideas on the activity 7.5

Expected answers for activity 7.5

Task1: Colours of flames are found in the table (See the student book).

Task2: Sodium sulphate provides the SO4^{2-} ions which react with Ba^{2+} ions to for a white precipitate.

The precipitate can be removed by filtration.

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$ (White precipitate)

d)Application activities (Checking up 7.5)

Ba2^{+} ions are harmful and can cause the health problems. To stop its absorption in digestive tube, it is necessary to create the precipitation reaction in the stomach.

Before vomiting, the physician gives to the patient, a solution of sodium sulphate.

In the stomach: $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaCl(aq)$

White precipitate

The precipitate is removed by vomiting.

Lesson 6: Uses of group 2 elements and their compounds

a)Introduction

Students have enough knowledge on:

- The use of compound of group1 elements.
- Decomposition reaction

b)Teaching resources

Use of the illustrations found on internet. Considering equations found in the student's book.

c)Learning activities

The activity is given to the students. Through the brainstorming, all answers from students are collected, harmonized and answered correctly.

Expected answers for activity 7.6

Some compounds can be used to prepare others.

Examples:

a) The limestone is natural; it cannot be prepared from either quicklime or slaked lime.

b) Decomposition of **limestone** by heating, a process called calcinations, giving **quicklime** and carbon dioxide.

Calcination: $CaCO3(s) \longrightarrow CaO(s) + CO2(g)$

c) The product formed, CaO(s), is called lime or quicklime. Hydration of quicklime giving **Slaked lime**

In the process of hydration, the reaction of **quicklime** with water produces Ca(OH)2(s) known as slaked lime.

Hydration: $CaO(s) + H2O(l) \longrightarrow Ca(OH)2(s)$

Expected answers for checking up 7.6

Refer to student's book

d)Application activities

Question1.

- **Limestone:** Is the starting material for the manufacture of cement.
- **Plaster of Paris**: Plaster of Paris is best known as the ingredient used in making casts for broken bones, but it is also used for sculptures and plasterboard walls.

Question2

First step: Decomposition of limestone by heating, a process called calcinations, giving quicklime.

Calcination: $CaCO3(s) \longrightarrow CaO(s) + CO2(g)$

Calcination is carried out in a high-temperature with continuous removal of CO2 (g) to promote the forward reaction. The product formed, CaO (s), is called lime or quicklime.

Second step: Hydration of quicklime giving Slaked lime

In the process of hydration, the reaction of quicklime with water produces Ca(OH)2(s) known as slaked lime.

Hydration: $CaO(s) + H2O(l) \longrightarrow Ca(OH)2(s)$

Question 3:

- -**Reactions with Water**: Beryllium does not react with water; however, magnesium, calcium, strontium, and barium do react to form metal hydroxides and hydrogen gas.

Example: $Ba(s) + 2H_2O(l) \longrightarrow Ba(OH)2(aq) + H_2(g)$

- -Reaction with alkalis: All the elements except beryllium do not react with alkalis. Beryllium reacts with aqueous alkalis forming complex called berryllate.

Example: $Be(s) + 2OH\text{-}(aq) + 2H_2O\ (l) \longrightarrow [Be(OH)4]_2\text{-}(aq) + H_2(g)$

7.6 Summary of the unit

Group 2 elements contain soft, silvery metals that are less metallic in character than group 1 elements. Although many characteristics are common across the group, the heavier metals such as Ca, Sr, Ba and Ra are almost as reactive as the group 1 metals.

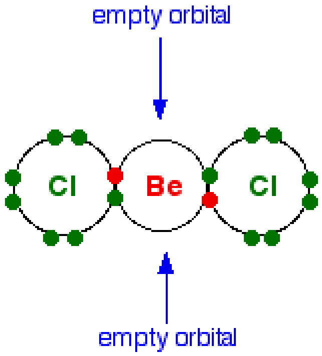
All the elements in group 2 have 2 electrons in their valence shells giving them an oxidation state of +2. This enables the metals to easily lose electrons, which increases their stability and allows them to form compounds via ionic bonds.

- In each case, the two outer electrons feel a net charge of 2+ from the nucleus.
- First ionization energy falls as you go down the group.
- All of these elements are held together by metallic bonds.
- Solubility of their hydroxides increases as you go up in the group, while that of sulphates decreases as you go down the group.
- Beryllium exhibits some abnormalities such as reaction with alkalis and formation of a covalent chloride.
- Limestone which is a calcium containing substance is used in the manufacture of cement and slaked lime.

7.7Additional information for teachers

a)Anomalous of beryllium

Group 2 elements react with chlorine to give the chlorides. Their chlorides become more ionic as you go down the group because as the size of metallic ion becomes larger, the resulting chloride will ionize easily. In this group, the exceptional case is beryllium chloride which is a covalent compound. Although beryllium is a metal, its size and place in the periodic table justify its low metallic character which will be the cause of forming a covalent chloride.



Beryllium chloride, BeCl2, melts at 405°C and boils at 520°C. That compares with 714°C and 1412°C for magnesium chloride.

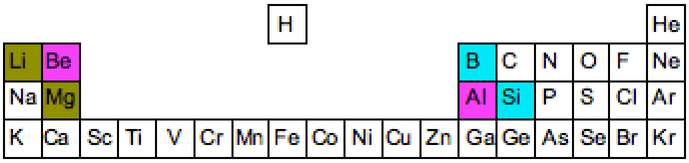
Notice how much dramatically lower the boiling point of beryllium chloride is compared with magnesium chloride. The much higher boiling point of magnesium chloride is what you might expect from the strong forces between the positive and negative ions present.

Because its boiling point is much lower, it follows that beryllium chloride can't contain ions , it must be covalent. On the other hand, the melting point is quite high for such a small covalent molecule.

Beryllium chloride reacts vigorously and exothermically with water with the evolution of acidic, steamy hydrogen chloride gas. This is typical of covalent chlorides.

b) Diagonal relationship

Three examples are shown in the diagram below. Notice that the similarities occur in elements which are diagonal to each other - not side-by-side.



							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr

At the beginning of periods 2 and 3 of the Periodic Table, there are several cases where an element at the top of one group has some similarities with an element in the next group.

For example, boron is a non-metal with some properties rather like silicon. Unlike the rest of Group 2, beryllium has some properties resembling aluminium. And lithium has some properties which differ from the other elements in Group 1, and in some ways resembles magnesium.

There is said to be a diagonal relationship between these elements.

There are several reasons for this, but each depends on the way atomic properties like electronegativity vary around the Periodic Table.

So we will have a quick look at this with regard to electronegativity - which is probably the simplest to explain.

7.8. End unit assessment answers

1. b) Potassium

2. True

3. Calcium

4. Beryllium: Because ionization energy increases as you go up in the group.

5. Ra: Because, the melting point decreases as you go down in the group.

6. Because most of them occur in the rock (Example: Limestone)

7.

-**Beryllium:** Bright white flame.

-**Magnesium**: Very bright white flame.

-**Calcium:** Brick red.

-**Strontium**: Crimson red.

-**Barium**: Apple green.

8. They lose 2 electrons to achieve to the structure of the nearest noble gases **(They become more stable).**

9. Radium is radioactive.

10. Be is a reducing agent.

11.a) the increasing atomic number,

i)Atomic radius increases.

ii)Ionisation energy decreases.

iii)Strength as reducing agent increases.

iv)Vigour of reaction with chlorine increases.

v)Electropositivity increases.

b)

i)Because, as the number of shells increases the atom becomes larger.

ii)As you go down, the energy required to remove electron becomes low. The outer electron will be more distant from the nucleus.

iii)Ability of losing electron increases as the size of atom increases.

iv)The reactivity of metals increase with the metallic character. It means, as you go down the group.

v)As you go down the group, the ability of losing electrons increases and element becomes more electropositive.

12. a) All elements are metals, they react by losing electrons and each exists in giant metallic structure.

b) Ca^{2+} only.

c) Mg has 2 outermost electrons. It forms compounds after losing two electrons to have the structure of the nearest noble gas (neon with 10 electrons).Therefore, the ion will be Mg^{2+} instead of Mg^{+} .

d) As you come from left to right (From group1 to group 2), the size of the metallic ion becomes smaller and more able to attract the great number of water molecules. There is high number of moles of water of crystallization in group2.

13. Group2 elements have oxidation state of +2 because they are reduced by transferring only 2 electrons.

b) They cannot be reduced by transfer of either 1 or 3 electrons.

c) The way of measuring the second ionization of magnesium.

$Mg \rightarrow Mg^{+} + e-$ First ionisation

$Mg+ \rightarrow Mg^{2+} + e-$ Second ionisation

7.8Additional activities

7.8.1. Remedial activities

1. Show how the following substances can be obtained.

a)CaO from Ca

b)BaCl2 from Ba

c)Mg(OH)2 from MgCl2

d)Ca(OH)2 from CaCO3

e)SrCl2 from SrCl2.6H2O

f)Na2Be(OH)4 from BeO

Expected answers

1.

$Ca(s) + O_2(g) \rightarrow CaO(S)$

b)Ba(s) + 2HCl(aq) →BaCl2(aq)

c)MgCl2 + 2NaOH(aq) →Mg(OH)2(s) + 2NaCl(aq)

d)Heating the salt:

CaCO3(S) →CaO(S) + CO2(aq)

CaO + H2O →Ca(OH)2

e)Heating the hydrated salt:

SrCl2.6H2O → SrCl2 + 6H2O

BeO(S) + H2O(l) →Be(OH)2(s)

Be(OH)2 + 2NaOH→Na2Be(OH)4

7.8.2. Consolidation activities

1. Magnesium and strontium are typical group 2 metals.

a) Complete the electron configuration of magnesium atom.

b) The second ionization energy of magnesium is $1064 kJ.mol^{-1}$.

i) Write an equation to represent the second ionization energy of magnesium. Include states and symbols.

ii) Magnesium has a greater, second ionization energy than strontium. Explain why?

c) A student watches a demonstration in which strontium is added to water.

The equation for the reaction is shown below.

Sr(s) + 2H2O(l) →Sr(OH)2(aq) + H2(aq)

i) Write the formulae of the aqueous ions formed when this reaction takes place.

ii) In terms of electron transfer, explain why strontium has been oxidized.

iii) Suggest two compounds which could be reacted together to produce Sr(OH)2

d) Suggest the formula of the acid used to form SrSO3.

Expected answers

1.a) Mg (z = 12):$1s^2 2s^2 2p^6 3s^2$

b) i) Mg → Mg^+ + e- First ionization

Mg+ →Mg^{2+} + e- Second ionization

ii) Magnesium is above strontium in the periodic table. The second ionization energy decreases as you go down the group, because the second electrons will be more distant from the nucleus when number of shells increases. The nuclear attraction decreases and the electron is removed easily.

c) i) The aqueous ions are:

Sr^{2+} (aq) and $2OH^-$(aq)

ii) Srontium has the ability of losing the electrons (electropositivity), while oxygen has the ability of gaining them. Strontium is oxidized by oxygen of water.

iii) Example:SrCl2 and NaOH

d)H2SO3 react with Sr(OH)2

7.8.2. Extended activities

1) Group2 carbonates undergo thermal decomposition.

a) Write the equation for the thermal decomposition of calcium carbonate.

b) Write the formula of the group2 carbonate which decomposes at the highest temperature.

2) Hydrated sodium chloride $SrCl_2.6H_2O$ has a molar mass of 266.6g.mol-1.A student heats 5.332g of $SrCl_2.6H_2O$.

The $SrCl_2.6H_2O$ loses some of its water of crystallization forming 3.892g of a solid product.

Use the information above to determine the formula of the solid product. Show your working.

3) A chemist carries out reactions of barium nitride, Ba_3N_2.

Reaction1: Barium is reacted with water.

Reaction2: Barium nitride is reacted with water, forming an alkaline solution and an alkaline gas.

Reaction3: Barium is reacted with an excess of oxygen at 500oC, forming barium peroxide, BaO_2

a)Write equations for reaction 1 and reaction2 (Ignore state and symbols)

b) Determine the oxidation states of barium and nitrogen in $Ba3N^{2-}$.

c) BaO2 formed in reaction 3 contains barium and peroxide ions. The peroxide ion has the structure $[O\text{-}O]^{2-}$.

Determine the oxidation states of barium and oxygen.

Expected answers

1.a) $CaCO_3(S) \rightarrow CaO(S) + CO_2(aq)$

b) $BaCO_3$

2) $SrCl_2.6H_2O \rightarrow SrCl_2 + 6H_2O$

The solid produced is $SrCl_2$

3 .a) Reaction1: $Ba + 2H_2O \rightarrow Ba(OH)_2 + H_2(g)$

Reactio2: $Ba3N_2 + 3H_2O \rightarrow 3Ba(OH)_2(aq) + N_2(g)$

b)Barium: Oxidation state = +2

Nitrogen: Oxidation state = -3

c) Ba: Oxidation state = +2

O: Oxidation state = -1

UNIT 8: TRENDS OF CHEMICAL PROPERTIES OF GROUP 13 ELEMENTS AND THEIR COMPOUNDS

8

8.1.Key unit competency

To be able to compare and contrast the chemical properties of the Group 13 elements and their compounds in relation to their position in the Periodic Table.

8.2.Prerequisite knowledge and skills

Components of an atom and their properties, definition of an atomic number, mass number and electronic structure, chemical reactions,trend in physical properties of elements in periodic table,handling laboratory equipments, safety rules and regulations in laboratory.

8.3.Cross-cutting issues to be addressed

Gender equality

There is a general need of people to complement one each over without conflict in order to be peaceful.

The nature of atoms can be related to relationship in human beings. There is a serious issue of misunderstanding of gender equality in our society. When introducing this unit, it would be an opportunity to guide learners on understanding the importance of gender equality and how the issues related to gender inequality may be addressed.

Help learners to:

a) Understand that complementarities are very important. Atoms react to form bond between them. Metals lose their electrons to get stable .the lost electrons are gained by nonmetals. There are complementarities between metals and non metals to give stable compounds. Students should know that female and male are both human beings and one needs each other to establish good relationship and no one should say that he/she is more indispensable than another.

b) Understand that gender equality plays a big role in the development of the country.

c) Understand that female needs male and vice-versa in different ways for their future achievement.

d) Underlining the necessity of cooperation and working in mixed group rather than working in single group)

You can do this in a short whole class discussion. This may be an opportunity for you as chemistry teacher to confront the individual students who need advise on relationship matter.

Environment and sustainability

We live in environment where human beings have an significant impact ,both positive and negative. The demand for survival requires hard working without thinking on direct impact of our action. Handling chemical requires taking into consideration their different effect on the environment .This unit is an opportunity to guide learners on understanding the impact of air, water and soil pollution. This issue should be addressed especially considering the different uses of chemicals and different ways of waste management mainly chemical wastes.

- Help learner to work in healthy environment
- Learners perform experiment by keeping the classroom environment clean before and after the experiment.
- Learner are skilled on the ways of waste management
- Learner are also skilled on the rational use of chemical by avoiding or reducing all means of pollution

Inclusive education

This unit involves a number of activities that involves practical work; observation, use of sense organ, reading and writing. This may be challenging to students with special educational needs especially children with physical impairment, hearing impairment, visual impairment. However, the teacher can make some arrangements like:

- Classroom should be accessible to all learners
- Grouping students. Students with special educational needs are grouped with others and assigned roles basing on individual student‘s abilities.
- Providing procedure earlier before the activity so that students get familiar with them. They can be written on the chalkboard or printed depending on available resources. If you have children with low vision remember to print in appropriate fonts or in Braille.
- Every important point is written and spoken. The written points helps students with hearing impairment and speaking aloud helps students with visual impairment.
- Remember to repeat the main points of the lessons
- Remember to allow learners with disabilities to get helped with their colleagues without disabilities

Financial education

As any field that involves some kind of expenses, the teacher should focus on the rational use of chemical while performing experiment ,strategies that should put into action to minimize the cost of manufactured products, so as to enhance the competition with products from various factories.

8.4. Guidance on introductory activity

Before introducing the first lesson (outline of the properties the first group elements by examining them in a table of physical properties and relating them to general trend in the group) of this unit, let learners attempt the introductory activity.

8.5. List of lessons

Heading	Lesson title	Learning objectives	No of periods
1.Physical properties of Group 13 elements	Physical properties of Group 13 Elements (physical state, metallic character, physical appearance).	State the physical properties of Group13 elements.	1
2.Reactions of group 13 elements	Reactions of group 13 elements with: oxygen, water, halogens, dilute acids and sodium hydroxide	Explain, Compare and contrast the reactivity of Group 13 elements with oxygen, water, halogens, dilute acids and sodium hydroxide. Develop attitude of orderliness when performing experiments.	3

3.Amphoteric character of aluminium and gallium oxides and hydroxides.	Amphoteric character of aluminium and gallium oxides and hydroxides	Perform experiments to show the solubility of Group 13 compounds Practically illustrate the amphoteric properties of aluminium oxides and hydroxides. Develop attitude of orderliness when performing experiments. Develop a team approach and respect of diverse opinions during group discussions and practical	1
4. Anomalous properties of boron and its compounds	Anomalous properties of boron and its compounds	Identify the anomalous properties of boron and its compounds.	1

5. Identification of Al^{3+} ion in aqueous solution.	Identification of Al^{3+} ion in aqueous solution.	Perform chemical tests for the presence of aluminium ion in solution. Develop attitude of orderliness when performing experiments. Develop a team approach and respect of diverse opinions during group discussions and practical activities	1

6.Uses of Group 13 elements and their compounds:	Uses of Group 13 elements and their compounds: - Boron: making electronic devices. - Aluminium: electric cables, kitchen utensils, construction, packaging....	State the uses of Group 13 elements and their compounds. Appreciate the uses of Group 13 elements in daily life)	1
7.Assessment			2

Lesson 1: Physical properties of Group 13elements

This is the first lesson of unit 6 and is divided into two periods. The first lesson also covers the introduction of the whole unit (introductory activity). You are advised not to spend a lot of time on this introductory activity. This is only intended to raise the curiosity of learners to group I elements

a) Introduction

- Students will learn better the physical **properties of group 13 elements** if they have understanding on: the variation in trends of physical properties of elements in periodic table, the arrangement of elements in the periodic table and writing the electronic configuration of elements, (refer to unit 5).
-

b) Teaching resources

- Periodic table of elements
- Use the table of physical properties of group 1 elements in the students' book for lesson 1 illustrations drawn on a manila paper.
- Other relevant chemistry text books if available in the library.

c) Learning activities

- With the aid of previous lessons (unit 5,6 ,7) learners are tasked to read deeply on the variation in trends of physical properties in the periodic table and the chemical properties of group 1 &2. This can be a basic to understand how is the trend in chemical properties of group 13 elements in comparison to their physical properties.
- Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt the introductory activity and thereafter proceed to activity 6.1 which leads students to the first lesson of the unit.
- Form groups of 3-4 depending on the size of the class.
- Distribute the introductory activity and estimate the time for it.
- Let the learners proceed and do activity 6.1 of lesson 1.
- Allows the learners to work together in groups.
- Invite group leaders to present their findings.
- Here brainstorming, think pair -share could be used
- In this step you can guide the learners to evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- You summarize the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated in step 2.
- Integrate crosscutting focus of uniting to reinforce strength between relationships and to keep peace and value.

Expected answers for the introductory activity

1a) B:$1s^2\ 2s^2\ 2p^1$

Al: $1s^2\ 2s^2\ 2p^6\ \mathbf{3s^2\ 3p^1}$

Ga: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^1$

In: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2 4d^{10}\ 5p^1$

Tl:$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6\ 6s^2\ 4f^{14}\ 5d^{10}\ 6p^1$

b) All of them belong to p-block since the orbital p in each case is being filled of electrons

B:: period 2

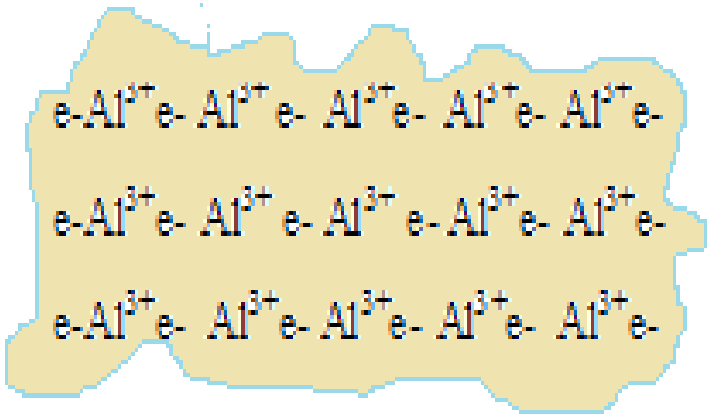
Al: period 3

Ga: period 4

In: period 5

Tl:period 6

2.



The metallic bonding consists of electrostatic attraction between the positive cation Al^{3+}and the negative electrons

3. Applications of group 13 elements (Aluminium):

- used in making cooking utensils.
- used as window frames or doors in buildings and houses.
- used as overhead high tension cables for distribution of electricity:
- used in alloys (e.g. Al and Mg) for the construction of airplanes and small boats
- for packaging food.

4. The electrical conductivity depends upon the number of free electrons that contribute to metallic bond formation. Each aluminium atom has 3 free electrons that contribute, while each sodium atom has only one electron that contributes. So aluminium is a better conductor of electricity than sodium.

Expected answers to activity 8.1

(a) Group 13 elements have higher melting point than group 1and 2 elements due to strong metallic bond resulting from 3 valency electrons involved in making metallic bonding

b) Boron has higher ionization energy due to its extremely low size and high nuclear charge/size ratio, so it is difficult to remove electrons from smaller atoms.

Expected answers to checking up 8.1

1. a) Al: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$

b) $Al \longrightarrow Al^{3+} + 3e^-$

c)The electrons in s and p orbital have almost the same energy and are available to participate at the same time in bond formation resulting in formation of Al^{3+}. In addition to this Al^{3+} is more stable than Al^{+}

2. The strength of metallic bond depends on the number of free electrons involved in the bond and the charge of the cation .The strong metallic bond in aluminium results from a strong electrostatic attraction exerted by the 3 charge

cation and a big number of sea electrons available.

3.i) The relationship between atomic radius and the boiling point.

Down the group atomic size increases and the smaller atoms are compactly held together. The greater the forces of attraction and hence the boiling point (melting point) decreases down the group as the atomic radius increases.

ii) The relationship between atomic radius and ionization energy: In small atoms electrons are held tightly and are difficult to remove while in large ones, they are less tightly held since they are far away from the nucleus and are easy to remove so that the ionization energy decreases down the group as the atomic radius increases.

4. A is Tl due its big size and low melting point, while B is boron because of small size and the higher melting point .Therefore the remaining C is Al because of the intermediate values of size and melting point .In fact the atomic size increases down the group from B, Al to Tl, while the melting point decreases as the atomic radius increases down the group i.e from B ,Al to Tl

5. Matching: 1.A 2. B 3.C

Lesson 2: Reactions of group 13 elements

a) Introduction:

Before beginning this lesson, learners should be able to write the electronic structure of elements, to determine the valences of elements in periodic table, to write formulae of compounds, to write and balance chemical reactions.

b) Teaching resources

- The Periodic Table of Chemical Elements
- Charts of the apparatus to carry out some experiments

c) Learning activities

- Learning activity 8.3 is suggested in students‘ book.
- Form groups of 3-5 students. The number of groups and members will depend on your class size.
- In the groups students attempt activity 8.3, discuss and record their answer. Learners perform suggested experiments in activity 8.3.1,8.3.2,8.3.3,8.3.4 .
- Each group representative presents their answers to the whole class.
- During the presentation ask some questions that lead to lesson conclusion such as writing equations of chemical reactions.
- Make a summary of the lesson (short notes) and assess your lesson. Let students do tasks on experiments in activity 8.3.1,8.3.2,8.3.3 and checking up 8.3. Learners should do the checking up activity in any method you wish to use.

Expected answers to activity 8.2(a)

a) Because of high charge (large positive) and small ionic radius when aluminium bonds to large anion, the compound shows covalent character

b) Aluminium oxide is amphoteric and

- it dissolves in mineral acids to form aluminium salts and acts as a base
- $Al_2O_3(s) + 6H^+(aq) \rightarrow 2Al^{3+}(aq) + 3H_2O(l)$
- it dissolves in caustic alkali to form aluminate and acts as an acid
- $Al_2O_3(aq) + 2OH^-(aq) + 3H_2O(l) \rightarrow 2[Al(OH)_4]^-(aq)$

Expected answers to task on experiment [activity 8.2.(b)]

c) the equations of reactions that take place when aluminium metal is burnt in air

$4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$

b) The product is aluminium oxide

c) the equations of reaction between the product in (b) with HCl and with NaOH

$Al_2O_3(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2O(g)$

$Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \rightarrow 2NaAl(OH)_4$

Expected answer to task on experiment (activity 8.2(c))

b) the equations of reaction when aluminium reacts with:

(i)moderately concentrated HCl

$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$

(ii) Concentrated H_2SO_4

$2Al(s) + 6H_2SO_4(aq) \rightarrow Al2(SO4)3(aq) + 3SO_2(g) + 6H_2O(g)$

b) Hydrogen released in reaction (a.i) is tested using a burning splint. A pop sound is heard during the test

Sulphur dioxide gas released in reaction (a.ii) is tested using a violet solution of potassium manganate that is decolorized after giving colourless

Expected results on activity 8.2(d)

Learners perform the experiment of reaction between sodium hydroxide and Al .They make report by writing involved chemical reaction:

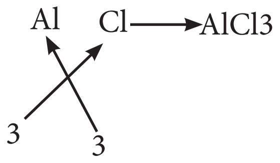
$2Al(s) + 2NaOH(aq) + 6H_2O(l) \rightarrow 2NaAl(OH)_4(aq) + 3H_2(g)$

Expected answers to activity 8.2(e)

a)$1s^2 2s^2 2p^6 3s^2 3p^1$

b) Valence electrons are 3 $3s^2 3p^1$

c)



d) AlCl is not formed when aluminium reacts because all the valence electrons have almost the same energy and are used at the same time in bond formation resulting in $AlCl_3$

d. Expected answer to checking up 8.2

1. Reaction of Al with acids

- **Reaction with HCl**

Aluminium reacts when warmed with moderately concentrated hydrochloric acid forming aluminium chloride and hydrogen gas

$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$

- **Reaction with H_2SO_4**

Aluminium does not react with dilute sulphuric acid but reacts with concentrated sulphuric acid forming aluminium sulphate, sulphur dioxide and water$2Al(s) + 6H_2SO_4(aq) \rightarrow Al_2(SO_4)_3(aq) + 3SO_2(g) + 6H_2O(g)$

Aluminium does not react with HNO_3 because of the insoluble layer of Al_2O_3 formed which prevents further reaction.

2. Aluminium utensils are not washed in a strong alkaline solution because aluminium will be destroyed due to its amphoteric character: it reacts with both acids and bases

3.a)$2Al(s) + 3Br_2(g) \rightarrow 2AlBr_3(s)$

b)$2Ga(s) + 3Cl_2(g) \rightarrow 2GaCl_3(s)$

c)$Ga(s) + 2HCl(aq) \rightarrow 2GaCl + H_2(g)$

d)Because of strong oxidizing power chlorine reacts with gallium giving gallium compounds in its higher oxidation state +3,while HCl as weaker oxidizing agent gives gallium compounds with +1 lower oxidation state resulting in inert pair of electrons in s-orbital of gallium that are not excited with weak oxidizing agent.

e) $2In(s) + I_2(s) \longrightarrow 2InI(s)$ Here the principle of inert pair of electrons works for indium in addition to weaker oxidizing power of iodine.

Lesson 3: Amphoteric character of aluminium and gallium oxides and hydroxides

a) Introduction:

Before beginning this lesson, learners should be able to recall the definition of the term amphoteric compounds and give some examples, to write the formula of compoundsto write and balance equations of chemical reactions.

b) Teaching resources

The Periodic Table of Chemical Elements

Text books

c) Learning activities

- Learning activity 8.4 is suggested in student's book. However the teacher is free to add more.
- Form groups of 3-5 students. The number of groups and members will depend on your class size.
- In the groups students attempt activity 8.4, discuss and record their answers.
- Each group representative presents their answers to the whole class.
- During the presentation ask some questions that lead to lesson conclusion such as writing and balancing chemical equations.
- Make a summary of the lesson (short notes) and assess your lesson. Let students do checking up 8.4. Learners should do the checking up activity in any method you wish to use

Expected answer of the activity 8.3

Aluminium hydroxide shows amphoteric properties.

- It reacts with basic solution and is acidic

$Al(OH)_3(s) + OH^-(aq) \rightarrow [Al(OH)_4]^-(aq)$

- It reacts with acidic solution and is basic

$Al(OH)_3(s) + 3H^+(aq) \rightarrow Al^{3+}(aq) + 3H_2O(l)$

d) Expected answer of the checking up 8.3

a) Aluminium oxide is amphoteric

- it dissolves in mineral acids to form aluminium salts and acts as a base

$Al_2O_3(s) + 6H^+(aq) \rightarrow 2Al^{3+}(aq) + 3H_2O(l)$

- it dissolves in caustic alkali to form aluminate and acts as an acid

$Al_2O_3(aq) + 2OH^-(aq) + 3H_2O(l) \rightarrow 2[Al(OH)_4]^-(aq)$

Ga_2O_3 is amphoteric as shown by these reactions.

$Ga_2O_3 + 6H^+ \rightarrow 2Ga^{3+} + 3H_2O$ (Ga_2O_3 is basic)

$Ga_2O_3 + 2OH^- + 3H_2O \rightarrow 2Ga(OH)^{4-}$ (Ga_2O_3 is acidic)

b) amphoterism is a property of a compound to show both acidic and basic character.

Example:

$Al(OH)_3$ as a base

$Al(OH)_{3(s)} + HCl_{(aq)} \rightarrow AlCl_{3(aq}) + H_2O_{(l)}$

$Al(OH)_3$ as an acid

$Al(OH)_{3(s)} + NaOH_{(aq)} \rightarrow NaAl(OH)_{4(aq)}$

Lesson 4: Anomalous properties of boron and its compounds

a) Introduction

Make sure that learners understood well the previous lessons about aluminium and its compounds. This should help them in a comparative study with boron. You can give learners some quick revision questions.

b) Teaching resources

Student books, books from library, and internet resources

c) Learning activities

This is a guided research activity. Students are asked to do research on functioning of mass spectrometer and answer questions in **activity 8.5.** You may help learners by giving them a list of important reference books available in the school library and the internet websites for relevant information.

Give to learners clear instructions keeping in mind that in addition to subject matter skills and knowledge, this lesson also tends to develop research skills (report writing and referencing), lifelong learning skills, and communication (reading, writing and speaking skills) in English.

The lesson starts with answering the activity 8.4 questions.

On each question you will have to first give learners time to share their answers then agree on what is right.

Summarize the lesson and assess the lesson using checking up 8.5.

Expected answers of the activity 8.4

a) Boron is a bad conductor of electricity: boron is a typical non- metal therefore it does not conduct electricity

b) Boron has higher boiling and melting points than other member of the group: this can be attributed to its small size and the strong attraction between nucleus and electrons.

c) Boron oxide is an acidic oxide: its non metallic character confers its acidic properties. Boron can therefore react with alkaline substances to form salts.

$$Be_2O_3 + N_2OH \longrightarrow N_2BO_2 + H_2O$$

d) Expected answers to checking up 8.4

a) The cause of anomalous behaviour of boron is its small size and high charge.

b) Boron exhibits the following abnormal properties:

Unexpected higher boiling point , non metallic properties, formation of acidic oxide, formation of polymolecules called boranes,…..

Lesson5: Identification test of aluminium ions in aqueous solution

a) Introduction

Before beginning this lesson, learners should have knowledge and skills on identification test for the cation as they have learnt it in senior 2 O'level, to observe and interpret the formation of precipitate by cations when reacted with basic solutions

b) Teaching resources

The Periodic Table of Chemical Elements

Charts illustrating formation of precipitate and their colors

c) Learning activities

Learning activity 8.5 is suggested in student's book.

Form groups of 3-5 students. The number of groups and members will depend on your class size.

In the groups students perform the experiment suggested in activity 8.6,observe and discuss about the results of the experiment

Each group representative presents their findings during practical activity to the whole class.

During the presentation ask some questions that lead to lesson conclusion such as interpretation of the experimental results, writing involved chemical reactions both ionic and molecular equations.

Make a summary of the lesson (short notes) and assess your lesson. Let students do checking up 8.5

Expected answers of the activity 8.5

Aluminium ions can be tested experimentally in laboratory using both sodium hydroxide solution and ammonium hydroxide solution.

To a small amount of aluminium salt solution addition of sodium hydroxide precipitates aluminium hydroxide which dissolves in excess solution of sodium hydroxide

When reacted with a solution of ammonia aluminium salts produce a white precipitate of $Al(OH)_3$ insoluble in excess ammonia

d) Expected answers of checking up 8.5

A test that can be used to differentiate aluminium salt and calcium salts.

Use sodium hydroxide until excess:

Aluminium ion gives a white precipitate soluble in excess

Calcium ion gives a white precipitate insoluble in excess

Use sodium carbonate:

Aluminium ions gives a gelatinous precipitate aluminium hydroxide and bubbles of carbon dioxide

Calcium ions give a white precipitate of calcium carbonate .No bubbles are observed.

Lesson 6: Uses of group 13 elements and their compounds.

a) Introduction

Make sure that learners understood well the previous lessons. You can give learners some quick revision questions.

b) Teaching resources

Student books, books from library, and internet resources

c) Learning activities

- This is a guided research activity. Students are asked to do research on the uses of group 13 elements. You may help learners by giving them a list of important reference books available in the school library and the internet websites for relevant information.
- Give to learners clear instructions keeping in mind that in addition to subject matter skills and knowledge, this lesson also tends to develop research skills (report writing and referencing), lifelong learning skills, and communication (reading, writing and speaking skills) in English.
- The lesson starts with answering the questions in activity8.6.
- On each question you will have to first give learners time to share their answers then agree on what is right.
- Summarize the lesson and assess the lesson using checking-up 8.6.

Expected answers to the activity 8.6

a) Uses of Aluminium:

- used in making cooking utensils (spoon, fork, plate, knife…)
- used as window frames or doors in buildings and houses.
- used as overhead high tension cables for distribution of electricity.
- used in alloys (e.g. Al and Mg) for the construction of airplanes and small boats
- for packaging food

b) Learners make research about the use of group 13 elements and their compounds and make presentations of their findings

Boron

- is used in control rods to keep nuclear reactions in balance .Boron absorbs therefore excess neutrons preventing them from zinging into to many uranium (fuel of nuclear reactors)
- Manufacture of hard boron steel.
- Is used as an additive to semi conductors silicon and germanium.
- Manufacture of borosilicate glass used in vacuum flasks.

Aluminium

- is used in making cooking utensils: this is because of its bright appearance and lightness and its thermal conductivity
- is used as overhead high tension cables for distribution of electricity: this is because of its low density and very good electrical conductivity.
- is used in alloys making.(e.g. Al and Mg) for the construction of airplanes and small boats due to its lightness, malleability and higher tensile strength in the alloy.
- Being completely resistant to corrosion it is ideal for packaging food
- The insulating property of aluminium arises from its ability to reflect radiant heat: fire fighters in USA wear suits which are coated with aluminium to reflect the heat from the fire and keep them cool.
- The polished surface of aluminium finds it a use in the reflectors of car headlights.

Gallium

- Is used as a semiconductor. e.g: with phosphorus and arsenic in light emitting diodes.

Note that sodium tetrahydroborate (III), $NaBH_4$, and lithium tetrahydridoaluminate (III), $LiAlH_4$, are used as reducing agents in organic chemistry but $LiAlH_4$ is the more vigorous.

d) Expected answers to checking up 8.6

1) is used in alloys making.(e.g. Al and Mg) for the construction of airplanes and small boats due to its lightness, malleability and higher tensile strength in the alloy.

1) used in making cooking utensils: this is because of its bright appearance and lightness, resistance to corrosion, and its thermal conductivity

2) An engineer in construction who would like to use laboratory sinks made in aluminium will be advised to stop the project because laboratories use both acid and bases that can react with aluminium so sinks made up of aluminium will be damaged easily

8.6.Summary of the unit

- Most of the elements of group 13 are metals showing non metallic character(amphoteric)
- Aluminium is a reactive metal but its reactivity is suppressed by a thin coating of inert unreactive oxide
- The high charge density is responsible for :

  i. the intermediate ionic/covalent bonding of aluminium oxide and its amphoteric character.

  ii. The polarisation of anions with which it is associate resulting in partially covalent nature of aluminium chloride and other aluminium salts;

iii. The hydration of Al^{3+} ions in aqueous aluminium salts

- Aluminium hydrides hydrolyse easily in aqueous medium
- Aluminium oxide and aluminium hydroxide are amphoteric,dissolving in acids to form aluminium salts and in alkalis to form aluminates
- The trihalides of boron (BX_3) exist as monomers. While the trihalides of other elements exist as dimers.
- Boron is a non metal with a very small size and form covalent compounds.
- Boron foms polymers (boranes)in which several molecules are held together and stabilised by hydrogen bridge.

8.7.Additional information to teachers

8.7.1 Compounds of aluminium

a) Halides (AlF_3, $AlCl_3$, $AlBr_3$, AlI_3)

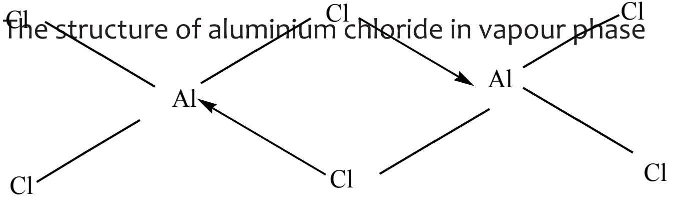
8.7.1.1 Bonding:

Aluminium shows an oxidation state of +3 in all of its compounds.

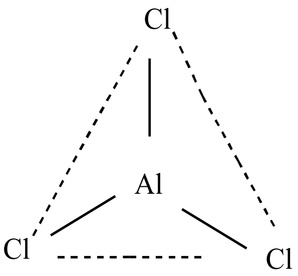
Because of high charge (large positive) and small ionic radius, $Al^{'}$ exerts polarizing effect on the halide ion in contact with it. This polarization is greatest as the size of the halide ion increases. Therefore the iodide (I^-) ion with greatest size is most polarized while the fluorine (F-) ion experiences negligible polarization. Therefore AlF_3 is ionic while $AlCl_3$ is intermediate between ionic and covalent. Aluminium chloride exists as dimmer, Al_2Cl_6 in vapour phase and on heating sublimes at 180°C.

In the dimeric structure each aluminium atom accepts a lone pair of electrons from the chlorineatom bonded to the other aluminium atom. In doing so each aluminium atom completes its octet.

The structure of aluminium chloride in vapour phase



At ordinary conditions, $AlCl_3$ adopts a trigonal plane structures



Aluminium bromide is typically covalent because of the large Br- size. Like aluminium chloride, it also exists as dimmer.Al_2I_6 is covalent and has also similar properties as

Al_2Br_6.

8.7.2. Behaviour in water

Aluminium chloride solution like other compounds of aluminium, soluble in water, contains hydrated aluminium ion: $[Al(H_2O)_6]^{3+}$, commonly written as $Al^{3+}(aq)$.

$AlCl_3(aq) \rightarrow Al^{3+}(aq) + 3Cl\text{-}(aq)$

$Al^{3+}(aq) + 6H_2O(l) \rightarrow [Al(H_2O)_6]^{3+}(aq)$

Aluminium chloride gives an acidic solution because of deprotonation (production of H+ions) from the hydrated aluminium ion:

$[Al(H_2O)_6]^{3+} \longrightarrow [Al(H_2O)_5OH]^{2+}(aq) + H^+(aq)$

The acidic properties prevent the formation of carbonate of aluminium when sodium carbonate is added to aluminium salt solution:

$2H^+(aq) + CO3^{2-}(aq) \longrightarrow CO_2(g) + H_2O(1)$

Therefore a gelatinous precipitate of aluminium hydroxide, Al(OH)3, and a colorless gas carbon dioxide are formed.

8.8.End unit assessment answers

1.a) $2Al(s) + 3Cl_2(g) \rightarrow 2AlCl_3(s)$

b) It is necessary to dry chlorine during preparation of aluminum chloride, to prevent reaction of the product with water molecules

c) Calcium chloride absorbs water vapour coming from the outside (from fume cupboard) which should interfere the products after the reaction.

d) $AlCl_{3(s)} + H_2O_{(l)} \longrightarrow Al^{3+}_{(aq)} + 3Cl^-_{(aq)}$

2. Aluminium oxide is amphoteric:

it dissolves in mineral acids to form aluminium salts: in this case it acts as a base.

it dissolves in caustic alkali to form aluminate: in this case it acts as an acid.

b. aluminium utensils are not washed in strong alkaline solutions because Al reacts with base as follows:

3. If you need to prepare aluminium hydroxide, it is better to add a solution of ammonia to a solution of aluminium salt, rather than to add a solution of sodium hydroxide because the use of sodium hydroxide should probably results in dissolution of the product when excess is added by mistake. However the use of ammonium hydroxide precipitates the product, even the excess results in the white precipitate of aluminium hydroxide.

4.

. $2Ga(s) + 6HCl(g) \rightarrow 2GaCl_3(s) + 3H_2(g)$

$2Ga(s) + 2NaOH(aq) + 6H_2O(l) \rightarrow 2NaGa(OH)_4(aq) + 3H_2(g)$

5. Why aluminium is suitable for:

(a) Manufacture of window frames due to its lightness, malleability and higher tensile strength

(b) Electrical wiring this is because of its low density and very good electrical conductivity.

(c) Packaging food because it is completely resistant to corrosion

(d) Suits for fire fighters from its ability to reflect radiant heat: fire fighters in USA wear suits which are coated with aluminium to reflect the heat from the fire and keep them cool.

6. A test that can be used to differentiate aluminium salt and calcium salts.

Use sodium hydroxide until excess:

Aluminium ion gives a white precipitate soluble in exces

$Al^{3+} + 3NaOH(aq) \longrightarrow Al(OH)3(S) + 3Na^{+}(aq)$

White precipitate

Al(OH)3(s) +OH-+ Water excess OH-Al(OH)-4(aq)

Transparent and colorless solution

Calcium ion gives a white precipitate insoluble in excess

$Ca^{2+}(aq) + 2OH^{-}(aq) \longrightarrow Ca(OH2(s)$

$Ca(OH)2(s)excess \longrightarrow OH^{-}$ no observable change

8.9.Additional activities

8.9.1. Remedial activities

1. Given the element Al (Z=13) and O (Z=8).

(i)Write their respective electronic structure in term of s, p, d, f orbitals.

(ii)Write the equation of reaction between Al and oxygen gas

(iii) The product formed in (ii) is amphoteric. What does it mean? Explain your answer using chemical reactions.

2. Explain why aluminium: a) conducts electric current.

b) Has high melting point

3. What do you observe when to aluminium chloride salt is:

a) Added sodium hydroxide solution until excess

b) Added ammonia solution until excess.

In each case give the formula of the final aluminium containing species

4. Explain why it is better to use cooking utensils made up of aluminium.

5. Boron exhibits an exceptional boiling point compared to other element of the same group. Explain why.

Expected answers to remedial activities

(i)Al (Z=13):$1s^2\ 2s^2\ 2p^6\ 3s^2 3p^1$

O (Z=8): $1S^2\ 2s^2\ 2p^4$

(ii) $2Al(s) + 3O2(g) \longrightarrow 2Al_2O_3(S)$

(iii) Amphoteric means compounds that react with both acids and bases

Example: Aluminium oxide is amphoteric:

it dissolves in mineral acids to form aluminium salts: in this case it acts as a base.

$Al_2O_3(s) + 6H^+(aq) \rightarrow 2Al^{3+}(aq) + 3H_2O(l)$

it dissolves in caustic alkali to form aluminate: in this case it acts as an acid.

$Al_2O_3(s) + 2OH^-(aq) + 3H_2O(l) \rightarrow 2[Al(OH)_4]^-(aq)$

2. (a) (i) Al conducts electricity due to free electrons

(ii) The higher melting point originates from strong metallic bond caused by 3 electrons lost by each atom involved.

3. By adding sodium hydroxide to an aluminium salt solution until excess a white precipitate of aliminium hydroxide is formed This one dissolves in excess sodium hydroxide forming tetrahydroxoaluminate $Al(OH)^-_4$

By adding to ammonia solution to aluminium salt solution until excess a white precipitate of $Al(OH)_3$ insoluble in excess is formed.

4. It is better to use cooking utensils made up of aluminium because of its bright appearance and lightness, resistance to corrosion, and its thermal conductivity

5. Boron exhibits an exceptional boiling point compared to other element of the same group because of its small size and high charge which results in strong attraction between the nucleus and electrons hence strong bond.

8.9.2. Consolidation activities

1. The list below is about the chloride of group 13 elements: $GaCl_3$, BCl_3, $InCl_3$, $AlCl_3$, $TlCl_3$. Arrange them according to their decreasing order of ionic character and explain the general trend in the character.

2. Arrange the following compounds in increasing order of the covalent character and justify.

GaI_3, $GaCl_3$, $GaBr_3$

3. The following table shows 3 unknown group 13 elements halides A, B, C and some of their melting points. Predict among the group 13 elements halides (AlF_3, $AlBr_3$, $AlCl_3$,), which one should correspond to A,B,C. Justify your answer

Element	Melting points (°C)
A	180
B	1265
C	97

Expected answers to consolidation activities

1. The decreasing order of ionic character is as follows: TlCl3, InCl3, GaCl3, AlCl3, BCl3, bigger cations give ionic compounds, smaller cations give covalent compounds. The ionic character increases down the group as the atomic radius increases.

2. The increasing order of the covalent character means from the more ionic to the less ionic or from the less covalent to the more covalent. We have therefore, GaCl3, GaBr3,GaI3

For a same cation the ionic character increases as the radius of the anion decreases.

3.A has an intermediate value of melting point.It is probably AlCl3

B has a higher melting point .It has an ionic character therefore it is AlF3 .Where Al is bonded to small anion fluoride.

C with lower melting point ,the property for covalent compounds. It is AlBr3Where Al is bonded to bigger anion bromide.

8.9.2. Extended activities

1. An element A reacts with another element B to form a AB_3 compound of formula .The element B exists as diatomic B_2.Some properties of AB_2, and AB_3 are tabulated below:

	A	B_2	AB_3
Melting point	High(in the range of700°C-1200°C)	Very low(less than -100°C)	High(in the range of 1000°C-1270°C)
Electrical conductivity of the solid	High	Very low	Very low
Electrical conductivity of molten material	High	Very low	High

Electrical conductivity of aqueous solution of the material			High

(a)Which particles will move when a potential difference is applied across on

(i) solid A (ii) Molten AB3

(b)Explain why the electrical conductivity of molten AB3 is high whereas that of the solid is very low.

(c)Suggest the type of bond present in each material and justify.

2. An element E of group 13 forms compound F when it is reacted with chlorine. The same element cannot react with oxygen to produce an oxide. However its oxide G is produced by heating its corresponding acid H. The study of the compound of this element E shows the following results:

F has low melting point and does not conduct electric current in molten and aqueous solution.

G is acidic and can react with a solution of sodium hydroxide

a) Identify the element E.

b) Write the equation of reaction between E and chlorine to form the compound F

c) Give the formula of the oxide G

d) Write the equation of reaction between the oxide G and sodium hydroxide.

e) (i) Give the formula of the acid H from which the oxide G is obtained.

(ii) Write the equation of thermal decomposition of the acid H to produce the oxide G.

Expected answers to extended activities

1.a) particles that will move when a potential difference is applied across on

(i) Solid A: Electrons

(ii) Molten AB_3: Free ions

b) in the molten state the ions are free to move in AB_3

c) A: has metallic bond due to high melting point and electrical conductivity in solid state

B_2: has covalent bond due to lower melting point and very low electrical conductivity in molten state

AB_3: ionic bond due to electrical conductivity in molten state, higher melting point and high electrical conductivity in aqueous solution.

2.a) E is boron

b) $2B(s) + 3Cl_2(g) \rightarrow 2BCl_3(g)$ (F)

UNIT 9:TRENDS IN CHEMICAL PROPERTIES OF GROUP 14 ELEMENTS AND THEIR COMPOUNDS

9

9.1.Key unit competency:

To be able to compare and contrast the chemical properties of the Group 14 elements and their compounds in relation to their position in the Periodic Table.

9.2.Prerequisite knowledge and skills

The physical properties of metals and of non-metals, electronegativity, atomic radius, metallic character and ionization energy of elements

9.3.Cross-cutting issues to be addressed

Gender

1. General needs of people to complement one each over without conflict in order to be peaceful.
2. The nature of atoms can be related to relationship in human beings. There is a serious issue of misunderstanding of gender equality in our society.
3. When introducing this unit, it would be an opportunity to guide learners on understanding the importance of gender equality and how the issues related to gender inequality may be addressed.
4. Help learners to:
   a) Understand that complementarities are very important. Atoms constituents such as protons and neutrons coexist in the atomic nuclei for playing the specific role. Students should know that females and males are both human beings and no one should assume to be more important than another.
   b) Understand that gender equality plays a big role in the development of the country.
   c) Understand that females need males and vice-versa in different ways for their future achievement.
   d) Underlining the necessity of cooperation and working in mixed groups rather than working in single groups)

   This can be done in a short whole class discussion. This may be an opportunity for you as chemistry teacher to confront the individual students who need advice on relationship matters.

Inclusive education

This unit involves a number of activities on the properties and means of extraction; the activities require reading and writing. This may be challenging to students with special educational needs especially children with visual impairment. However, the teacher can make some arrangements like:

1. Grouping students. Students with special educational needs are grouped with others and assigned roles basing on individual student's disabilities.
2. Providing the procedure early enough before the activity so that students get familiar with them. They can be written on the chalkboard or printed depending on available resources. If you have children with low vision, remember to print in appropriate fonts or in Braille.
3. Every important point is written and spoken. The written points help students with hearing impairment and speaking aloud helps students with visual impairment
4. Remember to repeat the main points of the lessons.

9.4.Guidance on introductory activity

Before introducing the first lesson (outline of electronegativity of elements down a group and the variation in properties down the group, let learners attempt the introductory activity).

9.5.List of lessons

Heading	Lesson title	Learning objectives	No of periods
9.1	Comparative study of physical properties of Group 14 elements (Physical state, metallic electrical conductivity character)	Compare and contrast the physical properties of Group 14 elements.	3
9.2	Reactions of C, Sn, Pb, Si (Reaction with oxygen, reaction with hydrogen, reaction with chlorine, reaction with dilute, acids/concentrated acids, reaction with hydroxides)	Compare the relative stabilities of the higher and lower oxidation states in oxides.	3

9.3	Comparative study of compounds of Group 14 elements (Reaction of oxides, chlorides with water, acids and strong alkaline solutions, thermal stability of oxides, halides and hydroxides, $SiO2$ as a giant structured covalent compound).	Illustrate practically the reactivity of Group14 oxides and chlorides.	3
9.4	Chemical tests for the presence of Sn^{2+}, Pb^{2+}, HCO_{3-}, $CO3^{2-}$ ions in the solutions. Trends in stability of oxidation states: +2 and +4 as a result of inert pair effect.	Perform chemical test for the presence of Sn^{2+}, Pb^{2+} and hydrogencarbonate ($HCO3^{-}$) carbonate ($CO3^{2-}$) ions in solutions.	2
9.5	Uses of Group 14 elements. Diagonal relationship of Groups 1, 2, 13 and 14	Analyze the similarities and differences among the elements of Group 1, 2, 13 and 14 due to diagonal relationship.	1
9.6	End Unit assessment		2

Lesson 1: Physical properties of group 14 elements

This is the first lesson of unit 9. It is a single lesson, it covers the introduction of the whole unit, it contains one period (40 minutes).

a) Introduction

Students will be assessed on the physical properties of metals and non-metals which they studied in O-level.

b) Teaching resources

Use the illustrations in the student's book and the laboratory materials.

c) Learning activities

Before introducing the lesson, you have to introduce the whole unit. Learners will attempt the introductory activity. This will lead them to understand the content much better since they will have had some ideas.

- Students will form groups of 3 to 5 learners and the teacher will suggest to choose a group leader and a secretary.

- The teacher will provide the activity 9.1 from the student book and write it on the chalkboard for the students to copy down. The teacher will ask the learners in their groups and ask every group to discuss questions which have been given in the activity then answers will be provided.
- Let learners work together in their groups with intervention where necessary.

Diamond

- Monitor how the learners are progressing towards knowledge to be learned and assist those who are still struggling (but only communicate to them the knowledge concepts).
- Invite group each leader to present the student's findings, but manage your time well.
- Record key points on every presentation in order to harmonize towards the end of the lesson.
- Evaluate the learner's findings and emphasize on which are correct, incomplete or false.
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the content by giving more examples. Let students do the checking up exercise. Learners should do the checking up activity in any method you prefer to use.

Activity 1

Expected answer for the introductory activity:

1. Various answers are expected for the first questions
2. The main allotropes of carbon are:
    - Graphite: it is soft and it conducts electricity.
    - Diamond: it is hard and it does not conduct electricity.

   For further information read unit 4 in student's book.
3. Electronegativity decreases down the group from boron to aluminium due to increase in atomic size down the group which results in decrease in nuclear attraction of the valence electrons.
4. When the size of the atom increases as you move down the group,

   a) The metallic character of elements increases due to loosely attracted valence electrons towards the nucleus.

b) The first ionisation energy decreases down the group due to loosely attracted valence electrons towards the nucleus.

c) The ability to form ionic compounds increases down the group because the ease to lose electrons increases down the group and therefore ions are produced readily to form ionic compounds.

The ability to form covalent compounds decreases as you move down the group due to a decrease in electronegativity as you move down the group from B to Al.

5. Down the group 11, the melting points decrease due to less inter-atomic attraction of the nucleus in larger atoms. So the atoms are less attracted to each other and therefore the melting point decreases.

Expected answers for the activity 9.1:

1. Electronic configuration of carbon: $1S^2\ 2S^2\ 2P^2$

   Silicon: $1S^2\ 2S^2\ 2P^6\ 3S^2\ 3P^2$

   Tin: $1S^2\ 2S^2\ 2P^6\ 3S^2\ 3P^6\ 4S^2\ 3d^{10}\ 4P^6\ 5S^2\ 4d^{10}\ 5P^2$

2. 2 uses of carbon :

   i) To make pencils

   ii) To use in the metallurgy of metals

   2 uses of leads:

   Pb is used in accumulator plates of batteries

   It is used in radiation shielding

3. Carbon has $1S^2\ 2S^2\ 2P^2$ configuration, one electron in the 2S orbital is excited to 2P orbital and the configuration becomes: $1S^2\ 2S^1\ 2P^3$ .So in this state, carbon can form 4 bonds by utilising all the single electrons in the valence shell.

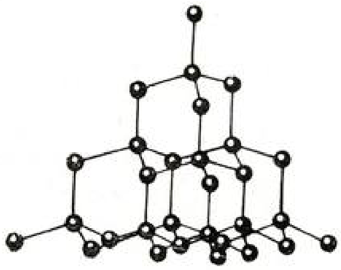
4. a) 2 Inorganic compounds of carbon: CO_3^{2-} ,HCO_3^-

   b)2 organic compounds of carbon:

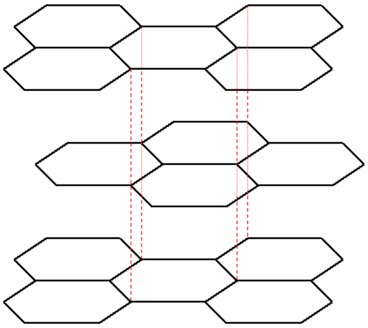
   CH_4 , CH_3CH_3

d) Expected answers for checking up 9.1

1. Diamond has a higher melting point than silicon because, the atoms of diamond are smaller than those of silicon, thus the inter atomic radius in diamond is smaller and the attraction of the valence electrons becomes weaker in silicon hence a lower melting point in silicon than diamond.
2. Down the group, the metallic character increases because the valence electrons are further away from the nucleus as you move down the group. So those valence electrons are loosely bound to the nucleus and can easily be lost to form metallic bonds in larger atoms.
3. a)Diamond structure:



Graphite structure:



b) Graphite has layers that are attracted to each other by weak van der waals forces such that the layers slide over each other to make the structure soft.

In diamond, each carbon is covalently bonded to 4 other carbon atoms forming a giant structure that makes to be very hard.

4. The type of bonds that exist in diamond and germanium are covalent bonds such that each carbon is bonded to 4 other carbons in a molecular giant structure so is Germanium.
5. The first element in a group such as carbon is very small and the valence electrons are much more attracted to the nucleus. So the first element up in a group possesses a high covalent character than the rest of the members of the same family.

Lesson 2: Reactions of C, Sn, Pb, Si (Reaction with oxygen, reaction with hydrogen, reaction with chlorine, reaction with dilute, acids/concentrated acids, reaction with hydroxides)

a) Introduction

Students will learn better a concept of the reactions with: oxygen, water, acids, bases, chlorine and hydrogen if they have understood: Definition of bonds, chemical reactions which they covered in O-level.

b) Teaching resources

- The Periodic Table Elements

- Diagrams illustrating structures of elements.

c) Learning activities

Learning activity 9.2 is given in the students' book. But the teacher is free to give more.

- Form groups of 3 to 6 learners and ask them to choose a group leader.
- Give the activity 1.2 from the student book (if the books are not enough, you can write the activity on the chalkboard) for the learners who are in groups and ask members of every group to do questions, and give them the answers.
- Let learners to work together in the groups with limited intervention.
- Monitor the progress of learners towards the knowledge to be learned and assist those who are slow (but communicating to them the necessary concepts).

- Invite group leaders to present the students' findings, but manage your time well.
- Record key points for every presentation in order to harmonize later.
- Evaluate the learners' findings properly.
- Ask learners to introduce the new findings in their presentations and to correct false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 9.2. Learners should do the checking up exercise a better suited methodology they are familiar with.

Expected answers for Activity 9.2 (a)

1 .Charcoal burns : Chemical equation: C(s)+ O2(g) $\longrightarrow$ CO2(g)

2. Carbon has been oxidised to CO_2 and HNO_3 (NO3-) has been reduced to NO_2 .
The equation is: $C(s) + 4HNO_3(conc) \longrightarrow CO_2(g) + 4NO_2(g) + 2H_2O(l)$

3. Carbon dioxide : O=C=O , Carbon monoxide: C=O

4. CO2 dissolves in water to form a colourless solution of carbonic acid, the solution is acidic.

5. An amphoteric compound such as Al2O3 reacts with acids to neutralise them, it also reacts with bases to neutralise them.

Expected answers for Activity 9.2 (b):

Observations:

1. - The red solution of HCl solution is changed to a pale yellow solution on adding Al_2O_3 solution.

   -The blue solution in NaOH is turned pale yellow on adding Al_2O_3 solution.

   -The pink colour solution of MgO solution turns colourless when HNO_3 is added.

   2. Interpretation: Al_2O_3 is amphoteric because it reacts with acids and with the bases.

-MgO is basic because it is neutralised by an acid.

d) Expected answers checking up 9.2

1. It is because CO2 is an acidic oxide itself.
2. CCl4 does not dissolve or react with water.

SiCl4 dissolves in water to get solid particles of SiO_2 on the bottom of the test tube.

Equation: No equation for CCl4 .

Equation with SiCl4 :

$SiCl_4 + 2H_2O \longrightarrow SiO_2 + 4HCl$

3.PbO which is pale yellow is stable. When it is heated, there is no observable change. PbO_2 (dark) is unstable. When it is heated, it decomposes to PbO and O2 .

$PbO_2(s) \longrightarrow PbO(s) + O_2(g)$

4.Pb reacts concentrated HNO3 :

$Pb(s) + 4HNO_3(aq) \longrightarrow Pb(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(l)$

Pb reacts with hot concentrated NaOH solution (base).

$Pb(s) + 2OH^-(aq) \longrightarrow PbO_3(aq) + H_2(g)$

Lesson 3: Distinguish between the chemical reactions of the oxides and chlorides of Group 14 elements

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt the introductory learning activity 9.1 which leads students to the third lesson of the unit.

This is the third lesson of unit 9. It is a single lesson, it involves lots of chemical equations, it has two periods (80 minutes).

a) Introduction

Students will be asked to write and balance some equations of reaction concerning combination, displacement, decomposition, salt hydrolysis and dissociation reactions they covered in o-level and in first term of S4 so that they can be reminded concepts that are related to this lesson.

b) Teaching resources

Use the illustrations in the students' book

c) Learning activities

- Form groups of 3 to 6 learners and ask them to choose a group leader.
- Provide the activity 9.3 from the student book (when the books are not enough, he/she can write the activity on the chalkboard) to the learners in their groups and ask every group to discuss the questions, and provide answers.
- Let learners work together in their groups without intervening directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without

communicating to them the knowledge).

- Invite group leaders to present the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving some other examples. Let students do checking up 9.3. Learners should do the checking up activity in any method you wish to use

Expected answers for Activity 9.3:

- Observation: The red colour of the universal indicator in HCl solution turns into pale yellow when it is put in PbO.
- The pink colour of phenolphthalein indicator in NaOH is turned colourless when the alkaline solution is poured in PbO solid.

  So, PbO is amphoteric since it reacts with both acids and bases.

Expected answers for checking up 9.3

1.a) Yes, Equation: $2Na(s) + 2H_2O(l) \longrightarrow 2NaOH(aq) + H_2(g)$
b) No, Carbon monoxide is neutral
c) Yes, Graphite does so
2. $PbO(s) + 2HCl(aq) \longrightarrow PbCl_2(aq) + H_2O(l)$
$PbO(s) + 2OH\text{-}(aq)\ PbO_2^-(aq) + H_2O(l)$
3.Tin II oxide reacts with hot dilute sulphuric acid:
$SnO(s) + H_2SO_4(aq) \longrightarrow SnSO_4 + H_2O(l)$
Lead II oxide reacts with hot concentrated sulphuric acid:
$PbO(s) + H_2SO_4(aq)\ \ PbSO_4(aq) + H_2O(l)$
4. Because they have vacant d-orbitals whereas carbon does not have them to accept H2O molecules.
$SiCl_4 + 2H_2O \longrightarrow SiO_2 + 4HCl$
$SnCl4 + H_2O \longrightarrow SnO_2 + 4HCl$
5. PbCl2: The Pb has a low oxidation state in $PbCl_2$ that makes it to be ionic such that it cannot hydrolyse H_2O molecules as it happens in $PbCl_4$ which is covalent.

Lesson 4: Explain the trends in thermal stability of the oxide, halides and hydroxides of Group 14 elements

This is the fourth lesson of the unit; the students will be required to do an activity before learning the major content of the lesson.

a) Introduction

Students will learn better the thermal decomposition of oxides, halides and hydroxides if they first do an exercise on some decomposition reactions they covered in o-level.

b) Teaching resources

Use the illustrations in the students' book and laboratory materials and chemicals.

c) Learning activities

Before introducing the lesson, you will have to introduce the whole unit. Let learners attempt the introductory activity first then the learning activity 9.4 which leads students to the fourth lesson of the unit.

- Form groups of 3 to 6 learners and ask them to choose a group leader
- Provide the activity 9.4 from the student book (when the books are not enough, he/she can writes the activity on the chalkboard) to the learners in their groups and ask every group to discuss questions and provide answers.
- Let learners to work together in their groups without intervening directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to present the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on those that are correct, incomplete or false.
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the content by giving more examples. Let students do the checking up 9.4 Learners should do the checking up activity in any method you wish to use.

Expected answers for Activity 9.4:

Observations: The $Pb(NO_3)_2$ solution forms a white precipitate of $Pb(OH)_2$ when it reacts with NaOH solution.

$Pb(NO_3)_2(aq) + 2OH\ (aq) \longrightarrow Pb(OH)_2(s) + 2NO_3\ (aq)$

The precipitate of Pb(OH)2 decomposes on heating to produce a colourless solution and white solid particles that settle on the bottom of the test tube.

$Pb(OH)_2 \longrightarrow PbO(s) + H_2O(l)$

Explanation:

The formation of $Pb(OH)_2$ is due to the precipitation of Pb with OH .

The formation of a colourless solution and white solid particles on the bottom of the test tube when heat is applied is due to decomposition of $Pb(OH)_2$.

d) Expected answers for checking up 9.4

1. Carbon tetrachloride molecule is tetrahedral in shape. Each chlorine atom attracts the bond pair electrons towards itself such that the net charge on the central carbon is zero. This is also caused by the geometry of the

molecule.

2. The solid lead dioxide dissolves to a colourless solution of PbCl2.

There is also liberation of a gas that turns blue litmus paper to red and eventually bleaches it (removes the red colour of litmus paper to white). The colourless solution precipitates on cooling.

Equation: $PbO_2(s) + 4HCl(aq) \xrightarrow{Heat} PbCl_2(aq) + 2H_2O(l) + Cl_2(g)$

3.a) $Pb(OH)_2(s) + 2H(aq) \longrightarrow Pb(aq) + 2H_2O(l)$

b) $Pb(OH)_2(s) + 2OH(aq) \longrightarrow Pb(OH)4^-(aq)$

4. PbCl4, lead tetrachloride is unstable because the stability of compounds of group 14 in oxidation state +4 decreases down the group.

5. Add the mixture to $Mg(NO_3)2$ solution and heat.

-In the presence of CO3 there is formation of a white precipitate.

-When SO2-4 is put in $Mg(NO3)_2$ solution, no precipitate is formed.

6. Sn^{2+} $H_2S \longrightarrow$ SnS (brown precipitate) + H2

And add bismuth nitrate to Sn2+ ions, there is formation of black solid Bi.

$3Sn^{2+} + 2Bi(NO3)3 \longrightarrow 3Sn(NO_3)_2(aq) + 2Bi(s)$ (black solid)

7. a) Add MgSO4 :The CO3 reacts to form a white precipitate.

The HCO3 does not form a precipitate but remains soluble in the solution.

-Both HCO3 and CO3 react with dilute HCl to liberate a gas that turns lime water milky.

b) $MgSO_4(aq) + CO^{2-}{}_3(aq) \longrightarrow MgCO_3(s) + SO^{2-}4(aq)$

$MgSO_4(aq) + 2HCO_3^-(aq) \longrightarrow Mg(HCO_3)_2(aq) + SO_4^{2-}(aq)$

8. The thermal stability of tetrachlorides of group 14 elements decreases down the group.

The stability of dichlorides of group 14 elements increases down the group because the larger ions have less nuclear attraction to the valence electrons.

So, the covalent bonds in PbCl4 are weaker than in $snCl_4$.

So, the bonds can easily break down to produce $PbCl_2$.

Lesson 5: Explain the variation in stability of oxidation state of +2 and +4 down the Group 14 elements

In this lesson students should be able to recall the electronic configuration and the concept of valence electrons.

a) Introduction

The concept of energy level, sub-energy level and orbitals should be emphasized. The students should be given an exercise on writing the electronic configuration of some atoms and the concept of hybridization of electrons in sub-shells should be part of the exercise so that they may be lead in the lesson content well.

b) Teaching resources

Use the illustrations in the students' book, the laboratory materials and chemicals.

c) Learning activities

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt the introductory activity first then learning activity 9.5 which leads students to the first lesson of the unit.

- Form groups of 3 to 6 learners and ask them to choose a group leader
- Provide the activity 9.5 from the student book (when the books are not enough, he/she can writes the activity on the chalkboard) to the learners in their groups and ask every group to discuss questions, and provide answers.
- Let learners to work together in their groups without intervening directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to present the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on those that are correct, incomplete or false.
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 9.5

Learners should do the checking up activity in any method you wish to use

Expected answers for Activity 9.5:

1. Electronic configuration:

   Carbon: 1s 2s 2p

   Silicon: 1s 2s 2p 3s 3p
2. The stability of dichlorides over tetrachlorides increase down the group because the atoms become larger and the nuclear attraction to the bond electrons decreases. So the bonds can easily break down to get a stable $PbCl_2$.
3. When electronegativity increases, the bond pair electrons in the bond MgCl2 are more attracted to the nucleus than in CaCl2 bond. So MgCl2has stronger bonds than CaCl2.

d) Expected answers for checking up 9.5

   1. In carbon, all the valence shell electrons are easily used up during bonding because the 2S electrons can easily be excited to 2p so that you get sp hybridised state than in the case bigger atoms like lead.

   2. Inert pair effect is the phenomenon whereby 2 electrons in the p sub-

energy level are lost from an atom during ion formation but the 2 electrons of the s sub-energy level in the valence shell remain in their orbital.

This is possible when the oxidising agent is not strong enough to remove the pair of electrons in the s sub shell.

3. $PbCl_2$ is more covalent than PF_2. It is because $PbCl_2$ bonds between Pb and Cl are longer than in PF_2 so the nuclear attraction to bonding in $PbCl_2$ is weaker which results in weaker bonds in $PbCl_2$ than PbF_2. The attraction between a smaller anion and a cation results in stronger ionic bonds, so the covalent bond becomes weaker. Therefore PbF_2 is less covalent than $PbCl_2$.
4. $PbBr_4$ and PbI_4: The anions re too large to be stable around the central Pb ion. This is due to very weak bonds since the nuclear attraction of the bond pair between Pb and Br is less attracted to the nucleus of Pb .Thus the bonds easily breaks in $PbBr_4$.

Lesson 6: Uses of group 14 elements

In this lesson students will be able to recall the uses of group 14 elements in daily life and in industrial processes.

a) Prerequisites/Revision/Introduction

Students learned group 14 elements in o-level, so they will first indicate the occurrence of elements like carbon. The students learnt organic chemistry in O-level. So they should first state some elements which are made of carbon and the other elements of the group.

b) Teaching resources

Use the illustrations in the students' book and laboratory materials and chemicals.

c) Learning activities

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt the introductory activity first then learning activity 9.6 which leads students to the first lesson of the unit.

- Form groups of 3 to 6 learners and ask them to choose a group leader
- Provide the activity 9.6 from the student book (when the books are not enough, he/she can write the activity on the chalkboard) to the learners in their groups and ask every group to discuss questions and provide answers.
- Let learners work together in their groups without intervening directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.

- Evaluate the learners'findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the content by giving more examples. Let students do the checking up 9.6 exercise. Learners should do the checking up activity in any method you wish to use.

Expected answers for Activity 9.6:

1. 2 uses of carbon:

-Carbon is used in metallurgy industry for extraction of metals.

-Carbon is used as graphite electrodes in electrolysis of aluminium.

2. Diamond can be used to cut glass and other materials.
3. Methane is obtained in lake Kivu in Rwanda.

-Methane is used for domestic heating in kitchens.

-Methane is used in industry for production hydrogen gas.

4. Silicon is used to produce diodes, transistors in radios, television and other electronic gadgets.
5. Tin is used in motor engines where it is in contact with water.

   -Tin is used in container boxes for preservation of food in tinned cans.

d) Expected answers for Checking up 9.6:

1. Diamond is used on a large scale to manufacture hard materials such as padlocks, materials for cutting other solid materials and in jewellery.
2. Materials that are manufactured:

-Lead is used to make electrodes in car batteries since it is in contact with concentrated sulphuric acid such that it resists corrosion of the acid.

-Tin: Is used to make materials that resist corrosion of acids like in food tinned cans and in motor vehicle engines.

-Silicon is used in materials which are semi-conductors of electricity in radios television sets etc.

3. Compounds that contain:

- -Silicon: SiO_2 is in sand, cement and in rocks. Silicon compounds are maily used in construction of roads, buildings and in electric gadgets.

  -$SiBr_4$ is also an important compound of silicon.

  -$NaAlSiO_3$

  Compounds that contain lead can be used to produce lead element:

  PbS (galena)

  Pb_3O_4 (tri-lead tetroxide)

  PbO_2 (lead dioxide)

Lesson 7: Define diagonal relationship

Learners should be able to indicate some chemical and physical properties of group 11, 12 and 13 with certain the concept of writing equations of chemical reactions.

a) Introduction

Students will understand well the diagonal relationship if they are in position to state and describe the chemical and physical properties of group 11, 12 and 13 respectively. It will be easy to understand the concept of diagonal relationship once a short exercise is given to them before the content is dealt with.

b) Teaching resources

Use the illustrations in the student's book and the periodic table

c) Learning activities

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt the introductory activity first then learning activity 9.7 which leads students to the first lesson of the unit.

- Form groups of 3 to 6 learners and ask them to choose a group leader
- Provide the activity 9.7 from the student book (when the books are not enough, he/she can write the activity on the chalkboard) to the learners in their groups and ask every group to discuss questions, and provide answers.
- Let learners to work together in their groups without intervening directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to present the student‘s findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.

- Evaluate the learners' findings and emphasize on those that are correct, incomplete or false.
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do the exercise in the checking up 9.7. Learners should do the checking up activity in any method you wish to use

Expected answers for activity 9.7

1. The type of bonding in beryllium and aluminium elements is covalent; both form chlorides that are dimers when they are in gaseous state.

2. 2 chemical properties of Be and Al:

   -Both Be and Al form amphoteric oxides.

   -Both beryllium and aluminium are not readily attacked by acids due to the oxide layer they form upon reaction with an acid.

3. Both lithium and magnesium do not react with cold water but react with hot steam.
4. -Both BeCl2 and AlCl3 form dimers when they are in vapour phase.

   -Both BeCl2 and AlCl3 react with water to liberate H+ ions.

Expected answers for Checking up 9.7:

1. a)Equation: $B_2O_3 + 2OH^- \longrightarrow 2BO_3^{2-}$

b) $SiO_2 + 2OH^- \longrightarrow SiO3^{2-} + H_2O$

2. It is due to the high electronegativity which are similar in both elements and their sizes are almost the same.

3. They form volatile hydrides which are easily hydrolysed.

4. They form acidic medium such that they hydrolyse water molecules to liberate H+ ions in solution.

9.6. Unit summary

- Non-metal elements of group 14 (C, Si) react with other non-metals to form covalent bonds by using 4 valency electrons.
- Elements of group 14 (C, Si) may react with metals to form carbide (e.g CaC3) or silicides (e.g Mg2Si) using 4 valency electrons.
- Metal elements of group 14 react by losing the p-sub-energy level electrons to form cations such as Pb2+ and these ions can form ionic bonds with anions present.
- Example: Pb2+(aq) + 2F-(aq) → PbF2(s) lead fluoride is ionic
- Metalloids of group 14 elements react with non-metals to form ionic bonds such as SnS or covalent bonds such as SnCl4.
- The nature of the bond formed depends on the oxidation state of Sn. If Sn is in Sn2+, it forms ionic bonds. If Sn is in Sn4+ form, it forms covalent bonds.
- All bonds formed by carbon and silicon are covalent.
- Germanium, tin and lead can form ionic bonds as well as covalent bonds in certain cases.

9.7. Additional information for teachers

Activity (1)

NB: This activity should be conducted in the presence of the teacher in the laboratory

- The concentrated nitric acid should be handled with care using glass droppers.
- Due to the toxic nature of the gases, the quantity of substances used in the

laboratory should be limited. It is advisable to work in less than 5 groups of students in the laboratory.

NB: To prepare MgO Get a magnesium ribbon and put it in a burning flame of a Bunsen burner, when it starts igniting, place it above a dry beaker so that the ash produced can be collected there for use in the experiment.

Activity (2)

NB: It is enough to add very little (about 0.5ml) of HCl or NaOH solution so that the observable change can be noticed.(teacher guide)

Lead does not directly react with chlorine, but $PbCl_4$ is prepared by reaction of PbO_2 with HCl.

$$PbO_2 + 4HCl \longrightarrow PbCl_2 + 2H_2O + Cl_2$$

PbCl4 is unstable, thus it readily decomposes to $PbCl_2$ and Cl_2 .The stability of tetrachlorides of group 14 elements decreases as we move down the group. This is due to the fact that moving down the group, the bond X-Cl becomes longer and the bond energy decreases.

Carbon does not directly react with chlorine, but carbon disulphide, CS_2 does react with chlorine to form carbon tetrachloride, CCl_4.

$$CS_2 + 3Cl_2 \longrightarrow CCl_4 + S_2Cl_2$$

Silicon and tin directly react with chlorine to form silicon tetrachloride, $SiCl_4$ and tin tetrachloride, $SnCl_4$ respectively.

Silane, SiH_4 can be synthesized by reaction of the magnesium compound, Mg_2Si with a dilute acid.

$$Mg_2Si + 4H^+ \longrightarrow 2Mg^{2+} + SiH_4$$

Also the synthesis of silane can be effected by reaction of silicon tetrachloride, $SiCl_4$ and lithium aluminium hydride, $LiAlH_4$:

$$SiCl_4 + LiAlH_4 \longrightarrow SiH_4 + LiAlCl_4$$

Stannane, SnH_4 can be synthesized by reaction of tin tetrachloride, $SnCl_4$ and lithium aluminium hydride, $LiAlH_4$:

$$SnCl_4 + LiAlH \longrightarrow SnH_4 + LiCl + AlCl_3$$

CH_4 , SiH_4 are stable up to high temperatures. SnH_4 decomposes slowly at room temperature and PbH_4 is too unstable to exist at room temperature.

Lead does not directly react with hydrogen gas. Lead hydride PbH_4 known as plumbane can be obtained by reaction of lead nitrate $Pb(NO_3)_2$ and sodium borohydride $NaBH_4$. Plumbane is an unstable gas which has a tetrahedral structure and it boils at -13 °C.

All the tetrahalides are volatile covalent compounds, except for the SnF_4 and PbF_4 which have some ionic character. Stability decreases down the group and decreases from fluorides to iodides.

Except for CCl_4 and CF_4, other tetrahalides are hydrolyzed in solution:

$SiCl_4$ (l) + $2H_2O$ (l)à SiO_2 (s) + 4HCl (g)

When silicon tetrafluoride is hydrolyzed, the products react to form the complex hexafluorosilicate ion, SiF_6^{2-} :

$SiF_4 + 3H_2O$ à$H_2SiO_3 + 4HF$

$H_2SiO_3 + 6\ HF$ à $H_2SiF_6 + 3H_2O$

These reactions are thought to proceed by the formation of a dative bond from the oxygen atom of a water molecule to the silicon atom. This explains the marked contrast in behavior of these compounds and the halides of carbon.

Occurrence:

Silicon is found in the forms of silicon dioxide and complex silicates and does not occur in the free elemental state. Silicon dioxide is the principal constituent of sand. The silicates (such as the complex aluminum, calcium, and magnesium silicates) are the main constituents of clays, soils, and rocks

Examples:

-Beryl: $Be_3Al_2(Si_6O_{18})$

-Phenakine: $BeSiO_4$

-Willemite: Zn_2SiO_4

-Forsterite: Mg_2SiO_4

-Almandine: $Fe_3Al_2(SiO_4)_3$

-Andradite: $Ca_3Fe_2(SiO_4)_3$

Portland cement:

It is obtained when some compounds of silicon (SiO_2 in sand or in clay) are mixed with other compounds.

-CaO (limestone)

-Al_2O_3 (bauxite)

-Fe_2O_3 (clay)

-$CaSO_4.2H_2O$ (gypsum)

Germanium:

-Occurs in small quantities in the ores of silver, copper, and zinc, and in the mineral germanite, which contains 8 percent of germanium.

-The principal ore of tin is the mineral cassiterite (or tinstone), SnO_2 . Tin often loses 2 valence electrons to form Sn^{2+}.Lead is widely distributed all over the world in the form of its sulfide, the ore galena (PbS).

Diagonal relationship

- A diagonal relationship exists between certain pairs of diagonally adjacent elements in the second and third periods of the periodic table. These pairs (Lithium (Li) and Mg, Be and Al, boron (B) and silicon (Si)) exhibit similar properties; for example, boron and silicon are both semiconductors, they form halides that are hydrolyzed in water and have acidic oxides.

- Both B and Si exist in amorphous and crystalline state and exhibit allotropy.
- Both B and Si possess close electronegativity values (B=2.0; Si=1.8).
- The chlorides of B and Si are liquid, fume in most air and readily hydrolyze in water:

$$BCl_3 + 3H_2O \longrightarrow B(OH)_3 + 3HCl$$
$$SiCl_4 + H_2O \longrightarrow Si(OH)_4 + 4HCl$$

- Both B and Si form binary compounds with several metals to give borides and silicide. These borides and silicides react with H_3PO_4 to give mixtures of boranes and silanes.

$$3Mg+2B \longrightarrow Mg_3B_2 \text{ (Magnesium boride);}$$
$$Mg_3B_2 + H_3PO \longrightarrow \text{Mixture of boranes}$$
$$2Mg + Si \longrightarrow Mg_2Si \text{ (magnesium silicide);}$$
$$Mg_2Si + H_3PO_4 \longrightarrow \text{Mixture of silanes}$$

- The carbides of Boron and silicon (B4C and SiC) are very hard and used as abrasive.
- Oxides of B and Si are acidic and can be reduced by limited amount of Mg. In excess of Mg, boride and silicide are formed.

$$B_2O_3 + 3Mg \longrightarrow 3MgO + 2B;$$
$$SiO_2 + 2Mg \longrightarrow 2MgO + Si$$

- Borates and silicates of B and Si have tetrahedral structural units. Their borosilicates are known in which boron replaces silicon in the three dimensional lattice. Boron can however form planar BO_3 units.
- Beryllium and aluminium ions have a strong tendency to form complexes. Hydrolysis of salts of Beryllium and aluminium produce an acidic medium.
- When chlorides of Beryllium and aluminium are dissolved in water and the water is evaporated, the loss of HCl occurs and the final products in the residue are not chlorides, but rather the oxides:
- Compounds of Be and Al are predominantly covalent as a result of the high charge-to-size ratio, which causes polarization of anions and very high heats of hydration of the ions (-2487KJmol-1 for Be^{2+} and -4690KJmol^{-1}for Al^{3+}).
- • Formation of electron-deficient covalent of chlorides, which tend to form dimers or polymers.The structure of aluminium chloride dimer and beryllium chloride polymer chain illustrate the types of bridge structures exhibited by these compounds.
- Li is the only Group 1 element which forms nitride, (Li_3N). Mg (Mg_3N_2), as well as other Group 2 elements.

$$6Li + N_2 \longrightarrow 2Li_3N;$$
$$3Mg + N_2 \longrightarrow Mg_3N_2.$$

Both nitrides are hydrolyzed in water to give NH_3:

$$Li_3N + 3H_2O \longrightarrow 3LiOH + NH_3;$$
$$Mg_3N_2 + 6H_2O \longrightarrow 3Mg(OH)_2 + 2NH_3$$

- Bicarbonates of Li and Mg are more soluble in water than carbonates whereas carbonates of alkali metals are more soluble. Lithium carbonate, phosphate and fluoride are sparingly soluble in water. The corresponding Group 2 salts are insoluble.

- Both Li and Mg form covalent organometallic compounds. The other Group 1 and Group 2 analogues are ionic and extremely reactive and hence are difficult to manipulate.
- Carbonates thermally decompose, to give oxides and carbon dioxide:

$$Li_2CO_3 \longrightarrow Li_2O + CO_2$$
$$Mg\ CO \longrightarrow MgO + CO_2$$

- Both Li and Mg combine with carbon on heating.

$$2Li + 2C \longrightarrow Li_2C_2$$
$$Mg + 2C \longrightarrow MgC_2$$

- Both Li and Mg have a high polarizing power.
- Polarizing Power = Ionic charge/(ionic radius)2
- Li_2SO_4 like $MgSO_4$ does not form alums.
- Both Lithium chloride and $MgCl_2$ are deliquescent and separate out from their aqueous solutions as hydrated crystals, $LiCl.2H_2O$ and $MgCl_2.2H_2O$.
- The periodic properties of Li and Mg are quite comparable.
- Stability of formation of cations with a valence of 2+ increases as we move down the group. So lead forms the most stable ion of Pb^{2+} than the rest of the elements of group 4.

Hazards caused by group 14 compounds

- The splaying of large areas of land with chlorine – containing pesticides has eliminated many insect – borne diseases, such as malaria. It also led to enormous improvement in the quality and yield of crops.
- Unfortunately, however, these chlorinated compounds are so stable that they remain unchanged on the crops or accumulate in the soil. Furthermore, these compounds are fat – soluble but not water – soluble.
- This means that they concentrate, after ingestion, in the fatty tissues of birds and animals, possibly reaching hazardous levels.
- In the spring, large numbers of seed – eating birds die in cereal – growing areas. Analysis showed that the corpses of these birds contained chlorine compounds which had been sprayed on the spring – sown wheat.
- In case of DDT and BHC, insects can develop a tolerance to small, non – lethal doses of these chemicals. These insects are eaten by small carnivorous animals and birds which concentrate the DDT in their own fatty tissue.
- Larger predators which eat these small carnivores concentrate the DDT even further. Ultimately, the DDT may reach toxic levels in animals or birds several stages along the food chain.

9.8. End unit assessment answers

1. Tetrahedral

2. Carbon
3. Silicon
4. Lead
5. Lead
6. a) $Pb(OH)2(s) \longrightarrow PbO(s) + H2O(l)$

   b) $SnCl4(l) \longrightarrow SnCl2(s) + Cl2(g)$
7. Tin reacts with acids and bases.

   With a base: $Sn + 2OH \longrightarrow SnO_2^{2-} + H_2$

   With an acid: $Sn + 2H_2SO_4 \longrightarrow SnO_2 + 2SO_2 + 2H_2O$
8. The stability of compounds in oxidation state of +2 increases down the group because as the size of ions increases, there is an increase (widening) in energy level difference between the s and p sub-energy level.
9. Down the group, the size of atoms increases and the inter-nuclear radii between neighbouring atoms increase.

   This results in weakening of bonds as you move down the group and therefore less energy is required to break the bonds as you move down the group.

   So melting points of group 14 elements decrease down the group.
10. Equation: $3Sn^{2+}_{(aq)} + 2Bi(NO_3)_3 \longrightarrow 2Bi(s) + 3Sn(NO_3)_2$

    The colourless bismuth nitrate solution turns black (precipitate of bismuth element)
11. -B and Si both form volatile hydrides that can catch fire on exposure to air.

    -Both B and Si form weak acids when they react with water.
12. -CCl_4, $SnCl_4$ are covalent and are liquids at room temperature.

    -SnCl2 is ionic solid at room temperature and conducts electricity when it is dissolved in water.
13. a) $Sn + 2Cl_2 \longrightarrow SnCl_4$

    b) $Sn + 2HCl \longrightarrow SnCl_2 + H_2$

9.9. Additional activities

9.9.1. Remedial activities

1. Explain the term" catenation" of carbon and write the chemical formula of 2 compounds formed as a result of catenation.
2. Which of the following bond energy ordering is correct?

   a) Sn-Sn>Si-Si>C-C

   b) C-Br>C-Cl

   c) C-Cl>Si-Cl>Pb-Cl

   d) Si-O>C-O>Sn-O
3. Which of the following statements is false?

   a) $Pb(NO_3)_2$ and PbO_2 are soluble in water.

b) $SnCl_2$ dissolves in water

- c) PbO reacts with NaOH solution.
- d) $SnCl_2$ is ionic

9.9.2.Consolidation activities

4. Explain why $SiCl_4$ hydrolyses in water.
5. Give 1 test reagent for Pb^{2+} ions in solution and indicate the observable changes as well as the equation of reaction.
6. Explain why silicon is a semi-metal.
7. Explain why graphite conducts electricity but diamond does not.

9.9.3. Extended activities

8. Explain why SiO_2 has a higher melting point than $SiCl_4$.
9. Carry out a brief research and write the chemical formula of 2 compounds of silicon in cement.
10. Describe 2 hazards caused by compounds of group 14 elements.

Answers of additional activities

1. Catenation is the formation of many bonds between carbon atoms to form chains such as in alkanes. Examples: C_4H_{10} ,C_6H_{14}
2. Answer is c)
3. Answer is a)
4. $SiCl_4$ hydrolyses in water because silicon atom possesses vacant d-orbitals available for bonding with H_2O while the reaction is taking place.
5. Reagent test: KI solution. There is a deep yellow precipitate.

   Equation: $Pb^{2+}_{(aq)} + 2I^-_{(aq)} \longrightarrow PbI_{2(s)}$
6. Silicon is a semi-metal because the electrons in the atoms are loosely held and they can easily be lost when they are in contact with more reducing agents.
7. -Graphite conducts electricity because each carbon forms 3 bonds with other carbons in the structure and the four electrons is free such that it can be delocalised to move and conduct electricity.

   -Diamond forms four bonds such that all the four electrons are used in bond formation. So diamond cannot conduct electricity.
8. SiO_2 has a higher melting point than $SiCl_4$ because:

   -SiO_2 has covalent bonds linked to others in a giant structure whereas $SiCl_4$ forms covalent bonds with individual molecules attracted to other by van der waals forces.
9. Compounds of silicon (formula in cement):

   i) Ca_2SiO_5 ii) $BeSiO_4$ iii) $FeSiO_4$
10. Hazards of compounds of carbon:

    i) Fluorochlorocarbons cause air pollution because it destroys the ozone layer in the atmosphere.

ii) Leaded petrol can emit lead toxic element in the atmosphere to cause pollution during the combustion of petrol in car engines.

The lead causes illnesses in humans if it has been inhaled in big quantities.

UNIT 10: TRENDS IN CHEMICAL PROPERTIES OF GROUP 15 ELEMENTS AND THEIR COMPOUNDS

10

10.1. Key unit competency

The learner should be able to compare and contrast the properties of the Group 15 elements and their compounds in relation to their position in the Periodic Table.

10.2. Prerequisite knowledge and skills

Students will learn better the Trends in chemical properties of Group 15 elements and their compounds if they have understood on: Chemical bonding, the arrangement of elements in the periodic table, Variation in trends of the physical properties of elements, the symbols of elements and compounds, concept of chemical reactions, and electronic configuration of elements.

10.3. Cross-cutting issues to be addressed

- **Environmental protection and sustainable development**

There is a serious issue of environmental protection and sustainable development in our society. When introducing this unit, it would be an opportunity to guide learners on understanding the importance of environmental protection and sustainable development and how the issues related to environmental protection and sustainable development may be addressed.

Help learners to:

a) Understand that sustainable development is a framework for a long-term vision of sustainability in which economic growth, social cohesion and environmental protection go hand in hand and are mutually supporting.

b) Understand that the key issue is to assess systematically the environmental impact of programmes, to quantify them and to integrate measures to limit any negative environmental impacts.

- **Inclusive education**

This unit involves a number of activities like experiments on the chemical properties of group 15 elements and their compounds. The activities require assembling of apparatus, writing, reading and observation of the results. This may be challenging to students with special educational needs especially children with visual impairment difficulties. However, the teacher can make some arrangements like:

Grouping students: Students with special educational needs are grouped with others and assigned roles basing on individual student’s abilities.

- Providing procedure earlier before the experiment so that students get familiar with them. They can be written on the board or printed depending on available resources. If you have children with low vision remember to print in appropriate fonts.
- Give extra time for them to write summary notes or write down observations after experiments.
- Every important point is written and spoken. The written points helps students with hearing impairment and speaking aloud helps students with visual impairment
- Remember to repeat the main points of the lessons.

For learners with **hearing difficulties**

Teacher has to encourage them to sit closer to the front of the classroom. While teaching, avoid asking learners whether they have understood, or if they need you to repeat a point. Encourage learners not to be afraid to ask questions. When teaching, speak clearly and ensure that all the learners can hear your voice. Avoid speaking hurriedly as this will make it difficult for learners with hearing difficulties to make sense of what you are saying.

Learners with mobility difficulties:

These include learners in crutches, wheelchairs, or with walking difficulties. Encourage other learners to look out for and help their classmates. Ask their follow learners to help them with their notes, if their conditions hinder them from writing well.

Learners with reading difficulties:

Learners with this kind of difficulties struggle to make sense of words or understand written work and take longer to read than other learners. 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.

- **Gender:**

During group activities try to form heterogeneous groups (with boys and girls) or when students start to present their findings encourage both (boys and girls) to present.

- **Financial education**

As the unit deals with the importance of group 16 elements and their compounds in modern life, the teacher will draw the learner’s attention on the economical impact of the making of common items made using knowledge of chemistry.

- **Peace and values education**

During group activities, the teacher will encourage learners to help each other’s and to respect opinions of colleagues.

10.4 Guidance on the introductory activity

Before introducing the first lesson of this unit, let learners attempt the introductory activity.

Expected answer for the introductory activity

1. a) Refer to learner's book

b) Group 15 elements

c) Nitrogen

d) Phosphorous

2.

a) A: An explosion, B: Matches box, C: Drugs

b) A: Dynamic breaching operations training, explosives testing, metal forming, and research & development, official police duties, fireworks testing, special effects for film and television, down-hole perforating, demolition, training purposes.

B: Burning purposes

C: Medicine

List of lessons/sub-headings

	Lesson title	Learning objectives	Number of periods
1	Physical properties of the Group 15 elements and relative inertness of nitrogen.	Describe the physical properties of the Group 15 elements. Describe the variation in the metallic and non-metallic character of the Group 15 elements. Explainthe relative inertness of nitrogen.	2
2	Reactions of the Group 15 elements with oxygen,water, chlorine, hydrogen, and metals (e.g. magnesium).	Describe the chemical reactions of nitrogen and phosphorous	2

3	Compounds of group 15 elements.	Describe the laboratory and industrial preparation of ammonia and nitric acid. Explain the reactions of nitric acid with metals and non-metals. Explain Environmental impact of industrial production of ammonia and nitric acid.	3
4	Phosphorous and its compounds	Recall the physical properties of the allotropes of phosphorus. Describe the chemical properties of phosphorus compounds. Explain the laboratory preparation of the phosphoric acid. - Describe identification of PO_4^{3-} and NO_3^- ions.	3
5	End unit assessment	Compare and contrast the properties of the Group 15 elements and their compounds in relation to their position in the Periodic Table	2

Lesson 1: Physical properties of the Group 15 elements and relative inertness of nitrogen

This is the first lesson of unit 15. It is a single lesson, but it also covers the introduction of the whole unit, it has two periods (80 minutes).

a) Introduction

Students will learn better the Physical properties of the Group 15 elements and relative inertness of nitrogen if they have understood the arrangement of elements in the periodic table, variation in trends of the physical properties of elements, the symbols of elements and compounds, concept of chemical reactions, and electronic configuration of elements.

b) Teaching resources

Use the illustrations in the student's book, the periodic table or draw the compounds under investigation on a manila paper.

c) Learning activities

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt introductory activity first then activity 10.1 which leads students to the first lesson of the unit.

Methodological steps As a facilitator, the teacher is expected to guide learners through the following steps:

- Form groups of 3 to 5 learners and ask them to choose a group leader
- Provide the activity 10.1 from the student book (when the books are not enough, he/she can writes the activity on the chalkboard) to the learners in their groups and ask every group to discuss questions 1 – 4, and provide answers.
- Let learners to work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the students‘findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners‘findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 10.1. Learners should do the checking up activity in any method you wish to use.

Expected answers for activity 10.1

1. Nitrogen is a gas while all others are solids

2. Metallic character is the property of an element that results from how easily its atoms lose valency electrons. The metallic character of elements decreases across each period due to the increase in nuclear charge and decrease in atomic radius. On the other hand, metallic character of elements increases down each group due to the increase in the screening effect caused by the extra energy levels.

3. Nitrogen and phosphorous are non-metals

Arsenic and antimony are metalloids

Bismuth is a metal

4. a) Nitrogen molecule

b) Covalent bond. Triple covalent bond

c) The bond is strong. This is because nitrogen is a diatomic molecule. The triple bond which is short between the two nitrogen atoms requires high energy to be broken down. It is not quite three times strong as a single bond, but it is a very strong bond.

d) Expected answers for Checking up 10.1

1. a) Down group 15, the atomic radius increases. This is because down the group, extra protons are added which increase nuclear charge. Also screening effect increases due to an extra full shell of electrons added. However, the increase in screening effect is more than the nuclear charge and this decreases the effective nuclear charge down the group. As such, down the group, nuclear attraction for the outermost electrons decreases which increase the atomic radius.

b)Electron affinity decreases down group 15 elements. This is because, down the group, the nuclear charge increases, atomic radius increases, screening effect increases rapidly due to the new electron shell added and out balances nuclear attraction. Force of attraction for the incoming electron decreases hence there is decrease in electron affinity.

c) For melting point, one needs to break the Van der waal's forces between molecules which requires energy. The higher the energy provided, the easier will be the breaking of Van Der Wal's forces. Now see, Nitrogen exists in the form of N2 consisting 2 molecules while Phosphorous exists as P4 consisting 4 molecules and so on. That is why the energy required to break the Van Der wal's force increases with increase in number of molecules. It continues till Arsenic but due to increase in metallic nature of elements going down further, the bonding of electrons becomes loose and hence causing the week interaction in between. In this way, the melting point increases up to Arsenic and then decreases till Bismuth.

d)There is a decrease in the first ionisation energy down group 15 elements. This is due to the increasing screening effect caused by extra energy levels added as atomic number increases. Both factors cause the outermost electrons to be less attracted by the nucleus hence making it easier for an electron to be removed.

2. a) Ore: a naturally occurring mineral containing a valuable constituent (such as metal) for which it is mined and worked. Or, a place where metals are extracted from.

b) Carbon

3. a) Down group 15 elements, the atomic radius increases which make the outermost electron to be less attracted by the nucleus as you move down the group. Therefore, less energy is required to remove the outermost electron, which results in the increase in the metallic character.

b)Element B has more metallic character. This is because; it has the greatest atomic radius compared to element A.

Lesson 2: Reactions of Group 15 elements

Reactions of the Group 15 elements, is the second lesson of the unit. Students are expected to be able to explain the reactions of group 15 elements with oxygen, water, chlorine, hydrogen, and metals.

a) Introduction:

Students will learn better the reactions of group 15 elements if they have the understanding on: the arrangement of elements in the periodic table, Variation in trends of the physical properties of elements, the symbols of elements and compounds, concept of chemical reactions, and electronic configuration of elements.

b) Teaching resources:

The periodic table of element

Where possible use manila papers, flipcharts and you-tube videos with computers and projectors.

c) Learning activities

Learning activity 10.2 is suggested in students‘ book. However you are free to add more.

- Form groups of 3 to 5 learners and ask them to choose a group leader
- Provide the activity 10.2 from the student book (when the books are not enough, you can write the activity on the chalkboard) to the learners in their groups and ask every group to do questions 1 – 4, and provide their answers.
- Let learners to work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the student’s findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners‘findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 10.2. Learners should do the checking up activity in any methodology you wish to use.

Expected answers for activity 10.2

1.

a) In chemistry, orbital hybridisation (or hybridization) is the concept of mixing atomic orbitals into new hybrid orbitals (with different energies, shapes, etc., than the component atomic orbitals) suitable for the pairing of electrons to form chemical bonds in valence bond theory.

b) Electronic configuration: is the distribution of electrons of an atom or molecule (or other physical structure) in atomic or molecular orbitals.

2.

Because of repulsive interactions between lone pairs of electrons on adjacent atoms. These interactions become important at the shorter inter-nuclear distances encountered with the smaller, second-period elements of groups 15, 16, and 17. Stable compounds with N–N bonds are limited to chains of no more than three N atoms, such as the azide ion (N_3^-).

3.

a) Acidic oxides are oxides that react with water to form an acid, or with a base to form a salt. They are oxides of either non metals or of metals in high oxidation states.

b) A basic oxide is an oxide that shows basic properties in opposition to acidic oxides and that either reacts with water to form a base, or reacts with an acid to form a salt and water. It is formed by reacting oxygen with metals.

c) An amphoteric oxide is an oxide that can react both as an acid as well as a base.

4.

a)True

B)True

C)True

DFalse

Expected answers for checking up 10.2

1.Nitrogen has a small size with high electronegativity for this it reacts by gaining electrons to form N_3^-. Other elements in the same group have big size and low electronegativity and tends to share or loose electrons.

2. The stability of +5 decreases down the group. Due to less attraction for the outer electrons and inert pair effect.

3.

1s2 2s2 2p6 3s2 3p6 4s2 3d10 4p3

A2O3, A2O5

c)

a) A2O3 is amphoteric, A2O5 is acidic

b) A2O3 + 6NaOH$\longrightarrow$2Na3AO3 + 3H2O (A2O3 as acidic oxide)

c) A2O3 + 6HCl$\longrightarrow$2ACl3 + 3H2O (A2O3 as basic oxide)

D) A2O5 + 6 NaOH$\longrightarrow$2Na3AO4 + 3H2O (A2O5 as acidic oxide)

Lesson 3: Ammonia and Nitric Acid

a) Introduction:

Before beginning this lesson, learners should be able to recall some of the properties of ammonia and nitric acid studied in senior three. The teacher may ask oral questions to name and explain some of the properties, uses and environmental impact of the industrial preparation of ammonia and nitric acid. If the learners are able to mention some, then he/she can proceed. If not he/she can ask some probing questions to give them a hint.

b)Teaching resources

The periodic table of element

Where possible use manila papers, flipcharts and youtube videos with computers and projectors.

c)Learning activities /methodological steps

Learners should carry out the experiments in activities 10.3 (a), (b) and (c). They should also do the study questions from each of the experiments performed in activity 10.3. Learners should do the checking up activity in any method you wish to use.

Activity 10.3	Materials
(a) Laboratory preparation of ammonia	Flip chart papers written on procedure to investigate the laboratory preparation of ammonia, hard glass test tube, U-tube, 3 corks, 10 grams of calcium hydroxide, gas jars, bent delivery tube and straight delivery tube, 5 grams of ammonium chloride on a watch glass, source of heat and calcium oxide lumps.
(b) Investigating reactions of HNO3 with metals	Concentrated nitric acid, copper turnings, magnesium ribbon, and aluminium powder, red and blue litmus paper, source of heat, beaker, and spatula.
(c) Investigate reaction of concentrated HNO3 with non-metals	Concentrated nitric acid, carbon (or charcoal), sulphur powder, red and blue litmus paper, spatula, source of heat.

d) Expected answers for checking up 10.3

1.

a) Ammonia is a Lewis base

b) This is because ammonia has a lone pair of electrons. Lewis base is any substance that is electron pair donor.

2. Ammonia is prepared by heating a mixture of any ammonium salt and an alkali

$$2NH_4Cl(s) + Ca(OH)_2(s) \longrightarrow CaCl_2(aq) + 2NH_3(g) + 2H_2O(l)$$

Nitric acid is prepared in the laboratory by the action of hot concentrated sulphuric acid on any nitrate salt.

$KNO_3(s) + H_2SO_4(l) \longrightarrow KHSO_4(s) + HNO_3(l)$

4.

a) Ammonia is a colourless gas,

Ammonia has a characteristic pungent odour

It is less dense than air.

b)

(i)$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

ii) Temperature: 450°C-500°C, Pressure: 200-1000atm, Catalyst: Finely divided iron catalyst

iii).

Step 1: Production of NO by oxidation of NH3

$4NH_3(g) + O_2(g) \xrightarrow{pt\ cat\ 600^0c} 4NO(g) + 6H_2O(g)$

Step 2: Oxidation of NO into NO_2

$2NO(g) + O_2(g) \xrightarrow{50^0c} 2NO_2(g)$

Step 3: Formation of HNO3 by mixing NO2 and water

$3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(l) + NO(g)$

4.

a) In the absence of a catalyst: $4NH_3(g) + 3O_2(g) \longrightarrow 2N_2(g) + 6H_2O(g)$

b) In the presence of a catalyst:

$4NH_3(g) + 5O_2(g) \xrightarrow{pt\ cat\ 600^0c} 4NO(g) + 6H_2O(g)$

Reaction with CuO: $3CuO(s) + 2NH_3(g) \longrightarrow 3Cu(s) + H_2O(l) + N_2(g)$

Reaction with HCl: $NH_3(g) + HCl(g) \longrightarrow NH_4Cl(s)$

Js

$Cu(s) + 4HNO_3(l) \longrightarrow Cu(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(l)$

$S(s) + 6HNO3(l \longrightarrow H2SO4(aq) + 6NO_2(g) + 2H_2O(l)$

$KOH(s) + HNO_3(aq) \longrightarrow KNO_3(aq) + H_2O(l)$

Lesson 4: Phosphorous and its compounds

a) Introduction

Students will learn better Phosphorous and its compounds if they have the understanding on: allotropy, the arrangement of elements in the periodic table, Variation in trends of the physical properties of elements, the symbols of elements and compounds, concept of chemical reactions, and electronic configuration of elements.

b) Teaching resources

Student‘s chemistry book and other relevant books from the school library

Internet resources

c) Learning activities

Activity 10.4: Guided Research

Students are asked to do research and answer questions in activity 10.4 (a) and (b). The teacher may help learners by giving them a list of important reference books available in the school library.

Methodological steps

- Introduce the lesson by allowing learners to do the learning activity 10.4 (a) in their respective groups. Let them work together in their groups without intervene directly.
- Learners should carry out the experiment in activities 10.4 (b). They should also do the study questions from the experiment performed in the activity.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the students‘ findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners‘ findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 10.4. Learners should do the checking up activity in any method you wish to use.

Expected answers for activity 10.4 (a)

Allotropes are two or more forms of the same element in the same physical state (solid, liquid, or gas) that differ from each other in their physical, and sometimes chemical, properties.

2. White phosphorous

- It exists as a tetrahedral structure
- It turns light yellow when exposed to sunlight.
- It is a crystalline, translucent, waxy solid, which glows faintly in moist air and is extremely poisonous.
- It ignites spontaneously in air at 34°C and in chlorine thus it must be stored under water.
- It is insoluble in water, slightly soluble in organic solvents, and very soluble

in carbon disulfide.

- White phosphorus melts at 44.1°C, boils at 280°C.
- When heated to between 230° and 300°C in the absence of air, white phosphorus is converted into the red form.

Red phosphorous

- Its structure is made of a chain of P4 units, a kind of polymer
- Red phosphorus is a dark red brittle powder formed from white phosphorus.
- It is a microcrystalline, non-poisonous powder.
- It has a density of 2.3g.cm-3, melts at 5900C.
- It sublimates (passes from the solid state directly to the gaseous state) at 416°C to form a non-toxic vapour.
- It is insoluble in CS2, benzene and ether.
- It ignites in air at 2600C and does not ignite in chlorine unless heated.

$P_4 + 3O_2 \longrightarrow 2P_2O_3$

$4P + 5O_2 \longrightarrow P_4O_{10}$ or, $P_4 + 5O_2 \longrightarrow P_4O_{10}$

$P4(s) + 6Cl2(g) \longrightarrow 4PCl_3(l)$

$P_4(s) + 10Cl_2(g) \longrightarrow 4PCl_5(s)$

Activity 10.4 (b)

Activity 10.3	Materials
Investigating the presence for nitrate ion (NO3-)	Freshly prepared iron (II) sulphate solution, Concentrated sulphuric acid, Test tubes, Droppers.

d) Expected answers for Checking up 10.4

1. Yellow phosphorus is another name for white phosphorus, an allotrope of phosphorus.

2. White phosphorus ignites suddenly in air at around 35°C, that is, at a temperature marginally higher than room temperature, to frame phosphorus pentoxide. Thus it is kept in water.

$P_4 + 5O_2 \longrightarrow 5P_2O5$ or P_4O_{10}

3. $2H_3PO_4(l) + Ca(OH)_2(s) \longrightarrow Ca_3(PO_4)_2(aq) + 6H_2O(l)$

4.

a) PCl_3 and P_2O_3

b) $PCl_5(l) + 4H_2O(l) \longrightarrow H_3PO_4(aq) + 5HCl(aq)$

c) $P_2O_5(s) + 3H_2O(l) \longrightarrow 2H_3PO_4(aq)$

c) Reaction: $H_3PO_4(aq) + 3NaOH(aq) \longrightarrow Na_3PO_4(aq) + 3H_2O(l)$

Number of moles of NaOH, n =n= 0.6moldm-3×25×10-3dm3

n= 0.015mol

According to mole ratio: H3PO4: NaOH

1:3

3moles of NaOH react with 1 mole of H3PO4

0.015moles of NaOH will react with $\frac{1\text{mole x}0.015\text{moles}}{5\text{moles}}$ =0.005moles of H3PO4

Concentration of the solution, M=$\frac{n}{v}$ $\frac{0.00\text{moles}}{25 \text{ x}10^{-3}\text{dm}^3}$ =0.2moldm-3

e) Trigonal bipyramidal shape

Bond angle: 120° or 90°

10.6.Summary of the unit

- Group 15 elements have the outer electron arrangement ns2 np3.
- There is a clear trend from non-metals to metals on descending the group.
- Nitrogen exists as N2 molecules due to the great strength of the nitrogen-nitrogen triple bond.
- The large N $\equiv$ N bond energy makes the N_2 molecule unreactive.
- Phosphorous atoms are too large to form effective pi bonds by overlap of p orbitals.
- Nitrogen can form three covalent bonds plus one dative covalent bond.
- Phosphorous can form five covalent bonds by promotion of an electron from 3s orbital to a 3d orbital.
- Nitrogen forms ionic nitrides containing the N3- ion with the more reactive s-block elements.
- There are no compounds containing the P3- ion.
- The hydrides become less stable on descending the group because the E-H bond gets weaker.
- Ammonia is a covalent compound, consisting of nitrogen bonded to three hydrogen atoms. It is prepared by heating a mixture of any ammonium salt and an alkali in the laboratory and using Haber process in industry.
- Ammonia can be oxidised to nitrogen monoxide, NO
- Nitric acid can be prepared in the laboratory by the action of hot concentrated sulphuric acid on any nitrate salt and using the Oswald's process in industry.
- Nitric acid is both a strong acid and an oxidising agent.
- Phosphorous exists as P4 white phosphorous molecules or giant structures

(red and black phosphorous). Each phosphorous atom form three single bonds.

- Phosphoric acid can be prepared by boiling a mixture of red phosphorus with nitric acid
- There are environmental effects of nitrates and phosphates fertilisers when used in excess

10.7 Additional information for teachers

1. Nitrogen dioxide, NO2, (nitrogen (IV) oxide)

Preparation

It is prepared by heating nitrates of heavy metals such as lead (II) nitrate. Oxygen is also evolved as a by-product.

$Pb(NO_3)_2\,(s) \longrightarrow 2PbO(s) + 4NO_2(g) + O_2(g)$

It is also prepared by reacting concentrated nitric (V) acid with copper turnings.

$Cu(s) + 4HNO3(aq) \longrightarrow Cu(NO3_{)2}(aq) + 2H_2O(l) + 2NO_2(g)$

Physical properties of Nitrogen dioxide

- Is brown in colour
- Dissolves in water to forms an acid solution
- Has a pungent, choking smell
- On heating, forms dinitrogen tetroxide, N_2O_4,
- Is denser than air
- Turns blue litmus red

Chemical properties of Nitrogen dioxide

Reacts with water

Nitrogen (IV) oxide is readily soluble in water forming a pale-yellow acidic solution consisting of nitric (III) and nitric (V) acids.

$2NO2(g) + H2O(l) \longrightarrow HNO2(aq) + HNO3(aq)$

The nitric (III) acid oxidizes readily to nitric (V) acid.

$2HNO_2(aq) + O2(g) \longrightarrow 2HNO_3(aq)$

The gas decomposes when heated forming nitrogen (II) oxide and oxygen.

$2NO2(g) \longrightarrow NO(g) + O2(l)$

Nitrogen (IV) oxide oxidizes hot metals and the gas is reduced to nitrogen

$4Mg(s) + 2NO2(g) \longrightarrow 4MgO(s) + N2(g)$

$4Cu(s) + 2NO2(s) + \longrightarrow 4CuO(s) + N2(g)$

Uses: NO2 gas is used in the:

- Manufacture of nitric acid
- Manufacture of explosives, plastics and nylon materials

2. Ntrates

Nitrates are prepared by reacting dilute nitric acid with a carbonates, hydroxides, oxide or metals.

$HNO3 + KOH \longrightarrow KNO_3 + H_2O$

$HNO_3 + NaOH \longrightarrow NaNO_3 + H_2O$

$Cu + HNO_3 \longrightarrow Cu(NO3)2 + 2NO_2 + H_2O$

$CaCO_3 + HNO_3 \longrightarrow Ca(NO3)2 + H_2O + CO_2$

$Mg + HNO_3 \longrightarrow Mg(NO_3)_2 + H2(g)$

$ZnO + 2HNO_3 \longrightarrow Zn(NO_3)_2 + H_2O$

Properties of nitrates

All are soluble in water

All are solid and ionic compounds

When heated with concentrated sulfuric acid, nitric acid is formed.

Action of heat on nitrates.

When heated, nitrates decompose to form various products:

Group I metal nitrates produce the nitrite and oxygen

$2NaNO_3(s) \longrightarrow 2NaNO_2(s) + O_2(g)$

Metals between Ca and Cu in the activity series produce the oxide of the metal, nitrogen dioxide (brown fumes) and oxygen.

$2Cu(NO3)2(s)$ $2CuO(s) +4NO(g) +O2(g)$

Green   Black   brown fumes

$2Pd(NO3)2(s) \longrightarrow 2PdO(s) + 4NO2(g) + O2(g)$

colourless   orange-hot brown fumes

$2Zn(NO3)2(s) \longrightarrow 2ZnO(s) + 4NO2(g) + O2(g)$

colourless   yellow-hot   brown fumes

Metals like silver and mercury lower than copper produce the metal, nitrogen dioxide and oxygen.

$Hg(NO3)2(s) \longrightarrow Hg(l) + 2NO2(g) + O2(g)$

$2AgNO3(s) \longrightarrow 2Ag(s) + 2NO2(g) + O2(g)$

Ammonium nitrate decomposes explosively.

$NH4NO3 \longrightarrow N2O + H2O$

10.8. End unit assessment answers

Multiple choice questions:

1.A   2.D   3.B   4.A   5.A   6.A   7.A

1. Short and long answer Open questions

Nitrogen valence electronic configuration ns2np3 due to absence empty d-orbitals, it cannot extend its valence to 5.

2. Unlike NH3, PH3 molecules are not associated through hydrogen bonding in liquid state. That is why the boiling point of PH3 is lower than NH3.

3.

a) Check student's book, the preparation of ammonia

b)$2NH_4Cl(s) + Ca(OH)_2(s) \longrightarrow CaCl_2(aq) + 2NH_3(g) + 2H_2O(l)$

b)

i) Ammonium nitrate (NH_4NO_3), Ammonium chloride (NH_4Cl), Ammonium sulphate $(NH4)_2SO_4$, Ammonium carbonate $(NH_4)_2CO_3$

ii) Use litmus paper. Ammonia gas will turn moist litmus paper from red to blue, and moist universal indicator paper to blue.

iii) Manufacture of nitrogenous fertilisers, explosives

4.

a) $Cu(s) + 4HNO_3(l) \longrightarrow Cu(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(l)$

Reddish brown fumes are evolved and a green solution is left

b) As an acid: It neutralises (reacts with) alkali and bases forming salts and water

- $CuO(s) + 2HNO_3(aq) \longrightarrow Cu(NO_3)_2(aq) + H_2O(l)$
- $NaOH(s) + HNO_3(aq) \longrightarrow NaNO3(aq) + H_2O(l)$

As an oxidizing agent: nitric acid shows this property when hot and concentrated.

- $C(s) + 4HNO_3(l) \longrightarrow CO_2(g) + 4NO_2(g) + 2H_2O(l)$
- $S(s) + 6HNO_3(l) \longrightarrow H_2SO_4(aq) + 6NO_2(g) + 2H_2O(l)$

Production of fertilizers, making gun powder

5

a) $4P(s) + 5O_2(g) \longrightarrow P_4O_{10}(s)$

Oxidation state:(+5)

Used in making matches, preparation of phosphate fertilizers

10.9 Additional activities

10.9.1. Remedial activities

Choose the correct answer

Concentrated nitric acid oxidizes cane sugar to:

A) CO_2 and H_2O B) CO and H_2O C) CO, CO_2 and H_2O D) Oxalic acid and water

2. Red Phosphorous can be obtained from white Phosphorous by

A) Heating it with a catalyst in an inert atmosphere

B) Distilling it in an inert atmosphere

C) Dissolving it in carbon disulphide and crystallising

D) Melting it an pouring the liquid into water

3. When aluminium phosphide is reacted with diluted H_2SO_4

A) SO2 is liberated B) PH_3 is evolved C) H_2S is evolved D) H_2 is evolved

4. Cyanamide process is used in the formation of

A) N_2 B) HNO_3 C) NH_3 D) PH_3

5. Which statement is wrong for NO

A) It is anhydride of nitrous acid B) It dipole moment in 0.22D C) It forms dimer D) It is paramagnetic

6. Solid PCl5 exists as

A) PCl_5 B) PCl_4^+ C) PCl6⁻ D) PCl_4+ and PCl_6^-

7. How can you synthesise nitric oxide in the lab?

A) Zinc with cold and dilute HNO_3 B) Zinc with Conc. HNO_3 C) Cu with cold and diluted HNO_3 D) Heating NH4 NO3

8. Which of the following is a cyclic phosphate?

A) $H_5P_3O_{10}$ B) $H_6P_4O_{13}$ C) $H_5P_5O_{15}$ D) $H_7P_5O_{16}$

9. Which catalyst is used in the Haber process for the manufacture of NH3?

A) Pt B) Fe+ C) CuO D) Al2O3

10. Which of the following has the highest dipole moment?

A) NH3 B) PH3 C) SbH3 D) ASH3

Answers

1. D 2.A 3.B 4.C 5.A 6.D 7.C 8.C 9.B 10.A

10.9.3. Consolidation activities

1. Give reasons for the following:

    a) Nitrogen is less reactive at room temperature

    b) Ammonia (NH3) has higher boiling point than PH3

    c) Bond angle in NH4+ is greater than that in NH3

Answer:

a) This is due to the presence of triple bond which has high bond dissociation enthalpy.

b) NH3 is associated with intermolecular hydrogen bonding, PH3 does not.

c) NH3 has lone pair of electrons, so, bond angle is 107°, whereas NH4+ does not, therefore bond angle is 109.5°.

2. Which poisonous gas is evolved when white phosphorous is heated with concentrated NaOH? Write equation for the reaction.

Answer:

Phosphine gas is formed

$P4 + 3NaOH + 3H_2O \longrightarrow 3NaH2PO_2 + PH3$

Why does PCl5 fume in moisture?

Answer:

It is because it gets hydrolysed to form HCl which fumes in moist air.

$PCl_5(l) + H_2O(l) \longrightarrow POCl_3(aq) + 2HCl(aq)$

4. Which allotrope of phosphorous is more reactive and why?

Answer:

The more reactive allotrope is white phosphorous. This is because it is monomeric and has low bond dissociation enthalpy due to angle of strain (bond angle 600°).

5.The atomic number of arsenic (As) is 33.

a)Using s,p,d, notation, give the electronic configuration of arsenic

b)Predict the molecular formulae of two chlorides of arsenic

c)Deduce the molecular shape and the bond angle of the chloride of arsenic in which arsenic shows a lower oxidation number.

Answers:

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$

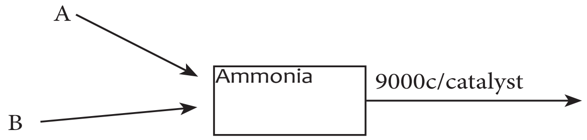
AsCl3 and AsCl5

The chloride in which arsenic shows a lower oxidation state is AsCl3

The molecular shape: trigonal pyramidal

Bond angle: 107°

6. The flow chart below shows the process that can be used to obtain substance C from ammonia gas when it is heated to about 90° in air and in the presence of a catalyst.



a) Ammonia is obtained on large scare by Haber process. Name the raw materials A and B.

b) Name the substance C and the catalyst used.

c) Write an equation to show the product formed when C is cooled in presence of air.

Answer:

A= Nitrogen, B= Hydrogen

C= Nitrogen (II) Oxide, the catalyst is platinum

$2NO(g) + O_2(g) \longrightarrow 2NO_2(g$

The catalytic combustion of hydrogen gas and nitrogen gas to produce ammonia is represented by the following equation.

$N2(g)+3H_2(g) \rightleftharpoons 2NH_3(g)$

a) Name the catalyst that can be used in this reaction

b) Give the test for identification of ammonia gas.

Answer:

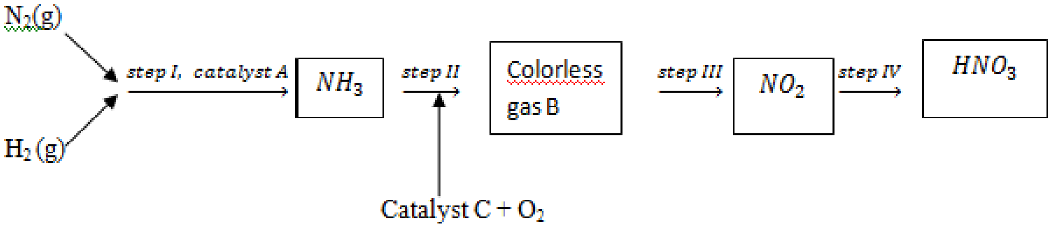
a) Finely divided iron catalyst

b)

- Ammonia forms dense white fumes of ammonium chloride when brought into contact with fumes of hydrogen chloride from the concentrated hydrogen chloride.
- $NH3(g) + HCl(g) \longrightarrow NH_4Cl(s)$ (white fumes)
- Expose damp red litmus paper to the gas, it is turned blue. Ammonia is the only common alkaline gas.

10.9.2. Extended activities

Study the flow chart below and answer the questions that follow.



Name catalysts A, C and colorless gas B

Write the equations for the reactions in step (IV).

State two industrial uses of nitric acid.

Answer:

Catalyst A: Finely divided iron catalyst, catalyst C: Platinum catalyst, gas B: Nitrogen (II) oxide, NO

$3NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(l) + NO(g)$ or,

$4NO_2(g) + 2H_2O(l) + O2(g) \longrightarrow 4HNO_3(l)$ or,

$2NO_2(g) + H_2O(l) \longrightarrow 2HNO_3(l) + HNO_2(l)$

c) Used in making explosives such as trinitrotoluene (TNT)

Used in the manufacture of dyes, fertilizers, artificial fibre and drugs.

2. Discuss the general characteristics of Group 15 elements with reference to their electronic configuration, oxidation state, atomic size, ionisation enthalpy and electronegativity.

Answer:

General trends in group 15 elements

Electronic configuration: All the elements in group 15 have 5 valence electrons. Their general electronic configuration is $ns^2\ np^3$.

ii) Oxidation states: All these elements have 5 valence electrons and require three more electrons to complete their octets. However, gaining electrons is very difficult as the nucleus will have to attract three more electrons. This can take place only with nitrogen as it is the smallest in size and the distance between the nucleus and the valence shell is relatively small. The remaining elements of this group show a formal oxidation state of −3 in their covalent compounds. In addition to the −3 state, N and P also show −1 and −2 oxidation states.

All the elements present in this group show +3 and +5 oxidation states. However, the stability of +5 oxidation state decreases down a group, whereas the stability of +3 oxidation state increases. This happens because of the inert pair effect.

iii) Ionization energy and electronegativity: First ionization decreases on moving down a group. This is because of increasing atomic sizes. As we move down a group, electronegativity decreases, owing to an increase in size.

iv) Atomic size: On moving down a group, the atomic size increases. This increase in the atomic size is attributed to an increase in the number of shells.

3. Why does the reactivity of nitrogen differ from phosphorus?

Answer

Nitrogen is chemically less reactive. This is because of the high stability of its molecule, N2. In N2, the two nitrogen atoms form a triple bond. This triple bond has very high bond strength, which is very difficult to break. It is because of nitrogen's small size that it is able to form pπ–pπ bonds with itself. This property is not exhibited by atoms such as phosphorus. Thus, phosphorus is more reactive than nitrogen.

4. Discuss the trends in chemical reactivity of group 15 elements.

Answer

General trends in chemical properties of group 15

i) Reactivity towards hydrogen: The elements of group 15 react with hydrogen to form hydrides of type EH3, where E = N, P, As, Sb, or Bi. The stability of hydrides decreases on moving down from NH3 to BiH3.

ii) Reactivity towards oxygen: The elements of group 15 form two types of oxides: E2O3 and E2O5, where E = N, P, As, Sb, or Bi. The oxide with the element in the higher oxidation state is more acidic than the other. However, the acidic character decreases on moving down a group.

iii) Reactivity towards halogens: The group 15 elements react with halogens to form two series of salts: EX3 and EX5. However, nitrogen does not form NX5 as it lacks the d-orbital. All trihalides (except NX3) are stable.

iv) Reactivity towards metals: The group 15 elements react with metals to form binary compounds in which metals exhibit –3 oxidation states.

5. Illustrate how copper metal can give different products on reaction with HNO_3.

Answer

Concentrated nitric acid is a strong oxidizing agent. It is used for oxidizing most metals. The products of oxidation depend on the concentration of the acid, temperature, and also on the material undergoing oxidation.

$3Cu(s) + 8HNO_3(dilute) \longrightarrow 3Cu(NO_3)_2(s) + 2NO(g) + 4H_2O(l)$

$Cu(s) + 4HNO_3(conc) \longrightarrow Cu(NO_3)_2(s) + 2NO(g) + 2H_2O(l)$

6. The HNH angle value is higher than HPH, HAsH and HSbH angles. Why? [Hint: Can be explained on the basis of sp3 hybridisation in NH3 and only s-p bonding between hydrogen and other elements of the group].

Answer

Hydride NH3 PH3 AsH3 SbH_3, H–M–H angle 107°,92°, 91°, 90° respectively.

The above trend in the H–M–H bond angle can be explained on the basis of the electronegativity of the central atom. Since nitrogen is highly electronegative, there is high electron density around nitrogen. This causes greater repulsion between the electron pairs around nitrogen, resulting in maximum bond angle. We know that electronegativity decreases on moving down a group. Consequently, the repulsive interactions between the electron pairs decrease, thereby decreasing the H–M–H bond angle.

7. Why are pentahalides more covalent than trihalides?

Answer:

In pentahalides, the oxidation state is +5 and in trihalides, the oxidation state is +3. Since the metal ion with a high charge has more polarizing power, pentahalides are more covalent than trihalides.

Why is BiH3 the strongest reducing agent amongst all the hydrides of Group 15 elements?

Answer:

As we move down a group, the atomic size increases and the stability of the hydrides of group 15 elements decreases. Since the stability of hydrides decreases on moving from NH3 to BiH_3, the reducing character of the hydrides increases on moving from NH_3 to BiH_3.

9.Write main differences between the properties of white phosphorus and red phosphorus.

Answer:

White phosphorus	Red Phosphorus
It is a soft and waxy solid. It possesses a garlic smell.	It is a hard and crystalline solid, without any smell.
It is poisonous.	It is non-poisonous.
It is insoluble in water but soluble in carbon disulphide.	It is insoluble in both water and carbon disulphide.
It undergoes spontaneous combustion in air.	it is relatively less reactive.
IIn both solid and vapour states, it exists as a P4 molecule.	It exists as a chain of tetrahedral P4 units.

UNIT 11: TRENDS IN CHEMICAL PROPERTIES OF GROUP 16 ELEMENTS AND THEIR COMPOUNDS

11

11.1 Key unit competency

The learner should be able to compare and contrast the chemical properties of the Group 16 elements and their compounds in relation to their position in the Periodic Table.

11.2 Prerequisite knowledge and skills

Students will learn better the **Trends in chemical properties of Group 16 elements and their compounds** if they have understanding on: Chemical bonding, the arrangement of elements in the periodic table, Variation in trends of the physical properties of elements, the symbols of elements and compounds, concept of chemical reactions, and electronic configuration of elements.

11.3 Cross-cutting issues to be addressed

- **Environmental protection and sustainable development**

There is a serious issue of environmental protection and sustainable development in our society. While dealing with this unit, it would be an opportunity to guide learners on understanding the importance of environmental protection and sustainable development and how the issues related to environmental protection and sustainable development may be addressed.

Help learners to:

a) Understand that sustainable development is a framework for a long-term vision of sustainability in which economic growth, social cohesion and environmental protection go hand in hand and are mutually supporting.

b) Understand that the key issue is to assess systematically the environmental impact of programmes, to quantify them and to integrate measures to limit any negative environmental impacts.

Inclusive education

This unit involves a number of activities like experiments on the chemical properties of group 16 elements and their compounds. The activities require assembling of apparatus, writing, reading and observation of the results. This may be challenging to students with special educational needs especially children with visual impairment difficulties. However, the teacher can make some arrangements like:

Grouping students: Students with special educational needs are grouped with others and assigned roles basing on individual student's abilities.

- Providing procedure earlier before the experiment so that students get familiar with them. They can be written on the board or printed depending on available resources. If you have children with low vision remember to print in appropriate fonts.
- Give extra time for them to write summary notes or write down observations after experiments.
- Every important point is written and spoken. The written points helps students with hearing impairment and speaking aloud helps students with visual impairment
- Remember to repeat the main points of the lessons.

For learners with **hearing difficulties**

Teacher has to encourage them to sit closer to the front of the classroom. While teaching, avoid asking learners whether they have understood, or if they need you to repeat a point. Encourage learners not to be afraid to ask questions. When teaching, speak clearly and ensure that all the learners can hear your voice. Avoid speaking hurriedly as this will make it difficult for learners with hearing difficulties to make sense of what you are saying.

Learners with mobility difficulties:

These include learners in crutches, wheelchairs, or with walking difficulties. Encourage other learners to look out for and help their classmates. Ask their follow learners to help them with their notes, if their conditions hinder them from writing well.

Learners with reading difficulties:

Learners with this kind of difficulties struggle to make sense of words or understand written work and take longer to read than other learners. 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.

- **Gender**

During group activities try to form heterogeneous groups (with boys and girls) or when students start to present their findings encourage both (boys and girls) to present.

- **Financial education**

As the unit deals with the importance of group 16 elements and their compounds in modern life, the teacher will draw the learner's attention on the economical impact of the making of common items made using knowledge of chemistry.

- **Peace and values education**

During group activities, the teacher will encourage learners to help each other's and to respect opinions of colleagues.

Guidance on the introductory activity

Before introducing the first lesson of this unit, let learners attempt the introductory activity.

Expected answer for the introductory activity

1. Section 4
2. O: $1s^2\ 2s^2\ 2p^4$, S: $[Ne]3s^2\ 3p^4$, Se: $[Ar]3d^{10}4s^2\ 4p^4$, Te: $[Kr]4d^{10}5s^2\ 5p^4$, Po: $[Xe]4f^{14}5d^{10}\ 6s^2\ 6p^4$
3. Six electrons on the last energy level.

11.5 List of lessons

	Lesson title	**Learning objectives**	**Number of periods**
1	Physical properties of Group 16 elements	Describe the physical properties of Group 16 elements.	1
2	Comparison of acidity and volatility of the Group 16 hydrides	Compare the acidity and volatility of hydrogen sulphide and water.	2
3	Preparation and properties of sulphuric acid	Describe the steps and conditions applied in the industrial preparations of sulphuric acid. Describe the chemical properties of sulphuric acid. Show experimentally the dehydrating and oxidising properties of sulphuric acid.	3
4	Properties of sulphur oxoanions	Describe the properties of sulphur oxoanions.	2
5	Identification of sulphite and sulphate ions.	Identify sulphite and sulphate ions in solutions.	1
6	Uses of the Group 16 elements and compounds.	State uses of the Group 16 elements and compounds.	1

7	End unit assessment	Compare and contrast the properties of the Group 16 elements and their compounds in relation to their position in the Periodic Table	2

Lesson 1: Physical properties of group 16 elements

This is the first lesson of unit 16. It is a single lesson, but it also covers the introduction of the whole unit, it has one period (40 minutes).

a) Introduction

Students will learn better the **Physical properties of the Group 16 elements** if they have the understanding on: Chemical bonding, the arrangement of elements in the periodic table, Variation in trends of the physical properties of elements, the symbols of elements and compounds, concept of chemical reactions, and electronic configuration of elements.

b) Teaching resources

Use the illustrations in the student's book, the periodic table or draw the compounds under investigation on a manila paper.

c) Learning activities

Before introducing the lesson, you have to introduce the whole unit. Let learners therefore attempt introductory activity first then activity 11.1 which leads students to the first lesson of the unit.

Methodological steps: As :a facilitator, the teacher is expected to guide learners through the following steps:

- Form groups of 3 to 5 learners and ask them to choose a group leader
- Provide the activity 11.1 from the student book (when the books are not enough, he/she can writes the activity on the chalkboard) to the learners in their groups and ask every group to discuss questions 1 – 3, and provide answers.
- Let learners to work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to present the student's findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learner's findings and emphasize on which are correct, incomplete

or false

- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 11.1. Learners should do the checking up activity in any method you wish to use.

Expected answers for activity 11.1

- 1 Group 16 elements
- Different allotropic forms of oxygen and sulphur

2. Oxygen is gas and all others are solids

3. A

d) Expected answers for Checking up 11.1

1. a) True
   b) False
2. Sulphur mainly exists in combined form in earth's crust primarily as sulphates (gypsum, $CaSO_4.2H_2O$, Epsom salt, $MgSO_4.7H_2O$, barite, $BaSO_4$,) and sulphides (galena, PbS, zinc blends, ZnS, copper pyrites, $CuFeS_2$).
3. Due to extra stable half-filled p-orbitals electronic configurations of Group 15 elements, larger amount of energy is required to remove electrons compared to Group 16 elements.

Lesson 2: Comparison of acidity and volatility of group 16 hydrides

Comparison of acidity and volatility of group 16 hydrides is the second lesson of the unit. Students are expected to be able to explain the trends in acidic character and thermal stability of hydrides of group 16 elements.

a) Introduction

Students will learn better the Comparison of acidity and volatility of group 16 hydrides if they have the understanding on: Chemical bonding, the arrangement of elements in the periodic table, Variation in trends of the physical properties of elements, the symbols of elements and compounds, concept of chemical reactions, and electronic configuration of elements.

b) Teaching resources

- The periodic table of element
- Where possible use manila papers, flipcharts and you-tube videos with computers and projectors.

c) Learning activities

Learning activity 11.2 is suggested in student's book. However you are free to add more.

- Form groups of 2 learners and ask them to choose a group leader

- Provide the activity 11.2 from the student book (when the books are not enough, you can write the activity on the chalkboard) to the learners in their groups and ask every group to do questions 1–3, and provide their answers.
- Let learners to work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the student's findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners findings and emphasize on which are correct, incomplete or false.
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 11.2. Learners should do the checking up activity in any methodology you wish to use.

Expected answers for activity 11.2

1.

a) In chemistry, a hydride is the anion of hydrogen, H^-, or, more commonly, it is a compound in which one or more hydrogen centres have nucleophilic, reducing, or basic properties. In compounds that are regarded as hydrides, the hydrogen atom is bonded to a more electropositive element or group. Compounds containing hydrogen bonded to metals or metalloid may also be referred to as hydrides.

b) The strength of an acid refers to its ability or tendency to lose a proton (H^+).

c) A weak acid is a substance that partially ionises (dissociates) in solution.

d) A strong acid is one that completely ionises (dissociates) in a solution (provided there is sufficient solvent).

2. A hydrogen bond is an electrostatic attraction between two polar groups that occurs when hydrogen (H) atom, bound to a highly electronegative atom such as nitrogen (N), oxygen (O), or fluorine (F), experiences the electrostatic field of another highly electronegative atom nearby.

d) Expected answers for Checking up 11.2

The acidic character of hydrides of group 16 elements increases from H_2O to H2Te. It is in the order, $H_2O < H_2S < H_2Se < H_2Te$.

The increase in acidic character can be explained in terms of decrease in bond enthalpy for the dissociation of H–E bond down the group.

This is due to the decrease in bond (Te–H) dissociation enthalpy down the group, which results in the increase in acidic character down the group.

H_2O is more thermally stable than H_2S. This is because of the decrease in energy of dissociation of H-E bond down the group, hence, the thermal stability of hydrides of group 16 elements also decreases from H_2O to H_2Po

The hydrogen bonding in water causes the water molecules to be associated with each other due to intermolecular forces of attraction, whereas in the case of hydrogen sulphide, these forces of attraction area much weaker.

So, lesser energy is required to overcome the forces of interaction between the hydrogen sulphide molecules than those between water molecules. This energy is available at room temperature and hence, hydrogen sulphide is a gas, while water is still a liquid.

Lesson 3: Preparation and properties of sulphuric acid

a) Introduction:

Before beginning this lesson, learners should be able to recall some of the properties of sulphuric acid studied in senior three. The teacher may ask oral questions to name and explain some of the properties, uses and environmental impact of the industrial preparation of sulphuric acid. If the learners are able to mention some, then he/she can proceed. If not he/she can ask some probing questions to give them a hint.

b) Teaching resources

The periodic table of element

Where possible use manila papers, flipcharts and you-tube videos with computers and projectors.

c) Learning activities/methodological steps

Learners should carry out the experiments in activities 11.3. They should also do the study questions from the experiments performed. Learners should do the checking up activity in any method you wish to use.

Activity 10.3	Materials
Investigating the dehydrating power of Sulfuric acid on sugar	4. 70 grams granulated sugar, $C_{12}H_{22}O_{11}$ 5. 70 ml of concentrated (18M) sulfuric acid, H_2SO_4 6. 300 ml tall-form beaker 7. 40cm stirring rod 8. Paper towels 9. Disposable gloves or 10. 100 ml graduated cylinder 11. Tray 12. 1 liter beaker 13. Sodium bicarbonate, $NaHCO_3$ 14. Spatula

d) Expected answers for Checking up 11.3

The contact process deals with industrial production of Sulphuric acid using catalytic oxidation of SO_2 to SO_3. There are 5 steps:

Step 1: Production of sulphur dioxide: $S_{(s)} + O_{2\ (g}) \rightarrow SO_{2\ (g)}$

Step 2: Purification of gases

Step 3: Oxidation of SO_2 to SO_3: $SO_{2(g)} + O_{2(g)} \rightleftharpoons 2SO_{3(g)}$

Step 4: Absorption of SO_3: $H_2SO_{4\ (aq)} + SO_{3(g)} \rightarrow H_2S_2O_{7(l)}$

Dilution of oleum: $H_2S_2O_{7(l)} + H_2O_{\ (l)} \rightarrow 2H_2SO_{4(l)}$

Direct absorption of SO_3 in water gives a very vigorous reaction and forms droplets of sulphuric acid.

Sulphuric acid has a great affinity for water. It readily removes elements of water from other compounds i.e, it acts as a dehydrating agent, and it being a hygroscopic substance absorbs water from other substances without dissolving in it. So it is considered as a good dessicating or drying agent. Remember, that only concentrated sulphuric acid is a good dehydrating agent. Not dilute sulphuric acid, because it contains water and will not be able to absorb water from other substances.

$Zn_{(s)} + 2H_2SO_{4(l)} \rightarrow ZnSO_{4(aq)} + SO_{2(g)} + H_2O_{(g)}$

$M_{g(s)} + 2H_2SO_{4(l)} \rightarrow MgSO_{4(aq)}\ H_{2(g)}$

$C(s) + 2H_2SO_{4(l)} \rightarrow 2H_2O_{(l)} + CO_{2(g)} + 2SO_{2(g)}$

Lesson 4: Properties of oxoanions of sulphur

a) Introduction

Students will learn better the properties of oxoanion of sulphur if they have understanding on: oxidation reduction reactions, action of heat of sulphates of the previous groups, the arrangement of elements in the periodic table, variation in trends of the physical properties of elements, the symbols of elements and compounds, concept of chemical reactions, and electronic configuration of elements.

b) Teaching resources

- Student's chemistry book and other relevant books from the school library
- Internet resources

c) Learning activities

Activity 11.4: Guided Research

Students are asked to do research and answer questions in activity 11.4 (a) and (b). The teacher may help learners by giving them a list of important reference books available in the school library.

Methodological steps

- Introduce the lesson by allowing learners to do the learning activity 11.4 (a) in their respective groups. Let them work together in their groups without intervene directly.
- Learners should carry out the experiment in activity 11.4 (b). They should also do the study questions from the experiment performed in the activity.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the student's findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 11.4. Learners should do the checking up activity in any method you wish to use.

Expected answers for activity 11.4 (a)

1. a) Oxidation

    i) In terms of oxidation state: this is the increase in oxidation state

    II) In terms of electron transfer: this is the loss of electrons

B) Reduction

    I) In terms of oxidation state: this is the decrease in oxidation state

    II) In terms of electron transfer: gain of electrons

C) An oxidizing agent (oxidant, oxidizer) is a substance that has the ability to oxidize other substances. In other words to cause them to lose electrons.

D) A reducing agent is a substance that has the ability to reduce other substances.

Activity 11.4 (b)

Activity 10.4 (b)	Materials
An experiment for Heating hydrated copper (II) sulfate	Two test-tubes, Delivery tube (right angled), 250cm^3 beaker for cold water bath, Bunsen burner, Clamp and stand, Hydrated copper (II) sulfate (powdered).

d) Expected answers for Checking up 11.4

1.

a) $2S_2O_3{}^{2-}{}_{(aq)} + I_{2(aq)} \rightarrow S_4O^{62-}{}_{(aq)} + 2I^-{}_{(aq)}$

b) $2Fe^{3+}{}_{(aq)} + 2\ 2S_2O_3{}^{2-}{}_{(aq)} \rightarrow 2Fe^{2+}{}_{(aq)} + S_4O_6{}^{2-}{}_{(aq)}$

c) $2Al^{3+}_{(aq)} + 3S_2O_3^{2-}{}_{(aq)} + 3H_2O_{(l)} \rightarrow 3SO_{2(g)} + 3S_{(s)} + 2Al(OH)_{3(s)}$

2.

a) $ZnSO_{4(s)} \rightarrow ZnO_{(s)} + SO_{3(g)}$

b) $Fe_2(SO_4)_{3(s)} \rightarrow Fe_2O_{3(s)} + 3SO_{3(g)}$

c) $CuSO_{4(s)} \rightarrow CuO_{(s)} + SO_{3(g)}$

3.

a) Hydrated copper (II) sulphate is heated according to the following equation

$CuSO_4.5H_2O_{(s)} \rightleftharpoons CuSO_{4(s)} + 5H_2O_{(l)}$

Solid Q is anhydrous copper (II) sulphate, $CuSO_4$

Liquid P is water, H_2O

b) Hydrated copper (II) sulphate loose water of crystallisation and become anhydrous. The blue colour disappears and a white solid is formed.

c) If water is added to white solid Q, the blue colour appear

Lesson 5: Identification of sulphite and sulphate ions

a) Introduction

Students will learn better the identification of sulphite and sulphate ions, if they have the understanding on: Identify and differentiate between elements and compounds, substances and mixtures, atoms and molecules, general structure of an atom and quantify the subatomic particles in an atom or ion. Write and interpret chemical symbols for elements and compounds, mono-atomic and polyatomic ions, concept of chemical reactions, and electronic configuration of elements.

b) Teaching resources.

- Student‘s chemistry book and other relevant books from the school library
- Internet resources

c) Learning activities

Activity 11.5: Guided Research

Students are asked to do research and answer questions in activity 11.5. The teacher may help learners by giving them a list of important reference books available in the school library.

Methodological steps

- Introduce the lesson by allowing learners to do the learning activity 11.5 in their respective groups. Learners should carry out the experiment in this activity and they should also do the study questions from the experiment performed in the activity.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the

knowledge).

- Invite group leaders to present the student's findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 11.5. Learners should do the checking up activity in any method you wish to use.

Activity 11.5	**Materials**
Identification of sulphate ions Substance Y: Use copper sulphate or any sulphate available	Test-tubes, 250cm³ beakers, spatula, nitric acid, barium nitrate, hydrochloric acid, barium chloride.

d) Expected answers for Checking up 11.5

1.

a) Reagent: Add nitric acid followed by barium nitrate solution, $BaNO_{3(aq)}$

Observations: For $BaSO_3$: A white precipitate of barium sulphite which is soluble in dilute nitric acid is formed.

For $BaSO_4$: A white precipitate of barium sulphate insoluble in dilute nitric acid is formed.

b) Reagent: Addition of potassium iodide solution, $KI_{(aq)}$

Observations: For $BaSO_4$: There is no observable change

For $PbSO_4$: A golden yellow precipitate soluble on warming and reforms on cooling is formed.

2. Provide the substance X which is lead (II) sulphate ($PbSO_4$) to learners

Cation: Pb^{2+}, anion: SO_4^{2-}

Lesson 6: Uses of group 16 elements and compounds

a) Introduction

Students will learn better the Uses of group 16 elements and compounds, if they have the understanding on: properties of group 16 elements and their compounds write and interpret chemical symbols for elements and compounds.

b) Teaching resources

- Student's chemistry book and other relevant books from the school library
- Internet resources

c) Learning activities

Activity 11.6: Guided Research

Students are asked to do research and answer questions in activity 11.6. The teacher may help learners by giving them a list of important reference books available in the school library.

Methodological steps

- Introduce the lesson by allowing learners to do the learning activity 11.6 in their respective groups. Let them work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to present the student's findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners‘ findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 11.6. Learners should do the checking up activity in any method you wish to use.

Expected answers for activity 11.6

1. Vulcanisation: This is a chemical process for converting natural rubber (sulphur)

   Used in the breathing and metabolism processes of all living organisms, combustion (oxygen)
2. Figure A: A patient assisted with oxygen

   Figure B: Oxygen containers

   Figure C: Car tires

   Figure D: battery
3. Metallurgical industry, storage batteries, chemistry laboratories, etc.…

d) Expected answers for Checking up 11.6

1. Used in the breathing and metabolism processes of all living organisms, combustion, and the manufacture of iron.
2. Metallurgical applications, Petroleum refining, Manufacture of pigments, paints and dyestuff intermediates
3. Vulcanisation: This is a chemical process for converting natural rubber or related polymers into more durable materials by heating them with sulphur or other equivalent curatives or accelerators. These additives modify the polymer by forming cross-links (bridges) between individual polymer chains).

4. Sulphuric acid is considered as a strong acid. This is because, sulphuric acid solution ionises completely to release H+ ions. Sulphuric acid ionises completely to form ions as:

$$H_2SO_{4(aq)} \rightarrow 2H^{+}_{(aq})+ SO_4^{-}{}_{(aq)}$$

A corrosive substance is one that will destroy and damage other substances with which it comes into contact. It may attack a great variety of materials, including metals and various organic compounds, but people are mostly concerned with its effects on living tissue: it causes chemical burns on contact and can lead to complications when ingested.

11.6 Summary of the Unit

- Group 16 elements have the outer electron arrangement ns^2 np^4.
- The group shows a clear trend from non-metals at the top to metals at the bottom.
- Oxygen exists as O_2 while sulphur forms S_8 ring-shaped molecules with s-s single bonds.
- Oxygen has an allotrope O_3 called ozone (trioxygen).
- Sulphur has two common allotropes, rhombic and monoclinic sulphur.
- The acidic character of hydrides of group 16 elements increases down the group.
- Sulphuric acid is manufactured industrially using the contact process which is based on the catalytic oxidation of SO_2 to SO_3.
- Sulphuric acid acts as a strong acid, an oxidising and as dehydrating agent.
- The thiosulphate ions act as reducing agents.
- Sulphite ion reacts with acids liberating sulphur dioxide.
- Most sulphate salts do not decompose by heat. Only certain sulphate salts are decomposed by heat when heated strongly.
- Sulphate ions are distinguished from sulphite ions by using nitric acid followed by barium nitrate solution.

11.7 Additional information

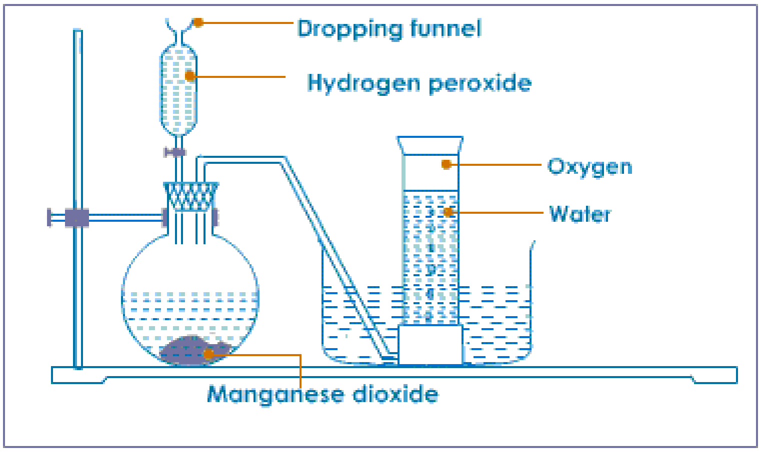
Oxygen

Preparation of oxygen

Laboratory preparation

Oxygen is most easily made in the laboratory from hydrogen peroxide solution (H_2O_2) using manganese (IV) oxide (MnO_2) as a catalyst. The reaction is known as the catalytic decomposition (splitting up using a catalyst) of hydrogen peroxide.

$$2H_2O_{2(aq)} \xrightarrow{MnO2} 2H_2O_{(l)} + O_{2(g)}$$

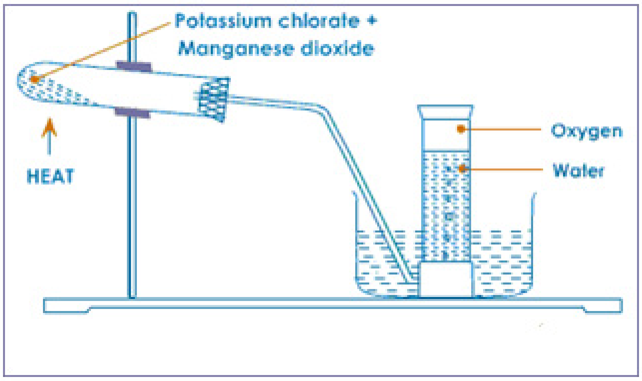


The oxygen produced is collected in an inverted glass cylinder by the downward displacement of water in a trough.

NOTE: -If the gas is required dry, it is passed through concentrated sulphuric acid (H_2SO_4) in wash bottle or in solid anhydrous calcium chloride ($CaCl_2$) in U-Tube or Phosphorus (V) oxide (P_2O_5) or quicklime (CaO) as dehydrating agents.

-We call catalyst, a substance which, although often present in small proportions, alters the rate of a chemical reaction but remains chemically unchanged at the end of the reaction.

Another method for the laboratory preparation of oxygen is the decomposition of potassium chlorate by heat in the presence of manganese (IV) oxide as a catalyst.



Equation: $2KClO_{3(s)} \xrightarrow{Heat+MnO2} 2KCl_{(s)} + 3O_{2(g)}$

Other methods

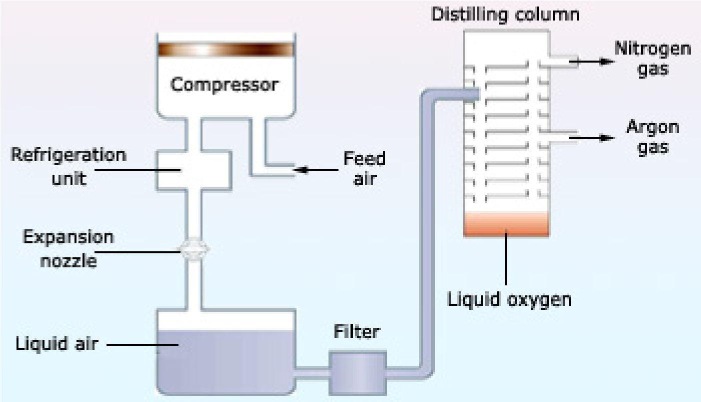
$2KNO_{3(s)} \xrightarrow{Heat} 2KNO_{2(s)} + O_{2(g)}$

$2NaNO_{3(s)} \xrightarrow{Heat} 2NaNO_{2(s)} + O_{2(g)}$

$2Na_2O_{2(s)} + 2H_2O_{(l)} \rightarrow 4\ NaOH_{(aq)} + O_{2(g)}$

Industrial preparation of oxygen

Nearly all commercial oxygen is obtained from air. The normal boiling point of O2 is –183°C, whereas that of N_2, the other principal component of air, is –196°C. Thus, when air is liquefied and then allowed to warm, the N_2 boils off, leaving liquid O_2 contaminated mainly by small amounts of N_2 and Ar.



Industrial production of oxygen by fractional distillation of liquefied air

NOTE: Water can be decomposed by electricity through electrolysis and produce oxygen at a large scale.

Properties of oxygen

Physical properties

Oxygen is a tasteless gas.

It has no smell or color.

Oxygen is denser than air (density: 1.43g/l)

Oxygen is slightly soluble in water

Boiling point of oxygen is -183°C and melts at -219°C

Chemical properties

It is neutral to litmus paper

Oxygen is a very reactive element and it takes a part of air called active part because it supports combustion (it is combustive). When a substance burns in air, it reacts with oxygen gas and is said to be oxidised. The compounds formed are called oxides.

We call combustion, the chemical reaction in which oxygen combines with another substance producing energy such as heat and/or light. Where a combustible, is a substance able to burn easily (e.g. charcoal, paper, wood...).

Oxygen reacts with hydrogen to produce two notable compounds: water (H_2O) or hydrogen peroxide (H_2O_2).

$$2H_{2\,(g)} + O_{2\,(g)} \rightarrow 2H_2O_{\,(l)}$$

$$H_{2(g)} + O_{2(g)} \rightarrow H_2O_{2(l)}$$

NOTE: The product of this reaction is called peroxide because oxygen is in the O_2^{2-} form (Hydrogen has a +1 oxidation state).

Oxygen reacts with metals to form non-metal oxides (usually acidic oxides)

Carbon burns quickly with a yellow flame or orange flame and makes bright sparks, to give colourless carbon dioxide which turns aqueous solution of lime water milky.

$C_{(s)} + O_{2\,(g)} \rightarrow CO_{2\,(g)}$

Sulphur burns with a bright blue flame to give colourless sulphur dioxide, a misty gas with a pungent smell. Remember, sulphur dioxide gas is poisonous, and forms acid rain, so it's acidic!

$S_{(s)} + O_{2\,(g)} \rightarrow SO_{2\,(g)}$

Phosphorus burns in air with a bright yellow flame producing white fumes (P2O5)

$P_{(s)} + 5O_{2(g)} \rightarrow 2P_2O_{5(s)}$

Oxygen reacts with metals to form metal oxides (usually basic oxides)

Magnesium burns with a bright white flame to give a white, powdery ash of magnesium oxide.

$2Mg_{(s)} + O_{2\,(g)} \rightarrow 2MgO_{(s)}$

Lithium reacts with oxygen to form Li_2O. This compound includes the usual oxide (O^{2-}).

$4\,Li_{(s)} + O_{2(g)} \rightarrow 2\,Li_2O_{(s)}$ (principal combustion product)

However, if there is excess oxygen present, it is possible that a small amount of the compound Li_2O_2 can be formed.

$2\,Li_{(s)} + O_{2(g)} \rightarrow Li_2O_{2(s)}$ (less likely- NOT principal combustion product)

Sodium burns in oxygen with brilliant, yellow-orange flame to form usually sodium peroxide, Na_2O_2 (principal combustion product), when reacting with excess oxygen:

$2\,Na_{(s)} + O_{2(g)} \rightarrow Na_2O_{2(s)}$

Calcium burns with a bright, red flame to form sodium white calcium oxide.

$2\,Ca_{(s)} + O_{2(g)} \rightarrow 2\,CaO_{(s)}$

Iron wires burn and makes a very bright white light and produces a bluish-black oxide.

$4Fe_{(s)} + 3O_{2(g)} \rightarrow 2Fe_2O_{3(s)}$

NOTE: Some metals have a higher affinity for oxygen than others. This makes them capable to replace other metals from their oxides (metal competition for oxygen). This is to mean, if a metal is very reactive in metal activity series, it can replace the lower one in that series. Order of reactivity in some metals: Mg>Zinc>Lead>Copper

Example: $ZnO_{(s)} + Mg_{(s)} \rightarrow MgO_{(s)} + Zn_{(s)}$

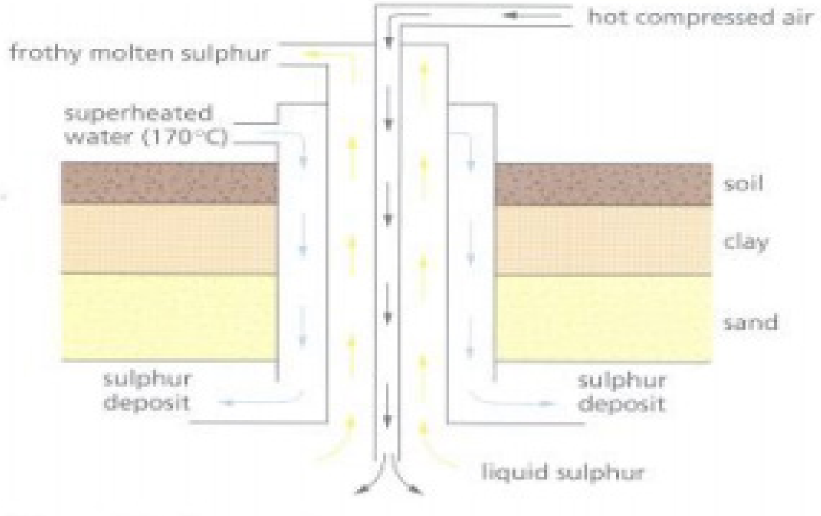
Sulphur

Extraction and production

Sulfur is extracted by mainly using Frasch process.

In this method, three concentric pipes are used: the outermost pipe contains superheated water, which melts the sulfur, and the innermost pipe is filled with hot compressed air, which serves to create foam and pressure. The resulting sulfur foam is then expelled through the middle pipe.

Through the outside pipe, you let out the water vapor with pressure (about 170˚C) that can make sulphur melting. Then in the middle pipe, run a stream of compressed air that makes up, by the intermediate pipe, water and molten sulfur. The sulfur is taken by a pipeline system, in large melting tanks where it solidified.



Allotropes of sulphur

Sulfur exists in a variety of forms called allotropes, which consist of several solid varieties, of which the most familiar are rhombic sulfur and monoclinic sulfur. Other forms include:

Amorphous sulphur

This is a non-crystalline form of sulphur. It is white in colour. Amorphous sulphur can be prepared in the following ways:

Action of dilute acid on sodium thiosulphate solution

$S_2O_3^{2-}{}_{(aq)} + 2H^+(aq) \rightarrow H_2O_{(l)} + SO_{2(g)} + S_{(s)}$

Saturating water with hydrogen sulphide gas and leaving the resultant solution to stand

$2H_2S_{(g)} + O_{2(g)} \rightarrow H_2O_{(l)} + 2S_{(s)}$

Plastic sulphur (sulphur)

It is a rubber-like form of sulphur obtained when powdered roll sulphur is heated to a temperature near its boiling point and poured into cold water. It is insoluble in carbon disulphide and readily changes to rhombic sulphur on standing.

Note: Sulphur eventually boils off at 445°C to give dark reddish-brown vapour (containing S_8, S_6, S_4 and S_2 molecules) which cools to give yellow powder called flowers of sulphur (sulphur butterfly) because of its shape. During heating, at about 190°C, the rings break up to form chains of sulphur atoms arranged in zig-zag manner. These forms of sulfur and changes they undergo are summarized in the temperature profile below.

$$S_\alpha \xrightarrow{95.5^oC} S_\beta \xrightarrow{119^oC} S_\lambda \xrightarrow{160^oC} S\mu \xrightarrow{445^oC} S_8(g) \longrightarrow S_6(g) \longrightarrow S_4(g) \xrightarrow{1000^oC} S_2(g) \xrightarrow{2000^oC} S(g)$$

11.8 End unit assessment answers

Multiple choice questions:

1.C 2.D 3.D 4.D 5.C 6.A 7.D 8.D

Short and long answer Open questions

9. Oxygen exists as diatomic gas in which two oxygen atoms are joined by a double bond. The rest exist as solid at room temperature. Due to lack of easily accessible vacant d orbitals in oxygen, oxygen exhibits a maximum covalency of 4 whereas other members can show a maximum covalency of 6. The small size of oxygen atoms enables them to form a few multiple bonds. The rest of the elements cannot form multiple bonds due to large atomic sizes.

10. Sources:

   - Oxygen occurs as a free element in the atmosphere where the majority is produced by photosynthesis.
   - It also occurs in oxides, silicates, silica and oxo-salts

Uses:

Oxygen is useful in respiration and combustion

It is used in making steel to oxidise impurities such as carbon, phosphorous and sulphur.

11.

a) Rhombic sulphur and monoclinic sulphur

b) $S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$

$Fe_{(s)} + S_{(s)} \rightarrow FeS_{(s)}$

$S_{(s)} + 2H_2SO_{4\,(aq)} \rightarrow 3SO_{2(g)} + 2H_2O_{(l)}$

c) $Cl_{2(g)} + H_2S_{(g)} \rightarrow 2HCl_{(g)} + S_{(S)}$

$2HNO_{3(l)} + H_2S_{(g)} \rightarrow SO_{2(g)} + 2H_2O_{(l)} + S_{(s)}$

12.

a) Traces of sulphur occur as hydrogen sulphide in volcanoes. Organic materials such as eggs, proteins, garlic, onion, mustard, hair and wool contain sulphur.

b) Sulphur dioxide is used as a fumigagant, a bleaching agent for straw, wool and silk, and also used as a refrigerant.

c) $S_{(s)} + O_{2\,(g)} \rightarrow SO_{2\,(g)}$

d) $H_2SO_{4\,(aq)} + SO_{3(g)} \rightarrow H_2S_2O_{7(l)}$

e) $H_2S_2O_{7(l)} + H_2O_{\,(l)} \rightarrow 2H_2SO_{4(l)}$

11.9 Additional activities

11.9.1. Remedial activities

1. Group 16 elements usually gain two electrons. This means:

   a) They get a -2 charge
   b) They have a -2 oxidation state
   c) They become an anion
   d) All answers are correct

2. Which of the following is a use for group 16 elements:

a) Rocket fuel
b) Fertilizer ingredient
c) Ceramic pigment
d) All answers are correct

3. Group 16 elements have valence electrons equal to:

a) 2
b) 6
c) 4
d) All answers are correct

4. How is the presence of SO_2 detected?

Answer

It can be detected with the help of potassium permanganate solution. When SO_2 is passed through an acidified potassium permanganate solution, it decolourises the solution as it reduces MnO_4^- into Mn^{2+}.

$$5SO_2 + MnO_4^- + 2H_2O \longrightarrow 5SO_4^{2-} + 4H^+ + 2Mn^{2+}$$

5. Write equations to show how sulphuric acid reacts with the following substances:

a) Hydrogen bromide
b) Hydrogen sulphide
c) Hydrated copper (II) sulphate
d) Carbon

Answer:

$$2HBr_{(g)} + H_2SO_{4(l)} \rightarrow 2H_2O_{(l)} + SO_{2(g)} + Br_{2(l)}$$

$$3H_2S_{(g)} + H_2SO4_{(l)} \rightarrow 4S(s) + 4H_2O_{(l)}$$

$$CuSO_4.5H_2O_{(s)} \rightarrow CuSO_{4(s)} + 5H_2O_{(l)}$$

$$C_{(s)} + 2H_2SO_{4(l)} \rightarrow 2H_2O_{(l)} + CO_{2(g)} + 2SO_{2(g)}$$

11.9.2. Consolidation activities

1. Which of the following does not react with oxygen directly?

Zn, Ti, Pt, Fe

Answer:

Pt is a noble metal it does not react with any atmospheric gases.

2. Why does O_3 act as a powerful oxidizing agent?

Answer:

Due to the ease with which it liberates atoms of nascent oxygen ($O_3 \rightarrow O_2 + O$), it acts as a powerful oxidising agent.

3. How is O_3 estimated quantitatively?

Answer:

When ozone reacts with an excess of potassium iodide solution buffered a borate buffer (pH 9.2), iodine is liberated which can be titrated against a standard solution of sodium thiosulphate. This is a quantitative method for estimating O_3 gas.

What happens when sulphur dioxide is passed through an aqueous solution of Fe (III) salt?

Answer:

When moist, sulphur dioxide behaves as a reducing agent. For example, it converts iron (III) ions to iron (II) ions.

$2Fe^{3+} + SO_2 + 2H_2O \rightarrow 2Fe^{2+} + SO_4^{2-} + 4H^+$

5. H_2Te is the strongest reducing agent amongst all the hydrides of group 16 elements. Give a reason.

Answer:

H_2Te has the longest bond length which has lowest bond dissociation enthalpy.

6. There is a large difference between the melting and boiling points of oxygen and sulphur. Explain why.

Answer:

Oxygen is a diatomic gas having weak Van der Waals' forces, while sulphur is octaatomic (S_8) solid, therefore, it has more Wan der Waals' forces of attraction. Hence sulphur has higher melting and boiling points than oxygen.

7.

a) Name the two most important allotropes of sulphur.
b) Which one of the two is stable at room temperature?
c) What happens when the stable form is heated above 97°C?

Answer:

a) Rhombic sulphur and monoclinic sulphur
b) Rhombic sulphur is more stable at room temperature
c) When rhombic sulphur is heated above 97°C, it changes to monoclinic sulphur.

11.9.3. Extended activities

1.The atomic number of sulphur is 16:

a) In terms of s, p, d, …….. notation, write the electronic configuration of sulphur.
b) In which block of the periodic table is sulphur located?
c) Explain briefly why the first ionization energy of sulphur is lower than that of phosphorus (atomic number 15).

Answer:

a) $1S^2\ 2S^2\ 2P^6\ 3S^2\ 3P^4$

b) Sulphur is located in p-block of the periodic table. This is because; the outermost electrons are distributed in p sub energy level.

c) P, Z=15: $1S^2\ 2S^2\ 2P^6\ 3S^2\ 3P^3$

According to their electronic configuration, the first ionisation energy of sulphur is lower than that of phosphorus. This is because, in sulphur the first electron will be removed from 3p4 orbital which is not stable. This will require less energy. On the other hand, for phosphorus, the first electron will be removed from 3p3 orbital which is half-filled and more stable. This will require higher energy.

2. Justify the placement of O, S, Se, Te and Po in the same group of the periodic table in terms of electronic configuration, oxidation state and hydride formation.

Answer:

The elements of group 16 are collectively called chalcogens.

i) Elements of group 16 have six valence electrons each. The general electronic configuration of these elements is $ns^2\ np^4$, where n varies from 2 to 6.

ii) Oxidation state: As these elements have six valence electrons ($ns^2\ np^4$), they should display an oxidation state of –2. However, only oxygen predominantly shows the oxidation state of –2 owing to its high electronegativity. It also exhibits the oxidation state of –1 (H_2O_2), zero (O_2), and +2 (OF_2). However, the stability of the –2 oxidation state decreases on moving down a group due to a decrease in the electronegativity of the elements. The heavier elements of the group show an oxidation state of +2, +4, and +6 due to the availability of d-orbitals.

iii) **Formation of hydrides:** These elements form hydrides of formula H_2E, where E = O, S, Se, Te, PO. Oxygen and sulphur also form hydrides of type H_2E_2. These hydrides are quite volatile in nature.

3. Explain how SO_2 is an air pollutant?

Answer:

Sulphur dioxide causes harm to the environment in many ways:

a) It combines with water vapour present in the atmosphere to form sulphuric acid. This causes acid rain. Acid rain damages soil, plants, and buildings, especially those made of marble.

b) Even in very low concentrations, SO_2 causes irritation in the respiratory tract. It causes throat and eye irritation and can also affect the larynx to cause breathlessness.

c) It is extremely harmful to plants. Plants exposed to sulphur dioxide for a long time lose colour from their leaves. This condition is known as chlorosis. This happens because the formation of chlorophyll is affected by the presence of sulphur dioxide.

4.

a) Describe one method of preparing a dilute aqueous solution of hydrogen sulphide in the laboratory.

b) State what would be observed on adding hydrogen sulphide to the following, and include reaction equations for your observations:

- i) Lead (II) nitrate solution
- ii) Copper (II) chloride solution
- iii) Acidified potassium manganate (VII) solution

Answer:

a) In the laboratory, H_2S is obtained by action of dilute hydrochloric acid on iron (II) sulphate.

$FeS_{(s)} + HCl_{(aq)} \longrightarrow FeCl_{2(aq)} + H_2S_{(g)}$

But pure hydrogen sulphide is obtained by warming concentrated hydrochloric acid with antimony (III) sulphide (stibnite).

$Sb_2S_3(s) + 6HCl(l) \longrightarrow 2SbCl_3(aq) + 3H_2S_{(g)}$

b)

- i) Hydrogen Sulphide can easily be identified by bringing a strip of filter paper soaked in Lead (II) nitrate (V) solution into the gas. H_2S turns the paper dark brown or black. The change in colour is as a result of formation of precipitate of black lead (II) Sulphide.

  $Pb(NO_3)_2(aq) + H_2S(g) \rightarrow PbS_(s) + 2HNO_3(aq)$
- ii) D
- iii) H_2S decolorizes $KMnO_4$, as it reduces it and deposits sulphur.

  $2MnO^-_4(aq) + 5H_2S(aq) + 6H^+(aq) \rightarrow 2Mn^{2+}(aq) + 8H_2O(l) + 5S(s)$

UNIT 12: TRENDS OF CHEMICAL PROPERTIES OF GROUP 17 ELEMENTS AND THEIRCOMPOUNDS

12

12.1 Key unit competency

To be able to compare and contrast the chemical properties of the Group 17 elements and their compounds in relation to their position in the periodic table.

12.2 Prerequisite (knowledge, skills, attitudes and values)

Electronegativity trend in elements down a group and then relationship between variation in metal and non-metal properties due to atom size in groups and in periods

12.3 Cross-cutting issues to be addressed

Inclusive education

Present clear visible hand writing on the chalkboard and speak aloud every important point for learners with low vision and those with hearing impairment. Get close near students who are physically handicapped for any eventual help and encourage them to work with others.

12.4 Guidance on Introductory Activity

- -Relate the unit content and learners‘daily life so as to capture their attention.
- -Assess learners‘prior knowledge in chemistry which is fundamental to the understanding of properties of halogens.

12.5. List of lessons

Heading	Lesson title	Learning objectives	No of periods
Trends of chemical properties of group 17 elements and their compounds	Natural occurrence, extraction and physical properties of halogens	Prepare and test halogens.	1
	Laboratory preparation and test of halogens	Perform experiments to prepare and test chlorine, bromine and iodine.	2
	Chemical properties of halogens	Relate the oxidizing power of Group17 elements to their reactivity.	3
	Preparation and behavior of hydrogen halides	Relate the acidity strength of oxoacids to the number of oxygen atoms combined with the halogen.	3
	Tests for halide ions in aqueous solution	Compare the reactions of the halogens with cold dilute sodium hydroxide and hot concentrated sodium hydroxide solutions.	2
	Properties of oxoacids	Describe the uses and hazards of halogens and their compounds.	1
	Properties of chlorates and iodates, perchlorates and periodates		
	Uses and hazards of halogens and their compounds		2

Lesson 1: Natural occurrence, extraction and physical properties of halogens

a)Introduction

For learners to learn better the extraction of halogens and their physical properties, they need to recall the physical properties of non- metals and the general trend of electronegativity down a group.

b)Teaching resources:

Use the diagram of the apparatus set up in activity 12.1 in the students' book for lesson 1. Use the Leaner's text book, Learning videos and/or printed images depending on the availability of each.

c)Learning activities :

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do introductory activity then proceed to activity 12.1which is specific to lesson 1.

- When you enter the class, greet students and inform them on the activity to take place.
- Ask learners to sit in groups of 4 to 6 students and choose a group leader.
- Ask students to observe the figure 12.1 in the student book and discuss the related questions.
- Monitor the progress of the group discussion and assist slow learners who are still struggling, avoid communicating to them while helping them. Only give the necessary hint to discover for themselves.
- Invite group leaders to present their findings.
- Think and share if the pairs were used.
- Evaluate the findings of the learners.
- Cross-cutting issues should be integrated to indicate the link of the lesson and real life situation.
- Summarise the learned knowledge and give examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements.

Expected answers for introductory activity

1. a) NaCl, CaF_2, KI

b) NaCl is found in sea water and it is used as table salt for humans.

CaF_2 is found in rocks, t is used for preparation of F_2 elements

KI is found in fish. It is used as table salt to prevent the illness of goitre.

2.F electronic configuration: $1s^2$, $2s^2$, $2p^5$. F forms an anion F^- which has he outermost shell full.

3.a) F has a higher electronegativity than Cl.

b) F is smaller in size and the outermost shell electrons are more strongly attracted the nucleus than for Cl atom.

Expected answers for activity 12.1 (A) and (B):

- Observations: When KI is used, there is a pale green colour which moves through the delivery tube. The gas turns the colourless solution of KI to red.

- When starch indicator is added to the resultant solution in the boiling tube; there is a blue-black solid formed.
- When NaBr is used, there is a red colour formed in the boiling tube from colourless solution.
- When the resultant solution is poured in cooking oil, the red colour disappears (discharges).

d)Checking up 12.1

1. Chlorine can be found in water in oceans, in minerals

2. NaCl, CaF_2 etc…

3. Lake Kivu

4. Evaporation method can be used when salt water is put in a container and heated to evaporate the water and leave the salt crystals.

5. Fluorine is the most electronegative element, so it is a very strong oxidising agent and a very weak reducing agent. Therefore it is difficult to oxidise a fluoride ion.

Lesson 2: Laboratory preparation and test of halogens

a)Introduction

Students are expected to have studied preparation of gases like chlorine in ordinary level.

They have also learnt the periodic table and have covered electronegativity and general influence of atomic size to the reactivity of the elements.

This knowledge can be built on to understand the content of this unit.

b)Teaching resources:

Use the diagram of the apparatus set up in activity 12.2 in the students' book . Use the student book, learning videos and/or printed images depending on the availability of each.

c)Learning activities :

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do the introductory activity then proceed to activity 12.2 which is specific to lesson 2.

- When you enter the class, greet students and inform them on the activity to take place.
- Ask learners to sit in groups of 4 to 6 students and choose a group leader.
- Ask students to observe the figure 12.2 in the student book and discuss the related questions.

- Monitor the progress of the group discussion and assist slow learners, who are still struggling, avoid communicating to them while helping them. Only give the necessary hint to discover for themselves.
- Invite group leaders to present their findings.
- Evaluate the findings of the learners.
- Cross-cutting issues should be integrated to indicate the link of the lesson and real life situation.
- Summarise the learned knowledge and give examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements.

Expected answers for Activity 12.2(a)

Observations: There is liberation of a pale green gas that turns blue litmus to red and bleaches it later. When the gas is put in KI solution, the solution turns red. When the resultant red solution is put in starch indicator, there is a blue-black precipitate formed. The colourless solution of KI turns red when the vapours dissolve in it.

Expected answers for Activity 12.2 (b)

- Observations: There is liberation of a red vapour from the round bottomed flask.
- The gas turns the colourless solution of $AgNO_3$ to cream precipitate.
- When KI is used, the colourless solution of KI is turned to red by the incoming vapour.
- Interpretation: The vapour that reacts with $AgNO_3$contains a halogen substance. The KI has been changed to red iodine solution by the vapour because there is a reaction of displacement.

Expected answers for Activity 12.2 (c)

Observations: There is evolution of a gas on the cathode in greater quantities than on the anode.

The phenolphthalein indicator turns pink on the cathode as the reaction takes place.

There is no red colour formation on the anode.

d)Expected answers for checking up 12.2

1. Chlorine is prepared by heating a mixture of HCl acid and MnO_2

KMnO4 can be used instead of MnO_2.

2. Chlorine is produced industrially when concentrated brine (NaCl solution) is electrolyzed using mercury as the cathode electrode so that Na can be collected as an amalgam. Chlorine gas is evolved at the anode.

3. Bromide compounds can be dissolved in water then chlorine gas is made to pass through the solution such that Br^- ions may be oxidized to Br_2.

4. The fluorine is poisonous, if it escapes to the environment, it can cause irritation of

the skin, causes other problems like those affecting respiration in humans.

5. No. Chlorine is more oxidising than Bromine; therefore Bromine ion can be oxidised by Chlorine, but Bromine cannot oxidise Chlorine ions.

Lesson 3: Chemical properties of halogens

a)Introduction

- -Students have already learnt physical properties of non-metals and the application of electronic configuration to deduce the type of ion formed by an element.
- -Students can also deduce the type of compound to be formed by that element when it reacts as well as the physical properties of the resultant compounds.

b)Teaching resources

Use the diagram of the apparatus set up in activity 12.3 in the students' book for lesson 3. Use the students' book or printed images depending on the availability of each.

c)Learning activities

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do the introductory activity then proceed to activity 12.3 which is specific to lesson 3.

- When you enter the class, greet students and inform them on the activity to take place.
- Ask learners to sit in groups of 4 to 6 students and choose a group leader.
- Ask students to observe the figure 12.3 in the student book and discuss the related questions.
- Monitor the progress of the group discussion and assist slow learners, who are still struggling, avoid communicating to them while helping them. Only give the necessary hint to discover for themselves.
- Invite group leaders to present their findings.
- Evaluate the findings of the learners.
- Cross-cutting issues should be integrated to indicate the link of the lesson and real life situation.
- Summarise the learned knowledge and give examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements

Expected answers for Activity 12.3

- Observations: When NaCl is used, there is liberation of a gas that turns blue litmus paper to red. There is no colour change in the solution.
- When NaBr is used, there is formation of a red solution that liberates

vapours. The vapours turn a blue litmus paper to red.

- When KI is used, there is formation of a red solution but the blue litmus paper does not change the colour.
- Interpretation: There is liberation of an acidic gas when NaCl is used. The evolved gas is HCl.
- $2NaCl(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2HCl(g)$
- There is formation of bromine when NaBr is used.
- $NaBr(aq) + H_2SO_4(aq) \rightarrow NaHSO4(aq) + HBr(aq)$
- $2HBr(aq) + H_2SO_4(aq) \rightarrow Br_2(g) + SO_2(g) + 2H_2O(l)$
- When iodine is used, there is formation of red iodine.
- $2KI(aq) + H_2SO_4(aq) \rightarrow K_2SO_4(aq) + 2HI(aq)$
- $2HI(aq) + H_2SO_4(aq) \rightarrow I2(aq) + SO_2(g) + 2H_2O(l)$
- So the $H_2SO_4(aq)$ reacts to give a displacement reaction with NaCl and produce HCl.
- HCl is not oxidised by $H_2SO_4(aq)$.
- With NaBr, there is a reaction of displacement to produce HBr.
- The HBr reacts further (oxidised) by the $H_2SO_4(aq)$ to produce B_{r2} (red) vapour.
- With KI, there is a displacement reaction in which HI is produced in the solution but it is readily oxidised to iodine (red in colour).
- The iodine being less volatile, it does not evaporate from the mixture. So the litmus paper will not be affected.

Expected answers for Checking up 12.3

1. hydrogen chloride, hydrogen iodide, hydrogen bromide.

2. Hydrogen halides are molecules with covalent bonds between hydrogen and a halogen atom. Hydrohalic acids exist as dissociated ions of hydrogen and halide ions.

3. HF is liquid at 15°C, the rest of hydrogen halides are gases at 15°C.

Fluorine dissociation bond energy F-F is lower than Cl-Cl and does not follow the general trend of halogen-halogen strength.

-HF forms hydrogen bonds, the other hydrogen halides are attracted by Van Der Waals forces.

4.a) $NaCl(s) + H_2SO_4(aq \rightarrow HCl(aq) + NaHSO_4(aq)$

b) $Br_2 + 6OH^- \rightarrow BrO_3^- + Br^- + 3H_2O(l)$

5. As you move down the group, there is an increase in boiling points from : HCl>HBr>HI but HF is far different because it has higher boiling point than the rest due to hydrogen bonds which are formed in HF.

6.HI is a stronger acid than HBr because the bond H-I is longer than H-Br and therefore weaker, this requires less energy to break H-I bond than H-Br bond so that you get H^+ ions easily in HI.

- The I^- ion is more stable since it is bigger than Br^- ion. This results in the electron on the I- ion to be more stable, so the electron is less available to pick a H^+ from the solution and therefore the H^+ ions in solution becomes higher in HI.

7. As you move down the group, solubility decreases because there is an increase in Van der Waals forces in halogens down the group.

8. Add AgNO3 solution to both test tubes: the test tube that contains chlorine will form a white precipitate with AgNO3 solution but no with water.

Lesson 4: Preparation and behaviour of hydrogen halides

a)Introduction

- Students have learnt the displacement reactions such that hydrogen halides synthesis can be explained with little difficulty.
- Students have also learnt combination reactions so that it can be easy to introduce the concept of halogen acid preparation.

b)Teaching resources

Use the students' book

b)Learning activities :

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do the introductory activity then proceed to activity 12.4 which is specific to lesson.

- When you enter the class, greet students and inform them on the activity to take place.
- Ask learners to sit in groups of 4 to 6 students and choose a group leader.
- Monitor the progress of the group discussion and assist slow learners who are still struggling, avoid communicating to them while helping them. Only give the necessary hint to discover for themselves.
- Invite group leaders to present their findings.
- Evaluate the findings of the learners.
- Cross-cutting issues should be integrated to indicate the link of the lesson and real life situation.
- Summarise the learned knowledge and give examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements.

Expected answers for activity 12.4

When KI is used there is formation of a red colour in the solution.

When NaCl is used, there is no change.

So, the I^- is more reducing than Cl^- since I^- are easily oxidised to I_2 (red).

d)Expected answers for checking up 12.4

1. Fluorine being the most electronegative in the group, it can capture electrons from other atoms easily.

2. Down the group, there is a decrease in bond energy H-halide due to increase in bond length. So H^+ ions can be obtained easily.

-The halide ions become more stable as you move down the group. This makes the solution to have more H^+ ions in the solution.

3. HF forms hydrogen bonds. HF forms polymers of (HF) and this molecular weight is high.

4. F_2 is a gas (yellow), Cl_2 is a green gas, Br_2 is a red liquid, I_2 is a solid (grey) crystalline at room temperature.

5. Solution A contains NaCl .

Solution B contains NaI.

Justification: NaI forms I_2 which is violet or red depending on is concentration. NaCl forms Cl_2 that is greenish and the solution mixture with Fe^{3+} (brown) give a yellow colour.

Lesson 5: Tests for halide ions in aqueous solution

a)Introduction

- Students have already learnt some reactions of precipitation and formation of different coloured products of reaction and the evolution of gases in certain reactions.
- These concepts can help students to understand the chemical tests of halides without much trouble.

b)Teaching resources

Use the students' book.

c)Learning activities

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do the introductory activity then proceed to activity 12.5 (c) which is specific to the lesson.

- When you enter the class, greet students and inform them on the activity to take place.
- Ask learners to sit in groups of 4 to 6 students and choose a group leader.
- Ask students to observe the table 12.5 in the student book and discuss the related questions.
- Monitor the progress of the group discussion and assist slow learners who are still struggling, avoid communicating to them while helping them. Only give the necessary hint to discover for themselves

- Invite group leaders to present their findings.
- Evaluate the findings of the learners.
- Cross-cutting issues should be integrated to indicate the link of the lesson and real life situation.
- Summarise the learned knowledge and give examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements

Expected answers for activity 12.5.(c)

a)The anion present is probably I^-

b)The anion present is probably I^-

c)The anion present is probably I^-

d)The anion present is I^-.

Conclusion: The iodide ion is confirmed in solution X.

Lesson 6: Properties of oxoacids

a)Introduction

Students have learnt the decomposition reactions already and oxidation of some elements. Students also learnt the properties of acid substances. So these concepts will lead them into the new content of oxoacids well.

b)Teaching resources

Use the students' book.

c)Learning activities

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do the introductory activity then proceed to activity 12.5(a) which is specific to lesson.

- When you enter the class, greet students and inform them on the activity to take place.
- Ask learners to sit in groups of 4 to 6 students and choose a group leader.
- Monitor the progress of the group discussion and assist slow learners who are still struggling, avoid communicating to them while helping them. Only give the necessary hint to discover for themselves
- Invite group leaders to present their findings.
- Evaluate the findings of the learners.
- Cross-cutting issues should be integrated to indicate the link of the lesson and real life situation.
- Summarise the learned knowledge and give examples which illustrate the learned content.

- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements

Expected answers for activity 12.5.(a)

a. When heating takes place, the gas evolved relights the glowing splint.

b) The residue substance solution turns to a white precipitate when AgNO3 is added to it.

Equations:

$2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$

$KCl(aq) + AgNO_3(aq) \longrightarrow AgCl(s) + KNO_3$

Expected answers for checking up 12.5.(b)

1. The anion present in solution Y is a chloride (Cl^-)

2.a) $3KClO_4(s) \longrightarrow 3KCl(s) + 6O_2(g)$

b) $ClO3- + 6Cl^- + H^+ \longrightarrow 3H_2O + 3C_{l2}$

3. In the laboratory, we prepare ClO_3^- as:

$Cl^2(g) + 6OH^-(hot,conc) \longrightarrow ClO_3^-(aq) + Cl^-(aq) + 3H_2O(l)$

4. Fluorine forms 1 oxoacid (HFO), because the fluorine atom does not have the vacant d-orbitals to be occupied by other oxygen atoms.

Lesson 7: Properties of chlorates and iodates, perchlorates and periodates

a)Introduction

The knowledge of decomposition of substances which students leant before can be exploited to introduce the content. Also students learnt the oxidation properties of some compounds like those of group 14 and group 15 which can be used to lead the students into the new content.

b)Teaching resources

Use the studens' book.

c)Learning activities

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do the introductory activity then proceed to activity 12.5 (b) which is specific to lesson.

- When you enter the class, greet students and inform them on the activity to take place.
- Ask learners to sit in groups of 4 to 6 students and choose a group leader.
- Monitor the progress of the group discussion and assist slow learners, who are still struggling, avoid communicating to them while helping them. Only give the necessary hint to discover for themselves.

- Invite group leaders to present their findings.
- Evaluate the findings of the learners.
- Cross-cutting issues should be integrated to indicate the link of the lesson and real life situation.
- Summarise the learned knowledge and give examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements

Expected answers for activity 12.5 (b)

Observation: The colourless mixture of KIO3 and HCl turns red when KI solution is added to it.

Equation: $5I^- + IO_3^- + 6H^+ \longrightarrow 3H_2O(l) + 3I_2(aq)$

The oxidising reagent is IO^{3-} .

The reducing agent is I^-.

d)Expected answers for Checking up 12.5. a

1. The oxidising power of oxoacids increases with increase in oxidation state of the halogen.

The more the number of oxygen attached to the halogen, the more acidic will be the oxoacid.

eg: HClO3 is more acidic than $HClO_2$.

The more electronegative the halogen is the more the acidity of its oxoacids. EG: HClO3 is more acidic than HIO_3.

2. Decomposition of KClO3 is important when oxygen gas is needed in some cases like in the explosion to destroy mountain rocks during road construction.

3. Equation: $2KClO_3(s) \longrightarrow 2KCl(s) + 3O_2(g)$

4. Observation: The colourless mixture of KIO3 and HCl turns red when KI solution is added to it.

Equation: $5I^- + IO^-3 + 6H^+ \longrightarrow 3H_2O(l) + 3I_2(aq)$

The oxidising reagent is IO3- .

The reducing agent is I- .

Lesson 8: Uses and hazards of halogens and their compounds

a)Introduction

Students have already learnt the different types of halogens, their compounds as well as the chemical and physical properties of their compounds. So it will be easy to lead them into the content of uses. Halogens were also encountered in ordinary level, therefore the knowledge they acquired at that level can be of significant use to understand better this lesson content.

b)Teaching resources

Use the students' book in order to explain the content of this lesson

c)Learning activities

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do the introductory activity then proceed to Activity 12.6 which is specific to lesson.

- When you enter the class, greet students and inform them on the activity to take place.
- Ask learners to sit in groups of 4 to 6 students and choose a group leader.
- Monitor the progress of the group discussion and assist low achiever learners who are still struggling, avoid communicating to them while helping them. Only give the necessary hint to discover for themselves
- Invite group leaders to present their findings.
- Evaluate the findings of the learners.
- and real life situation.
- Summarise the learned knowledge and give examples which illustrate the learned content.
- Confirm the correct answers, eliminate the wrong ones or complete the incomplete statements.

Expected answers for activity 12.6

1. The chemical composition of salt is NaCl crystal. Its natural occurrence is in the sea and lakes.

2. Chlorine reacts with water to produce ClO^-. This substance releases oxygen later in water so that germs die.

3. a) Observations: There is evolution of a gas on the cathode in greater quantities than on the anode.

The phenolphthalein indicator turns pink on the cathode as the reaction takes place.

There is no red colour formation on the anode.

b)The chemical product formed at the anode is chlorine Cl2 ,because that is where oxidation of Cl- ions takes place to give Cl2.

c. Expected answers checking up 8

1. Chlorine is used for:

- Treatment of water
- Table salt for eating in NaCl.
- To produce NaOH in industry.

2. Bromine is used for:

- Photography
- To manufacture polymers

3. Iodine is used in table salt to avoid goitre illness. Iodine is also used to disinfect wounds in humans.

4. Halogens are used for:

- HCl in the human stomach for digestion.
- They are used to produce medical drugs.

5. Halogen compounds cause:

- Chlorofluorocarbons deplete the ozone layer.
- BrF5 reacts with water to produce toxic and corrosive fumes.

12.6 Summary of the unit

- Halogens are naturally found mainly in sea water and in rocks.
- Halogens are prepared by electrolysis of aqueous solutions of salt halides and by displacement reactions.
- The melting and boiling points of halogens increases down the group.
- Solubility of halogens in water decreases down the group.
- Reactivity of halogens decreases down the group.
- Acidity of aqueous solutions of hydrogen halides increases down the group.
- Halogens react to combine with metals and non-metals.
- Oxoacids and oxosalts of halogens are strong oxidising agents.
- Halide ions can be detected in aqueous solution using AgNO3 and other methods.
- Halogens are useful in some cases but they may cause hazards in other cases, for example chlorofluorocarbons that cause the hazard of depleting the ozone layer in the atmosphere.

12.7 Additional information for teachers

- Halogens are the only elements in one group of the periodic table that exist in the three familiar states of matter (solid, liquid and gas) at room temperature and pressure.
- The fluorine atom has no d-orbitals in its valence shell and therefore cannot expand its octet to form more than one valency.
- Fluorine exhibits anomalous behaviour in many properties.
- Examples:
- Ionization enthalpy, electronegativity, and electrode potential are all higher for fluorine than the expected values compared to other halogens.
- Ionic and covalent radii, melting point , boiling point, enthalpy of bond dissociation and electron affinity enthalpy are quite lower than expected.

a) Chlorine displaces bromine and iodine:

$Cl2(g) + 2Br^-(aq) \longrightarrow 2Cl^-(aq) + Br2(g)$

$Cl2(g) + 2I^-(aq) \longrightarrow 2Cl^-(aq) + I2(g)$

b) Bromine displaces iodine

$Br_2(g) + 2I\text{-}(aq) \longrightarrow 2Br\text{-}(aq) + I_2(g)$

c) Iodine displaces neither of the other two; it is a very weak oxidizing agent, i.e. strong reducing agent.

Fluorine displaces other halogens from ionic and covalent compounds.

$2KCl(s) + F_2 \longrightarrow 2F^- + Cl_2 + 2K^+$

$CH4(g) + F_2 \longrightarrow CF_4 + 2H_2$

$2NH3(g) + 3F_2(g) \longrightarrow N2 + 2NF_3 + 3H_2$

H2S burns in the gas (F2) to form SF6 and HF.

- Fluorine forms two oxides OF2 and O_2F_2.

However, only OF2 is thermally stable at 25oC. These oxides are essentially oxygen fluorides because of the higher electronegativity of fluorine than oxygen. Both oxides are strong fluorinating agents.

- Chlorine oxides, Cl_2O, ClO_2, $C_{l2}O6$ and Cl2O7 are highly reactive oxidising agents and tend to explode.

The bromine oxides, Br_2O, BrO_2, BrO3are unstable halogen oxides and exist only at low temperatures. They are very powerful oxidising agents.

- Iodine oxides, I2O4, I2O5, and I2O7 are insoluble solids and decompose on heating.
- Iodine is the only halogen that forms an XY7 interhalogen compound, and it does so only with fluorine.

-In oxoacids:

Amongst halic acids, chloric acid has the highest acidity.

$HClO_3$ >	$HBrO_3$ >	HIO_3
chloric acid	bromic	iodic acid

- Since chlorine is more electronegative than bromine and iodine, the shared electron pair lies moderately closer to chlorine in a Cl-O bond than bromine in Br-O bond or iodine in an I-O bond.
- As a result, the O-H bond turns out to be much weaker if there should arise an occurrence of chloric acid, along these lines encouraging the release of a proton well.
- Halogens are very poisonous and should be handled with care.
- Iodine solution is prepared by dissolving KI in water then iodine solid (I2) is added to provide iodide ions that enables the dissolution of I2 to be high.
- Solubility of I2 improves due to the formation of a stable triiodide complex ion.

$KI(aq) + I_2(s \longrightarrow I3^-(aq) \text{ or } I^-(aq) + I_2(s)\ I3^-(aq)$

- -Silver bromide is used in photographic films. It breaks down in sunlight, the same as silver chloride:

$2AgBr(s) \longrightarrow 2Ag(s) + Br_2(g)$

- The small deposits of silver create the dark areas on a black and white negative film. This can be used to distinguish between silver chloride and silver bromide. A precipitate of silver chloride turns a greyish purple colour in sunlight.
- Voltage used is between 6V and 9V
- Students can be organised in 6 groups in the laboratory in most activities

Advice to the teacher:

- Note: Halogens are very poisonous and should be handled with care.
- Iodine solution is prepared by dissolving iodine solid (I2) in water then KI is added to provide iodide ions that enables the dissolution of I2 to be high.

  Solubility of I2 improves due to the formation of a stable triiodide complex ion.

$I\text{-}(aq) + I_2(s \longrightarrow I3^-(aq)$

Voltage used in laboratory electrolysis is between 6V and 9V

- It is advisable to form about 6 groups of students in 1 laboratory foran activity.

12.8 End unit assessment

Expected answers

1.a) i)$H2O + Cl2 \longrightarrow HCl + HClO$

ClO- is a bleaching agent.

ii) Chlorine in Cl^- is in -1 oxidation state.

Chlorine in ClO^- is in the oxidation state +1.

The change in oxidation state is a disproportionation reaction because one chlorine atom gains an electron while another chlorine atom loses an electron.

b) i) $2Br^- + Cl2 \longrightarrow Br2 + 2Cl^-$

ii) Chlorine is a strong oxidising agent because of its high electronegativity that enables chlorine atoms to capture electrons from other atoms.

2.a) After adding AgNO3 the student saw a white precipitate.

b) $Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$

c)-When AgNO3 is added to Cl- ions, there is formation of AgCl which is a white precipitate. The precipitate dissolves in NH3 solution.

- When AgBr cream precipitate is added to NH3 solution, the precipitate remains but dissolves on addition of excess NH3 solution.
- When AgI pale yellow precipitate is formed and we add NH3 solution, the precipitate does not dissolve even in excess of NH3 solution.

d)i) Oxidation number: Cl_2 is 0

Oxidation state of Cl in HClO is +1

Oxidation state of Cl in HCl is -1

ii) It is because there may be chloride ions with a high concentration in tap water, so these ions may react with Ag+ to form AgCl(s) .

3.a)The number of moles of HCl used was :

$0.2x\frac{50}{1000}$ =0.01 mole

b) Volume of Cl2 produced:

Number of moles of Cl_2 produced=$0.01x\frac{11}{44}$=0.0025 mole

Volume of Cl_2 produced = 0.0025x24 = 0.06 dm^3

4.a) $2Na(s) + Cl(g) \longrightarrow 2NaCl(s)$

b) The structure of NaCl in the solid state is:

Face centred cubic structure where each Na atom is surrounded by 6 Cl atoms and each Cl atom is surrounded by 6 Na atoms.

5.a) In Br^- ions, a pale red solution is obtained.

In I^- ions, a deep red solution is obtained.

The red solution of I2 distributes in the organic layer more than in the aqueous solution.

The red solution of Br2 is more soluble in the organic solvent. So the red colour is in the organic layer more than in the aqueous solution.

b)Equations: $Cl_2 + 2Br^- \longrightarrow Br_2 + 2Cl^-$

$Cl_2 + 2I^- \longrightarrow I_2 + 2Cl^-$

c) The trend in reactivity: Cl2 is more oxidising than Br^-,Cl2 is more oxidising than I^- .

6. Chlorine has a stronger oxidising power than bromine because it is more electronegative due to its small size.

7.Eqaution of reaction:

$Cl2 + 6OH^-(hot, conc) \longrightarrow ClO3^- + 3H_2O + Cl^-$Additional activities

12.9.1. Remedial activity

1. Write the chemical formula of a halogen ion that is displaced by bromine in solution.

2. Write the electronic configuration of bromine (atomic number of Br=35).

3. Explain the change that takes place when chlorine comes in contact with :

a) Blue litmus paper

b) Is bubbled in cold dilute NaOH solution.

4. a)State the reaction that takes place when chlorine comes in contact with sodium.

b) Write the equation of reaction between Cl_2 and Na.

12.9.2. Consolidation activity

5. Describe how you can distinguish between Br^- ions and Cl^- ions.

6. Explain why HF is a weaker acid than HCl.

7.a) Describe the observation seen when HCl gas is made to be in contact with NH3 gas.

b) Write the equation of reaction between HCl and NH3.

12.9.3. Extended activity

8. Explain why chlorine can form compounds in oxidation state of -1, +1, +3 and +5 but fluorine cannot form such compounds.

9. Explain why the bond energy of F-F is weaker than Cl-Cl.

10. Find 3 cases where chlorine is changed to another useful compound.

11. Describe the change in pH of water when chlorine gas is dissolved in it.

12. Describe the type of bonds formed between chlorine and :

a) Phosphorous

b) Sodium.

Expected answers for additional activities

1. I- ions

2. Configuration: $1S^2\ 2S^2\ 2P^6\ 3S^2\ 3P^6\ 4S^2\ 3d^{10}\ 4P^5$

3. a) Blue litmus paper turns red and the red colour disappears in excess of Cl2 gas to give a white colour.

b)Sodium hydroxide reacts to give sodium hypochlorite, ClO^- .

4.a)Chlorine burns to produce NaCl, so there is a reaction of combination.

b) $2Na(s) + Cl_2(g) \longrightarrow 2NaCl(s)$

5. Heat a solution of Br- in a 2 mol/litre $H_2SO_4(aq)$, there is a red liquid formed which give out red vapours gas.

When Cl^- ions are heated with the 2 mol/litre $H_2SO_4(aq)$,there is no colour change.

6. HF is a weaker acid than HCl because of 2 reasons.

i) The H-F bond is stronger than H-Cl. So less H^+ ions are obtained in HF acid.

ii) The Cl^- ion is larger than F^- , so the electron on the Cl^- is more stable than on the F^- The electron on $Cl^-$is less available to pick a H^+ ion from the solution. Therefore, more H^+ ions in HCl acid is expected.

7.a) There is formation of white fumes when HCl gets in contact with NH3 .

b) $HCl(g) + NH_3(g) \longrightarrow NH_4Cl(S)$

8. It is because fluorine does not have vacant orbitals tto be occupied by other molecules.

9. The bond F-F is weaker than Cl-Cl because the lone pairs in the F atoms repel each other and the bond weakens.

10. NaCl, KCl , $CaCl_2$

11. The pH turns acidic because the pH will read less than 7.

12. The bonds formed between chlorine and:

i) Phosphorous are covalent bonds.

ii) Sodium is ionic

UNIT 13: PROPERTIES AND USES OF GROUP 18 ELEMENTS AND THEIR COMPOUNDS

13

13.1. Key unit competency

The learner should be able to compare and contrast the properties of the group 18 elements in relation to their position in the periodic table

13.2. Prerequisite knowledge and skills

Students have the enough knowledge on

- Reactivity of metals
- Reactivity of non metals
- Properties of metallic, covalent and molecular structures
- Types of oxides

13.3. Cross-cutting issues addressed

- **Environmental sustainability**

The use of noble gases has replaced the use of other reactive elements. Being unreactive, their combustion is not possible.

- **Inclusive education**

This unit involves a number of activities like experiments on the chemical properties of group 15 elements and their compounds. The activities require assembling of apparatus, writing, reading and observation of the results. This may be challenging to students with special educational needs especially children with visual impairment difficulties. However, the teacher can make some arrangements like:

Grouping students: Students with special educational needs are grouped with others and assigned roles basing on individual student's abilities.

- Providing procedure earlier before the experiment so that students get familiar with them. They can be written on the board or printed depending on available resources. If you have children with low vision remember to print in appropriate fonts.
- Give extra time for them to write summary notes or write down observations after experiments.
- Every important point is written and spoken. The written points helps students with hearing impairment and speaking aloud helps students with visual impairment
- Remember to repeat the main points of the lessons.

For learners with **hearing difficulties**

Teacher has to encourage them to sit closer to the front of the classroom. While teaching, avoid asking learners whether they have understood, or if they need you to repeat a point. Encourage learners not to be afraid to ask questions. When teaching, speak clearly and ensure that all the learners can hear your voice. Avoid speaking hurriedly as this will make it difficult for learners with hearing difficulties to make sense of what you are saying.

Learners with mobility difficulties:

- These include learners in crutches, wheelchairs, or with walking difficulties. Encourage other learners to look out for and help their classmates. Ask their follow learners to help them with their notes, if their conditions hinder them from writing well.

Learners with reading difficulties:

Learners with this kind of difficulties struggle to make sense of words or understand written work and take longer to read than other learners. 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.

- **Gender:**

During group activities try to form heterogeneous groups (with boys and girls) or when students start to present their findings encourage both (boys and girls) to present.

- **Financial education**

As the unit deals with the importance of group 16 elements and their compounds in modern life, the teacher will draw the learner's attention on the economical impact of the making of common items made using knowledge of chemistry.

- **Peace and values education**

During group activities, the teacher will encourage learners to help each other's and to respect opinions of colleagues.

13.4. Guidance on introductory activity

The study of noble gases is based on their inertness and how they are used to prevent the oxidation of some metals or to prevent the explosion.

Expected answer for the introductory activity

Xenon is used in fluorescent bulb because it emit an instant light

Argon is used in light bulb to prevent the oxidation of a metal filament inside

Example of neon application: Neon glows when the electricity passes through it. It is used in many tubes of lamps.

List of lessons

Heading	Lesson title	Learning objectives	Number of periods= 2
13.1	Occurrence and physical properties of noble gases	• State the physical properties of the Group 18 elements	1
13.2	Reactivity and inertness of noble gases	• Explain the lack of reactivity of the group 18 elements. • Associate chemical inertia of the group 18 elements to their full valence shell	
13.3	Discovery of the first noble gas compounds and uses of noble gases	• Recognize the importance of noble gases or group 18 elements in the daily life.	1
13.4	End unit assessment		

Lesson 1: Occurrence and physical properties of noble gases

a)Introduction

Students have studied:

- The occurrence of other gases
- Lewis structures and dot-cross diagrams.
- The physical properties of gases which exists in molecular structures

(Examples: Halogens)

b) Teaching resources

The fact that noble gases are not easily available, the teacher will use illustration from books. Use of document cameras or projection of pictures is suggested.

c) Learning activities

- The students form groups composed by 5 students maximum.
- The activity 13.1 is given to engage students
- Students discuss and each group selects a presenter.

After harmonization of activity 13.1, the students take the activity 13.2

Expected answer for activity 13.1

Main components of air:

UNIT 14: TRENDS IN CHEMICAL PROPERTIES OF PERIOD 3 ELEMENTS AND THEIR COMPOUNDS

14

14.1. Key unit competence

Compare and contrast the properties of the Period 3 elements and their compounds in relation to their positions in the Periodic Table.

14.2. Prerequisite knowledge and skills

To understand and conceptualise this unit, learners should remember the variations of different physical properties in different groups and some reactions of elements.

14.3. Cross-cutting issues to be addressed

Environment and sustainability: Education and research-related institutions, in most laboratories contribute to the generation of small quantities of waste as a result of chemical reactions, many of them highly toxic. Such as disposal of acids, metals, solvents, chemicals and toxicity of selected products of synthesis, whose toxicity is often unknown? Harmonization of procedures for waste management and waste minimization procedures such as reduction, reuse and recycling of chemicals should be applied in any laboratory irrespective of its size and location.

14.4. Guidance on Introductory activity

This introductory activity is intended to relate the elements of period 3 with other elements on the period table and Related knowledge about the compounds of the elements .

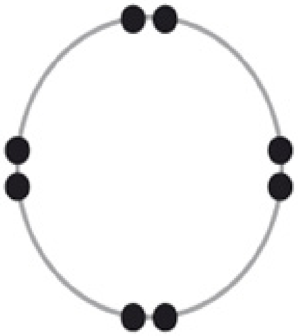
14.5. List of lessons (including assessment).

Heading	Lesson title	objectives	No of periods
14.1 Physical Properties of the Period 3 elements	14.1 Physical Properties of the Period 3 elements	Compare the physical properties of the Period 3 elements and relate their position and nature of bonds in the periodic table.	3
14.2 Chemical properties of period 3 elements	14.2Chemical properties of period 3 elements	Describe the chemical properties of elements of period 3	1

- Nitrogen; oxygen; carbon dioxide, noble gases
- Nitrogen reacts with oxygen to produce NO. The reaction is facilitated by the lightening.
- Carbon dioxide reacts with water vapour to produce carbonic acid (The origin of acidic rain)
- No condition can allow noble gas to react with nitrogen, oxygen, carbon dioxide or water vapour in the atmosphere. They cannot even react between them because they are the best examples of the unreactive elements.
- In neon lamp, the gas (neon) glows when the electrical current passes through it.

d) Application activities (Checking up 13.1)

a) Dot and cross diagram of neon (Z=10)



Ne atom
$1s^2 2s^2 2p^6$

ii) Helium is placed in group 18, because it exhibits the stability similar to those of other noble gas elements which respect the t octet rule (Having 8 outermost electrons and absence of unpaired electron).

Lesson 2: Reactivity and inertness of noble gases

a) Introduction

This point will be combined with the first point and studied in one period.

The prerequisite knowledge obtained in the first activity will be used

- A dot and cross diagram of neon
- The properties of noble gases.

b) Teaching resources

The teacher use different library books. Movies about the atomic structure of noble gases are suggested.

c) Learning activities

- After discussing the activity 13.1, the activity 13.2 will be the continuity of the first one. Students maintain the previous groups until the end of the first period.

Expected answers for activity 13.2

1. The compound made by a noble gas is XePtF6
2. The noble gases cannot react with any reagent in normal conditions.

d) Application activities (Checking up 13.2)

Before, the air balloon contained hydrogen. Hydrogen burns in air explosively. To prevent the danger caused by combustion of hydrogen, they used helium which could not react with oxygen.

Lesson 3: Discovery of the first noble gas compounds and uses of noble gases

a) Introduction

The lesson will be short and will be directly followed by the end unit assessment. All of those two activities will be realized in one period.

Students have the knowledge on the recently discovered noble gas compounds.

b) Teaching resources

The teacher use different library books. Movies about the uses of noble gas are suggested.

c) Learning activities

- To bring in the class some lamp tubes
- To analyze the component of the lamp tube and to identify the role of a noble gas in it.
- Students discuss the issues and select a group member to present the findings.
- The teacher harmonizes the students' findings in order to correct some errors committed by the students in their groups.

Expected answer for activity 13.3

The four noble gases discovered before were: Neon; argon; krypton and xenon.

The formation of the entire family of new elements motivated the scientists to add helium and radon.

Most of them are use in laser and lamp tubes (Details of uses are found in the student's book).

After trying the oxidation of oxygen from O_2 to O^{2-}, the similar trials have been done on noble gases. The noble gas compounds which have been synthesized were:

XeFPt2F11, XeF4, XeF2 and KrF2.

d) Application activities (Checking up 13.3)

1 →c

2→ d

3→ e

4→b

5→ a

13.6. Summary of the unit

Noble gases are also known as inert gases and do not take part in chemical reactions. They have their outermost shell complete and thus remain stable. They do not generally combine with other substances, nor are they affected by oxidising agents or by reducing agents. They are placed in the 18 group. Since, the outermost shell is complete, the valency is zero.

Noble gases always occur in free state because of their inert nature. All the noble gases, except radon are present in air in small amounts. It is also present in small quantities in the minerals of radioactive elements. Water from certain springs also gives off gases, which are rich in helium and argon.

Argon is used mainly to provide an inert atmosphere in high temperature metallurgical processes (arc welding of metals or alloys) and for filling electric bulbs. It is also used in the laboratory for handling substances that are air-sensitive.

Helium is a non-flammable and light gas. Hence, it is used in filling balloons for meteorological observations.

Neon is used in discharge tubes and fluorescent bulbs for advertisement display purposes. There are no significant uses of xenon and krypton. They are used in light bulbs designed for special purposes.

13.7. End unit assessment answers.

1. a) All outermost electrons are paired .They are more stable and the higher energy is required to remove an electron.

   b) Neon is used in the lamp tube, because it glows when electric current passes through it.

   c) Among noble gases, the atomic radius increases as you go down the group.

   d) Noble gases are more stable and they can neither lose nor gain electrons in normal conditions.

2. Because they don’t form compounds easily.

3. Noble gases exist in atomic structures. The greater atom of an element, the more reactive element. The sizes of Xe and Kr are greater than those of He and Ne

13.8. Additional activities

Remedial activities

1. What common property is shared by all the noble gas.
2. Describe correctly the position of the noble gases in the periodic table.

Answers:

1. They are inert and do not easily form chemical compounds.

2. All the noble gases form a single column, at the rightmost of the table, and the halogens are located to their left.

13.8.1. Consolidation activities

1. Who is credited with the discovery of 4 of the 6 noble gases and the isolation of 5 of them?

2. Which noble gas is formed as a result of the decay of the radioactive elements? The gas itself is radioactive, and is the heaviest of all the noble gas.

Answers:

1. Sir William Ramsay
2. Radon

13.8.2.Extended activities

1. What happens to argon in the Haber –Bosch process?
2. Why is Xenon hexafluoride not stored in glass?
3. What is the molecular structure of xenon hexafluoride?

Answers:

1. The process requires high temperature and pressure. The argon mixed with nitrogen from air is eliminated in a separation plant where argon is extracted.

2. $XeF6$ is not stable; it can react with silica that makes up the glass.

$2XeF6 + SiO2 \rightarrow 2XeOF4 + SiF4$

It is stored in nickel containers at room temperature.

3. The molecular structure of xenon hexafluoride.

14.3Compounds of period 3 elements	14.3(a)Acid-base Behaviour of the Oxides	Explain the acid base character of period 3 elements and type of bonding in the oxides	2
	14.2(b) The Chlorides of Period 3 Elements	Explain the nature of bonding in chlorides and their reaction with water	1
	14.3(c) The hydrides of period 3 elements	Explain the nature of bonding in the hydrides and their reaction with water	1
	End of unit assessment		2

Lesson 1: Physical Properties of the Period 3 elements

a)Prerequisites/Revision/Introduction:

Writing electronic structure /electron arrangement of elements in terms of s, p , d and f. Notation and variation of physical properties of elements in each group on the periodic table.

b) Teaching resources:

Periodic table and manila charts.

c) Learning activities:

Provide the introductory activity to students together with activity 14.1 and allow students to do the activity in their groups or individually.

Ask the students to make their presentations by selecting who to present.

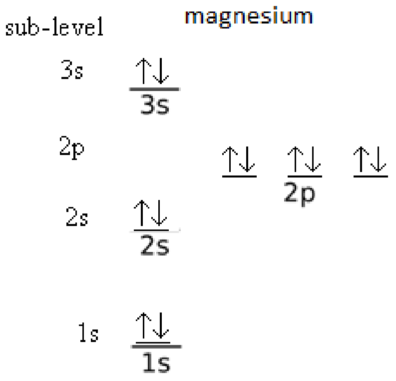
This should take little time as most of these physical properties were covered in groups.

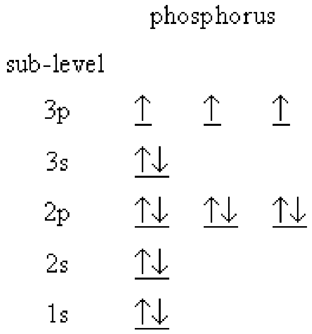
You can make any corrections if any and provide checking up 14.1.

Make corrections with students to make sure there are no misconceptions.

d) Answers to Checking up 14.1

1. (i) Ionization energy increases across period due to increase in effective nuclear attraction caused by decrease in size . Similarly, electronegativity increase across due to decrease in size thus the ability attracts the electrons increases.





(ii)

The electronic configurations of both magnesium and phosphorous are thermodynamically stable with full 3s orbital and 3p orbital half- filled respectively.

2. (a) Magnesium has more delocalized electrons in than sodium hence more attraction between delocalize electrons with central cations thus more energy required to break them down.

   (b) About 113°K

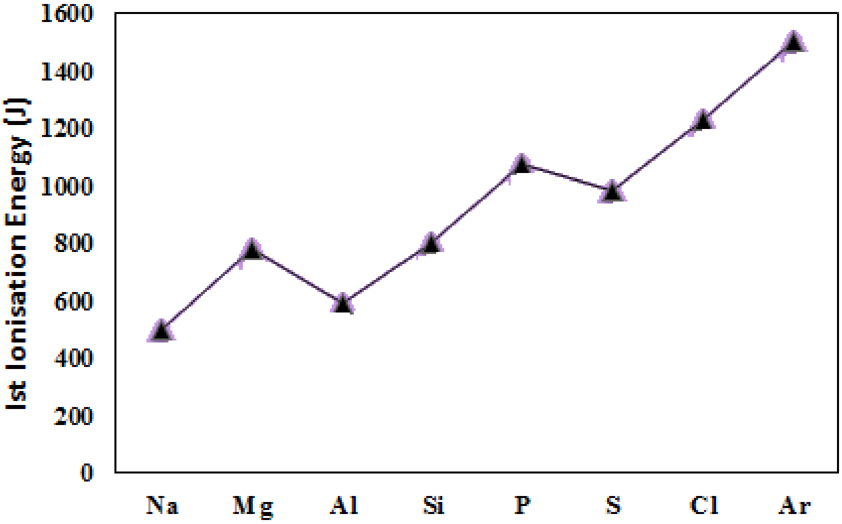
   (c) Chlorine exists as simple di molecular structure with weak van der Waal's forces.

   (d) Approximately 340k, decrease in melting reflects the decrease in the strength of each metallic bond. The atoms in a metal are held together by the attraction of the nuclei to electrons which are delocalized over the whole metal mass

   (e) Refer to notes.

2. (a) The second ionization energy is the energy it takes to remove second electron to form an ion in the gas phase.

(b)



There are more protons in each nucleus so the nuclear charge in each element increases. Therefore the force of attraction between the nucleus and outer electron is increased, and there is a negligible increase in shielding because each successive electron enters the same energy level. So more energy is needed to remove the outer electron.

Magnesium: $1s^2 2s^2 2p^6 3s^2$ and aluminium: $1s^2 2s^2 2p^6 3s^2 3p^1$

The outer electron in aluminium is in a p sub-level. This is higher in energy than the outer electron in magnesium, which is in an s sub-level, so less energy is needed to remove it.

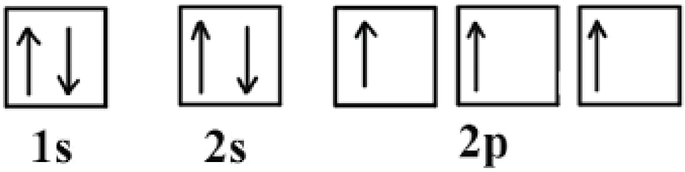
Phosphorus: $1s^2 2s^2 2p^6 3s^2 3p^3$ and sulphur: $1s^2 2s^2 2p^6 3s^2 3p^4$ the 3p electrons in phosphorus are all unpaired. In sulphur, two of the 3p electrons are paired. There is some repulsion between paired electrons in the same sub-level. This reduces the force of their attraction to the nucleus, so less energy is needed to remove one of these paired electrons than is needed to remove an unpaired electron from phosphorus.

(c) For (i) , (ii) and (iii) refer to notes

3. (i)Group (V) , Since removing the sixth electron is much bigger (five times) than the energy required to remove the fifth electron indicating another shell which is stable.

(ii) Write the electronic configuration of A and explain how this electronic configuration obe

Nitrogen



According to **Hund's rule**, every orbital in a sub shell is singly occupied with one electron before any one orbital is doubly occupied, and all electrons in singly occupied orbitals have the same spin.

Lesson 2: Chemical properties of period 3 elements

a)Prerequisites/Revision/Introduction:

Writing electronic structure /electron arrangement of elements in terms of s, p , d and f. Notation and variation of physical properties of elements in each group on the periodic table.

b) Teaching resources:

Periodic table and manila charts.

c) Learning activities:

Provide the Materials /apparatus as indicated in student book activity 14.2

Water , test tubes, a piece of sodium metal, aluminium powder, magnesium ribbon/ powder, red litmus paper/ universal indicator.

Provide the procedure for the experiment and allow them to perform the experiment .

Let them answer the study questions found in the student book or can provide them during the experiment if the books are not enough.

Let the students summarize lesson.

d) Answers to checking up 14.2

1. (a)

Oxide	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO3

Melting point /oC	1275	2827	2017	1607	580	33
(i)Bonding	Ionic	Ionic	Ionic	Covalent	Covalent	Covalent
(ii)Structure	Giant	Giant	Giant	Giant	simple molecular	simple molecular

(iii) MgO has a giant ionic structure with strong electrostatic forces of attraction which require more energy to break. In SO3 , it exists as simple molecular structure with weak intermolecular forces of attraction which need less energy to break.

(b) $Na_2O(s) + H_2O(l) \longrightarrow 2NaOH(aq)$

Al_2O_3 is insoluble in water

$SO_3(g) + H_2O(l) \longrightarrow H_2SO_4(aq)$

Lesson 3: Acid-base Behavior of the Oxides

a)Prerequisites/Revision/Introduction:

Writing electronic structure /electron arrangement of elements in terms of s, p, d and f..... Notation and variation of physical properties of elements in each group on the periodic table.

b) Teaching resources:

Periodic table and manila charts.

c) Learning activities:

Provide activity 14.3(a) and allow them to do it.

Allow presentations and correct any misconceptions and provide the checking up 14.3(a)

d) Answers to checking up 14.3(a)

1. (a) (i)Basic oxides: Na_2O , CaO and MgO
   (ii) acidic oxides: P_2O_5 , SO_2 and SiO_2
   (iii) neutral oxides: none
   (iv)Amphoteric oxides: Al_2O_3

(b) Procedure: separately adding water and drop a piece of red and blue litmus paper.

Observation: for Basic oxides: a strongly alkaline solution which turn red litmus paper blue.

For acidic oxides: acidic solution which turns blue litmus paper red.

For Amphoteric oxides: fumes of hydrogen chloride or a solution turns a blue litmus paper red.

2. (a)Na_2O : ionic

Al_2O_3 : partially ionic

(b) (i) This is sufficient information to describe the bonding in oxides with giant structure since it does not dissolve in water.

(ii) Dissolve the oxide in water electrolyze the solution, if it does not conduct electric current it justifies the covalence nature of the oxide.

Lesson 4: The Chlorides of Period 3 Elements

a)Prerequisites/Revision/Introduction:

Writing electronic structure /electron arrangement of elements in terms of s, p , d and f..... Notation and variation of physical properties of elements in each group on the periodic table.

b) Teaching resources:

Periodic table and manila charts.

c) Learning activities:

Provide activity 14.3(b) and allow the to do the activity in groups or individually.

Let the students present their work as you make some corrections if any.

Provide the checking up 14.3(b). You can allow them to it individually if you wish.

d) Answers to checking up 14.3(b)

1. (a) Hydrolysis is the chemical breakdown of a compound due to reaction with water. Dissolution is a process by which the original states of matter turn into a liquid or other solvent and become solutes - dissolved components.

(b) Sodium Chloride dissolves in water,

(c) Aluminium Chloride hydrolyzes in water

Formula of chlorides	LiCl	$BeCl_2$	BCl_3	CCl_4	NCl_3	Cl_2O or OCl_2	ClF or FCl
bonding and structure of chlorides	ionic lattice	layered covalent lattice	small covalent gaseous molecule	small covalent liquid molecule	small covalent liquid molecule	non-polar small covalent gaseous molecule	small covalent gaseous molecule

formula of chlorides	NaCl	$MgCl_2$	$AlCl_3$	$SiCl_4$	PCl_3, PCl_5	S_2Cl_2, SCl_2, SCl_4	Cl_2

bonding in chlorides	ionic lattice	ionic lattice	ionic lattice, readily vaporises to covalent dimer molecules Al2Cl6	covalent small liquid molecules	liquid covalent small molecules	covalent small liquid molecules	small diatomic gaseous molecule

(d) formation of white fumes of hydrogen chloride

- in excess water a solution of hydrochloric acid which turn bleu litmus paper red

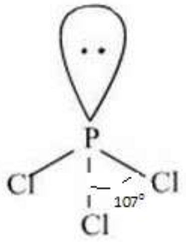
2. (a)$BeCl_2(s) + 2H_2O(l) \rightleftharpoons Be(OH)_2(s) + 2HCl(aq)$ or

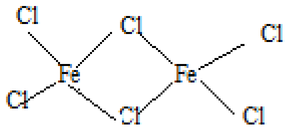
$Be^{2+} (aq) + H_2O(l) \rightleftharpoons [Be(H_2O)4]^{2+}(aq)$

$[Be(H_2O)4]^{2+}(aq) + H_2O(l) \rightleftharpoons [Be(OH)(H2O)_3]^+ + H_3O_+ (aq)$

$[Be($ $(l) \rightleftharpoons [Be(OH)2(H2O)_2] + H_3O^+ (aq)$

(b)





(c)

4. (a) hydrogen chloride gas

(b) $SiCl_4+2H_2O \longrightarrow SiO_2+4HCl$ or $SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$

(c) CCl_4 is not hydrolyzed because of following reasons. Carbon is smaller in size. Absence of d-orbitals in Carbon thus it difficult for carbon to expand its valence or coordination number. $CCl_4+H_2O\rightarrow$ No hydrolysis. Where as in $SiCl_4$ its available 3d-orbitals make possible for the hydrolysis of SiCl4. More over Silcion has comparatively higher atomic size compared to Carbon. $SiCl_4+2H_2O \longrightarrow SiO_2+4HCl$ or $SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$

Lesson 5: The hydrides of period 3 elements

a)Prerequisites/Revision/Introduction:

Writing electronic structure /electron arrangement of elements in terms of s, p , d and f….. Notation and variation of physical properties of elements in each group on the periodic table.

b) Teaching resources:

Periodic table and manila charts.

c) Learning activities:

Provide activity 14.3(c) and allow the to do the activity either in groups or indivually.

Let them present their findings as you make some corrections.

Provide the checking up 14.3(c) .

d) Answers to checking up 14.3(c)

1. (a)the melting points of the oxides increases from Na_2O to Al_2O_3 via MgO due to increase in lattice energy of the oxides which is caused by the reducing cation that attracts the anion more strongly and hence need more energy to separate them.

(b) (i) $SO_3 (g) + H_2O (l) \xrightarrow{\hspace{3cm}} H_2SO_4 (aq)$

(ii) $Na_2O (s) + H_2O (l) \xrightarrow{\hspace{3cm}} NaOH (aq)$

(c) (i) Al_2O_3

(ii) $Al_2O_3+2NaOH+3H_2O \xrightarrow{\hspace{3cm}} 2NaAl(OH)_4$

$Al_2O_3+6HCl \xrightarrow{\hspace{3cm}} 2AlCl_3+3H_2O$

2. 2(i) SiO_2

(ii) $SO_{3.}$

(iii) Na_2O

(iv) MgO

3. (a)Na_2O: giant ionic structure is expected to have high melting due to strong electrostatic forces that require more energy to break.

SiO_2: giant molecular structure with very many strong covalent bonds that need more energy to break

(b)Li_2O: Expect to have lower melting point than sodium oxide due to small size of lithium ion will polarize a big oxide and distorts the arrangement of electrons in the oxygen atom hence causes covalency character in li_2O.

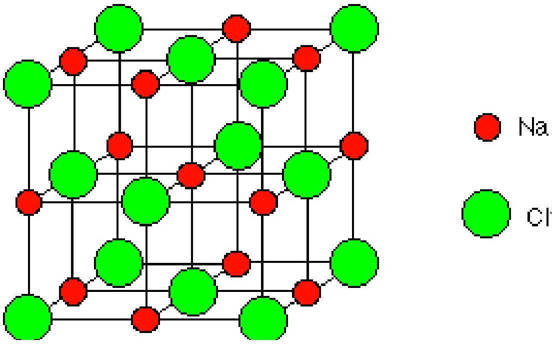
(c)(i) Structure: simple molecular

(ii) The only forces that exist are weak intermolecular forces that require low energy to break.

(d)$P_4O_6+6H_2O \xrightarrow{\hspace{3cm}} 4H_3PO_3$ acidic solution

$NaOH + H_2O \xrightarrow{\hspace{3cm}}$ NaOH (aq) basic solution

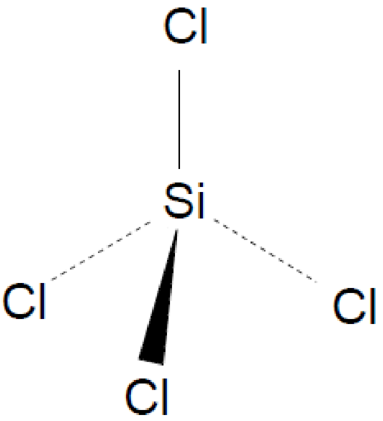
4. a)



b) There are strong electrostatic forces between the ions which take a lot of heat energy to break tomake the liquid.

4 as a covalent molecule would do:

3D shape:



Silicon (IV) chloride is a liquid at room temperature because the forces between one SiCl4 molecule and its neighbors are only van der Waals dispersion forces. These don't take anything like as much energy to break as ionic bonds.

(You could possibly also add that it isn't a gas because the molecule is big enough with enough electrons to undergo temporary polarization that the van der Waals forces are strong enough to hold it as a liquid.)

d) The difference is between the ionic sodium chloride and the covalent silicon (IV) chloride.

Whether it is ionic or covalent depends on the electronegativity difference between the atoms in the bond.

Electronegativity increases as you go across the period. There is a large enough electronegativity difference between sodium and chlorine for the bond to be ionic. There isn't enough difference between silicon and chlorine, and so the bond is covalent. The molecule is big enough with enough electrons to undergo temporary polarization that the van der Waals forces are strong enough to hold it as a liquid.

e) The difference is between the ionic sodium chloride and the covalent silicon (IV) chloride.

Whether it is ionic or covalent depends on the electronegativity difference between the atoms in the bond. Electronegativity increases as you go across the period. There is a large enough electronegativity difference between sodium and chlorine for the bond to be ionic. There isn't enough difference between silicon and chlorine, and so the bond is covalent.

e) Sodium chloride doesn't conduct electricity as a solid because it has no mobile electrons and the ions aren't free to move. It undergoes electrolysis when it is molten. The covalent silicon (IV) chloride doesn't conduct electricity under any conditions.

f) $SiCl_4 + 2H_2O \longrightarrow SiO_2 + 4HCl$

g) Like sodium chloride: magnesium chloride. Like silicon(IV) chloride: any of the other covalent chlorides - for example, PCl_3, PCl_5, S_2Cl_2, or even $AlCl_3$ although because of its complex behavior, it isn't quite the same as $SiCl_4$, so is perhaps better avoided.

5. Refer to student's book for this information

14.6. Unit Summary

General properties of period 3 elements

Name of element(symbol)	Sodium (Na)	Magnesium (Mg)	Aluminium (Al)	Silicon (Si)	Phosphorus (P)	Sulfur (S)	Chlorine (Cl)	Argon (Ar)
Atomic number(Z)	11	12	13	14	15	16	17	18
Electronic configuration	2,8,1	2,8,2	2,8,3	2,8,4	2,8,5	2,8,6	2,8,7	2,8,8
Atomic radius(picometers)	186	160	143	118	110	102	99	94
1st ionization Energy(kJmol-1)	502	744	584	793	1017	1006	1257	1526
Electronegativity(Pauling	0.93	1.31	1.61	1.9	2.19	2.58	3.16	-
Melting point(oC)	98	639	660	1410	44	113	-101	-186
Boiling point(oC)	883	1090	2467	2680	280	445	-35	-186
Metallic character	metal	metal	metal	metalloid	Non-metal	Non-metal	Non-metal	Non -metal

Summary of chloride s of period 3(structure conductivity and Melting temperature)

Property	NaCl	$MgCl_2$	Al_2Cl_6	$SiCl_4$	PCl_3	PCl_5	Cl_2
With water	Dissociates	Dissociates	Hydrolyses	Reacts	Reacts	Reacts	Disproportionate
Products	free ions	free ions	$[Al(H_2O)_6]^{3+}$ + Cl- ions	HCl + $Si(OH)_4$	H_3PO_3 + HCl	H_3PO_4 + HCl	HOCl + HCl

Structure	ionic	ionic	covalent	covalent	covalent	covalent	covalent
Conductivity	Good	Good	None	None	None	None	None
m.p./°C	801	714	178	-70	-112		-101

Summary Bonding in the oxides and chlorides of the third period

element	sodium	magnesium	aluminium	silicon	phosphorus	sulfur	chlorine
formula	Na2O	Mg	Al2O3	SiO2	P4O10	SO2 and SO3	Cl2O and Cl2O7
oxide	(Giant) ionic		(Giant) ionic with covalent character	(Giant) covalent macromolecular	(Simple) covalent molecular		
chloride	ionic	ionic	covalent	covalent	covalent	covalent	covalent

Reaction summary of the period 3 oxides

	Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10} (or P_4O_6)	SO_3 (or SO_2)	Cl_2O_7
Adding H2O	$Na_2O + H_2O \rightarrow 2NaOH$	$MgO + H_2O \rightarrow Mg(OH)_2$	Insoluble	Insoluble	$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	$SO_3 + H_2O \rightarrow H_2SO_4$	$Cl_2O_7 + H_2O \rightarrow HClO_4$
Adding HCl	Na2O + H^+ →2Na+ + H2O	MgO + 2H+ →Mg_2+ + H_2O	Al2O3 + 6H+ →$2Al^{3+}$ + 3H2O	No reaction	No reaction	No reaction	No reaction
Add NaOH	No reaction	No reaction	Al2O3 + $2OH^-$ + 3H2O →2Al(OH)4	SiO^{2+} 2OH- →$SiO3^{2+}$+ + H2O	$P_4O_{10} + 12OH^- \rightarrow 4PO_4^{3-} + 6H_2O$	$SO_3 + OH^- \rightarrow SO_4^{2-} + H_2O$	$Cl_2O_7 + OH^- \rightarrow 2ClO_4^- + H_2O$
Nature	Basic Oxide	Basic Oxide	Amphoteric Oxide	Acidic Oxide	Acidic Oxide	Acidic Oxide	Acidic Oxide
Conductivity	Good	Good	Good	None	None	None	None
mp / ºC	1275	2852	2027	1610	24	17	-92

14.7 End unit assessment

1. (a)Trend: decrease across the period

Reason: the number of protons in the nucleus increases so, the nuclear charge increases. There are more electrons, but the increase in shielding is negligible because each extra electron enters the same principal energy level. Therefore, the force of attraction between the nucleus and the electrons increases

(b) Positive ions are smaller than the atoms they come from. Sodium is 2,8,1; Na+ is 2,8. Have lost a whole layer of electrons, and the remaining 10 electrons are being pulled in by the full force of 11 protons.

Negative ions are bigger than the atoms they come from. Chlorine is 2,8,7; Cl- is 2,8,8. Although the electrons are still all in the 3-level, the extra repulsion produced by the incoming electron causes the atom to expand. There are still only 17 protons, but they are now having to hold 18 electrons

(c) Trend: increases across the period

Reason: there are more protons in each nucleus so the nuclear charge in each element increases. Therefore the force of attraction between the nucleus and outer electron is increased, and there is a negligible increase in shielding because each successive electron enters the same energy level. So more energy is needed to remove the outer electron

(d) Magnesium: $1s^2\ 2s^2\ 2p^6$ 3s2and aluminium: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^1$

The outer electron in aluminium is in a p sub-level. This is higher in energy than the outer electron in magnesium, which is in an s sub-level, so less energy is needed to remove it.

2. (a)Magnesium's metallic bonds are stronger than Sodium's. A metallic bond is the electrostatic attraction between positively charged ions and its sea negatively charged delocalized electrons. Magnesium has 2 outer electrons compared to Sodium's 1. Therefore it releases more electrons into the sea of delocalized electrons and it's nucleus has a greater positive charge of +2 compared to Sodium's +1. This means that Magnesium's nucleus has a greater attraction on the delocalized electrons. Stronger attraction = more energy required to overcome metallic bond.

(b) Structure: giant atomic molecule

Bonding: Covalent

(c) Approximately 1130K

(d) Sulphur has the highest melting point as it exists as S_8 molecules. These molecules are quite large, so the number of electrons in the molecule is high and the Van der Waal's forces are quite strong. Phosphorus exists as P4 molecules, which have fewer electrons in them and so have weaker Van der Waal's forces.

(e) Approximately 340K

In these metals, they exist as metal ions in a sea of delocalised electrons. However, since potassium has a larger ionic radius than sodium, the attraction between the valence electron and the nucleus is weaker, so it is easier to overcome those forces to change potassium's state from liquid to gas.

3. (a)(i)

Sodium	Magnesium	Aluminium	Silicon	phosphorous	Chlorine
Na	Mg	Al	Si	P	Cl
Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	Cl_2O7
				P4O6	Cl_2O

Ionic	Ionic	Partially ionic	Covalent	Covalent	covalent

(ii) Refer to student's book

(b)(i) Al_2O_3

(ii) Burns when heated in air to form the ionic white solid oxides, sodium oxide,

$4Na(s) + O_2(g) \longrightarrow 2Na_2O(s)$ sodium oxide

Or $2Na(s) + O_2(g) \longrightarrow Na_2O_2(s)$ sodium peroxide,

Burns brightly when heated in air to form a white powder of ionic magnesium oxide

$2Mg(s) + O_2(g) \longrightarrow 2MgO(s)$ or $4Mg(s) + 3N_2\,(g) \longrightarrow 2Mg_2N_3(s)$

Aluminium reacts when heated strongly in air to form the white powder of aluminium oxide .

$4Al(s) + 3O_2(g) \longrightarrow 2Al_2O_3(s)$

The above reaction occurs very rapidly on a freshly cut aluminium surface, but the microscopic oxide layer inhibits any further reaction, giving aluminium a 'lower reactivity' than expected, and its excellent anti–corrosion properties

Reacts when strongly heated in air to form silicon dioxide (silica, silicon(IV) oxide).

$Si(s) + O_2(g) \longrightarrow SiO_2(s)$

Like aluminium, silicon is protected by a thin oxide layer.

With limited air/oxygen, on heating the phosphorus, the covalent white solid phosphorus(III) oxide is formed.

$P_4(s) + 3O_2(g) \longrightarrow P_4O_6(s)$

With excess air/oxygen, on heating the phosphorus, the covalent white solid phosphorus(V) oxide is formed.

$P_4(s) + 5O_2(g) \longrightarrow P_4O_{10}(s)$

(iii) Na2O is a very basic oxide, readily dissolving/reacting to form an alkaline solution of sodium hydroxide of pH 14.

$Na_2O(s) + H_2O(l) \longrightarrow 2NaOH(aq)$

It is slightly soluble in water, and is a basic oxide forming an alkaline solution magnesium hydroxide of about pH12.

$MgO(s) + H_2O(l) \longrightarrow Mg(OH)_2(aq)$

Aluminium oxide: Insoluble, no reaction but it is an amphoteric oxide and forms salts with both strong acids and bases (alkalis)

Silicon dioxide: None and insoluble

Phosphorous oxides: Both oxides are acidic, typical non–metallic element behavior, and both phosphorus oxides dissolve in water to form acidic solutions.

$P_4O_6(s) + 6H_2O(l) \longrightarrow 4H_3PO_3(aq)$

Phosphorus (V) oxide forms phosphoric(V) acid,

$P_4O_{10}(s) + 6H_2O(l) \longrightarrow 4H_3PO_4(aq)$

Chlorine oxides: Chlorine(I) oxide forms weak chloric (I) acid.

$Cl_2O(g) + H_2O(l) \longrightarrow 2HClO(aq)$

Chlorine (V) oxide forms the strong chloric (VII) acid.

$Cl_2O7(l) + H_2O(l) \longrightarrow 2HClO_4(aq)$

(c)Mg: Metallic bonds with weak metallic attractions which need less energy.

Si: Forms a giant atomic structure with a three dimensional net work of bonds joining silicon atom that will more energy to break.

S: simple molecular structure with weak intermolecular forces.

(d) Refer to students book.

4. (a)Refer to No 3 (iii) above.

(b)Non metallic hydrides since they exist as simple molecular structures with weak intermolecular forces.

(c) Metals forms nitrates e.g. Sodium nitrate , $NaNO_3$; Magnesium Nitrate , $Mg(NO_3)_2$ Aluminium nitrate , $Al(NO_3)_3$

(d)Sodium and Chlorine

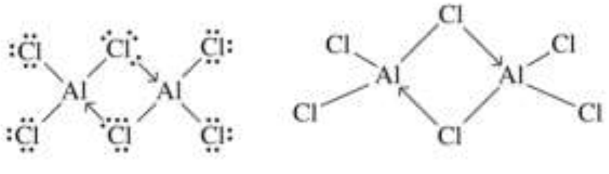
(e) Silicon

(f) Phosphorous and sulphur and chlorine.

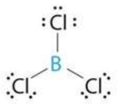
5.(a) AlCl3 has a Trigonal planar structure. There is an aluminium atom with 3 sp2 hybridized orbitals which bond to 3 chlorine atoms. The bond angle is 120 degrees. Each chlorine atom shares 1 electron with aluminium in the chemical bond in order to complete it's valence shell.

Aluminium has 3 valence electrons and gets 3 more by sharing one with each of the 3 chlorine atoms which brings its total valence electron count to 6 electrons. In order to complete its electron shell aluminium requires 2 more electrons.

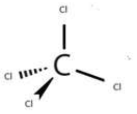
Chlorine has 6 electrons which aren't involved in bonding which form 3 non bonding pairs. In order to complete aluminium's valence electron shell two AlCl3 molecules dimerise. A chlorine atom from each of the two molecules forms a dative covalent bond with one of its lone electron pairs to the aluminium centre making the molecule Al2Cl6 as



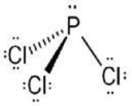
(b)



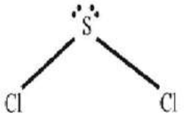
Trigonal planar



Tetrahedral

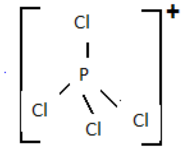


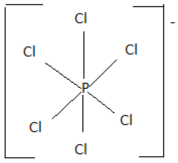
Trigonal pyramid

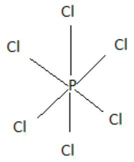


Bent / V-shape

(c)







N atom ($1s^2 2s^2 p^3$) does not have a vacant d-orbitals in the valence shell. Its maximum covalency is therefore 3, i.e. equal to number of half filled orbitals. Since N atom cannot exhibit a valency of five, formation of NCl5 does not occur.

14.8. Additional activities

14.8.1. Remedial activity

1. The elements of period 3 are as follows: Sodium, magnesium aluminium, silicon, phosphorous, chorine and argon.

   All your answers below should relate to those elements.

   (a) Which elements can exist as:

   (i) Chlorine

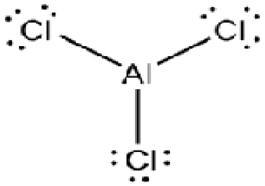
   (ii) Silicon

   (c) Which pairs of elements combine to produce compounds with formulae of type XY?

   Sodium and chlorine

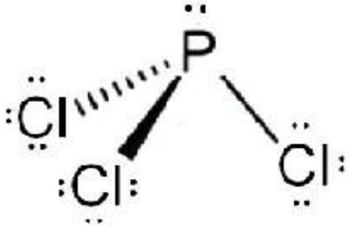
   (d)Two elements form chlorides with formulae of the type XCl3. Draw displayed formulae for these two chlorides, and suggest values for the bond angles.

Aluminium and chlorine



Displayed formula :

Phosphorous (iii) chloride



Displayed formula:

(e)(i) One element combines with oxygen to form an oxide which reacts with water to give a strongly alkaline solution. Name the element and write a balanced equation for the oxide reacting with water.

Sodium

$Na(s) + H_2O(l) \xrightarrow{\quad\quad\quad} NaOH(aq)$

(ii) One element combines with oxygen to form an oxide of the type XO2, which reacts with water to give an acidic solution. Name the element and write a balanced equation for the oxide reacting with water.

Sulphur

$SO_2(g) + H_2O\ (l) \xrightarrow{\quad\quad\quad} H_2SO_3(aq)$

2. This question is about some Period 3 elements and their oxides.

(a) Describe what you would observe when, in the absence of air, magnesium is heated strongly with water vapor at temperatures above 373 K. Write an equation for the reaction that occurs.

Bubbles of a colorless gas is evolved that produces a pop sound when lit.

$Mg(s) + H_2O(g) \xrightarrow{\quad\quad\quad} MgO(s) + H_2(g)$

(a)Explain why magnesium has a higher melting point than sodium.

Magnesium has more delocalized electrons than sodium hence more attraction forces that require more energy to break.

(b)State the structure of, and bonding in, silicon dioxide.

Other than a high melting point, give two physical properties of silicon dioxide that are characteristic of its structure and bonding.

Tetrahedral Giant covalent structure with a net work of covalent bonds where silicon atoms are surrounded by four atom of oxygen.

(c)Give the formula of the species in a sample of solid phosphorus (V) oxide. State the structure of, and describe fully the bonding in, this oxide.

Formula : P_4O_{10}

Structure: simple molecular

Bonding : covalent

(d)Sulfur (IV) oxide reacts with water to form a solution containing ions. Write an equation for this reaction.

$SO_2(g) + H_2O(l) \longrightarrow H_2SO_3(aq)$

(e)Write an equation for the reaction between the acidic oxide, phosphorus (V) oxide, and the basic oxide, magnesium oxide.

$P_4O_{10} + H_2O \longrightarrow H_3PO_4$

3. (a) Describe in detail the bonding which occurs in the compounds formed between hydrogen and

(i) Sodium (in sodium hydride),

Giant ionic structure with strong electrostatic forces of attraction.

(ii) Carbon (in methane),

Simple molecular structure with only Van der Waals forces exixting between molecules.

(iii) Nitrogen (in ammonia).

Simple molecular structure with only Van der Waals forces existing between molecules.

(b) Describe the reactions, if any, which take place between water and the hydrides of the elements in (a).

Refer to student book page for reaction of hydrides with water.

(c) Comment upon the significance of the relative values of the following boiling points of the halogen hydrides:

Hydride	HF	HCl	HBr	HI
Temperature/ ^{0}C	19.5	-85	-67	-36

Boiling temperatures increase as the size of the molecule increase due to increase in van derWaals forces. However, hydrogen fluoride has extra hydrogen bonding that require more energy to separate the molecules.

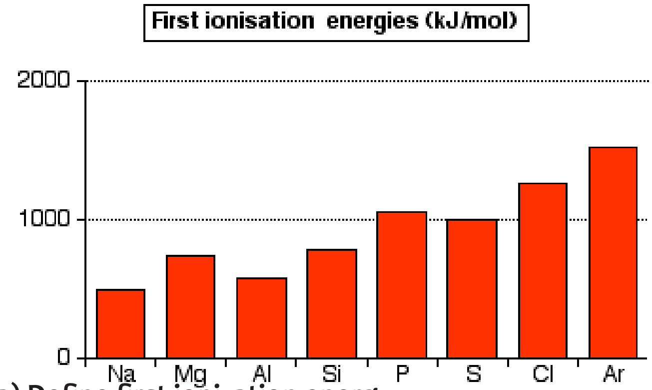
4. Write the full electronic structures for

a) silicon,

b) Sulphur. In terms of s, p, d of f

11. a) silicon:

b) sulphur:



ents are shown in the bar chart

a) Define first ionization energy.

b) The general trend across the period is for first ionization energy to increase. Explain why that is.

c) There is a break in this trend between magnesium and aluminium. Explain why the first ionization energy of aluminium is less than that of magnesium.

d) There is also a break in the trend between phosphorus and sulphur. Explain why the first Ionization energy of sulphur is less than that of phosphorus.

5. (a) The first ionization energy is the energy required to remove the most loosely held electron from one mole of gaseous atoms to produce 1 mole of gaseous ions each with a charge of 1+.

b) The electrons being removed are all in 3-level orbitals, and at much the same distance from the nucleus. They are all screened by the same inner 1- and 2-level electrons. As you go from one element to the next, the nucleus gains an extra proton each time, and so the attraction from the nucleus increases, making it harder to remove one of the outer electrons. (If you have also mentioned the fact that the atomic radius tends to decrease across the period, make sure that you just quote that as an extra, not as the main reason.)

c) Magnesium is $1s^2 2s^2 2p^6 3s^2$; aluminium is $1s^2 2s^2 2p^6 3s^2 3p^1$ The extra electron has gone into a 3porbital which is slightly more distant from the nucleus than a 3s orbital, and screened from it by the 3s electrons. This extra distance and screening offsets the effect of the extra proton, and the electron becomes a bit easier to remove.

d) Phosphorus is : $1s^2 2s^2\ 2p^6 3s^2\ 3p^3$

Sulphur is : $1s^2 2s^2 2p^6 3s^2\ 3p^4$

The extra electron in sulphur has gone into a 3p orbital which already has an electron in it. This produces repulsion. Given the fact that the screening is the same in both cases, that more than offsets the effect of the extra proton, and the electron in sulphur is slightly easier to remove.

6. Excepting argon, the atomic radii of the Period 3 elements fall as you go across the period.

a) Why is it necessary to calculate the atomic radius by taking the half-distance between the two nuclui, except argon?

b) Explain why the atomic radii fall across the period.

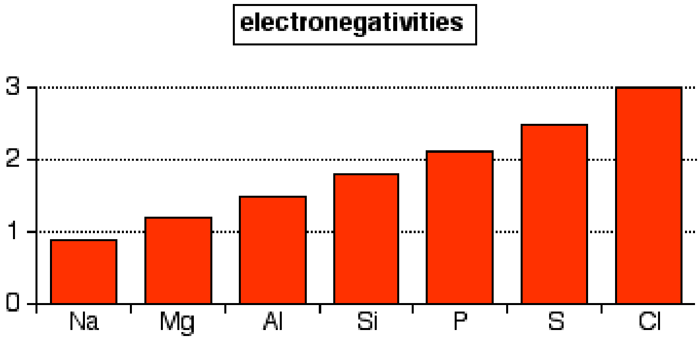
6. a) For all the elements other than argon, the atomic radius is measured in cases where the atom is bonded to its neighbours - either by metallic bonding in the case of sodium, magnesium and aluminium, or by covalent bonds in the elements from silicon to chlorine. In each case, the atom in the bond is being pulled towards its neighbour, and that reduces the measured radius which is calculated as half the distance between the two bonded atoms. The atomic radius for argon is measured as a van der Waals radius where the argon atoms are touching each other, but not pulled towards each other by strong forces. You can't include argon in the pattern because you aren't comparing like with like.

b) From sodium to chlorine, the bonding electrons are all in the 3-level, being screened by the electrons in the first and second levels. The amount of screening is constant for all of these elements.

The increasing number of protons in the nucleus as you go across the period pulls the

the measured radius.

e Period 3 elements on the



a) Define electronegativity and explain why the chart doesn't include argon.

b) Why does electronegativity increase across the period?

7. a) Electronegativity is a measure of the tendency of an atom to attract a bonding pair of electrons.

b) As you go across the period, the bonding electrons are always in the 3-level. They are always being screened by the same inner electrons. All that differs is the number of protons in the nucleus.

As you go from sodium to chlorine, the number of protons steadily increases and so attracts the bonding pair more closely.

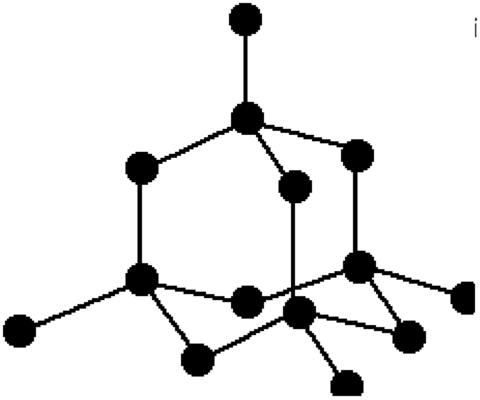
8. This question is about the way the structure of the elements changes across the period.

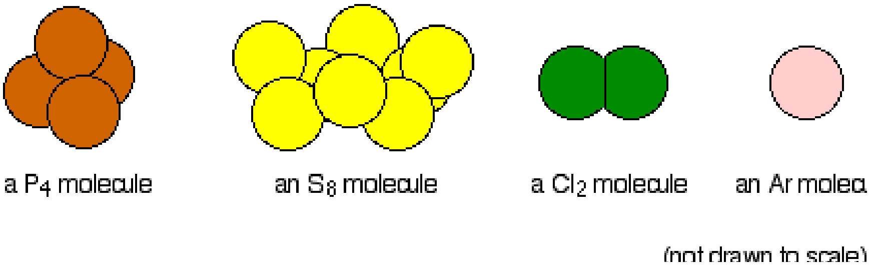
a) Types of structure include ionic, giant covalent, metallic and molecular. Assign each of the elements to one of these structure types.

b) Draw diagrams to show how the atoms are arranged in the basic structures which make up silicon, white phosphorus, crystalline sulphur, chlorine and argon.

8. a) Metallic: sodium, magnesium, aluminium

Giant covalent: silicone, argon

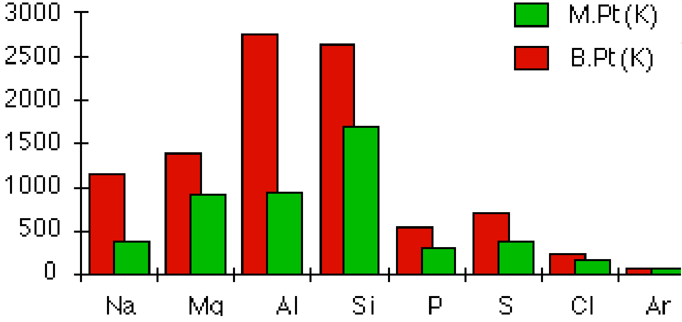




9. Briefly, how does the pattern of electrical conductivity of the elements vary as you go across the period?

Sodium, magnesium and aluminium are all metals and good conductors of electricity. Conductivity increases as you go from sodium to aluminium.

Silicon is a semi-conductor. The rest don't conduct electricity.



hown in the following

a) Why do the boiling points of the elements from sodium to aluminium increase across the period?

b) Explain why silicon has a high melting point.

c) Explain the pattern in melting points of the elements from phosphorus to argon. The phosphorus melting point given is for white phosphorus, and the sulphur one for crystalline sulphur.

10. a) The strength of the metallic bond increases from sodium to aluminium. There are more electrons available to delocalize (go into the "sea of electrons"), and more protons in the nuclei. There is therefore more attraction between the delocalized electrons and the nuclei. The atoms also get smaller as you go from sodium to aluminium, and so the delocalized electrons are closer to the nuclei as well.

b) It has a giant covalent structure with strong Si-Si bonds.

c) The molecules of these elements are attracted to each other by van der Waals intermolecular attractions. These depend on the number of electrons in the molecules and their shapes, but will always be weaker than the metallic or covalent bonds holding the previous elements together. Phosphorus has P4 molecules whereas sulphur is S8. Sulphur therefore has a bigger molecule with more electrons and therefore stronger van der Waals forces and a higher melting point. Chlorine is Cl2 - a smaller molecule with fewer electrons and therefore weaker intermolecular forces and a lower melting point than sulphur. Argon exists as single atoms and so has the least number of electrons, the weakest intermolecular forces and the lowest melting point.

14.8.2. Consolidation activity

Short answer questions

1. Magnesium oxide, silicon dioxide and phosphorus (V) oxide are white solids but each oxide has a different type of structure and bonding.

(a)State the type of bonding in magnesium oxide.

(a)ionic bonding

(b)Outline a simple experiment to demonstrate that magnesium oxide has this type of bonding.

Electrodes: Carbon rods (Graphite)
Electrolyte: Molten Magnesium Oxide
Ions present in electrolyte: Magnesium ions (Mg^{2+}), Oxygen ions (O^{2-}).
Overall Reaction
every two moles of magnesium oxide produce two moles of magnesium metal and one mole of oxygen gas.
$2MgO\ (l) \xrightarrow{\qquad} 2Mg\ (s) + O_2\ (g)$
Reaction at the Cathode
Mg^{2+}, Mg^{2+} ions are attracted to the cathode.
Each Mg^{2+} ion gains two electrons from the cathode to form one magnesium atom.
$Mg^{2+}(l) + 2e \xrightarrow{\qquad} Mg(s)$
Reaction at the Anode
O^{2-} ions are attracted to the anode.
Each O^{2-}– ion loses two electrons to the anode to form one oxygen atom.
$2O^{2-}\ (l) \xrightarrow{\qquad} O_2\ (g) + 4e^-$
Conclusion: production of bubbles of colorless at the anode indicate that MgO

contains ions.

(c) By reference to the structure of, and the bonding in, silicon dioxide, suggest why it is insoluble in water.

Covalent bonds with almost the same electronegativity difference and tends to be non polar.

(d) State how the melting point of phosphorus (V) oxide compares with that of silicon dioxide. Explain your answer in terms of the structure of, and the bonding in, phosphorus (V) oxide.

Silicon exists as a giant covalent molecule and phosphorus (V) oxide as simple molecule only with weak van der Waals that need less energy to break.

(d) Magnesium oxide is classified as a basic oxide.

Write an equation for a reaction that shows magnesium oxide acting as a base with another reagent.

$MgO(s) + HCl(aq) \longrightarrow MgCl_2(aq) + H_2O(l)$

(e) Phosphorus (V) oxide is classified as an acidic oxide.

Write an equation for its reaction with sodium hydroxide.

$12NaOH(aq)+P4O_{10}(s) \longrightarrow 4Na_3PO_4(aq)+6H_2O(l)$

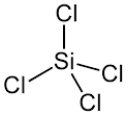
2. Sodium chloride is a high melting point solid which dissolves in water to make a colorless solution. Silicon (IV) chloride is a liquid at room temperature which fumes in moist air, and reacts violently with water.

(a) Explain why the arrangement of particles in solid sodium chloride leads to a high melting point.

Sodium chloride has a high melting and boiling point. There are strong electrostatic attractions between the positive and negative ions, and it takes a lot of heat energy to overcome them.

c) Draw a simple diagram to show the structure of silicon (IV) chloride, and explain why silicon (IV) chloride is a liquid at room temperature.

Silicon (IV) chloride structure:



Silicon tetrachloride is a colorless liquid at room temperature which fumes in moist air. The only attractions between the molecules are van der Waals dispersion forces.

d) Why is there such a big difference between the chlorides of sodium and silicon?

Sodium chloride: giant ionic structure and exists a solid at room temperature

Silicon chloride: simple molecular structure and exists as a liquid at room temperature.

e) Briefly describe and explain the difference in electrical conductivity between sodium chloride and silicon (IV) chloride.

Both in solid state they do not conduct electric current. However, in molten state sodium chloride conducts since it forms whereas silicon (IV) does not in molten state since it does not form ions.

f) Write an equation to show what happens when silicon (IV) chloride reacts with water.

Refer to student's book page For reaction of silicon (IV) chloride reacts with water.

Multiple choice questions

1. Greater difference in electronegativity of Oxygen and Period 3 elements, highly likely is formation of

   A. Ionic bonds

   B. Covalent bonds

   C. Dative Covalent Bonds

   D. Metallic bonds

2. Potassium oxide is a/an

   A. acidic oxide

   B. basic oxide

   C. amphoteric oxide

   D. neutral oxide

3. Which is the most soluble in water?

A	$Mg(OH)_2$
B	$Ca(OH)_2$
C	$Sr(OH)_2$
D	$Ba(OH)_2$

4. Which of given metals of Period 3 use outer shell electrons in bonding with Chlorine?

A. Sodium (Na)
B. Aluminum (Al)
C. Silicon (Si)
D. All of Above

5. On hydration, [Al(H2O)6]3+ (aq) produces

A.H^+ and $[Al(H_2O)_5]^{2+}$(aq)

B. H_2(g) and $[Al(H_2O)_4]^{2+}$(aq)

C. H_2(g) and [Al(H_2O)3]$^+$(aq)

D. All of Above

6. Solution is turned acidic upon hydration of $AlCl^{3+}$, because

A. Al^{+3} ions are formed

B. Cl^- are formed

C. H^+ ions are formed

D. All of Above

7.What causes the largest changes in melting point across period 2 elements?

A	change in bonding structure
B	greater electronegativity
C	greater number of electrons
D	increase in nuclear charge

8.What causes the trend in first ionization energy from left to right across the periodic table?

A	greater number of electrons
B	greater shielding
C	increased nuclear charge
D	larger atomic radii

9.Which test will identify Na2SO4?

A	Reaction with acid causing effervescence.	These tests for carbonates.
B	Reaction with $BaCl_2$ forming a white precipitate.	This is the test for sulphates.
C	Reaction with silver nitrate forming a precipitate.	This is the test for halides.
D	Reaction with sodium hydroxide forming a characteristic gas which turns blue litmus red.	This is the test for ammonium cations.

10.What causes the largest changes in melting point across period 2 elements?

A	change in bonding structure	The jump in melting point between giant and simple covalent compounds is huge.
B	greater electronegativity	Electronegativity does not have an effect on the melting point of elements.

C	greater number of electrons	This will affect the melting point down a group (e.g. group 17) when there are no other factors.
D	increase in nuclear charge	This has little effect on intermolecular forces and melting points.

11.What causes the trend in first ionization energy from left to right across the periodic table?

A	greater number of electrons	Number of electrons simply increases with number of protons.
B	greater shielding	Number of electron shells is constant across a period.
C	increased nuclear charge	More protons mean greater attraction to the nucleus.
D	larger atomic radii	Radii decrease as nuclear charge has greater effect on outer electrons.

Answers to multiple choice questions:

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

14.8.3. Extended activities

1. Aluminium chloride changes its structure on heating. At room temperature the aluminium is 6-coordinated – each aluminium is surrounded by 6 chlorines. The structure is essentially ionic although with a high degree of covalent character. At about 180°C, its structure changes and the aluminium become 4-coordinated.

a) Write the structure of in vapor phase at 180°C

e) If you only add a small amount of formula, and draw the electronic structure of the form of aluminium chloride at 180°C.

b) What effect does this change have on the physical properties of the aluminium chloride? Explain your answer.

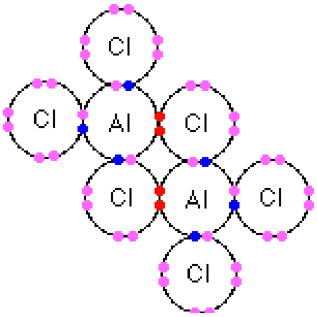
c) The structure changes again at higher temperatures. Write an equation to show that change.

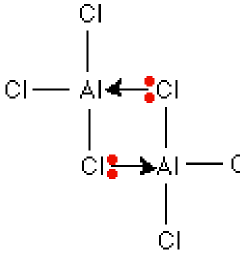
d) The reaction of aluminium chloride with an excess of water could be written as

$AlCl_3(s)+6H_2O(l) \longrightarrow [Al(H_2O)_6]^{3+}(aq)^{+3}Cl^{-}(aq)$

(e)The solution formed is acidic. Explain why that is? When Water added to some solid aluminium chloride, you get a vigorous reaction with some steamy fumes given off. Explain what is happening.

1. a) Al_2Cl_6





b) Because this is a covalent molecule, it only has relatively weak van der Waals forces to hold it to its neighbors instead of ionic bonds. This causes it to sublime once it has taken up this structure.

c) $Al_2Cl_6 \rightleftharpoons 2AlCl_3$

d) The highly positive aluminium ion at the centre of the complex with the water molecules pulls electrons from the water strongly towards the aluminium. The net effect is to make the hydrogens in the water molecules fairly positive. These can react with water molecules in the solution to give hydroxonium ions, and therefore an acidic solution.

$[Al(H_2O)_6]^{3+}(aq) + H_2O(l) \rightleftharpoons [Al(H_2O)_5(OH)]^{2+} + H_3O^+(aq)$

or, more simply:

$[Al(H_2O)_6]^{3+}(aq) \rightleftharpoons [Al(H_2O)_5(OH)]^{2+}(aq) + H^+(aq)$

e) The reaction is strongly exothermic. The hydrogen ions (hydroxonium ions) produced as above and the chloride ions already present (from the reaction of the aluminium chloride with the water) will form a solution containing hydrochloric acid. If there is only a small amount of water present, the heat released will boil off steamy fumes of hydrogen chloride.

2. Phosphorus (V) chloride is a white solid which sublimes at 163°C.

a) In the solid, the compound contains ions. Write the formulae for the ions it contains.

b) At the sublimation point, the structure is simple covalent PCl5 molecules, but these go through a further change as temperature increases. Write the equation for that change.

c) In the reactions of the covalent Period 3 chlorides with water, there is one observation that is common to all of them. What is it?

d) Write the equation for the reaction of phosphorus (III) chloride and water

2. a) $[PCl_4]^+$ $[PCl_6]^-$

b) $PCl_5 \rightleftharpoons PCl_3 + Cl_2$

c) You get steamy fumes of hydrogen chloride.

d) $PCl_5+4H_2O \longrightarrow POCl_3+2HCl$ (in cold conditions)

$POCl_3+3H_2O \longrightarrow H_3PO_4+3HCl$ (hot conditions)

Or Generally $PCl_3+3H_2O \longrightarrow H_3PO_3+3HCl$

3. Answer the following questions by considering only the highest oxides of the Period 3 elements:

Na_2O MgO Al_2O_3 SiO_2 P_4O_{10} SO_3 Cl_2O_7

(a)(i) Which is the most basic oxide?

(ii) What is it about this oxide which makes it basic?

(iii) Write an equation to show its reaction with dilute hydrochloric acid.

(iv)Write an equation to show its reaction with water.

(b)(i) Which is the next most basic oxide?

(ii) Why is it less basic than the one you have described in part (a)?

c) (i) Name an amphoteric oxide.

(ii) Explain what the term Amphoteric means. Your answer should include one or more equations as necessary, relating to the reactions of the oxide you have named.

d) The acidic oxides are often thought of in terms of in terms of the strengths of the acids formed when they react with water.

(i) Write the equations for the reactions of SO_3 and P_4O_{10} with water.

(ii) Which of the two acids that you have produced in part (i) is the stronger? Draw the structures for the two acids, and use these to help to explain why that acid is stronger.

(iii) SO3 can also act as an acid in its own right by reacting with a base. Write an equation to show it reacting with a base.

3.(a)(i) Na2O

(ii) The presence of the very basic oxide ions, O^{2-}

(iii) $Na_2O + HCl \longrightarrow NaCl + H_2O(l)$

(iv) $Na_2O + H_2O \longrightarrow NaOH(aq)$

b)

(i) MgO

(ii) There are much stronger attractions between 2+ and 2- ions than between 1+ and 2- ions.

The oxide ions aren’t so free to react with acids as they are in sodium oxide.

c) (i) Aluminium oxide

(ii) Amphoteric means that it reacts as both a base and an acid. That means that it will react with an acid or with a base.

Reacting as a base (reacting with an acid)

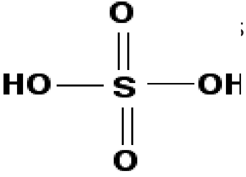
$Al_2O_3(s)+6HCl(aq) \longrightarrow 2AlCl_3(aq)+3H_2O(l)$

Reacting as an acid (reacting with a base):

$Al_2O_3(s)+2NaOH(aq)+3H_2O(l) \longrightarrow 2NaAl(OH)_4(aq)$

(If you have been taught a different version of this equation producing either $NaAlO_2$ or

e that o ke sure that it balances properly.)



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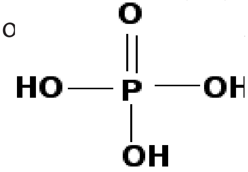


When either acid loses a hydrogen ion from one of the OH groups, it leaves a negative charge on the oxygen. This can be delocalized over the rest of the structure by interaction with the electrons in the C=O double bond(s). There are two such bonds in the ion from the sulphuric acid, but only one with the phosphoric (V) acid. The more the delocalization, the more stable the ion, and the more likely it is to form, and remain as an ion rather than reacting with a hydrogen ion again.

(iii) $CaO + SO_3 \longrightarrow CaSO_4$ but you could equally well give an equation with MgO (just like the one above) or with Na2O to produce Na2SO4 - or something similar.

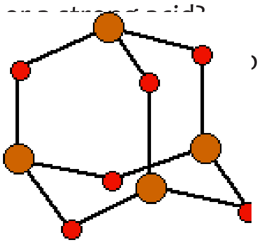
4. Choose one of the oxides P_4O_6 or Cl_2O.

a) Draw its structure.

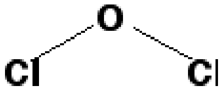
b) Write an equation to show its reaction with water, and draw the structure of the product.

c) Is the product of that reaction a strong base, a weak base, amphoteric, a weak acid

owing:



a P4O6 molecule

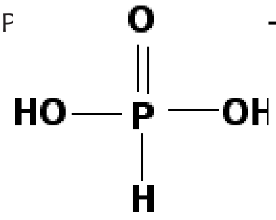


The small red ones are oxygen and the larger orange-brown ones are phosphorus.

b) One of the following:

$P_4O_6(s)+6H_2O(l) \longrightarrow 4H_3PO_3(aq)$

P $\longrightarrow 4H_3PO_3(aq)$



$Cl_2O(s)+H_2O(l) \rightleftharpoons 2HOCl(aq)$

c) Which ever you choose, they are all weak acids.

UNIT 15: FACTORS THAT AFFECT CHEMICAL EQUILIBRIUM

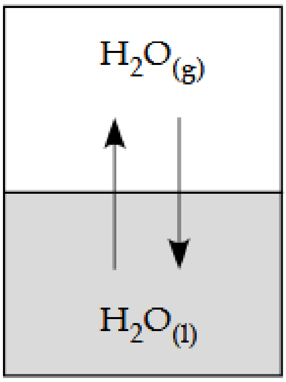
15

15.1. Key unit competence

Deduce how concentration, pressure, catalyst and temperature affect the chemical processes in industry.

15.2. Prerequisite knowledge and skills

As a teacher you need to a simple example boiling water, water (H_2O (l)) is in equilibrium with its vapor (H_2O (g)). The rate of evaporation is equal to the rate of condensation in a closed container at a constant temperature. At the particulate level, for every one molecule of water (H_2O (l)) that evaporates, another water vapor molecule (H_2O (g)) condenses to the liquid state. This is an example of a reversible reaction for a physical equilibrium. At least many of your students could have boiled water. This example is used to conceptualize reversible.



In addition to the above, learners need to remember the concept of limiting reactants studied in ordinary level and moles.

15.3. Cross-cutting issues to be addressed

Gender studies:

People fighting for gender equality are feminists. Actuality, gender equality concerns every single person in society, both males and females. People who fight for gender equality have to fight to females, who have been oppressed in the male-dominated-and-favoured society that we live in and who is at a disadvantage due to this particular perception. It isn’t that people favour women over men, it simply is that women deserve the same opportunities that men receive and the same respect that men receive.

Advocates of gender equality aren’t fighting for women to get better treatment; they just want them to be regarded with respect as men. This brings balance/equilibrium in the society or families and foster peace.

15.4. Guidance on introductory activity

Before introducing the first lesson of this unit learners should look at the diagram in the introductory activity and attempt the questions in groups.Let learners attempt activity 15.1. The introductory and learning activities are intended to:

- Relate the unit with learners’ daily life to capture their attention.
- Assess learners’ understanding of the concept of reversible and irreversible reactions or reactions that undergo completion.

15.5. List of lessons:

Heading	Lessontitle	objectives	No of periods
15.1 Complete versus reversible reactions	15.1 Complete versus reversible reactions	Distinguish between complete and reversible reactions.	1
15.2 Concept and characteristics of a dynamic equilibrium	15.2 Concept and characteristics of a dynamic equilibrium	Explain dynamic equilibrium. State the characteristics of dynamic equilibrium.	2
15.3. Factors that affect the reactions in equilibrium and Le Châtelier's principle	15.3.1. Effect of Temperature on equilibrium 15.3.2. Effect of pressure on the equilibrium 15.3.3. The effect of change in concentration on equilibrium 15.3.4. The effect of a catalyst	. Explain the factors that affect the position of the equilibrium in a reversible reaction. . Apply Le Châtelier's principle to explain the effects of changes in the temperature, concentration and pressure on a system in equilibrium. . Compare and contrast theoretical and actual optimal conditions in the industrial processes. . Relate the effect of concentration, temperature, pressure and catalyst to the amount of products in the manufacturing industries. . Recognize the importance of Le Châtelier's principle in Haber and Contact processes.	5
End of unit assessment			2

Lesson 1: Difference between complete and incomplete reactions (reversible versus irreversible reactions)

This is the first lesson of unit 15 and is a single lesson. The first lesson also covers the introduction of the whole unit.

a) Prerequisites/Revision/Introduction:

Students will learn better the concept of reactions that undergo completion and those

b) Teaching resources:

-Use the illustrations in the learners'book or draw them on a Manila paper or a black board may be enough.

c) Learning activities:

Provide the exercise 15.1 from a student book or you can write it on a black board or on pieces of paper.

Ask the learners to do activity 15.1 individually in their exercise books.

Allow some learners to present their answers on the black/white board

Learners compare the equations written on the black/white board and make conclusion.

d) Checking up 15.1

1.(a)$HCl + NaOH \longrightarrow NaCl + H_2O$ (irreversible)

(b) $BaCl_2 + 2\ AgNO_3 \longrightarrow 2\ AgCl + Ba(NO_3)_2$(irreversible)

(c)$CaCO_3 + 2\ HCl \longrightarrow CaCl_2 + H2CO_3$ (irreversible)

(d)$4NH_3(g) + 5O2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$ (reversible)

(e)$2SO_3(g) \rightleftharpoons 2SO_2(g) + O2(g)$(reversible)

(f)$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$(reversible)

(g)$2H2O(g) + 2SO_2(g) \rightleftharpoons 2H2S(g) + 3O_2(g)$ (reversible)

Lesson 2: Concept of equilibrium (dynamic equilibrium) and their Characteristics

a) Prerequisites/Revision/Introduction:

The same as for the unit.

b) Teaching resources:

Ropes.

c) Learning activities

- Provide the ropes and ask learners to go out of the classroom
- Divide learners into two groups(you can create many other groups if learners are many)

- Note that the number of learners should be equal to create the equilibrium.
- Provide the instructions about the tug-of-war game.
- Provide learners with activity 15.2 and allow them to do activity.
- Select the learners to read the answers to the whole class when the corrections are made.
- Ask learners to comment and relate the game with the lesson about concept of equilibrium
- Answers for the activity 15.2 refer to students' book

d) Answers to checking up 15.2

1 -The rate of the forward reaction is equal to the rate of the reverse reaction

-Microscopic processes (the forward and reverse reaction) continue in a balance which yields no macroscopic changes (nothing appears to be happening.)

-The system is closed and the temperature is constant and uniform throughout.

-The equilibrium can be approached from the left (starting with reactants) or from the right (starting with products)

2.Homogeneous reaction have reactants and products in the same phase. For example:

(i) $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

(ii) $4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$

While in heterogeneous, the reactants and products are in different phases. For example:

(i) $S(s) + H_2SO_3(aq) \rightleftharpoons H_2S2O_3(aq)$

(ii) $2ZnS(s) + 3O_2(g) \rightleftharpoons 2ZnO(s) + 2SO_2(g)$

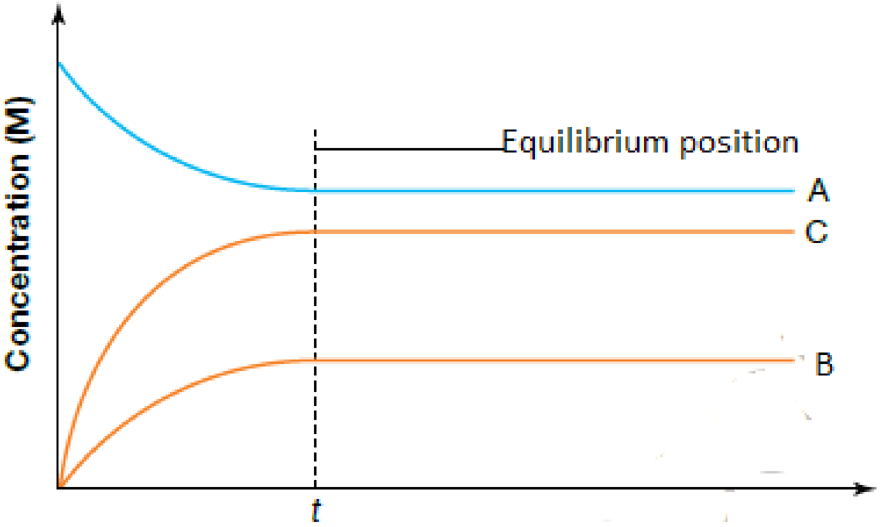
3.A dynamic equilibrium is a process where the forward and reverse reactions proceed at the same rate and after a period of time, the concentrations of reactants and products remain constant (do not change).

Example: $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

4. When a chemical reaction takes place in a container which prevents the entry or escape of any of the substances involved in the reaction, the quantities of these components change as some are consumed and others are formed. The system is then said to be in its equilibrium state.

5. For $A \rightleftharpoons C + B$

During a reversible reaction towards the equilibrium concentration of reactants decrease while that of products increase. When the equilibrium is attained, the concentration of reactants is equal that of products.



Lesson 3: Effect of Temperature on equilibrium

a)Prerequisites/Revision/Introduction:

For learners to understand the effect of temperature on equilibrium, they should be able to explain Le Châtelier's principle and its relationship with the concept of equilibrium.

b) Teaching resources

Manila papers or black or white board.

c) Learning activities

- Provide activity 15.3(a) and 15.3 (b) on a manila paper and allow the learners to do activity in groups of 3 or 4.
- Select some two or three groups to present their answers on a board and correct some wrong and misconceptions provided.
- Ask the learners to do the checking up 15.3.1

d) Answers to Checking up 15.3.1

$2SO_2(g) + O_2(g) \rightleftharpoons 2\,SO_3(g)$; $\Delta Ho = -180$ kJ (low temperature)

$CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g)$; $\Delta Ho = -46$ kJ (low temperature)

$CO(g) + Cl_2(g) \rightleftharpoons COCl_2(g)$; $\Delta Ho = -108$ kJ (low temperature)

$N_2O_4(g) \rightleftharpoons 2\,NO_2(g)$; $\Delta Ho = +57$ kJ (high temperature)

Lesson 3: The effect of change in concentration on equilibrium

a)Prerequisites/Revision/Introduction:

Explain the effect of temperature on equilibrium in relation to Le Châtelier's principle.

b) Teaching resources

Refer to learner's book experiment 15.3.2

Manila papers

c) Learning activities

- Provide the written procedure on a manila paper if the learners are not enough.
- Allow the learners to the experiment in groups of 3 or 4
- Provide study questions and ask learners to answer them.
- Correct the study questions in their groups and ask learners to summarize the effect of concentration on equilibrium.
- Ask the learners to do the checking up 15.3.2

Answers to checking up 15.3.2

(1)Le Châtelier's Principle, when the temperature, pressure or concentration of a reaction in equilibrium is changed, the reaction shifts in the direction where the effect of these changes is reduced.

2. Concentration, temperature, pressure and catalyst.

3. Increasing the concentration of any one of the reactants shifts the equilibrium to right to reduce the concentration. On the other hand removing any one of the reactants or reducing the concentration of the reactants will shift the equilibrium to left to replace the removed species and maintain the equilibrium.

4.If H_2 is added, there is now more reactant, so the reaction will shift toward products to reduce the added H_2.

If NH_3 is added, there is now more products, so the reaction will shift toward reactants to reduce the added NH_3.

If NH_3 is removed, there is now fewer products, so the reaction will shift toward products to replace the product removed.

Lesson 4: Effect of pressure

a)Prerequisites/Revision/Introduction:

Learners should explain how concentration affects the position of equilibrium by either adding a reactant or removing the product.

b) Teaching resources

Manila papers, black or white board.

c) Learning activities

- Provide activity 15.3.3 and allow doing it in groups of 3 or 4 depending on the size of your class.
- Select some groups to present their answers as you make corrections

together in class.

- Provide the checking up activity 15.3.3

Answers to checking up 15.3.3

$2SO_2(g) + O_2(g) \rightleftharpoons 2\ SO_3(g)$ (high pressures)
$PCl_5(g) \rightleftharpoons PCl3(g) + Cl_2(g)$ (low pressures)
$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$(high pressures)
$N_2O_4(g) \rightleftharpoons 2\ NO_2(g)$(low pressures)
5.$H_2(g) + F_2(g) \rightleftharpoons 2\ HF(g)$(no effect)

6. (a) According to Le Châtelier's principle, if the pressure is increased, the equilibrium shifts to the side with the fewer number of moles of gas. This particular reaction shows a total of 4 mol of gas as reactants and 2 mol of gas as products, so the reaction shifts toward the products side.

(b) Reaction shifts towards the reactants.

Lesson 5: Effect of catalyst

a)Prerequisites/Revision/Introduction:

Explain the effect of temperature, concentration, and pressure on equilibrium position in relation to Le Châtelier's principle.

b) Teaching resources

Manila papers or black/white board.

c) Learning activities

Provide activity 15.3.4 to the learners and allow them to do the activity individually.

Select some learners to present and explain the concept of a catalyst on equilibrium reactions.

Provide them with checking up 15.3.4 to find out their understanding level.

Answers to checking up 15.3.4

1. The position of the equilibrium always move forward to increase the yield of SO_3.

2. Increase in temperature would reduce the production of SO_3 whereas the increase in pressure would increase the production of SO_3

3. No effect on the production of SO_3

4. To favour the formation of the product since the equilibrium will always move forward.

5. Higher temperature (more than 450°C) would reduce the production by shifting the equilibrium to the left. However, the temperature lowers than 450°C would slow the reaction.

Higher pressures would be increase the yield as it favours the forward reaction. since the foward reaction proceeds by reduction in moles/ volume. However, it is very expensive to maintain.

7. It is very expensive

8. Refer to answers above from 5-7

15.6. Unit summary

The factors that affect the equilibrium state of a reaction:

1. Temperature
2. Pressure
3. Concentration of reactants and products
4. Catalyst

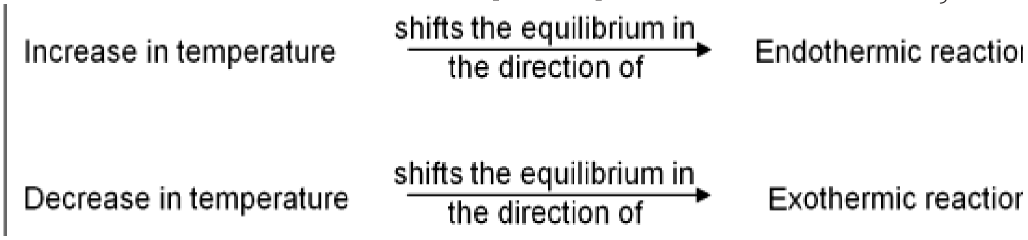
The effect of these factors on chemical equilibrium can be understood with the help of **Le Châtelier's principle.**

The statement of Le Châtelier's principle: When the temperature, pressure or concentration of a reaction in equilibrium is changed, the reaction shifts in the direction where the effect of these changes is reduced.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

Effect of change in temperature: For exothermic reactions and Endothermic reactions.

Consider a reversible in Haber process; $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

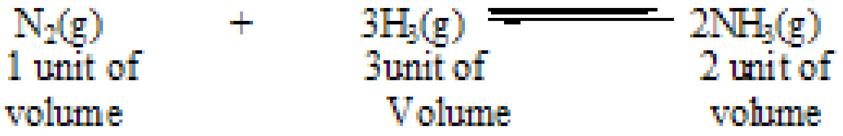


Increase in temperature $\xrightarrow[\text{the direction of}]{\text{shifts the equilibrium in}}$ Endothermic reactio

Decrease in temperature $\xrightarrow[\text{the direction of}]{\text{shifts the equilibrium in}}$ Exothermic reactior

Effect of pressure

According to Le Châtelier's principle, an increase in pressure will favor the reaction in the direction where the volume of reactants is reduced and the decrease in pressure will favor the reaction in thedirection where the volume of reactants is increased.



$$\underset{\text{1 unit of volume}}{N_2(g)} + \underset{\text{3unit of Volume}}{3H_2(g)} \rightleftharpoons \underset{\text{2 unit of volume}}{2NH_3(g)}$$

In this reaction the volume of reactants is 4 units while the volume of products is 2 units. So according to Le Châtelier's principle, an increase in pressure of this reaction will favour the forward reaction to form more ammonia while a decrease in pressure of the reaction will favour the backward reaction to form more nitrogen and hydrogen. Thus,

Increase in pressure $\xrightarrow[\text{the direction of}]{\text{shifts the equilibrium in}}$ decreased volume

Decrease in pressure $\xrightarrow[\text{the direction of}]{\text{shifts the equilibrium in}}$ increased volume

Effect of change in concentration

1. Effect of change in concentration of reactants: consider the reversible reaction:

$N2\ (g) + 3H_2\ (g) \rightleftharpoons 2NH_3\ (g)$

2. Effect of change in concentration of products

Increase in concentration of reactants $\xrightarrow[\text{the direction of}]{\text{shifts the equilibrium in}}$ forward direction

Increase in concentration of products $\xrightarrow[\text{the direction of}]{\text{shifts the equilibrium in}}$ backward direction

Effect of catalyst

A catalyst has no effect on equilibrium state of a reaction. It is added into the reaction mixture only to achieve the equilibrium state quickly because the addition of a catalyst increases the rate of both the forward and backward reactions equally.

15.7. End unit assessment answers

1. The answers to question (a) and (b) are the same. If we add eitherN2 or H2, we increase the collisions between N2 and H2, thereby forming more product NH3. This is how the equilibrium counteracts the applied stress; we say the equilibrium shifts from left to right.

(c) If we add more NH3, we increase the concentration of NH3. As a result, some NH3 decomposes and forms more reactants. We say the equilibrium shifts from right to left.

(d) and (e). The answers to question (d) and (e) are the same. If we remove either N2 or H2, now there is less concentration of N2 and H2. To offset the applied stress, the equilibrium shifts from right to left.

(f) If we remove some NH3, the equilibrium shifts from left to right to counteract the applied stress.

2. When the concentration of CO2 (g) increases, the system responds by reducing the

change.

The position of equilibrium of the first system will shift to the right.

The concentration of CO2 (aq) will increase.

When the concentration of CO2 (aq) increases, the position of equilibrium of the second system will shift to the right. The concentration of hydrogen ions will increase.

Thus, the pH of the water at the ocean surface will decrease.

(c) Slight cooling of the water saturated with carbon dioxide can reduce the solubility of carbon dioxide.

Some carbon dioxide bubbles out of the solution and the concentration of carbon dioxide decreases.

The system responds by reducing the change.

The position of equilibrium of the system represented by equation (3) shifts to the left, resulting in the precipitation of calcium carbonate.

3. An increase in pressure will bring about a net reaction that decreases the number of moles of gas. This helps to reduce the pressure.

A net backward reaction will occur. Thus, the yield of hydrogen will decrease.

OR

A decrease in pressure will bring about a net reaction that increases the number of moles of gas. This helps to increase the pressure.

A net forward reaction will occur. Thus, the yield of hydrogen will increase.

- When the temperature is increased, the system will respond by reducing the temperature.

As the production of hydrogen is endothermic, the system will undergo a net forward reaction. Thus, the yield of hydrogen will increase.

OR

When the temperature is decreased, the system will respond by raising the temperature.

As the production of hydrogen is endothermic, the system will undergo a net backward reaction. Thus, the yield of hydrogen will decrease.

- The yield of hydrogen is not affected by a catalyst.

A catalyst increases the rates of both the forward reaction and the backward reaction to the same extent.

4. (a)Le Châtelier's principle states that if the conditions of a system in equilibrium is changed, the position of equilibrium will shift so as to reduce that change.

(b)Decreasing the pH of the chlorinated water means increasing the concentration of hydrogen ions.

The system will respond by reducing this change.

The position of equilibrium will shift to the left.

More hypochlorous acid will form.

OR Increasing the pH of the chlorinated water means decreasing the concentration of hydrogen ions.

The system will respond by reducing this change.

The position of equilibrium will shift to the right.

More hypochlorite ions will form.

(d)When sodium hydroxide solution is added, the hydroxide ions react with the hydrogen ions to form water. Thus, the concentration of hydrogen ions decreases.

The system responds by reducing this change. A net backward reaction occurs to produce more hydrogen ions. Thus, the concentration of chlorine will decrease.

(5)(a) Case A

An increase in pressure will bring about a net reaction that decreases the number of moles of gas. This helps to reduce the pressure.

A net forward reaction occurs.

Thus, a high pressure will increase the yield of SO3(g).

When the temperature is decreased, the system will respond by raising the temperature.

As the forward reaction is exothermic, the system will undergo a net forward reaction.

Thus, a low temperature will increase the yield of $SO_3(g)$.

(b)Case D

Air is readily available and cheap.

At lower pressure, the cost of building and running the plant is lower.

At lower temperature, the cost of energy is lower / less fuel is required.

6. (a)- Rate of forward reaction = rate of backward reaction

Concentration of the reactants and product remain constant.

(b)(i)The percentage conversion increases with pressure.

An increase in pressure will bring about a net reaction that decreases the number of moles of gas. This helps to reduce the pressure.

The position of equilibrium will shift to the side of the equation with a fewer number of moles of gas, i.e. shift to the right.

(ii)When the temperature is increased, the percentage conversion decreases.

It can be deduced that when the temperature is increased, the system will undergo a net backward reaction so as to lower the temperature.

Hence the backward reaction should be an endothermic reaction / the forward reaction should be an exothermic reaction.

The sign of the enthalpy change for the forward reaction should be negative.

(c)Using excess steam will shift the position of equilibrium to the right.

(a)(i)An increase in pressure will bring about a net reaction that decreases the number of moles of gas. This helps to reduce the pressure.

A net forward reaction occurs.

Thus, the percentage yield of ammonia increases.

(ii)Too expensive to generate. The cost of building and running the plant is too high.

(b)(i)The yield of ammonia increases.

When the temperature is decreased, the system will respond by raising the temperature.

As the forward reaction is exothermic, the system will undergo a net forward reaction.

(ii)The rate of production of ammonia is higher.

(iii)723 K is a balance between rate and yield.

7.(a) Equilibrium shifts to the left

(b) To the right

(c) (No change on the equilibrium position

(d) To the left

(e) No change on the position of equilibrium

8. (a) Refer to learners book

(b) (i) Equilibrium shift to right to replace sulphurdioxide

(ii) Equilibrium shift to left

(iii) No effect on the position of Equilibrium

(iv) Equilibrium shift to left

(c) Refer to learner's book .

(d) Removing hydrogen from equilibrium will shift the equilibrium to left to replace it thus reducing the concentration of products.

15.8. Additional information

Effect of adding an inert gas in the equilibrium mixture

The effect of adding an inert gas depends on whether it is added at constant pressure or constant volume.

a) Addition inert gas at constant volume

At constant volume, the presence of an inert gas has no effect on the position of equilibrium or value of equilibrium constant, since it does not take part in the reaction.

(b) Addition at constant pressure

The introduction of an inert gas at constant pressure results in dilution effect on the system which reduces the partial pressure of the component. This favors the dissociation. The equilibrium position shifts to the side with large number of molecules.

For instance, $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$

Introducing an inert gas to the system would dilute it and reduce the partial pressure of the components. As a result, PCl5dissociates and the equilibrium shift from left to the right so as to maintain the equilibrium.

15.9. Additional activities

15.9.1. Remedial activities

Multiple choice questions

1. In a reversible reaction, the catalyst:

(a) Decreases activation energy of forward reaction

(b) Increases activation energy of forward reaction

(c) Decreases activation energy of both forward and backward reactions

(d) Increases activation energy of backward reaction

3. The chemical equilibrium of a reversible reaction is not influenced by:

(a) Temperature

(b) Pressure

(c) Catalyst

(d) Concentration

4. The reaction: $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ is in equilibrium. If the equilibrium concentration of PCl3(g) is doubled then concentration would become:

(a) 1/2 of its initial value

(b) 1/4 of its initial value

(c) Four times of its initial value

(d) Two times of its initial value

5. Which of the following reactions will be favored at low pressure?

(a) $N_2 + 3H_2 \rightleftharpoons 2NH_3(g)$

(b) $H_2I_2 \rightleftharpoons 2HI$

(c) $PCl_5 \rightleftharpoons PCl_3 + Cl_2$

(d) $N_2 + O_2 \rightleftharpoons 2NO$

6. For equilibrium reaction:, $2NO_2(g) \rightleftharpoons N_2O_4(g)$14.6J increase in temperature would:

(a) Favour the formation of N2O4

(b)Stop reaction

(c) Favour the decomposition of N_2O_4

(d) Not alter the equilibrium

7. in the reaction: H2 + I2 $\rightleftharpoons$ 2HI at equilibrium, some $I_2$is added. What happens to the equilibrium?

(a) It gets shifted to the right

(b) It remains unchanged

(c) It gets shifted to the left

(d) First (b), then (c)

8. Which of the following changes will shift the reaction in forward direction? $I_2(g) \leftrightharpoons 2I(g)$Take $\Delta H^0 = +150$ Kj

(a) Increase in concentration of I_2

(b) Increase in total volume

(c) Decrease in concentration of I2

(d) Increase in temperature

9. Which of the following equilibria, in gaseous phase, would be unaffected by an increase in pressure?

(a) $N_2 + 3H_2 \rightleftharpoons NH_3$

(b) $N_2 + O_2 \rightleftharpoons 2NO$

(c) $N_2O_4 \rightleftharpoons 2NO$

(d) CO + ½ O2 $\rightleftharpoons$ CO_2

10. A reversible reaction is said to have attained equilibrium, when:

(a) A backward reaction stops

(b) Both backward and forward reactions take place at equal speed

(c) Both backward and forward reactions stop

(d) Concentration of each of the reactants and products becomes equal

11. The equilibrium between water and its vapor, in an Open—vessel:

(a) Can be achieved

(b) Depends upon pressure

(c) Cannot be achieved

(d) Depends upon temperature

12. Chemical equilibrium is dynamic in nature, because:

(a) The equilibrium is maintained rapidly

(b) The concentration of reactants and products is constant but different

(c) The concentration of reactants and products becomes same at equilibrium.

(d) Both forward and backward reactions occur at all times with same speed

13. A liquid is in equilibrium with its vapor at its boiling point. The molecules in these two phases will have equal:

(a) Potential energy

(b) Internal energy

(c) Intermolecular

(d) Kinetic energy

14. Just before attaining equilibrium by a reversible reaction, it is found that:

(a) Velocity of forward reaction decreases but backward reaction increases.

(b) Velocity of both forward and backward reactions decreases.

(c) Velocity of both forward and backward reactions increases.

(d) Velocity of forward reaction increases but that of backward reaction decreases.

15. A characteristic feature of reversible reactions is that they:

(a) Proceed to completion

(b) Never proceed to completion.

(c) Proceed to completion when the concentration of the reactants decreases

(d) Proceed to completion when the concentration of the reactants increases

16. The reaction $PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ is an example of:

(a) Backward

(b) Forward

(c) Irreversible

(d) Reversible

17. Consider the following reaction at equilibrium:

$2NH_3(g) \rightleftharpoons N2(g) + 3H_2(g)\ \Delta H° = +92.4\ kJ$

Le Châtelier's principle predicts that adding N2 to the system at equilibrium will result in

(a)a decrease in the concentration of NH_3

(b)a decrease in the concentration of H_2

(c)an increase in the value of the equilibrium constant

(d)a lower partial pressure of N2

(e)removal of all of the H2

18. Consider the following reaction at equilibrium:

$2CO_2(g) \rightleftharpoons 2CO(g) + O_2(g)\quad \Delta H° = -514\ kJ$

Le Châtelier's principle predicts that adding O_2 (g) to the reaction container will

(a) Increase the partial pressure of CO at equilibrium

(b) Decrease the partial pressure of CO2 at equilibrium

(c)increase the value of the equilibrium constant

(d) Increase the partial pressure of CO_2 at equilibrium.

(e) Decrease the value of the equilibrium constant

19. Consider the following reaction at equilibrium:

$2CO2(g) \rightleftharpoons 2CO(g) + O_2(g)\quad \Delta H° = -514\ kJ$

Le Châtelier's principle predicts that an increase in temperature will

(a) Increase the partial pressure of O_2

(b) Decrease the partial pressure of CO_2

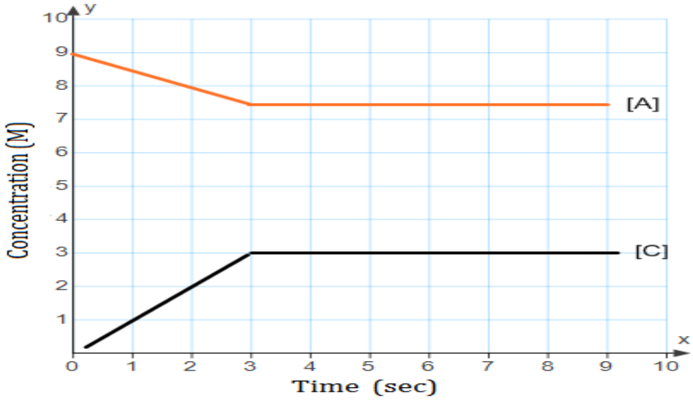
(c)decrease the value of the equilibrium constant

(d) Increase the value of the equilibrium constant

(e) Increase the partial pressure of CO_2

20.Use the following information on the graph to answer question below

$A(g) \rightleftharpoons 2C(g) + D(s)$



At what time does the reaction above reach equilibrium?

(a)Around 2 minutes

(b)Around 3 minutes

(c)Around 5 minutes

(d)Around 8 minutes

(e)Around 10 minutes

21.Of the following equilibria, only __________ will shift to the left in response to a decrease in volume.

(a)$H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)$

(b)$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$

(c)$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

(d)$4Fe(s) + 3O_2(g) \rightleftharpoons 2Fe_2O_3(s)$

(e)$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$

22.The reaction below is exothermic: $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

Le Châtelier's Principle predicts that …….. will result in an increase in the number of moles of SO_3 in the reaction container.

(a) Increasing the pressure

(b) Decreasing the pressure

(c)increasing the temperature

(d) Removing some oxygen

(e) Increasing the volume of the container

23.The effect of a catalyst on equilibrium is to

(a) Increase the rate of the forward reaction only

(b) Increase the equilibrium constant so that products are favored

(c) Slow the reverse reaction only

(d) Increase the rate at which equilibrium is achieved without changing the composition of the equilibrium mixture.

(e) Shift the equilibrium to the right

Answers to the multiple choice questions

1C, 2C , 3D, 4C, 5A, 6A, 7D, 8B, 9B, 10C, 11C, 12D,13D, 14D, 15B, 16D, 17B, 18D, 19E, 20B, 21B, 22A, 23 D.

15.9.2. Consolidation activities

1. In the Haber process, ammonia is synthesized by the exothermic reaction of nitrogen and hydrogen.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

The table shows the percentage yield of ammonia, under different conditions of pressure and temperature, when the reaction has reached equilibrium.

Temperature/ K	600	800	1000
% yield of ammonia at 100 atmospheres	50	10	2
% yield of ammonia at 200 atmospheres	60	16	4
% yield of ammonia at 50000 atmospheres	75	25	7

a) i) Explain why, at a given temperature, the percentage yield of ammonia increases with an increase in pressure.

ii) Give a reason why a high pressure of 500 atmospheres is NOT normally used in the Haber process.

b) Many industrial ammonia plants operate at a compromise temperature of about 723 K.

i) State one advantage, other than cost, of using a temperature lowers than 723 K. Explain your answer.

ii) State the major advantage of using a temperature higher than 723 K.

iii) Hence explain why 723 K is referred to as a compromise temperature.

Answer

(a)(i)According to Le Châtelier's principle, increasing the pressure shifts the equilibrium to the right, increasing the yield of ammonia

(ii) High pressure is very expensive

(b) Very high temperature shifts the equilibrium to the left since the reaction is exothermic however; a lower temperature slows the reaction. Therefore, optimum temperature should be used.

(i) It favours the exothermic direction thus increasing the yield of ammonia.

(ii) It increases the speed of the reaction

(iii) It favours the formation of ammonia at a moderate rate.

2. When bromine is dissolved in water, the following equilibrium system is established

$Br2(l) + H_2O(l) \rightleftharpoons H^+(aq) + Br^-(aq) + HOBr(aq)$

Yellow-brown colorless

In an experiment, dilute sodium hydroxide solution and then dilute hydrochloric acid are added to the system. The observations made listed below

Step	Procedure	observation
I	Adding dilute sodium hydroxide solution	A colorless solution is formed
II	Adding dilute hydrochloric acid to the resulting solution	A yellow brown solution is formed.

Explain the observations made from the table above using Le Châtelier's principle .

Answer

In step I: addition of sodium hydroxide to the equilibrium above removes hydrogen ions and shifts the equilibrium to replace hydrogen ions.

In step II: addition of dilute hydrochloric acid increases the concentration of hydrogen ions thus shifting the equilibrium to the left.

3. Each of the following equilibrium systems is disturbed by increasing the pressure as a result of decreasing the volume of the reaction vessel. Decide whether the number of moles of reaction product(s) will increase, decrease, or remain the same. Explain your answer in each case.

a) $2CO2(g) \rightleftharpoons 2CO(g) + O2(g)$ (**no change**)

b) $CO(g) + H2O(g) \rightleftharpoons CO2(g) + H2(g)$ (**no change**)

c) $Si(s) + 2Cl2(g) \rightleftharpoons SiCl4(g)$ (**decrease**)

4. Does the number of moles of reaction products increase, decrease, or remain the same when each of the following equilibria is subjected to a decrease in pressure by increasing the volume?

(a) $CaO(s) + CO2(g) \rightleftharpoons CaCO3(s)$ (**no change**)

(b) $PCl5(g) \rightleftharpoons PCl3(g) + Cl2(g)$ (**increase**)

(c) $3\ Fe(s) + 4\ H2O(g) \rightleftharpoons Fe3O4(s) + 4\ H2(g)$ (**no change**)

5. In the first step of the Ostwald process for the synthesis of nitric acid, ammonia is oxidized to nitric oxide by the reaction

$4\ NH_3(g) + 5\ O_2(g) \rightleftharpoons 4\ NO(g) + 6\ H_2O(g)$ $\Delta H° = -901.2$ kJ

How does the equilibrium amount of NO vary with an increase in temperature?

Answer:

The amount of NO decrease since the reacton shifts to the endothermic direction(backward)

6. Consider the equilibrium $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ $\Delta HO= 58.0kj$

In which direction will the equilibrium shift when (a) N_2O_4 is added , (b) NO_2 is removed , (c)the total pressure is increased by addition of N_2 gas , (d) the volume is increased , (e) the temperature is increased.

a) N_2O_4 is added : equilibrium shifts to the forward

b) NO_2 is removed: equilibrium shifts to the backward

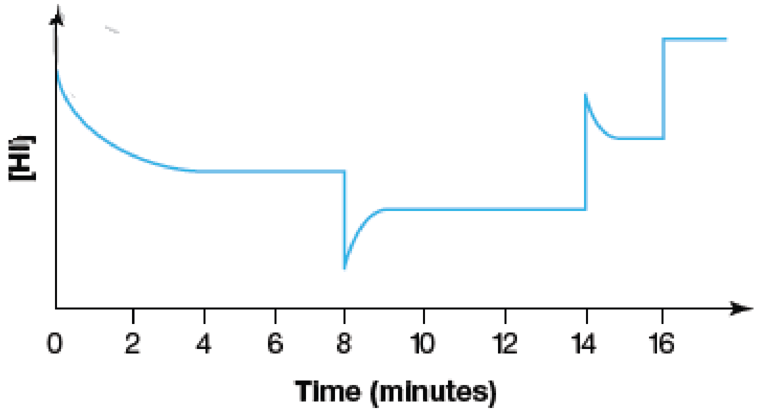
c) the total pressure is increased by addition of N_2 gas: no change on equilibrium position

d) the volume is increased: equilibrium shifts to the backward

e) the temperature is increased: equilibrium shifts to the forward

7. In an investigation of the decomposition of hydrogen iodide, represented by the equation:

$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$ the concentration versus time graph shown in the figure below was obtained.



(a)Describe what happened during the first 2 minutes of the experiment.

(b)Describe what was happening from the 4- to 8-minute marks.

(c)Give an explanation for the cause of the dip in the graph at the 8-minute mark.

(d)What do you think might have happened at the 14-minute mark?

(e)What do you think might have happened at the 16-minute mark?

(f)Did the change occurring at the 16-minute mark affect the equilibrium or not?

Explain.

Answer

(a)Decrease in concentrating of hydrogen iodide

(b)The concentration of hydrogen iodide remains the same.

(c)Equilibrium shifts to the right reducing the concentration of hydrogen iodide.

(d)Either hydrogen gas or iodine could have been added to thus shifting the equilibrium to left increasing the concentration of hydrogen iodide.

(f)It did affect the equilibrium since the concentration of hydrogen iodide increase

(e)Equilibrium shifts to the left thus increasing the concentration of hydrogen iodide

8. Account for the increase in reaction rate brought about by a catalyst.

Answer

In the presence of a catalyst, both the forward and reverse reaction rates will speed up equally, thereby allowing the system to reach equilibrium faster. However, it is very important to keep in mind that the addition of a catalyst has no effect on the final equilibrium position of the reaction. It simply makes the reaction faster.

9. Consider this scenario and answer the following questions: Chlorine atoms resulting from decomposition of chlorofluoromethanes, such as CCl2F2, catalyze the decomposition of ozone in the atmosphere. One simplified mechanism for the decomposition is:

$O_3 \xrightarrow{\text{sunlight}} O_2 + O$

$O_3 + Cl \longrightarrow O + ClO$

$ClO + O \longrightarrow Cl + O_2$

(a) Explain why chlorine atoms are catalysts in the gas-phase transformation:

$2O_3 \qquad 3O_2$

(b) Nitric oxide is also involved in the decomposition of ozone by the mechanism:

$O_3 \longrightarrow O_2 + O$

$O_3 + NO \longrightarrow NO + O_2$

$NO + O \longrightarrow NO + O_2$

Is NO a catalyst for the decomposition? Explain your answer.

10. The general mode of action for a catalyst is to provide a mechanism by which the reactants can unite more readily by taking a path with a lower reaction energy. The rates of both the forward and the reverse reactions are increased, leading to a faster achievement of equilibrium.

11. (a) Chlorine atoms are a catalyst because they react in the second step but are regenerated in the third step. Thus, they are not used up, which is a characteristic of catalysts. (b) NO is a catalyst for the same reason as in part (a).

12. Does the number of moles of reaction products increase, decrease, or remain the same

when each of the following equilibria is subjected to a decrease in pressure by increasing the volume?

(a) $CaO(s) + CO_2(g) \rightleftharpoons CaCO_3(s)$

(b) $PCl_5(g) \rightleftharpoons$ PCl3(g) + Cl2(g)

(c) $3\ Fe(s) + 4\ H2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g)$

(a) Because the forward reaction converts 1 mol of gas to 2 mol of gas, net reaction will go from reactants to products, thus increasing the number of moles of PCl_3 and Cl_2.

(b) Because there is 1 mol of gas on the reactant side of the balanced equation and none on the product side, the stress of a decrease in pressure is relieved by net reaction from products to reactants. The number of moles of $CaCO_3$ therefore decreases.

(c) Because there are 4 mol of gas on both sides of the balanced equation, the composition of the equilibrium mixture is unaffected by a change in pressure. The number of moles of Fe_3O_4 and H2 remains the same.

13.In the first step of the Ostwald process for the synthesis of nitric acid, ammonia is oxidized to nitric oxide by the reaction

$4\ NH_3\ (g) + 5\ O_2(g) \rightleftharpoons 4\ NO(g) + 6\ H_2O(g)\ \ \Delta H° = -901.2\ kJ$

How does the equilibrium amount of NO vary with an increase in temperature?

Because the oxidation of ammonia is exothermic, we include the heat (901.2 kJ) on the product side:

$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6\ H_2O(g)\ \Delta H°\ \ + 901.2\ kJ$

The stress of added heat when the temperature is increased will be relieved by net reaction from products to reactants, which absorbs the added heat. The equilibrium will therefore shift to the reactant side will decrease) with an increase in temperature. Consequently, the equilibrium mixture will contain less NO at higher temperatures.

14. A platinum catalyst is used in automobile catalytic converters to hasten the oxidation of carbon monoxide:

$2\ CO(g) + O_2(g) \rightleftharpoons 2\ CO_2(g)\ \Delta H° = -566\ kJ$

Suppose that you have a reaction vessel containing an equilibrium mixture of CO(g), $O_2(g)$ and $CO_2(g)$. Under the following conditions, will the amount of CO increase, decrease, or remain the same?

(a) A platinum catalyst is added. (No change in the amount of either CO(g), $O_2(g)$ or $CO_2(g)$

(b) The temperature is increased.(the amount of CO(g), $O_2(g)$ increase while $CO_2(g)$ decrease)

(c) The pressure is increased by decreasing the volume.(the amount of CO(g), $O_2(g)$ increasewhile $CO_2(g)$ decrease)

(d) The pressure is increased by adding argon gas.(neither of the CO(g), $O_2(g)$ and $CO_2(g)$ is increased or decreased)

(e) Adding O2 gas.($CO_2(g)$ increase while CO(g) decrease.)

15.9.3. Extended activities

1. The hydrogen used in the Haber process is made in the reaction shown below, which is an equilibrium.

$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3\ H_2(g)$ $\Delta H = +206$ kJ/mol

a) i) If the temperature of this equilibrium was increased, what would happen to the yield of hydrogen?

ii) Explain your reasoning.

b) i) If the pressure of this equilibrium was increased, what would happen to the yield of hydrogen?

ii) Explain your reasoning.

c) i) If more steam was added to this system, what would happen to the yield of hydrogen?

ii) Explain your reasoning.

Answer

a) i) increase yield of H_2

ii) Equilibrium moves to lower the temperature, so moves right in endothermic direction

b) i) decrease yield of H_2

ii) Equilibrium moves to lower the pressure, so moves left to side with less gas molecules

c) i) increase yield of H_2

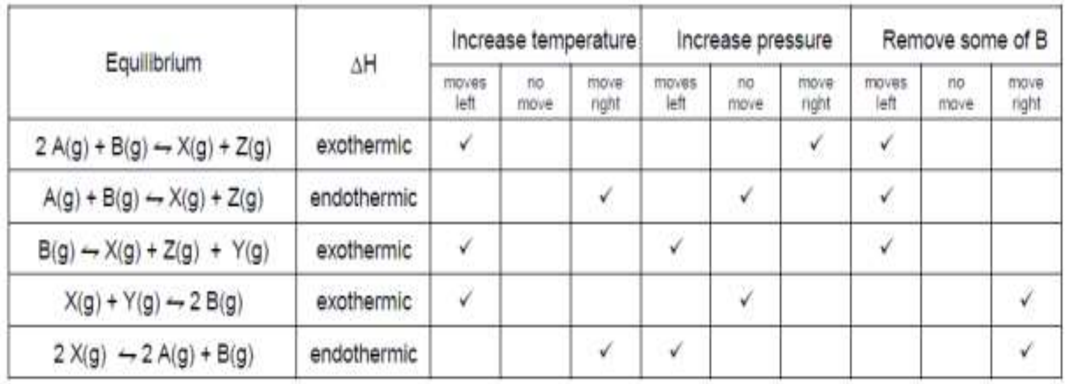
ii) Equilibrium moves to remove steam, so moves right to convert it to hydrogen

2. Complete the table to show what would happen to the position of the following gas phase equilibria if the following changes were made. Tick the correct column in each case.

	ΔH	Increase temperature			Increase pressure			Remove some of B		
Equilibrium		Moves left	No move	Move right	Moves left	No move	Move right	Moves left	No move	Move right
$2A(g)+B(g) \rightleftharpoons X(g)+Z(g)$	Exothermic									
$2A(g)+B(g) \rightleftharpoons X(g)+Z(g)$	endothermic									
$B(g) \rightleftharpoons X(g) + Z(g) + Y(g)$	Exothermic									

$X(g) + Y(g) \rightleftharpoons 2B(g)$	Exothermic									
$2X(g) \rightleftharpoons 2A(g) + B(g)$	endothermic									

Answer



Equilibrium	ΔH	Increase temperature			Increase pressure			Remove some of B		
		moves left	no move	move right	moves left	no move	move right	moves left	no move	move right
$2A(g) + B(g) \rightleftharpoons X(g) + Z(g)$	exothermic	✓					✓	✓		
$A(g) + B(g) \rightleftharpoons X(g) + Z(g)$	endothermic			✓		✓		✓		
$B(g) \rightleftharpoons X(g) + Z(g) + Y(g)$	exothermic	✓			✓			✓		
$X(g) + Y(g) \rightleftharpoons 2B(g)$	exothermic	✓				✓				✓
$2X(g) \rightleftharpoons 2A(g) + B(g)$	endothermic			✓	✓					✓

3. When bismuth chloride is added to water, a reaction occurs and a white precipitate forms. The following equilibrium is set up

$BiCl_3(aq) + H_2O(l) \rightleftharpoons BiOCl(s) + 2HCl(aq)$

What would be the effect on the amount of precipitate if sodium hydroxide solution is added to the mixture (explain your answer)?

Answer

3) NaOH reacts with HCl and removes it; equilibrium shifts right to replace lost HCl; therefore more BiOCl white precipitate formed.

4. A simple form of colorimetric analysis may be used to study the equilibrium represented by the following equation.

$Br_2(aq) + 2OH^-(aq) \rightleftharpoons OBr^-(aq) + Br–(aq) + H2O(l)\ \Delta H = +15\ kJ\ mol–1$

As molecular bromine, Br2, is the only coloured species in this reaction, its red-brown colour may be used to monitor various changes made to this equilibrium.

A student performed an experiment where 10 ml samples of reaction mixture were poured into identical test tubes. The four changes listed below were then made to different samples of the equilibrium mixture. The colors before and after the changes were compared.

Change 1: A small amount of solid potassium bromide was added and the mixture stirred to dissolve it.

Change 2: A small amount of solid sodium chloride was added and the mixture stirred to dissolve it.

Change 3: The solution was warmed from room temperature to 50 °C.

For each of these three changes:

(a) State whether you would expect the solution to darken, lighten or stay the same 3 marks

(b)Use Le Châtelier's principle to explain your answer in (a).

Answer

Change 1: the solution turns red-brown

Change 2: no observable change

Change 3: the red-brown colour fades

5. The following equilibrium takes place in a rigid container.

$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$ $\Delta H = +56$ kJ

In which direction does the equilibrium shift as a result of each change?

(a) Adding phosphorus pentachloride gas

(b) Removing chlorine gas

(c) Decreasing the temperature

(d) Increasing the pressure by adding helium gas

(e) Using a catalyst

Answer

1. a)i) $[PCl_5]$ increases. Therefore, the equilibrium must shift to minimize $[PCl_5]$. The reaction shifts to the right.

(b) $[Cl_2]$ is reduced. Therefore, the equilibrium must shift to increase $[Cl_2]$. The reaction shifts to the right.

(c) The temperature decreases. Therefore, the equilibrium must shift in the direction in which the reaction is exothermic. From left to right, the reaction is endothermic. Thus, the reaction must be exothermic from right to left. The reaction shifts to the left if the temperature is decreased.

(d) Helium does not react with any of the gases in the mixture so it does not change the position of equilibrium.

(e) A catalyst has no effect on the position of equilibrium.

UNIT 16: ACIDS AND BASES

16

16.1. Key unit competence

To explain the acid-base theory according to Arrhenius, Bronsted-Lowry and Lewis.

16.2. Prerequisite knowledge and skills

Distinguish between acidic and basic substances encountered in everyday life from the point of view taste, feel, their effect on litmus paper and reading on a pH scale.

16.3. Cross-cutting issues to be addressed

Environment sustainability

During the lesson you should emphasize that acids and bases cover a wide range of uses in everyday life. However, they have harmful effects on both living organisms and inert organisms. A great attention should be paid when carrying out laboratory experiments. The used chemicals should be disposed accordingly so as to preserve and protect our environment.

16.4. Guidance on Introductory activity

Have the learners attempt introductory activity. This activity intends to identify the prerequisite learners have on acids and bases and relate them to everyday life circumstances.

16.5. List of lessons

Unit No	Lesson title	Objectives	No of periods
16.1	Acid-base theory (Arrhenius theory of acid and base, Bronsted-Lowry theory of acid and base and Lewis'theory of acid and base).	Define Arrhenius acid and Arrhenius base. Explain the behaviour of Arrhenius acid and base in aqueous solution. Define Bronsted-Lowry acid and Arrhenius base. Explain the behaviour of Arrhenius acid and base Identify the acid-base conjugate complex in a reaction involving Bronsted-Lowry acid and Arrhenius base. Define Lewis acid and Arrhenius base. Identify Lewis lewis acid and base for a given reaction involving Lewis acid and base.	2
	End unit assessment		1

Lesson 1: Acid-base theories.

This is an introduction to acid-base equilibrium. You are advised to recall the prior knowedge of learners about acids and bases through the introductory activities suggested in the student book. This is intended to raise the curiosity of learners and relate the lesson to real/daily life.

a) Prerequisites/Revision/Introduction

For students to learn better the acid-base theories, they should have some knowledge on the existence of acids and bases and bases among the wide range of products daily met. They should know how to distinguish between acids and bases from point of view taste, feel and effect on litmus paper.

b) Teaching resources:

- Illustrations in the students' book for lesson unit 16 or draw them on a manila paper.
- Teaching videos downloaded videos from youtube.
- Chemistry text books if available in the library.

c) Learning activities:

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do introductory activity and then proceed to activities 16.1.

- Form groups of 4-5 depending on the size of the class.
- Distribute the introductory activity and estimate the time for it.
- Have the learners do activities 16.1of lesson.
- Allows the learners to work together in groups.
- Invite group leaders to present their findings.
- In this step you can guide the learners to evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- You summarise the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated in step 2.
- Integrate cross-cutting and real life experiences by linking them with the lesson learned.

Expected answers to Introductory activity

The pictures A, B, C, D and E represent some of the products used in everyday life.

1.You are advised to guide learners answering the questions given in the activity and correct the wrong answers.

2.a. A is called milk of magnesia which is a solution of magnesium hydroxide.

b. The substance B is cheese. It is essentially of lactic acid (2-ydroxypropanoic acid).

c. The image in B is a lemon fruit. It is essentially citric acid.

d. The substance B is soap. It is mainly made of fatty acid such as lauric acid, myristic acid, palmitic acid.

e. The image E shows pepper. It is mainly butyric acid.

Substance	Main use
Magnesium hydroxide	Magnesium hydroxide is a common component of antacids, such as milk of magnesia, as well as laxatives
Lactic acid	Lactic acid is used as a food preservative, curing agent, and flavoring agent.
Citric acid.	It is a natural preservative and is also used to add an acidic (sour) taste to foods and soft drinks.
Lauric acid	lauric acid has multiple uses in cosmetics. It's also used as a base for cleansing agents.

Butyric acid	The acid is of considerable commercial importance as a raw material in the manufacture of esters of lower alcohols for use as flavouring agents.

3. i.

Magnesium hydroxide	A	Milk of magnesia
Lactic acid	B	Butter
Citric acid.	C	Lemon
Lauric acid	D	Soap
Butyric acid	F	Pepper

ii. The substances could be classified in two groups.

iii. The mentioned in 2(i) groups are acids and bases.

Expected answers to activity 16.1

Table 16.1. Results of acid-base testing

Reagent	**Red Litmus**	Blue Litmus	**Acid, base or neutral?**
Hydrochloric acid (HCl)	Red	Red	Acid
Sodium hydroxide (NaOH)	Blue	Blue	Base
Sodium chloride (NaCl)	Purple	Purple	Neutral
Distilled water (H_2O)	Purple	Purple	Neutral
Glucose ($C_6H_{12}O_6$)	Purple	Purple	Neutral
Sulphuric acid (H_2SO_4)	Red	Red	Acid
Ammonia (NH_3)	Blue	Blue	Base
Ethanoic acid (CH_3^- 3CooH)	Blue	Blue	Base

The acidic chemicals are Hydrochloric acid (HCl) and Sulphuric acid (H2SO4).

The basic chemicals are Sodium hydroxide (NaOH) and Ammonia (NH3).

The neutral chemicals are Sodium chloride (NaCl), Distilled water (H2O) and Glucose (C6H12O6).

Expected answers to Checking up 16.1(a)

The filled table

Subsatance	Acid/Base	Positive ions in water	Negative ions in water
HCl	Acid	H^+	Cl^-
HBr	Acid	H_+	Br^-
HNO_3	Acid	H^+	NO_3^-
KOH	Base	K^+	OH^-
$Ca(OH)_2$	Base	Ca^{2+}	OH^-
NH_4OH	Base	NH_4^+	OH^-
HCOOH	Acid	H^+	HCOO-

2.The information in the given table revealed the following:

- Two strongest acidic substances are battery acid (pH=0.3) and stomach acid (PH=1.5 to 3.5)
- Two weakest acidic substances are beer (pH=5) and milk or urine which have both pH=6.
- Two strongest alkaline substances Human blood (PH=7.45) and sea water (pH=8).
- Two weakest alkaline substances are sodium hydroxide (pH=14.0)and bleach (pH=12.6)

The neutral substance is pure H2O.

Take two different solutions with equal concentrations of acids such as HCl and CH3COOH, and measure their pHs.

Take two different solutions with equal concentrations of bases such as NaOH and NH4OH, and measure their pH.

Expected Answers to Study questions:

Both pH values for HCl and CH_3COOH are less than 7.

The pH of HCl is lower than that of CH_3COOH.

Both pH values for NaOH and NH_4OH are higher than 7.

The pH of NaOH is higher than that of NH_4OH.

The results show that HCl is stronger than CH_3COOH and NaOH is stronger than NH_4OH.

Expected answers to Checking up 16.1(b)

Labelling of the acid (A), base (B), conjugate acid (CA) and conjugate base (CB) in given chemical equations.

$HCl(aq) + H_2O(l) \rightleftharpoons H_3O+(aq) + Cl–(aq)$

A B CA CB

$H_2PO_4^-(aq) + NH_3(aq) \rightleftharpoons NH_4^+(aq) + HPO_4^{2-}(aq)$

A B CA CB

$NH_4^+(aq) + CN^-(aq) \rightleftharpoons HCN(aq) + NH_3(aq)$

A B CA CB

H2SO4(aq) + H2O(l) $\rightleftharpoons$ $H_3O^+(aq) + HSO_4^-(aq)$

A B CA CB

1. The conjugate base for the given Brønsted-Lowry acid.

	Molecule/ Ion	Conjugate base
a	HI	I^-
b	NH_4^+:	NH_3
c	H_2CO_3	
d	HNO_3	

2. The conjugate acid for each of the following Brønsted-Lowry bases.

CN– : HCN

O^{2-} : OH^-

CH_3COO^-: CH_3COOH

NH_3: NH^+_4

Expected answers to Checking up 16.1 (c)

a. $Fe^{3+}(aq)+6H_2O(l) \rightleftharpoons$ [Fe (H2O)6]$^{3+}$(aq)

b. $Cu^{2+}(aq)+ 4\ NH_3 \rightleftharpoons [Cu(NH_3)_4]^{2+}(aq)$

c. Cu^{2+}(aq)+ 6H2O(l) $\rightleftharpoons$ [Cu (H2O)6]$^{2+}$(aq)

2. c

3. b

End unit Summary

- According to Arrhenius, the pioneer of the acid-base theory an acid is any chemical species that produces hydrogen ions (H^+) in aqueous solution while a base is any chemical species that produces hydroxide ions (OH^-) in aqueous solution. The strength of an acid or base is determined by the extent to which it liberates H^+ or OH^- ions.
- Brønsted-Lowry's theory of acids and bases helped to overcome the drawbacks of the Arrhenius theory. He defines an acid as proton donor and a base as a proton receptor.
- Lewis's theory defines an acid as any chemical species that is electron deficient and a base as an electron rich species.

16.6. Expected answers to end unit assessment

1. Equation for the dissociation of the given acids in water.

HClO4 : HClO4(aq) → $H^+(aq) + ClO_4^-(aq)$

H2SO4(aq) : H2SO4 → $2H^+(aq)$ + SO4^{2-} (aq)

$CH3COOH(aq) \rightleftharpoons H^{+}(aq)+ CH3COO^{-}(aq)$

$H2S\ (aq) \rightarrow 2H^{+}(aq)+S^{2-}(aq)$

$HNO3(aq) \rightarrow H^{+}(aq)+\ NO^{-}_{3}(aq)$

2.The balanced reaction for the dissociation of nitric acid when put in water

$HNO3(aq) + H2O(l) \rightarrow NO3^{-}(aq) + H3O^{+}(aq)$

3.The balanced reaction for the dissociation of acetic acid when put in water

$CH3COOH(aq) + H2O(l) \rightleftharpoons H3O^{+}(aq)+ CH3COO^{-}(aq)$

4.Equation for the dissociation of barium hydroxide is put in water.

$Ba(OH)_2 \rightarrow Ba^{2+} + 2OH^{-}$

5.The conjugate base of HSO_4^{-} is SO_4^{2-}.

6.The formula and name of the conjugate acid corresponding to the following bases:

	Molecule/ Ion	Conjugate acid	Name of conjugate acid
a	NH3	NH_3	Ammonium ion
b	PO_4^{3-}	HPO_4^{2-}	Monohydrogen phosphate ion
c	CN^{-}	HCN	Hydrogen cyanide
d	HCO_3^{-}	H_2CO_3	Hydrogen carbonate

7.The balanced equation for the Bronsted-Lowry acid HPO42- in water.

$HPO_4^{2-} + H2O(l) \rightleftharpoons H3O+(aq) + PO4^{3-}(aq)$

8The reaction for the dissolution of ammonia in water.

$NH3(aq) + H2O(l) \rightleftharpoons NH4^{+}(aq) + OH^{-}(aq)$

9.The increasing order of alkalinity strength :D<C<B<A

Reason: The stronger the acid the weaker its conjugate base and vice versa.

10.A>B>C>D

A depicts the strongest acid and strongest electrolyte.

B depicts the weakest acid and weakest electrolyte.

Reason:

- In A, all four molecules (100%) of the acid are dissociated.
- In B, three out of four molecules (75%) of the acid are dissociated.
- In C, two out of four molecules (50%) of the acid are dissociated.
- In D, no molecule of the acid (0%) is dissociated.

16.7. Additional Activities

16.7.1. Remedial Activity

Which of the following gases is a contributor to the formation of acid rain?

A. H2

B. O3

C. SO2

D. NH_3

2.Consider the following:

I	PO_4^{3-}
II	HPO_4^{2-}
III	$H2PO_4^{-}$
IV	H3PO4

2.The term amphiprotic can be used to describe

A. I only.

B. II and III only.

C. I, II and III only.

D. II, III and IV only.

3.An Arrhenius acid is defined as a chemical species that

A. is a proton donor.

B. is a proton acceptor.

C. produces hydrogen ions in solution.

D. produces hydroxide ions in solution.

4.Which statement about Arrhenius acids is false?

A. Their water solutions are called aqueous acids.

B. They are molecular compounds with ionisable hydrogen atoms.

C. Their pure aqueous solutions are electrolytes.

D. They increase the concentration of hydroxide ions in aqueous solution.

5.Strong bases are:

A.Strong electrolytes.

B.Non-electrolytes.

C.Weak electrolytes.

D.Also strong acids

6.Whose definition of acids and bases emphasizes the role of protons?

A.Arrhenius

B.Brønsted and Lowry

C.Lewis

D.Faraday

7.An electron pair acceptor is a

A.Lewis acid.

B.Brønsted Lowry base.

C.Traditional acid.

D.Lewis base.

8.Expected answers to remedial activity

1.C 2.B 3.C 4.D 5.A 6.B 7.A

16.7.2. Consolidation Activity

1.For each each of the following , identify the acids and bases in both the forward and reverse reactions.

$HClO2+H2O \rightleftharpoons ClO_2^-+H3O^+$

$OCl-+H2O \rightleftharpoons HOCl+OH^-$

$NH3+H2PO_4^- \rightleftharpoons NH4^+ + HPO^{2-}_4$

$HCl+H2PO_4^- \rightleftharpoons Cl^- +H3PO4$

2.The dihydrogen phosphate ion, $H_2PO_4^-$, is amphiprotic. In which of the following reactions is it serving as a base?

$H_3O+(aq) + H_2PO^-_4(aq) \rightleftharpoons H_3PO_4(aq)+ H_2O(l)$

$H_3O^+(aq) + HPO^{2-}(aq) \rightleftharpoons H_2PO_4^-(aq)+ H_2O(l)$

$H3PO4(aq)+ HPO_4^{2-}(aq) \rightleftharpoons 2\ H_2PO_4^-(aq)$

A.i only

B.i and ii

C.i and iii

D.ii and iii

E.i, ii and iii.

3.The probe of the pH meter shown here is sitting on a beaker that contains a clear liquid. You are told that the liquid is:

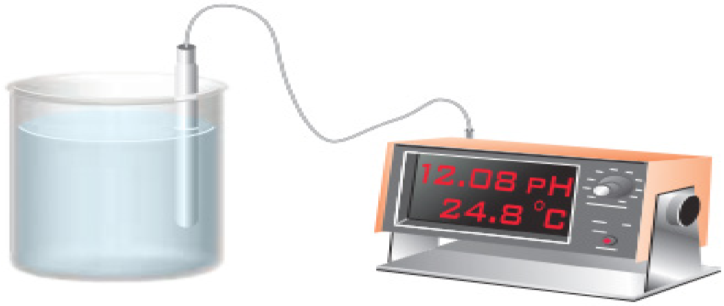
A.Pure water

B.A solution of HCl

C.A solution of KOH

D.A weak base.

pure water, a solution of HCl(*aq*), or a solution of KOH(*aq*). Which one is it? (**b**) If the liquid is one of the solutions, what is its molarity? (**c**) Why is the temperature given on the pH meter? [Sections 16.4 and 16.5]



4.Consider the following Brönsted-Lowry equilibrium system:

$HSO_3^- + H_2PO_4^- \rightleftharpoons SO_3^{2-} + H_3PO4$

What are the two Brönsted-Lowry bases in the equilibrium above?

A. HSO_3 and SO_3^{2-}
B. $H_2PO_4^-$ and SO_3^{2-}
C. HSO_3^- and H_3PO_4
D. $H_2PO_4^-$ and H_3PO_4

5.Consider the acid-base equilibrium system

$HC_2O_4^- + H_2BO_3^- \rightleftharpoons H_3BO_3 + C_2O_4^{2-}$

Identify the Brønsted-Lowry acids in this equilibrium.

$HC_2O_4^-$ and $C_2O_4^-$
$HC_2O_4^-$ and H_3BO_3
H2BO3- and H_3BO_3
H_2BO_3 and $C_2O_4^{2-}$

Answers

The acids and bases involved in the given equations are given in the following table.

	Acid 1	Base 1	Acid 2	Base 2
a	HClO2	ClO_2^-	$H3O^+$	H2O
b	HOCl	OCl^-	H2O	OH^-
c	NH_4^+	NH3	$H2PO4^-$	$HPO4^{2-}$
d	HCl	Cl^-	H3PO4	$H2PO4^-$

2. B
3. B

16.7.3. Extended activity

Model 1: A Definition of Acids and Bases

$HCl(g)+H_2O(l) \rightleftharpoons H_3O^+(aq)+Cl^-(aq)$
$NH_3(aq)+H_2O(l) \rightleftharpoons NH_4^+(aq)+OH^-(aq)$

1. (a) What chemical species are the Brønsted-Lowry acids in the forward reactions in the table above?

(b) What chemical species are the Brønsted-Lowry bases in the forward reactions in the table above?

2. Is it possible for a substance to act as both an acid and a base? Explain your reasoning.

3. (a) What species results from the loss of a proton from the Brønsted-Lowry acid in the forward reaction?

(b) Does this species act as an acid or a base when the reverse of reaction (i) occurs?

(c) What species results from the gain of a proton from the Brønsted-Lowry base in the forward reaction (i).

(d) Does this species act as an acid or a base when the reverse of reaction (i) occurs?

4. Repeat questions (a) – (d) for reaction (ii).

Model 2: Conjugate Pairs

As you discovered in Model 1, certain pairs of molecules are related through their acid and base properties. These pairs are described as conjugate acid-base pairs. They differ by a single proton. A base has one less proton than its conjugate acid. An acid has one more proton than its conjugate base.

Acid	Base
$H_2CO^-_3$	HCO^-_3
HCO_3^-	CO_3^{2-}
H_3O+	H_2O
H_2S	HS^-

Critical thinking questions

There are two conjugate pairs in the following reaction. Identify both pairs.

$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

6. Amino acids have both an acidic (-COOH) and a basic ($-NH_2$) functional group. The simplest amino acid is glycine, H_2N-CH_2-COOH. Give the structure of the conjugate acid and the conjugate base of glycine.

Expected answers to extended activity

1.(a) (i) HCl (ii) H_2O

(b) (i) H_2O (ii) NH_3

2. Yes, a substance can act as an acid when it interacts with bases or a base when it interacts with.Such a substance is known as amphoteric substance or amphiprotic substance.

3. (a) In the forward reaction (i) Cl- is the result from the loss of a proton from the Brønsted-Lowry acid.

(b) This species act as a base when the reverse of reaction (i) occurs.

(c) In the forward reaction (i) the result from the gain of a proton by the Brønsted-Lowry base is the conjugate acid (H3O$^+$).

(d) This species act as an acid when the reverse of reaction (i) occurs.

4. (a) In the forward reaction (ii) OH^- is the result from the loss of a proton from the Brønsted-Lowry acid.

(b) This species act as a base when the reverse of reaction (iii) occurs.

(c) In the forward reaction (iii) the result from the gain of a proton by the Brønsted-Lowry base is the conjugate acid (NH_4^+).

(d) This species act as an acid when the reverse of reaction (i) occurs.

5. The two acid-base conjugate pairs are $H_2O(l)/ OH^-(aq)$ and $H_3O^+(aq)/H_2O(l)$.

6. The conjugate acid is $H_3N^+\text{-}CH_2\text{-}COOH$ and the conjugate base is $H2N\text{-}CH_2\text{-}COO^-$

UNIT 17: REDOX REACTIONS

17

17.1. Key unit competence

The learner should be able to explain the concept of reduction and oxidation and balance equations for redox reactions.

17.2. Prerequisite, knowledge and skills

Categories of chemical reactions, electrolysis and its application

17.3. Cross-cutting issues to be addressed

Environmental protection and sustainable development

There is a serious issue of environmental protection and sustainable development in our society. When introducing this unit, it would be an opportunity to guide learners on understanding the importance of environmental protection and sustainable development and how the issues related to environmental protection and sustainable development may be addressed in relation with the prevention of the electrochemical process of corrosion which is damaging the metallic materials.

Inclusive education

This unit involves a number of activities such as the experiments on redox reactions and reactivity series of metals. The activities require assembling of apparatus, writing, reading and observation of the results. This may be challenging to students with special educational needs especially children with visual impairment difficulties. However, the teacher can make some arrangements like:

Grouping students: Students with special educational needs are grouped with others and assigned roles basing on individual student's abilities.

- Providing procedure earlier before the experiment so that students get familiar with them. They can be written on the board or printed depending on available resources. If you have children with low vision remember to print in appropriate fonts.
- Give extra time for them to write summary notes or write down observations after experiments.
- Every important point is written and spoken. The written points helps students with hearing impairment and speaking aloud helps students with visual impairment

- Remember to repeat the main points of the lessons.

For learners with hearing difficulties: Teacher has to encourage them to sit closer to the front of the classroom. While teaching, avoid asking learners whether they have understood, or if they need you to repeat a point. Encourage learners not to be afraid to ask questions. When teaching, speak clearly and ensure that all the learners can hear your voice. Avoid speaking hurriedly as this will make it difficult for learners with hearing difficulties to make sense of what you are saying.

Learners with mobility difficulties: These include learners in crutches, wheelchairs, or with walking difficulties. Encourage other learners to look out for and help their classmates. Ask their follow learners to help them with their notes, if their conditions hinder them from writing well.

Learners with reading difficulties: Learners with this kind of difficulties struggle to make sense of words or understand written work and take longer to read than other learners. 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.

Gender:

During group activities try to form heterogeneous groups (boys and girls where applicable) or when students start to present their findings encourage both (boys and girls) to present.

Peace and values education

During group activities, the teacher will encourage learners to help each other's and to respect opinions of colleagues.

17.4. Guidance on introductory activity

Before introducing the first lesson (Definition of electrochemistry and its relationship with redox reactions) of this unit, let learners attempt the introductory activity.

Expected answer for the introductory activity

1. Title: Corrosion of iron

2. $2Fe + 2O_2 + 2H_2O \rightarrow 2Fe_2+ + 4HO^-$

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:

1. 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) by painting the surface.

(ii) by coating the surface with a thin film of oil or grease

(iii) by 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 in contact with iron and rusting starts. This rusting extends beneath the protective layer and eventually peels off the protective layer.

2. 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, C02 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.

3. 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

17.5. List of lessons

Heading	Lesson title	Learning objectives	No. of periods(22)
17.1 Definition of electrochemistry and its relationship with redox reactions.	Definition of electrochemistry and its relationship with redox reactions.	Explain the redox reactions in terms of electron transfer and changes in oxidation state (number)	2
17.2. Definitions of reduction and oxidation reactions.	Definitions of reduction and oxidation reactions.	Explain the reduction and reduction in terms of loss and gain of electron	1
17.3. Explanation of oxidizing and reducing agents	Explanation of oxidizing and reducing agents	Differentiate the reducing agent from the oxidizing agent in a redox reaction	2
17.4. Rules used to determine oxidation number of elements in chemical compounds and species	Rules used to determine oxidation number of elements	Work out the oxidation numbers of elements in the compounds.	4

17.5 Balancing redox equations	Balancing redox equations using ion-electron half equations method(including disproportionation reactions)	Apply half-reaction method to balance redox reactions. Deduce balanced equations for redox reactions from relevant half equations. Explain the concept of disproportionation	6
17.6. Reactivity series of metals	Reactivity series of metals	Perform simple displacement reactions to order elements in terms of oxidizing or reducing ability.	5
Assessment			2

Lesson 1: Definition of electrochemistry and its relationship with redox reactions

a) Prerequisites/Revision/Introduction

Students will learn better the relationship between electrochemistry and redox reactions if they have understanding on electrolysis and its application (S3 chemistry: Unit 8)

b) Teaching resources

Use the illustrations in the students' book

c) Learning activities

Before introducing the lesson, you will have to introduce the whole unit. Let learners therefore attempt the introductory activity first then learning activity 17.1 which leads students to the first lesson of the unit.

- Form groups of 3 to 5 learners and ask them to choose a group leader
- Provide the activity 17.1 from the student book (when the books are not

enough, he/she can writes the activity on the chalkboard) to the learners in their groups and ask every group to discuss questions 1and 2, and provide answers.

- Let learners to work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 17.1. Learners should do the checking up activity in any method you wish to use

d)Expected answers for activity 17.1

1. Redox reactions occur with variation of oxidation number of atoms while other chemical reactions do without the change in oxidation number.

2. Electrochemistry is concerned for the chemical reactions with electrons transfer which its motion is producing electricity.

d) Checking up17.1: Expected answers

1. a) precipitation
   b) Oxidation-reduction
   c)acid-base neutralization
2. Redox reaction is d)

Lesson 2: Definitions of reduction and oxidation reactions

Concept of atomic number, mass number, and isotopic mass is the second lesson of the unit. Students are expected to compare reduction and oxidation reactions as different but complementary reactions.

a)Prerequisites/Revision/Introduction:

Students will learn better a concept of reduction and oxidation reactions if they have understanding on categories of chemical reactions (S2 chemistry: unit 5) and electrolysis and its application (S3 chemistry: Unit 8)

b)Teaching resources:

Charts illustrating some reduction and oxidation reactions.

c)Learning activities

Learning activity 17.2 is suggested in students' book. However you are free to add more.

- Form groups of 3 to 5 learners and ask them to choose a group leader
- Provide the activity 17.2 from the student book (when the books are not enough, you can write the activity on the chalkboard) to the learners in their groups and ask every group to do questions 1 – 8, and provide their answers.
- Let learners to work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 17.2. Learners should do the checking up activity in any methodology you wish to use.

d) Expected answers for activity 17.2

(See the content of this unit)

e)Checking up 1.2: Expected answers

1. (a) reduction (b) oxidation (c) reduction (d) reduction

2. (a) $Te(s) \rightarrow TeO_2(s)$(oxidation)

$NO_3^-(aq) \rightarrow NO(g)$(reduction)

(b) H2O2(aq) →H2O(l)(oxidation)

$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq)$(reduction)

3. a) Silicon is oxidized(its O.N changes from 0 to +4)

chlorine is reduced(its O.N changes from 0 to -1)

b) Chlorine is reduced (its O.N changes from 0 to -1)

Bromine is oxidized (its O.N changes from -1 to 0)

Lesson 3: Explanation of oxidizing and reducing agents

a) Prerequisites/Revision/Introduction

All previous lessons have to be understood

b) Teaching resources

Student's chemistry book and other relevant books from the school library

c) Learning activities 17.3

- Introduce the lesson by allowing learners to do the learning activity 17.3 in their respective groups. Let them work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 17.3. Learners should do the checking up activity in any method you wish to use.

d)Expected answer for activity 17.3

1. Reactions that is expected to occur are a) and b)

2. $2Cu^{2+}(aq) + I^{-}(aq) \rightarrow 2CuI(s) + I_2(aq$

(+2) (-1) (+1) (0)

3. Oxidizing agent: Cu^{2+}

Reducing agent: I^{-}

e) Checking up 17.3: Expected answers

1. Fe(s): oxidizing agent, $Ni(NO_3)_2(aq)$: reducing agent

2. Cu(s): oxidizing agent, $4HNO_3(aq)$: reducing agent

3. $C2H_4(g)$: oxidizing agent, $H_2(g)$: reducing agent

4. This is a non redox equation

Lesson 4: Rules used to determine oxidation number of elements in chemical compounds and species

a)Prerequisites/Revision/Introduction:

Before beginning this lesson, learners should be able to recall the definition of oxidation number

b)Teaching resources

Student book and other books from the school library

c)Learning activities

- Learning activity 17.3 is suggested in students' book. However the teacher is free to add more.
- Form groups of 3-5 students. The number of groups and members will depend on your class size.
- In the groups students attempt activity 17.4, discuss and record their answers.
- Each group representative presents their answers to the whole class.
- During the presentation ask some questions that lead to lesson conclusion such as calculating the relative atomic mass of an element, given isotopic masses and abundances.
- Make a summary of the lesson (short notes) and assess your lesson. Let students do checking up 17.4. Learners should do the checking up activity in any method you wish to use.

d)Expected answer for Activity 17.4

1. Redox reaction is always accompanied by changes in the oxidation number of the element

2. see the content of this unit

3. $K_2Cr_2O_7$ (+6), $Na_2C_2O_4$(+3), $KMnO_4$(+7) , $MnSO_4$ (+2), CO_2(+4), CrC_{l3}(+3), NO(+2), HNO_3(+5), SO_3(+6)

e) Checking up 17.4 :Expected answers

1. (a) Cd(+2), S(-2) (b) Al(+3), H3(-1) (c) S2(+3), O3(-2) (d) Na2(+1), Cr2(+6), O7(-2)
(e) Sn(+4), Cl4(-1) (f) Cr(+6), O3(-2) (j) V(+5), O(-2), Cl3(-1)
(h) V2(+3), O3(-2) (e) H(+1), N(+5), O3(-2) (f) Fe(+2), S(+6), O4(-2)

2. a) oxidation (b) oxidation (c) oxidation

3. (a) Cr: 0 (b) CrO3: +6 (c) CrCl3:+3 (d) Cr2O3: +3 (e) Cr2O72- : +6 (f) CrO42- :-6

4. The oxidation state (oxidation number) of N in these species is NO2 (+4), NO (+2), HNO3 (+5), N2 (0), HNO2 (+3), N2O (+1), Na3N (-3). Thus N has its highest oxidation number in HNO3 and its lowest in Na3N.

Lesson 5: Balancing redox equations (including disproportionation reactions)

a)Prerequisites/Revision/Introduction:

Introduce the lesson by allowing learners to read the procedure of the experimental activity 17.5 in the groups or any other appropriate method chosen. This activity is diagnostic i.e. intended to check on the previous information about redox reactions. Learners will be asked to follow procedure in their respective groups.

b)Teaching resources

Well equipped laboratory

c)Learning activities 17.5

- After organizing the learners in their respective groups, let them work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are still struggling (but without communicating to them the knowledge).
- Invite group leaders to presents the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 17.5. Learners should do the checking up activity in any method you wish to use.

d)Explanation for activity 17.5

1. Iron atoms react with dilute sulphuric acid to form iron(II) sulphate and hydrogen gas

$Fe(s) + H_2SO_4(aq) \rightarrow FeSO_4(aq) + H_2(g)$

Iron atoms are oxidized to form iron(II) ions

$Fe(s) \rightarrow Fe^{2+}(aq) + 2e-$

Hydrogen ions in the acid are reduced and form hydrogen gas

$2H^+(aq) + 2e- \rightarrow H_2$

Iron atoms can react with hydrochloric acid to form hydrogen gas and iron (II) chloride. Iron atoms are oxidized and hydrogen ions are reduced.

$Fe(s) \rightarrow Fe^{2+}(aq) + 2e-$

$2H+ (aq) +2e\rightarrow H_2$

Redox reaction:

$Fe(s) + 2H^+(aq) \rightarrow H2(g) + Fe^{2+}(aq)$ or $Fe(s) + 2H_3O+(aq) \rightarrow H_2(g) + 2H_2O(l) + Fe^{2+}(aq)$

2. Hydrogen peroxide can convert an iron (II) salt to an iron (III) salt. For example when iron (II) sulphate was reacted with acidified hydrogen peroxide, iron (III) sulphate is formed

$2Fe^{2+}(aq) + H_2O_2(l) + 2H+(aq) \rightarrow 2Fe^{3+}(aq) + 2H_2O(l)$

Half equation for oxidation: $2Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + 2e-$

Half equation for reduction: $H_2O_2(l) + 2H^+(aq) + 2e- \rightarrow 2H_2O(l)$

Redox reaction

$2Fe^{3+}(aq) + H_2O_2(l) + 2H+(aq) \rightarrow 2Fe^{3+}(aq) +2H_2O(l)$

Note:

Iron and other transition metals catalyse the decomposition of hydrogen peroxide to water and oxygen. This is why oxygen produced in this reaction: explain why bubbles of oxygen are observed when hydrogen peroxide is used to dress a wound

3. Ammonia solution or sodium hydroxide 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.

$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(aq)$

(green solid)

Iron(III) hydroxide appears as a reddish brown solid

$Fe^{2+}(aq) + 3OH^-(aq) \rightarrow Fe(OH)_3(aq)$

4. Iron(II) sulphate reacts with chlorine gas to form iron(III) chloride. The solution turns from green to pale yellow which is iron(III) chloride.

e) Checking up 17.5: Expected answer

1. $CN- + MnO_4^- \rightarrow CNO^- + MnO_2$ (basic solution)

$3CN^- + H_2O + 2MnO_4^- \rightarrow 3CNO^- + 2MnO_2 + 2OH^-$

2. $Cr_2O_7^{2-} + I- \rightarrow Cr^{3+} + IO_3^-$ (acidic solution)

$Cr_2O_7^{2-} + 8H^+ + I- \rightarrow 2Cr3^+ + 4H_2O + IO_3^-$

3. $MnO_4^- + CH_3OH \rightarrow Mn^{2+} + HCO_2H$ (acidic solution)

$12H^+ + 4MnO_4^- + 5CH_3OH \rightarrow 4Mn^{2+} +11H_2O + 5HCO_2H$

4. $As + ClO_3- \rightarrow H_3AsO_3 + HClO$(acidic solution)

$6H_2O + 4As + 3H^+ + 3ClO_3- \rightarrow 4H_3AsO_3+3HClO$

5. $H_2O_2 + ClO_2 \rightarrow ClO_2^- + O_2$(basic solution)

$2ClO_2 +H_2O_2 + 2OH- \rightarrow 2ClO_2^- + O_2 + 2H_2O$

Lesson 6: Reactivity series of metals

a) Prerequisites/Revision/Introduction

All previous lessons have to be understood

b) Teaching resources

Well equipped chemistry laboratory

c) Learning activities 17.6

- After organizing the learners in their respective groups, recall them the safety measures and let them work together in their groups without intervene directly.
- Monitor how the learners are progressing towards the knowledge to be learned and assist those who are doing experiment
- Invite group leaders to presents the students' findings, but manage your time well.
- Record the key points for each presentation in order to harmonize later.
- Evaluate the learners' findings and emphasize on which are correct, incomplete or false
- Ask learners to insert the new knowledge in their presentations and to correct the false information by eliminating all mistakes.
- Summarize the contents by giving more examples. Let students do checking up 17.6.

d)Expected answer for activity 17.6

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
$Mg(s) + CuSO_4(aq) \rightarrow MgSO_4(aq) + Cu(s)$

e) Checking up 17.6: expected answers

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; being a weaker metal can't displace the stronger zinc from zinc suplphate.

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 + magnesiun**

2. Least reactive X, then Y and Z (Most reactive)

3. a)Yes b)No c)Yes d) Yes

17.6. Unit Summary

- **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.
- 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 poor. 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. Whenever one substance loses one or more electrons (is oxidized), another substance gains the electrons (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.**
- The reducing agent is itself oxidized when it gives up electrons, and the oxidizing agent is itself reduced when it accepts electrons.
- Among the simplest of redox processes is the reaction of an aqueous cation, usually a metal ion, with a free element to give a different ion and a different element. Noting the results from a succession of different reactions makes it possible to organize an activity series, which ranks the elements in order of their reducing ability in aqueous solution.
- 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.

17.7. Expected Answers for "end unit assessment"

1. B(gold is highly non reactive in such way it cannot be oxidized by O2 to form gold oxide)

2. B, 3.D, 4.A, 5.CO

6. Metals corrode because they oxidize easily. Referencing Table 17.2, 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 than most of the metals. 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, O2 is not capable of oxidizing these metals at standard conditions.

7. $Au + HNO_3 + HCl \rightarrow AuCl_4^{-} + NO$

Only deal with ions that are reacting (omit H+): Au + NO^{3-} + Cl– → AuCl4– + 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+ + Cr2O72– → 2 Cr3+ + 7 H2O)

$3\ H_2O + C_2H_5OH \rightarrow 2\ CO_2 + 12\ H^{+} + 12\ e^{-}$

b) $16\ H^{+} + 2\ Cr_2O_7^{2-} + C_2H_5OH \rightarrow 4\ Cr_3+ + 2\ CO_2 + 11\ H_2O$

10. Aluminum 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 Al3+, 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 $3Cl_2 + 6NaOH(conc.,hot) \rightarrow 5NaCl(aq) \rightarrow NaClO_3(aq) + 3H_2O(l)$

This is a disproportionation reaction where the O.N of Cl_2 chenges from zero to -1 and zero to +5, the answer is B

14. A and C

15. **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 agents are any species that cause oxidation and thus are themselves reduced - e.g. the oxidizing agent O2 is reduced to O2- when it oxidizes a metal such as Zn to Zn2+.

Oxidant: Another name for an oxidizing agent - oxidants cause an oxidation to occur and are themselves reduced in the redox reaction.

Reducing agents are any species that cause reduction and thus are themselves oxidized - e.g. the reducing agent H2S is oxidized to S when it reduces

Fe^{3+} to Fe^{2+}

Reductant: Another name for a reducing agent - reductants cause a reduction to occur and are themselves oxidized in the redox reaction.

16. Oxidation of a species occurs when:

(i) it gains oxygen atoms e.g. $2Mg + O_2 \rightarrow 2MgO$

(ii) it loses electrons e.g. $Mg \rightarrow Mg^{2+} + 2e-$

(iii) its oxidation number increases.

e.g. the oxidation number of Mg in both (i) and (ii) increases from zero on

the LHS to +2 on the RHS.

Reduction of a species occurs when:

(i) it loses oxygen atoms e.g. $CuO + H_2 \rightarrow Cu + H_2O$

(ii) it gains electrons e.g. $Cu_2+ + 2e- \rightarrow Cu$

(iii) its oxidation number decreases.

e.g. the oxidation number of Cu in both (i) and (ii) decreases from +2 on the

LHS to zero on the RHS.

17. (i) $Fe^{3+} + e- \rightarrow Fe^{2+}$ (reduction)

$2I– \rightarrow I2 + 2e-$ (oxidation)

$2Fe^{3+} + 2I^- \rightarrow 2Fe^{2+} + I_2$

(ii) $Sn^{2+} \rightarrow Sn^{4+} + 2e-$ (oxidation)

$Fe^{3+} + e- \rightarrow Fe^{2+}$ (reduction)

$Sn^{2+} + 2Fe^{3+} \rightarrow Sn^{4+} + 2Fe^{2+}$

(iii) $Ag^+ + e- \rightarrow Ag$ (reduction)

$Cu \rightarrow Cu^{2+} + 2e^-$ (oxidation)

$Cu + 2Ag^+ \rightarrow Cu_2+ + 2Ag$

(iv) $2H^+ + 2e^- \rightarrow H_2$ (reduction)

$Al \rightarrow Al^{3+} + 3e^-$ (oxidation)

$6H^+ + 2Al \rightarrow 3H_2 + 2Al^{3+}$

(v) $Fe^{3+} + e^- \rightarrow Fe^{2+}$ (reduction)

$H_2S \rightarrow S + 2H^+ + 2e^-$ (oxidation)

$H_2S + 2Fe^{3+} \rightarrow 2H^+ + S + 2Fe^{2+}$

18. (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.

19. These are the Displacement reaction based on the reactivity series of the metals

	Mg(NO3)2	FeSO4	Cu(NO3)2	Pb(NO3)2	Zn(NO3)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


K Potassium
Na Sodium
Ca Calcium
Mg Magnesium
Al Aluminium
C *Carbon*
Zn Zinc
Fe Iron
Sn Tin
Pb Lead
H *Hydrogen*
Cu Copper
Ag Silver
Au Gold
Pt Platinum
(added for comparison)

20. 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.

21. (a) Reducing agent: Cl^- Oxidizing agent: MnO2

Atom oxidized: Cl as C^{l-} (O.N. = -1) to Cl in Cl_2 (O.N. = 0).

Atom reduced: Mn in MnO_2 (O.N. = +4) to Mn as Mn2+ (O.N. = +2).

(b) Reducing agent: SO_2 Oxidizing agent: NO_3^-

Atom oxidized: S in SO2 (O.N. = +4) to S in SO42S (O.N. = +6).

Atom reduced: N in NO3- (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 Ag2S (O.N. = +1).

Atom reduced: H in H_2S (O.N. = +1) to H in H_2 (O.N. = 0).

(d) Reducing agent: H2S 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: MnO4-

Atom oxidized: Fe as Fe2+ (O.N. = +2) to Fe as Fe^{3+} (O.N. = +3).

Atom reduced: Mn in MnO_4^- (O.N. = +7) to Mn as Mn2+ (O.N. = +2).

(f) Reducing agent: Fe2+ Oxidizing agent: Cr2O72-

Atom oxidized: Fe as Fe2+ (O.N. = +2) to Fe as Fe3+ (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: Cl2

Atom oxidized: Br as Br- (O.N. = -1) to Br as the element Br_2 (O.N. = 0).

Atom reduced: Cl as the element Cl2 (O.N. = 0) to Cl as Cl^- (O.N. = -1).

(h) Reducing agent: H2 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 Sn4+ (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 Pb2+ (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).

22. (a). magnesium, zinc, iron, copper

(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.

17.8. Additional activities

17.8.1. Remedial activity

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 postive 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. $CH4\ (g) + H_2O(g) \rightarrow CO(g) + 3H_2\ (g)$

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.

	Redox?	Ox. Agent	Red. Agent	Substance Oxidized	Substance 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)

d. 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. $4\ NH_3(g) + 5\ O_2(g) \longrightarrow 4\ NO(g) + 6\ H2O(g)$

$-3\ +1 \quad 0 \quad +2\ -2 \quad +1\ -2$ oxidation numbers

$2\ NO(g) + O2(g) \longrightarrow 2\ NO2(g)$

$+2\ -2 \quad 0 \quad +4\ -2$

$3\ NO2(g) + H2O(l) \longrightarrow 2\ HNO3(aq) + NO(g)$

$+4\ -2 \quad +1\ -2 \quad +1\ +5\ -2 \quad +2\ -2$

All three reactions are oxidation-reduction reactions since there is a change in oxidation numbers of some of the elements in each reaction.

b. $4\ NH3 + 5\ O_2 \rightarrow 4\ NO + 6\ H2O$; O_2 is the oxidizing agent and NH3 is the reducing agent.

$2\ NO + O_2 \rightarrow 2\ NO_2$; O2 is the oxidizing agent and NO is the reducing agent.

$3\ NO_2 + H_2O \rightarrow 2\ HNO3 + NO$; NO_2 is both the oxidizing and reducing agent.

17.8.2. Consolidation activity

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. $Cr2O7\ 2\text{-}\ (aq) + Cl\text{-}(aq) \rightarrow Cr^{3+}(aq) + Cl_2\ (g)$

c. $Pb(s) + PbO_2\ (s) + H2SO_4\ (aq) \rightarrow PbSO_4\ (s)$

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. $(\text{Cu} \rightarrow \text{Cu}^{2+} + 2\ \text{e}^-) \times 3$ $\text{NO}_3^- \rightarrow \text{NO} + 2\ \text{H}_2\text{O}$

$(3\ \text{e}^- + 4\ \text{H}^+ + \text{NO}_3^- \rightarrow \text{NO} + 2\ \text{H}_2\text{O}) \times 2$

Adding the two balanced half-reactions so that electrons cancel:

$$3\ \text{Cu} \rightarrow 3\ \text{Cu}^{2+} + 6\ \text{e}^-$$

$$\underline{6\ \text{e}^- + 8\ \text{H}^+ + 2\ \text{NO}_3^- \rightarrow 2\ \text{NO} + 4\ \text{H}_2\text{O}}$$

$$3\ \text{Cu(s)} + 8\ \text{H}^+\text{(aq)} + 2\ \text{NO}_3^-\text{(aq)} \rightarrow 3\ \text{Cu}^{2+}\text{(aq)} + 2\ \text{NO(g)} + 4\ \text{H}_2\text{O(l)}$$

b. $(2\ \text{Cl}^- \rightarrow \text{Cl}_2 + 2\ \text{e}^-) \times 3$ $\text{Cr}_2\text{O}_7^{2-} \rightarrow 2\ \text{Cr}^{3+} + 7\ \text{H}_2\text{O}$

$6\ \text{e}^- + 14\ \text{H}^+ + \text{Cr}_2\text{O}_7^{2-} \rightarrow 2\ \text{Cr}^{3+} + 7\ \text{H}_2\text{O}$

Add the two half-reactions with six electrons transferred:

$$6\ \text{Cl}^- \rightarrow 3\ \text{Cl}_2 + 6\ \text{e}^-$$

$$\underline{6\ \text{e}^- + 14\ \text{H}^+ + \text{Cr}_2\text{O}_7^{2-} \rightarrow 2\ \text{Cr}^{3+} + 7\ \text{H}_2\text{O}}$$

$$14\ \text{H}^+\text{(aq)} + \text{Cr}_2\text{O}_7^{2-}\text{(aq)} + 6\ \text{Cl}^-\text{(aq)} \rightarrow 3\ \text{Cl}_2\text{(g)} + 2\ \text{Cr}^{3+}\text{(aq)} + 7\ \text{H}_2\text{O(l)}$$

c. $\text{Pb} \rightarrow \text{PbSO}_4$ $\text{PbO}_2 \rightarrow \text{PbSO}_4$

$\text{Pb} + \text{H}_2\text{SO}_4 \rightarrow \text{PbSO}_4 + 2\ \text{H}^+$ $\text{PbO}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{PbSO}_4 + 2\ \text{H}_2\text{O}$

$\text{Pb} + \text{H}_2\text{SO}_4 \rightarrow \text{PbSO}_4 + 2\ \text{H}^+ + 2\ \text{e}^-$ $2\ \text{e}^- + 2\ \text{H}^+ + \text{PbO}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{PbSO}_4 + 2\ \text{H}_2\text{O}$

Add the two half-reactions with two electrons transferred:

$$2\ \text{e}^- + 2\ \text{H}^+ + \text{PbO}_2 + \text{H}_2\text{SO}_4 \rightarrow \text{PbSO}_4 + 2\ \text{H}_2\text{O}$$

$$\underline{\text{Pb} + \text{H}_2\text{SO}_4 \rightarrow \text{PbSO}_4 + 2\ \text{H}^+ + 2\ \text{e}^-}$$

$$\text{Pb(s)} + 2\ \text{H}_2\text{SO}_4\text{(aq)} + \text{PbO}_2\text{(s)} \rightarrow 2\ \text{PbSO}_4\text{(s)} + 2\ \text{H}_2\text{O(l)}$$

This is the reaction that occurs in an atomobile lead-storage battery.

d. $Mn^{2+} \rightarrow MnO_4^-$

$(4\ H_2O + Mn^{2+} \rightarrow MnO_4^- + 8\ H^+ + 5\ e^-) \times 2$

$NaBiO_3 \rightarrow Bi^{3+} + Na^+$

$6\ H^+ + NaBiO_3 \rightarrow Bi^{3+} + Na^+ + 3\ H_2O$

$(2\ e^- + 6\ H^+ + NaBiO_3 \rightarrow Bi^{3+} + Na^+ + 3\ H_2O) \times 5$

$8\ H_2O + 2\ Mn^{2+} \rightarrow 2\ MnO_4^- + 16\ H^+ + 10\ e^-$

.

$10\ e^- + 30\ H^+ + 5\ NaBiO_3 \rightarrow 5\ Bi^{3+} + 5\ Na^+ + 15\ H_2O$

$8\ H_2O + 30\ H^+ + 2\ Mn^{2+} + 5\ NaBiO_3 \rightarrow 2\ MnO_4^- + 5\ Bi^{3+} + 5\ Na^+ + 15\ H_2O + 16\ H^+$

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

Use the same method as with acidic solutions. After the final balanced equation, convert H+ to OH– as described in Section 18.1 of the text. The extra step involves converting H+ into H2O by adding equal moles of OH– to each side of the reaction. This converts the reaction to a basic solution while still keeping it balanced.

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

$4\ H_2O + Al \rightarrow Al(OH)_4^- + 4\ H^+ + 3\ e^-$

$$\begin{array}{c} 4\ H_2O + Al \rightarrow Al(OH)_4^- + 4\ H^+ + 3\ e^- \\ 3\ e^- + 4\ H^+ + MnO_4^- \rightarrow MnO_2 + 2\ H_2O \\ \hline 2\ H_2O(l) + Al(s) + MnO_4^-(aq) \rightarrow Al(OH)_4^-(aq) + MnO_2(s) \end{array}$$

H^+ doesn't appear in the final balanced reaction, so we are done.

b. $Cl_2 \rightarrow Cl^-$ $Cl_2 \rightarrow OCl^-$

$2\ e^- + Cl_2 \rightarrow 2\ Cl^-$ $2\ H_2O + Cl_2 \rightarrow 2\ OCl^- + 4\ H^+ + 2\ e^-$

$$\begin{array}{c} 2\ e^- + Cl_2 \rightarrow 2\ Cl^- \\ 2\ H_2O + Cl_2 \rightarrow 2\ OCl^- + 4\ H^+ + 2\ e^- \\ \hline 2\ H_2O + 2\ Cl_2 \rightarrow 2\ Cl^- + 2\ OCl^- + 4\ H^+ \end{array}$$

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 (2H2O). 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^-.

$$6e^- + 7\ H^+ + NO_2^- \rightarrow NH_3 + 2\ H_2O$$

$$\underline{4\ H_2O + 2\ Al \rightarrow 2\ AlO_2^- + 8\ H^+ + 6\ e^-}$$

$$OH^- + 2\ H_2O + NO_2^- + 2\ Al \rightarrow NH_3 + 2\ AlO_2^- + H^+ + OH^-$$

Reducing gives $OH^-(aq) + H_2O(l) + NO_2^-(aq) + 2\ Al(s) \rightarrow NH_3(g) + 2\ AlO_2^-(aq)$.

Solution:

6. Chlorine gas was first prepared in 1774 by C. W. Scheele by oxidizing sodium chloride with manganese(IV) oxide. The reaction is

$NaCl\ (aq) + H_2SO_4\ (aq) + MnO2\ (s) \rightarrow Na_2SO4\ (aq) + MnCl2\ (aq) + H_2O(\ l\ ) + Cl_2\ (g)$

Balance this equation.

Solution:

$NaCl + H2SO4 + MnO2 \rightarrow Na2SO4 + MnCl2 + Cl2 + H2O$

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:

$$4\ NaCl + H_2SO_4 + MnO2 \rightarrow Na_2SO_4 + MnCl_2 + Cl2 + H_2O$$

Balance the Na^+ and SO_4^{2-} ions next:

$$4\ NaCl + 2\ H_2SO_4 + MnO_2 \longrightarrow 2\ Na_2SO4 + MnCl_2 + Cl_2 + H_2O$$

On the left side: 4 H and 10 O; on the right side: 8 O not counting H2O

We need 2 H2O on the right side to balance H and O:

$$4\ NaCl(aq) + 2\ H_2SO_4(aq) + MnO2(s) \longrightarrow 2\ Na_2SO_4(aq) + MnCl_2(aq) + Cl_2(g) + 2\ H_2O(l)$$

17.8. 3. Extended activity

7. Sulfur dioxide (SO2) is a chemical of major industrial significance.

a. SO2 gas can be produced in a reaction between concentrated sulfuric acid and nickel metal. A containing Ni2+ 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 sulfite (ZnSO3) and hydrochloric acid according to the equation

$ZnSO_3(s) + 2H+(aq) \rightarrow Zn2+(aq) + SO_2(g) + H_2O(l)$

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 sulfuric acid and zinc metal?

A. H_2

B. H_2S

C. SO_2

D. SO_3

Solution:

a) i) Ni(s) → Ni^{2+}(aq) + 2e- ii) H_2SO_4(aq) + $2H^+$(aq) + 2e- → SO2(g) + $2H^2O$(l)

iii) Ni(s) + H_2SO_4(aq) + $2H^+$(aq) → 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 sulfuric acid, zinc metal would be the reductant(and be oxidized) and sulfuric acid would be the source of the oxidant(which will be reduced). In dilute sulfuric acid, the oxidant is H+, which is reduced to H2 according to

$2H^+$(aq) + 2e- → H_2(g)

In conc. Sulfuric acid the oxidant is H_2SO_4(l). When H_2SO_4 is reacting as an oxidant, and hence being reduced, the O.N of sulfur, which is +6), must decrease: the O.N of S in the suggested products are H_2S-(-), SO^{2-}(+4); SO3–(+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 → Pb^{2+}, Cl^- → Cl_2

ii) $S_2O_3^{2-}$ → S4O62-, I2 → 2I-

iii) IO_3-→ I2, I^- → I2

iv) ClO^- → ClO_3^-, ClO- → Cl-

v) H_2SO_4 → SO_2, Br^- → Br_2

vi) H2SO4→ S, I-→ I2

vii) H_2SO_4 → H_2S, I- → I_2

viii) ClO^- → Cl^-, I-→ I_2

ix) PbO_2 → Pb^{2+}, SO_3^{2-} → 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

a) 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) $2IO_3^- + 12H^+ + 10e- \rightarrow I_2 + 6H_2O$

$2I^- \rightarrow I_2 + 2e-$

$IO_3^- + 6H^+ + 5I^- \rightarrow$ 3I2 + $3H_2O$

iv) $ClO^- + 2H_2O \rightarrow ClO_3^-$ + 4H+ + 4e-

$ClO^- + 2H^+ + 2e- \rightarrow$ Cl- + H_2O

3ClO- → $2Cl^-$ + ClO3-

v) $H_2SO_4 + 2H^+ + 2e- \rightarrow SO2 + 2H_2O$

$2Br \rightarrow Br_2 + 2e-$

$H_2SO_4 + 2H+ + 2Br^- \rightarrow SO_2 + Br_2 + 2H_2O$

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) $H_2SO4 + 8H^+ + 8e- \rightarrow H_2S + 4H_2O$

$2I- \rightarrow I_2 + 2e-$

$H_2SO_4 + 8H^+ + 8I- \rightarrow H_2S + 4I_2 + 4H_2O$

viii) $ClO^- + 2H^+ + 2e- \rightarrow Cl^- + H_2O$

$2I^- \rightarrow I_2 + 2e-$

$ClO^- + 2H+ + 2I- \rightarrow Cl- + H2O + I2$

ix) $PbO_2 + 4H^+ + 2e- \rightarrow Pb^{2+} + 2H_2O$

$SO_3^{2-} + H_2O \rightarrow SO_4^{2-} + 2H^+ + 2e-$

$PbO_2 + 2H^+ + SO_3^{2-} \rightarrow Pb^{2+} + SO_4^{2-} + H_2O$

b)

Equation	Oxidising agent	Reducing agent
i)	PbO_2	Cl^-
ii)	I2	$S2O_3^{2-}$
iii)	IO_3^-	I^-
iv)	ClO^-	ClO^-
v)	$H2SO_4$	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, SO2 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 (O3), 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, O3 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 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) → $I_3^-(aq)$ (in Acid medium)

c. Cr(NCS)64-(aq) + Ce4+(aq) → Cr3+(aq) + Ce3+(aq) + NO3-(aq) + CO2 (g) + SO42-(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)64-(aq) + Ce4+(aq) → Ce(OH)3(s) + Fe(OH)3(s) + CO32-(aq) + NO3-(aq)(Base medium)

Solution

a.HCl(aq) dissociates to $H^+(aq) + Cl^-(aq)$. For simplicity, let's use H^+ and Cl^- separately.

$H^+ \rightarrow H_2$ $\qquad\qquad$ $Fe \rightarrow HFeCl_4$

$(2\,H^+ + 2\,e^- \rightarrow H_2) \times 3$ $\qquad\qquad$ $(H^+ + 4\,Cl^- + Fe \rightarrow HFeCl_4 + 3\,e^-) \times 2$

$$6\,H^+ + 6\,e^- \rightarrow 3\,H_2$$

$$\underline{2\,H^+ + 8\,Cl^- + 2\,Fe \rightarrow 2\,HFeCl_4 + 6\,e^-}$$

$$8\,H^+ + 8\,Cl^- + 2\,Fe \rightarrow 2\,HFeCl_4 + 3\,H_2$$

or $8\,HCl(aq) + 2\,Fe(s) \rightarrow 2\,HFeCl_4(aq) + 3\,H_2(g)$

b. $IO_3^- \rightarrow I_3^-$ $\qquad\qquad$ $I^- \rightarrow I_3^-$

$3\,IO_3^- \rightarrow I_3^-$ $\qquad\qquad$ $(3\,I^- \rightarrow I_3^- + 2\,e^-) \times 8$

$3\,IO_3^- \rightarrow I_3^- + 9\,H_2O$

$16\ e^- + 18\ H^+ + 3\ IO_3^- \rightarrow I_3^- + 9\ H_2O$

$16\ e^- + 18\ H^+ + 3\ IO_3^- \rightarrow I_3^- + 9\ H_2O$

$24\ I^- \rightarrow 8\ I_3^- + 16\ e^-$

$18\ H^+ + 24\ I^- + 3\ IO_3^- \rightarrow 9\ I_3^- + 9\ H_2O$

Reducing: $6\ H^+(aq) + 8\ I^-(aq) + IO_3^-(aq) \rightarrow 3\ I_3^-(aq) + 3\ H_2O(l)$

c. $(Ce^{4+} + e^- \rightarrow Ce^{3+}) \times 97$

$Cr(NCS)_6^{4-} \rightarrow Cr^{3+} + NO_3^- + CO_2 + SO_4^{2-}$

$54\ H_2O + Cr(NCS)_6^{4-} \rightarrow Cr^{3+} + 6\ NO_3^- + 6\ CO_2 + 6\ SO_4^{2-} + 108\ H^+$

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:

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.

$$39\ H_2O + Fe(CN)_6^{4-} \rightarrow Fe(OH)_3 + 6\ CO_3^- + 6\ NO_3^- + 75\ H^+ + 61\ e^-$$

$$\underline{61\ e^- + 183\ H_2O + 61\ Ce^{4+} \rightarrow 61\ Ce(OH)_3 + 183\ H^+}$$

$$222\ H_2O + Fe(CN)_6^{4-} + 61\ Ce^{4+} \rightarrow 61\ Ce(OH)_3 + Fe(OH)_3 + 6\ CO_3^{2-} + 6\ NO_3^- + 258\ H^+$$

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 18: ENERGY CHANGES AND ENERGY PROFILE DIAGRAMS

18

18.1. Key unit competence

To explain the concept of energy changes and energy profile diagrams for the exothermic and endothermic processes.

18.2. Prerequisite knowledge and skills

- Interpret the experimental results about energy changes occurring during chemical reactions.
- Carefully deal with reactions that produce a lot of energy.
- Respect the experimental protocol during chemistry practicals.

18.3. Cross-cutting issues to be addressed

Inclusive education

This unit involves number of structures that require experiment. It is therefore imperative to note that learners with visual impairment are helped by team working.

Standardisation culture

During the lesson of standard enthalpy changes, the word standard must be emphasised to remind the learners about the importance of standardization culture in daily life especially when purchasing and selling items on the market to always check their expiry dates. It is important to mention that expired items are very likely to exert negative side effects on the health of the consumers. This would stain the reputation of the traders.

18.4. Guidance on Introductory activity

Organise the learners in groups of 4 or 5 depending on the size of the class. Have the learners carry out the laboratory experiment. This activity intends to identify the prerequisite learners have on energy and types of reactions according to the absorption or release of heat.

Before introducing the lesson, you will have to introduce the whole unit by allowing learners to do introductory activity i form of experimental activity 18.1

- Form groups of 4-5 depending on the size of the class.
- Distribute the introductory activity and estimate the time for it.
- Assign working groups with tasks.

- Have the learners do activities 18.1 of lesson.
- Allows the learners to work together in groups.
- Collect the recorded information by different working groups.
- Invite group leaders to present their findings.
- In this step you can guide the learners to evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- You summarise the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples that could have not indicated in step 2.
- Integrate cross-cutting and real life experiences by linking them with the lesson learned.

Explanation to Introductory Activity 18

1. The chemicals (reactants and products) represent the part of universe under the study. They represent the system. Everything outside the **system** is called **surroundings.** In our context the surroundings are represented by the container of the reactants and products.

   Confirm the right findings from the recorded observations made by learners and correct the wrong ones.
2. Some reactions produce heat that is manifested by the increase in the temperature of the surroundings or heating up of the beaker in our case. They are called **exothermic reactions**. The reaction between calcium oxide and water and that between Zinc and hydrochloric acid are examples of such reactions.

3. Others absorb energy from the surroundings which results in the decrease in temperature of the surroundings, beaker in our case. They are called endothermic reactions. The reaction of Ammonium chloride and water and that of sodium thiosulphate and water are some examples of such reactions.

18.5. List of lessons (including assessments)

Unit No	Lesson title	Objectives	No of periods
18.1	Concept of systems	Explain the concept of system and distinguish between the types of systems.	3
18.2	The internal Energy of a system, heat energy and temperature	Distinguish between Temperature and heat.	3

18.3	The fist law of thermodynamics and some forms of standard enthalpy changes	Explain the concept of Exothermic and endothermic reactions and represent them using energy profile diagrams.	4
18.4	Energy profile diagrams for Exothermic and Endothermic reactions.	• Relate the type of reaction to its energy profile diagram. • Interprete the experimental results about energy changes occurring during chemical reactions. • Explain the energy change as a function of the breaking and formation of chemical bonds.	3
End unit assessment			2

Lesson 1: Concept of Systems

Guide on Activity 18.1

- Form groups of 4-5 depending on the dimensions of the Laboratory.
- Give the printed experimental protocol one copy per group.
- Give clear instructions related to the procedure for the safety of learners.
- Have learners work to work in groups.
- Collect the recorded observations by different working groups.
- Invite group leaders to present their findings.
- In this step you can guide the learners to evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- You summarise the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples.
- Integrate crosscutting issues and real life experiences by linking them with the learning activity.

Expected answers to Activity 18.1

1. Experiments 1 and 3 are exothermic, experiment 2 is endothermic.
2. Copper(II) sulfate + zinc →zinc sulfate + copper

   $CuSO4(aq) + Zn \rightarrow ZnSO4(aq) + Cu(s)$
3. Citric acid and sodium hydrogen carbonate.

N.B The endothermic reactions constitute the working principle of a cold pack.

4. Anhydrous copper(II) sulfate and water, or copper(II) sulfate solution and powdered zinc.

Expected answers to Checking up 18.1

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°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: The internal energy of a system, heat energy and temperature

Guide on Activity 18.2

- Organise learners in groups of 4-5 depending on the dimensions of the Laboratory.
- Give the printed experimental protocol one copy per group.
- Give clear instructions related to the procedure for the safety of learners.
- Collect the recorded observations by different working groups.
- Invite group leaders to present their findings.
- In this step you can guide the learners to evaluate the findings by confirming the correct answers, eliminating the wrong ones or completing some statements.
- You summarise the learned knowledge and gives examples which illustrate the learned content. Here you can also give other necessary examples.
- Integrate crosscutting issues and real life experiences by linking them with

1.a) $KE=\frac{1}{2}mv^2$

$$=\frac{1}{2}(80kg)\times(8ms^{-1})^2=2,560J.$$

b) PE= mgh

=0.154kg×9.81ms-2×1.5=2.27J

c) ME=KE+PE

Therefore,

=50,725J -3 4,300J =16,425J

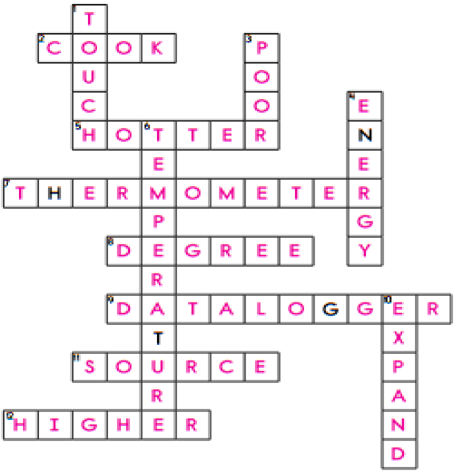
2. **a)** Warmed water feels hotter. It has more heat than the hands. Heat is flowing from water to hands.

b) Water collected from tape is colder. It has less heat than the hands. Heat is flowing from hands to water.

c) After mixing warm and cold water the same temperature is reached.The two types of water have the same amount of heat.

Expected answers to Checking up 18.2

1. a. S
   b. P
2. A
3. B Complete the statement below.
4. Hotter, colder
5.



Lesson 3: Standard enthalpy changes

Guide on Activity 18.3

In order to acquire a good understanding of the different forms of standard enthalpy changes, the learners need to remember the meaning of concept Standard. This part highlights some of the forms of standard enthalpy changes. The term is used to describe things which are usual and normal.

Expected answers to activity 18.3

1. The standard conditions of temperature and pressure refer to 0oC (273 K) and 1atmosphere(1atm=101,325Pa).

2. The term that describes the sum of kinetic energy and Potential energy?

Expected answers to checking up 18.3

1. w = (-2.8 atm)(89.3L-26.7L)
   w = (-2.8 atm)(62.6L)
   w= -175.28 atm × L(101.3 J/ atm X L) = 17756 J

2. ΔU = q + w
   w is positive because the surroundings are working on the system, 462J.

q is negative because the system is transferring heat to the surroundings, -128J.
ΔU = (-128J) + (462J)
ΔU = 334J

3. All bonds in the compound are broken in atomization (exothermic) and none are formed so enthalpies of atom are always positive.

Lesson4: Energy profile diagrams for Exothermic and Endothermic reactions.

Guide on activity 18.4

You are advised to have learners understand new terms especially the term profile. The term profile means the representation of something in outline.

Expected answers to Activity 18.4

1. The term energy of an object means the ability of that object to do work.

2. In points A, B and C the moving car has kinetic,

3. 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.

4. The points corresponding to maximum stability are A and C because they are the ones corresponding to minimum potential energy.

d) Expected answers to Checking up 18.4

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?

1.The activation energy of a reaction is the minimum energy required to start that reaction.

2. E (Reactants)=52 kJ

3. E (Products)=16 kJ

4. Ea (Forward)= (80-52) kJ=+28 kJ

5. Ea (Reverse)= (52-16) kJ=+64 kJ

6. ΔH (Forward)= (16-52) kJ= -36 kJ

7.ΔH (Reverse)= (52-16) kJ= +36 kJ

8. a.The forward reaction is exothermic

b.The reverse reaction is endothermic

9. Activated complex is AXM

10. 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).

11. 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.

12. 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.

18.6. Unit summary

- Thermodynamics is the study of energy changes that accompany chemical reactions or physical transformations. The part of universe under the study using laws of Thermodynamics is called System. Everything outside the system is known as surroundings.
- Internal energy represents the sum of energy of particles. According to the first law of Thermodynamics energy can neither be created nor destroyed. This holds well for isolated systems. The heat of an object is the total energy of all the molecular motion inside that object. The temperature is refers to the flow of thermal energy from a hotter object to a colder one. The standard conditions referring to thermochemical measurements are:
- The standard temperature corresponds to 250C (298 K), the standard pressure is equivalent to 1 atmosphere (1atm=101, 325 Pa.) while the concentration of solutions is 1.0 mol.dm-3 or 1.0 mol L-1. The standard enthalpy changes are heat changes accompanying chemical reactions or

physical transformations under standard conditions.

- Finally Energy profile diagrams are representations of the energy change occurring as the chemical reactions progresses. They represent both exothermic and endothermic reactions

18.7. Expected answers to End unit Assessment

1.

a. Exothermic, - 30 kJ

b. Endothermic, 30 kJ

c. 100 kJ

d. 60 kJ

e. The addition of a catalyst reduces the activation energy.

The curve with a catalyst will be under the curve without a catalyst.

2. $\Delta U = Q + W$

w is positive because the surroundings are working on the system, 73 J.
q is negative because the system is transferring heat to the surroundings, -26J
$\Delta U = (-26\ J) + (73\ J)$
$\Delta U = 47\ J$

18.8. Additional activities

18.7.1. Remedial Activity

1. Which statement about enthalpy is true?

a. Heat is given off to the surroundings in endothermic reactions.

b. Some substances have a negative specific heat capacity.

c. Specific heat capacity is the same for all liquids.

d. 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?

$C2H5OH\ (l) + 3O_2(g) \longrightarrow 2CO2\ (g) + 3H_2O(l) \qquad \Delta H = -1370\ kJ$

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 H2O?

a. Condensation

b. Melting

c. Solidification

d. Vaporization

8. The following decomposition reaction may occur in an air bag.

$2NaN3(s) \rightarrow 3N2(g) + 2Na(s)$ $\Delta H = -43.5$ kJ

What is the heat of formation, ΔHf, 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? (ΔHvap = 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.

$H2(g) + Cl2(g) \rightarrow 2HCl(g)$

What is the standard enthalpy of formation, ΔHf, 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 H2O(l) is formed from the combustion of H2(g) and O2(g)?

$H2(g) + \frac{1}{2} O2(g) \rightarrow H2O(l)$ $\Delta H = -285.8$ 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

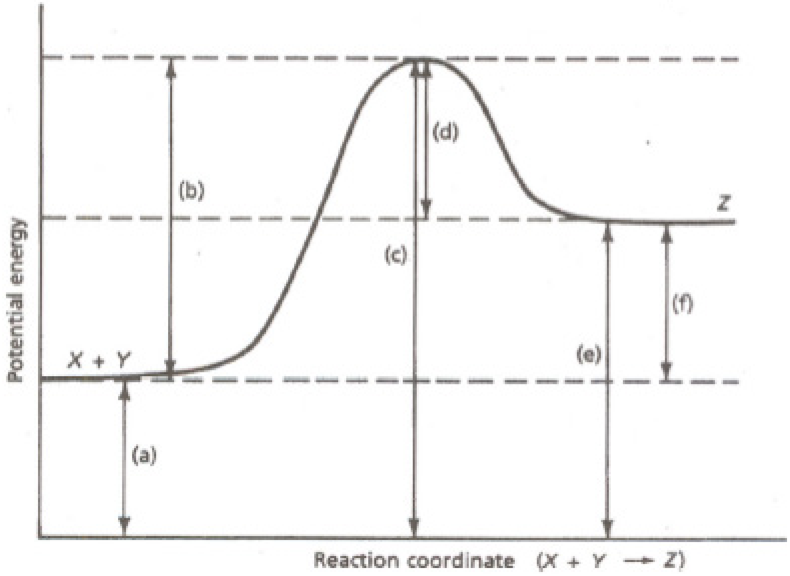
    d. In the amount of kinetic energy

Expected answers to remedial activity

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

18.7.2. Consolidation Activity

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?

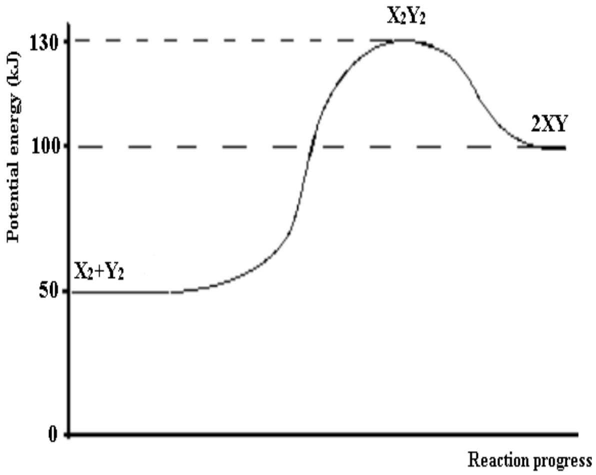
12. Would the heat of reaction increase, decrease, or remain unchanged?

Expected answers to Consolidation Activity

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

18.7.3. Extended Activity

Study the following Potential energy diagram and answer the questions related to it.



1. Is the overall reaction as shown exothermic or endothermic?
2. What is the activation energy for the forward reaction?
3. What is the activation energy for the reverse reaction?
4. What is the enthalpy change of reaction (ΔH) for the forward reaction?
5. What is the enthalpy change of reaction (ΔH) for the reverse reaction?
6. Is the reverse reaction exothermic or endothermic?
7. Which species forms the activated complex?
8. Which species or set of species has the strongest bonds?
9. Which species or set of species has the weakest bonds?
10. What is the enthalpy change of reaction for the reaction X2Y2→2XY?

Expected Answers to Extended Activity

1. The overall reaction is endothermic because ΔH (products) > ΔH (Reactants).
2. Ea (Forward)=(130-50) kJ=+80 kJ
3. Ea(Reverse)=(130-100) kJ=+30 kJ
4. ΔH (Forward)= (130-50) kJ= +50 kJ
5. ΔH (Reverse)= (50-100) kJ= -50 kJ
6. The reverse reaction is endothermic
7. The activated complex is X_2Y_2
8. The reactants X_2+Y_2 have the strongest bond because they have the lowest energy and therefore are in a maximum stability state. It requires high energy to break bonds in X_2+Y_2.
9. The products 2XY have the weakest bond because they have the highest energy and therefore are in a minimum stability state. It requires low energy to break bonds in 2XY.
10. ΔH for the reaction $X_2Y_2 \rightarrow 2XY$ =-30 kJ.

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