Physical Sciences Grade 12 Paper 2

Summaries, Terms, Definitions & Questions per Topic

2023

Secondary Schools Directorate

education
Department of Education
FREE STATE PROVINCE

TABLE OF CONTENTS

CREDITS

The following question papers were used to compile this book:
Department of Basic Education, *National Senior Certificate Physical Sciences Question Papers*, 2014 – 2022, Pretoria

HOW TO USE THIS DOCUMENT

Dear grade 12 learner

1. This document was compiled as an extra resource to help you to perform well in Physical Sciences.

2. Firstly, you must make sure that you study the summaries, terms and definitions provided for each topic. Theory always forms part of any test or examination, and you should ensure that you obtain full marks for ALL theory questions. Always be prepared to write a test on terms and definitions as soon as a topic is completed in class. Frequently revise terms and definitions of topics already completed so that you know them by the time you are sitting for a test or an examination.

3. Short summaries are supplied at each topic. Model answers are also supplied at the summary of topics that include questions requiring explanations. Answer all the questions on a certain topic in your homework book as soon as the topic is completed. Numerical answers are given at the questions where such answers are required. Use them to guide you about the correctness of your answers. If you differ from a given answer, you may want to check the correctness of your answer. Ensure you follow the steps indicated when answering such questions. A separate book with fully worked out answers is available. Your teacher will decide when he/she will hand out that specific booklet.

4. If you have the answer book, DO NOT look at the answers before attempting the questions. First try it yourself. Compare your answers with the given answers. Mark your work with a pencil and do corrections for your incorrect answers. If you do not know how to answer a question, the answers are there to guide you. Acquaint yourself with the way in which a particular type of question should be answered. Answers supplied are from memoranda used to mark the questions in previous years.

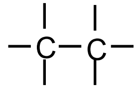
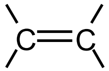
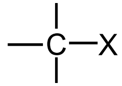
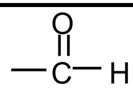
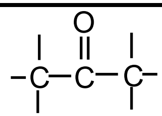
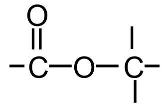
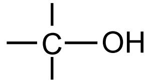
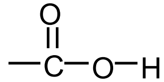
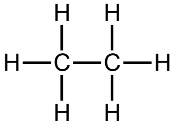
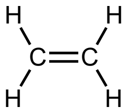
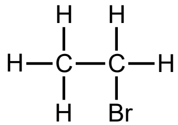
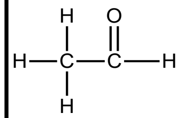
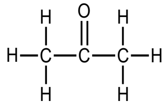
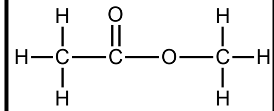
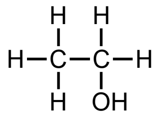
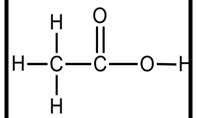
5. Your teacher can, for example, give you two of the questions in this document as homework. The following day he/she will just check whether you answered them and whether you marked your answers. The teacher will only discuss those questions in which you do not understand the answers supplied in the document. Therefore, a lot of time will be saved, depending on when you receive the answer booklet.

6. The answers are meant to help you to prepare for your tests and examinations. If you choose to copy answers into your homework book without trying them out yourself, you will be the losing the developmental aspect of trying to solve problems yourself!

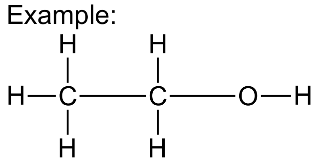
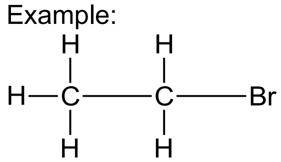
7. Work through all the questions and answers of a particular topic before you sit for an examination, even if you answered the questions before.

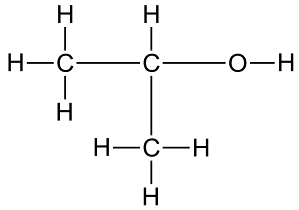
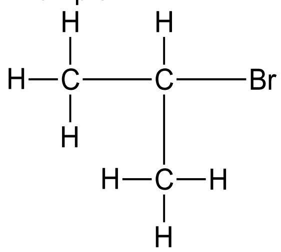
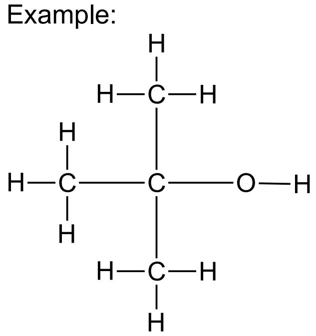
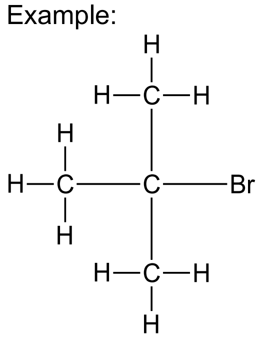
8. Any additional resource is only of help when used correctly. Ensure that you make use of all help provided in the correct way to enable you to be successful. All the best and may you perform very well in Physical Sciences.

ORGANIC MOLECULES

ORGANIC MOLECULES									
Homologous series	**Hydrocarbons** Alkanes	Alkenes	Alkynes	Haloalkanes	Aldehydes	Ketones	Esters	Alcohols	Carboxylic acids
General formula	C_nH_{2n+2}	C_nH_{2n}	C_nH_{2n-2}	$C_nH_{2n+1}X$ X = F, Cℓ, Br or I	$C_nH_{2n}O$	$C_nH_{2n}O$	$C_nH_{2n}O_2$	$C_nH_{2n+1}OH$	$C_nH_{2n}O_2$
Functional group	 Only C-H and C-C single bonds	 Carbon-carbon double bond	 Carbon-carbon triple bond	 Halogen atom bonded to a saturated C atom	 Formyl group	 Carbonyl group bonded to two C atoms		 Hydroxyl group bonded to a saturated C atom	 Carboxyl group
Example structural formula									
Example IUPAC name	Ethane	Ethene	Ethyne	Bromoethane	Ethanal	Propanone	Methyl ethanoate	Ethanol	Ethanoic acid
Intermolecular forces	**London forces**								
				Dipole-dipole forces					
								Hydrogen Bonding	
Chemical reactions	Oxidation Substitution Elimination	Addition		Substitution Elimination				Substitution Elimination Esterification	Esterification

NOMENCLATURE OF ORGANIC COMPOUNDS

TERMS AND DEFINITIONS	
Alcohol	An organic compound in which H atoms in an alkane have been substituted with hydroxyl groups (-OH groups). General formula: $C_nH_{2n+1}OH$
Aldehydes	Organic compounds having the general structure RCHO where R = H or alkyl. General formula: RCHO (R = alkyl group)
Alkane	An organic compound containing only C-H and C-C single bonds. General formula: C_nH_{2n+2}
Alkene	A compound of carbon and hydrogen that contains a carbon-carbon double bond. General formula: C_nH_{2n}
Alkyl group	A group formed by removing one H atom from an alkane.
Alkyne	A compound of carbon and hydrogen that contains a carbon-carbon triple bond.
Carbonyl group	Functional group of ketones (>C=O)
Carboxyl group	Functional group of carboxylic acids (-COOH)
Carboxylic acid	An organic compound containing a carboxyl group (-COOH group). General formula: $C_nH_{2n+1}COOH$ (or RCOOH)
Chain isomers	Compounds with the same molecular formula, but different types of chains.
Condensed structural formula	A formula that shows the way in which atoms are bonded together in the molecule but DOES NOT SHOW ALL bond lines.
Functional group	A bond or an atom or a group of atoms that determine(s) the physical and chemical properties of a group of organic compounds.
Functional isomers	Compounds with the same molecular formula, but different functional groups.
Haloalkane (Alkyl halide)	An organic compound in which one or more H atoms in an alkane have been replaced with halogen atoms. General formula: $C_nH_{2n+1}X$ (X = F, Cℓ, Br or I)
Homologous series	A series of organic compounds that can be described by the same general formula and that have the same functional group. OR A series of organic compounds in which one member differs from the next with a CH_2 group.
Hydrocarbon	Organic compounds that consist of hydrogen and carbon only.
IUPAC naming	A chemical nomenclature (set of rules) created and developed by the International Union of Pure and Applied Chemistry (IUPAC) to generate systematic names for chemical compounds.
Molecular formula	A chemical formula that indicates the type of atoms and the correct number of each in a molecule, e.g. CH_4.
Organic chemistry	Chemistry of carbon compounds.
Positional isomer	Compounds with the same molecular formula, but different positions of the side chain, substituents or functional groups on the parent chain.
Primary alcohol	The C atom bonded to the hydroxyl group is bonded to ONE other C atom. Example: 
Primary haloalkane	The C atom bonded to the halogen is bonded to ONE other C atom. Example: 
Saturated compounds	Compounds in which there are no multiple bonds between C atoms in their hydrocarbon chains. OR Compounds with only single bonds between C atoms in their hydrocarbon chains.

TERMS AND DEFINITIONS	
Secondary alcohol	The C atom bonded to hydroxyl group is bonded to TWO other C atoms. Example: 
Secondary haloalkane	The C atom bonded to the halogen is bonded to ONE other C atom. Example: 
Structural formula	A structural formula of a compound shows which atoms are attached to which within the molecule. Atoms are represented by their chemical symbols and lines are used to represent ALL the bonds that hold the atoms together.
Structural isomer	Organic molecules with the same molecular formula, but different structural formulae.
Substituent (branch)	A group or branch attached to the longest continuous chain of C atoms in an organic compound.
Tertiary alcohol	The C atom bonded to the hydroxyl group is bonded to THREE other C atoms. Example: 
Tertiary haloalkane	The C atom bonded to the halogen is bonded to THREE other C atoms. Example: 
Unsaturated compounds	Compounds in which there are multiple bonds (double or triple bonds) between C atoms in their hydrocarbon chains.

WRITING IUPAC NAMES OF ORGANIC COMPOUNDS

The name of each organic molecule has three parts:

prefix	parent	suffix
Type and position of substituents	Number of C atoms in the longest chain?	Type of functional group or homologous series

Step 1: Suffix
- Determine the **functional group** in the structure of the given compound or the homologous series to which the compound belongs.
- The functional group or homologous series determines the **suffix** (last part of the name).

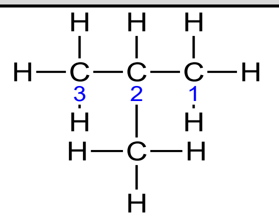
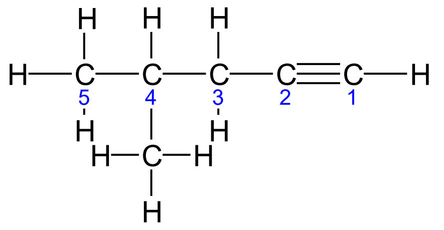
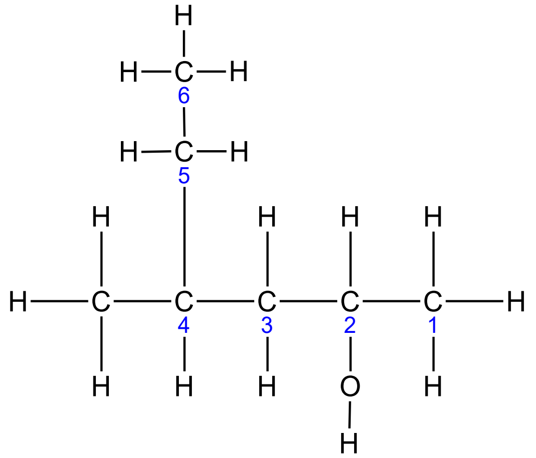
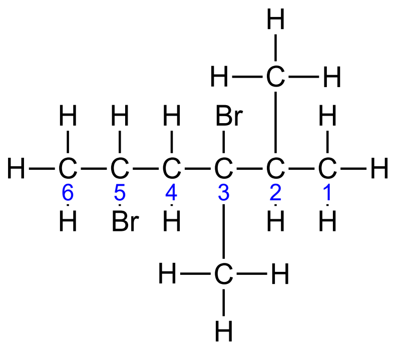
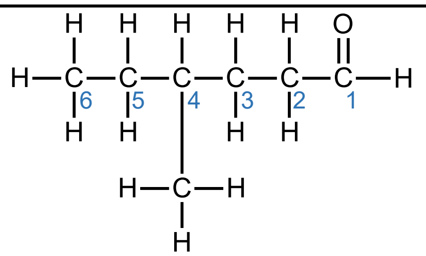
Step 2: Parent name
- The number of C atoms in the longest carbon chain that contains the functional group determines the **parent name**.
- Count the number of C atoms in the longest chain containing the functional group.

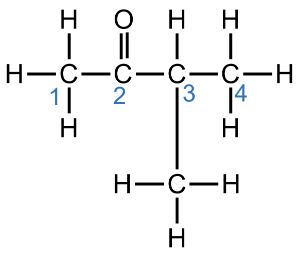
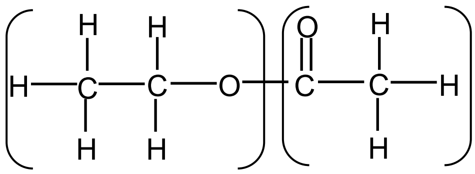
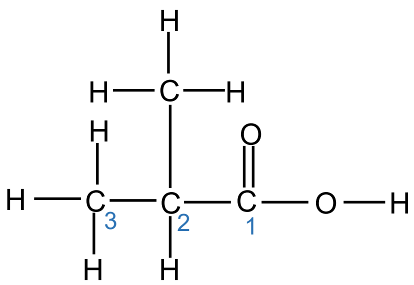
Number of carbon atoms	1	2	3	4	5	6	7	8
Parent name	meth	eth	prop	but	pent	hex	hept	oct

- **Alkanes and haloalkanes:** Number from the side that will give the substituents the smallest numbers.
- **Alkenes, alkynes, alcohols, ketones:** Number from the side that will the functional group the smallest number. The functional group receives a number that is written between parent name and suffix.
- **Aldehydes and carboxylic acids:** Number from the C atom that forms part of the functional group.
- **Esters:** To determine the first part of the name, count the C atoms attached to the single bonded O atom of the functional group. Add *–yl* to this part e.g. ethyl.
  To determine the last part of the name, number from the C atom bonded to the O atom with a double bond. Add the *-anoate* to this part e.g. but**anoate**.

Step 3: Prefix
- **Identify substituents** on the parent chain. Substituents can be *methyl* (one C atom i.e. $–CH_3$) or *ethyl* (2 C atoms i.e. $–CH_2CH_3$).
- **Use numbers on the parent chain to indicate the position of the substituents** on the parent chain.
- **Arrange substituents in alphabetical order** in the IUPAC name (*bromo, chloro, ethyl, methyl*)
- If two or more of the same substituents occur, use di- and tri- in front of the name of the substituent e.g. *dimethyl* or *tribromo*. (*Di-* and *tri* are ignored when arranging substituents in alphabetical order.)
- When there are two (or more) identical groups on the same C atom, the number of the C atom is repeated with commas between the numbers e.g. ***2,4,4-tri****methylhexan-3-one*
- Final IUPAC names, except those of esters, are written as **one word** with **COMMAS BETWEEN NUMBERS** and **HYPHENS BETWEEN NUMBERS AND WORDS** e.g. *2,4,4-trimethylhexan-3-*one. IUPAC names of esters and carboxylic acids are written as two words e.g. *ethyl methanoate and pentanoic acid*.

EXAMPLES

Compound	Step 1: Suffix	Step 2: Parent name	Step 3: Substituents
	A hydrocarbon with C-C single bonds only, thus an alkane. Ends on **-ane**	Three C atoms in longest chain: -prop- **prop**ane	Methyl group on C2. **2-methyl**propane
	A triple bond between C atoms, thus an alkyne. Ends on **-yne**	Five C atoms in longest chain: -pent- Triple bond after C1. **pent-1-**yne	One methyl group on C4. **4-methyl**pent-1-yne
	An –OH group, thus an alcohol. Ends on –ol	Six C atoms in longest chain. -OH group on C2. **hexan-2-**ol	Methyl group on C4. **4-methyl**hexan-2-ol
	C-C single bonds and Br groups, thus haloalkane. Name ends on **-ane** with halogen substituents in prefix.	Six C atoms in longest chain. Number from side that results in smallest number for substituents. Br does not get preference when numbering. **hex**ane	Two methyl groups on C2 and C3. Two Br groups on C3 and C5. **3,5-dibromo-2,3-dimethyl**hexane
	A –CHO group, thus an aldehyde. Name ends on −anal	Six C atoms in longest chain. Number from C atom of functional group. **Hex**anal	One substituent is present: a *methyl* group on C4 (the carbonyl C atom is always C1). **4-methylhexanal**

Compound	Step 1: Suffix	Step 2: Parent name	Step 3: Substituents
	A carbonyl group bonded to C atoms on both sides thus a ketone. Ends on **-2-one**	Four C atoms in longest chain: - **but-** Count from side giving carbonyl lowest number i.e. from left. **Carbonyl on 2nd C atom** **butan-2-one**	Methyl group on C3. **3-methyl**butan-2-one
 alkyl 2 C atoms ethyl 2 C atoms ethanoate	A –COO – functional group i.e. an ester. Divide ester between two O atoms: 1. Alkyl group: bonded to the sigle bonded O atom 2. Group containing the carbonyl group	Alkyl group has 2 C atoms: ethyl Group containing carbonyl has 2 C atoms: ethanoate	The name of alkyl group written first in name of ester: **ethyl ethanoate**
	A – COOH group, thus a carboxylic acid. Ends on –**oic acid**	Three C atoms in longest chain. C atom of functional group always C1. **Prop**anoic acid	Methyl group on C2. **2-methyl**propanoic acid

WRITING STRUCTURAL FORMULAE FROM IUPAC NAMES

1. Identify the parent name in the IUPAC name. Draw a carbon skeleton with the number of C atoms indicated by the parent name.
2. Identify the functional group (suffix) or homologous series to which this compound belongs. Use the number in front of the functional group (suffix) to place the functional on the correct C atom.
3. Identify the substituents (prefix). Use the number in front of each substituent to place the substituents on the correct C atoms.
4. Ensure that each C atom is surrounded by 4 bonds (lines indicating bonds).
5. Include H atoms at all open bonds after ensuring that each C atom is surrounded by 4 bonds.
6. All bonds should be shown. Do not draw any part of the molecule condensed e.g. $–CH_3$.
7. As a final check **ensure all C atoms form 4 bonds**, all O atoms 2 bonds and all H atoms, Br atoms and Cℓ atoms 1 bond.

STRUCTURAL ISOMERS

Same molecular formula, different structural formulae.

Chain isomers

Same molecular formula, different chains.

Example:
Butane
&
methylpropane

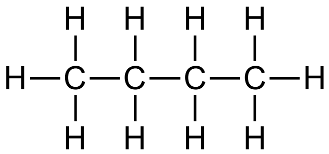
Positional isomers
Same molecular formula, different positions of functional group or side chain.

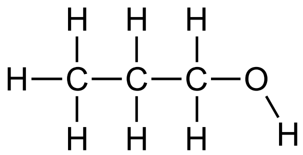
Example:
propan-1-ol
&
propan-2-ol

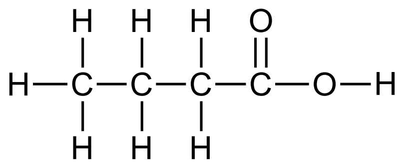
Functional isomers

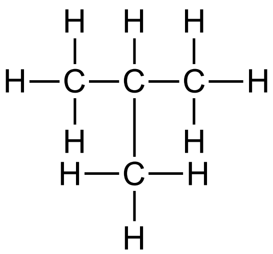
Same molecular formula, different functional groups.

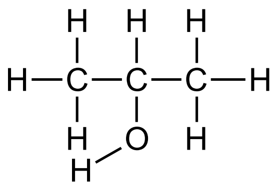
Example:
butanoic acid
&
ethyl ethanoate

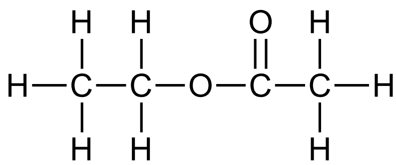

butane


propan-1-ol

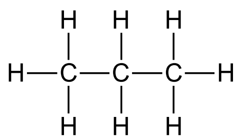

butanoic acid


methylpropane


propan-2-ol


ethyl ethanoate

FORMULAE FOR REPRESENTING MOLECULES

Type of formula	Definition	Example	
		Name	**Formula**
Molecular formula	A chemical formula that indicates the type of atoms and the correct number of each in a molecule.	propane	C_3H_8
Condensed structural formula	Shows the way in which atoms are bonded together in a molecule but DOES NOT SHOW ALL bond lines.	propane	$CH_3CH_2CH_3$
Structural formula	Shows which atoms are attached to which within the molecule. Atoms are represented by chemical symbols and lines are used to represent ALL the bonds that hold atoms together. Structural formulae usually do NOT depict the actual geometry/shape of molecules.	propane	

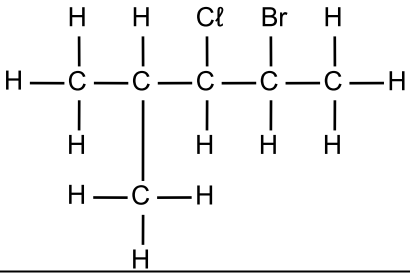
NOTE: When drawing **condensed structural formulae,** the following conventions are used:

- All atoms are drawn in, but the **bond lines are usually omitted**
- Atoms are usually drawn next to atoms to which they are bonded
- Brackets are used around similar groups bonded to the same atom

TYPICAL QUESTIONS

QUESTION 1 (November 2014)

Consider the organic compounds represented by the letters **A** to **F** in the table below.

A	2,2,4-trimethylhexane	**B**	$CH_3CH_2CH_2CH_2CHO$
C		**D**	Pentan-2-one

1.1 Write down the LETTER that represents the following:

1.1.1 An aldehyde (1)

1.1.2 A compound which has a carbonyl group bonded to two carbon atoms as its functional group (1)

1.2 Write down the IUPAC name of Compound **C.** (3)

1.3 Write down the structural formula of:

1.3.1 Compound **A** (2)

1.3.2 Compound **D** (2)

1.4 The table contains compounds which are functional isomers.

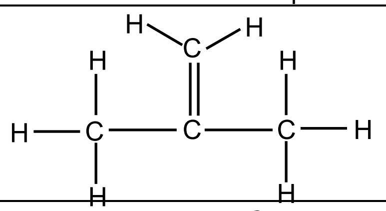
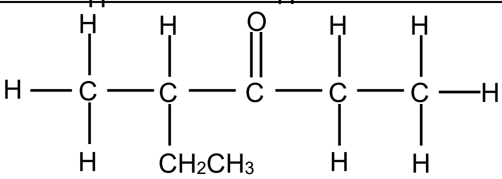
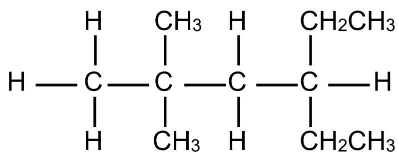
1.4.1 Define the term *functional isomer*. (2)

1.4.2 Write down the LETTERS that represent two compounds that are functional isomers. (1)

[12]

QUESTION 2 (March 2015)

The letters **A** to **F** in the table below represent six organic compounds.

A		**B**	2-methylbutanoic acid
C		**D**	
E	But-2-ene		

2.1 Write down the:

2.1.1 NAME of the functional group of compound **B** (1)

2.1.2 Homologous series to which compound **C** belongs (1)

2.2 Write down the IUPAC name of:

2.2.1 Compound **C** (2)

2.2.2 Compound **D** (2)

2.3 Write down the NAME or FORMULA of each product formed during the complete combustion of compound **D**. (2)

2.4 Write down the structural formula of:

2.4.1 Compound **B** (2)

2.4.2 A CHAIN ISOMER of compound **A** (2)

2.5 A laboratory assistant uses bromine water to distinguish between compounds **D** and **E**. She adds bromine water to a sample of each in two different test tubes. She observes that the one compound decolourises the bromine water immediately, whilst the other one only reacts after placing the test tube in direct sunlight. Write down the:

2.5.1 Letter (**D** or **E**) of the compound that will immediately decolourise the bromine water (1)

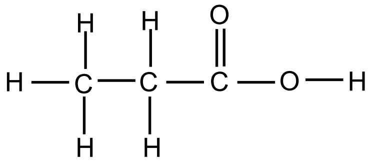
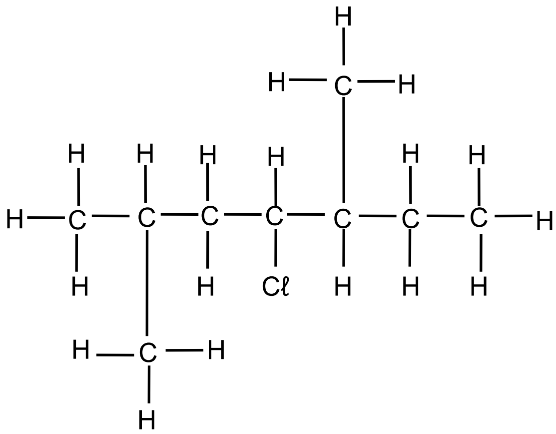
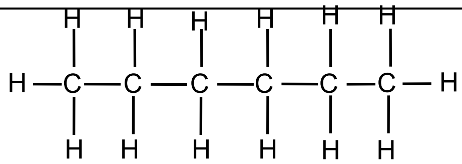
2.5.2 Name of the type of reaction that takes place in the test tube containing compound **D** (1)

2.5.3 Structural formula of the organic product formed in the test tube containing compound **E** (2)

[18]

QUESTION 3 (June 2015)

The letters **A** to **F** in the table below represent six organic compounds.

A		**B**	
C	C_4H_8	**D**	$CH_3CH_2COCH_3$
E	$CH_3CH(CH_3)CH_2OH$	**F**	

Use the information in the table (where applicable) to answer the questions that follow.

3.1 Write down the LETTER that represents a compound that:

3.1.1 Is a haloalkane (1)

3.1.2 Has a hydroxyl group as functional group (1)

3.1.3 Belongs to the same homologous series as ethanoic acid (1)

3.2 Write down the:

3.2.1 IUPAC name of compound **B** (3)

3.2.2 IUPAC name of compound **E** (2)

3.2.3 Structural formula of the functional group of compound **D** (1)

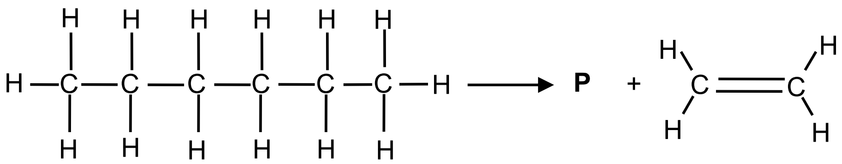
3.3 Compound C has CHAIN and POSITIONAL isomers.

3.3.1 Define the term *positional isomer*. (2)

3.3.2 Write down the IUPAC name of each of the TWO positional isomers of compound **C**. (4)

3.3.3 Write down the structural formula of a chain isomer of compound **C**. (2)

3.4 Compound **F** reacts at high pressure and high temperature to form compounds **P** and **Q** as given below.



Compound **F** Compound **Q**

Write down the:

3.4.1 Type of reaction that takes place (1)

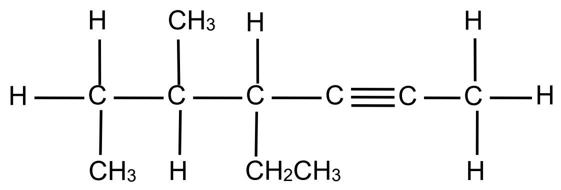
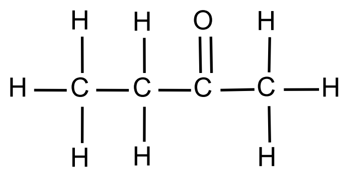
3.4.2 IUPAC name of compound **Q** (1)

3.4.3 Molecular formula of compound **P** (1)

[20]

QUESTION 4 (November 2015)

The letters **A** to **D** in the table below represent four organic compounds.

A		**B**	
C	CH_3CH_2CHO	**D**	Butane

4.1 Write down the:

4.1.1 Letter that represents a ketone (1)

4.1.2 Structural formula of the functional group of compound **C** (1)

4.1.3 General formula of the homologous series to which compound **A** belongs (1)

4.1.4 IUPAC name of compound **A** (3)

4.1.5 IUPAC name of compound **B** (2)

4.2 Compound **D** is a gas used in cigarette lighters.

4.2.1 To which homologous series does compound **D** belong? (1)

4.2.2 Write down the STRUCTURAL FORMULA and IUPAC NAME of a structural isomer of compound **D**. (4)

4.2.3 Is the isomer in QUESTION 4.2.2 a CHAIN, POSITIONAL or FUNCTIONAL isomer? (1)

4.3 Compound **D** reacts with bromine (Br_2) to form 2-bromobutane.

Write down the:

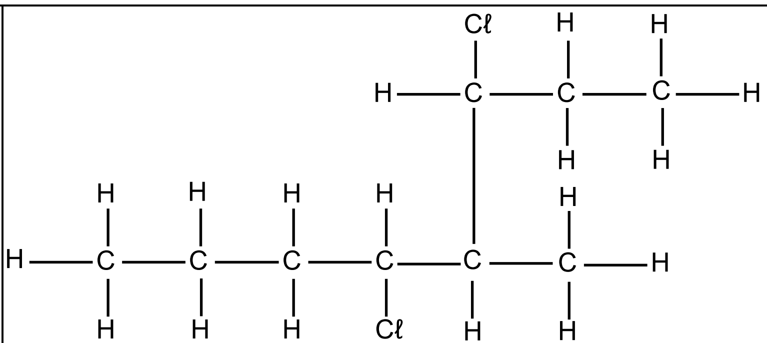
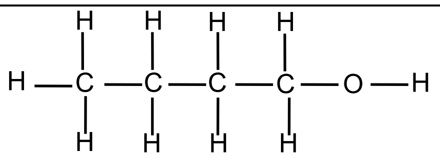
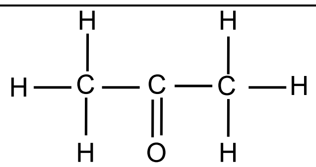
4.3.1 Name of the homologous series to which 2-bromobutane belongs (1)

4.3.2 Type of reaction that takes place (1)

[16]

QUESTION 5 (March 2016)

5.1 Consider the organic compounds represented by the letters **A** to **C** below.

A			
B		**C**	

Write down the:

5.1.1 Name of the homologous series to which compound **C** belongs (1)

5.1.2 IUPAC name of compound **A** (3)

5.1.3 Structural formula of a tertiary alcohol that is a structural isomer of compound **B** (2)

5.2 An alcohol and methanoic acid are heated in the presence of concentrated sulphuric acid to form an ester.

5.2.1 What is the role of the concentrated sulphuric acid in this reaction? (1)

5.2.2 Write down the NAME or FORMULA of the inorganic product formed. (1)

The ester contains 6,67% hydrogen (H), 40% carbon (C) and 53,33% oxygen (O). The molar mass of the ester is 60 $g·mol^{-1}$. Use a calculation to determine its:

5.2.3 Empirical formula (5)

5.2.4 Molecular formula (3)

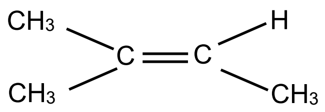
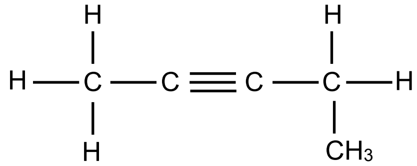
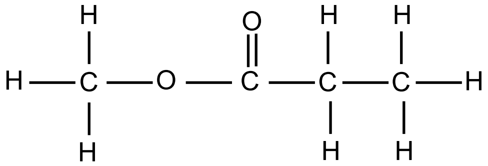
Write down the:

5.2.5 Structural formula of methanoic acid (1)

5.2.6 IUPAC name of the ester (2)

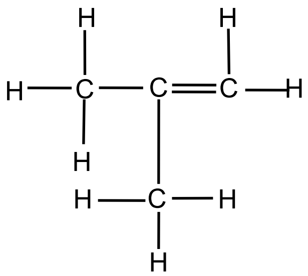
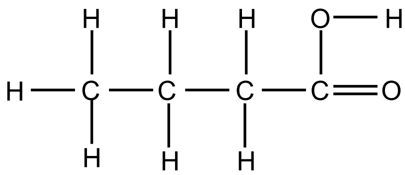
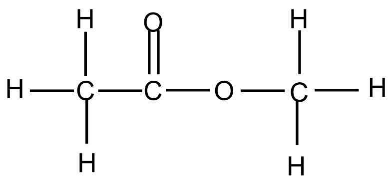
[19]

QUESTION 6 (June 2016)
Consider the organic compounds **A** to **F** below.

A		**B**	
C	$CH_3CH_2CH_2CH_2OH$	**D**	2,2-dimethylpropane
E		**F**	$CH_3CHC(CH_3)_2$

6.1 Write down the LETTER that represents a compound that:
6.1.1 Has a carbonyl group (1)
6.1.2 Is an alcohol (1)
6.1.3 Is a CHAIN ISOMER of $CH_3(CH_2)_3CH_3$ (1)
6.2 Write down the:
6.2.1 IUPAC name of compound **B** (2)
6.2.2 Structural formula of compound **F** (2)
6.2.3 IUPAC name of a POSITIONAL isomer of compound **A** (3)
6.3 Compound E is formed when a carboxylic acid reacts with another organic compound.
Write down the:
6.3.1 Homologous series to which compound **E** belongs (1)
6.3.2 NAME or FORMULA of the catalyst used for the preparation of compound **E** (1)
6.3.3 IUPAC name of compound **E** (2)
[14]

QUESTION 7 (November 2016)
The letters **A** to **F** in the table below represent six organic compounds.

A		**B**	
C	2,3-dibromo-3-methylpentane	**D**	Ethyl ethanoate
E			

7.1 Write down the LETTER that represents the following:
7.1.1 A hydrocarbon (1)
7.1.2 A functional isomer of compound **B** (1)
7.1.3 A compound which belongs to the same homologous series as compound **D** (1)
7.2 Write down the STRUCTURAL FORMULA of EACH of the following:
7.2.1 Compound **C** (3)
7.2.2 The acid used to prepare compound **D** (2)
7.3 Compound **A** reacts with an unknown reactant, **X**, to form 2-methylpropane.
Write down the:
7.3.1 NAME of reactant **X** (1)
7.3.2 Type of reaction that takes place (1)
[10]

QUESTION 8 (March 2017)

8.1 Define the term *functional group* of organic compounds. (2)

8.2 Write down the:

8.2.1 Structural formula of the functional group of aldehydes (1)

8.2.2 Name of the functional group of carboxylic acids (1)

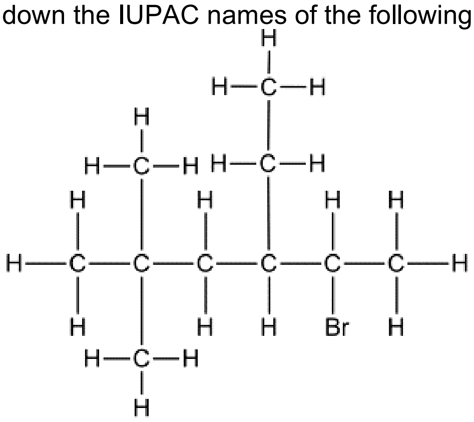
8.3 The IUPAC name of an organic compound is 2,4-dimethylhexan-3-one. For this compound, write down the:

8.3.1 Homologous series to which it belongs (1)

8.3.2 Structural formula (3)

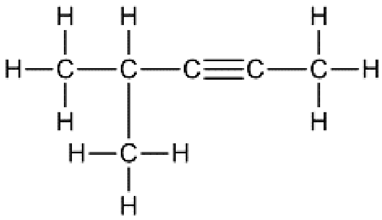
8.4 Write down the IUPAC names of the following compounds:

8.4.1



(3)

8.4.2

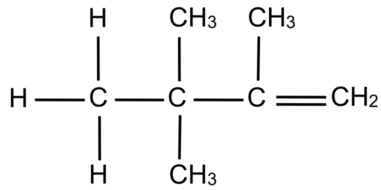
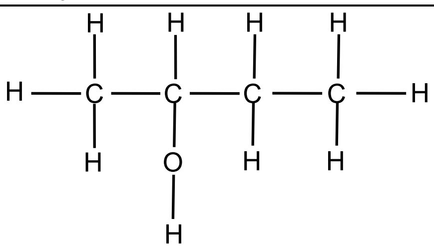
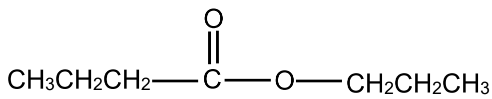


(2)

[13]

QUESTION 9 (June 2017)

The letters **A** to **F** in the table below represent six organic compounds.

A	$CH_3CH_2CH_2CHO$	**B**	
C	C_4H_8O	**D**	C_3H_8O
E		**F**	

9.1 Write down the letter that represents EACH of the following:

9.1.1 A hydrocarbon (1)

9.1.2 An alcohol (1)

9.1.3 An ester (1)

9.2 Write down the IUPAC name of:

9.2.1 Compound **A** (1)

9.2.2 Compound **B** (3)

9.3 Compound C is a functional isomer of compound **A**. Write down the structural formula of compound **C**.(2)

9.4 Compound **D** is used as one of the reactants to prepare compound **F**. Write down the:

9.4.1 Type of reaction which takes place to prepare compound **F** (1)

9.4.2 IUPAC name of compound **D** (2)

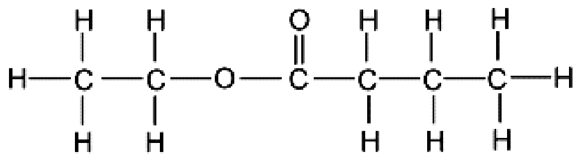
9.4.3 Structural formula of the other organic reactant used (2)

9.4.4 IUPAC name of compound **F** (2)

[16]

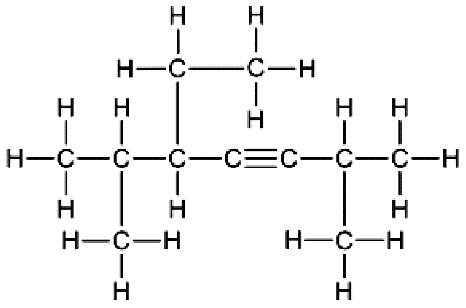
QUESTION 10 (November 2017)

10.1 Study the structural formula below. For this compound, write down the:



10.1.1 Homologous series to which it belongs (1)
10.1.2 IUPAC name (2)
10.1.3 IUPAC name of the organic acid used in its preparation (1)
10.1.4 STRUCTURAL FORMULA of its straight chain (unbranched) functional isomer (2)

10.2 Write down the structural formula of 4-methylpentan-2-one. (3)



10.3 Consider the structural formula alongside. For this compound, write down the:

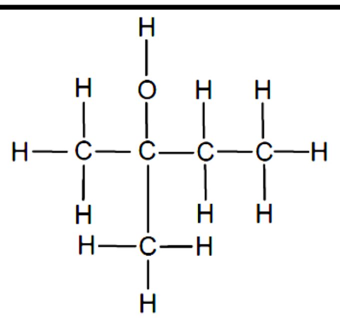
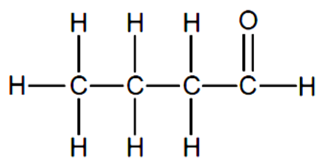
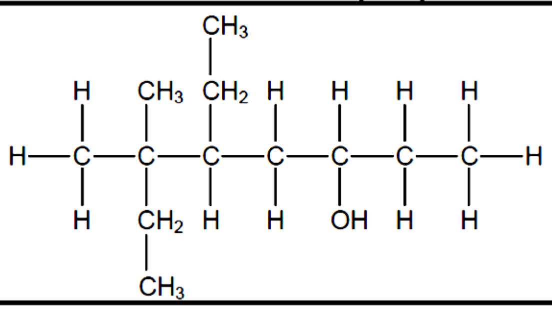
10.3.1 General formula of the homologous series to which it belongs (1)

10.3.2 IUPAC name (3)

[13]

QUESTION 11 (June 2018)

The letters **A** to **E** in the table below represent six organic compounds.

A		**B**	
C	Butan-1-ol	**D**	Butan-2-one
E			

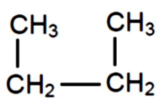
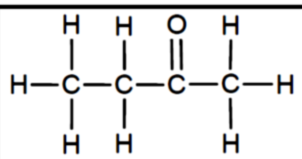
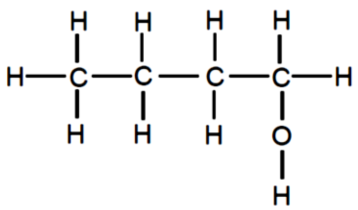
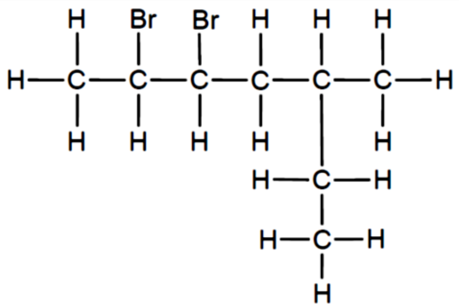
11.1 Write down the LETTER that represents EACH of the following:
11.1.1 A tertiary alcohol (1)
11.1.2 An aldehyde (1)
11.1.3 A ketone (1)
11.1.4 A functional isomer of compound **B** (1)
11.2 Write down the IUPAC name of:
11.2.1 Compound **B** (1)
11.2.2 Compound **E** (4)
11.3 Define the term *positional isomers*. (2)
11.4 Write down the STRUCTURAL FORMULA of:
11.4.1 A positional isomer of compound **C** (2)
11.4.2 Compound **D** (2)
11.4.3 The organic acid that will react with compound **C** to form butyl propanoate (2)
[17]

QUESTION 12 (June 2018)
Next to each letter, **A** to **F**, in the table below is the molecular formula of an organic compound.

A	C_2H_5Br	**B**	C_2H_4
C	C_4H_{10}	**D**	C_2H_6O
E	C_3H_6O	**F**	$C_3H_6O_2$

12.1 Choose a molecular formula above that represents an organic compound below. Write down only the letter (**A** to **F**) next to the question numbers.
12.1.1 A haloalkane (1)
12.1.2 An alcohol (1)
12.1.3 An unsaturated hydrocarbon (1)
12.1.4 An aldehyde (1)
12.1.5 A product of thermal cracking of compound **C** (1)
12.2 If compound **F** is a carboxylic acid, write down the following:
12.2.1 The structural formula of a FUNCTIONAL isomer of **F** (2)
12.2.2 The IUPAC name of a FUNCTIONAL isomer of **F** (2)
12.3 Compound **B** is a monomer used to make a polymer. Write down the:
12.3.1 Definition of a *polymer*. (2)
12.3.2 IUPAC name of the polymer (1)
12.3.3 Balanced equation for the polymerisation reaction (3)
12.4 Compound **A** is used as a reactant in the production of compound **D**. Name the type of reaction that takes place. (1)
12.5 State TWO changes that can be made to the reaction conditions in QUESTION 12.4 to obtain compound **B**, instead of **D**, as product. (2)
[18]

QUESTION 13 (June 2019)
The letters **A** to **F** in the table below represent six organic compounds.

A		**B**	
C	$CH_3CCCH_2CH_3$	**D**	Butyl propanoate
E		**F**	

13.1 Is compound **C** SATURATED or UNSATURATED? Give a reason for the answer. (2)
13.2 Write down the LETTER that represents each of the following:
13.2.1 An ester (1)
13.2.2 A FUNCTIONAL ISOMER of butanal (1)
13.2.3 A compound with the general formula C_nH_{2n-2} (1)
13.2.4 A compound used as reactant in the preparation of compound **D** (1)
13.3 Write down the STRUCTURAL FORMULA of:
13.3.1 The functional group of compound **C** (1)
13.3.2 Compound **D** (2)
13.3.3 A CHAIN ISOMER of compound **A** (2)
13.4 Write down the:
13.4.1 IUPAC name of compound **F** (3)
13.4.2 Balanced equation, using MOLECULAR FORMULAE, for the complete combustion of compound **A** (3)
[17]

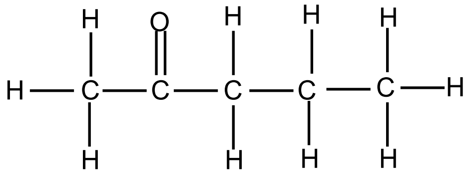
QUESTION 14 (November 2019)

14.1 The IUPAC name of an organic compound is 4,4-dimethylpent-2-yne.

14.1.1 Write down the GENERAL FORMULA of the homologous series to which this compound belongs. (1)

14.1.2 Write down the STRUCTURAL formula of this compound. (3)

14.2 The organic compound below has one positional isomer and one functional isomer.



15.2.1 Define the term *positional isomer*. (2)

For this compound, write down the:

14.2.2 IUPAC name of its POSITIONAL isomer (2)

14.2.3 Structural formula of its FUNCTIONAL isomer (2)

14.3 Consider the condensed structural formula of an organic compound below.

$CH_3CH_2C(CH_3)CH_3$
|
OH

14.3.1 Is this a PRIMARY, SECONDARY or TERTIARY alcohol? Give a reason for the answer. (2)

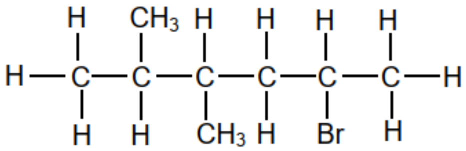
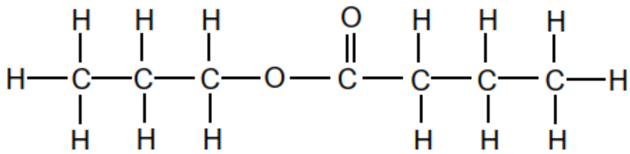
14.3.2 Write down the IUPAC name of the above compound. (2)

14.3.3 Write down the IUPAC name of the MAJOR ORGANIC PRODUCT formed when this compound undergoes an elimination reaction. (2)

[16]

QUESTION 15 (November 2020)

The letters **A** to **E** in the table below represent five organic compounds.

A		**B**	C_3H_8O
C		**D**	Pentan-2-one
E	4-methylpent-2-yne		

Use the information in the table to answer the questions that follow.

15.1 For compound **D**, write down the:

15.1.1 Homologous series to which it belongs (1)

15.1.2 IUPAC name of a FUNCTIONAL ISOMER (2)

15.2 Write down the:

15.2.1 IUPAC name of compound **A** (3)

15.2.2 STRUCTURAL FORMULA of compound **E** (2)

15.3 Compound **B** is a primary alcohol.

15.3.1 Write down the meaning of the term *primary alcohol*. (2)

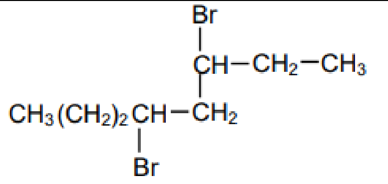
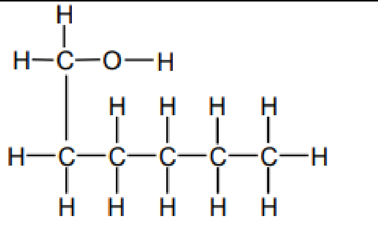
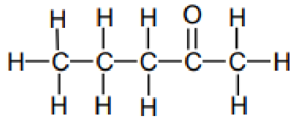
Compound **B** reacts with another organic compound **X** to form compound **C**. Write down the:

15.3.2 Type of reaction that takes place (1)

15.3.3 IUPAC name of compound **X** (1)

[12]

QUESTION 16 (June 2021)
The letters **A** to **F** in the table below represent six organic compounds.

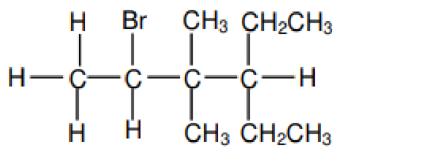
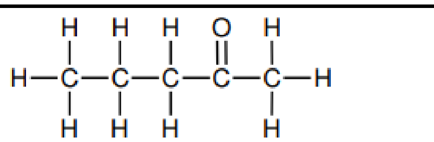
A	Methanoic acid	**B**	Pentanal
C	$C_{10}H_{22}$	**D**	
E		**F**	

16.1 Write down the LETTER(S) that represent(s) the following:
16.1.1 A ketone (1)
16.1.2 TWO compounds that are FUNCTIONAL ISOMERS (1)
16.1.3 A hydrocarbon (1)
16.2 For compound **D**, write down the:
16.2.1 Homologous series to which it belongs (1)
16.2.2 IUPAC name (3)
16.3 Consider compound **F**. Write down the IUPAC name of its:
16.3.1 POSITIONAL isomer (2)
16.3.2 CHAIN isomer (2)
16.4 During the reaction of compound **A** with compound **E** in the presence of an acid catalyst, two products are formed. For the ORGANIC product formed, write down the:
16.4.1 IUPAC name (2)
16.4.2 STRUCTURAL FORMULA of its FUNCTIONAL GROUP (1)
16.5 Compound **C** ($C_{10}H_{22}$) reacts at high temperatures and pressures to form a three-carbon alkene **P** and an alkane **Q**, as shown below.

$$C_{10}H_{22} \rightarrow \mathbf{P} + \mathbf{Q}$$

Write down the:
16.5.1 Type of reaction that takes place (1)
16.5.2 Molecular formula of compound **Q** (2)
16.5.3 STRUCTURAL FORMULA of compound **P** (2)
[19]

QUESTION 17 (September 2021)
The letters **A** to **E** in the table below represent five organic compounds.

A		**B**	C_xH_y
C		**D**	$CH_3(CH_2)_2CH(OH)CH_2CH_3$
E	$CH_3CH_2CH_2CH_2CH_2CH_2CHCH_2$		

17.1 Write down the LETTER that represents EACH of the following:
17.1.1 A ketone (1)
17.1.2 A hydrocarbon (1)
17.1.3 An alkene (1)

17.2 Write down the:
- 17.2.1 IUPAC name of compound **A** (3)
- 17.2.2 STRUCTURAL FORMULA of compound **D** (2)
- 17.2.3 IUPAC name of the STRAIGHT CHAIN FUNCTIONAL ISOMER of compound **C** (2)

17.3 Compound **B** is a straight chain compound that undergoes the following exothermic reaction:

$$2C_xH_y + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(g)$$

- 17.3.1 Besides being exothermic, what type of reaction is represented above? (1)
- 17.3.2 Determine the MOLECULAR FORMULA of compound **B**. (2)

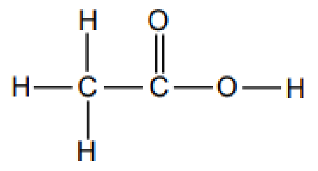
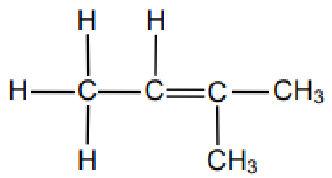
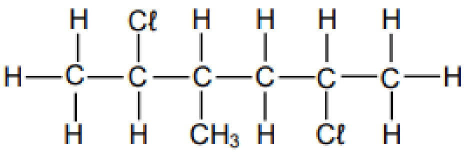
The reaction above takes place in a closed container at a constant temperature higher than 100 °C and at constant pressure.

- 17.3.3 Calculate the TOTAL VOLUME of gas formed in the container when 50 cm^3 of C_xH_y reacts completely with oxygen. (Answer: 850 cm^3) (3)

[16]

QUESTION 18 (November 2021)

The letters **A** to **H** in the table below represent eight organic compounds.

A		**B**	
C	$CH_3CH_2CH_2COCH_3$	**D**	C_2H_6O
E	C_2H_4	**F**	3-methylbutan-2-one
G		**H**	3-methylbutanal

18.1 Define the term *unsaturated compound*. (2)

18.2 Write down the:
- 18.2.1 Letter that represents an UNSATURATED compound (1)
- 18.2.2 NAME of the functional group of compound **C** (1)
- 18.2.3 Letter that represents a CHAIN ISOMER of compound **C** (2)
- 18.2.4 IUPAC name of compound **G** (3)
- 18.2.5 General formula of the homologous series to which compound **E** belongs (1)

18.3 Define the term *functional isomers*. (2)

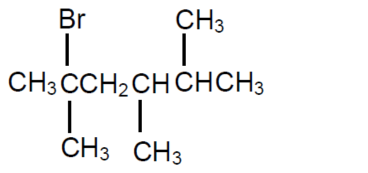
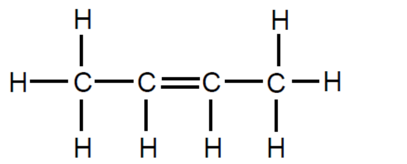
18.4 For compound **A**, write down the:
- 18.4.1 Homologous series to which it belongs (1)
- 18.4.2 STRUCTURAL FORMULA of its FUNCTIONAL isomer (2)

18.5 Compound **D** undergoes a dehydration reaction. Write down the:
- 18.5.1 IUPAC name of compound **D** (1)
- 18.5.2 Letter that represents a product of this reaction (1)
- 18.5.3 NAME or FORMULA of the inorganic reactant that is used in this reaction (1)

[18]

QUESTION 19 (June 2022)

The letters **A** to **H** in the table below represent eight organic compounds.

A		**B**	
C	Pent-2-ene	**D**	$CH_3CH_2CH_2CHO$
E	Butan-2-one	**F**	4,4-dimethylpent-2-yne
G	Butane	**H**	$CH_3CH_2CH_2COOH$

19.1 Write down the LETTER that represents a compound that:
- 19.1.1 Is a ketone (1)
- 19.1.2 Has the general formula C_nH_{2n-2} (1)
- 19.1.3 Is an isomer of 2-methylbut-2-ene (1)
- 19.1.4 Has the same molecular formula as ethyl ethanoate (1)

19.2 Write down the:
- 19.2.1 IUPAC name of compound **A** (3)
- 19.2.2 STRUCTURAL FORMULA of compound **F** (3)

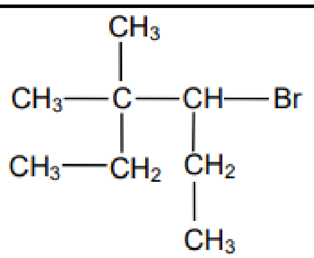
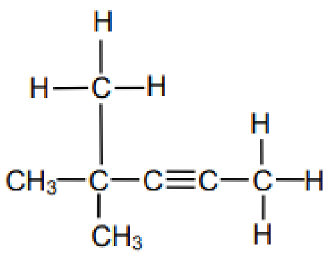
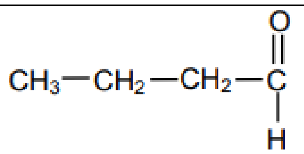
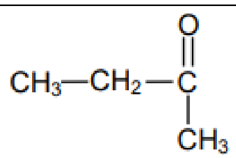
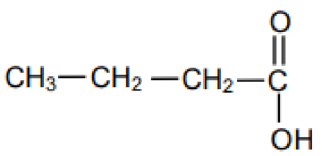
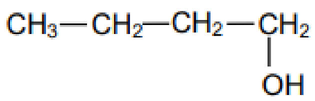
19.3 For compound **D**, write down the:
- 19.3.1 Homologous series to which it belongs (1)
- 19.3.2 NAME of its functional group (1)
- 19.3.3 STRUCTURAL FORMULA of its functional isomer (2)

19.4 For compound **G**, write down:
- 19.4.1 The IUPAC name of a chain isomer (2)
- 19.4.2 A balanced equation, using molecular formulae, for its complete combustion (3)

[19]

QUESTION 20 (November 2022)

A to **F** in the table below represent six organic compounds

A		**B**	
C		**D**	
E		**F**	

20.1 Write down the:
- 20.1.1 Letters that represent TWO organic compounds that are isomers of each other (1)
- 20.1.2 Type of isomers (CHAIN, FUNCTIONAL or POSITIONAL) identified in QUESTION 21.1.1 (1)
- 20.1.3 GENERAL FORMULA of the homologous series to which compound **B** belongs (1)
- 20.1.4 NAME of the functional group of compound **F** (1)

20.2 Write down the IUPAC name of:

20.2.1 Compound **A** (3)

20.2.2 Compound **B** (2)

20.2.3 Compound **C** (2)

20.3 Compound **F** reacts with a carboxylic acid to form compound **S** in the presence of a strong acid.

20.3.1 Write down the type of reaction that takes place. (1)

Compound **S** has an EMPIRICAL FORMULA of C_3H_6O and a molecular mass of 116 $g{\cdot}mol^{-1}$.

20.3.2 Write down the MOLECULAR FORMULA of the carboxylic acid. (3)

[15]

PHYSICAL PROPERTIES

PHYSICAL PROPERTIES — Melting point, Boiling point, Vapour pressure

depends on

Strength of intermolecular forces

- decreases → Lower boiling point, Higher vapour pressure, Lower melting point
- increases → Higher boiling point, Lower vapour pressure, Higher melting point

depends on

Chain length

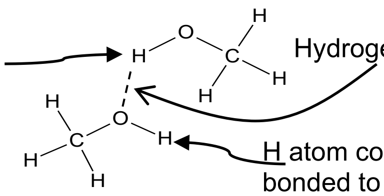
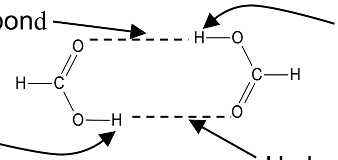
- Longer chain length
  Larger surface area
- Stronger IMF
- More energy needed to overcome IMF
- Higher boiling point
  Lower vapour pressure
  Higher melting point

Functional group
Homologous series

Determine type of IMF

- More branched
  More compact
  Smaller surface area
- Weaker IMF
- Less energy needed to overcome IMF
- Lower boiling point
  Higher vapour pressure
  Lower melting point

<table>
<tr><th>Homologous series</th><th colspan="3">Type of intermolecular forces</th></tr>
<tr><td>Alkanes
Alkenes
Alkynes</td><td rowspan="3">London forces WEAK</td><td></td><td rowspan="2"></td></tr>
<tr><td>Aldehydes
Ketones
Esters
Haloalkanes</td><td rowspan="2">Dipole-dipole forces STRONGER</td></tr>
<tr><td>Alcohols
Carboxylic acids</td><td>Hydrogen bonding STRONGEST</td></tr>
</table>

Alcohols – one site for hydrogen bonding	**Carboxylic acids – two sites for hydrogen bonding**
H atom covalently bonded to O atom  Hydrogen bond; H atom covalently bonded to O atom	Hydrogen bond; H atom covalently bonded to O atom  H atom covalently bonded to O atom; Hydrogen bond

EXPLANING DIFFERENCES IN PHYSICAL PROPERTIES

FOLLOW THE FOLLOWING STEPS:

STEP 1: State the **DIFFERENCE IN STRUCTURE** (chain length/branching/functional group) responsible for the difference in boiling point/melting point/vapour pressure.

STEP 2: State the **EFFECT** of this factor **ON INTERMOLECULAR FORCES**.

STEP 3: State the **EFFECT ON ENERGY NEEDED TO OVERCOME INTERMOLECULAR FORCES**.

TYPICAL EXAMPLES

EXAMPLE 1:
Explain the increase in boiling point from methane to butane.
Answer:
- **Increase in chain length** from methane to butane.
- **Increase** in **strength** of London forces/**intermolecular forces** from methane to butane.
- **More energy needed to overcome intermolecular forces**.
- Thus, increase in boiling point.

EXAMPLE 2:
Explain the increase in boiling point from compound A to compound C.

COMPOUNDS		***BOILING POINT (°C)***
A	*2,2-dimethylpropane*	*9*
B	*2-methylbutane*	*28*
C	*pentane*	*36*

(The compounds are isomers and have the same molecular mass, but different structural formulae.)
Answer:
- **Increase in chain length** from A to C OR **decrease in branching** from A to C.
- **Increase** in **strength** of London forces/**intermolecular forces** from A to C.
- **More energy needed to overcome intermolecular forces**
- Thus, increase in boiling point from A to C.

EXAMPLE 3:
Explain the increase in boiling point from compound A to compound C by referring to the type of intermolecular forces present in each.

COMPOUND		***MOLECULAR MASS ($g \cdot mol^{-1}$)***	***BOILING POINT (°C)***
A	*Butane*	*58*	*– 0,5*
B	*Propan-1-ol*	*60*	*98*
C	*Ethanoic acid*	*60*	*118*

Answer:
- **Butane**, an alkane, has **London forces** between molecules.
- **Propan-1-ol**, an alcohol, has **one site for hydrogen bonding**.
- **Ethanoic acid**, a carboxylic acid, has **two sites for hydrogen bonding**.
- **Strength of intermolecular forces increases from A to C**.
- **More energy is needed to overcome intermolecular forces from A to C**.

TERMS AND DEFINITIONS	
Boiling point	The temperature at which the vapour pressure of a liquid equals atmospheric pressure.
Dipole-dipole force	Intermolecular forces found between polar molecules i.e. molecules in which there is an uneven distribution of charge so that the molecule has a positive and a negative side.
Hydrogen bond	A strong intermolecular force found between molecules in which an H atom is covalently bonded to wither an N, O or F atom.
Intermolecular force	Forces between molecules that determine physical properties of compounds.
London force	A weak intermolecular force between non-polar molecules.
Melting point	The temperature at which the solid and liquid phases of a substance are at equilibrium.
Van der Waals forces	A combined name used for the different types of intermolecular forces.
Vapour pressure	The pressure exerted by a vapour at equilibrium with its liquid in a closed system.
Volatility	

TYPICAL QUESTIONS

QUESTION 1 (November 2014)

1.1 Give a reason why alkanes are saturated hydrocarbons. (1)

1.2 Write down the structural formula of:

1.2.1 The functional group of alcohols (1)

1.2.2 A tertiary alcohol that is a structural isomer of butan-1-ol (2)

1.3 Learners investigate factors that influence the boiling points of alkanes and alcohols. In one of the investigations, they determine the boiling points of the first three alkanes.

1.3.1 Write down an investigative question for this investigation. (2)

1.3.2 Fully explain why the boiling point increases from methane to propane. (3)

1.4 The learners find that the boiling point of propan-1-ol is higher than that of propane. Explain this observation by referring to the TYPE of INTERMOLECULAR FORCES present in each of these compounds. (3)

[12]

QUESTION 2 (March 2015)

Learners use compounds **A** to **C**, shown in the table below, to investigate a factor which influences the boiling point of organic compounds.

A	$CH_3CH_2CH_2CH_3$
B	$CH_3CH_2CH_2CH_2CH_3$
C	$CH_3CH_2CH_2CH_2CH_2CH_3$

2.1 Which ONE of the compounds (**A**, **B** or **C**) has the highest boiling point? (1)

2.2 For this investigation, write down the:

2.2.1 Independent variable (1)

2.2.2 Dependent variable (1)

2.3 Write down the name of the type of Van der Waals force that occurs between the molecules of compound **B**. (1)

2.4 How will the vapour pressure of 2-methylpentane compare to that of compound **C**? Write down only HIGHER THAN, LOWER THAN or EQUAL TO. (1)

The learners now compare the boiling points of compounds **D** and **E**, shown in the table below.

D	$CH_3CH_2CH_2CH_2CH_2OH$
E	$CH_3CH_2CH_2COOH$

2.5 How does the boiling point of compound **D** compare to that of compound **E**? Write down HIGHER THAN, LOWER THAN or EQUAL TO. Fully explain the answer. (4)

[9]

QUESTION 3 (June 2015)

The table below shows five organic compounds represented by the letters **A** to **E**.

A	CH_4
B	CH_3CH_3
C	$CH_3CH_2CH_3$
D	$CH_3CH_2CH_2CH_3$
E	CH_3CH_2OH

3.1 Is compound **B** SATURATED or UNSATURATED? Give a reason for the answer. (2)

Consider the boiling points of compounds **A** to **E** given in random order below and use them, where applicable, to answer the questions that follow.

0 °C	- 162 °C	- 42 °C	- 89 °C	78 °C

3.2 Write down the boiling point of:

3.2.1 Compound **C** (1)

3.2.2 Compound **E** (1)

3.3 Explain the difference in boiling points of compounds **C** and **E** by referring to the TYPE of intermolecular forces present in EACH of these compounds. (3)

3.4 Does vapour pressure INCREASE or DECREASE from compounds **A** to **D**? Fully explain the answer. (4)

3.5 How will the vapour pressure of 2-methylpropane compare to the vapour pressure of compound **D**? Write down only HIGHER THAN, LOWER THAN or EQUAL TO. (1)

[12]

QUESTION 4 (November 2015)

Four compounds of comparable molecular mass are used to investigate the effect of functional groups on vapour pressure. The results obtained are shown in the table below.

COMPOUND		**VAPOUR PRESSURE (kPa at 20 °C)**
A	Butane	204
B	Propan-2-one	24,6
C	Propan-1-ol	2
D	Ethanoic acid	1,6

4.1 Define the term *functional group* of an organic compound. (2)

4.2 Which ONE of the compounds (**A**, **B**, **C** or **D**) in the table has the:

4.2.1 Highest boiling point
(Refer to the vapour pressures in the table to give a reason for the answer.) (2)

4.2.2 Weakest intermolecular forces (1)

4.3 Refer to the type of intermolecular forces to explain the difference between the vapour pressure of compound **A** and compound **B**. (3)

4.4 The vapour pressures of compounds **C** and **D** are much lower than those of compounds **A** and **B**. Name the type of intermolecular force in **A** and **B** that is responsible for this difference. (1)

4.5 Briefly explain the difference in vapour pressure between compound **C** and compound **D**. (2)

4.6 During a combustion reaction in a closed container of adjustable volume, 8 cm^3 of compound **A** (butane) reacts in excess oxygen according to the following balanced equation:

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$$

If the initial volume of the oxygen in the container was 60 cm^3, calculate the TOTAL volume of the gases that are present in the container at the end of the reaction. All the gases in the container are at the same temperature and pressure. *(Answer: 80 cm^3)* (5)

[16]

QUESTION 5 (March 2016)

5.1 Define the term *boiling point*. (2)

5.2 What is the relationship between strength of intermolecular forces and boiling point? (1)

The relationship between strength of intermolecular forces and boiling point is investigated using four organic compounds from different homologous series. The compounds and their boiling points are given in the table below.

COMPOUND		BOILING POINT (°C)
A	Propane	- 42
B	Propan-2-one	56
C	Propan-1-ol	97
D	Propanoic acid	141

5.3 Refer to the TYPE and the STRENGTH of intermolecular forces to explain the difference in boiling points between:

5.3.1 Compounds **A** and **B** (3)

5.3.2 Compounds **C** and **D** (3)

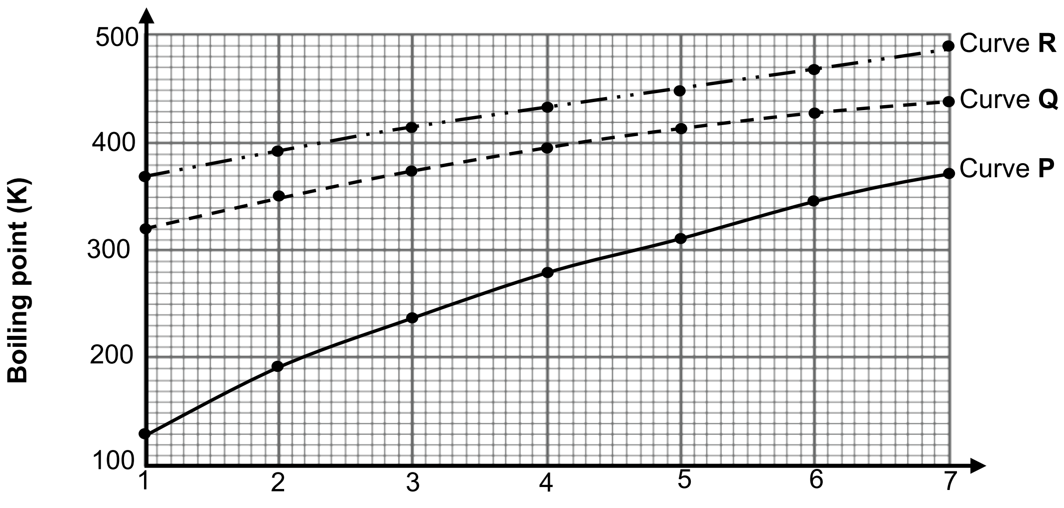
5.4 Is compound **B** a GAS or a LIQUID at room temperature? (1)

[10]

QUESTION 6 (June 2016)

The relationship between boiling point and the number of carbon atoms in straight chain molecules of alkanes, carboxylic acids and alcohols is investigated. Curves **P**, **Q** and **R** are obtained.

GRAPH OF BOILING POINT VERSUS NUMBER OF C ATOMS



6.1 Define the term *boiling point*. (2)

6.2 For curve **P**, write down a conclusion that can be drawn from the above results. (2)

6.3 Identify the curve (**P**, **Q** or **R**) that represents each of the following:

6.3.1 Alkanes (1)

6.3.2 Carboxylic acids (1)

6.4 Explain the answer to QUESTION 6.3.2 by referring to the:

- Types of intermolecular forces present in alkanes, carboxylic acids and alcohols
- Relative strengths of these intermolecular forces
- Energy needed (5)

[11]

QUESTION 7 (November 2016)

The boiling points of three isomers are given in the table below.

	ISOMERS	BOILING POINT (°C)
A	2,2-dimethylpropane	9
B	2-methylbutane	28
C	pentane	36

7.1 Define the term *structural isomer*. (2)

7.2 What type of isomers (POSITIONAL, CHAIN or FUNCTIONAL) are these three compounds? (1)

7.3 Explain the trend in the boiling points from compound **A** to compound **C**. (3)

7.4 Which ONE of the three compounds (**A**, **B** or **C**) has the highest vapour pressure? Refer to the data in the table to give a reason for the answer. (2)

7.5 Use MOLECULAR FORMULAE and write down a balanced equation for the complete combustion of compound **B**. (3)

[11]

QUESTION 8 (March 2017)

The boiling points of some organic compounds are given in the table below. **Y** represents an unknown boiling point.

	COMPOUND	BOILING POINT (°C)
A	Methanol	64,7
B	Ethanol	78,3
C	Propan-1-ol	97,2
D	Butan-1-ol	117,7
E	Butan-2-ol	99,5
F	2-methylpropan-1-ol	**Y**
G	2-methylpropan-2-ol	82,5

8.1 For the compounds listed above, write down the:

8.1.1 Structural formula of compound **F** (3)

8.1.2 LETTER that represents a POSITIONAL isomer of compound **E** (1)

8.1.3 LETTER that represents a CHAIN isomer of compound **E** (1)

8.2 The boiling points increase from compound **A** to compound **D**.

8.2.1 Give a reason for this increase in terms of the molecular structure. (1)

8.2.2 Name the intermolecular force in these compounds responsible for this increase. (1)

8.3 Consider the boiling points given below.

85 °C	108 °C	122 °C

8.3.1 From these boiling points, choose the boiling point represented by **Y** in the table above. (1)

8.2.2 Fully explain how you arrived at the answer to QUESTION 8.3.1. (4)

8.4 Hydrogen bonding is responsible for the relatively high boiling points of compounds **A** to **G** in comparison with hydrocarbons of similar molecular size. Draw TWO structural formulae of compound **A**. Use a dotted line to show the hydrogen bonding between the two structural formulae. (2)

8.5 Compound **B** reacts with propanoic acid in the presence of concentrated sulphuric acid. Write down the:

8.5.1 Type of reaction that takes place (1)

8.5.2 Structural formula of the organic product formed (2)

[17]

QUESTION 9 (June 2017)

Learners investigate factors which influence the boiling points of alcohols.
They use equal volumes of each of the alcohols and heat them separately in a water bath. The temperature at which each boil is measured. The results obtained are shown in the table below.

ALCOHOLS	BOILING POINTS OF ALCOHOLS (°C)
Butan-1-ol	117,7
Pentan-1-ol	138,5
Hexan-1-ol	157,0

9.1 Define the term *boiling point*. (2)

9.2 What property of alcohols requires them to be heated in a water bath? (1)

9.3 The boiling points of the alcohols are compared with each other.

9.3.1 What structural requirements must the alcohols meet to make it a fair comparison? (2)

9.3.2 Fully explain the trend in the boiling points. (3)

9.4 How will the boiling point of hexan-1-ol be affected if the volume of hexan-1-ol used is doubled? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

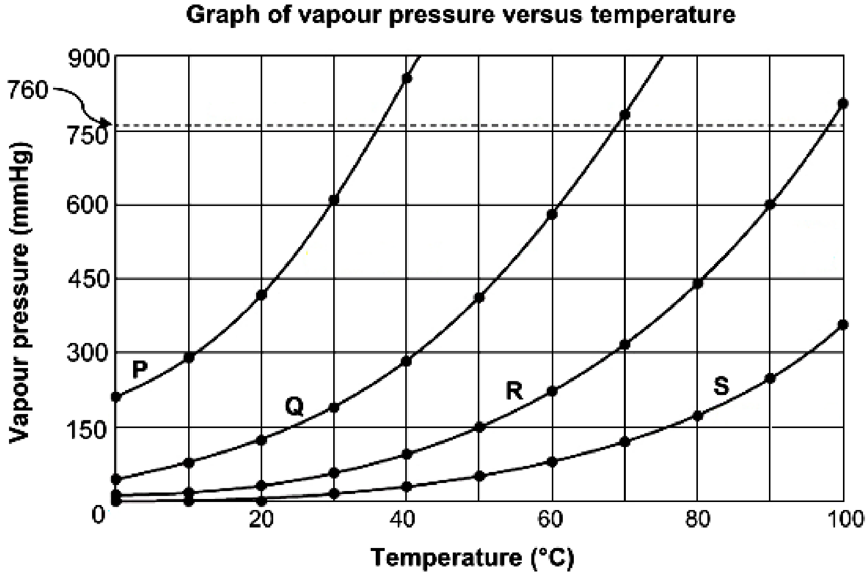
9.5 In another investigation the learners compare the boiling points of hexan-1-ol and hexanal.

9.5.1 Write down the independent variable for this comparison. (1)

9.5.2 They find that the boiling point of hexan-1-ol is higher than that of hexanal. Fully explain this observation. (4)

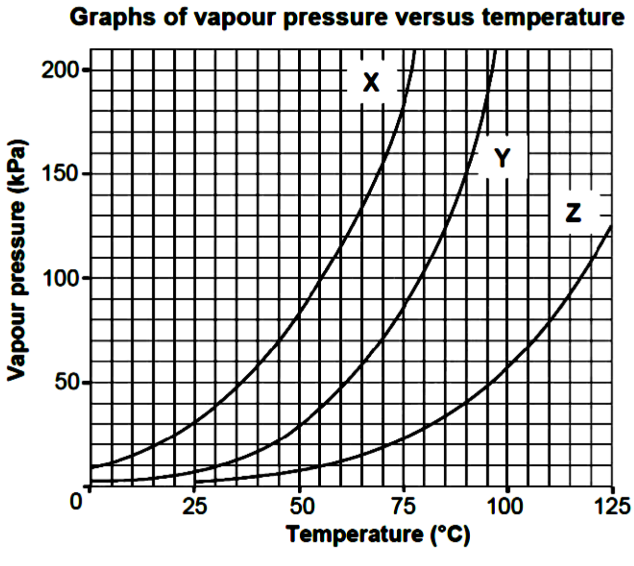
[14]

QUESTION 10 (November 2017)
The vapour pressure versus temperature graph below was obtained for four straight chain (unbranched) alkanes (**P**, **Q**, **R** and **S**). FROM **P** TO **S**, EACH COMPOUND DIFFERS FROM THE PREVIOUS COMPOUND BY A $-CH_2$ GROUP. The vapour pressures are measured in mmHg. Atmospheric pressure is 760 mmHg.



10.1 Give a reason why alkanes are said to be SATURATED. (1)
10.2 Define *vapour pressure*. (2)
10.3 Use the information in the graph above to answer the following questions.
10.3.1 What is the effect of an increase in temperature on vapour pressure? Choose from INCREASES, DECREASES or NO EFFECT. (1)
10.3.2 Which compound has a boiling point of approximately 68 °C? Give a reason for the answer. (2)
10.3.3 Which compound has the longest chain length? Fully explain the answer. (4)
10.4 Compound **P** has FIVE carbon atoms.
10.4.1 Draw the structural formula of a chain isomer of **P**. Write down the IUPAC name of this isomer. (3)
10.4.2 How will the vapour pressure of this isomer compare with that of compound **P**? Choose from HIGHER THAN, LOWER THAN or EQUAL TO. (1)
[14]

QUESTION 11 (March 2018)
Study the vapour pressure versus temperature graphs for three organic compounds, **X**, **Y** and **Z**, below which belong to different homologous series. Atmospheric pressure is 100 kPa.



11.1 Write down the vapour pressure of compound **Y** at 90 °C. (1)
11.2 The graphs can be used to determine the boiling points of the three compounds.
11.2.1 Define *boiling point*. (2)
11.2.2 Determine the boiling point of compound **X**. (1)

11.3 The homologous series to which the three compounds of similar molecular masses belong, were identified in random order as: alcohol; carboxylic acid; ketone

11.3.1 Which compound (**X**, **Y** or **Z**) is the carboxylic acid? (1)

11.3.2 Explain the answer to QUESTION 11.3.1 by referring to the type of intermolecular forces in compounds of each of the homologous series above. (4)

11.3.3 Compound **X** has three carbon atoms per molecule. Write down its IUPAC name. (1)

[10]

QUESTION 12 (June 2018)

The boiling points of straight-chain alkanes and straight-chain alcohols are compared in the table.

NUMBER OF CARBON ATOMS	BOILING POINTS OF ALKANES (°C)	BOILING POINTS OF ALCOHOLS (°C)
1	– 162	64
2	– 89	78
3	– 42	98
4	– 0,5	118

12.1 Explain the increase in boiling points of the alkanes, as indicated in the table. (3)

12.2 Explain the difference between the boiling points of an alkane and an alcohol, each having THREE carbon atoms per molecule, by referring to the TYPE of intermolecular forces. (4)

12.3 Does the vapour pressure of the alcohols INCREASE or DECREASE with an increase in the number of carbon atoms? (1)

12.4 How will the boiling point of 2-methylpropane compare to that of its chain isomer? Write down HIGHER THAN, LOWER THAN or EQUAL TO. Give a reason for the answer by referring to the structural differences between the two compounds. (2)

[10]

QUESTION 13 (November 2018)

The boiling points of different organic compounds are given below.

COMPOUND		BOILING POINT (°C)
A	HCOOH	101
B	CH_3COOH	118
C	CH_3CH_2COOH	141
D	$CH_3CH_2CH_2COOH$	164

13.1 Define *boiling point*. (2)

13.2 Write down the:

13.2.1 Name of the FUNCTIONAL GROUP of these compounds (1)

13.2.2 IUPAC name of compound **C** (1)

13.2.3 Structural formula of the FUNCTIONAL isomer of compound **B** (2)

13.3 Which ONE of the compounds, **A** or **B** or **C**, has the highest vapour pressure? Refer to the data in the table to give a reason for the answer. (2)

13.4 The boiling point of compound **B** is now compared with of compound **X**.

COMPOUND		BOILING POINT (°C)
B	CH_3COOH	118
X	$CH_3CH_2CH_2OH$	98

13.4.1 Besides the conditions used to determine boiling points, give a reason why this is a fair comparison. (1)

13.4.2 Is compound **X** a PRIMARY, SECONDARY or TERTIARY alcohol? Give a reason for the answer. (2)

13.4.3 Fully explain the difference between the boiling points by referring to the types of intermolecular forces present in each of these compounds. (4)

[15]

QUESTION 14 (June 2019)

Three compounds are used to investigate one of the factors that influences boiling point. The results obtained are shown in the table below.

COMPOUND		MOLECULAR MASS ($g·mol^{-1}$)	BOILING POINT (°C)
A	Butane	58	– 0,5
B	Propan-1-ol	60	98
C	Ethanoic acid	60	118

14.1 In one investigation, the boiling points of compound **B** and compound **C** are compared.

14.1.1 Is this a fair investigation? Write down YES or NO. Refer to the data in the table and give a reason for the answer. (2)

14.1.2 Write down the independent variable for this investigation. (1)

14.2 Which ONE of the compounds (**A**, **B** or **C**) has the highest vapour pressure? Give a reason for the answer. (2)

14.3 Refer to the intermolecular forces present in each compound and FULLY explain the trend in boiling points, as shown in the above table. (5)

14.4 Which compound, BUTAN-1-OL or PROPAN-1-OL, has the higher boiling point? Give a reason for the answer. (2)

[12]

QUESTION 15 (November 2019)

The boiling points of five organic compounds (**P**, **Q**, **R, S** and **T**) are studied.

COMPOUND	IUPAC NAME
P	Pentanal
Q	2,2-dimethylbutane
R	3-methylpentane
S	Hexane
T	Pentan-1-ol

15.1 Define the term *boiling point*. (2)

The boiling points of compounds **Q**, **R** and **S** are compared.

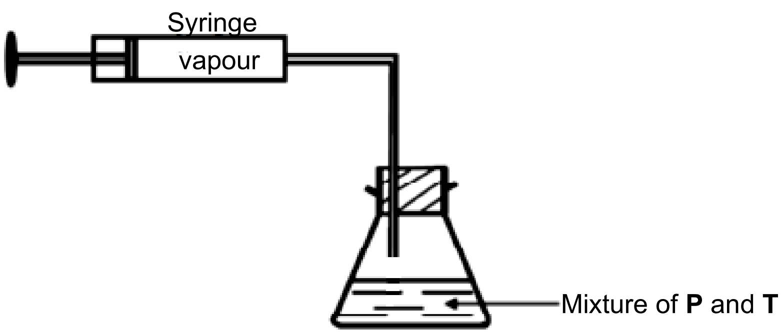
15.2 Give a reason why this is a fair comparison. (1)

The boiling points of **Q**, **R** and **S** are given below (NOT necessarily in the correct order).

55 °C	49,7 °C	68 °C

15.3 Which ONE of the three boiling points is most likely the boiling point of compound **R**? Explain the answer. (4)

15.4 A mixture of equal amounts of **P** and **T** is placed in a flask and heated to a temperature below their boiling points. Assume that no reaction or condensation takes place. The vapour produced is collected in a syringe.



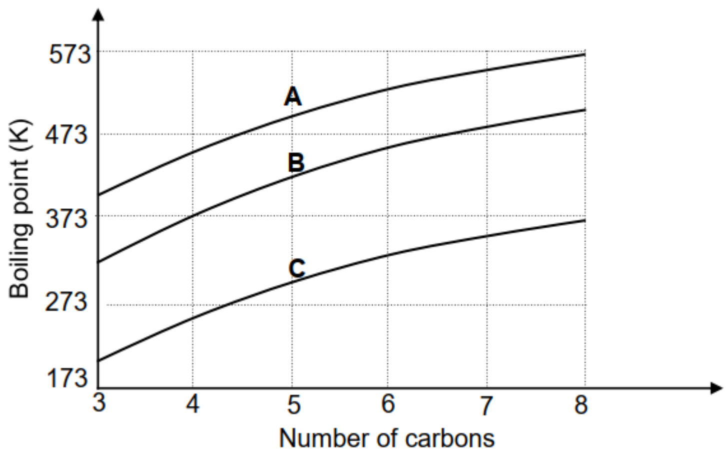
15.4.1 Which compound (**P** or **T**) will be present in a greater amount in the SYRINGE? (2)

15.4.2 Explain the answer to QUESTION 15.4.1 by referring to the TYPES and STRENGTHS of intermolecular forces. (3)

[12]

QUESTION 16 (November 2020)

The relationship between boiling point and the number of carbon atoms in straight chain molecules of aldehydes, alkanes and primary alcohols is investigated. Curves **A**, **B** and **C** are obtained.



16.1 Define the term *boiling point*. (2)

16.2 Write down the STRUCTURAL FORMULA of the functional group of the aldehydes. (1)

16.3 The graph shows that the boiling points increase as the number of carbon atoms increases. Fully explain this trend. (3)

16.4 Identify the curve (**A**, **B** or **C**) that represents the following:

16.4.1 Compounds with London forces only (1)

16.4.2 The aldehydes and explain the answer. (4)

16.5 Use the information in the graph and write down the IUPAC name of the compound with a boiling point of 373 K. (2)

16.6 Write down the IUPAC name of the compound containing five carbon atoms, which has the lowest vapour pressure at a given temperature. (2)

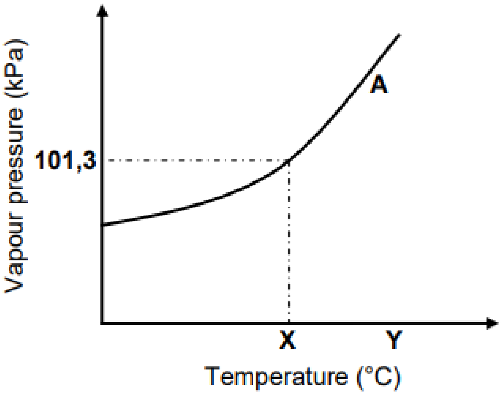
[15]

QUESTION 17 (June 2021)

Learners use compounds A, B and C to investigate one of the factors that influences the VAPOUR PRESSURE of organic compounds.

A	Butan-1-ol
B	Butan-2-one
C	Propanoic acid

17.1 Define the term *vapour pressure*. (2)
17.2 Write down the independent variable for this investigation. (1)
17.3 Which compound, **A** or **B**, has the higher vapour pressure? (1)
17.4 Fully explain the answer to QUESTION 17.3. Include the TYPES OF INTERMOLECULAR FORCES in your explanation. (4)
17.5 The graph below represents the relationship between vapour pressure and temperature for compound **A** at sea level. **X** and **Y** represent different temperatures.



17.5.1 Write down the term for the temperature represented by **X**. (1)
17.5.2 State the phase of compound **A** at temperature **Y**. Choose from GAS, LIQUID or SOLID. (1)
17.5.3 Redraw the graph above in your ANSWER BOOK. On the same set of axes, sketch the curve that will be obtained for compound **C**. Clearly label curve **A** and curve **C**. (2)
[12]

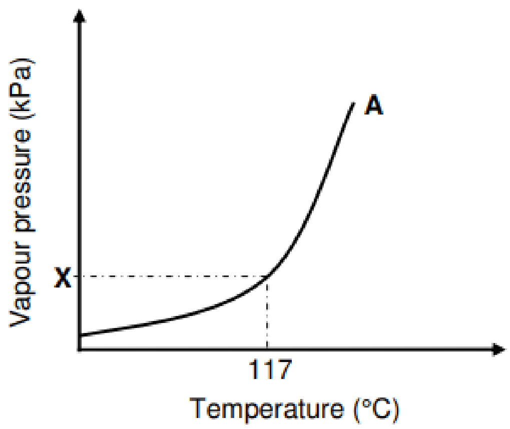
QUESTION 18 (September 2021)

Compounds **A**, **B** and **C** are used to investigate a factor which influences the boiling points of organic compounds. The results of the investigation are given in the table below.

COMPOUND		BOILING POINT (°C)
A	Butan-1-ol	117
B	Butan-2-ol	100
C	2-methylpropan-2-ol	82

18.1 Is this a fair investigation? Choose from YES or NO. (1)
18.2 Give a reason for the answer to QUESTION 18.1. (1)
18.3 Fully explain the difference in the boiling points of compounds **B** and **C**. (3)
18.4 Define the term *positional isomer*. (2)
18.5 From compounds **A**, **B** and **C**, choose the letter(s) that represent(s) EACH of the following:
18.5.1 Positional isomers (1)
18.5.2 A tertiary alcohol
Give a reason for the answer. (2)

18.6 The graph represents the relationship between vapour pressure and temperature for compound **A** (butan-1-ol).



18.6.1 Write down the value of **X**. (1)

18.6.2 Redraw the graph above in the ANSWER BOOK. On the same set of axes, sketch the curve that will be obtained for compound **C**. Clearly label the curves **A** and **C**.
Indicate the relevant boiling point for compound **C** on the graph. (2)
[13]

QUESTION 19 (November 2021)

The melting points and boiling points of four straight-chain ALKANES are shown in the table below.

COMPOUND	MELTING POINT (°C)	BOILING POINT (°C)
Pentane	-130	36,1
Hexane	-94	69
Heptane	-90,6	98,4
Octane	-57	125

19.1 Define the term *melting point*. (2)

19.2 Write down the general conclusion that can be made about the melting points of straight chain alkanes. (2)

19.3 Name the type of Van der Waals forces between molecules of octane. (1)

19.4 Write down the predominant phase of the following alkanes at -100 °C.
Choose from GAS, LIQUID or SOLID.

19.4.1 Pentane (1)

19.4.2 Octane (1)

19.5 Hexane is now compared to 2,2-dimethylbutane.

19.5.1 Is the molecular mass of hexane GREATER THAN, LESS THAN or EQUAL to that of 2,2-dimethylbutane? Give a reason for the answer. (2)

19.5.2 Is the boiling point of 2,2-dimethylbutane HIGHER THAN, LOWER THAN or EQUAL TO that of hexane? (1)

19.5.3 Fully explain the answer to QUESTION 19.5.2. (3)

[13]

QUESTION 20 (June 2022)

Learners investigate factors that influence the boiling points of organic compounds. The boiling points of some organic compounds obtained are shown in the table below.

COMPOUND		MOLECULAR MASS ($g\cdot mol^{-1}$)	BOILING POINT (°C)
A	Propane	44	- 42
B	Butane	58	- 0,5
C	Pentane	72	36
D	Methylbutane	72	28
E	Ethanol	46	78
F	Ethanal	44	20

20.1 Define the term *boiling point*. (2)

20.2 The boiling points of compounds **A**, **B** and **C** are compared.

20.2.1 How do the boiling points vary from compound **A** to compound **C**?
Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

20.2.2 Explain the answer to QUESTION 20.2.1. (3)

20.3 The boiling points of compounds **B**, **C** and **D** are compared.
Is this a fair comparison?
Choose from YES or NO. Give a reason for the answer. (2)

20.4 The boiling points of compounds **E** and **F** are compared.

20.4.1 State the independent variable for this comparison. (1)

20.4.2 Write down the name of the strongest Van der Waals force present in compound **F**. (1)

20.5 Which compound, **D** or **E**, has a higher vapour pressure? Give a reason for the answer. (2)

[12]

QUESTION 21 (November 2022)

21.1 The melting points of some organic compounds are given in the table below.

COMPOUND	IUPAC NAME	MELTING POINTS (°C)
A	Propanone	– 95,4
B	Butanone	– 86,9
C	Pentan-2-one	– 77,8
D	3-methylbutanone	– 92

21.1.1 To which homologous series do the above compounds belong? (1)

The melting points of compounds **A**, **B** and **C** are compared.

21.1.2 Write down the controlled variable for this comparison. (1)

The melting points of compounds **C** and **D** are compared.

21.1.3 Fully explain the difference in the melting points of these two compounds. (4)

21.2 The table below shows the results obtained from an experiment to determine the vapour pressure of different STRAIGHT CHAIN primary alcohols at 300 K.

ALCOHOL	VAPOUR PRESSURE (kPa)
CH_3OH	16,8
C_2H_5OH	7,88
C_3H_7OH	2,8
C_4H_9OH	0,91
$C_5H_{11}OH$	0,88
$C_6H_{13}OH$	0,124

21.2.1 Define the term *vapour pressure*. (2)

21.2.2 Write down a suitable conclusion for this investigation. (2)

21.2.3 Write down the IUPAC name of the alcohol with the HIGHEST boiling point. (3)

21.2.4 The experiment is now repeated at 320 K.

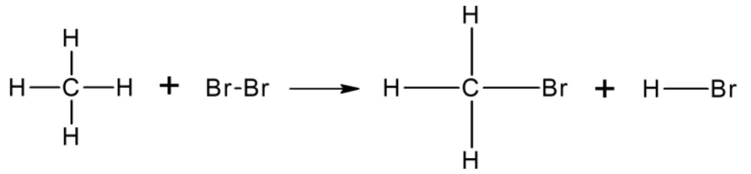
Will the vapour pressure of each compound INCREASE, DECREASE or REMAIN THE SAME? (1)

[14]

ORGANIC REACTIONS

REACTIONS OF ALKANES

SUBSTITUTION
Alkane → haloalkane

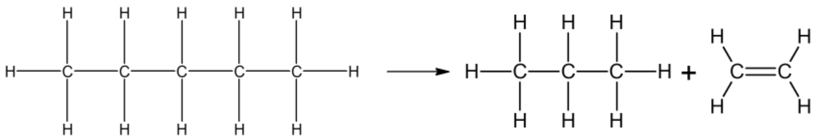


Type of substitution: halogenation
Reaction conditions: heat OR sunlight
Reactants: alkane + X_2 (F, Cℓ, Br, I)
Products: haloalkane + HX

OXIDATION (COMBUSTION)

$2C_6H_{14} + 19O_2 \rightarrow 12CO_2 + 14H_2O$
Alkane + oxygen → carbon dioxide + water + **energy**
Reaction conditions: Burns in EXCESS oxygen

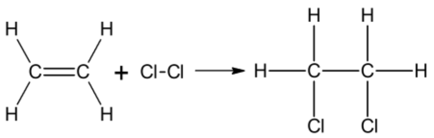
ELIMINATION
Alkane → alkene(s) + alkane with shorter chain



Type of elimination: cracking
Reaction conditions: heat + high pressure OR catalyst
Reactant: alkane
Products: alkene(s) + alkane / alkene + H_2

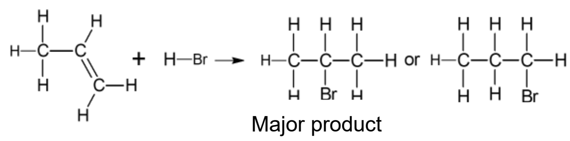
REACTIONS OF ALKENES

ADDITION



Type of addition: halogenation
Reaction conditions: unreactive solvent
Reactants: alkene + X_2 (X = Cℓ, Br)
Product: haloalkane

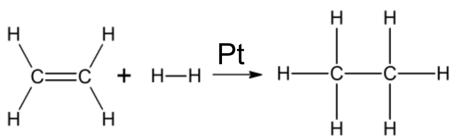
ADDITION



Major product

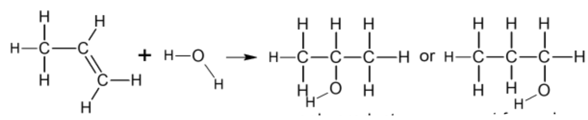
Type of addition: hydrohalogenation
Reaction conditions: no water; unreactive solvent
Reactants: alkene + HX (X = I, Br, Cℓ)
Product(s): haloalkane(s)
Major product: H atom bonds to the C atom already having the greater number of H atoms.

ADDITION



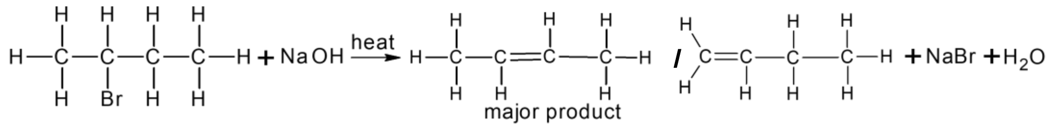
Type of addition: hydrogenation
Reaction conditions: Pt, Pd or Ni as catalyst
Reactants: alkene + H_2
Product: alkane

ADDITION



Major product

Type of addition: hydration
Reaction conditions: excess H_2O; small amount of acid (H_2SO_4) as catalyst
Reactants: alkene + H_2O
Product: alcohol(s)
Major product: H atom bonds to the C atom already having the greater number of H atoms.

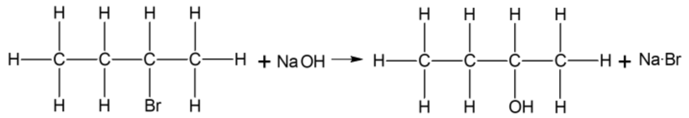


Type of elimination: dehydrohalogenation
Conditions: concentrated strong base (NaOH, KOH, LiOH) in ethanol + heat
Reactants: haloalkane + concentrated strong base **Products:** alkene + NaBr + H_2O
Major product: The one where the H atom is removed from the C atom with the least number of H atoms (most substituted double bond forms i.e. double bond with most alkyl groups)

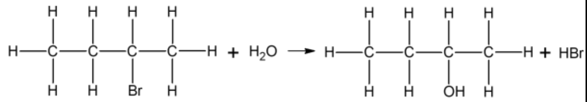
ELIMINATION

REACTIONS OF HALOALKANES

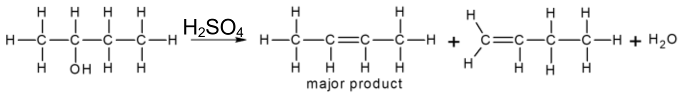
SUBSTITUTION



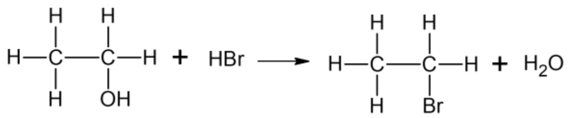
Type of substitution: hydrolysis
Conditions: dilute strong base (NaOH/KOH/LiOH) + mild heat
Reactants: haloalkane + dilute strong base
Products: alcohol + NaBr/KBr/LiBr



Type of substitution: hydrolysis
Conditions: excess H_2O + mild heat
Reactants: haloalkane + H_2O
Products: alcohol + HBr



Type of elimination: dehydration
Conditions: dehydrating agent (H_2SO_4/H_3PO_4) + heat
Reactants: alcohol + H_2SO_4
Products: alkene(s) + H_2O
Major product: The one where the H atom is removed from the C atom with the least number of H atoms



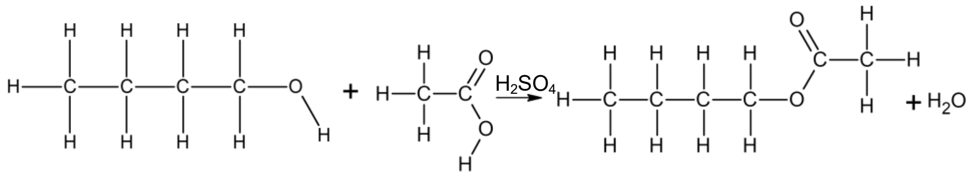
Conditions: heat
Reactants needed: alcohol + HX
Primary & secondary alcohols:
NaBr + H_2SO_4 used to make HBr in reaction flask
Tertiary alcohols: water free HBr (or HCℓ)
Products: haloalkane + H_2O

ELIMINATION
Alcohol → alkene

SUBSTITUTION

REACTIONS OF ALCOHOLS

ESTERIFICATION

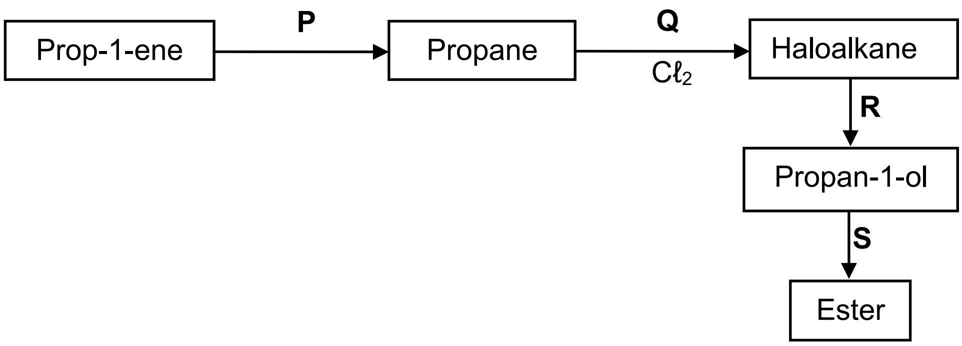


Type of reaction: esterification **Conditions:** concentrated sulphuric acid as catalyst + heat
Reactants: alcohol + carboxylic acid **Products:** ester + water

TERMS AND DEFINTIONS	
Addition reaction	A reaction in which a double bond in the starting material is broken and elements are added to it.
Cracking	The chemical process in which longer chain hydrocarbon molecules are broken down to shorter more useful molecules.
Dehydration	Elimination of water from a compound usually such as an alcohol.
Dehydrohalogenation	The elimination of hydrogen and a halogen from a haloalkane.
Elimination reaction	A reaction in which elements of the starting material are "lost" and a double bond is formed.
Esterification	The preparation of an ester from the reaction of a carboxylic acid with an alcohol.
Halogenation	The reaction of a halogen (Br_2, $C\ell_2$) with a compound.
Hydration	The addition of water to a compound.
Hydrogenation	The addition of hydrogen to an alkene
Hydrohalogenation	The addition of a hydrogen halide to an alkene.
Hydrolysis	The reaction of a compound with water.
Substitution reaction	A reaction in which an atom or a group of atoms in a molecule is replaced by another atom or group of atoms.

TYPICAL QUESTIONS

QUESTION 1 (November 2014)
The flow diagram below shows the preparation of an ester using prop-1-ene as a starting reagent. **P**, **Q**, **R** and **S** represent different organic reactions.



1.1 Write down the type of reaction represented by:
- 1.1.1 **Q** (1)
- 1.1.2 **R** (1)

1.2 For reaction **P** write down the:
- 1.2.1 Type of addition reaction (1)
- 1.2.2 Balanced equation using structural formulae (3)

1.3 Write down the structural formula of the haloalkane formed in reaction **Q**. (2)

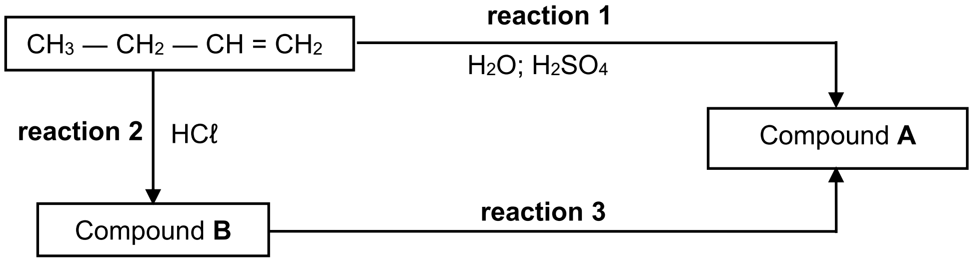
1.4 In reaction **S** propan-1-ol reacts with ethanoic acid to form the ester. For this reaction write down the:
- 1.4.1 Name of the reaction that takes place (1)
- 1.4.2 FORMULA or NAME of the catalyst needed (1)
- 1.4.3 Structural formula of the ester formed (2)
- 1.4.4 IUPAC name of the ester formed (2)

1.5 The propan-1-ol formed in reaction **R** can be converted to prop-1-ene. Write down the FORMULA or NAME of the inorganic reagent needed. (1)

[15]

QUESTION 2 (March 2015)

In the flow diagram below, but-1-ene is used as starting material in the preparation of compound **A**



2.1 Is but-1-ene a SATURATED or UNSATURATED compound? Give a reason for the answer. (2)

2.2 Compound **A** is the major product formed in **reaction 1**. Write down the:

2.2.1 Structural formula of compound **A** (2)

2.2.2 Type of reaction that takes place (1)

2.3 For compound **B**, write down the:

2.3.1 IUPAC name (2)

2.3.2 Structural formula of the positional isomer (2)

2.4 For **reaction 3**, write down:

2.4.1 TWO reaction conditions needed (2)

2.4.2 The type of reaction that occurs (1)

2.4.3 A balanced equation, using molecular formulae (3)

[15]

QUESTION 3 (June 2015)

Consider the incomplete equations of two reactions below. **X** represents the organic product formed in **reaction 1**, which is a SUBSTITUTION REACTION. In **reaction 2**, **X** reacts with reactant **Y** as shown.

Reaction 1: $C_2H_5Br \xrightarrow{\text{strong base}} NaBr + \mathbf{X}$

Reaction 2: $\mathbf{X} + \mathbf{Y} \xrightarrow{\text{Concentrated } H_2SO_4} C_3H_6O_2 + H_2O$

3.1 Consider **reaction 1**. Write down the:

3.1.1 Type of substitution reaction that takes place (1)

3.1.2 TWO reaction conditions (2)

3.1.3 IUPAC name of compound **X** (1)

3.2 Consider **reaction 2**. Write down the:

3.2.1 Type of reaction that takes place (1)

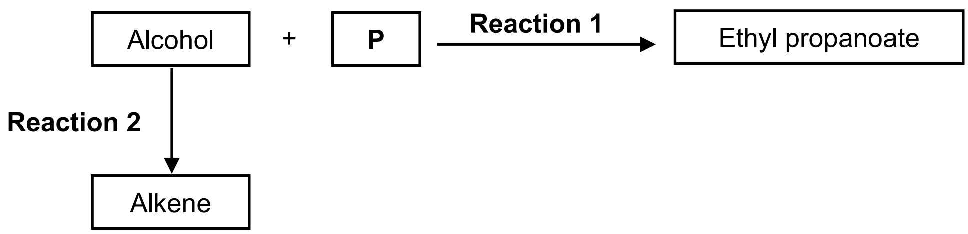
3.2.2 Structural formula of compound **Y** (2)

3.2.3 IUPAC name of the organic product (2)

[9]

QUESTION 4 (November 2015)

4.1 The flow diagram below shows two organic reactions. The letter **P** represents an organic compound.



Use the information in the flow diagram to answer the questions that follow. Write down the:

4.1.1 Type of reaction of which **Reaction 1** is an example (1)

4.1.2 STRUCTURAL FORMULA of the functional group of ethyl propanoate (1)

4.1.3 IUPAC name of compound **P** (1)

Reaction 2 takes place in the presence of an acid catalyst and heat. Write down the:

4.1.4 Type of reaction of which **Reaction 2** is an example (1)

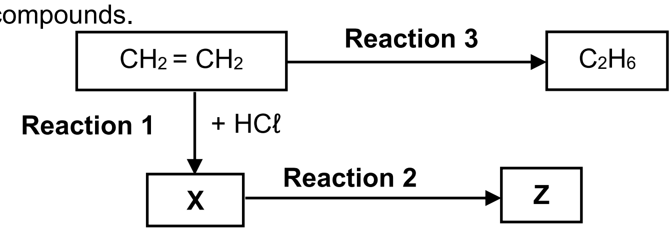
4.1.5 NAME or FORMULA of the acid catalyst (1)

4.1.6 STRUCTURAL FORMULA of the alkene (2)

[7]

QUESTION 5 (March 2016)

The flow diagram below shows different organic reactions using $CH_2 = CH_2$ as the starting reactant. **X** and **Z** represent different organic compounds.



5.1 For **Reaction 1**, write down the:
- 5.1.1 IUPAC name of compound **X** (2)
- 5.1.2 Type of addition reaction of which this is an example (1)

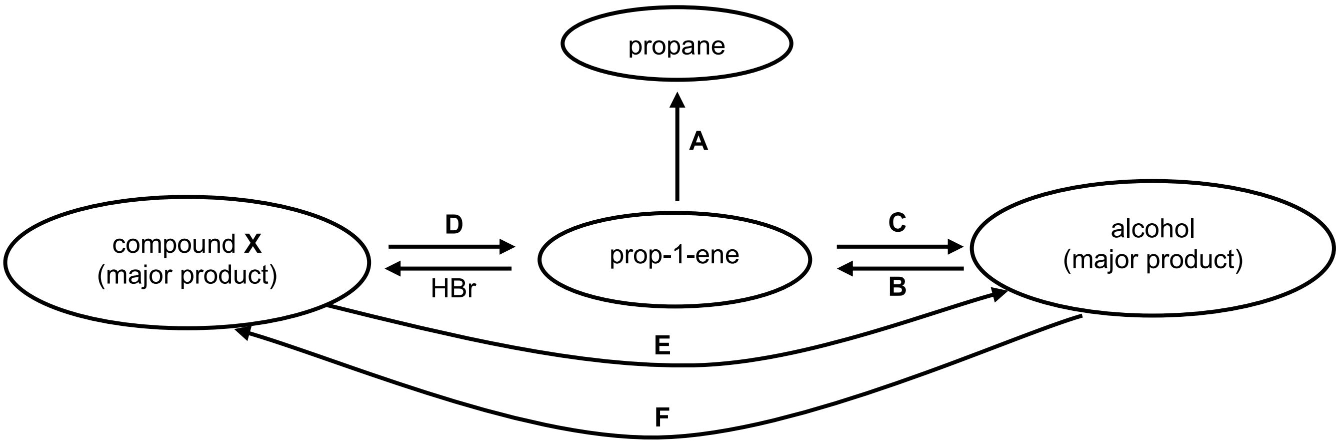
5.2 During **Reaction 2**, compound X reacts with excess hot water. Write down the:
- 5.2.1 STRUCTURAL FORMULA of compound **Z** (2)
- 5.2.2 NAME or FORMULA of the INORGANIC product (1)

5.4 **Reaction 3** is an addition reaction.
- 5.4.1 Is C_2H_6 a SATURATED or an UNSATURATED compound? Give a reason for the answer. (2)
- 5.4.2 Write down the NAME or FORMULA of the INORGANIC reactant needed for this reaction. (1)
- 5.4.3 Using molecular formulae, write down a balanced equation for the complete combustion of C_2H_6. (3)

[12]

QUESTION 6 (June 2016)

The flow diagram below shows how prop-1-ene can be used to prepare other organic compounds.



6.1 Write down the type of reaction represented by:
- 6.1.1 **A** (1)
- 6.1.2 **D** (1)
- 6.1.3 **F** (1)

6.2 Write down the:
- 6.2.1 NAME or FORMULA of the catalyst needed for reaction **A** (1)
- 6.2.2 NAME or FORMULA of the inorganic reagent needed for reaction **B** (1)
- 6.2.3 Type of addition reaction represented by reaction **C** (1)
- 6.2.4 IUPAC name of compound **X** (2)

6.3 Use structural formulae to write down a balanced equation for reaction **B**. (5)

6.4 Both reactions **D** and **E** take place in the presence of a strong base. State TWO conditions that will favour reaction **D** over reaction **E**. (2)

[15]

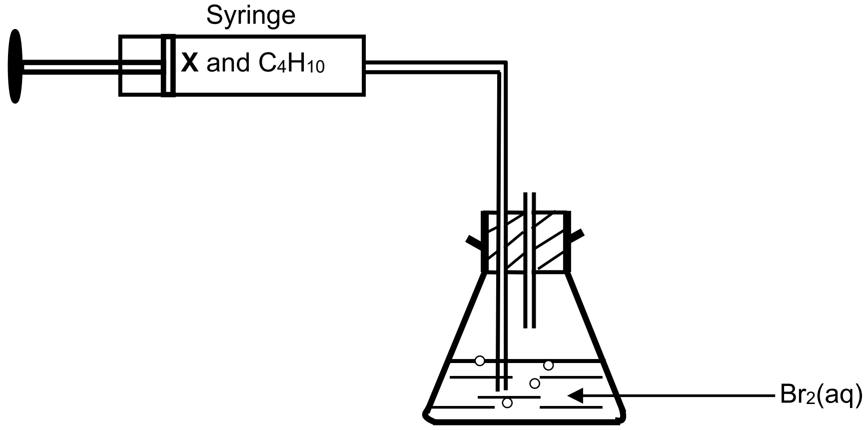
QUESTION 7 (November 2016)

Butane (C_4H_{10}) is produced in industry by the THERMAL cracking of long-chain hydrocarbon molecules, as shown in the equation below. **X** represents an organic compound that is produced.

$$C_{10}H_{22} \rightarrow \mathbf{X} + C_4H_{10}$$

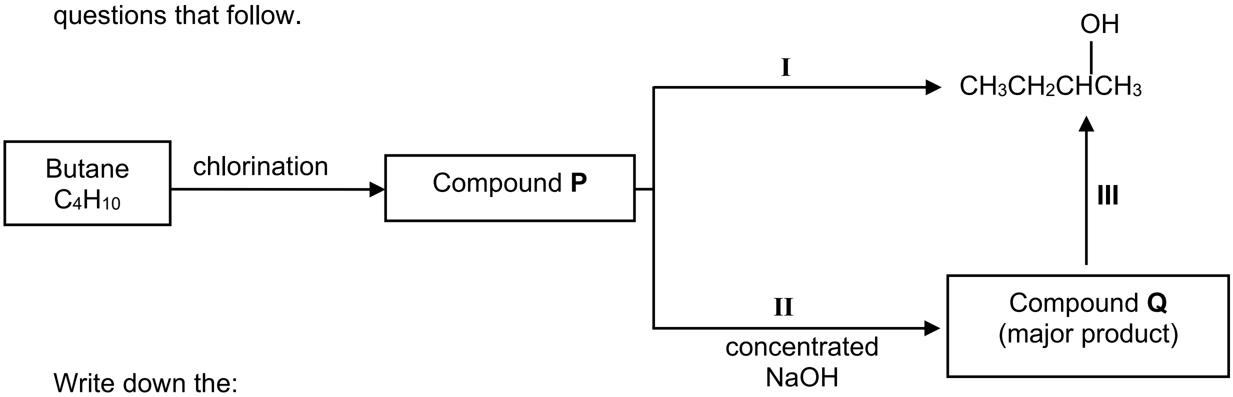
7.1 Write down:
- 7.1.1 ONE condition required for THERMAL cracking to take place (1)
- 7.1.2 The molecular formula of compound **X** (1)
- 7.1.3 The homologous series to which compound **X** belongs (1)

7.2 A mixture of the two gases, compound **X** and butane, is bubbled through bromine water, $Br_2(aq)$, in a conical flask, as illustrated. THE REACTION IS CARRIED OUT IN A DARKENED ROOM.



The colour of the bromine water changes from reddish brown to colourless when the mixture of the two gases is bubbled through it. Which ONE of the gases (**X** or BUTANE) decolorises the bromine water? Explain the answer. (4)

7.3 Study the flow diagram below, which represents various organic reactions, and answer the questions that follow.



Write down the:

7.3.1 IUPAC name of compound **P** (2)

7.3.2 Type of reaction labelled **I** (1)

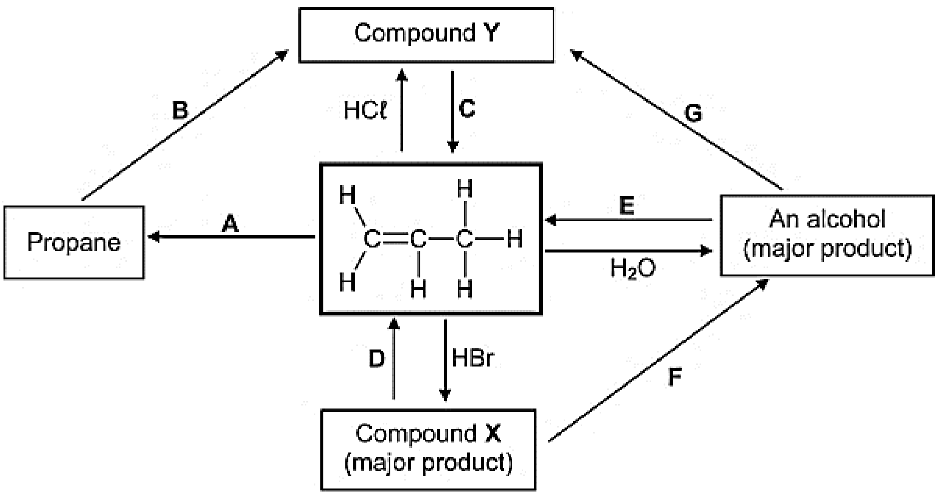
7.3.3 Structural formula of compound **Q** (2)

7.3.4 The type of addition reaction represented by reaction **III** (1)

[13]

QUESTION 8 (March 2017)

The flow diagram below shows how an alkene can be used to prepare other organic compounds. The letters **A** to **G** represent different organic reactions.



8.1 Write down the type of reaction represented by:

8.1.1 **A** (1)

8.1.2 **B** (1)

8.1.3 **E** (1)

8.2 Write down the IUPAC name of compound **X**. (2)

8.3 For reaction **D**, write down:

8.3.1 The type of elimination reaction (1)

8.3.2 TWO reaction conditions (2)

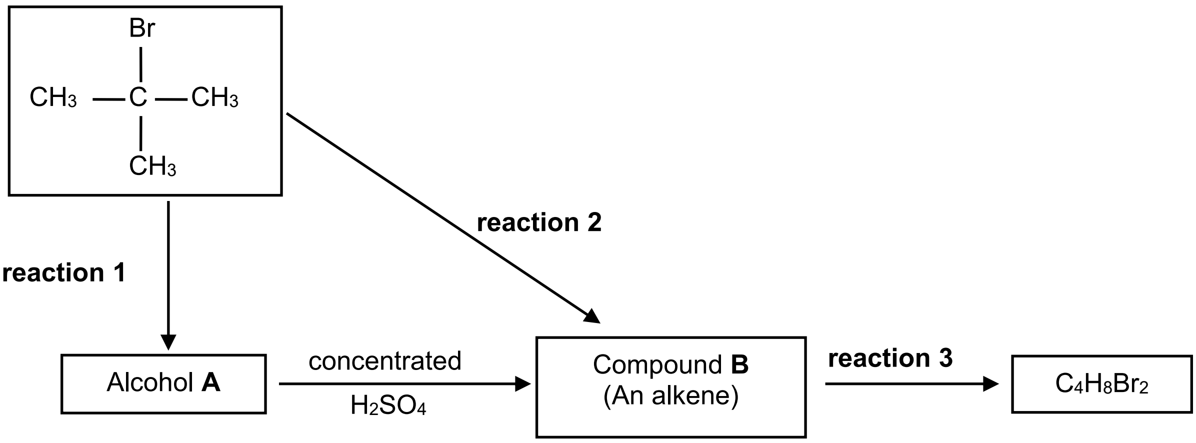
8.4 Write down the:

8.4.1 FORMULA of an inorganic reactant needed for reaction **F** (1)

8.4.2 Balanced equation, using structural formulae, for reaction **G** (4)

[13]

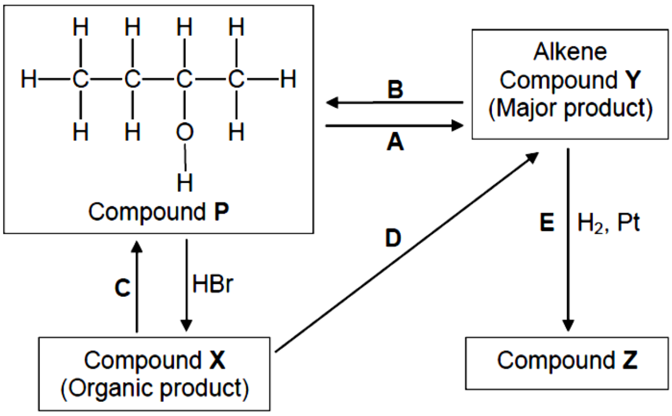
QUESTION 9 (June 2017)
Consider the reactions represented in the flow diagram below.



Write down the:

9.1	Type of reaction represented by **reaction 1**	(1)
9.2	NAME or FORMULA of the inorganic reactant needed for **reaction 1**	(1)
9.3	Type of alcohol (PRIMARY, SECONDARY or TERTIARY) of which alcohol **A** is an example	(1)
9.4	Type of reaction represented by **reaction 2**	(1)
9.5	IUPAC name of compound **B**	(2)
9.6	Type of addition reaction represented by **reaction 3**	(1)
9.7	Balanced equation for **reaction 3** using structural formulae	(4)
		[11]

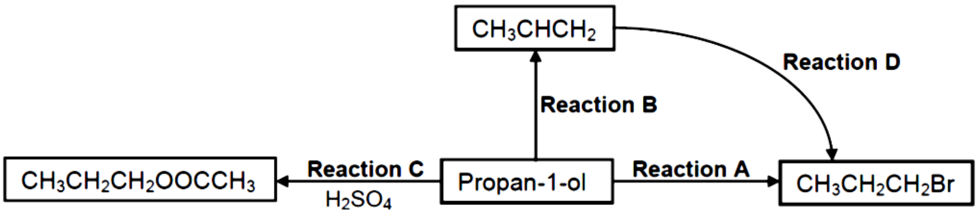
QUESTION 10 (November 2017)
The flow diagram below shows how an alcohol (compound **P**) can be used to prepare other organic compounds. The letters **A** to **E** represent different organic reactions. **X**, **Y** and **Z** are organic compounds.



10.1	Is compound **P** a PRIMARY, SECONDARY or TERTIARY alcohol? Give a reason for the answer.	(2)
10.2	Write down the type of:	
	10.2.1 Elimination reaction represented by **A**	(1)
	10.2.2 Addition reaction represented by **B**	(1)
	10.2.3 Elimination reaction represented by **D**	(1)
10.3	Sodium hydroxide is used as one of the reactants in reaction **C**.	
	10.3.1 What type of reaction takes place here?	(1)
	10.3.2 State the TWO reaction conditions for this reaction.	(2)
	10.3.3 Write down the IUPAC name of compound **X**.	(2)
10.4	Write down the FORMULA of an inorganic reactant needed for reaction **D**.	(1)
10.5	Using STRUCTURAL FORMULAE, write down a balanced equation for reaction **E**.	(3)
10.6	Write down the IUPAC name of compound **Z**.	(1)
		[15]

QUESTION 11 (June 2018)

Propan-1-ol can undergo a number of organic reactions, as indicated by the letters **A** to **D** in the diagram below.



11.1 Write down the type of reaction represented by:

11.1.1 **A** (1)

11.1.2 **B** (1)

11.1.3 **C** (1)

11.1.4 **D** (1)

11.2 For reaction **C**, write down the:

11.2.1 Function of H_2SO_4 (1)

11.2.2 IUPAC name of the organic product (2)

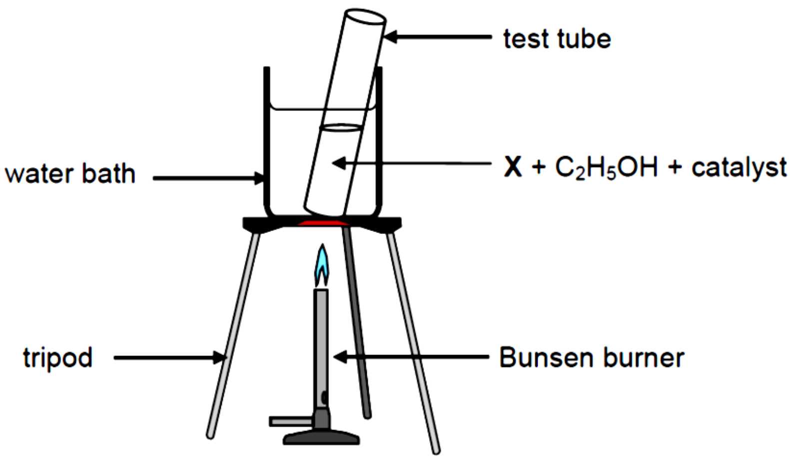
11.2.3 Structural formula of the other organic reactant (2)

11.3 Use STRUCTURAL FORMULAE for all organic reactants and products to write a balanced equation for reaction **A**. (5)

[14]

QUESTION 12 (November 2018)

A test tube containing a straight chain organic acid **X**, ethanol and a catalyst is heated in a water bath, as illustrated.



Organic compound **Y** is produced according to the following equation:

$$\mathbf{X} + C_2H_5OH \longrightarrow \mathbf{Y} + H_2O$$

12.1 Give a reason why the test tube is heated in a water bath instead of directly over the flame. (1)

12.2 Write down the:

12.2.1 Type of reaction that takes place here (1)

12.2.2 FORMULA of the catalyst needed (1)

12.2.3 Homologous series to which compound **Y** belongs (1)

The molecular mass of compound Y is 144 $g \cdot mol^{-1}$ and its empirical formula is C_4H_8O.

12.3 Determine the molecular formula of compound **Y**. (2)

12.4 Write down the IUPAC name of compound **Y**. (2)

12.5 Write down the structural formula of the organic acid **X**. (2)

[10]

QUESTION 13 (November 2018)

13.1 Three reactions of organic compounds from the same homologous series are shown below.

I:	Butane + Br_2 $\longrightarrow$ 2-bromobutane + **P**
II:	Pentane + excess oxygen $\xrightarrow{\text{heat}}$
III:	Hexane $\longrightarrow$ C_2H_4 + **Q**

13.1.1 Define a *homologous series*. (2)

13.1.2 Name the type of reaction represented by **I**. (1)

13.1.3 Write down the formula of the inorganic compound **P**. (1)

13.1.4 Give the structural formula of a POSITIONAL isomer of 2-bromobutane. (2)

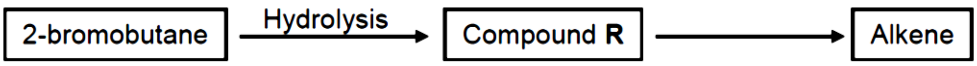
13.1.5 Using molecular formulae, write down a balanced equation for reaction **II**. (3)

Reaction **III** is an example of a cracking reaction.

13.1.6 Define a *cracking reaction*. (2)

13.1.7 Give the structural formula of organic compound **Q**. (2)

13.2 Study the flow diagram below.



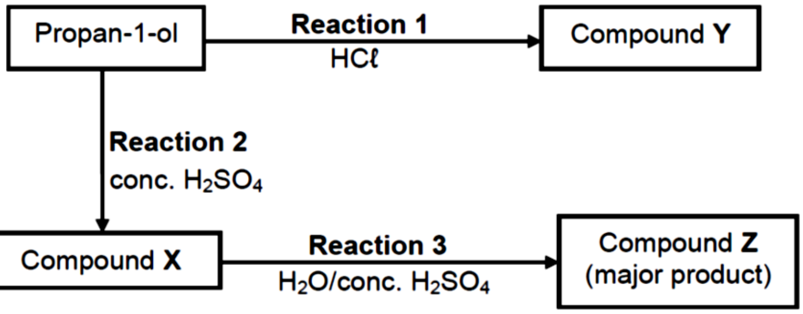
13.2.1 Write down the IUPAC name of compound **R**. (2)

13.2.2 Compound **R** reacts in the presence of concentrated phosphoric acid to form an alkene. Write down the structural formula of the MAJOR PRODUCT in this reaction. (2)

[17]

QUESTION 14 (June 2019)

Propan-1-ol undergoes two different reactions, as shown in the diagram below.



Write down the:

14.1 Type of reaction represented by **reaction 2** (1)

14.2 Function of concentrated H_2SO_4 in **reaction 2** (1)

14.3 IUPAC name of compound **X** (2)

14.4 STRUCTURAL FORMULA of compound **Y** (2)

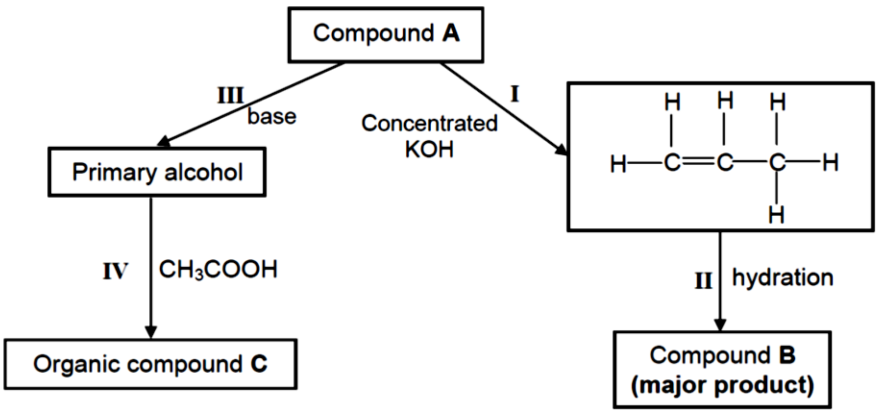
14.5 Type of reaction represented by **reaction 3** (1)

14.6 IUPAC name of compound **Z** (2)

[9]

QUESTION 15 (November 2019)

The flow diagram below shows how compound **A** can be used to prepare other organic compounds. The numbers **I, II, III** and **IV** represent different organic reactions. Use the information in the flow diagram to answer the following questions.



15.1 Name the homologous series to which compound **A** belongs. (1)

15.2 Write down the TYPE of reaction represented by:

15.2.1 **I** (1)

15.2.2 **III** (1)

15.2.3 **IV** (1)

15.3 Consider reaction **III**. Write down the:

15.3.1 TWO reaction conditions for this reaction (2)

15.3.2 IUPAC name of the primary alcohol that is formed (2)

15.4 Draw the STRUCTURAL FORMULA for compound **B**. (2)

15.5 Consider reaction **IV**. Write down the:

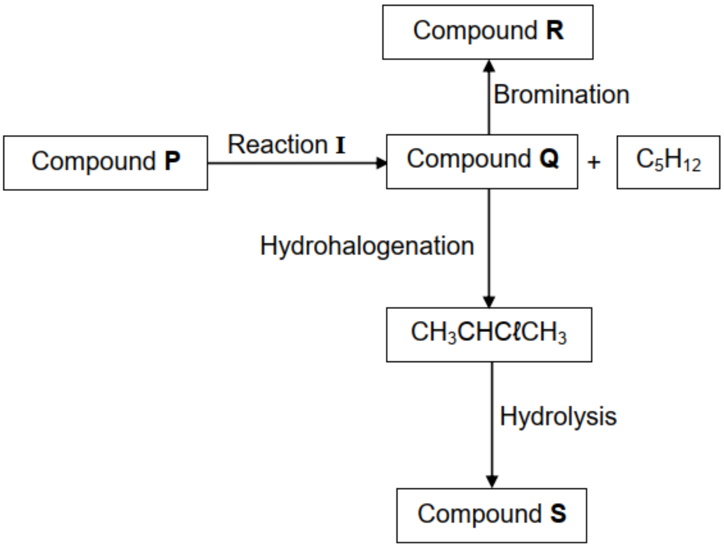
15.5.1 Structural formula of organic compound **C** (2)

15.5.2 NAME or FORMULA of the catalyst that is used (1)

[13]

QUESTION 16 (November 2020)

The flow diagram shows how various organic compounds can be prepared using compound **P** as starting reagent.



16.1 Write down the meaning of the term *hydrohalogenation*. (2)

16.2 Write down the STRUCTURAL FORMULA of compound **Q**. (2)

16.3 **Reaction I** is an elimination reaction. Write down the:

16.3.1 TYPE of elimination reaction (1)

16.3.2 MOLECULAR FORMULA of compound **P** (1)

16.4 Write down the IUPAC name of compound **R**. (2)

16.5 For the HYDROLYSIS REACTION, write down the:

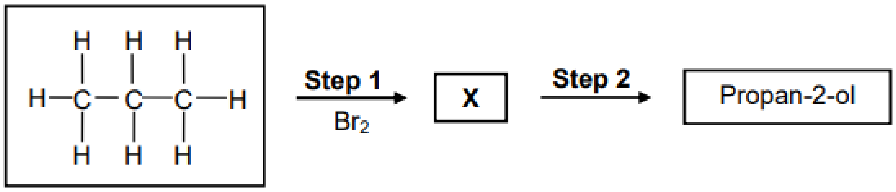
16.5.1 Balanced equation using structural formulae (5)

16.5.2 TWO reaction conditions (2)

[15]

QUESTION 17 (June 2021)

17.1 The flow diagram below shows the conversion of propane to propan-2-ol.



17.1.1 State ONE reaction condition for **Step 1**. (1)

17.1.2 Write down the NAME or FORMULA of the INORGANIC product formed in **Step 1**. (1)

17.1.3 Name the TYPE of substitution reaction represented by **Step 2**. (1)

17.1.4 Write down the NAME or FORMULA of the INORGANIC reagent needed in **Step 2**. (1)

17.1.5 Write down the IUPAC name of compound **X**. (2)

17.2 Ethane can be prepared from chloroethane ($CH_3CH_2C\ell$) by a TWO-STEP process. You are supplied with the following chemicals:

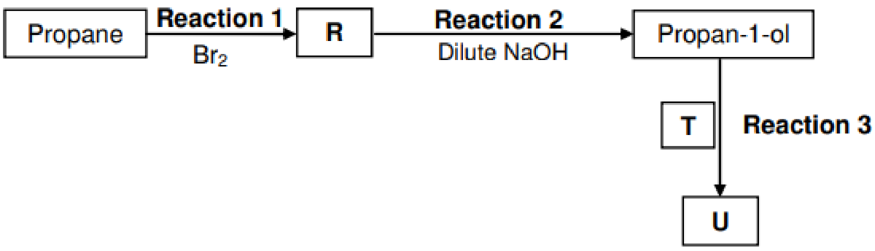
H_2	$HC\ell$	$C\ell_2$	H_2O	Pt	ethanol	concentrated H_2SO_4	concentrated NaOH

Select chemicals in the table above that can be used for this preparation. Using CONDENSED structural formulae, write down a balanced equation for EACH reaction. Indicate the reaction conditions for EACH reaction. (8)

[14]

QUESTION 18 (September 2021)

18.1 The flow diagram below shows various organic reactions using propane as starting reactant. **R**, **T** and **U** represent different organic compounds. Compound **T** is a CARBOXYLIC ACID and compound **U** is a FUNCTIONAL ISOMER of pentanoic acid.



Write down the NAME of the type of reaction represented by:

18.1.1 **Reaction 1** (1)

18.1.2 **Reaction 2** (1)

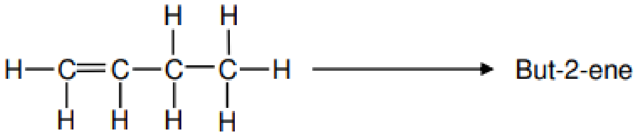
Consider **reaction 1** and **reaction 2**.

18.1.3 Write down the IUPAC name of compound **R**. (2)

Reaction 3 takes place in the presence of a catalyst and heat.
Write down the:

18.1.4 NAME or FORMULA of the catalyst (1)
18.1.5 IUPAC name of compound **T** (2)
18.1.6 STRUCTURAL FORMULA of compound **U** (2)

18.2 A laboratory technician wants to prepare but-2-ene using but-1-ene as starting reagent, as shown below.



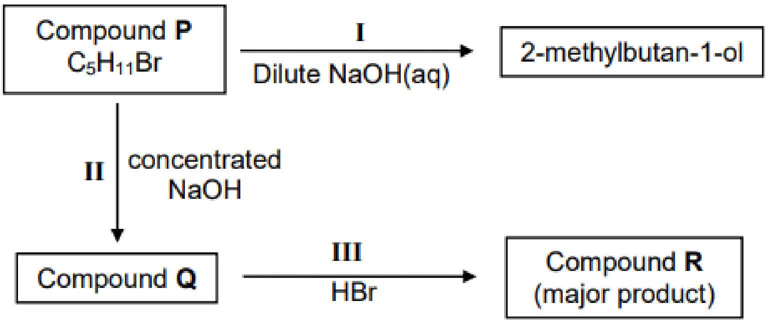
The following chemicals are available in the laboratory:

concentrated H_2SO_4	H_2O	concentrated NaOH

Select the chemicals required to design this preparation from the list above. For EACH step of the preparation, write down the balanced equation, using STRUCTURAL FORMULAE for all organic compounds. Indicate the chemicals needed in each step. (6)
[15]

QUESTION 19 (November 2021)

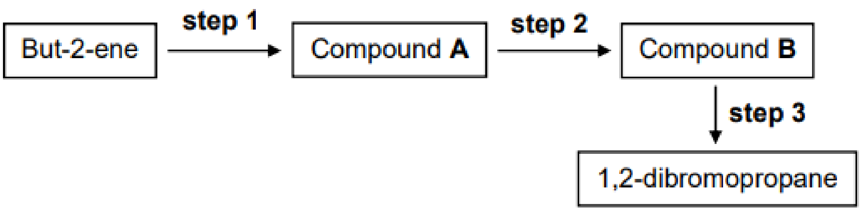
19.1 Compound **P** is used as a starting reactant in each of two reactions as shown in the flow diagram below.



I, **II** and **III** represent organic reactions.

19.1.1 Name the type of reaction represented by **I**. (1)
19.1.2 Is 2-methylbutan-1-ol a PRIMARY, SECONDARY or TERTIARY alcohol? Give a reason for the answer. (2)
19.1.3 Write down the STRUCTURAL FORMULA of compound **P**. (3)
19.1.4 Name the type of reaction represented by **II**. (1)
19.1.5 To which homologous series does compound **Q** belong? (1)
19.1.6 Name the type of reaction represented by **III**. Choose from ADDITION, ELIMINATION or SUBSTITUTION. (1)
19.1.7 Write down the IUPAC name of compound **R**. (2)

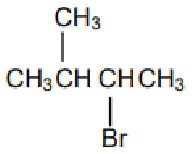
19.2 1,2-dibromopropane can be prepared from but-2-ene by a three-step process as shown in the flow diagram below.



19.2.1 Using CONDENSED STRUCTURAL FORMULAE, write down a balanced equation for **step 1**. Indicate the reaction conditions on the arrow. (4)
19.2.2 Write down the type of reaction in **step 2**. (1)
19.2.3 Write down the IUPAC name of compound **B**. (2)
19.2.4 Using CONDENSED STRUCTURAL FORMULAE, write down a balanced equation for **step 3**. (3)
[21]

QUESTION 20 (June 2022)

20.1 Study the following incomplete equations for organic reactions **I** and **II**.
Compounds **P** and **Q** are ORGANIC compounds and **T** is an INORGANIC compound.

I	 + NaOH (conc.) $\rightarrow$ **P** (major product) + NaBr + **T**
II	CH_3COOH + compound **Q** $\rightarrow$ butyl ethanoate + H_2O

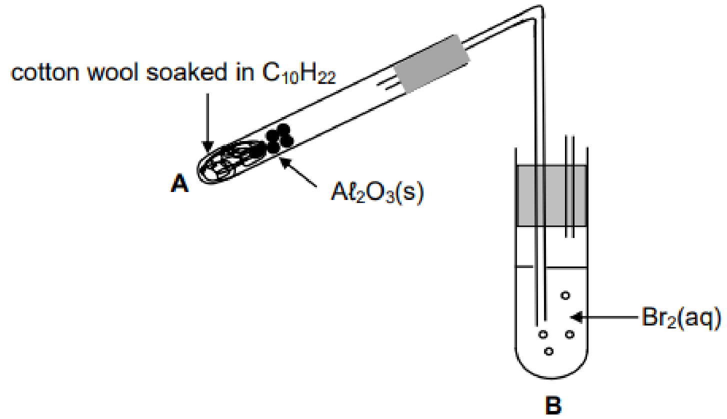
For reaction **I**, write down the:

20.1.1 Type of reaction that takes place (1)
20.1.2 IUPAC name of compound **P** (2)
20.1.3 NAME or FORMULA of compound **T** (1)

For reaction **II**, write down:

20.1.4 TWO reaction conditions needed (2)
20.1.5 The STRUCTURAL FORMULA of compound **Q** (2)

20.2 The cracking of a long chain hydrocarbon, $C_{10}H_{22}$, takes place in test tube **A**, as shown below.



Two STRAIGHT CHAIN organic compounds, X and Z, are produced in test tube A according to the following balanced equation:

$$C_{10}H_{22}(\ell) \rightarrow 2X(g) + Z(g)$$

20.2.1 State the function of the $A\ell_2O_3(s)$ in test tube **A**. (1)

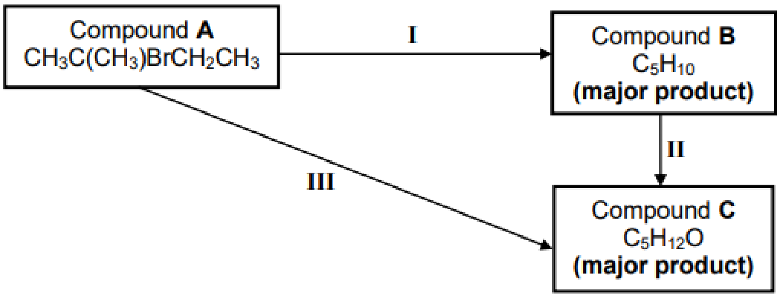
The organic compounds, **X** and **Z**, are now passed through bromine water, $Br_2(aq)$, at room temperature in test tube **B**. Only compound **X** reacts with the bromine water.

20.2.2 Apart from gas bubbles being formed, state another observable change in test tube **B**. (1)
20.2.3 Write down the TYPE of reaction that takes place in test tube **B**. (1)
20.2.4 Write down the molecular formula of compound **Z**. (3)
201.2.5 Write down the STRUCTURAL FORMULA of compound **X**. (3)

[17]

QUESTION 21 (November 2022)

The flow diagram below shows how compound **A** can be used as a starting reactant to prepare two different compounds.
I, **II** and **III** represent three organic reactions.



21.1 Is compound **A** a PRIMARY, SECONDARY or TERTIARY haloalkane? Give a reason for the answer. (2)

21.2 Consider reaction **I**.

21.2.1 Besides heat, write down the other reaction condition needed. (1)

21.2.2 Write down the type of reaction that takes place. (1)

21.2.3 Using STRUCTURAL FORMULAE for the organic compounds, write down a balanced equation for the reaction. (5)

21.3 Consider reaction **II**.

Write down the:

21.3.1 STRUCTURAL FORMULA of compound **C** (2)

21.3.2 NAME or FORMULA of the inorganic reagent needed (1)

21.3.3 Type of addition reaction that takes place (1)

21.4 Consider reaction **III**.

21.4.1 Write down of the type of reaction that takes place. (1)

21.4.2 Besides heat, write down the other reaction condition needed. (1)

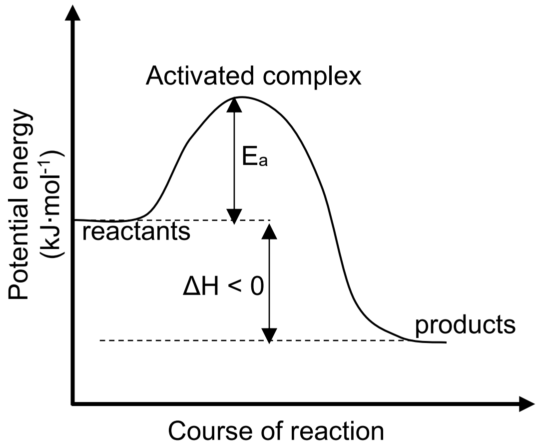
[15]

REACTION RATE AND ENERGY IN CHEMICAL REACTIONS

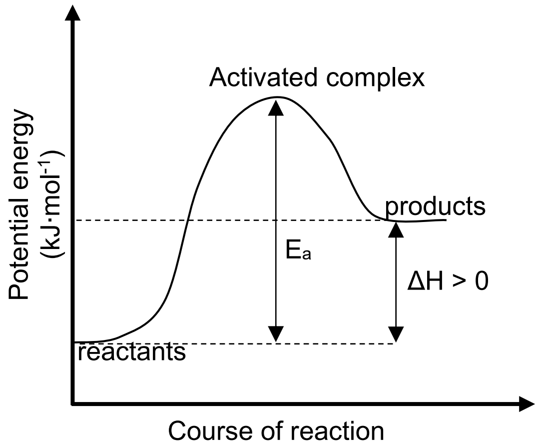
ENERGY IN CHEMICAL REACTIONS

HEAT OF REACTION (ΔH): The energy absorbed or released in a chemical reaction.

EXOTHERMIC REACTIONS
Reactions that release energy.



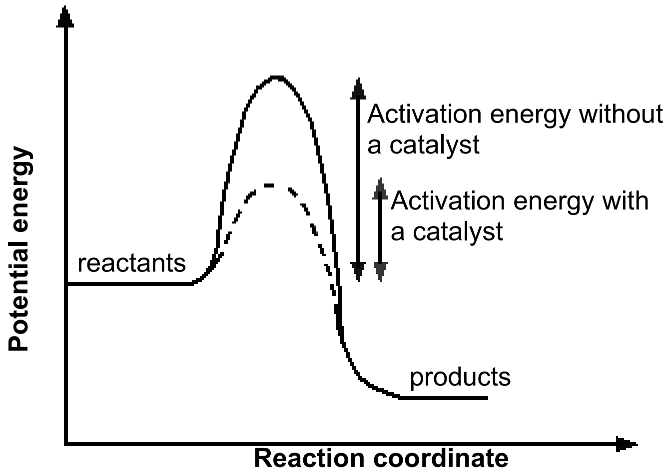
ENDOTHERMIC REACTIONS
Reactions that absorb energy.



Activation energy
The minimum energy needed for a reaction to take place.

Activated complex
The unstable transition state from reactants to products.

EFFECT OF A CATALYST



Catalyst
Increases reaction rate witout undergoing a permanent change.

Mechanism of catalyst:
Increase reaction rate by lowering the total activation energy

REACTION RATE

Change in concentration of reactants or products per unit time

↓

FACTORS AFFECTING REACTION RATES

1. **The nature of reactants**
2. **Concentration – higher concentration, faster rate**
3. **Surface Area – greater surface area, faster rate**
4. **Temperature – higher temperature, faster rate**
5. **Catalyst – increases reaction rate without undergoing a permanent change**

↓

CALCULTING REACTION RATE

Determine rate in terms of products	Rate = $\frac{\Delta c}{\Delta t}$	Rate = $\frac{\Delta m}{\Delta t}$	Rate = $\frac{\Delta V}{\Delta t}$	Rate = $\frac{\Delta n}{\Delta t}$
Determine rate in terms of reactants	Rate = $-\frac{\Delta c}{\Delta t}$	Rate = $-\frac{\Delta m}{\Delta t}$	Rate = $-\frac{\Delta V}{\Delta t}$	Rate = $-\frac{\Delta n}{\Delta t}$

Unit of reaction rate: Any unit of the above quantities per second

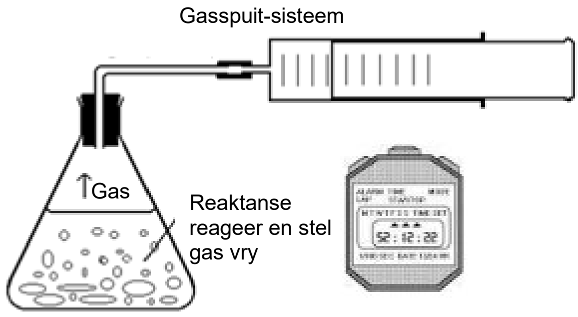
Examples: $mol \cdot dm^{-3} \cdot s^{-1}$ OR $g \cdot s^{-1}$ OR $dm^{-3} \cdot s^{-1}$ OR $mol \cdot s^{-1}$

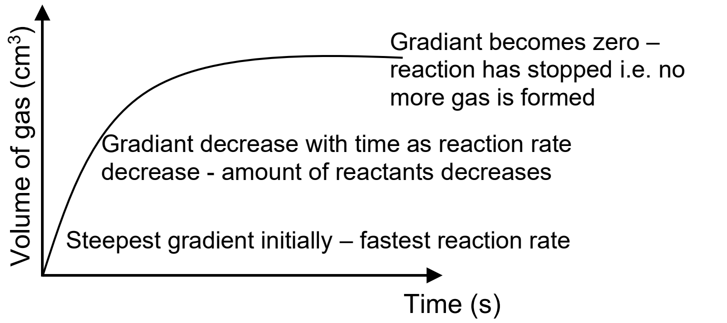
PRACTICAL SKILLS

Independent variable	The variable that is changed e.g. an increase in temperature.
Dependent variable	The variable that changes due to a change in the independent variable e.g., reaction rate changes due to a change in temperature.
Controlled variable	The variable(s) that are kept constant e.g. concentration and surface area are kept constant to measure the effect of temperature on reaction rate.
Investigative question	A question about the relationship between the dependent and independent variables. Must have both the independent and dependent variable and is a question about the relationship between them. Example: What is the relationship between temperature and reaction rate?
Hypothesis	A prediction on the answer to the investigative question prior to the investigation. Must have both the independent and dependent variable and predict the relationship between them. Example: When temperature increases, reaction rate will decrease. OR When temperature increases, reaction rate will increase.
Conclusion	The conclusion is drawn after the investigation and answers the investigative question. Must have both the independent and dependent variable and state the relationship between them. Example: When temperature increases, the reaction rate increases.

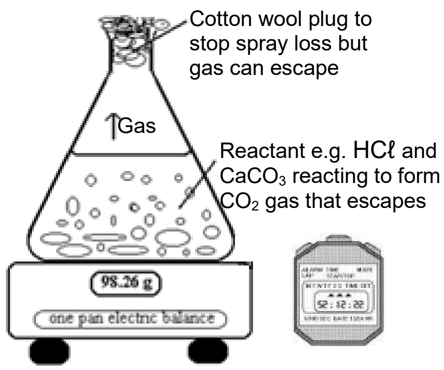
MEASURING REACTION RATE

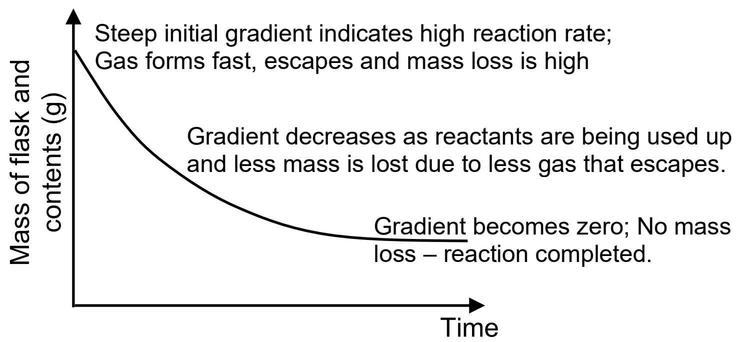
MEASURING VOLUME OF GAS RELEASED PER TIME





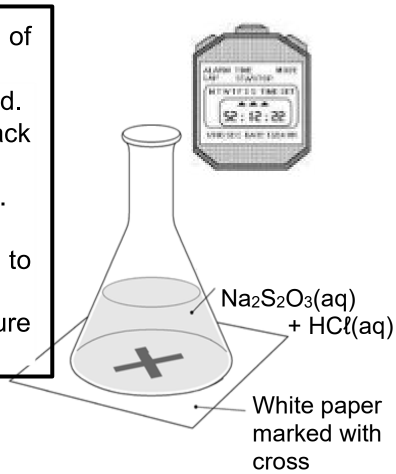
MEASURING LOSS IN MASS OF REACTANTS PER TIME

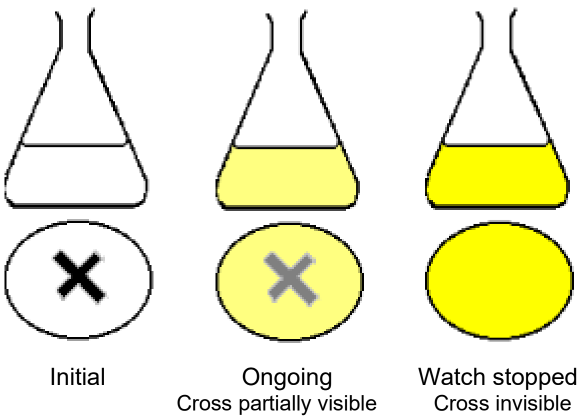




MEASURING THE TIME FOR THE FORMATION ON AN AMOUNT OF PRECIPITATE

- When sodium thiosulphate ($Na_2S_2O_3$) reacts with HCℓ, a yellow precipitate of sulphur is formed.
- The time how long it takes a certain amount of sulphur to form, is measured.
- The reaction is observed from the top through a conical flask, viewing a black cross (**X**) on white paper.
- The **X** is eventually obscured by the sulphur precipitate and the time noted.
- The reaction can be repeated at:
  - **Different temperatures** (same concentration of $Na_2S_2O_3$ and HCℓ), to measure the effect of temperature on rate
  - **Different concentrations** of $Na_2S_2O_3$ at the same temperature to measure the effect of concentration on reaction rate.





- Reaction rate is calculated as $\frac{1}{\text{time}}$.
- For the cross to become invisible, the same amount of precipitate (sulphur) is formed in each experiment and therefore the mass of S formed is the same (constant) and is represented by the 1.

THE COLLISION THEORY

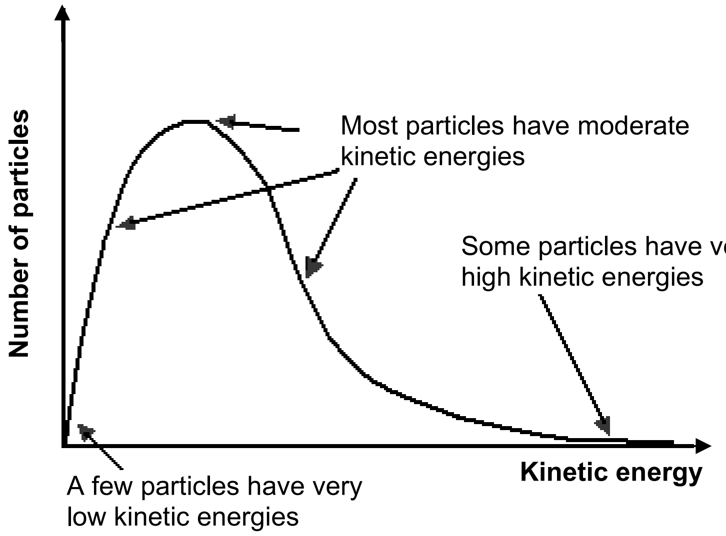
The collision theory explains the factors influencing reaction rate.

The collision theory states that for a chemical reaction to occur, the reacting particles must collide with one another. The rate of the reaction depends on the frequency of collisions i.e. the number of collisions per unit time. The theory also tells us that reacting particles often collide without reacting.

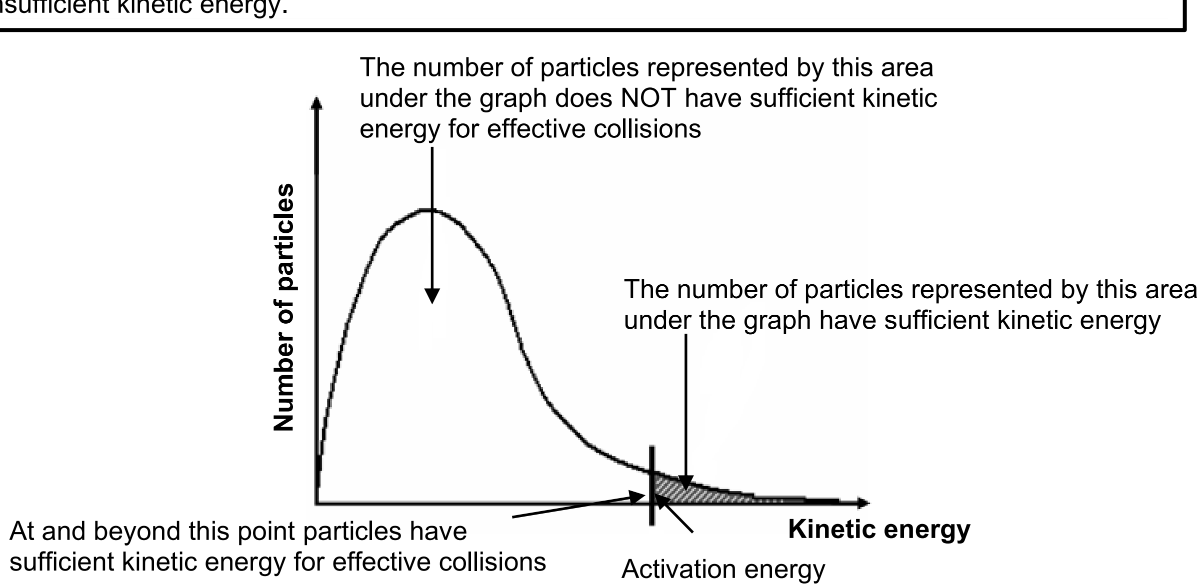
For collisions to be successful or effective, reacting particles must:
- **Collide with sufficient kinetic energy**
- **Have the correct orientation**

BOLTZMANN-MAXWELL DISTRIBUTION CURVE OR ENERGY DISTRIBUTION CURVE

As energy is one of the determining factors for a reaction, it is necessary to know which **number of particles (e.g. molecules) have kinetic energies equal to or greater than the activation energy**. Particles in any system represent a variety of kinetic energies. This distribution of kinetic energies can be shown on a curve known as the Maxwell-Boltzmann distribution curve.



The **area under the graph** is a measure of the total number of particles, e.g. molecules, present. The **magnitude of the activation energy** is indicated on the Maxwell-Boltzmann distribution curve **as a line at the specific kinetic energy**. Only a few numbers of particles have sufficient kinetic energy i.e. kinetic energy equal to or greater than the activation energy. Most of the particles have insufficient kinetic energy.

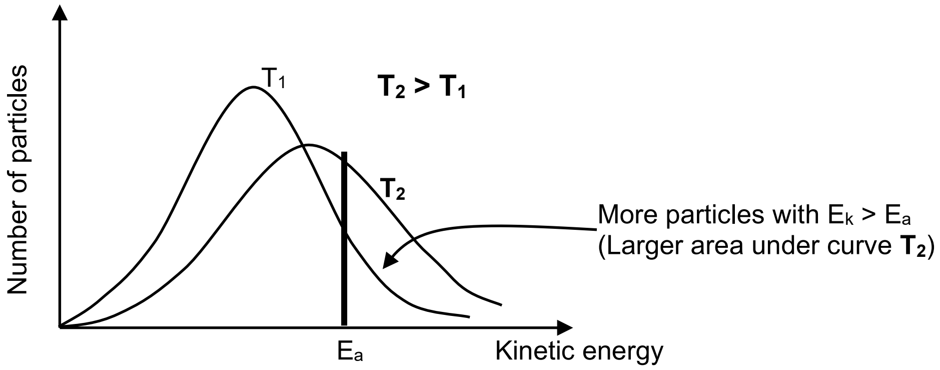


EXPLANATIONS IN TERMS OF THE COLLISION THEORY

EFFECT OF INCREASE IN TEMPERATURE ON REACTION RATE

- **At a higher temperature, the average KINETIC ENERGY of particles INCREASES.**
- More particles have sufficient /enough kinetic energy.
- More effective collisions take place per unit time.
- Reaction rate increases.

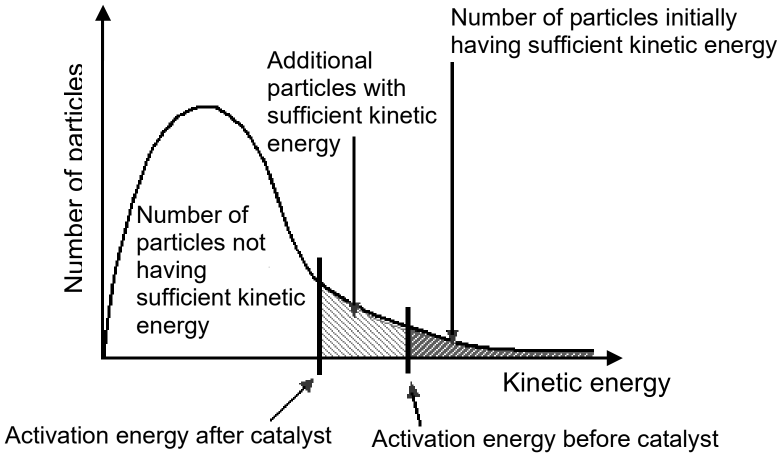
Maxwell-Boltzmann distribution curve/Energy distribution curve



EFFECT OF A CATALYST ON REACTION RATE

- **The catalyst provides a path of LOWER ACTIVATION ENERGY.**
- More particles have sufficient kinetic energy.
- More effective collisions take place per unit time.
- Reaction rate increases.

Maxwell- Boltzmann distribution curve/Energy distribution curve

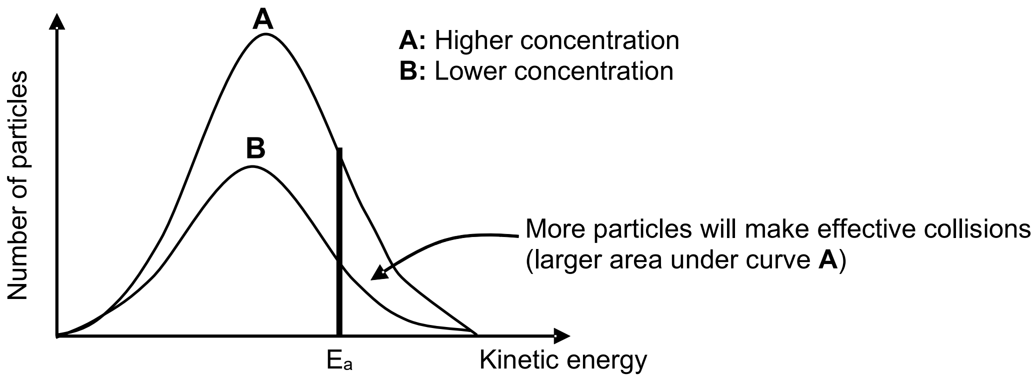


EPLANATIONS IN TERMS OF THE COLLISION THEORY

EFFECT OF INCREASE IN CONCENTRATION ON REACTION RATE

- **At a higher concentration, there are more particles s per unit volume.**
- More particles will have correct orientation./More collisions per unit time.
- More effective collisions take place per unit time.
- Reaction rate increases.

Maxwell-Boltzmann distribution curve/Energy distribution curve



EFFECT OF INCREASE IN SURFACE AREA ON REACTION RATE

- **With a greater surface area/state of division, more particles are exposed per unit volume.**
- More particles will have correct orientation./More collisions per unit time.
- More effective collisions per (unit) time.
- Reaction rate increases.

Maxwell-Boltzmann distribution curve/Energy distribution curve

TERMS AND DEFINITIONS	
Mole	One mole of a substance is the amount of substance having the same number of particles as there are atoms in 12 g carbon-12.
Molar gas volume at STP	The volume of one mole of a gas. (1 mole of any gas occupies 22,4 dm^3 at 0 °C (273 K) and 1 atmosphere (101,3 kPa).
Molar mass	The mass of one mole of a substance. Symbol: M Unit: $g \cdot mol^{-1}$
Avogadro's Law	Under the same conditions of temperature and pressure, the same number of moles of all gases occupy the same volume.
Concentration	The amount of solute per litre/cubic decimeter of solution. In symbols: $c = \frac{n}{V}$ Unit: $mol \cdot dm^{-3}$
Empirical formula	The simplest positive integer ratio of atoms present in a compound.
Percentage yield	Yield is the amount of product obtained from a reaction. $\text{percentage yield} = \frac{\text{actual mass obtained}}{\text{calculated mass}} \times 100$
Percentage purity	$\text{percentage purity} = \frac{\text{mass of pure chemical}}{\text{total mass of sample}} \times 100$
Percentage composition	The percentage of each of the components in a substance. $\text{Percentage of component} = \frac{\text{mass contributed by component}}{\text{mass of all components}} \times 100$
Limiting reagents	The substance that is totally consumed when the chemical reaction is complete.
Heat of reaction (ΔH)	The energy absorbed or released in a chemical reaction.
Exothermic reactions	Reactions that release energy. ($\Delta H < 0$)
Endothermic reactions	Reactions that absorb energy. ($\Delta H > 0$)
Activation energy	The minimum energy needed for a reaction to take place.
Activated complex	The unstable transition state from reactants to products.
Reaction rate	The change in concentration of reactants or products per unit time. Rate at which <u>reactants</u> are <u>used</u>: Rate = $-\frac{\Delta c}{\Delta t}$ Unit: $mol \cdot dm^{-3} \cdot s^{-1}$ Rate at which <u>products</u> are <u>formed</u>: Rate = $\frac{\Delta c}{\Delta t}$ Unit: $mol \cdot dm^{-3} \cdot s^{-1}$ (When calculating reaction rate, the final answer is always positive!)
Collision theory	A model that explains reaction rate as the result of particles colliding with a certain minimum energy.
Catalyst	A substance that increases the rate of a chemical reaction without itself undergoing a permanent change. (A catalyst increases the rate of a reaction by providing an alternative path of lower activation energy. It therefore decreases the net/total activation energy.)
Factors that affect reaction rate	Nature of reacting substances, surface area, concentration (pressure for gases), temperature and the presence of a catalyst.

TYPICAL QUESTIONS

QUESTION 1 (November 2014)

1.1 Define the term *reaction rate* in words. (2)

Learners use the reaction between IMPURE POWDERED calcium carbonate and excess hydrochloric acid to investigate reaction rate. The balanced equation for the reaction is:

$$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + H_2O(\ell) + CO_2(g)$$

They perform four experiments under different conditions of concentration, mass and temperature as shown in the table below. They use identical apparatus in the four experiments and measure the volume of gas released in each experiment.

	EXPERIMENT			
	1	**2**	**3**	**4**
Concentration of acid (mol·dm^{-3})	1	0,5	1	1
Mass of impure calcium carbonate (g)	15	15	15	25
Initial temperature of acid (°C)	30	30	40	40

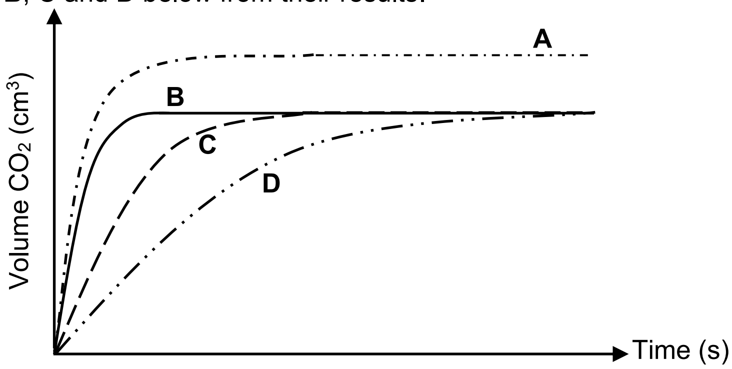
1.2 The results of experiments **1** and **3** are compared in the investigation. Write down the:

1.2.1 Independent variable (1)

1.2.2 Dependent variable (1)

1.3 Use the collision theory to explain why the reaction rate in experiment **4** will be higher than that in experiment **3**. (3)

The learners obtain graphs **A**, **B**, **C** and **D** below from their results.



1.4 Which ONE of the graphs (**A**, **B**, **C** or **D**) represents experiment **1**? Fully explain the answer by comparing experiment **1** with experiments **2**, **3** and **4**. (6)

1.5 When the reaction in experiment **4** reaches completion, the volume of gas formed is 4,5 dm^3. Assume that the molar gas volume at 40 °C is equal to 25,7 dm^3. Calculate the mass of the impurities present in the calcium carbonate. *(Answer: 7,00 g)* (5)

[18]

QUESTION 2 (March 2015)

A group of learners uses the reaction of EXCESS hydrochloric acid (HCℓ) with zinc (Zn) to investigate factors which influence reaction rate. The balanced equation for the reaction is:

$$Zn(s) + 2HC\ell(aq) \rightarrow ZnC\ell_2(aq) + H_2(g)$$

They use the same volume of hydrochloric acid and 1,2 g of zinc in each of five experiments. The reaction conditions and temperature readings before and after completion of the reaction in each experiment are summarised in the table below.

Experiment	**REACTION CONDITIONS**				**Time (s)**
	Concentration of HCℓ (mol·dm^{-3})	**Temperature (°C)**		**State of division of the 1,2 g of Zn**	
		Before	**After**		
1	0,5	20	34	granules	50
2	0,5	20	35	powder	10
3	0,8	20	36	powder	6
4	0,5	35	50	granules	8
5	0,5	20	34	granules	11

2.1 Is the reaction between hydrochloric acid and zinc EXOTHERMIC or ENDOTHERMIC? Give a reason for the answer by referring to the data in the table. (2)

2.2 Give a reason for the difference in reaction rate observed for **Experiments 1 and 2**. (1)

2.3 The learners compare the results of **Experiments 1 and 3** to draw a conclusion regarding the effect of concentration on reaction rate. Give a reason why this is not a fair comparison. (1)

2.4 How does the rate of the reaction in **Experiment 5** compare to that in **Experiment 1**? Write down FASTER THAN, SLOWER THAN or EQUAL TO.
Write down the factor responsible for the difference in the rate of reaction and fully explain, by referring to the collision theory, how this factor affects reaction rate. (5)

2.5 Calculate the rate at which the hydrochloric acid reacts in **Experiment 4** in $mol \cdot s^{-1}$.
(Answer: 4,63 x 10^{-3} $mol \cdot s^{-1}$) (6)
[15]

QUESTION 3 (June 2015)

A group of learners uses the reaction of clean magnesium ribbon with dilute hydrochloric acid to investigate factors that influence reaction rate. The balanced equation for the reaction is:

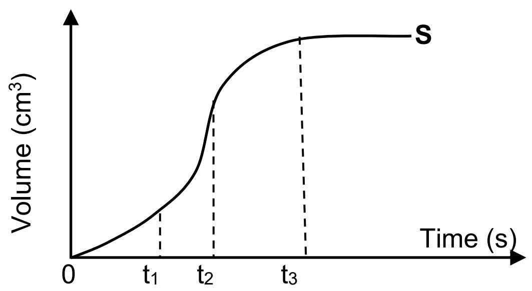
$$Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g) \qquad \Delta H < 0$$

3.1 Is the above reaction EXOTHERMIC or ENDOTHERMIC? Give a reason for the answer. (2)

3.2 In one of the experiments 5 g magnesium ribbon was added to the hydrochloric acid solution.

3.2.1 If 30 cm^3 dilute hydrochloric acid solution of concentration 1,5 $mol \cdot dm^{-3}$ is USED UP in 1 minute, calculate the average reaction rate in $mol \cdot s^{-1}$.
(Answer: 7,5 x 10^{-4} $mol \cdot s^{-1}$) (5)

The volume of hydrogen gas produced as a function of time in this experiment is represented by graph **S** below. (The graph is NOT drawn to scale.)

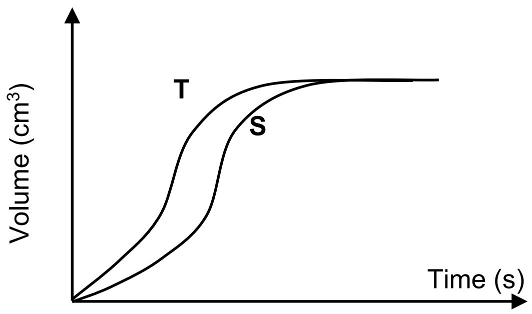


3.2.2 How does the rate of the reaction change between:
(Write down INCREASES, DECREASES or NO CHANGE.)

(a) t_1 and t_2
Use the collision theory to explain the answer. (4)

(b) t_2 and t_3
Give a reason for the answer without referring to the graph. (2)

3.3 In another experiment they add 5 g of magnesium to 30 cm^3 of dilute hydrochloric acid of concentration 1,5 $mol \cdot dm^{-3}$. They obtained graph **T** below.
(The graph is NOT drawn to scale.)



Give TWO possible reasons why graph **T** differs from graph **S**. (2)
[15]

QUESTION 4 (November 2015)

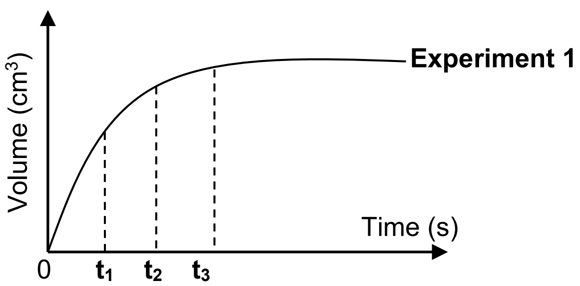
Dilute acids, indicated in the table below, react with EXCESS zinc in each of the three experiments to produce hydrogen gas. The zinc is completely covered with the acid in each experiment.

EXPERIMENT	DILUTE ACID
1	100 cm^3 of 0,1 $mol \cdot dm^{-3}$ H_2SO_4
2	50 cm^3 of 0,2 $mol \cdot dm^{-3}$ H_2SO_4
3	100 cm^3 of 0,1 $mol \cdot dm^{-3}$ $HC\ell$

The volume of hydrogen gas produced is measured in each experiment.

4.1 Name TWO essential apparatuses needed to determine the rate of hydrogen production. (2)

The graph below was obtained for **Experiment 1**.



Use this graph and answer the questions that follow.

4.2 At which time (**t_1**, **t_2** or **t_3**) is the:

4.2.1 Reaction rate the highest (1)

4.2.2 Mass of zinc present in the flask the smallest (1)

4.3 In which time interval, between t_1 and t_2 OR between t_2 and t_3, does the largest volume of hydrogen gas form per second? (1)

4.4 Redraw the graph for **Experiment 1** in the ANSWER BOOK. On the same set of axes, sketch the graphs that will be obtained for **Experiments 2** and **3**. Clearly label the three graphs as **EXPERIMENT 1**, **EXPERIMENT 2** and **EXPERIMENT 3**. (4)

4.5 The initial mass of zinc used in each experiment is 0,8 g. The balanced equation for the reaction in **Experiment 3** is:

$$Zn(s) + 2HC\ell(aq) \rightarrow ZnC\ell_2(aq) + H_2(g)$$

4.5.1 Calculate the mass of zinc present in the flask after completion of the reaction in **Experiment 3**. *(Answer: 0,48 g)* (5)

4.5.2 How will the mass of zinc present in the flask after completion of the reaction in **Experiment 2** compare to the answer to QUESTION 4.5.1? Write down only LARGER THAN, SMALLER THAN or EQUAL TO. (1)

[15]

QUESTION 5 (March 2016)

Methanol and hydrochloric acid react according to the following balanced equation:

$$CH_3OH(aq) + HC\ell(aq) \rightarrow CH_3C\ell(aq) + H_2O(\ell)$$

5.1 State TWO factors that can INCREASE the rate of this reaction. (2)

5.2 Define the term *reaction rate*. (2)

5.3 The rate of the reaction between methanol and hydrochloric acid is investigated. The concentration of $HC\ell(aq)$ was measured at different time intervals. The following results were obtained:

TIME (MINUTES)	$HC\ell$ CONCENTRATION ($mol\cdot dm^{-3}$)
0	1,90
15	1,45
55	1,10
100	0,85
215	0,60

5.3.1 Calculate the average reaction rate, in $(mol\cdot dm^{-3})\cdot min^{-1}$ during the first 15 minutes. *[Answer: 0,03 $(mol\cdot dm^{-3})\cdot min^{-1}$]* (3)

5.3.2 Use the data in the table to draw a graph of concentration versus time on a graph paper. NOTE: The graph is not a straight line. (3)

5.3.3 From the graph, determine the concentration of $HC\ell(aq)$ at the 40th minute. (1)

5.3.4 Use the collision theory to explain why the reaction rate decreases with time. Assume that the temperature remains constant. (3)

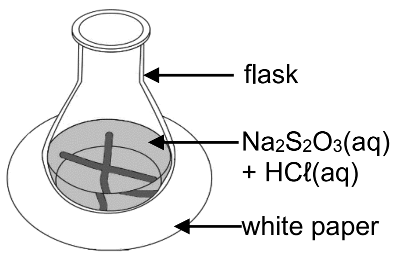
5.3.5 Calculate the mass of $CH_3C\ell(aq)$ in the flask at the 215th minute. The volume of the reagents remains 60 cm^3 during the reaction. *(Answer: 3,54 to 4,0 g)* (5)

[19]

QUESTION 6 (June 2016)

The reaction between dilute hydrochloric acid and sodium thiosulphate ($Na_2S_2O_3$) is used to investigate one of the factors that influences reaction rate. The balanced equation for the reaction is:

$$Na_2S_2O_3(aq) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + S(s) + H_2O(\ell) + SO_2(g)$$



The hydrochloric acid solution is added to the sodium thiosulphate solution in a flask. The flask is placed over a cross drawn on a sheet of white paper, as shown in the diagram below. The time that it takes for the cross to become invisible is measured to determine the reaction rate. Four experiments, **A** to **D**, are conducted during this investigation. The volumes of reactants used in each of the four experiments and the times of the reactions are summarised in the table below.

Experiment	Volume of $Na_2S_2O_3(aq)$ (cm^3)	Volume of $H_2O(\ell)$ (cm^3)	Volume of $HC\ell(aq)$ (cm^3)	Time (s)
A	25	0	5	50,0
B	20	5	5	62,5
C	15	10	5	83,3
D	10	15	5	125,0

6.1 State TWO factors that can influence the rate of the reaction above. (2)

6.2 Write down the NAME or FORMULA of the product that causes the cross to become invisible. (1)

6.3 Give a reason why water is added to the reaction mixture in experiments **B** to **D**. (1)

6.4 Write down an investigative question for this investigation. (2)

6.5 In which experiment (**A**, **B**, **C** or **D**) is the reaction rate the highest? (1)

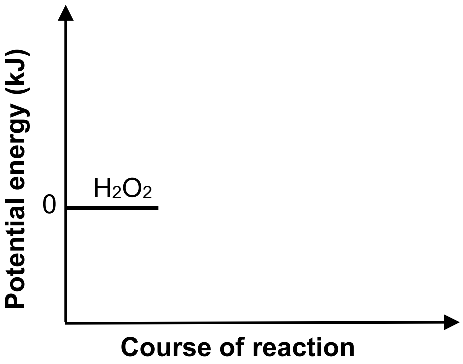
6.6 Use the collision theory to explain the difference in reaction rate between experiments **B** and **D**. (3)

6.7 The original $Na_2S_2O_3$ solution was prepared by dissolving 62,50 g $Na_2S_2O_3$ crystals in distilled water in a 250 cm^3 volumetric flask. Calculate the mass of sulphur, S, that will form in experiment **D** if $Na_2S_2O_3$ is the limiting reactant. . *(Answer: 0,51 g)* (7)

[17]

QUESTION 7 (November 2016)

Hydrogen peroxide, H_2O_2, decomposes to produce water and oxygen according to the following balanced equation: $2H_2O_2(\ell) \rightarrow 2H_2O(\ell) + O_2(g)$



7.1 The activation energy (E_A) for this reaction is 75 kJ and the heat of reaction (ΔH) is –196 kJ.

7.1.1 Define the term *activation energy*. (2)

7.1.2 Redraw the set of axes alongside in your ANSWER BOOK and then complete the potential energy diagram for this reaction. Indicate the value of the potential energy of the following on the y-axis:

- Activated complex
- Products

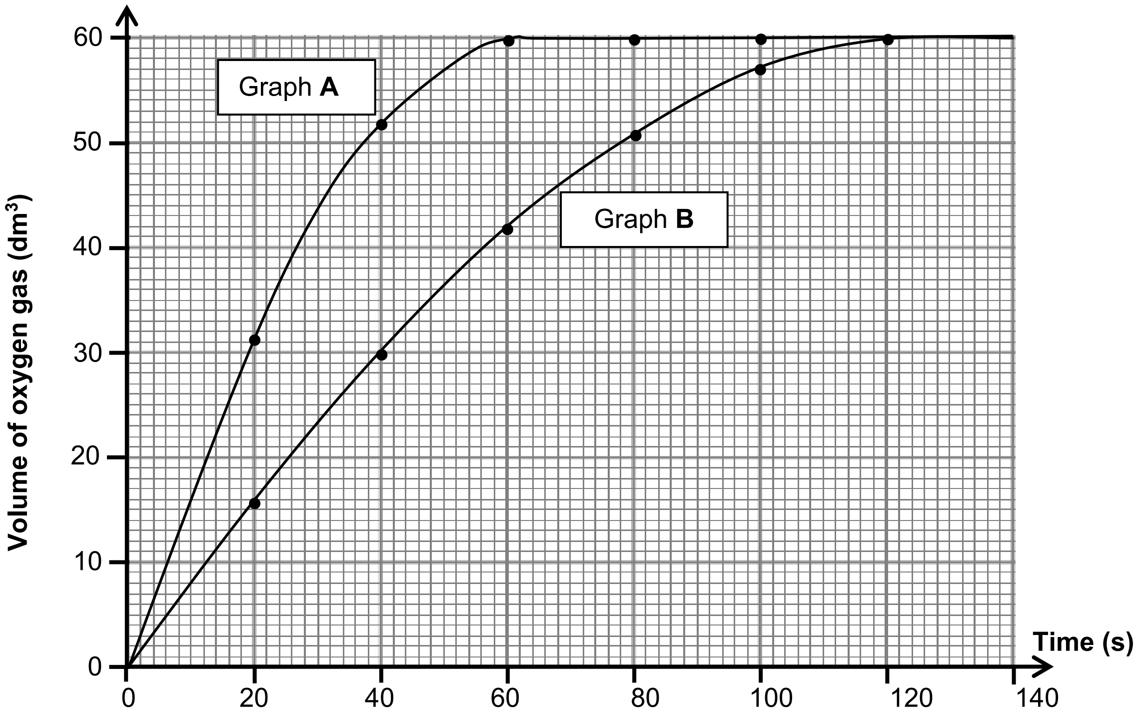
(The graph does NOT have to be drawn to scale.) 3)

When powdered manganese dioxide is added to the reaction mixture, the rate of the reaction increases.

7.1.3 On the graph drawn for QUESTION 7.1.2, use broken lines to show the path of the reaction when the manganese dioxide is added. (2)

7.1.4 Use the collision theory to explain how manganese dioxide influences the rate of decomposition of hydrogen peroxide. (3)

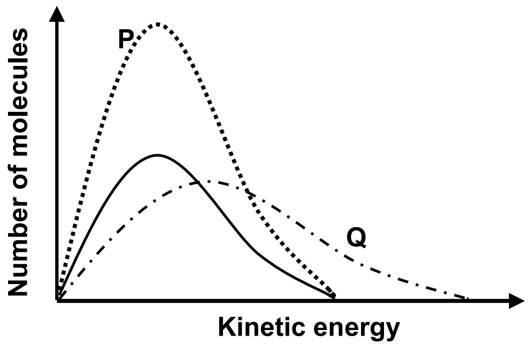
7.2 Graphs **A** and **B** below were obtained for the volume of oxygen produced over time under different conditions.



7.2.1 Calculate the average rate of the reaction (in $dm^3 \cdot s^{-1}$) between t = 10 s and t = 40 s for graph **A**. *(Answer: 1,2 $dm^3 \cdot s^{-1}$)* (3)

7.2.2 Use the information in graph **A** to calculate the mass of hydrogen peroxide used in the reaction. Assume that all the hydrogen peroxide decomposed. Use 24 $dm^3 \cdot mol^{-1}$ as the molar volume of oxygen. *(Answer: 170 g)* (4)

7.2.3 How does the mass of hydrogen peroxide used to obtain graph **B** compare to that used to obtain graph **A**? Choose from GREATER THAN, SMALLER THAN or EQUAL TO. (1)



7.3 Three energy distribution curves for the oxygen gas produced under different conditions are shown in the graph alongside. The curve with the solid line represents 1 mol of oxygen gas at 90 °C.
Choose the curve (**P** or **Q**) that best represents EACH of the following situations:

7.3.1 1 mol of oxygen gas produced at 120 °C (1)

7.3.2 2 moles of oxygen gas produced at 90 °C (1)

[20]

QUESTION 8 (June 2017)

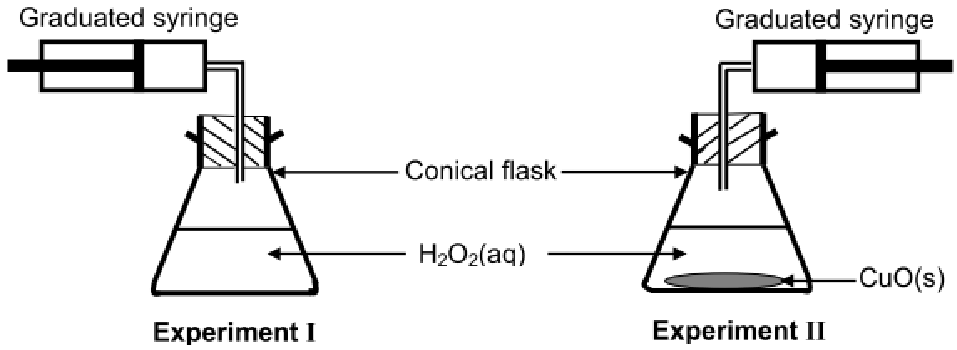
The apparatus below is used to investigate one of the factors that affects the rate of decomposition of hydrogen peroxide, H_2O_2. The balanced equation for the reaction is:

$$2H_2O_2(\ell) \rightarrow 2H_2O(\ell) + O_2(g)$$

Two experiments are conducted. The reaction conditions are as follows:

Experiment I: 50 cm^3 of hydrogen peroxide is allowed to decompose at 30 °C.

Experiment II: 50 cm^3 of hydrogen peroxide decompose at 30 °C in the presence of copper(II) oxide powder (CuO).



The results of the investigation are summarised in the table below.

Experiment	Total volume of O_2(g) produced(dm^3)	Time taken for complete decomposition (min.)
I	0,4	12,3
II	0,4	5,8

8.1 For this investigation, write down the function of the:

8.1.1 Graduated syringe (1)

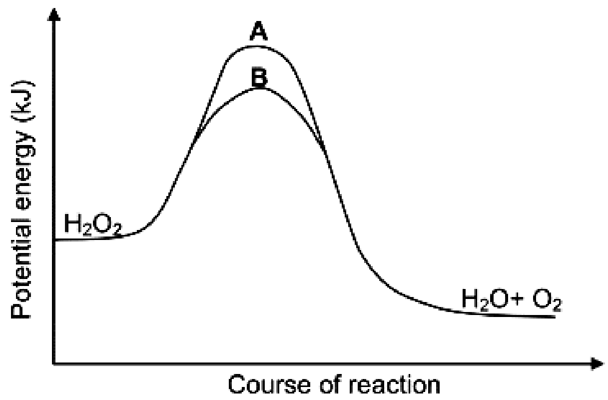
8.1.2 Copper(II) oxide (1)

8.2 How will you know when the reaction is completed? (1)

8.3 Write down the independent variable for this investigation. (1)

8.4 Use the collision theory to fully explain the difference in reaction rates of **experiment I** and **II**. (3)

8.5 The graphs below show changes in the potential energy during the decomposition of hydrogen peroxide in **experiment I** and **experiment II**.



8.5.1 Is energy ABSORBED or RELEASED during this reaction? Give a reason for the answer. (2)

8.5.2 Which ONE of the curves, **A** or **B**, represents experiment **II**? (1)

8.6 Calculate the rate, in mol·dm^{-3}·min^{-1}, at which 50 cm^3 of hydrogen peroxide decomposes in **experiment II**. Assume that 1 mole of gas occupies a volume of 25 dm^3 at 30 °C.
(Answer: 0,11 mol·dm^{-3}·min^{-1}) (6)

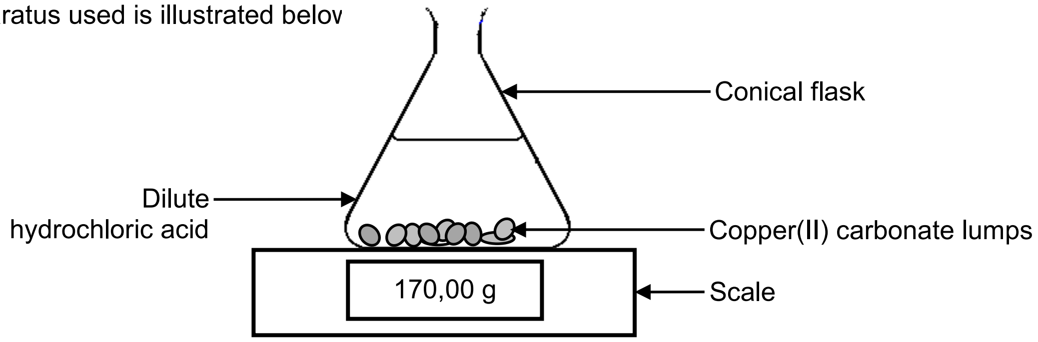
[16]

QUESTION 9 (March 2017)

The reaction of copper(II) carbonate with excess dilute hydrochloric acid is used to investigate the rate of reaction. The balanced equation for the reaction is:

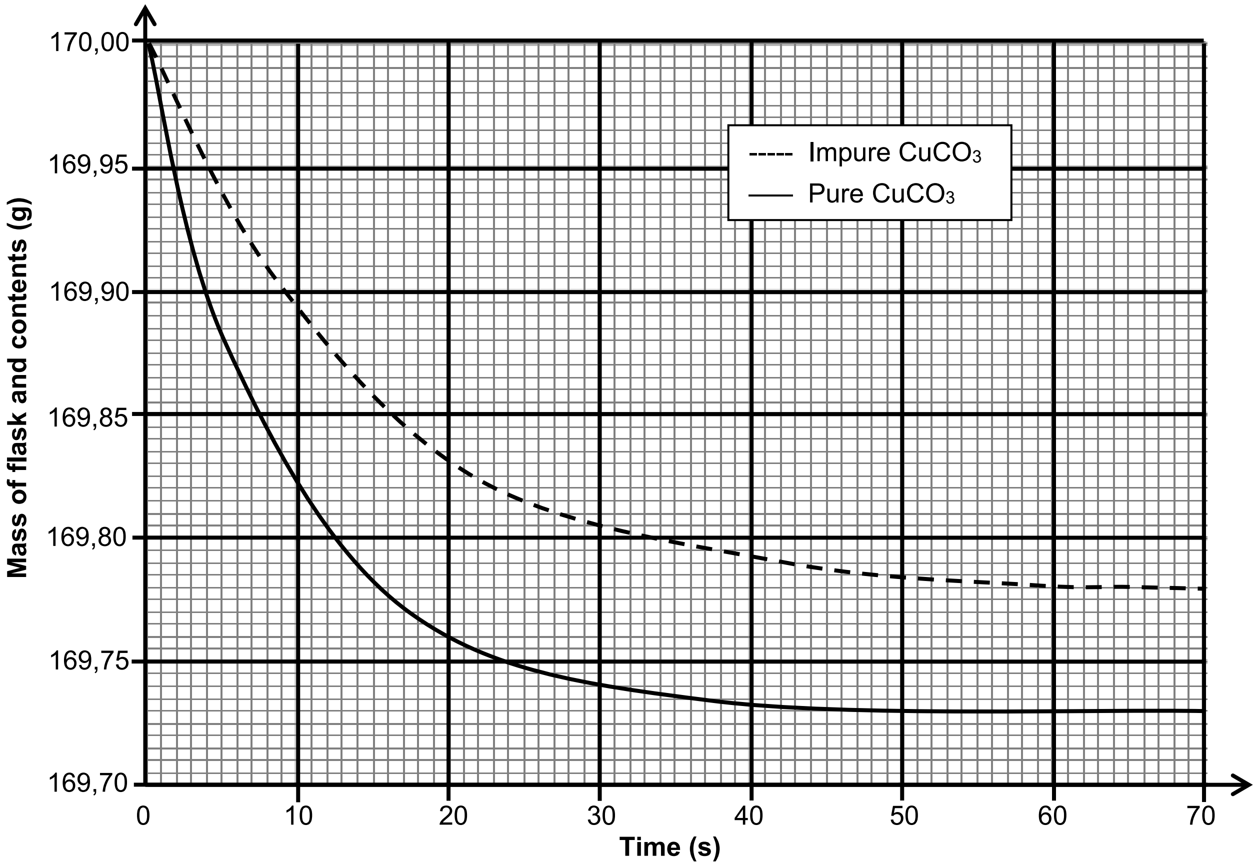
$$CuCO_3(s) + 2HC\ell(aq) \rightarrow CuC\ell_2(aq) + H_2O(\ell) + CO_2(g)$$

The apparatus used is illustrated belov



9.1 State TWO ways in which the rate of the reaction above can be increased. (2)

During the investigation, samples of both PURE and IMPURE copper(II) carbonate of EQUAL mass are used. The graphs below are obtained from the results.



9.2 Write down the reaction time for the reaction of the pure $CuCO_3$ with $HC\ell$. (1)

9.3 Assume that all the gas formed during the two reactions escape from the flask and that the impurities do not react.
Calculate the:

9.3.1 Average rate of the reaction of the pure sample over the first 20 s
(Answer: 0,012 g·s⁻¹) (3)

9.3.2 Percentage purity of the impure sample
(Answer: 81,48%) (4)

9.3.3 Maximum volume of $CO_2(g)$ produced during the reaction of the pure sample of $CuCO_3$ if the reaction takes place at STANDARD CONDITIONS *(Answer: 0,137 dm³)* (3)

9.4 Sketch a graph of the volume of gas produced versus time for the reaction of the pure $CuCO_3$. Indicate the reaction time on the x-axis. (2)

[15]

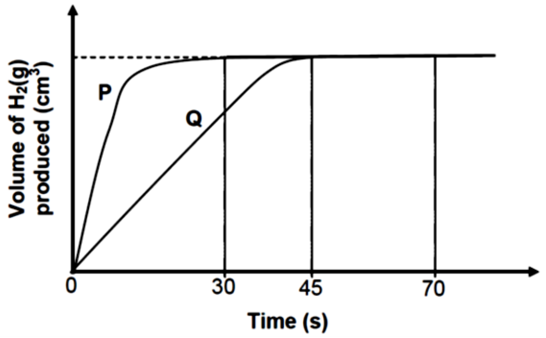
QUESTION 10 (November 2017)

A group of learners uses the reaction between powdered zinc and EXCESS dilute hydrochloric acid to investigate one of the factors that affects the rate of a chemical reaction. The balanced equation for the reaction is:

$$Zn(s) + 2HC\ell(aq) \rightarrow ZnC\ell_2(aq) + H_2(g)$$

They conduct two experiments. The reaction conditions used are summarised in the table below.

EXPERIMENT	TEMPERATURE (°C)	VOLUME OF HCℓ (cm^3)	CONCENTRATION OF HCℓ ($mol{\cdot}dm^{-3}$)	MASS OF Zn (g)
I	25	200	0,25	x
II	25	200	0,40	x



The results obtained are shown in the graph (not drawn to scale).

10.1 Define *reaction rate*. (2)

10.2 Write down an investigative question for this investigation. (2)

10.3 Which curve, **P** or **Q**, represents the results of **experiment I**? Explain the answer. (3)

10.4 The average rate of the production of hydrogen gas, as represented by graph **P**, was 15 $cm^3{\cdot}s^{-1}$. Calculate the mass of zinc used. Take the molar gas volume at 25 °C as 24 000 cm^3.
(Answer: 1,22 g) (5)

10.5 In a third experiment (**experiment III**), 200 cm^3 of a 0,25 $mol{\cdot}dm^{-3}$ dilute hydrochloric acid solution at 35 °C reacts with the same amount of zinc powder as in **experiment I** and **experiment II**.

10.5.1 How will the heat of reaction of **experiment II** compare with that of **experiment III**? Choose from MORE THAN, LESS THAN or EQUAL TO. (1)

10.5.2 How will the activation energy of the reaction in **experiment I** compare with that of the reaction in **experiment III**? Choose from MORE THAN, LESS THAN or EQUAL TO. (1)

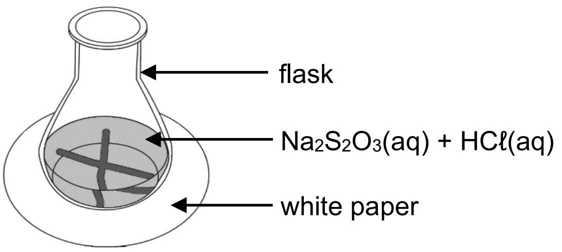
10.6 The rate of the reaction in **experiment III** is higher than that of **experiment I**.
Fully explain this statement by referring to the collision theory. (3)

[17]

QUESTION 11 (March 2018)

Learners use the reaction between sodium thiosulphate and hydrochloric acid to investigate one of the factors that affects reaction rate. The balanced equation for the reaction is:

$$Na_2S_2O_3(aq) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + H_2O(\ell) + SO_2(g) + S(s)$$



In the first experiment, 50 cm^3 of the sodium thiosulphate solution is added to 100 cm^3 of a 2 $mol{\cdot}dm^{-3}$ dilute hydrochloric acid solution in a flask that is placed over a cross drawn on a sheet of white paper. The hydrochloric acid is in EXCESS.
The time taken for the cross to become invisible, when viewed from the top, is recorded. The experiment is then repeated four times with different volumes of the sodium thiosulphate solution. The results obtained are shown in the table below.

EXPERIMENT	VOLUME OF $Na_2S_2O_3$ (cm^3)	VOLUME OF H_2O (cm^3)	TIME (s)	AVERAGE RATE $(\frac{1}{time})$ ($\times 10^{-2}\ s^{-1}$)
1	50	0	22,7	4,4
2	40	10	28,6	3,5
3	30	20	38,5	2,6
4	20	30	58,8	1,7
5	10	40	111,1	0,9

11.1 Define *reaction rate*. (2)

11.2 How does the concentration of the sodium thiosulphate solution used in **experiment 2** compare to that used in **experiment 5**? Choose from MORE THAN, LESS THAN or EQUAL TO. (1)

11.3 Draw a graph of average reaction rate versus volume of sodium thiosulphate used on a GRAPH SHEET. (3)

11.4 Use the information in the graph to answer the following questions.

11.4.1 Determine the volume of dilute sodium thiosulphate solution that needs to react in order for the cross to become invisible in 40 seconds. USE DOTTED LINES ON THE GRAPH TO SHOW HOW YOU ARRIVED AT THE ANSWER. (3)

11.4.2 Write down a conclusion for this investigation. (2)

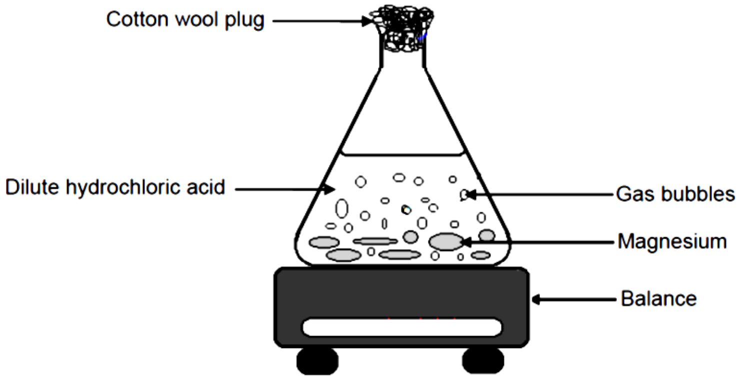
11.5 Use the collision theory to explain the effect of an increase in concentration on reaction rate. (3)

11.6 The mass of sulphur produced in **experiment 1** is 1,62 g. Calculate the mass of the sodium thiosulphate used in **experiment 1**.
(Answer: 7,90 g) (4)

[18]

QUESTION 12 (June 2018)

Two experiments are carried out to investigate one of the factors that affects the reaction rate between magnesium and dilute hydrochloric acid. The reaction that takes place is represented by the following balanced equation:



$Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g)$

In **experiment 1** a certain mass of magnesium *ribbon* reacts with excess dilute hydrochloric acid.

In **experiment 2** magnesium *powder* of the same mass as the magnesium ribbon, reacts with the same volume of excess dilute hydrochloric acid. The concentration of the acid is the same in both experiments.

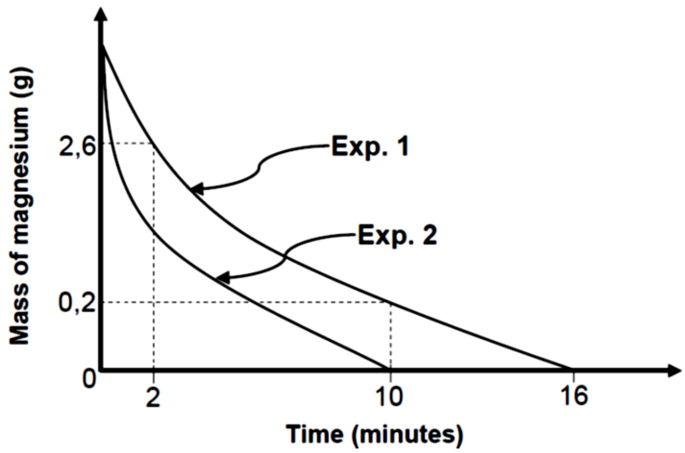
12.1 Define *reaction rate*. (2)

12.2 For this investigation, write down the:

12.2.1 Independent variable (1)

12.2.2 Controlled variable (1)

The change in mass of magnesium is calculated and recorded in 2-minute intervals for both experiments. The results obtained are shown in the graph alongside (NOT drawn to scale).



12.3 Use the information on the graph to:

12.3.1 Calculate the volume of hydrogen gas produced in **experiment 1** from t = 2 minutes to t = 10 minutes (Take the molar gas volume as 25 $dm^3 \cdot mol^{-1}$.)
(Answer: 2,5 dm^3) (5)

12.3.2 Calculate the initial mass of magnesium used if the average rate of formation of hydrogen gas in **experiment 2** was $2{,}08 \times 10^{-4}$ $mol \cdot s^{-1}$.
(Answer: 2,995 g) (5)

12.4 Use the collision theory to explain why the curve of **experiment 2** is steeper than that of **experiment 1**. (3)

[17]

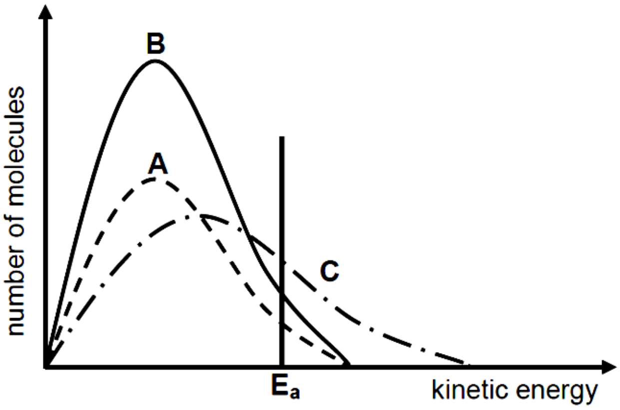
QUESTION 13 (November 2018)
The reaction of zinc and EXCESS dilute hydrochloric acid is used to investigate factors that affect reaction rate. The balanced equation for the reaction is:

$$Zn(s) + 2HC\ell(aq) \longrightarrow ZnC\ell_2(aq) + H_2(g)$$

The reaction conditions used and the results obtained for each experiment are summarised in the table below. The same mass of zinc is used in all the experiments. The zinc is completely covered in all reactions. The reaction time is the time it takes the reaction to be completed.

EXPERIMENT	CONCENTRATION OF HCℓ (mol·dm^{-3})	VOLUME OF HCℓ (cm^3)	STATE OF DIVISION OF HCℓ	TEMPERATURE OF HCℓ (°C)	REACTION TIME (min.)
1	2,0	200	Powder	25	7
2	1,5	200	Granules	25	14
3	5,0	200	Powder	25	5
4	1,5	400	Granules	25	**x**
5	2,0	200	powder	35	4

13.1 **Experiment 1** and **experiment 5** are compared. Write down the independent variable. (1)
13.2 Define *reaction rate*. (2)
13.3 Write down the value of **x** in **experiment 4**. (2)



13.4 The Maxwell-Boltzmann energy distribution curves for particles in each of **experiments 1**, **3** and **5** are shown alongside.
Identify the graph (**A** or **B** or **C**) that represents the following:
13.4.1 **Experiment 3**
Give a reason for the answer. (2)
13.4.2 **Experiment 5**
Give a reason for the answer. (2)

13.5 **Experiment 6** is now conducted using a catalyst and the SAME reaction conditions as for **experiment 1**.
13.5.1 What is the function of the catalyst in this experiment? (1)
13.5.2 How will the heat of reaction in **experiment 6** compare to that in **experiment 1**?
Choose from: GREATER THAN, EQUAL TO or LESS THAN. (1)
13.6 Calculate the average rate of the reaction (in mol·min^{-1}) with respect to zinc for **experiment 2** if 1,5 g of zinc is used. *(Answer: 1,65 x 10^{-3} mol·min^{-1})* (4)
[15]

QUESTION 14 (June 2019)
Learners use the reaction of a sodium thiosulphate solution with dilute hydrochloric acid to investigate several factors that affect the rate of a chemical reaction. The balanced equation for the reaction is:

$$Na_2S_2O_3(aq) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + SO_2(g) + S(s) + H_2O(\ell)$$

14.1 Define *reaction rate*. (2)

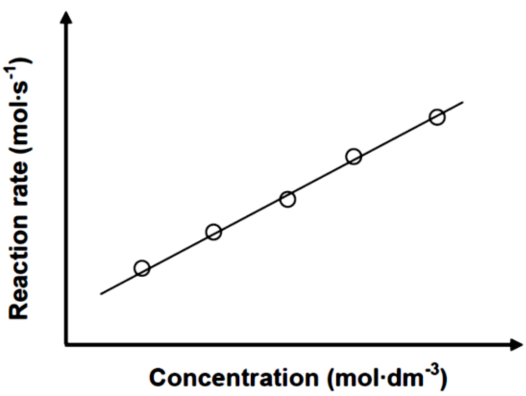
Three investigations (**I**, **II** and **III**) are carried out.

14.2 **INVESTIGATION I**
The results obtained in **INVESTIGATION I** are shown in the graph.

For this investigation, write down the:

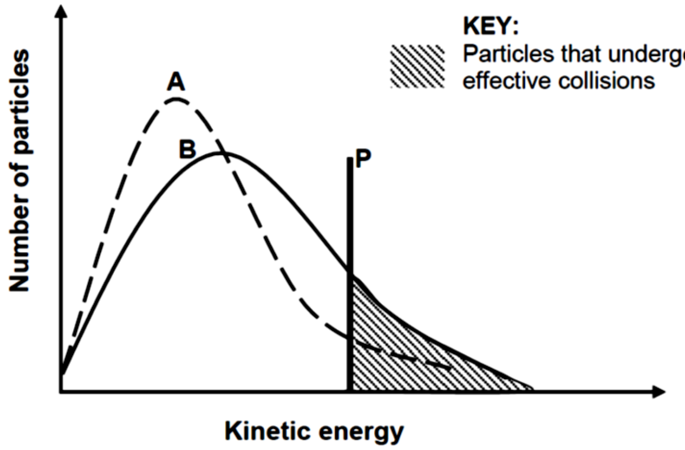
14.2.1 Dependent variable (1)
14.2.2 Conclusion that can be drawn from the results (2)

GRAPH OF REACTION RATE VERSUS CONCENTRATION OF $Na_2S_2O_3$(aq)



14.3 **INVESTIGATION II**

The Maxwell-Boltzmann distribution curves, **A** and **B**, represent the number of particles against kinetic energy for the reaction at two different temperatures.



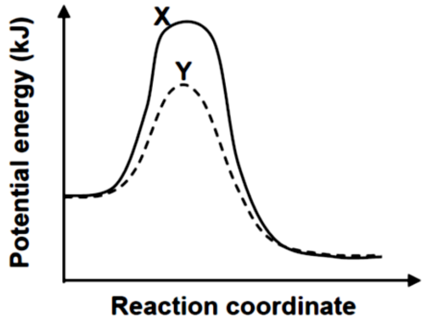
14.3.1 What does line **P** represent? (1)

14.3.2 Which curve (**A** or **B**) was obtained at the higher temperature? (1)

14.3.3 Explain, in terms of the collision theory, how an increase in temperature influences the rate of a reaction. (4)

14.4 **INVESTIGATION III**

The potential energy diagrams, **X** and **Y**, represent the reaction under two different conditions.



Give a reason why curve **Y** differs from curve **X**. (1)

14.5 In one of the investigations, 100 cm³ of 0,2 mol·dm⁻³ HCℓ(aq) reacts with excess $Na_2S_2O_3$(aq) and the solution is then filtered. After filtration of the solution, 0,18 g of sulphur is obtained. Calculate the PERCENTAGE YIELD of sulphur. *(Answer: 56,25%)* (6)

[18]

QUESTION 15 (November 2019)

The calcium carbonate ($CaCO_3$) in antacid tablets reacts with dilute hydrochloric acid (HCℓ) according to the following balanced equation:

$$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + CO_2(g) + H_2O(\ell) \qquad \Delta H < 0$$

15.1 Is the above reaction EXOTHERMIC or ENDOTHERMIC? Give a reason for the answer. (2)

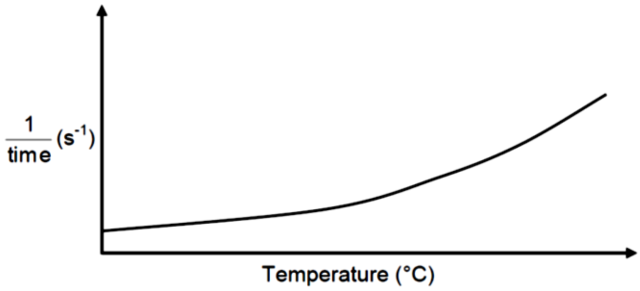
An antacid tablet of mass 2 g is placed in HCℓ(aq). After 30 s the mass of the tablet was found to be 0,25 g.

15.2 Calculate the average rate (in $g \cdot s^{-1}$) of the above reaction.
(Answer: 0,0583 $g \cdot s^{-1}$) (3)

The antacid tablet contains 40% calcium carbonate. Another antacid tablet of mass 2 g is allowed to react completely with HCℓ(aq).

15.3 Calculate the volume of carbon dioxide, CO_2(g) that will be collected at STP. Assume that all the CO_2(g) produced is from the calcium carbonate.
(Answer: 0,18 dm^3) (5)

The reaction rate of similar antacid tablets with excess HCℓ(aq) of concentration 0,1 mol·dm^{-3} at DIFFERENT TEMPERATURES is measured. The graph below was obtained.



Use the information in the graph to answer the following questions.

15.4 Write down ONE controlled variable for this investigation. (1)
15.5 Write down a conclusion that can be made from the graph. (2)
15.6 Use the collision theory to fully explain the answer to QUESTION 15.5. (3)
15.7 Redraw the graph above in the ANSWER BOOK. On the same set of axes, sketch the curve that will be obtained if HCℓ(aq) of concentration 0,2 mol·dm^{-3} is now used. Label this curve **Y**. (2)
[18]

QUESTION 16 (November 2020)

The reaction of calcium carbonate ($CaCO_3$) and EXCESS dilute hydrochloric acid (HCℓ) is used to investigate one of the factors that affects reaction rate. The balanced equation for the reaction is:

$$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + H_2O(\ell) + CO_2(g)$$

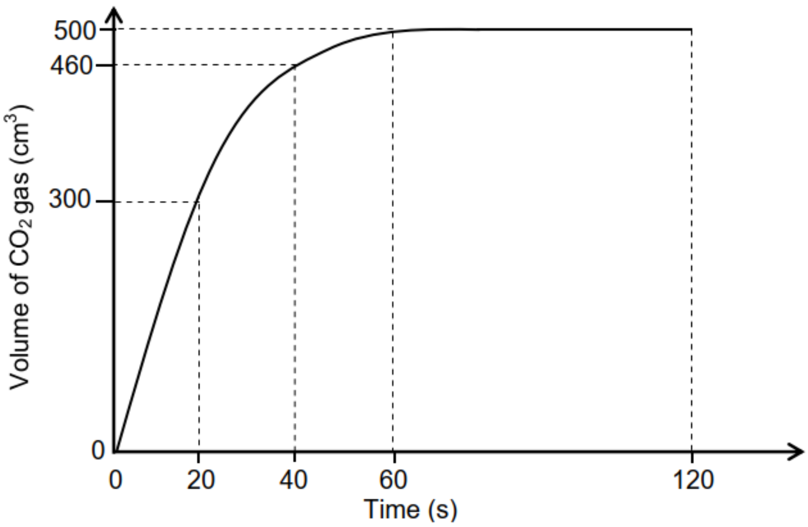
The same mass of $CaCO_3$ is used in all the experiments and the temperature of the hydrochloric acid in all experiments is 40°C.

The reaction conditions for each experiment are summarised in the table below.

EXPERIMENT	VOLUME OF HCℓ(aq) (cm^3)	CONCENTRATION OF HCℓ(aq) (mol·dm^{-3})	STATE OF DIVISION OF $CaCO_3$
A	500	0,1	granules
B	500	0,1	lumps
C	500	0,1	powder

16.1 For this investigation write down the:
16.1.1 Dependent variable (1)
16.1.2 Independent variable (1)

The carbon dioxide gas, $CO_2(g)$, produced during EXPERIMENT **A**, is collected in a gas syringe. The volume of gas collected is measured every 20 s and the results obtained are shown in the graph.



16.2 What can be deduced from the graph regarding the RATE OF THE REACTION during the time interval:
16.2.1 20 s to 40 s (1)
16.2.2 60 s to 120 s (1)
16.3 Calculate the average rate (in cm^3·s^{-1}) at which $CO_2(g)$ is produced in the experiment. *(Answer: 8,33 cm^3·s^{-1})* (3)
16.4 How will the volume of $CO_2(g)$ produced in experiment **B** compare to that produced in experiment **A**? Choose from GREATER THAN, SMALLER THAN or EQUAL TO. (1)
16.5 A graph is now drawn for experiment **C** on the same set of axes. How will the gradient of this graph compare to the gradient of the graph for experiment **A**? Choose from GREATER THAN, SMALLER THAN or EQUAL TO. Use the collision theory to fully explain the answer. (4)
16.6 Assume that the molar gas volume at 40°C is 25,7 dm^3·mol^{-1}. Calculate the mass of $CaCO_3(s)$ used in experiment **A**. *(Answer: 1,95 g)* (4)
[16]

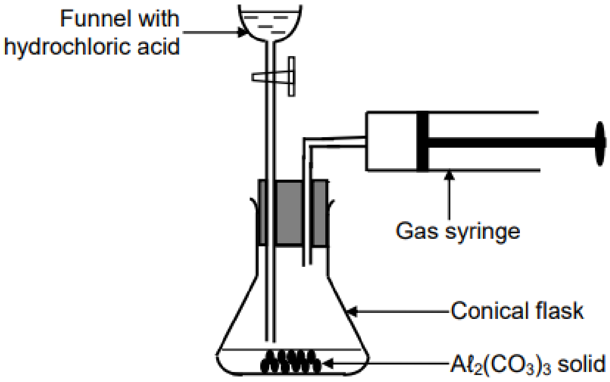
QUESTION 17 (June 2021)

Two experiments, **I** and **II**, are conducted to investigate one of the factors that affects the rate of the reaction of aluminium carbonate, $A\ell_2(CO_3)_3$, with EXCESS hydrochloric acid, $HC\ell$.

The balanced equation for the reaction is:

$$A\ell_2(CO_3)_3(s) + 6HC\ell(aq) \rightarrow 2A\ell C\ell_3(aq) + 3H_2O(\ell) + 3CO_2(g)$$

The apparatus used is shown below.



The reaction conditions used for each experiment are as follows:

Experiment I: 100 cm^3 of 1,5 $mol\cdot dm^{-3}$ $HC\ell(aq)$ reacts with 0,016 mol $A\ell_2(CO_3)_3$ granules at 25 °C

Experiment II: 50 cm^3 of 2 $mol\cdot dm^{-3}$ $HC\ell(aq)$ reacts with 0,016 mol $A\ell_2(CO_3)_3$ granules at 25 °C

17.1 Define the term *rate of a reaction*. (2)

17.2 Using the experimental setup above, state the measurements that must be made to determine the rate of this reaction. (2)

17.3 Use the collision theory to explain how the average reaction rate in **Experiment I** differs from the average reaction rate in **Experiment II**. (3)

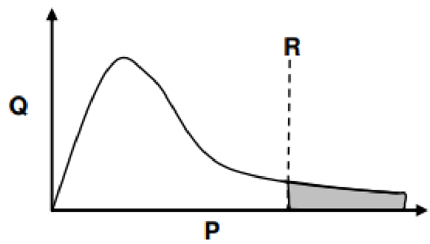
17.4 The average rate of the reaction in **Experiment II** during the first 2,5 minutes is $4,4 \times 10^{-3}$ $mol\cdot min^{-1}$. Calculate the number of moles of $A\ell_2(CO_3)_3$ that remains in the flask after 2,5 minutes.
(Answer: 0,005 mol) (3)

17.5 Calculate the maximum volume of $CO_2(g)$ that can be prepared at 25 °C in **Experiment I**. Take molar gas volume at 25 °C as 24 000 $cm^3\cdot mol^{-1}$.
(Answer: 1 152 cm^3) (3)

[13]

QUESTION 18 (September 2021)

18.1 Study the Maxwell-Boltzmann distribution curve for a certain reaction below.



P and **Q** are the labels of the axes. What quantity is represented by:

18.1.1 **P** (1)

18.1.2 **Q** (1)

18.2 Line **R** represents <u>the minimum energy required for the reaction to take place</u>.

18.2.1 Write down the term for the underlined phrase. (1)

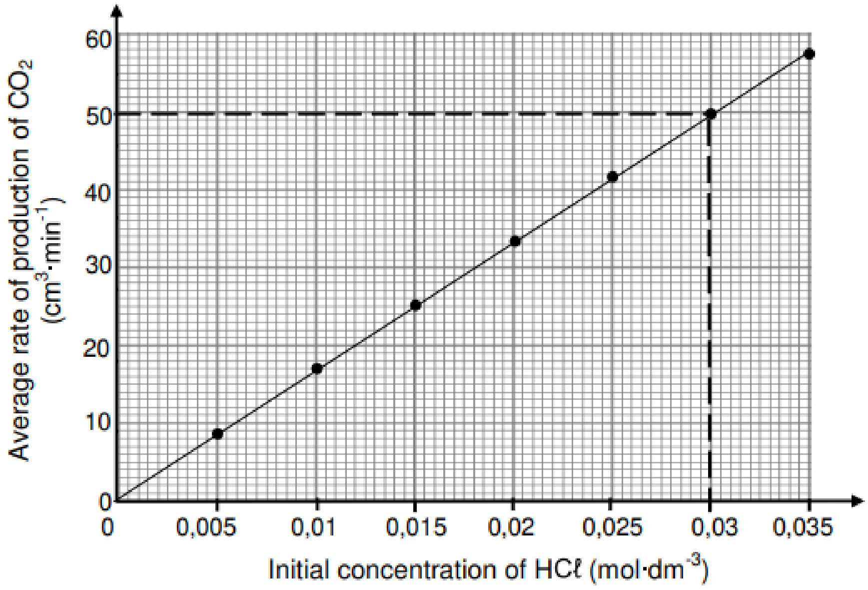
18.2.2 How will the shaded area on the graph be affected when a catalyst is added? Choose from INCREASE, DECREASE or REMAINS THE SAME. (1)

18.3 Use the collision theory to explain how a catalyst influences the rate of reaction. (4)

18.4 The reaction between POWDERED calcium carbonate, $CaCO_3(s)$, and EXCESS hydrochloric acid, $HC\ell(aq)$, is used to investigate reaction rate at 25 °C. The balanced equation for the reaction is:

$$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + H_2O(\ell) + CO_2(g)$$

Several experiments are conducted using the same mass of IMPURE calcium carbonate and different initial concentrations of dilute hydrochloric acid. The graph below represents the results obtained. Assume that the impurities do not react.



For this investigation, write down a:

18.4.1 Controlled variable (1)

18.4.2 Conclusion (2)

The $CaCO_3(s)$ in 6 g of the impure sample reacts completely with 0,03 mol dm^{-3} in 26 minutes.

18.4.3 Use the information in the graph to calculate the percentage purity of the calcium carbonate. Assume that the molar gas volume at 25 °C is 24 000 cm^3. *(Answer: 83,33% to 90,33%)* (6)

[17]

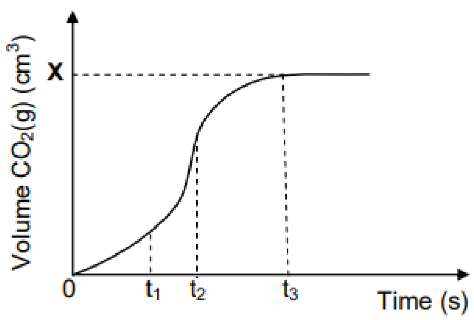
QUESTION 19 (November 2021)

The reaction of 15 g of an IMPURE sample of calcium carbonate, $CaCO_3$, with EXCESS hydrochloric acid, $HC\ell$, of concentration 1,0 mol·dm^{-3}, is used to investigate the rate of a reaction.

The balanced equation for the reaction is:

$$CaCO_3(s) + 2HC\ell(aq) \rightarrow CaC\ell_2(aq) + H_2O(\ell) + CO_2(g)$$

The volume of $CO_2(g)$ produced is measured at regular intervals. A sketch graph representing the total volume of carbon dioxide gas produced as a function of time is shown below.



19.1 Define the term *reaction rate*. (2)

19.2 Give a reason why the gradient of the graph decreases between t_2 and t_3. (1)

19.3 Changes in the graph between t_1 and t_2 are due to temperature changes within the reaction mixture.

19.3.1 Is the reaction EXOTHERMIC or ENDOTHERMIC? (1)

19.3.2 Explain the answer by referring to the graph. (3)

19.4 The percentage purity of the sample is 82,5%. Calculate the value of X on the graph assuming that the gas is collected at 25 °C. Take the molar gas volume at 25 °C as 24 000 cm^3.
(Answer: 2880 to 2970 cm^3) (5)

19.5 How will the reaction rate change if 15 g of a PURE sample of $CaCO_3$ reacts with the same $HC\ell$ solution? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

19.6 Use the collision theory to explain the answer to QUESTION 19.5. (2)

[15]

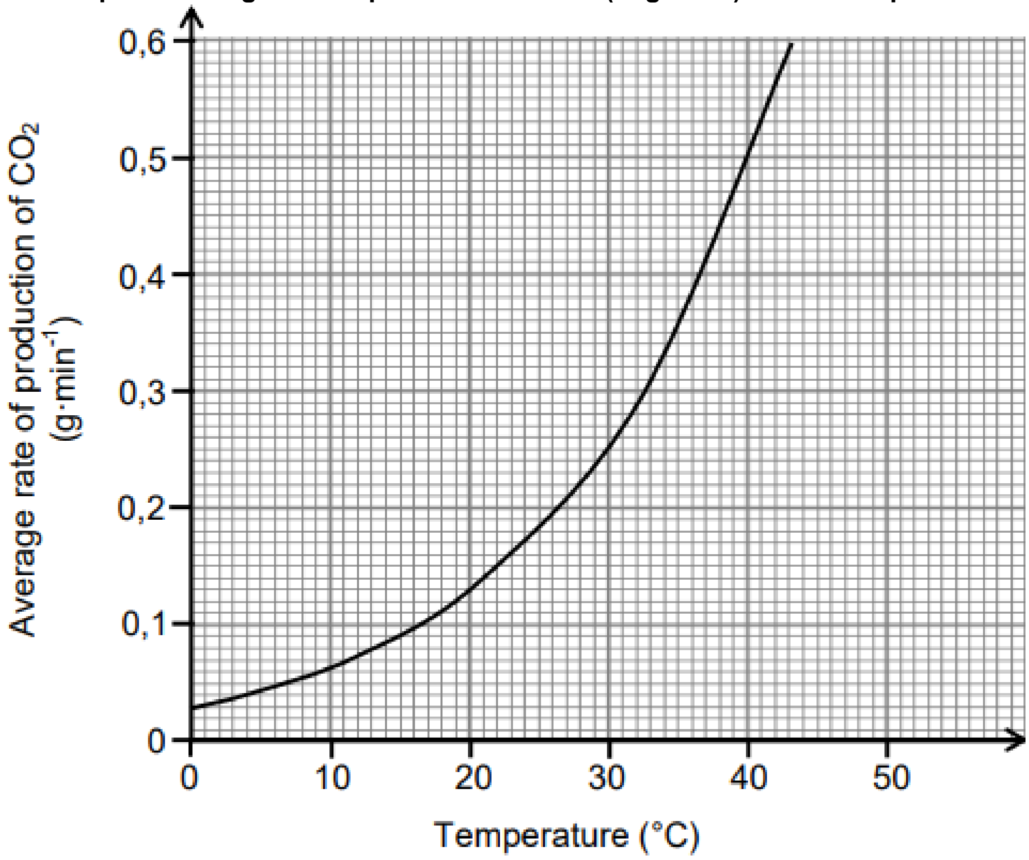
QUESTION 20 (June 2022)

Learners use the reaction of $MgCO_3$(s) with EXCESS dilute HCℓ(aq) to investigate the relationship between temperature and the rate of a chemical reaction. The balanced equation for the reaction is:

$$MgCO_3(s) + 2HCℓ(aq) \rightarrow MgCℓ_2(aq) + CO_2(g) + H2O(ℓ)$$

The results obtained are represented in the graph below.

Graph of average rate of production of CO_2 (in $g \cdot min^{-1}$) versus temperature



20.1 Define the term *rate of reaction*. (2)

20.2 State TWO conditions that must be kept constant during this investigation. (2)

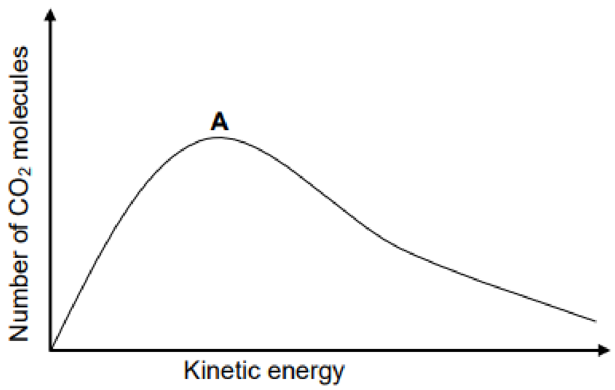
20.3 Use the collision theory to explain the relationship shown in the graph. (4)

20.4 The learners obtained the graph above using 5 g $MgCO_3$(s) with EXCESS HCℓ at 40 °C. Calculate the:

20.4.1 Time taken for the reaction to run to completion
(Answer: 5,238 to 5,28 min) (6)

20.4.2 Molar gas volume at 40 °C if 1,5 dm^3 CO_2 is collected in a syringe
(Answer: 25 to 25,21 $dm^3 \cdot mol^{-1}$) (2)

20.5 The graph below represents the Maxwell-Boltzmann distribution curve for CO_2(g) at 40 °C.



Redraw the graph above in the ANSWER BOOK. Clearly label the curve as **A**.
On the same set of axes, sketch the curve that will be obtained for the CO_2(g) at 20 °C. Label this curve as **B**. (2)

[18]

QUESTION 21 (November 2022)
Three experiments, **A**, **B** and **C**, are carried out to investigate some of the factors that affect the rate of decomposition of hydrogen peroxide, $H_2O_2(\ell)$.

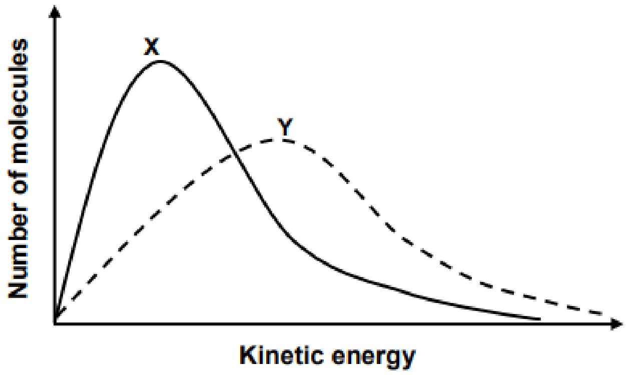
The balanced equation for the reaction is: $2H_2O_2(\ell) \rightarrow 2H_2O(\ell) + O_2(g)$

Identical samples of hydrogen peroxide are used in each experiment.
The conditions used in each experiment are summarised in the table below.

EXPERIMENT	TEMPERATURE (°C)	
A	25	Without catalyst
B	25	With catalyst
C	35	Without catalyst

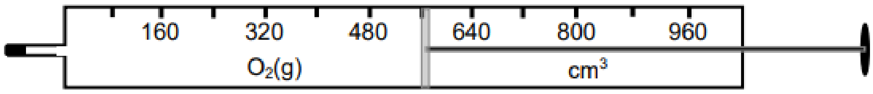
21.1 In which experiment, **A** or **B**, is the reaction rate higher? Use the collision theory to explain the answer. (4)

21.2 The Maxwell-Boltzmann distribution curves, **X** and **Y**, for two of the above experiments are shown below.



Identify the curve (**X** or **Y**) that represents experiment **C**. (2)

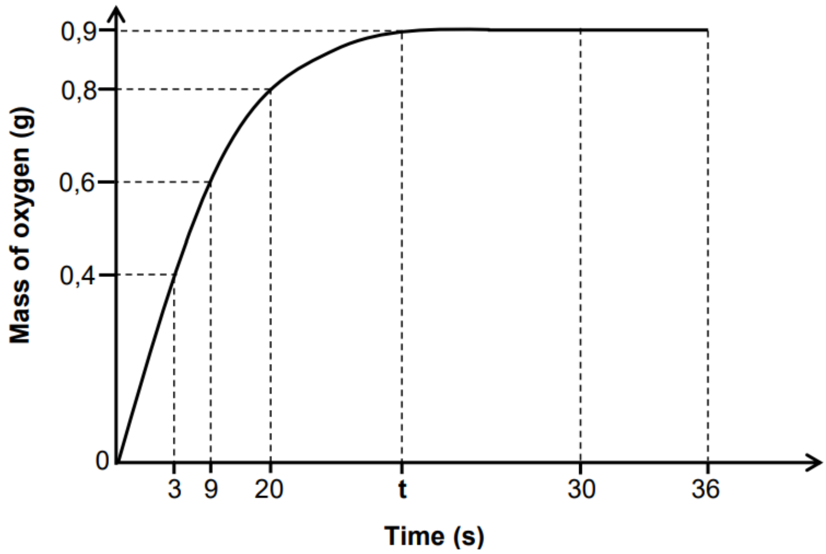
21.3 The volume of oxygen gas, $O_2(g)$, produced in experiment **B** during the first 3,6 s is collected in a syringe, as shown below.



21.3.1 Write down the volume of $O_2(g)$ collected in the syringe. *(Answer: 560 cm³)* (2)

21.3.2 Calculate the mass of water, $H_2O(\ell)$, that was produced during the first 3,6 s. Take the molar gas volume to be 24 000 $cm^3 \cdot mol^{-1}$ at 25 °C. *(Answer: 0,72 to 0,9 g)* (4)

21.4 The graph below, NOT drawn to scale, is obtained for the mass of oxygen gas produced over a period of time in experiment **A**.



Use the information in the graph to answer the following questions:

21.4.1 Write down the rate of production of oxygen gas for the interval 30 s to 36 s. (1)

21.4.2 Will the rate of the reaction in the interval 3 s to 9 s be GREATER THAN, SMALLER THAN or EQUAL TO the rate of the reaction in the interval 9 s to 20 s? (1)

21.4.3 The average rate of decomposition of hydrogen peroxide is $2,1 \times 10^{-3}$ $mol \cdot s^{-1}$
Calculate the value of time **t** on the graph. *(Answer: 26,67 to 28,57 s)* (5)

[19]

CHEMICAL EQUILIBRIUM

CHEMICAL EQUILIBRIUM

Requirements

- A REVERSIBLE chemical reaction
- A CLOSED system

Products can be converted back to reactants

Only exchanges energy, not matter, with its surroundings.

Dynamic equilibrium:

- Rate of forward reaction equals the rate of the reverse reaction.
- Amount of reactants and amount of products remain constant.

FACTORS AFFECTING EQUILIBRIUM

A CATALYST has NO EFFECT on the equilibrium position. It only shortens the time it takes to reach equilibrium.

Le Chatelier's principle
When the equilibrium in a closed system is disturbed, the system will re-instate a new equilibrium by favouring the reaction that opposes the disturbance.

Predict and explain the effect on equilibrium

CONCENTRATION

- increase: Reaction that DECREASES concentration is favoured.
- decrease: Reaction that INCREASES concentration is favoured.

Example: $H_2(g) + S(s) \rightleftharpoons H_2S(g)$

- $[H_2]$ increases: Forward reaction is favoured to decrease $[H_2]$.
- $[H_2]$ decreases: Reverse reaction is favoured to increase $[H_2]$.
- $[H_2S]$ increases: Reverse reaction is favoured to decrease $[H_2S]$.

TEMPERATURE

- increase: Endothermic reaction is favoured.
- decrease: Exothermic reaction is favoured.

Example: $2NO_2(g) \rightleftharpoons N_2O_4(g \quad \Delta H < 0$

- T decreases: forward reaction is favoured.
- T increases: reverse reaction is favoured.

PRESSURE (Gases only)

- increase: Reaction that produces the smallest number of moles of gas is favoured.
- decrease: Reaction that produces the greatest number of moles of gas is favoured.

Example: $2NO_2(g) \rightleftharpoons N_2O_4(g)$
2 moles of gas 1 mole of gas

- p increases: forward reaction is favoured.
- p decreases: reverse reaction is favoured.

TERMS AND DEFINITIONS	
Open system	A system which continuously interacts with the environment – it exchanges matter and energy with its environment.
Closed system	A system that only exchanges energy with its surroundings, but it does not exchange matter with its surroundings.
Reversible reaction	A reaction is reversible when products can be converted back to reactants.
Chemical equilibrium	Dynamic equilibrium when the rate of the forward reaction equals the rate of the reverse reaction.
Factors that influence the equilibrium position	Pressure (gases only), concentration and temperature.
Le Chatelier's principle	When the equilibrium in a closed system is disturbed, the system will re-instate a new equilibrium by favouring the reaction that will oppose the disturbance.

STEPS WHEN EXPLAINING IN TERMS OF LE CHATELIER'S PRINCIPLE

When explaining in terms of Le Chatelier's principle, the following steps should be used:

1. Identify the disturbance e.g. *increase in temperature.*
2. State that the system will act to oppose this disturbance e.g. *the system will decrease the temperature.*
3. State how the system will manage to oppose the disturbance e.g. *the increase in temperature will favour the endothermic reaction.*
4. State which reaction will be favoured when opposing the disturbance e.g. *the reverse will be favoured.*
5. State the effect on the number of moles of products/reactants e.g. *the number of moles of products will decrease or number of moles of reactants will increase.*

WRITING AN EXPRESSION FOR THE EQUILIBRIUM CONSTANT (K_c)

- For the reaction $aA(g) + bB(g) \rightleftharpoons cC(g) + dD(g)$, $K_c = \dfrac{[C]^c[D]^d}{[A]^a[B]^b}$
- Only gases (g) and solutions (aq) appear in the K_c expression – no solids (s) and pure liquids (ℓ) are included.
- The equilibrium constant does not have a unit.
- Large K_c values: Reactions in which the concentration of products is high in comparison to that of reactants. Such a reaction proceeded well to form products.
- Small K_c values: Reactions in which the concentration of products is low in comparison to that of reactants. Such a reaction did not proceed well to form products.
- Only temperature can change the K_c value. Therefore, the K_c value for a reaction is given at a specific temperature.
- $K_c = \dfrac{[\text{products}]}{[\text{reac tan ts}]}$ is NOT a K_c expression!

SOLVING PROBLEMS INVOLVING K_C CALCULATIONS

The best way to solve K_c calculations is to use a table.

- Draw a table with SIX rows. The number of columns will depend on the number of reactants and products in the balanced equation.
- 1st row: **Reactants and products** in the balanced equation
- 2nd row: **Ratio** in which reactants react and products form in balanced equation
- 3rd row: **Initial quantities** (number of moles) of reactants and products
- 4th row: **Change** i.e., the decrease in number of moles of reactants and increase in number of moles of products during the reaction
- 5th row: **Equilibrium quantities, $n_{equilibrium}$** (number of moles)
- 6th row: **Equilibrium concentrations, $c_{equilibrium}$**

EXAMPLE 1

Question:

A hypothetical reaction is represented by the following balanced equation: $A(g) + 2B(g) \rightleftharpoons 2C(g)$

Initially 3 moles of A(g) and 6 moles of B(g) are mixed in a 5 dm^3 sealed container. When the reaction reaches equilibrium at 25 °C, it is found that 4 moles of B(g) is present. Calculate the equilibrium constant for this reaction.

Solution:

To calculate the equilibrium constant, the concentrations of reactants and products at equilibrium are needed. The only information available is the initial number of moles of the reactants and products, the volume of the container and the balanced equation shows the *ratio in which reactants react and products form.*

Step 1: *Draw a table with SIX rows. Fill all information available in the table i.e., reactants and products, ratio, initial amounts (3 moles of A, 6 moles of B and 0 moles of the product).*

Reactants and products	**A**	**B**	**C**
Ratio	1	2	2
Initial quantity (mol)	**3**	**6**	**0**
Change (mol)			
Quantity at equilibrium (mol)		**4**	
Equilibrium concentration ($mol \cdot dm^{-3}$)			

Step 2: *The initial number of moles of B and the final number of moles of B are known and therefore, the number of moles of B that has reacted can be calculated by subtraction:*
$B_{react} = B_{change} = B_{initial} – B_{equilibrium} = 6 – 4 = 2$ *moles. Initially there were 6 mole of B and at equilibrium there are 4 moles of B – therefore 2 moles of B reacted.*

	A	**B**	**C**
Ratio	1	2	2
Initial quantity (mol)	3	6	0
Change (mol)		**2**	
Quantity at equilibrium (mol)		4	
Equilibrium concentration ($mol \cdot dm^{-3}$)			

Step 3: *Use the mole ratios from the balanced equation and $n(B)_{change}$ to determine the number of moles of A that has reacted and the number of moles of C that has formed.*
From equation: 1 mole of A reacts with 2 moles of B to from 2 moles of C. The ratio is thus 1 : 2 : 2.
To react with 2 moles of B, 1 mole of A is needed and then 2 moles of C will be formed.

	A	**B**	**C**
Ratio	1	2	2
Initial quantity (mol)	3	6	0
Change (mol)	**1**	2	**2**
Quantity at equilibrium (mol)		4	
Equilibrium concentration ($mol \cdot dm^{-3}$)			

Step 4: *No calculate the number of moles of A at equilibrium by subtracting the 1 mole that has reacted from the initial 3 moles i.e., 3 – 1 = 2 moles. Calculate the number of moles of C at equilibrium by adding the 2 moles that has formed to the initial number of moles i.e., 0 + 2 = 2 moles.*

	A	**B**	**C**
Ratio	1	2	2
Initial quantity (mol)	3	6	0
Change (mol)	1	2	2
Quantity at equilibrium (mol)	**2**	4	**2**
Equilibrium concentration ($mol \cdot dm^{-3}$)			

Step 5: *Divide the equilibrium number of moles of reactants and products by the volume (5 dm^3) to obtain the equilibrium concentrations. The formula $c = \frac{n}{V}$ is used.*

	A	**B**	**C**
Ratio	1	2	2
Initial quantity (mol)	3	6	0
Change (mol)	1	2	2
Quantity at equilibrium (mol)	2	4	2
Equilibrium concentration ($mol \cdot dm^{-3}$)	**0,4**	**0,8**	**0,4**

Step 6: *Follow the rules given for the writing of K_c expressions to write a correct K_c expression for this reaction. Substitute the CONCENTRATION values of the reactants and products in the K_c expression and calculate the final answer.*

$$K_c = \frac{[C]^2}{[A][B]^2} = \frac{(0,4)^2}{(0,4)(0,8)^2} = 0,625$$

<u>EXAMPLE 2</u>

<u>Question:</u>

Hydrogen and iodine are sealed in a 2 dm^3 container. The reaction is allowed to reach equilibrium at 700 K according to the following balanced equation: $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

At equilibrium, 0,028 mol $H_2(g)$ and 0,017 mol $I_2(g)$ are present in the container.

Calculate the initial mass of $I_2(g)$, in grams, that was sealed in the container, if K_c for the reaction is 55,3 at 700 K.

<u>Solution 1:</u>

Step 1: *Draw a table with SIX rows. Fill all available information in the table i.e., reactants and products, ratio, $n(H_2)_{equilibrium}$ = 0,028 mol and $n(I_2)_{equilibrium}$ = 0,017 mol. Initially only hydrogen and iodine are sealed in the container – therefore $n(HI)_{initial}$ = 0.*

	H_2	I_2	2HI
Ratio	**1**	**1**	**2**
Initial quantity (mol)			**0**
Change (mol)			
Quantity at equilibrium (mol)	**0,028**	**0,017**	
Equilibrium concentration (mol·dm^{-3})			

Step 2: *Divide the equilibrium number of moles of reactants by the volume (2 dm^3) to obtain the equilibrium concentration for each reactant.*

	H_2	I_2	2HI
Ratio	1	1	2
Initial quantity (mol)			0
Change (mol)			
Quantity at equilibrium (mol)	0,028	0,017	
Equilibrium concentration (mol·dm^{-3})	**0,014**	**0,0085**	

Step 3: *The equilibrium concentrations of reactants and K_c is known. Write the K_c expression for the reaction and calculate the equilibrium concentration of HI i.e. [HI].*

$$K_c = \frac{[HI]^2}{[H_2][I_2]} \quad \therefore \; 55,3 = \frac{[HI]^2}{(0,014)(0,0085)} \quad \therefore \; [HI] = 0,081 \text{ mol·dm}^{-3}$$

Fill the value for [HI] in he table and multiply it by 2 dm^3 to obtain $n(HI)_{equilibrium}$.

	H_2	I_2	HI
Ratio	1	1	2
Initial quantity (mol)			0
Change (mol)			
Quantity at equilibrium (mol)	0,028	0,017	**0,162**
Equilibrium concentration (mol·dm^{-3})	**0,014**	**0,0085**	**0,081**

Step 4: *The initial number of moles of HI and the equilibrium number of moles of HI are known. Calculate the number of moles of HI formed during the reaction by subtraction:*
$n(HI)_{reacted} = n(HI)_{equilibrium} - n(HI)_{initial}$ = 0,162 – 0 = 0,162 mol

	H_2	I_2	HI
Ratio	1	1	2
Initial quantity (mol)			0
Change (mol)			**0,162**
Quantity at equilibrium (mol)	0,028	0,017	0,162
Equilibrium concentration (mol·dm^{-3})	0,014	0,0085	0,081

Step 5: *Use the mole ratios from the balanced equation and $n(HI)_{formed}$ to determine the number of moles of H_2 and I_2 that has reacted. To form 0,162 mol of HI, ½(0,162) mol H_2 and ½(0,162) mol I_2 must react because the mole ratio is as follows: $H_2 : I_2 : HI = 1 : 1 : 2$*

	H_2	I_2	HI
Ratio	1	1	2
Initial quantity (mol)			0
Change (mol)	**0,081**	**0,081**	0,162
Quantity at equilibrium (mol)	0,028	0,017	0,162
Equilibrium concentration (mol·dm^{-3})	0,014	0,0085	0,081

Step 6: *Calculate $n(I_2)_{initial}$ by addition i.e. $n(I_2)_{initial} = n(I_2)_{equilibrium} + n(I_2)_{react} = 0,017 + 0,081 = 0,098$ mol*

	H_2	I_2	HI
Ratio	1	1	2
Initial quantity (mol)		**0,098**	0
Change (mol)	0,081	0,081	0,162
Quantity at equilibrium (mol)	0,028	0,017	0,162
Equilibrium concentration (mol·dm^{-3})	0,014	0,0085	0,081

Step 7: *Calculate the initial mass of I_2 using $n(I_2) = \frac{m}{M}$ $\therefore 0,098 = \frac{m}{254}$ $\therefore m = 24,89$ g*

Solution 2:

Step 2: *From the balanced equation 1 mole of H_2 reacts with 1 mole of I_2 to from 2 moles of HI. The number of moles that reacted are unknown, therefore we use x. The mole ratio is 1 : 1 : 2, thus x, x and 2x.*

	H_2	I_2	HI
Ratio	1	1	2
Initial quantity (mol)			0
Change (mol)	**x**	**x**	**2x**
Quantity at equilibrium (mol)	0,028	0,017	
Equilibrium concentration (mol·dm^{-3})			

Step 3: *Calculate the initial moles of I_2 (unknown whose mass must be determined) by addition:*
$n(I_2)_{initial} = n(I_2)_{equilibrium} + n(I_2)_{react} = 0,017 + x$.
The number of moles of HI at equilibrium: $(HI)_{equilibrium} = n(HI)_{initial} + n(HI)_{formed} = 0 + 2x = 2x$.

	H_2	I_2	HI
Ratio	1	1	2
Initial quantity (mol)		0,017 + x	0
Change (mol)	x	x	2x
Quantity at equilibrium (mol)	0,028	0,017	**2x**
Equilibrium concentration (mol·dm^{-3})			

Step 4: *Divide the equilibrium number of moles of reactants and product by the volume (2 dm^3) to obtain the equilibrium concentrations i.e $[H_2]$, $[I_2]$ and [HI]. The formula $c = \frac{n}{V}$ is used.*

	H_2	I_2	2HI
Ratio	1	1	2
Initial quantity (mol)		0,017 + x	0
Change (mol)	x	x	2x
Quantity at equilibrium (mol)	0,028	0,017	2x
Equilibrium concentration (mol·dm^{-3})	$\frac{0,028}{2} = 0,014$	$\frac{0,017}{2} = 0,0085$	$\frac{2x}{2} = x$

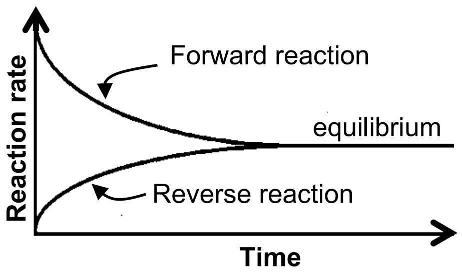
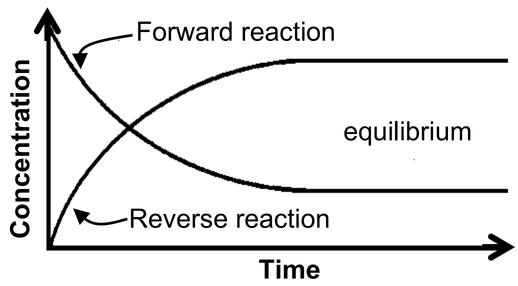
Step 5: *Follow the rules given for the writing of K_c expressions to write a correct K_c expression for this reaction. Substitute the CONCENTRATION values of the reactants and product in the K_c expression and solve for x.*

$$K_c = \frac{[HI]^2}{[H_2][I_2]} \checkmark \quad \therefore \quad 55,3 = \frac{(x)^2}{(0,014)(0,0085)} \checkmark \therefore x = 0,081 \text{ mol}$$

Step 6: *Substitute x with 0,081 in $n(I_2)_{initial} = 0,017 + x = 0,017 + 0,081 = 0,098$ mol*

Step 7: *Calculate the initial mass of I_2 as* $n(I_2) = \frac{m}{M}$ $\therefore 0,098 = \frac{m}{254}$ $\therefore m = 24,89$ g

CHEMICAL EQUILIBRIUM GRAPHS

<u>Rate versus time graph</u> • Initially only reactants are present, and the rate of the forward reaction is high but decreases with time as reactants are being used up. • As products are formed, the rate of the reverse reaction increases from zero. • **At equilibrium, the rate of the forward reaction equals the rate of the reverse reaction**. Remember, it is a dynamic equilibrium. Hence the rates graph should indicate that both the forward and reverse rates are equal.	
<u>Concentration versus time graph</u> • Initially there are only reactants, and the concentration is high but decreases as reactants react to form products. • Initially there is no product, but the concentration of the product increases as the reactants react to form products. • **At equilibrium, the concentrations/amounts of the reactants and products remain constant**. • Notice how the concentrations of products and reactants do not have to be the same, as is the case for rates graphs. • Hence, when looking at a concentration-time graph we can tell when a system has reached equilibrium by the flat line of the concentration graphs.	

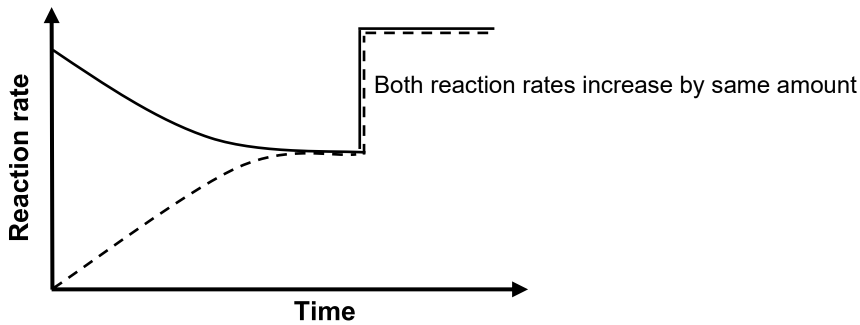
EXPLAINING EQUILIBRIUM GRAPHS

Note: When analysing a graph, step one is to determine the quantities on the axis.

EFFECT OF A CATALYST

<u>RATE VERSUS TIME GRAPH</u>

The ADDITION OF A CATALYST would favour both the forward and reverse reactions by the same amount.



<u>CONCENTRATION VERSUS TIME GRAPH</u>

When you add a catalyst to a system at equilibrium, both the forward and the reverse reactions speed up, so there is no change in the concentrations of any of the species in the mixture. **Adding a catalyst would have no effect on a graph of concentration versus time!**

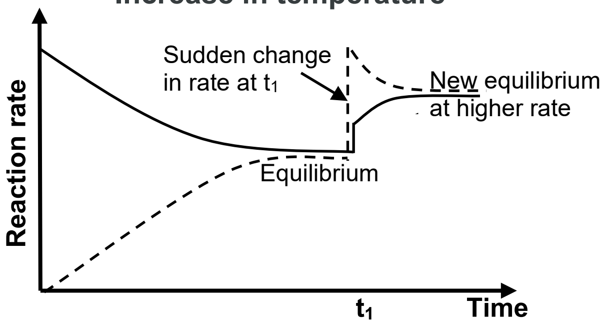
EFFECT OF TEMPERATURE

RATE VERSUS TIME GRAPHS

A CHANGE IN TEMPERATURE would affect both forward and reverse rates in the same direction (either both increase or both decrease). However, the effect will be unequal, with the endothermic reaction favoured by an increase in temperature, and the exothermic reaction favoured by a decrease in temperature.

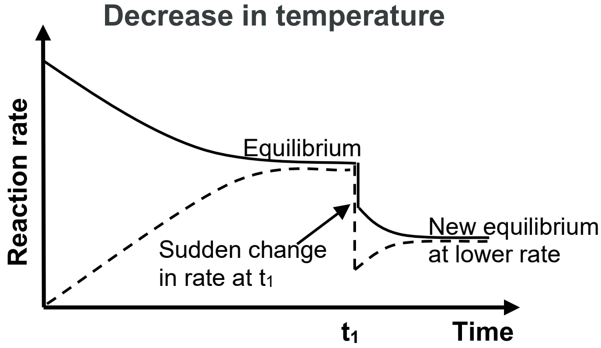
$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H < 0$$

Increase in temperature



- Initially the reaction reaches equilibrium - both the forward and the reverse rates are equal.
- The **rate of BOTH forward and reverse reactions increases** instantly at t_1 **due to the increase in T.**
- The rate of the reverse increases more – the **reverse reaction is endothermic and is favoured by increasing T**. The forward reaction is **exothermic.**
- The rates then change, reverse rate declines steadily as products are being used up and the forward rate increases steadily as the reactant concentration increases, until they are equal at the new equilibrium at a higher rate than before.

Decrease in temperature



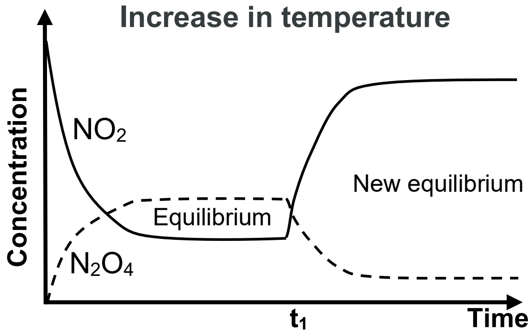
- Initially the reaction reaches equilibrium - both the forward and the reverse rates are equal.
- The **rate of BOTH forward and reverse reactions decreases instantly** at t_1 due to the decrease in T.
- The **rate of the forward decreases less** – the **forward reaction it is exothermic and is favoured by decreasing T**.
- The rates then change, forward rate declines steadily as reactants are being used up and the reverse rate increases steadily as the product concentration increases, until they are equal at the new equilibrium at a lower rate than before.

CONCENTRATION VERSUS TIME GRAPHS

A CHANGE IN TEMPERATURE will cause a **gradual change** in the concentrations of all species present. If the concentrations of products increase, that of reactants will decrease and vice versa.

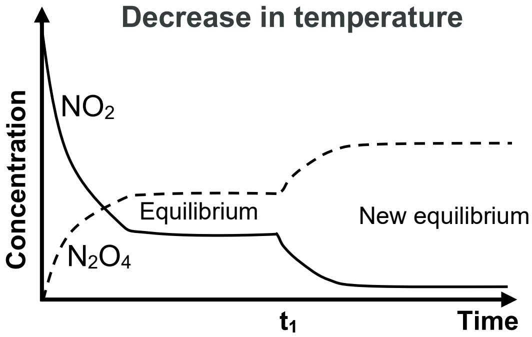
$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H < 0$$

Increase in temperature



- Initially, the system reaches equilibrium.
- Increase in T favours the endothermic reaction.
- When T is INCREASED at t_1 the concentration of the reactant increases rapidly because the reverse endothermic reaction is favoured. The concentration of the product decreases.
- There is a net increase in reactant. The increase in concentration of the reactant causes the forward reaction to also increase in rate until a new equilibrium is established.

Decrease in temperature



- Initially, the system reaches equilibrium.
- Decrease in T favours the exothermic reaction.
- When T is DECREASED at t_1 the concentration of the products increases rapidly because the forward reaction is favoured. The concentration of the reactant decreases.
- There is a net increase in product. The increase in concentration of the product causes the reverse reaction to also increase in rate until a new equilibrium is established.

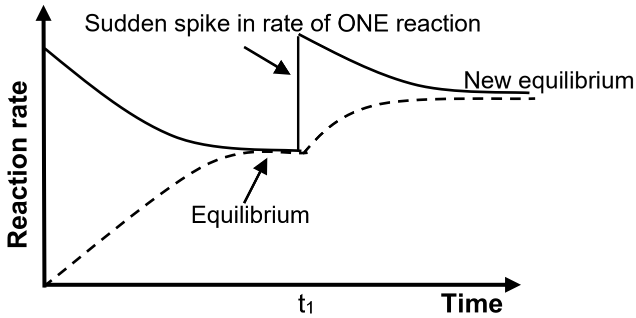
EFFECT OF CONCENTRATION

RATE VERSUS TIME GRAPHS

A CHANGE IN CONCENTRATION of a substance would favour the reaction that decreases the amount of that substance. This will appear as a sharp increase in the rate of either the forward or reverse reaction. The increased rate will then gradually decrease, and the decreased rate will gradually increase until they are equal again.

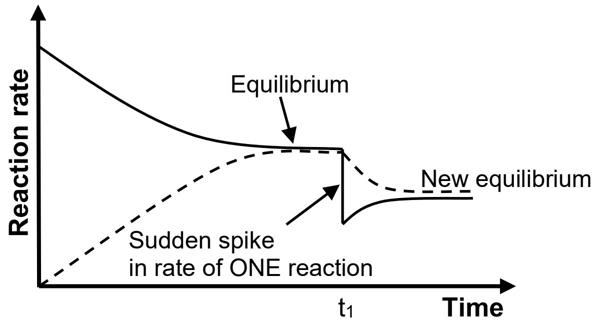
$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H < 0$

Increase in concentration of reactant



- Initially the reaction reaches equilibrium - both the forward and the reverse rates are equal.
- At the instant (t_1) when more reactant (NO_2) is added, the forward rate increases sharply.
- As the reactant is consumed in the reaction, the forward rate decreases to a constant value.
- Initially the reverse rate is unchanged. However, as more product is formed, the rate of the reverse reaction increases to the new constant value.
- Eventually, the rates of the forward and reverse reactions become equal.

Decrease in concentration of reactant

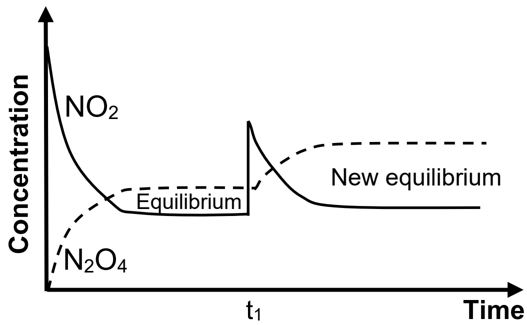


- Initially the reaction reaches equilibrium - both the forward and reverse rates are equal.
- At the instant (t_1) when some of reactant (NO_2) is removed, the forward rate decreases sharply. Since the reverse rate is larger than the forward rate, there is initially a net production of NO_2. The net production of NO_2 causes the forward rate to increase to a new constant value.
- Initially the reverse rate is unchanged. However, since product is no longer being formed at the same rate, the reverse rate decreases as the amount of product decreases.
- Eventually, the rates of the forward and reverse reactions become equal.

CONCENTRATION VERSUS TIME GRAPHS

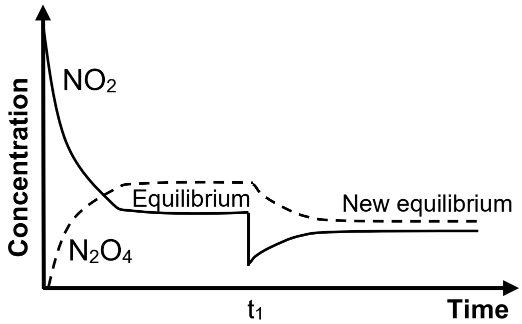
$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H < 0$

Increase in concentration of reactant



- Initially the reaction reaches equilibrium - the concentrations of reactant (NO_2) and product (N_2O_4) are constant.
- At the instant (t_1) when more reactant (NO_2) is ADDED, the concentration of NO_2 increases abruptly. The concentration of NO_2 begins to decrease almost immediately. As NO_2 is consumed in the reaction, its concentration decreases back to a constant value.
- Initially the concentration of N_2O_4 is unchanged. However, as the equilibrium adjusts, more product is formed and the concentration of N_2O_4 increases to a new constant value. A new equilibrium is reached.

Decrease in concentration of reactant



- Initially the reaction reaches equilibrium - the concentrations of reactant (NO_2) and product (N_2O_4) are constant.
- At the instant (t_1) when NO_2 is REMOVED, the concentration of NO_2 decreases sharply. Almost immediately, the concentration of N_2O_4 begins to decrease as the system adjusts to replace some of the lost NO_2.
- As more NO_2 is produced through the reverse reaction, its concentration begins to increase and eventually the concentrations of both reactants and products reaches a new constant value.

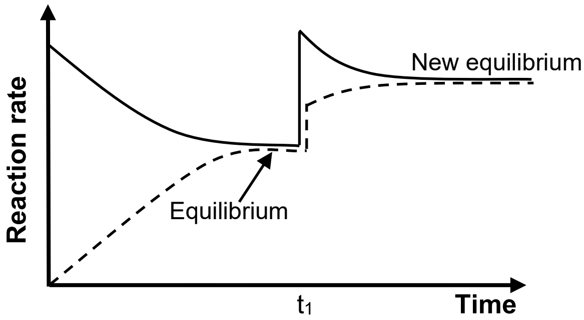
EFFECT OF PRESSURE (GASES ONLY)

RATE VERSUS TIME GRAPHS

A CHANGE IN PRESSURE of a system would cause a sharp increase or decrease in concentration of all the reactants and products in the gaseous phase. This will have the same effect as a change in concentration, although the increase or decrease would be more gradual.

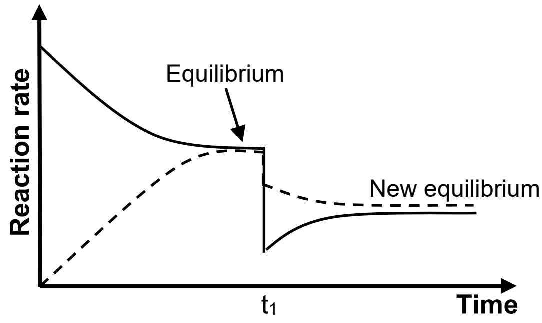
$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H < 0$

Increase in pressure/decrease in volume



- Initially the reaction reaches equilibrium - both the forward and the reverse rates are equal.
- A pressure increase / volume decrease (t_1) causes an increase in concentrations of both reactant and product and both the forward and reverse reaction rates increase.
- Since the forward reaction is favoured (2 mole gas to form 1 mole gas) the rate of the forward reaction increases more than that of the reverse reaction.
- Both rates adjust to be equal for a new equilibrium to be reached.

Decrease in pressure/increase in volume



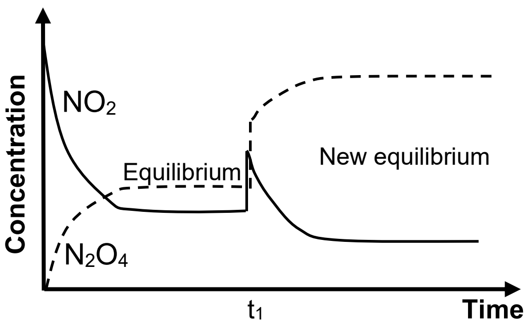
- Initially the reaction reaches equilibrium - both the forward and the reverse rates are equal.
- A pressure decrease / volume increase (t_1) causes a decrease in concentrations of both reactant and product and both the forward and reverse reaction rates decrease.
- Since the reverse reaction is favoured (1 mol gas to form 2 moles gas) the rate of the reverse reaction decreases less than that of the forward reaction.
- Both rates adjust to be equal for a new equilibrium to be reached.

CONCENTRATION VERSUS TIME GRAPHS

A CHANGE IN PRESSURE will cause ALL GAS curves to change VERTICALLY up or down. *Up* means an increase in pressure/decrease in volume and *down* means a decrease in pressure/increase in volume.

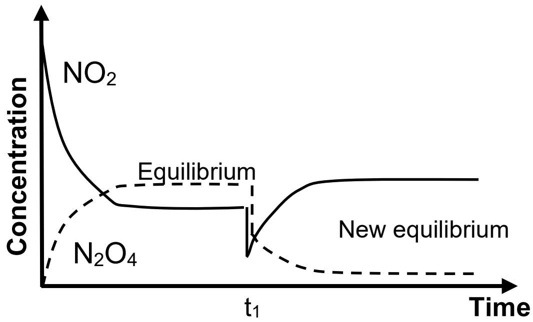
$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H < 0$

Increase in pressure/decrease in volume



- Initially the reaction reches equilibrium - the concentrations of reactant (NO_2) and product (N_2O_4) are constant.
- At the instant (t_1) when the pressure is increased (volume decreased), the concentrations of both reactant and product increase abruptly.
- The concentration of NO_2 begins to decrease almost immediately, because the forward reaction is favoured (2 moles of gas react to form 1 mole of gas). As NO_2 is consumed in the reaction, its concentration decreases back to a constant value.
- More product is formed and the concentration of N_2O_4 increases to a new constant value. A new equilibrium is reached.

Decrease in pressure/increase in volume



- Initially the reaction reaches equilibrium - the concentrations of reactant (NO_2) and product (N_2O_4) are constant.
- At the instant (t_1) when the pressure is decreased (volume increased), the concentrations of both reactant and product decrease abruptly.
- The concentration of NO_2 begins to increase almost immediately, because the reverse reaction is favoured (1 mole of gas react to form 2 moles of gas). As N_2O_4 is consumed in the reaction, its concentration decreases back to a constant value.
- More reactant is formed and the concentration of NO_2 increases to a new constant value. A new equilibrium is reached.

QUESTION 1 (November 2014)

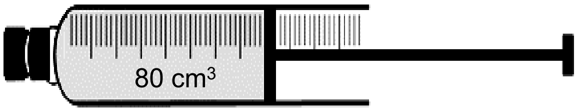
A certain amount of nitrogen dioxide gas (NO_2) is sealed in a gas syringe at 25 °C. When equilibrium is reached, the volume occupied by the reaction mixture in the gas syringe is 80 cm^3. The balanced chemical equation for the reaction taking place is:

$$\underset{\text{dark brown}}{2NO_2(g)} \rightleftharpoons \underset{\text{colourless}}{N_2O_4(g)} \qquad \Delta H < 0$$

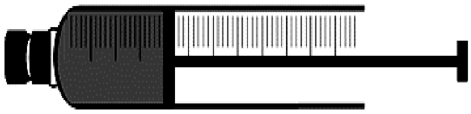
1.1 Define the term *chemical equilibrium*. (2)

1.2 At equilibrium the concentration of the $NO_2(g)$ is 0,2 $mol\cdot dm^{-3}$. The equilibrium constant for the reaction is 171 at 25 °C. Calculate the initial number of moles of $NO_2(g)$ placed in the gas syringe. *(Answer: 1,11 mol)* (8)

1.3 The diagram shows the reaction mixture in the gas syringe after equilibrium is established.

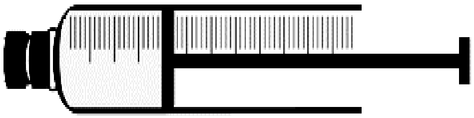


The pressure is now increased by decreasing the volume of the gas syringe at constant temperature as illustrated in the diagram below.



1.3.1 IMMEDIATELY after increasing the pressure, the colour of the reaction mixture in the gas syringe appears darker than before. Give a reason for this observation. (1)

After a while a new equilibrium is established as illustrated below.



The colour of the reaction mixture in the gas syringe now appears lighter than the initial colour.

1.3.2 Use Le Chatelier's principle to explain the colour change observed in the gas syringe. (3)

1.4 The temperature of the reaction mixture in the gas syringe is now increased and a new equilibrium is established. How will each of the following be affected?

1.4.1 Colour of the reaction mixture
Write down only DARKER, LIGHTER or REMAINS THE SAME. (1)

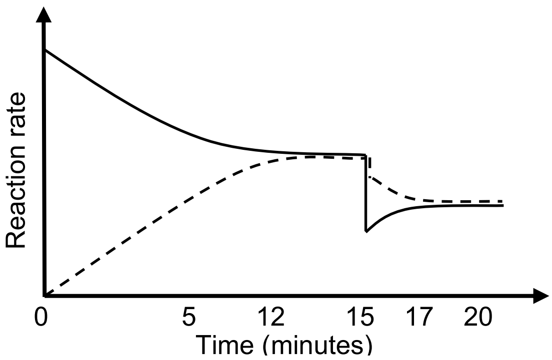
1.4.2 Value of the equilibrium constant (K_c)
Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

[16]

QUESTION 2 (March 2015)

Pure hydrogen iodide, sealed in a 2 dm^3 container at 721 K, decomposes according to the following balanced equation: $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$ $\Delta H = +26\ kJ\cdot mol^{-1}$

The graph below shows how reaction rate changes with time for this reversible reaction.



2.1 Write down the meaning of the term reversible reaction. (1)

2.2 How does the concentration of the reactant change between the 12th and the 15th minute? Write down only INCREASES, DECREASES or NO CHANGE. (1)

2.3 The rates of both the forward and the reverse reactions suddenly change at t = 15 minutes.

2.3.1 Give a reason for the sudden change in reaction rate. (1)

2.3.2 Fully explain how you arrived at the answer to QUESTION 2.3.1. (3)

The equilibrium constant (K_c) for the forward reaction is 0,02 at 721 K.

2.4 At equilibrium it is found that 0,04 mol HI(g) is present in the container. Calculate the concentration of $H_2(g)$ at equilibrium. *(Answer: $2,83 \times 10^{-3}$ $mol\cdot dm^{-3}$)* (6)

2.5 Calculate the equilibrium constant for the reverse reaction. *(Answer: 50)* (1)

2.6 The temperature is now increased to 800 K. How will the value of the equilibrium constant (K_c) for the forward reaction change? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

[14]

QUESTION 3 (June 2015)

Initially excess $NH_4HS(s)$ is placed in a 5 dm^3 container at 218 °C. The container is sealed and the reaction is allowed to reach equilibrium according to the following balanced equation:

$$NH_4HS(s) \rightleftharpoons NH_3(g) + H_2S(g) \qquad \Delta H > 0$$

3.1 State Le Chatelier's principle. (2)

3.2 What effect will each of the following changes have on the amount of $NH_3(g)$ at equilibrium? Write down only INCREASES, DECREASES or REMAINS THE SAME.

3.2.1 More $NH_4HS(s)$ is added (1)

3.2.2 The temperature is increased (1)

3.3 The equilibrium constant for this reaction at 218 °C is 1,2 x 10^{-4}. Calculate the minimum mass of $NH_4HS(s)$ that must be sealed in the container to obtain equilibrium.
(Answer: 2,79 to 2,81 g) (6)

The pressure in the container is now increased by decreasing the volume of the container at constant temperature.

3.4 How will this change affect the number of moles of $H_2S(g)$ produced? Fully explain the answer. (3)

[13]

QUESTION 4 (November 2015)

An unknown gas, $X_2(g)$, is sealed in a container and allowed to form $X_3(g)$ at 300 °C. The reaction reaches equilibrium according to the following balanced equation: $3X_2(g) \rightleftharpoons 2X_3(g)$

4.1 How will the rate of formation of $X_3(g)$ compare to the rate of formation of $X_2(g)$ at equilibrium? Write down only HIGHER THAN, LOWER THAN or EQUAL TO. (1)

The reaction mixture is analysed at regular time intervals. The results obtained are shown in the table below.

TIME (s)	**[X_2] ($mol \cdot dm^{-3}$)**	**[X_3] ($mol \cdot dm^{-3}$)**
0	0,4	0
2	0,22	0,120
4	0,08	0,213
6	0,06	0,226
8	0,06	0,226
10	0,06	0,226

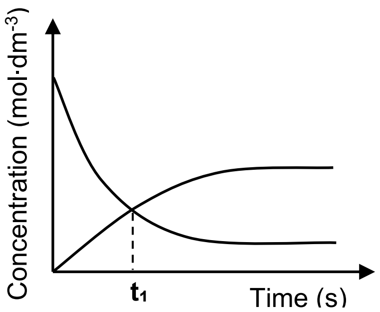
4.2 Calculate the equilibrium constant, K_c, for this reaction at 300 °C. *(Answer: 236,46)* (4)

4.3 More $X_3(g)$ is now added to the container.

4.3.1 How will this change affect the amount of $X_2(g)$? Write down INCREASES, DECREASES or REMAINS THE SAME. (1)

4.3.2 Use Le Chatelier's principle to explain the answer to QUESTION 4.3.1. (2)

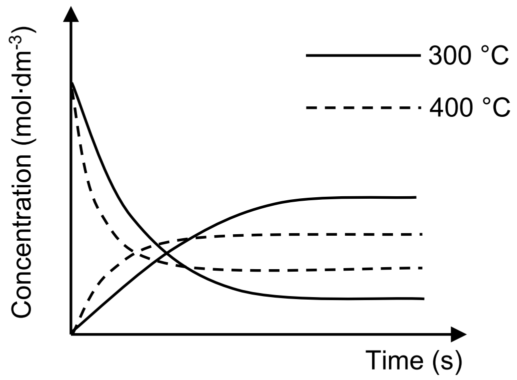
The curves on the set of axes below (not drawn to scale) was obtained from the results in the table.



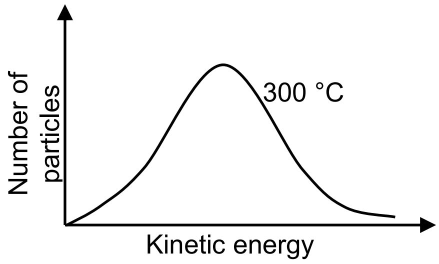
4.4 How does the rate of the forward reaction compare to that of the reverse reaction at t_1? Write down only HIGHER THAN, LOWER THAN or EQUAL TO. (1)

The reaction is now repeated at a temperature of 400 °C. The curves indicated by the dotted lines alongside were obtained at this temperature.

4.5 Is the forward reaction EXOTHERMIC or ENDOTHERMIC? Fully explain how you arrived at the answer. (4)



The Maxwell-Boltzmann distribution curve represents the number of particles against kinetic energy at 300 °C.



4.6 Redraw this curve in the ANSWER BOOK. On the same set of axes, sketch the curve that will be obtained at 400 °C. Clearly label the curves as 300°C and 400°C respectively. (2)

[15]

QUESTION 5 (March 2016)

Initially, 2,2 g of pure $CO_2(g)$ is sealed in an empty 5 dm^3 container at 900 °C.

5.1 Calculate the initial concentration of $CO_2(g)$.
(Answer: 0,01 mol·dm^{-3}) (4)

5.2 Give a reason why equilibrium will not be established. (1)

$CaCO_3(s)$ is now added to the 2,2 g $CO_2(g)$ in the container and after a while equilibrium is established at 900 °C according to the following balanced equation:

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

The equilibrium constant for this reaction at 900 °C is 0,0108.

5.3 Give a reason why this reaction will only reach equilibrium in a SEALED container. (1)

5.4 Calculate the minimum mass of $CaCO_3(s)$ that must be added to the container to achieve equilibrium.
(Answer: 0,4 g) (7)

5.5 How will EACH of the following changes affect the amount of $CO_2(g)$? Write down only INCREASES, DECREASES or REMAINS THE SAME.

5.5.1 More $CaCO_3(s)$ is added at 900 °C (1)

5.5.2 The pressure is increased (1)

5.6 It is found that the equilibrium constant (K_c) for this reaction is 2,6 x 10^{-6} at 727 °C. Is the reaction EXOTHERMIC or ENDOTHERMIC? Fully explain how you arrived at the answer. (4)

[19]

QUESTION 6 (June 2016)

Carbon dioxide reacts with carbon in a closed system to produce carbon monoxide, CO(g), according to the following balanced equation:

$$CO_2(g) + C(s) \rightleftharpoons 2CO(g) \qquad \Delta H > 0$$

6.1 What does the double arrow indicate in the equation above? (1)

6.2 Is the above reaction an EXOTHERMIC reaction or an ENDOTHERMIC reaction? Give a reason for the answer. (2)

Initially an unknown amount of carbon dioxide is exposed to hot carbon at 800 °C in a sealed 2 dm^3 container. The equilibrium constant, K_c, for the reaction at this temperature is 14. At equilibrium it is found that 168,00 g carbon monoxide is present.

6.3 How will the equilibrium concentration of the product compare to that of the reactants? Choose from LARGER THAN, SMALLER THAN or EQUAL TO. Give a reason for the answer. (No calculation is required.) (2)

6.4 Calculate the initial amount (in moles) of $CO_2(g)$ present.
(Answer: 4,29 mol) (9)

6.5 State how EACH of the following will affect the yield of CO(g) at equilibrium. Choose from INCREASES, DECREASES or REMAINS THE SAME.

6.5.1 More carbon is added at constant temperature. (1)

6.5.2 The pressure is increased. (1)

6.5.3 The temperature is increased. (1)

[17]

QUESTION 7 (November 2016)

Hydrogen gas, $H_2(g)$, reacts with sulphur powder, S(s), according to the following balanced equation:

$$H_2(g) + S(s) \rightleftharpoons H_2S(g) \qquad \Delta H < 0$$

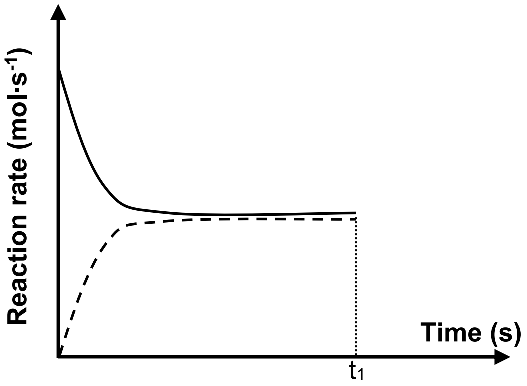
The system reaches equilibrium at 90 °C.

7.1 Define the term chemical equilibrium. (2)

7.2 How will EACH of the following changes affect the number of moles of H2S(g) at equilibrium? Choose from INCREASES, DECREASES or REMAINS THE SAME.

7.2.1 The addition of more sulphur (1)

7.2.2 An increase in temperature
Use Le Chatelier's principle to explain the answer. (4)



7.3 The sketch graph alongside was obtained for the equilibrium mixture. A catalyst is added to the equilibrium mixture at time t_1.
Redraw the graph in your book. On the same set of axes, complete the graph showing the effect of the catalyst on the reaction rates. (2)

Initially 0,16 mol $H_2(g)$ and excess S(s) are sealed in a 2 dm^3 container and the system is allowed to reach equilibrium at 90 °C.
An exact amount of $Pb(NO_3)_2$ solution is now added to the container so that ALL the $H_2S(g)$ present in the container at EQUILIBRIUM is converted to PbS(s) according to the following balanced equation:

$$Pb(NO_3)_2(aq) + H_2S(g) \rightarrow PbS(s) + 2HNO_3(aq)$$

The mass of the PbS precipitate is 2,39 g.

7.4 Calculate the equilibrium constant K_c for the reaction $H_2(g) + S(s) \rightleftharpoons H_2S(g)$ at 90 °C.
(Answer: 0,067) (9)

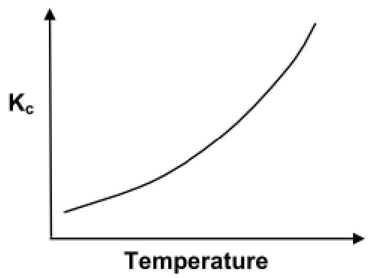
[18]

QUESTION 8 (March 2017)

8.1 Consider the balanced equation for a reversible reaction:

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$$

8.1.1 What is meant by the term *reversible reaction*? (1)



The sketch graph alongside shows the relationship between the value of the equilibrium constant (K_c) for this reaction and temperature.

8.1.2 Is the reaction ENDOTHERMIC or EXOTHERMIC? (1)

8.1.3 Fully explain the answer to QUESTION 8.1.2. (3)

How will EACH of the following changes affect the amount of NO(g) at equilibrium? Choose from INCREASES, DECREASES or REMAINS THE SAME.

8.1.4 More $N_2(g)$ is added. (1)

8.1.5 The pressure is increased by decreasing the volume. (1)

8.2 Initially 336 g titanium (Ti) and 426 g chlorine gas ($C\ell_2$) are mixed in a sealed 2 dm^3 container at a certain temperature. The reaction reaches equilibrium according to the following balanced equation:

$$Ti(s) + 2C\ell_2(g) \rightleftharpoons TiC\ell_4(s)$$

At equilibrium it is found that 288 g titanium is left in the container.

8.2.1 Calculate the equilibrium constant (K_c) for the reaction at this temperature.
(Answer: 0,25) (8)

8.2.2 More titanium is now added to the equilibrium mixture. How will this change affect the yield of $TiC\ell_4(s)$? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

[16]

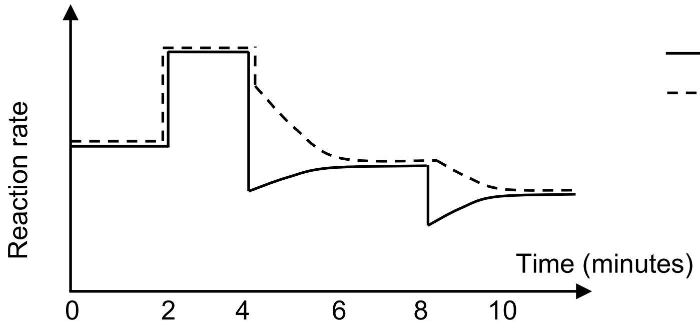
QUESTION 9 (June 2017)

Hydrogen and iodine are sealed in a 2 dm^3 container. The reaction is allowed to reach equilibrium at 700 K according to the following balanced equation: $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$

9.1 Give a reason why changes in pressure will have no effect on the equilibrium position. (1)

9.2 At equilibrium, 0,028 mol $H_2(g)$ and 0,017 mol $I_2(g)$ are present in the container. Calculate the initial mass of $I_2(g)$, in grams, that was sealed in the container, if K_c for the reaction is 55,3 at 700 K.
(Answer: 24, 92 g) (9)

The reaction rate versus time graph below represents different changes made to the equilibrium mixture.



9.3 What do the parallel lines in the first two minutes indicate? (1)

9.4 State TWO possible changes that could be made to the reaction conditions at t = 2 minutes. (2)

9.5 The temperature of the equilibrium mixture was changed at t = 4 minutes.

9.5.1 Is the forward reaction EXOTHERMIC or ENDOTHERMIC? Fully explain the answer. (3)

9.5.2 How will this change influence the K_c value? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

9.6 What change was made to the equilibrium mixture at t = 8 minutes? (1)

[18]

QUESTION 10 (November 2017)

Carbonyl bromide, $COBr_2$, decomposes into carbon monoxide and bromine according to the following balanced equation:

$$COBr_2(g) \rightleftharpoons CO(g) + Br_2(g) \qquad \Delta H > 0$$

Initially $COBr_2(g)$ is sealed in a 2 dm^3 container and heated to 73 °C. The reaction is allowed to reach equilibrium at this temperature. The equilibrium constant for the reaction at this temperature is 0,19.

10.1 Define *chemical equilibrium*. (2)

At equilibrium it is found that 1,12 g CO(g) is present in the container.

10.2 Calculate the equilibrium concentration of the $COBr_2(g)$.
(Answer: 2,11 x 10^{-3} mol·dm^{-3}) (7)

10.3 Calculate the percentage of $COBr_2(g)$ that decomposed at 73 °C.
(Answer: 90,3 – 90,9%) (4)

10.4 Which ONE of the following CORRECTLY describes the K_c value when equilibrium is reached at a lower temperature?

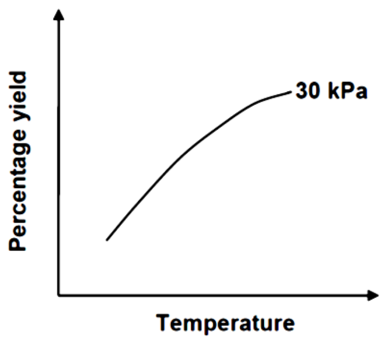
$K_c < 0,19$	$K_c > 0,19$	$K_c = 0,19$

(1)

10.5 The pressure of the system is now decreased by increasing the volume of the container at 73 °C and the system is allowed to reach equilibrium. How will the number of moles of $COBr_2(g)$ be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME. Explain the answer. (3)

[17]

QUESTION 11 (March 2018)

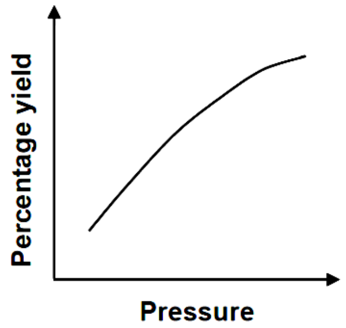


11.1 A reversible gaseous reaction is allowed to reach equilibrium in a closed container at different temperatures and pressures. The graph shows the percentage yield for this reaction at 30 kPa as the temperature is increased.
Use the information in the graph above to answer the following questions

11.1.1 State Le Chatelier's principle. (2)

11.1.2 The heat of reaction (ΔH) for the forward reaction is POSITIVE. Use Le Chatelier's principle to explain this statement. (3

The graph below shows the percentage yield for this reaction as pressure changes at constant temperature.



11.1.3 Explain the effect of an increase in pressure on the equilibrium position of a reaction. (2)

11.1.4 Which ONE of the following equations (**I**, **II** or **III**) represents the equilibrium above?

I: $2A(g) + 3B(g) \rightleftharpoons 3C(g)$
II: $A(g) + B(g) \rightleftharpoons 3C(g)$
III: $A(g) + B(g) \rightleftharpoons 2C(g)$ (2)

11.2 A mixture of 0,2 moles of hydrogen chloride ($HC\ell$) and 0,11 moles of oxygen gas (O_2) is sealed in a 200 cm^3 flask at a certain temperature. The reaction reaches equilibrium according to the balanced equation:

$$4HC\ell(g) + O_2(g) \rightleftharpoons 2C\ell_2(g) + 2H_2O(g)$$

It is found that 1,825 g of hydrogen chloride is present at equilibrium. Calculate the equilibrium constant, K_c, for this reaction at this temperature. *(Answer: 13,97)* (9)

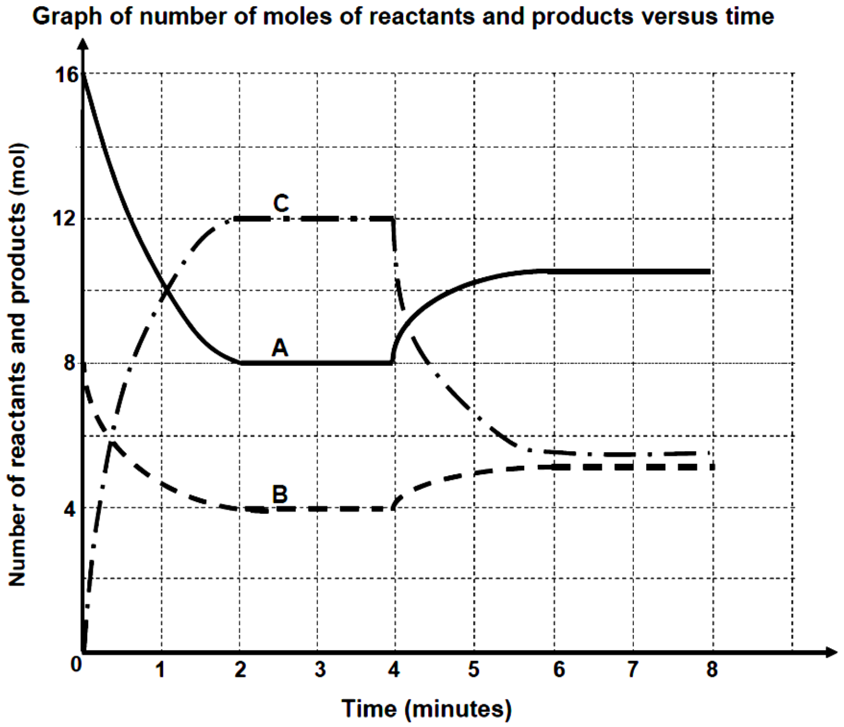
[18]

QUESTION 12 (June 2018)

The equation below represents a hypothetical reaction that reaches equilibrium in a closed container after 2 minutes at room temperature. The letters **x**, **y** and **z** represent the number of moles in the balanced equation.

$$\mathbf{x}A(aq) + \mathbf{y}B(aq) \rightleftharpoons \mathbf{z}C(aq)$$

The graph shows the change in the number of moles of reactants and products versus time during the reaction.



12.1 Define a *dynamic equilibrium*. (2)

12.2 Use the information in the graph and write down the value of:

12.2.1 **x** (1)
12.2.2 **y** (1)
12.2.2 **z** (1)

12.3 Calculate the equilibrium constant, K_c, for this hypothetical reaction at room temperature if the volume of the closed container is 3 dm^3.
(Answer: 6,75) (7)

12.4 At t = 4 minutes, the temperature of the system was increased to 60 °C. Is the REVERSE reaction EXOTHERMIC or ENDOTHERMIC? Explain how you arrived at the answer. (3)

[15]

QUESTION 13 (November 2018)

Dinitrogen tetraoxide, $N_2O_4(g)$, decomposes to nitrogen dioxide, $NO_2(g)$, in a sealed syringe of volume 2 dm^3.

The mixture reaches equilibrium at 325 °C according to the following balanced equation:

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

Colourless brown

When equilibrium is reached, it is observed that the colour of the gas in the syringe is brown.

13.1 State Le Chatelier's principle. (2)

13.2 The syringe is now dipped into a beaker of ice water. After a while the brown colour disappears. Is the forward reaction EXOTHERMIC or ENDOTHERMIC? Explain the answer using Le Chatelier's principle. (3)

13.3 The volume of the syringe is now decreased while the temperature is kept constant. How will EACH of the following be affected? Choose from: INCREASES, DECREASES or REMAINS THE SAME.

13.3.1 The number of moles of $N_2O_4(g)$ (1)

13.3.2 The value of the equilibrium constant (1)

13.3.2 The rate of the forward and reverse reactions (1)

13.4 Initially X moles of $N_2O_4(g)$ were placed in the syringe of volume 2 dm^3. When equilibrium was reached, it was found that 20% of the $N_2O_4(g)$ had decomposed. If the equilibrium constant, K_c, for the reaction is 0,16 at 325 °C, calculate the value of X. *(Answer: 1,6 mol)* (8)

[16]

QUESTION 14 (June 2019)

The balanced equation below represents the reaction used in the Haber process to produce ammonia.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H < 0$$

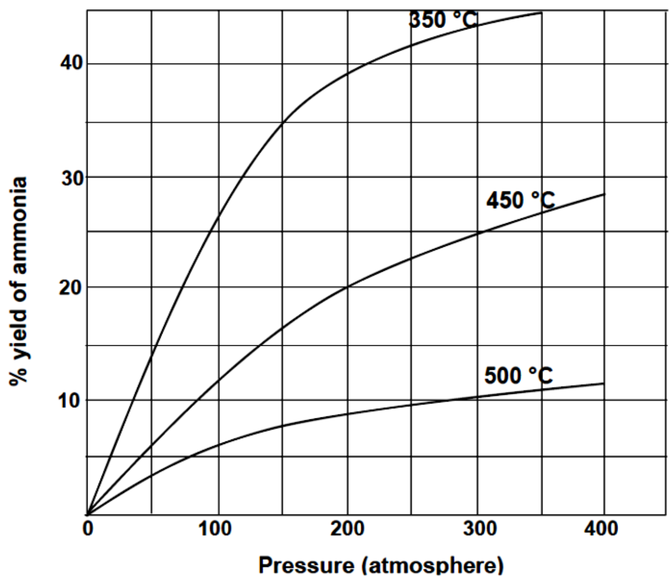
In industry the product is removed as quickly as it forms.

14.1 Write down the meaning of the double arrow used in the equation above. (1)

14.2 Give ONE reason why ammonia is removed from the reaction vessel as quickly as it forms. (1)

The graph below shows the percentage yield of ammonia at different temperatures and pressures.

GRAPH OF PERCENTAGE YIELD OF AMMONIA VERSUS PRESSURE



14.3 Write down the percentage yield of ammonia at a temperature of 450 °C and a pressure of 200 atmospheres. (1)

14.4 Refer to Le Chatelier's principle to explain EACH of the following deductions made from the graph:

14.4.1 For a given pressure, the yield of ammonia at 500 °C is much lower than that at 350 °C (3)

14.4.2 For a given temperature, the yield of ammonia at 350 atmospheres is much higher than that at 150 atmospheres (2)

14.5 A technician prepares $NH_3(g)$ by reacting 6 moles of $H_2(g)$ and 6 moles of $N_2(g)$.

14.5.1 Calculate the maximum number of moles of $NH_3(g)$ that can be obtained in this reaction. (2)

14.5.2 The above reaction now takes place in a 500 cm^3 container at a temperature of 350 °C and a pressure of 150 atmospheres. The system is allowed to reach equilibrium. Use the graph above and calculate the equilibrium constant, K_c, for this reaction under these conditions. (7)

(Answers: 14.5.1: 4 moles; 14.5.2: 0,002) **[17]**

QUESTION 15 (November 2019)

Initially 60,8 g pure carbon dioxide, $CO_2(g)$, is reacted with carbon, C(s), in a sealed container of volume 3 dm^3. The reaction reaches equilibrium at temperature T according to the following balanced equation:

$$C(s) + CO_2(g) \rightleftharpoons 2CO(g)$$

15.1 Define the term *chemical equilibrium*. (2)

15.2 At equilibrium it is found that the concentration of the carbon dioxide is 0,054 $mol{\cdot}dm^{-3}$.
Calculate the:

15.2.1 Equilibrium constant, K_c, for this reaction at temperature T
(Answer: 12,24) (7)

15.2.2 Minimum mass of C(s) that must be present in the container to obtain this equilibrium
(Answer: 14,64 g) (3)

15.3 How will EACH of the following changes affect the AMOUNT of CO(g) at equilibrium?
Choose from INCREASES, DECREASES or REMAINS THE SAME.

15.3.1 More carbon is added to the container (1)

15.3.2 The pressure is increased by reducing the volume of the container at constant temperature. Use Le Chatelier's principle to explain the answer. (3)

15.4 The table below shows the mole percentages of $CO_2(g)$ and CO(g) in the container at different temperatures.

TEMPERATURE (°C)	% CO_2(g)	% CO(g)
827	6,23	93,77
950	1,32	98,68
1 050	0,37	99,63
1 200	0,06	99,94

15.4.1 Is the reaction EXOTHERMIC or ENDOTHERMIC? Refer to the data in the table and explain the answer. (3)

15.4.2 Use the information in the table to determine temperature T. Show clearly how you arrived at the answer.
(Answer: 827 °C) (3)

[22]

QUESTION 16 (November 2020)

The dissociation of iodine molecules to iodine atoms (I) is a reversible reaction taking place in a sealed container at 727°C. The balanced equation for the reaction is:

$$I_2(g) \rightleftharpoons 2I(g)$$

K_c for the reaction at 727°C is 3,76 x 10^{-3}.

16.1 Write down the meaning of the term *reversible reaction*. (1)

16.2 At equilibrium the pressure of the system is increased by decreasing the volume of the container at constant temperature. How will EACH of the following be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME.

16.2.1 The value of the equilibrium constant (1)

16.2.2 The number of I_2 molecules (1)

16.3 Explain the answer to QUESTION 16.2.2 by referring to Le Chatelier's principle. (2)

16.4 At 227°C, the K_C value for the reaction above is 5,6 x 10^{-12}. Is the forward reaction ENDOTHERMIC or EXOTHERMIC? Fully explain the answer. (4)

16.5 A certain mass of iodine molecules (I_2) is sealed in a 12,3 dm^3 flask at a temperature of 727°C (K_c = 3,76 x 10^{-3}). When equilibrium is reached, the concentration of the iodine atoms is found to be 4,79 x 10^{-3} $mol{\cdot}dm^{-3}$. Calculate the INITIAL MASS of the iodine molecules in the flask.
(Answer: 26,543 g) (9)

[18]

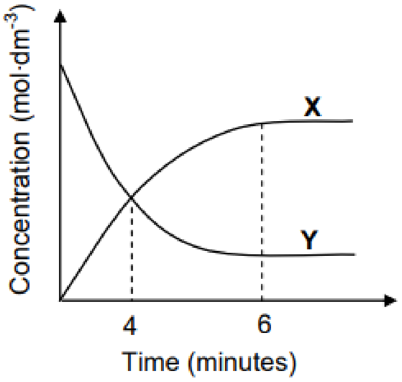
QUESTION 17 (June 2021)

Pure hydrogen iodide gas, HI(g), of concentration 1 mol·dm^{-3}, is sealed in a 500 cm^3 container at temperature T. The reaction reaches equilibrium according to the following balanced equation:

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

17.1 Define the term *chemical equilibrium*. (2)

17.2 The graph below shows how the concentrations of the reactant and products vary with time during the reaction.

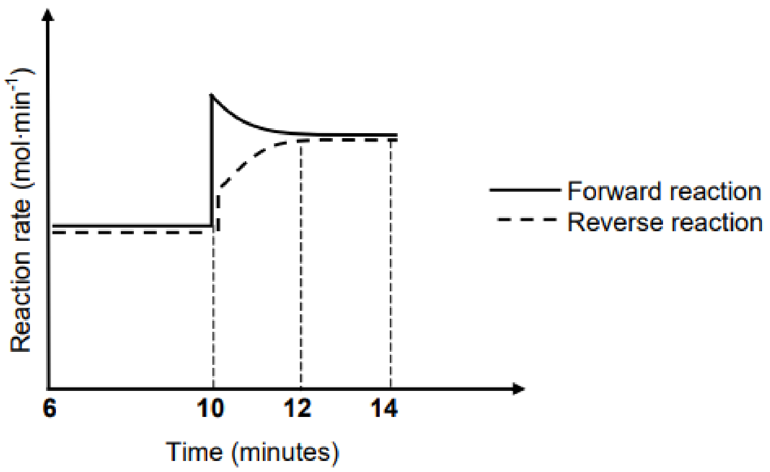


17.2.1 Which ONE of the curves, **X** or **Y**, represents the changes in the concentration of the products? Give a reason for the answer. (2)

17.2.2 How does the rate of the forward reaction compare to that of the reverse reaction at t = 4 minutes? Choose from HIGHER THAN, LOWER THAN or EQUAL TO. (1)

17.3 The equilibrium constant, K_c, for the reaction is 0,04 at temperature T. Calculate the number of moles of iodine, $I_2(g)$, present at time t = 6 minutes.
(Answer: 0,071 – 0,072 mol) (9)

17.4 The graph below shows how the rates of the forward and reverse reactions change with time.



The temperature of the container is increased at t = 10 minutes.

17.4.1 Which reaction(s) show(s) an increase in rate at t = 10 minutes? Choose from FORWARD, REVERSE or BOTH FORWARD AND REVERSE. (1)

17.4.2 Is the heat of reaction (ΔH) for this reaction POSITIVE or NEGATIVE? Fully explain the answer. (4)

[19]

QUESTION 18 (September 2021)

Steam, $H_2O(g)$, reacts with hot carbon, C(s), at 1 000 °C according to the following balanced equation:

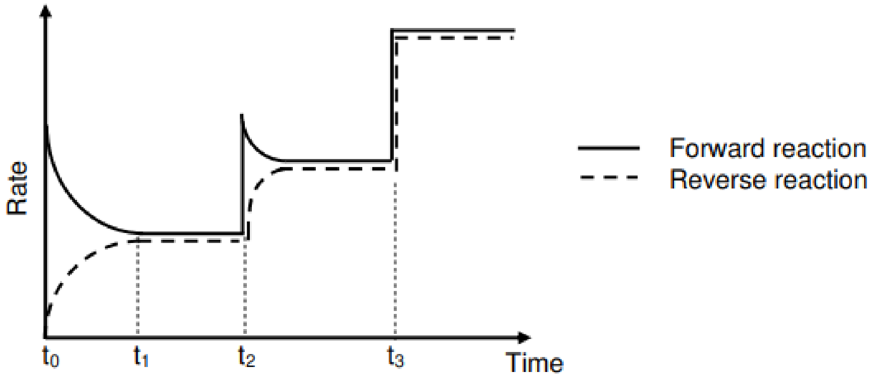
$$2H_2O(g) + C(s) \rightarrow 2H_2(g) + CO_2(g)$$

Initially, 36 g of steam and a certain amount of carbon were placed in a 2 dm^3 sealed container and allowed to react. At equilibrium it was found that the amount of carbon changed by 0,225 mol.

18.1 Define the term *dynamic equilibrium*. (2)

18.2 Calculate the equilibrium constant, K_c, for the reaction at 1 000 °C.
(Answer: 9,48 x 10^{-3} to 1 x 10^{-2}) (8)

18.3 The graph shows how the rates of the forward and reverse reactions change with time.



18.3.1 Give a reason why the rate of the forward reaction decreases between t_0 and t_1. (1)

18.3.2 What change was made to the equilibrium mixture at t_3? (1)

At time t_2, the temperature of the system is increased.

18.3.3 Is the forward reaction EXOTHERMIC or ENDOTHERMIC? (1)

18.3.4 Refer to Le Chatelier's principle to explain the answer to QUESTION 18.3.3. (2)

[15]

QUESTION 19 (November 2021)

Consider the balanced equation below for a hypothetical reaction that takes place in a sealed 2 dm^3 container at 300 K.

$$2P(g) + Q_2(g) \rightleftharpoons 2PQ(g)$$

19.1 Define the term *chemical equilibrium*. (2)

19.2 The amount of each substance present in the equilibrium mixture at 300 K is shown in the table below.

	AMOUNT (mol) AT EQUILIBRIUM
P	0,8
Q_2	0,8
PQ	3,2

The temperature of the container is now increased to 350 K. When a NEW equilibrium is established, it is found that 1,2 mol P(g) is present in the container.

19.2.1 Is the heat of the reaction (ΔH) POSITIVE or NEGATIVE? (1)

19.2.2 Use Le Chatelier's principle to explain the answer to QUESTION 19.2.1. (3)

19.2.3 Calculate the equilibrium constant at 350 K.
(Answer: 10,89) (8)

19.2.4 How will the equilibrium constant calculated in QUESTION 19.2.3 be affected when the volume of the container is decreased at constant temperature? Choose from INCREASES, DECREASES or REMAINS THE SAME. Give a reason for the answer. (2)

19.3 More $Q_2(g)$ is now added to the reaction mixture at constant temperature. How will EACH of the following be affected? Choose from INCREASES, DECREASES or REMAINS THE SAME.

19.3.1 The yield of PQ(g) (1)

19.3.2 Number of moles of P(g) (1)

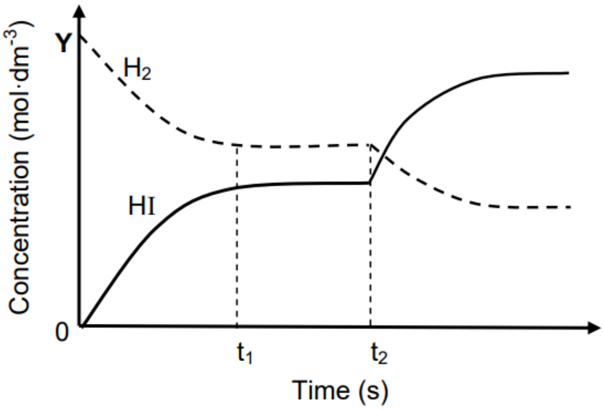
[18]

QUESTION 20 (June 2022)

20.1 Initially, 4 moles $H_2(g)$ and 4 moles $I_2(g)$ are allowed to react in a sealed 2 dm^3 flask according to the following balanced equation:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad \Delta H < 0$$

The graph below shows the concentrations of $H_2(g)$ and $HI(g)$ versus time during the reaction.



20.1.1 Write down the value of **Y**. (1)

20.1.2 State Le Chatelier's principle. (2)

20.1.3 Changes were made to the temperature of the flask at time t_2. Was the flask HEATED or COOLED? (1)

20.1.4 Fully explain the answer to QUESTION 20.1.3. (3)

20.2 The equation below represents the reversible reaction that takes place when $NO_2(g)$ is converted to $N_2O_4(g)$.

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

Initially, x mol of $NO_2(g)$ is sealed in a 1 dm^3 container at 350 K. When equilibrium is established at this temperature, 0,81 mol $N_2O_4(g)$ is present in the container.

20.2.1 Write down the meaning of the term reversible reaction. (1)

20.2.2 Show that the equilibrium constant for this reaction is given by $\frac{0,81}{(x-1,62)^2}$. (5)

0,79 moles of $N_2O_4(g)$ is now added to the equilibrium mixture above. When the NEW equilibrium is established at 350 K, it is found that the amount of $NO_2(g)$ increased by 1,2 moles.

20.2.3 Calculate the value of x.
(Answer: 11,27 to 12,42) (6)

[19]

QUESTION 21 (November 2022)

Carbon, C(s), reacts with sulphur, S(g), according to the following balanced equation:

$$C(s) + 2S(g) \rightleftharpoons CS_2(g) \quad \Delta H > 0$$

The system reaches equilibrium at temperature T in a sealed 2 dm^3 container.
The K_c value is 9,4 at temperature T.

21.1 State Le Chatelier's principle. (2)

At equilibrium, 1 mole of carbon disulphide, $CS_2(g)$, is present in the container.

21.2 Calculate the concentration of S(g) present at equilibrium.
(Answer: 0,23 mol·dm^{-3}) (4)

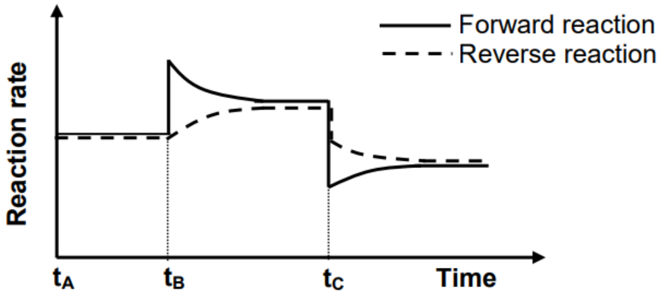
The volume of the container is now DOUBLED at temperature T. After a while, a NEW equilibrium is established.

21.3 How will the amount of S(g) change as this new equilibrium is established?
Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

21.4 Explain the answer to QUESTION 21.3 in terms of Le Chatelier's principle. (3)

21.5 If the concentration of $CS_2(g)$ CHANGES by x mol·dm^{-3}, write down an expression for the equilibrium constant, K_c, in terms of x. Show ALL your workings. NO simplification or solving for x is required.
(Answer: $\frac{0,25 - x}{(0,115 + 2x)^2}$) (5)

21.6 The reaction rate-time graph below represents further changes made to the equilibrium mixture. The volume of the container is kept constant.



21.6.1 What do the parallel lines between t_A and t_B represent? (1)

21.6.2 What change was made to the equilibrium mixture at t_B? (1)

21.6.3 Give a reason for the sudden change in the reaction rate at t_C. (1)

21.6.4 Fully explain the answer to QUESTION 21.6.3. (3)

[21]

ACIDS AND BASES

PROPERTIES

ACIDS
- Taste sour
- Turn BLUE litmus paper RED
- Increase the concentration of hydrogen ions (H^+) in a solution
- Decrease the concentration of hydroxide ions (OH^-) in a solution
- Have pH values of LESS THAN 7

BASES
- Taste bitter and have a soapy feel
- Turn RED litmus paper BLUE
- Decrease the concentration of hydrogen ions (H^+) in a solution
- Increase the concentration of hydroxide ions (OH^-) in a solution
- Have pH values of MORE THAN 7

ACID-BASE THEORIES

Arrhenius Theory
Only explains acids & bases when dissolved IN WATER

Acid: A substance that produces H^+/H_3O^+ ions in water.
Base: A substance that produces OH^- ions in water.

Lowry-Brønsted Theory
Explains acid & bases in both SOLID and LIQUID PHASE – no water needed

Acid: An acid is a proton (H^+) DONOR.
Base: A base is a proton (H^+) ACCEPTOR.

CONJUGATE ACID-BASE PAIRS

A pair of substances that differ from one another by a proton within an acid-base reaction.

When an ACID donates a proton, its CONJUGATE BASE is produced.
When a BASE accepts a proton, its CONJUGATE ACID is produced.

Examples:

1. $\underset{\text{base 1}}{NH_3} + \underset{\text{acid 2}}{H_2O} \rightleftharpoons \underset{\text{acid 1}}{NH_4^+} + \underset{\text{base 2}}{OH^-}$

conjugate acid-base pair (base 1 – acid 1)
conjugate acid-base pair (acid 2 – base 2)

2. $\underset{\text{acid 1}}{HC\ell} + \underset{\text{base 2}}{H_2O} \rightleftharpoons \underset{\text{acid 2}}{H_3O^+} + \underset{\text{base 1}}{C\ell^-}$

conjugate acid-base pair (base 2 – acid 2)
conjugate acid-base pair (acid 1 – base 1)

<u>Conjugate acid of a base:</u>
ADD H^+ to the given compound or ion

Example: Conjugate acid of NH_3
$NH_3 + H^+ \rightarrow NH_4^+$

<u>Conjugate base of an acid:</u>
REMOVE H^+ from the given compound or ion

Example: Conjugate base of H_2O:
$H_2O - H^+ \rightarrow OH^-$

AMPHIPROTIC substances (ampholytes)
A substance that can act as either an acid or a base.

H_2O acts as acid in Example 1 and as a base in Example 2. H_2O is an example of an ampholyte.

In presence of a STRONG acid, an amphiprotic substance reacts as a base.
In presence of a STRONG base, an amphiprotic substance reacts as an acid.

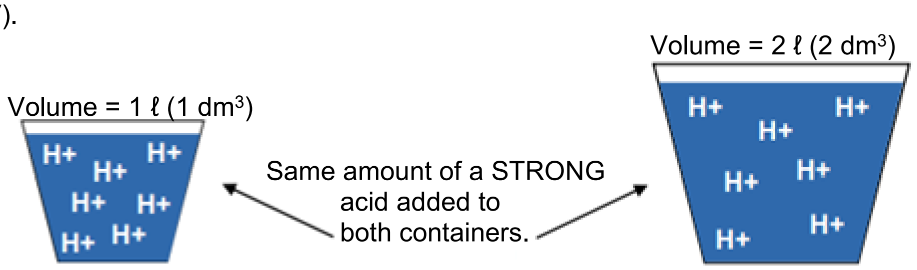
STRONG AND WEAK ACIDS AND BASES

Strength of an acid or base refers to extent of ionisation or dissociation that takes place in a solution.

STRONG ACIDS	WEAK ACIDS
Strong acids IONISE COMPLETELY in solution to form a high concentration of H_3O^+ ions	Weak acids IONISE INCOMPLETELY in solution to form a low concentration of H_3O^+ ions
High K_a values (> 1)	Low K_a values (< 1)
<u>Examples</u> Hydrochloric acid ($HC\ell$) Sulphuric acid (H_2SO_4) Nitric Acid (HNO_3) Hydrobromic acid (HBr)	**<u>Examples</u>** Ethanoic acid (CH_3COOH) Oxalic acid [$(COOH)_2$] Hydrofluoric acid (HF) Phosphoric acid (H_3PO_4)

STRONG BASES	WEAK BASES
Strong bases DISSOCIATE COMPLETELY in solution to form a high concentration of OH^- ions	Weak bases DISSOCIATE INCOMPLETELY in solution to form a low concentration of OH^- ions
High K_b values (> 1)	Low K_b values (< 1)
<u>Examples</u> Sodium hydroxide ($NaOH$) Potassium hydroxide (KOH) Lithium hydroxide ($LiOH$) Calcium hydroxide [$Ca(OH)_2$]	**<u>Examples</u>** Ammonium hydroxide (NH_4OH) / Ammonia (NH_3) Magnesium hydroxide [$Mg(OH)_2$] Sodium carbonate (Na_2CO_3) Potassium carbonate (K_2CO_3) Calcium carbonate ($CaCO_3$) Sodium hydrogen carbonate ($NHCO_3$)

Acid/Base strength must NOT be confused with concentration (c) which refer to the amount of acid/base with certain volume of solution. The concentration is the number of moles (n) per unit volume (V).



More concentrated Less concentrated

How concentrated or dilute an acid or base may be is a measure of the amount of water present in the solution.

Acids and Bases, Cape Town Science Centre In collaboration with the Western Cape Education Department, p5

AUTO-IONISATION OF WATER

Water is an ampholyte and can act as both an acid and a base. Two water molecules can undergo auto-protolysis or auto-ionisation where two molecules react with one another and were one acts an acid (H^+ donor) and the other a base (proton acceptor).

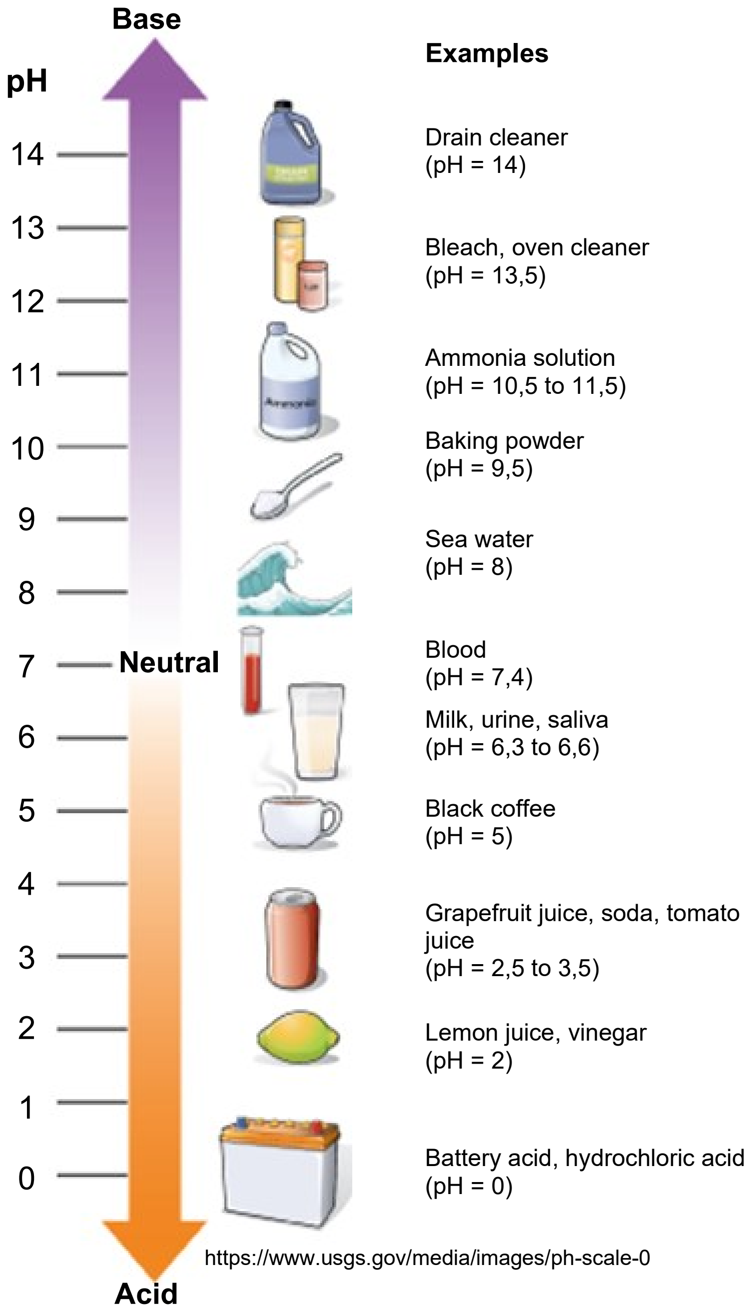
$$\mathbf{H_2O(\ell) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + OH^-(aq)}$$

The equilibrium constant is: $K_c = [H_3O^+][OH^-] = K_w$ (ionisation constant of water)

In pure water, $[H_3O^+] = 1 \times 10^{-7}$ mol.dm^{-3} and $[OH^-] = 1 \times 10^{-7}$ mol.dm^{-3}

$$\mathbf{K_w = [H_3O^+][OH^-] = 1 \times 10^{-14} \text{ at room temperature (25 °C)}}$$

pH SCALE & pH CALCULATIONS



$pH = -\log[H_3O^+]$ & $[H_3O^+] = 10^{-pH}$

$pOH = -\log[OH^-]$

$pH + pOH = 14$

Acidic Solution
$[H_3O^+] > [OH^-]$
$[H_3O^+] > 1\times10^{-7}\ mol\cdot dm^{-3}$

Neutral Solution
$[H_3O^+] = [OH^-]$
$[H_3O^+] = 1\times10^{-7}\ mol\cdot dm^{-3}$

Basic Solution
$[H_3O^+] < [OH^-]$
$[H_3O^+] < 1\times10^{-7}\ mol\cdot dm^{-3}$

ACID-BASE INDICATORS

INDICATOR	COLOUR IN ACID	COLOUR IN BASE	pH Range
Methyl orange	Orange	Yellow	3.1 – 4.4
Bromothymol blue	Yellow	Blue	6 – 7.6
Phenolphthalein	Colourless	Pink	8.3 – 10

HYDROLYSIS OF SALTS

Hydrolysis is the reaction of a salt with water.

The salt of a strong acid and a weak base is acidic, pH < 7.
The salt of a weak acid and a strong base is basic, pH > 7.
The salt of a strong acid and a strong base does not undergo hydrolysis, pH = 7

STEPS HOW TO DETERMINE THE WHETHER A SALT IS ACIDIC, BASIC OR NEUTRAL

1. Determine the positive and negative ion in the salt.
2. Determine the base from which the positive ion comes.
3. Determine the acid from which the negative ion comes.
4. If BOTH THE ACID AND BASE IDENTIFIED ARE STRONG OR IF BOTH ARE WEAK, NO hydrolysis will take place. The pH of the salt will be NEUTRAL (pH = 7).
5. If identified as a STRONG ACID and a WEAK BASE:
   - The positive ion coming from the WEAK BASE will undergo hydrolysis and the pH of the salt will be acidic (< 7).
   - To write the hydrolysis reaction, react the positive ion with H_2O to obtain H_3O^+ and the WEAK BASE from which the positive ion comes.
   - Explain acidity of salt in terms of the formation of H_3O^+ ions
6. If identified as a WEAK ACID and a STRONG BASE:
   - The negative ion coming from the WEAK ACID will undergo hydrolysis and the pH of the salt will be basic (> 7).
   - To write the hydrolysis reaction, react the negative ion with H_2O to obtain OH^- and the WEAK ACID from which the negative ion comes.
   - Explain alkalinity/basic properties of salt in terms of the formation of OH^- ions

Example 1
Will $CaCO_3$ be acidic, basis or neutral? Write an equation to explain the answer.

Answer:
- Two ions in $CaCO_3$: Ca^{2+} and CO_3^{2-}
- Ca^{2+} comes from a base - $Ca(OH)_2$ which is a STRONG BASE
- CO_3^{2-} comes from an acid - H_2CO_3 which is a WEAK ACID
- Salt of a STRONG base and WEAK acid: BASIC
- Equation: $CO_3^{2-} + H_2O \rightarrow H_2CO_3 + OH^-$
- Due to the formation of OH^- the hydrolysis of the salt forms a BASIC solution.

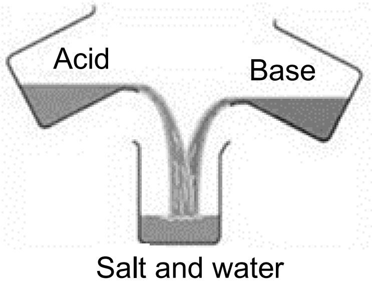
Example 2
Will $NH_4C\ell$ be acidic, basis or neutral? Write an equation to explain the answer.

Answer:
- Two ions in $NH_4C\ell$: NH_4^+ and $C\ell^-$
- NH_4^+ comes from a base – NH_4OH / NH_3 which is a WEAK BASE
- $C\ell^-$ comes from an acid - $HC\ell$ which is a STONG ACID
- Salt of a WEAK base and STRONG acid: BASIC
- Equation: React the ion coming from the weak base with H2O to form H_3O^+ and the weak base
  $NH_4^+ + H_2O \rightarrow NH_3 + H_3O^+$ OR $NH_4^+ + 2H_2O \rightarrow NH_4OH + H_3O^+$
- Due to the formation of H_3O^+ the hydrolysis of the salt forms an ACIDIC solution.

Example 3
Will $NaC\ell$ be acidic, basis or neutral? Write an equation to explain the answer.

Answer:
- Two ions in $NaC\ell$: Na^+ and $C\ell^-$
- Na^+ comes from a base – $NaOH$ which is a STRONG BASE
- $C\ell^-$ comes from an acid - $HC\ell$ which is a STONG ACID
- Salt of a STRONG base and STRONG acid: No hydrolysis – NEUTRAL solution

ACID-BASE NEUTRALISATION REACTIONS



Reaction of an acid and a base to form a salt and water

acid + base →salt + H_2O

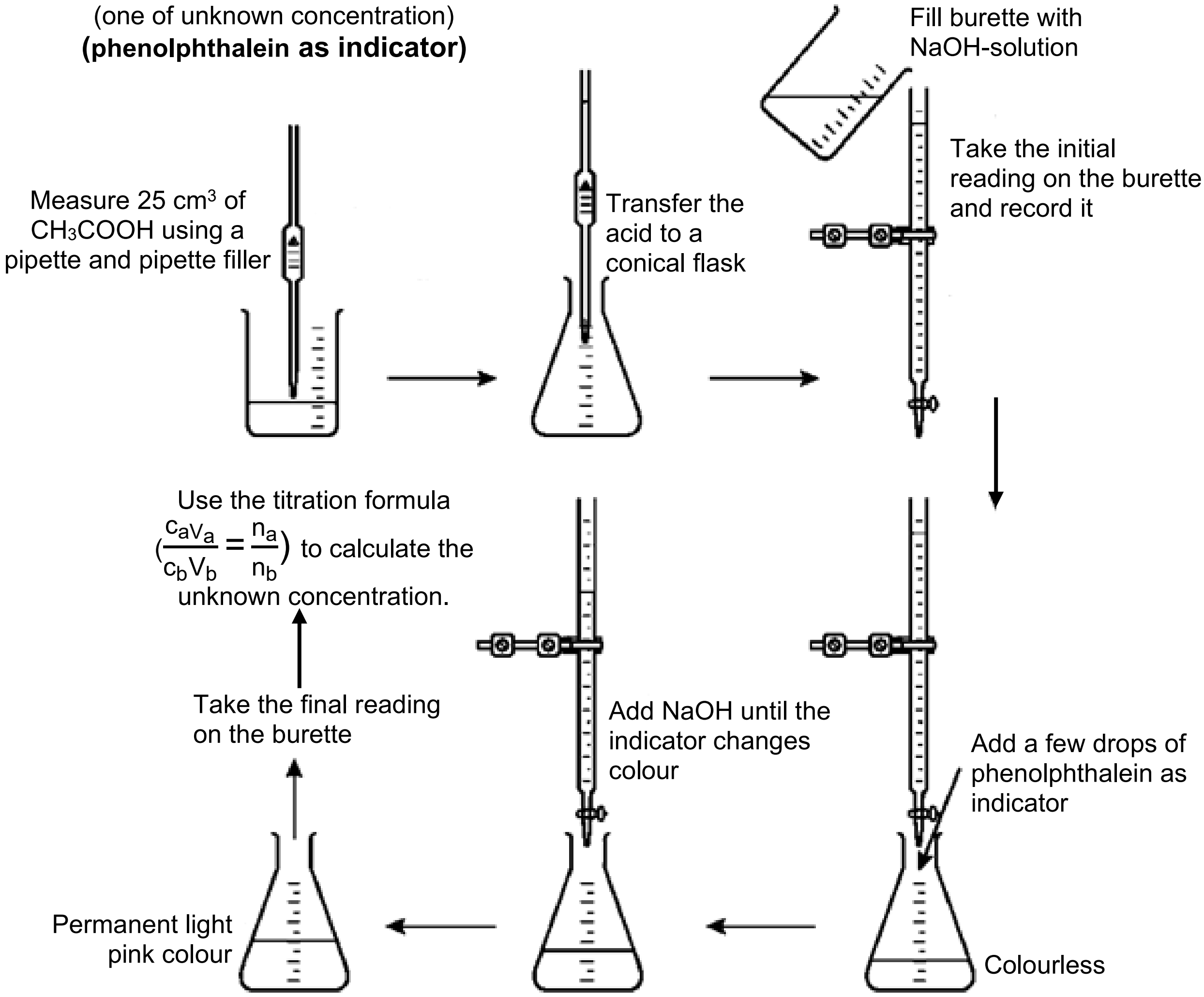
ACID-BASE TITRATIONS

TITRATION: When a standard solution (solution of known concentration) is added to the sample solution (unknown concentration) until the end point (the point where the indicator changes colour) is reached.

An **ACID-BASE INDICATOR** is used to determine the end point of a titration. You must be able to choose the correct indicator for a titration

ACID	BASE	INDICATOR	pH COLOUR CHANGE RANGE
Strong	Strong	Bromothymol blue	6,0 – 7,6
Strong	Weak	Methyl orange	3,2 – 4,4
Weak	Strong	Phenolphthalein	8,2, - 10

Titration of CH_3COOH with NaOH
(one of unknown concentration)
(phenolphthalein as indicator)



IMPORTANT TIPS FOR ACID-BASE STOICHIOMETRIC CALCULATIONS

- Ensure you know stoichiometry from grades10 and 11.
- You must be able to calculate:
  - Number of moles (n) from a given mass (m) using $n = \frac{m}{M}$ where M is the molar mass
  - Number of moles (n) from a given concentration (c) using $c = \frac{n}{V}$ where V is the volume in dm^3
  - Number of moles from a given number of particles N using $n = \frac{N}{N_A}$ where N_A is the Avogadro constant (N_A = 6,02 x 10^{23} mol^{-1})
  - Number of moles for **gases only** from a given gas volume using $n = \frac{V}{V_M}$ where V_M is the molar gas volume. **Only at STP the molar gas volume is 22,4 $dm^3 \cdot mol^{-1}$**.
- After calculating number of moles of acid/base that has reacted, **use the ratio of the acid to the base** to find the number of moles of base/acid that reacted.
- When either the acid or base is in **excess**, calculate the:
  - The number of moles in excess through subtraction:
    n(excess) = n(initial) – n(reacted)
  - The number of moles reacted through subtraction:
    n(reacted) = n(initial) – n(excess)
  - The initial number of moles through addition:
    n(initial) = n(excess) + n(reacted)
- Always label your formulae clearly in a multistep calculation for example, when calculating the:
  - Number of moles of HCℓ write it as n(HCℓ) = …
  - Concentration of sodium hydroxide write it as c(NaOH) = …
  - Excess of sodium hydroxide write as n(NaOH)excess = n(NaOH)initial - n(NaOH)reacted
- Use the titration formula ($\frac{c_aV_a}{c_bV_b} = \frac{n_a}{n_b}$) only for acid-base neutralisations.
- Only use the formula $c = \frac{m}{MV}$ when dealing with solutions. DO NOT use it for solids that are not dissolved in water.
- Do not round off when substituting values given in the question paper. All given values should be substituted as is for example, if a value is given as 0,00687 in the question paper, it should be substituted as such and NOT rounded to 0,01.
- Do NOT round off answers to two decimal places in each step of a multistep calculation. It might lead to an incorrect final answer. Rounding off to two decimal places should only be done in the final answer.
- Remember to give correct units at the final answer, for example:
  - The unit of concentration is $mol \cdot dm^{-3}$ and NOT $mol \cdot dm^3$
  - The unit of volume is cm^3 and NOT cm^{-3}
  - pH has NO unit.
- Convert correctly from cm^3 to dm^3. Volumes are usually given in cm^3 but in the formula $c = \frac{n}{V}$ the volume must be substituted in dm^3. Volumes in cm^3 must be DIVIDED by 1000 to obtain the volume in dm^3.

TERMS AND DEFINITIONS	
Acid-base indicator	A dye used to distinguish between acidic and basic solutions by means of the colour changes it undergoes in these solutions.
Amphiprotic substance/ampholyte	A substance that can act as either an acid or a base.
Arrhenius theory	An acid is a substance that produces hydrogen ions (H^+)/ hydronium ions (H_3O^+) when it dissolves in water. A base is a substance that produces hydroxide ions (OH^-) when it dissolves in water.
Auto-ionisation of water	A reaction in which water reacts with itself to form ions (hydronium ions and hydroxide ions).
Concentrated acids/bases	Contain a large amount (number of moles) of acid/base in proportion to the volume of water.
Conjugate acid-base pair	A pair of compounds or ions that differ by the presence of one H^+ ion. Example: CO_3^{2-} and HCO_3^- OR $HC\ell$ and $C\ell^-$
Conjugate acid and base	A conjugate acid has one H^+ ion more than its conjugate base. Example: HCO_3^- is the conjugate acid of base CO_3^{2-} CO_3^{2-} is the conjugate base of acid HCO_3^-.
Dilute acids/bases	Contain a small amount (number of moles) of acid/base in proportion to the volume of water.
Diprotic acid	An acid that can donate two protons. Example: H_2SO_4
Dissociation	The process in which ionic compounds split into ions.
Endpoint	The point in a titration where the indicator changes colour.
Equivalence point	The point in a reaction where equivalent amounts of acid and base have reacted completely.
Hydrolysis	The reaction of a salt with water.
Ionisation	The process in which ions are formed during a chemical reaction.
Ion product of water	The product of the ions formed during auto-ionisation of water i.e. $[H_3O^+][OH^-]$ at 25 °C.
Ionisation constant of water (K_w)	The equilibrium value of the ion product $[H_3O^+][OH^-]$ at 25 °C.
K_a value	Ionisation constant for an acid.
K_b value	Dissociation or ionisation constant for a base.
Lowry-Brønsted theory	An acid is a proton (H^+ ion) donor. A base is a proton (H^+ ion) acceptor.
Monoprotic acid	An acid that can donate one proton. Example: $HC\ell$
Neutralisation	The reaction of an acid with a base to form a salt (ionic compound) and water.
pH	The negative of the logarithm of the hydronium ion concentration in $mol \cdot dm^{-3}$. In symbols: $pH = -log[H_3O^+]$ Unit: None
pH scale	A scale from 0 – 14 used as a measure of the acidity and basicity of solutions where pH = 7 is neutral, pH > 7 is basic and pH < 7 is acidic.
Salt	The ionic compound that is the product of a neutralisation reaction.
Standard solution	A solution of precisely known concentration.
Strong bases	Dissociate COMPLETELY in water to form a high concentration of OH^- ions. Examples: sodium hydroxide (NaOH) and potassium hydroxide (KOH)
Strong acids	Ionise COMPLETELY in water to form a high concentration of H_3O^+ ions. Examples: hydrochloric acid ($HC\ell$), sulphuric acid (H_2SO_4) and nitric acid (HNO_3)
Titration	The procedure for determining the amount of acid (or base) in a solution by determining the volume of base (or acid) of known concentration that will completely react with it.
Weak acids	Ionise INCOMPLETELY in water to form a low concentration of H_3O^+ ions. Examples: ethanoic acid (CH_3COOH) and oxalic acid $(COOH)_2$
Weak bases	Dissociate/ionise INCOMPLETELY in water to form a low concentration of OH^- ions. Examples: ammonia (NH_3), sodium hydrogen carbonate ($NaHCO_3$), sodium carbonate (Na_2CO_3), potassium carbonate (K_2CO_3), calcium carbonate ($CaCO_3$)

QUESTION 1 (November 2014)

1.1 Nitric acid (HNO_3), an important acid used in industry, is a strong acid.

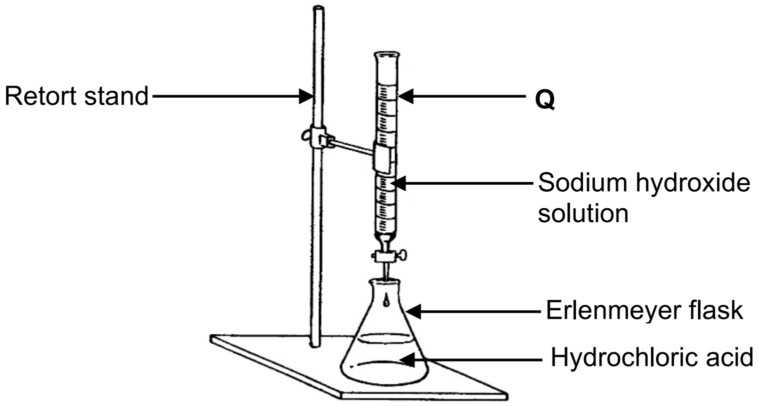
1.1.1 Give a reason why nitric acid is classified as a strong acid. (1)

1.1.2 Write down the NAME or FORMULA of the conjugate base of nitric acid. (1)

1.1.3 Calculate the pH of a 0,3 $mol \cdot dm^{-3}$ nitric acid solution.
(Answer: 0,52) (3)

1.2 A laboratory technician wants to determine the percentage purity of magnesium oxide. He dissolves a 4,5 g sample of the magnesium oxide in 100 cm^3 hydrochloric acid of concentration 2 $mol \cdot dm^{-3}$.

1.2.1 Calculate the number of moles of hydrochloric acid added to the magnesium oxide.
(Answer: 0,2 mol) (3)



He then uses the apparatus alongside to titrate the EXCESS hydrochloric acid in the above solution against a sodium hydroxide solution.

1.2.2 Write down the name of apparatus **Q** in the diagram. (1)

1.2.3 The following indicators are available for the titration:

INDICATOR	pH RANGE
A	3,1 – 4,4
B	6,0 – 7,6
C	8,3 – 10,0

Which ONE of the above indicators (**A**, **B** or **C**) is most suitable to indicate the exact endpoint in this titration? Give a reason for the answer. (3)

1.2.4 During the titration, the technician uses distilled water to wash any sodium hydroxide spilled against the sides of the Erlenmeyer flask into the solution. Give a reason why the addition of distilled water to the Erlenmeyer flask will not influence the results. (1)

1.2.5 At the endpoint of the titration he finds that 21 cm^3 of a 0,2 mol dm^{-3} sodium hydroxide solution has neutralised the EXCESS hydrochloric acid. Calculate the number of moles of hydrochloric acid in excess.
(Answer: 4,2 x 10^{-3} mol) (3)

1.2.6 The balanced equation for the reaction between hydrochloric acid and magnesium oxide is:

$$MgO(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2O(\ell)$$

Calculate the percentage purity of the magnesium oxide. Assume that only the magnesium oxide in the 4,5 g sample reacted with the acid.
(Answer: 87,11%) (5)

[21]

QUESTION 2 (March 2015)

2.1 Sulphuric acid is a diprotic acid.

2.1.1 Define an *acid* in terms of the Lowry-Brønsted theory. (2)

2.1.2 Give a reason why sulphuric acid is referred to as a diprotic acid. (1)

2.2 The hydrogen carbonate ion <u>can act as both an acid and a base</u>. It reacts with water according to the following balanced equation:

$$HCO_3^-(aq) + H_2O(\ell) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$$

2.2.1 Write down ONE word for the underlined phrase. (1)

2.2.2 $HCO_3^-(aq)$ acts as base in the above reaction. Write down the formula of the conjugate acid of $HCO_3^-(aq)$. (1)

2.3 A learner accidentally spills some sulphuric acid of concentration 6 mol·dm^{-3} from a flask on the laboratory bench. Her teacher tells her to neutralise the spilled acid by sprinkling sodium hydrogen carbonate powder onto it. The reaction that takes place is: (Assume that the H_2SO_4 ionises completely.)

$$H_2SO_4(aq) + 2NaHCO_3(s) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell) + 2CO_2(g)$$

The fizzing, due to the formation of carbon dioxide, stops after the learner has added 27 g sodium hydrogen carbonate to the spilled acid.

2.3.1 Calculate the volume of sulphuric acid that spilled. Assume that all the sodium hydrogen carbonate reacts with all the acid. *(Answer: 30 cm³/27 cm³)* (6)

The learner now dilutes some of the 6 mol·dm^{-3} sulphuric acid solution in the flask to 0,1 mol·dm^{-3}.

2.3.2 Calculate the volume of the 6 mol·dm^{-3} sulphuric acid solution needed to prepare 1 dm^3 of the dilute acid. *(Answer: 20 cm³/ 16,7 cm³)* (2)

During a titration 25 cm^3 of the 0,1 mol·dm^{-3} sulphuric acid solution is added to an Erlenmeyer flask and titrated with a 0,1 mol·dm^{-3} sodium hydroxide solution.

2.3.3 The learner uses bromothymol blue as indicator. What is the purpose of this indicator? (1)

2.3.4 Calculate the pH of the solution in the flask after the addition of 30 cm^3 of sodium hydroxide. The endpoint of the titration is not yet reached at this point. *(Answer: pH = 1,44)* (8)

[22]

QUESTION 3 (June 2015)

Anhydrous oxalic acid is an example of an acid that can donate two protons and thus ionises in two steps as represented by the equations below:

I: $(COOH)_2(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + H(COO)_2^-(aq)$

II: $H(COO)_2^-(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + (COO)_2^{2-}(aq)$

3.1 Write down:

3.1.1 ONE word for the underlined phrase in the above sentence (1)

3.1.2 The FORMULA of each of the TWO bases in reaction **II** (2)

3.1.3 The FORMULA of the substance that acts as ampholyte in reactions **I** and **II.** Give a reason for the answer. (2)

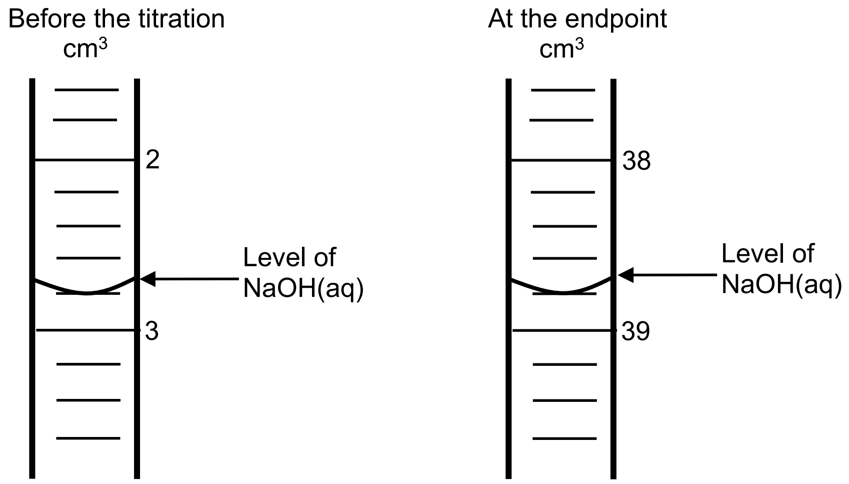
3.2 Give a reason why oxalic acid is a weak acid. (1)

3.3 A standard solution of $(COOH)_2$ of concentration 0,20 mol·dm^{-3} is prepared by dissolving a certain amount of $(COOH)_2$ in water in a 250 cm^3 volumetric flask. Calculate the mass of $(COOH)_2$ needed to prepare the standard solution. *(Answer: 4,5 g)* (4)

3.4 During a titration 25 cm^3 of the standard solution of $(COOH)_2$ prepared in QUESTION 3.3 is neutralised by a sodium hydroxide solution from a burette. The balanced equation for the reaction is:

$$(COOH)_2(aq) + 2NaOH(aq) \rightarrow (COONa)_2(aq) + 2H_2O(\ell)$$

The diagrams below show the burette readings before the titration commenced and at the endpoint respectively.



3.4.1 Use the burette readings and calculate the concentration of the sodium hydroxide solution. *(Answer: 0,28 mol·dm⁻³)* (5)

3.4.2 Write down a balanced equation that explains why the solution has a pH greater than 7 at the endpoint. (3)

[18]

QUESTION 4 (November 2015)

1.1 Ammonium chloride crystals, $NH_4C\ell(s)$, dissolve in water to form ammonium and chloride ions. The ammonium ions react with water according to the following balanced equation:

$$NH_4^+(aq) + H_2O(\ell) \rightleftharpoons NH_3(aq) + H_3O^+(aq)$$

4.1.1 Write down the name of the process described by the underlined sentence. (1)

4.1.2 Is ammonium chloride ACIDIC or BASIC in aqueous solution? Give a reason for the answer. (2)

1.2 A certain fertiliser consists of 92% ammonium chloride. A sample of mass x g of this fertiliser is dissolved in 100 cm^3 of a 0,10 mol·dm^{-3} sodium hydroxide solution, NaOH(aq). The NaOH is in excess. The balanced equation for the reaction is:

$$NH_4C\ell(s) + NaOH(aq) \rightarrow NH_3(g) + H_2O(\ell) + NaC\ell(aq)$$

4.2.1 Calculate the number of moles of sodium hydroxide in which the sample is dissolved.
(Answer: 0,01 mol) (3)

During a titration, 25 cm^3 of the excess sodium hydroxide solution is titrated with a 0,11 mol·dm^{-3} hydrochloric acid solution, $HC\ell(aq)$. At the endpoint it is found that 14,55 cm^3 of the hydrochloric acid was used to neutralise the sodium hydroxide solution according to the following balanced equation:

$$HC\ell(aq) + NaOH(aq) \rightarrow NaC\ell(aq) + H_2O(\ell)$$

4.2.2 Calculate the mass x (in grams) of the fertiliser sample used.
(Answer: 0,21 g) (8)

4.3 Calculate the pH of a 0,5 mol·dm^{-3} sodium hydroxide solution at 25 °C.
(Answer: pH = 13,7) (4)

[18]

QUESTION 5 (March 2016)

5.1 Define an acid in terms of the Lowry-Brønsted theory. (2)

5.2 Carbonated water is an aqueous solution of carbonic acid, H_2CO_3. $H_2CO_3(aq)$ ionises in two steps when it dissolves in water.

5.2.1 Write down the FORMULA of the conjugate base of $H_2CO_3(aq)$. (1)

5.2.2 Write down a balanced equation for the first step in the ionisation of carbonic acid. (3)

5.2.3 The pH of a carbonic acid solution at 25 °C is 3,4. Calculate the hydroxide ion concentration in the solution.
(Answer: 2,51 x 10^{-11} mol·dm^{-3}) (5)

5.3 **X** is a monoprotic acid.

5.3.1 State the meaning of the term *monoprotic*. (1)

5.3.2 A sample of acid **X** is titrated with a standard sodium hydroxide solution using a suitable indicator. At the endpoint it is found that 25 cm^3 of acid **X** is neutralised by 27,5 cm^3 of the sodium hydroxide solution of concentration 0,1 mol·dm^{-3}. Calculate the concentration of acid **X**.
(Answer: 0,11 mol·dm^{-3}) (5)

5.3.3 The concentration of H_3O^+ ions in the sample of acid **X** is 2,4 x 10^{-4} mol·dm^{-3}. Is acid **X** a WEAK or a STRONG acid? Explain the answer by referring to the answer in QUESTION 5.3.2. (3)

[20]

QUESTION 6 (June 2016)

6.1 Hydrogen carbonate ions react with water according to the following balanced equation:

$$HCO_3^-(aq) + H_2O(\ell) \rightleftharpoons H_2CO_3(aq) + OH^-(aq)$$

6.1.1 Define an *acid according to the Lowry-Brønsted theory*. (2)

6.1.2 Write down the FORMULAE of the two acids in the equation above. (2)

6.1.3 Write down the formula of a substance in the reaction above that can act as an ampholyte. (1)

6.2 During an experiment 0,50 dm^3 of a 0,10 mol·dm^{-3} $HC\ell$ solution is added to 0,80 dm^3 of a $NaHCO_3$ solution of concentration 0,25 mol·dm^{-3}. The balanced equation for the reaction is:

$$NaHCO_3(aq) + HC\ell(aq) \rightarrow NaC\ell(aq) + CO_2(g) + H_2O(\ell)$$

6.2.1 Calculate the concentration of the hydroxide ions in the solution on completion of the reaction.
(Answer: 0,12 mol·dm^{-3}) (8)

6.2.2 Calculate the pH of the solution on completion of the reaction.
(Answer: pH = 13,08) (4)

[17]

QUESTION 7 (November 2016)

7.1 A learner dissolves ammonium chloride ($NH_4C\ell$) crystals in water and measures the pH of the solution.

7.1.1 Define the term *hydrolysis of a salt*. (2)

7.1.2 Will the pH of the solution be GREATER THAN, SMALLER THAN or EQUAL TO 7? Write a relevant equation to support your answer. (3)

7.2 A sulphuric acid solution is prepared by dissolving 7,35 g of $H_2SO_4(\ell)$ in 500 cm^3 of water.

7.2.1 Calculate the number of moles of H_2SO_4 present in this solution.
(Answer: 0,08 mol) (2)

Sodium hydroxide (NaOH) pellets are added to the 500 cm^3 H_2SO_4 solution. The balanced equation for the reaction is:

$$H_2SO_4(aq) + 2NaOH(s) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell)$$

After completion of the reaction, the pH of the solution was found to be 1,3. Assume complete ionisation of H_2SO_4.

7.2.2 Calculate the mass of NaOH added to the H_2SO_4 solution. Assume that the volume of the solution does not change.
(Answer: 5 g) (9)

[16]

QUESTION 8 (March 2017)

8.1 Ethanoic acid (CH_3COOH) is an acid that ionises incompletely in water according to the following balanced equation:

$$CH_3COOH(aq) + H_2O(\ell) \rightarrow CH_3COO^-(aq) + H_3O^+(aq)$$

8.1.1 Write down the term used for the underlined phrase above. (1)

8.1.2 An ethanoic acid solution has a pH of 4 at 25°C. Calculate the concentration of the hydronium ions, $H_3O^+(aq)$ in the solution.
(Answer: 1×10^{-4} mol·dm^{-3}) (3)

8.2 A standard solution of potassium hydroxide (KOH) is prepared in a 250 cm^3 volumetric flask. During a titration, 12,5 cm^3 of this solution neutralises 25 cm^3 of a 0,16 mol·dm^{-3} ethanoic acid solution. The balanced equation for the reaction is:

$$CH_3COOH(aq) + KOH(aq) \rightarrow CH_3COOK(aq) + H_2O(\ell)$$

8.2.1 Define a *base according to the Arrhenius theory*. (2)

8.2.2 Calculate the mass of potassium hydroxide used to prepare the solution above in the 250 cm^3 volumetric flask.
(Answer: 4,48 g) (7)

8.2.3 Will the pH of the solution in the conical flask at the end point be GREATER THAN 7, SMALLER THAN 7 or EQUAL TO 7? (1)

8.2.4 Explain the answer to QUESTION 8.2.3 with the aid of a balanced chemical equation. (3)

[17]

QUESTION 9 (June 2017)

The K_a values for two weak acids, oxalic acid and carbonic acid, are as follows:

NAME	FORMULA	K_a
Oxalic acid	$(COOH)_2$	$5,6 \times 10^{-2}$
Carbonic acid	H_2CO_3	$4,3 \times 10^{-7}$

9.1 Define the term *weak acid.* (2)

9.2 Which acid, OXALIC ACID or CARBONIC ACID, is stronger? Give a reason for the answer. (2)

9.3 Oxalic acid ionises in water according to the following balanced equation:

$$(COOH)_2(s) + 2H_2O(\ell) \rightleftharpoons (COO)_2^{2-}(aq) + 2H_3O^+(aq)$$

Write down the FORMULAE of the TWO bases in this equation. (2)

9.4 Learners prepare 2 dm^3 of a sodium hydroxide solution of concentration 0,1 mol·dm^{-3}. Calculate the pH of the solution.
(Answer: pH = 13) (4)

9.5 During a titration of the sodium hydroxide solution in QUESTION 9.4 with dilute oxalic acid, the learners find that 25,1 cm^3 of the NaOH(aq) neutralises exactly 14,2 cm^3 of the $(COOH)_2(aq)$. The balanced equation for the reaction is as follows:

$$2NaOH(aq) + (COOH)_2(aq) \rightarrow (COO)_2Na_2(aq) + 2H_2O(\ell)$$

9.5.1 Calculate the concentration of the oxalic acid solution.
(Answer: 0,09 mol·dm^{-3}) (5)

The following indicators are available for the titration:

INDICATOR	pH RANGE
A	3,1–4,4
B	6,0–7,6
C	8,3–10,0

9.5.2 Which ONE of the indicators above is most suitable for this titration? Give a reason for the answer. (2)

[17]

QUESTION 10 (November 2017)

10.1 Ammonia ionises in water to form a basic solution according to the following balanced equation:

$$NH_3(aq) + H_2O(\ell) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

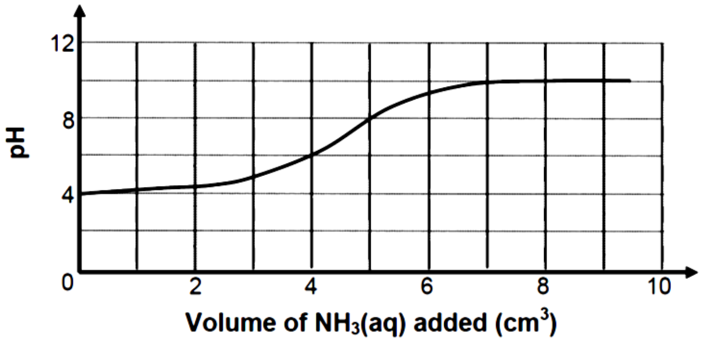
10.1.1 Is ammonia a WEAK or a STRONG base? Give a reason for the answer. (2)

10.1.2 Write down the conjugate acid of $NH_3(g)$. (1)

10.1.3 Identify ONE substance in this reaction that can behave as an ampholyte in some reactions. (1)

10.2 A learner adds distilled water to a soil sample and then filters the mixture. The pH of the filtered liquid is then measured. He then gradually adds an ammonia solution, $NH_3(aq)$, to this liquid and measures the pH of the solution at regular intervals. The graph alongside shows the results obtained.

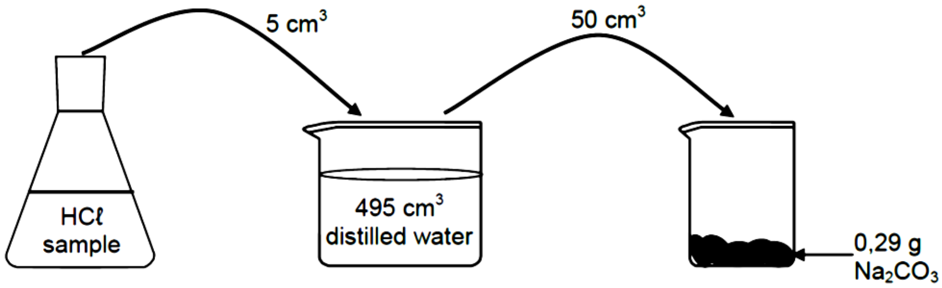
Graph of pH versus volume of NH_3(aq)



10.2.1 Is the soil sample ACIDIC or BASIC? Refer to the graph above and give a reason for the answer. (2)

10.2.2 Calculate the concentration of the hydroxide ions (OH^-) in the reaction mixture after the addition of 4 cm^3 of NH_3(aq). *(Answer: 1 x 10^{-8} mol·dm^{-3})* (4)

10.3 A laboratory technician wants to determine the concentration of a hydrochloric acid (HCℓ) sample. He adds 5 cm^3 of the HCℓ sample to 495 cm^3 of distilled water to give 500 cm^3 of dilute hydrochloric acid, HCℓ(aq). During a reaction 50 cm^3 of this dilute hydrochloric acid solution, HCℓ(aq), reacts completely with 0,29 g of sodium carbonate, Na_2CO_3(s).



The balanced equation for the reaction is: $Na_2CO_3(s) + 2HC\ell(aq) \rightarrow 2NaC\ell(aq) + CO_2(g) + H_2O(\ell)$

Calculate the concentration of the hydrochloric acid sample.

(Answer: 10,94 mol·dm^{-3}) (7)

[17]

QUESTION 11 (March 2018)

11.1 The balanced equation below represents the first step in the ionisation of sulphuric acid (H_2SO_4) in water: $H_2SO_4(\ell) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HSO_4^-(aq)$

11.1.1 Write down the FORMULAE of the TWO bases in the equation above. (2)

11.1.2 Is sulphuric acid a STRONG or a WEAK acid? Give a reason for the answer. (2)

11.2 Learners use the reaction of a 0,15 mol·dm^{-3} sulphuric acid solution with a sodium hydroxide solution in two different experiments. The balanced equation for the reaction is:

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + H_2O(\ell)$$

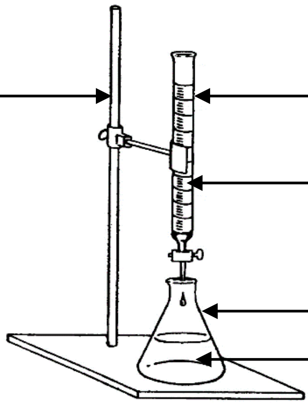
11.2.1 They use 24 cm^3 of H_2SO_4(aq) in a titration to neutralise 26 cm^3 of NaOH(aq). Calculate the concentration of the NaOH(aq). *(Answer: 0,28 mol·dm^{-3})* (5)

11.2.2 In another experiment, 30 cm^3 of the H_2SO_4(aq) is added to 20 cm^3 of a 0,28 mol·dm^{-3} NaOH solution in a beaker. Calculate the pH of the final solution. *(Answer: pH = 1,17)* (8)

[17]

QUESTION 12 (June 2018)

The reaction between a sulphuric acid (H_2SO_4) solution and a sodium hydroxide (NaOH) solution is investigated using the apparatus illustrated below.



12.1 Write down the name of the experimental procedure illustrated above. (1)

12.2 What is the function of the burette? (1)

12.3 Define an acid in terms of the Arrhenius theory. (2)

12.4 Give a reason why sulphuric acid is regarded as a strong acid. (1)

12.5 Bromothymol blue is used as indicator. Write down the colour change that will take place in the Erlenmeyer flask on reaching the endpoint of the titration. Choose from the following:
BLUE TO YELLOW YELLOW TO BLUE GREEN TO YELLOW (1)

During the titration a learner adds 25 cm^3 of NaOH(aq) of concentration 0,1 $mol \cdot dm^{-3}$ to an Erlenmeyer flask and titrates this solution with H_2SO_4 (aq) of concentration 0,1 $mol \cdot dm^{-3}$. The balanced equation for the reaction that takes place is:

$$2NaOH(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(\ell)$$

12.6 Determine the volume of H_2SO_4(aq) which must be added to neutralise the NaOH(aq) in the Erlenmeyer flask completely.
(Answer: 12,5 cm^3) (4)

12.7 If the learner passes the endpoint by adding 5 cm^3 of the same H_2SO_4(aq) in excess, calculate the pH of the solution in the flask. *(Answer: pH = 1,63)* (7)

[17]

QUESTION 13 (November 2018)

13.1 Sulphuric acid is a strong acid present in acid rain. It ionises in two steps as follows:

I: $H_2SO_4(\ell) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HSO_4^-(aq)$

II: $HSO_4^-(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + SO_4^{2-}(aq)$

13.1.1 Define *an acid* in terms of the Lowry-Brønsted theory. (2)

13.1.2 Write down the FORMULA of the conjugate base of H_3O^+(aq). (1)

13.1.3 Write down the FORMULA of the substance that acts as an ampholyte in the ionisation of sulphuric acid. (2)

13.2 Acid rain does not cause damage to lakes that have rocks containing limestone ($CaCO_3$). Hydrolysis of $CaCO_3$ results in the formation of ions, which neutralise the acid.

13.2.1 Define *hydrolysis of a salt*. (2)

13.2.2 Explain, with the aid of the relevant HYDROLYSIS reaction, how limestone can neutralise the acid. (3)

13.3 The water in a certain lake has a pH of 5.

13.1.1 Calculate the concentration of the hydronium ions in the water.
(Answer: 1 x 10^{-5} $mol \cdot dm^{-3}$) (3)

The volume of water in the lake is 4 x 10^9 dm^3. Lime, CaO, is added to the water to neutralise the acid according to the following reaction:

$$CaO + 2H_3O^+ \rightleftharpoons Ca^{2+} + 3H_2O$$

13.3.2 If the final amount of hydronium ions is 1,26 x 10^3 moles, calculate the mass of lime that was added to the lake.
(Answer: 1,09 x 10^6 g) (7)

[20]

QUESTION 14 (June 2019)

14.1 Define a *base* in terms of the Arrhenius theory. (2)

14.2 Explain how a weak base differs from a strong base. (2)

14.3 Write down the balanced equation for the hydrolysis of $NaHCO_3$. (3)

14.4 A learner wishes to identify element **X** in the hydrogen carbonate, $XHCO_3$. To do this she dissolves 0,4 g of **X**HCO_3 in 100 cm^3 of water. She then titrates all of this solution with a 0,2 mol dm^{-3} hydrochloric acid (HCℓ) solution. Methyl orange is used as the indicator during the titration.

14.4.1 Calculate the pH of the hydrochloric acid solution.
(Answer: pH = 0,7) (3)

14.4.2 Give a reason why methyl orange is a suitable indicator in this titration. (1)

At the endpoint she finds that 20 cm^3 of the acid neutralised ALL the hydrogen carbonate solution. The balanced equation for the reaction is:

$$\mathbf{X}HCO_3(aq) + HC\ell(aq) \rightarrow \mathbf{X}C\ell(aq) + CO_2(g) + H_2O(\ell)$$

14.4.3 Identify element **X** by means of a calculation.
(Answer: M(X) = 39 g·mol^{-1} thus X = K/potassium) (6)

[17]

QUESTION 15 (November 2019)

A hydrogen bromide solution, HBr(aq), reacts with water according to the following balanced chemical equation: $HBr(aq) + H_2O(\ell) \rightleftharpoons Br^-(aq) + H_3O^+(aq)$

The K_a value of HBr(aq) at 25 °C is 1 x 10^9.

15.1 Is hydrogen bromide a STRONG ACID or a WEAK ACID? Give a reason for the answer. (2)

15.2 Write down the FORMULAE of the TWO bases in the above reaction. (2)

15.3 HBr(aq) reacts with $Zn(OH)_2(s)$ according to the following balanced equation:

$$Zn(OH)_2(s) + 2HBr(aq) \rightarrow ZnBr_2(aq) + 2H_2O(\ell)$$

An unknown quantity of $Zn(OH)_2(s)$ is reacted with 90 cm^3 of HBr(aq) in a flask. (Assume that the volume of the solution does not change during the reaction.)
The EXCESS HBr(aq) is then neutralised by 16,5 cm^3 of NaOH(aq) of concentration 0,5 mol·dm^{-3}. The balanced equation for the reaction is:

$$HBr(aq) + NaOH(aq) \rightarrow NaBr(aq) + H_2O(\ell)$$

15.3.1 Calculate the pH of the HBr solution remaining in the flask AFTER the reaction with $Zn(OH)_2(s)$.
(Answer: pH = 1,04) (7)

15.3.2 Calculate the mass of $Zn(OH)_2(s)$ INITIALLY present in the flask if the initial concentration of HBr(aq) was 0,45 mol·dm^{-3}.
(Answer: 1,60 g) (6)

[17]

QUESTION 16 (November 2020)

16.1 Ethanoic acid (CH_3COOH) is an ingredient of household vinegar.

16.1.1 Is ethanoic acid a WEAK acid or a STRONG acid? Give a reason for the answer. (2)

16.1.2 An ethanoic acid solution has a pH of 3,85 at 25°C. Calculate the concentration of the hydronium ions, $H_3O^+(aq)$, in the solution. *(Answer: 1,41 x 10^{-4} mol·dm^{-3})* (3)

Sodium ethanoate, $CH_3COONa(aq)$, forms when ethanoic acid reacts with sodium hydroxide.

16.1.3 Will the pH of a sodium ethanoate solution be GREATER THAN 7, LESS THAN 7 or EQUAL TO 7? (1)

16.1.4 Explain the answer to QUESTION 16.1.3 with the aid of a balanced chemical equation. (3)

16.2 Household vinegar contains 4,52% ethanoic acid, CH_3COOH by volume. A 1,2 g impure sample of calcium carbonate ($CaCO_3$) is added to 25 cm^3 household vinegar. On completion of the reaction, the EXCESS ethanoic acid in the household vinegar is neutralised by 14,5 cm^3 of a sodium hydroxide solution of concentration 1 mol·dm^{-3}. The balanced equation for the reaction is:

$$CH_3COOH(aq) + NaOH(aq) \rightarrow CH_3COONa(aq) + H_2O(\ell)$$

16.2.1 Calculate the number of moles of the unreacted ethanoic acid. *(Answer: 0,0145 mol)* (3)

16.2.2 Calcium carbonate reacts with ethanoic acid according to the following balanced equation:

$$CaCO_3(s) + 2CH_3COOH(aq) \rightarrow (CH_3COO)_2Ca(aq) + H_2O + CO_2(g)$$

Calculate the percentage calcium carbonate in the impure sample if 1 cm^3 of household vinegar has a mass of 1 g. *(Answer: 18,08%)* (8)

[20]

QUESTION 17 (June 2021)

Learners prepare a <u>solution of known concentration</u> by dissolving 2 g pure sodium hydroxide crystals, NaOH, in water in a 250 cm³ volumetric flask.

17.1 Write down the term for the underlined phrase. (1)

17.2 Calculate the:

17.2.1 Concentration of the sodium hydroxide solution *(Answer: 0,20 mol·dm⁻³)* (4)

17.2.2 pH of the solution *(Answer: 13,30)* (4)

The learners now react 1,5 g of pure $CaCO_3$ with 50 cm³ dilute HCℓ of unknown concentration. The EXCESS HCℓ is neutralised with 25 cm³ of the NaOH solution that they prepared. The balanced equations for the reactions are:

$$2HC\ell(aq) + CaCO_3(s) \rightarrow CaC\ell_2(aq) + CO_2(g) + H_2O(\ell)$$

$$HC\ell(aq) + NaOH(aq) \rightarrow NaC\ell(aq) + H_2O(\ell)$$

17.3 Calculate the initial concentration of the dilute HCℓ(aq). *(Answer: 0,70 to 0,90 mol·dm⁻³)* (8)

[17]

QUESTION 18 (September 2021)

Two beakers, **A** and **B**, contain strong bases.

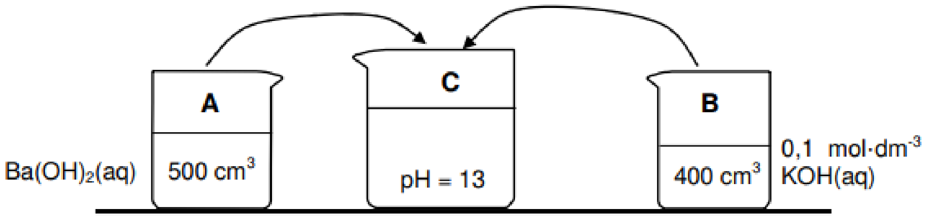
Beaker **A**: 500 cm³ of barium hydroxide, $Ba(OH)_2(aq)$ of unknown concentration **X**

Beaker **B**: 400 cm³ of potassium hydroxide, KOH(aq) of concentration 0,1 mol·dm⁻³

18.1 Define a *base* according to the Arrhenius theory. (2)

18.2 Calculate the number of moles of hydroxide ions (OH) in beaker **B**. *(Answer: 0,04 mol)* (2)

18.3 The contents of beakers **A** and **B** are added together in beaker **C**. The solution in beaker **C** has a pH of 13. Assume that the volumes are additive and that the temperature of the solutions is 25 °C.



18.3.1 Calculate the concentration, **X**, of the $Ba(OH)_2$ in beaker **A**. *(Answer: 0,05 to 0,06 mol·dm⁻³)* (8)

The solution in beaker **C** is titrated with ethanoic acid. It was found that 15 cm³ of the solution neutralises 30 cm³ of the acid. The balanced equation for the reaction is:

$$CH_3COOH(aq) + OH\ (aq) \rightarrow CH_3COO\ (aq) + H_2O($$

18.3.2 Is ethanoic acid, $CH_3COOH(aq)$, a WEAK acid or a STRONG acid? Give a reason for the answer. (2)

18.3.3 Calculate the concentration of the ethanoic acid. *(Answer: 0,05 mol·dm⁻³)* (4)

[18]

QUESTION 19 (November 2021)

19.1 Sulphuric acid, H_2SO_4, ionises into two steps as follows:

I: $H_2SO_4(\ell) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + HSO_4^-(aq)$ $K_a = 1 \times 10^3$

II: $HSO_4^-(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + SO_4^{2-}(aq)$ $K_a = 1 \times 10^{-2}$

19.1.1 Define an *acid* in terms of the Lowry-Brønsted theory. (2)

19.1.2 Write down the NAME or FORMULA of the substance that acts as an ampholyte in the above equations. Give a reason for the answer. (2)

19.1.3 The conductivity of solutions of $HSO_4^-(aq)$ and $H_2SO_4(aq)$ are compared. Which solution will have a LOWER conductivity? Explain the answer. (3)

19.2 The pH of a hydrochloric acid solution, HCℓ(aq), is 1,02 at 25 °C.

19.2.1 Calculate the concentration of the HCℓ(aq). *(Answer: 0,096/0,1 mol·dm⁻³)* (3)

This HCℓ solution reacts with sodium carbonate, Na_2CO_3, according to the following balanced equation:

$$2HC\ell(aq) + Na_2CO_3(aq) \rightarrow 2NaC\ell(aq) + CO_2(g) + H_2O(\ell)$$

50 cm³ of the HCℓ solution is added to 25 cm³ of a 0,075 mol·dm⁻³ Na_2CO_3 solution.

19.2.2 Calculate the concentration of the EXCESS HCℓ in the new solution. *(Answer: 0,01 to 0,02 mol·dm⁻³)* (8)

[18]

QUESTION 20 (June 2022)

7.1 Two acids, HX and HY, of EQUAL CONCENTRATIONS are compared.
The pH of HX is 2,7 and the pH of HY is 0,7.

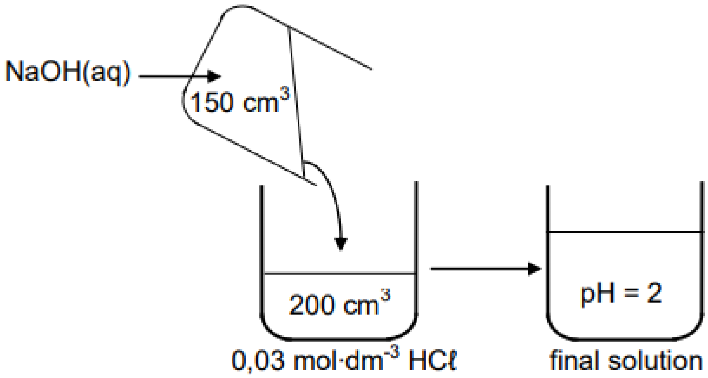
7.1.1 Define an *acid* in terms of the Lowry-Brønsted theory. (2)
7.1.2 Which acid, HX or HY, is STRONGER? Give a reason for the answer. (2)
7.1.3 Acid HX ionises in water according to the following equation:

$$HX(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + X^-(aq)$$

The K_a value for the reaction is $1,8 \times 10^{-5}$ at 25 °C.

Is the concentration of the hydronium ions HIGHER THAN, LOWER THAN or EQUAL TO the concentration of HX? Give a reason for the answer. (2)

7.2 Learners add 150 cm^3 of a sodium hydroxide solution, NaOH, of unknown concentration to 200 cm^3 of a 0,03 $mol \cdot dm^{-3}$ hydrochloric acid solution, $HC\ell$, as illustrated below. They find that the pH of the final solution is 2. Assume that the volumes are additive.



The balanced equation for the reaction is:

$$HC\ell(aq) + NaOH(aq) \rightarrow NaC\ell(aq) + H2O(\ell)$$

Calculate the:

7.2.1 Concentration of the H_3O^+ ions in the final solution
(Answer: 0,01 mol·dm⁻³) (3)

7.2.2 Initial concentration of the NaOH(aq)
(Answer: 0,02 mol·dm⁻³) (7)

[16]

QUESTION 21 (November 2022)

7.1 Ethanoic acid is a weak acid that reacts with water according to the following balanced equation:

$$CH_3COOH(aq) + H_2O(\ell) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$$

7.1.1 Define an *acid* in terms of the Lowry-Brønsted theory. (2)
7.1.2 Give a reason why ethanoic acid is classified as a WEAK acid. (1)
7.1.3 Write down the formulae of the TWO bases in the equation above. (2)

7.2 A flask contains 300 cm^3 of dilute sodium hydroxide, NaOH(aq), of concentration 0,167 $mol \cdot dm^{-3}$.

7.2.1 Calculate the number of moles of sodium hydroxide in the flask.
(Answer: 0,05 mol) (3)

Ethanoic acid of volume 500 cm^3 and of unknown concentration, **X**, is now added to this flask to give a solution of volume 800 cm^3. It is found that the pH of the mixture is 11,4.
The balanced equation for the reaction is:

$$NaOH(aq) + CH_3COOH(aq) \rightarrow CH_3COONa(aq) + H_2O(\ell)$$

Calculate the:

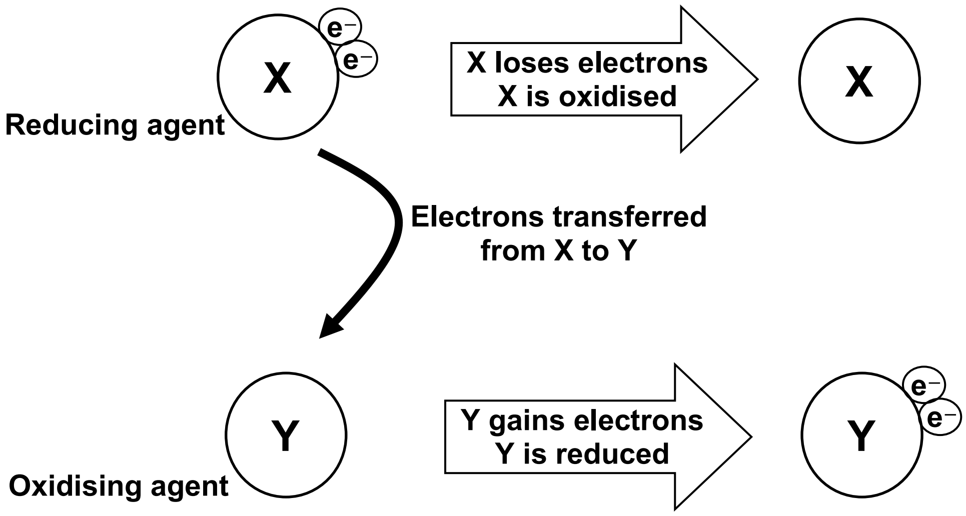
7.2.2 Concentration of the $OH^-(aq)$ in the mixture
(Answer: $2,51 \times 10^{-3}$ mol·dm⁻³) (4)

7.2.3 Initial concentration, **X**, of the ethanoic acid solution
(*Answer: 0,095 to 0,1 mol·dm⁻³)* (6)

[18]

ELECTROCHEMICAL REACTIONS

Electron transfer reactions

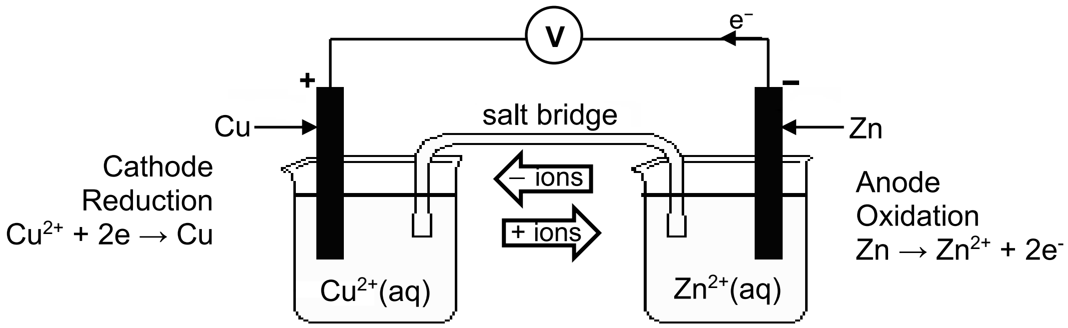


TERMS AND DEFINITIONS	
Redox reaction	A reaction in which an electron transfer takes place.
Oxidation	A loss of electrons. /An increase in oxidation number.
Reduction	A gain of electrons. /A decrease in oxidation number.
Oxidising agent	A substance that is reduced/gains electrons/whose oxidation number decreases.
Reducing agent	A substance that is oxidised/loses electrons/whose oxidation number increases.
Overall redox reaction	The reaction obtained by combining two half-reactions.

A. GALVANIC CELLS

Galvanic cell OR Voltaic cell

- **TYPE OF ELECTROCHEMICAL CELL** in which chemical energy is converted to electrical energy.
- Spontaneous redox reaction takes place. The reaction is exothermic i.e. energy is released.



Cell reaction: $Cu^{2+} + Zn \rightarrow Zn^{2+} + Cu$

Cell notation: $Zn \mid Zn^{2+} \parallel Cu^{2+} \mid Cu$
Reducing agent | oxidised species || oxidising agent | reduced species

Cell potential: $E^{\theta}_{cell} = E^{\theta}_{cathode} - E^{\theta}_{anode} = 0,34 - (-0,76) = 1,1\ V$

When two half-reactions are combined in the cell reaction of a galvanic cell:

1. The half-reaction with the **SMALLER REDUCTION POTENTIAL** is always the **OXIDATION** and takes place at the **ANODE**.
2. The half-reaction with the **LARGER REDUCTION POTENTIAL** is always the **REDUCTION** and takes place at the **CATHODE**.

Section of the TABLE OF STANDARD REDUCTION POTENTIALS (4B)

Weakest oxidising agent for section shown.

Strongest reducing agent for section shown.

Increasing strength of oxidising agents

Increasing strength of reducing agents

$Na^+ + e^-$	$\rightleftharpoons$	Na
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	Mg
$Al^{3+} + 3e^-$	$\rightleftharpoons$	Al
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	Mn
$Cr^{2+} + 2e^-$	$\rightleftharpoons$	Cr
$2H_2O + 2e^-$	$\rightleftharpoons$	$H_2(g) + 2OH^-$
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	Zn
$Cr^{3+} + 3e^-$	$\rightleftharpoons$	Cr
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	Fe
$Cr^{3+} + e^-$	$\rightleftharpoons$	Cr^{2+}
$Cd^{2+} + 2e^-$	$\rightleftharpoons$	Cd
$Co^{2+} + 2e^-$	$\rightleftharpoons$	Co
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	Ni
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	Sn
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	Pb
$Fe^{3+} + 3e^-$	$\rightleftharpoons$	Fe
$\mathbf{2H^+ + 2e^-}$	$\rightleftharpoons$	$\mathbf{H_2(g)}$
$S + 2H^+ + 2e^-$	$\rightleftharpoons$	$H_2S(g)$
$Sn^{4+} + 2e^-$	$\rightleftharpoons$	Sn^{2+}
$Cu^{2+} + e^-$	$\rightleftharpoons$	Cu^+
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2(g) + 2H_2O$
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu
$2H_2O + O_2 + 4e^-$	$\rightleftharpoons$	$4OH^-$
$SO_2 + 4H^+ + 4e^-$	$\rightleftharpoons$	$S + 2H_2O$
$Cu^+ + e^-$	$\rightleftharpoons$	Cu
$I_2 + 2e^-$	$\rightleftharpoons$	$2I^-$
$O_2(g) + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O_2
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}
$NO_3^- + 2H^+ + e^-$	$\rightleftharpoons$	$NO_2(g) + H_2O$
$Ag^+ + e^-$	$\rightleftharpoons$	Ag

Strongest oxidising agent for section shown.

Weakest reducing agent for section shown.

EXPLANATIONS IN TERMS OF RELATIVE STRENGTHS OF REDUCING AGENTS OR OXIDISING AGENTS

Follow the following steps:
STEP 1: Identify the stronger oxidising agent *(or reducing agent)*.
STEP 2: Identify the species/substance with which it is compared i.e. the weaker oxidising agent *(or reducing agent).*
STEP 3: State the action i.e. which species will be reduced *(or oxidised).*
STEP 4: State to what species will it be reduced *(or oxidised)*.

EXAMPLE 1:
Can a copper(II) sulphate solution be stored in a zinc container? Explain by referring to the Table of Standard Reduction Potentials.

ANSWER

In terms of relative strength of oxidising agents:
No. ✓
Cu^{2+} is a stronger oxidising agent ✓ than Zn^{2+} ✓ and will oxidise Zn ✓ to Zn^{2+}. ✓

Note: Species on the left of the double arrow in the Table of Standard Reduction Potentials are oxidising agents. Those to the right of the double arrow are reducing agents. When comparing, an oxidising agent should always be compared to another oxidising agent and not with a reducing agent (to the right of the double arrow in the Table of Standard Reduction Potentials).

In terms of relative strengths of reducing agents:
No. ✓
Zn is a stronger reducing agent✓ than Cu ✓ and will reduce Cu^{2+} ✓ to Cu. ✓

EXAMPLE 2:
It is found that silver does not react with a hydrochloric acid solution. Refer to the relative strengths of reducing agents to explain this observation.

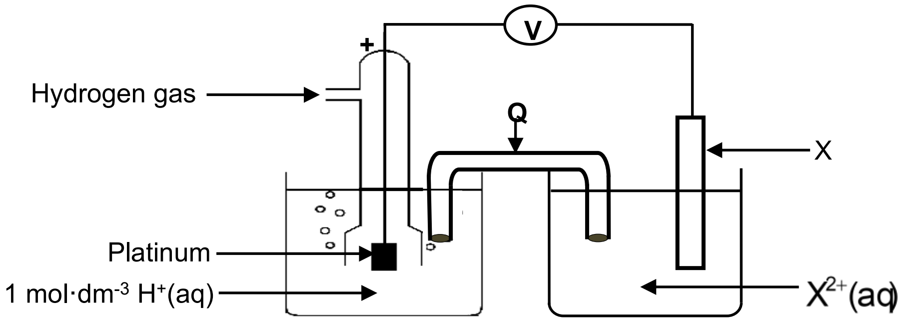
ANSWER
Ag is a weaker reducing agent ✓ than H_2 ✓ and Ag CANNOT reduce H^+ ✓ to H_2. ✓

TERMS AND DEFINITIONS	
Galvanic cell	A cell in which chemical energy is converted into electrical energy. A galvanic (voltaic) cell has self-sustaining electrode reactions.
Anode	The electrode where oxidation takes place.
Cathode	The electrode where reduction takes place.
Electrolyte	A solution that conducts electricity through the movement of ions.
Salt bridge	The connection between two half-cells needed to ensure electrical neutrality in the cell. OR: A component used in a galvanic cell to complete the circuit.
Electrodes	An electrical conductor used in a galvanic cell to make contact with a non-metallic part of the circuit e.g. the electrolyte.
Cell notation	A short way to represent a galvanic cell. When writing cell notation, the following convention should be used: o The H_2|H^+ half-cell is treated just like any other half-cell. o Cell terminals (electrodes) are written on the outside of the cell notation. o Active electrodes: reducing agent | oxidised species || oxidising agent | reduced species o Inert electrodes (usually Pt or C): Pt | reducing agent | oxidised species || oxidising agent | reduced species | Pt Example: Pt | $C\ell^-$(aq) |$C\ell_2$(g) || F_2(g) | F^-(aq) | Pt
Overall cell reaction	The reaction obtained by combining two half-reactions.
Positive value of the standard emf	The reaction is spontaneous under standard conditions.
Standard conditions for a galvanic cell	Temperature: 25 °C / 298 K Concentration: 1 $mol{\cdot}dm^{-3}$ Pressure (gases only): 101,3 kPa / 1 atmosphere
Standard hydrogen electrode	The reference electrode used to compile the Table of Standard Reduction Potentials. The hydrogen half-cell was given a standard reduction potential of 0 V. Half-cell notation: Pt | H_2(g) | H^+(aq) Half-reaction: $2H^+ + 2e^- \rightleftharpoons H_2$

TYPICAL QUESTIONS

QUESTION 1 (November 2014)

A standard electrochemical cell is set up using a standard hydrogen half-cell and a standard $X|X^{2+}$ half-cell as shown below. A voltmeter connected across the cell, initially registers 0,31 V.



1.1 Besides concentration write down TWO conditions needed for the hydrogen half-cell to function under standard conditions. (2)

1.2 Give TWO reasons, besides being a solid, why platinum is suitable to be used as electrode in the above cell. (2)

1.3 Write down the:

1.3.1 NAME of component **Q** (1)

1.3.2 Standard reduction potential of the $X|X^{2+}$ half-cell (1)

1.3.3 Half-reaction that takes place at the cathode of this cell (2)

1.4 The hydrogen half-cell is now replaced by a $M|M^{2+}$ half-cell. The cell notation of this cell is:

$$M(s)\ |\ M^{2+}(aq)\ ||\ X^{2+}(aq)\ |\ X(s)$$

The initial reading on the voltmeter is now 2,05 V.

1.4.1 Identify metal **M**. Show how you arrived at the answer. (5)

1.4.2 Is the cell reaction EXOTHERMIC or ENDOTHERMIC? (1)

1.5 The reading on the voltmeter becomes zero after using this cell for several hours. Give a reason for this reading by referring to the cell reaction. (1)

[15]

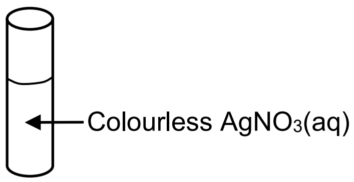
QUESTION 2 (March 2015)

A learner conducts two experiments to investigate the reaction between copper (Cu) and a silver nitrate solution, $AgNO_3$(aq).

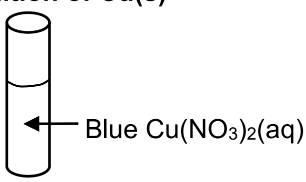
EXPERIMENT 1

The learner adds a small amount of copper (Cu) powder to a test tube containing silver nitrate solution, $AgNO_3$(aq). The solution changes from colourless to blue after a while.

Before addition of Cu(s)



After addition of Cu(s)

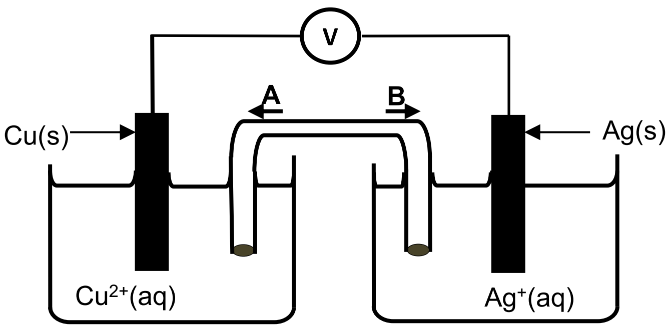


2.1 Define the term *oxidising agent*. (2)

2.2 Explain why the solution turns blue by referring to the relative strength of oxidising agents. (4)

EXPERIMENT 2

The learner now sets up a galvanic cell as shown below. The cell functions under standard conditions.



2.3 Write down the energy conversion that takes place in this cell. (1)

2.4 In which direction (**A** or **B**) will ANIONS move in the salt bridge? (1)

2.5 Calculate the emf of this cell under standard conditions.
(Answer: 0,46 V) (4)

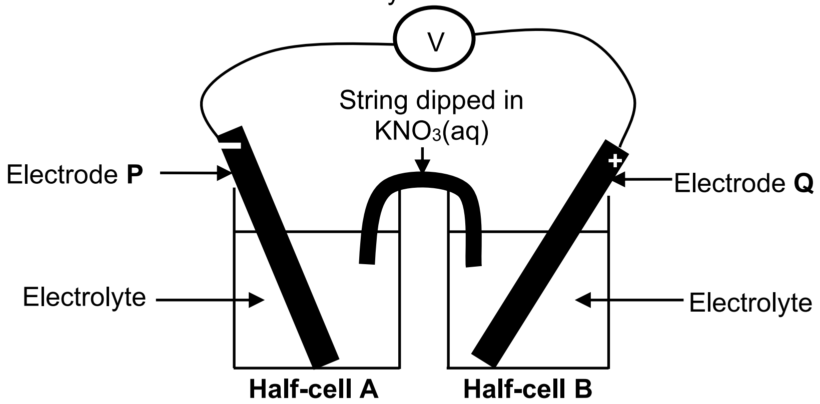
2.6 Write down the balanced equation for the net cell reaction that takes place in this cell. (3)

2.7 How will the addition of 100 cm^3 of a 1 mol dm^{-3} silver nitrate solution to the silver half-cell influence the initial emf of this cell? Write down only INCREASES, DECREASES or REMAINS THE SAME. (1)

[16]

QUESTION 3 (June 2015)

Learners set up an electrochemical cell, shown in the simplified diagram below, using magnesium and lead as electrodes. Nitrate solutions are used as electrolytes in both half-cells.



3.1 What type of reaction (NEUTRALISATION, REDOX or PRECIPITATION) takes place in this cell? (1)

3.2 Which electrode, **P** or **Q**, is magnesium? Give a reason for the answer. (2)

3.3 Write down the:

3.3.1 Standard conditions under which this cell functions (2)

3.3.2 Cell notation for this cell (3)

3.3.3 NAME or FORMULA of the oxidising agent in the cell (1)

3.4 Calculate the initial emf of the cell above under standard conditions. *(Answer: 2,23 V)* (4)

3.5 How will the voltmeter reading change if the:
(Write down only INCREASES, DECREASES or REMAINS THE SAME.)

3.5.1 Size of electrode **P** is increased (1)

3.5.2 Initial concentration of the electrolyte in half-cell **B** is increased (1)

[15]

QUESTION 4 (November 2015)

Learners are given the following two unknown half-cells:

Half-cell 1: Q^{2+} (aq) | Q(s) **Half-cell 2:** Pt | R_2(g) | R^-(aq)

During an investigation to identify the two half-cells, the learners connect each half-cell alternately to a Cd^{2+}(aq) | Cd(s) half-cell under standard conditions. For each combination of two half-cells, they write down the net cell reaction and measure the cell potential. The results obtained for the two half-cell combinations are given in the table below.

COMBINATION	NET CELL REACTION	CELL POTENTIAL
I	$\mathbf{Q}^{2+}$(aq) + Cd(s) → Cd^{2+}(aq) + **Q**(s)	0,13 V
II	$\mathbf{R}_2$(g) + Cd(s) → Cd^{2+}(aq) + 2$\mathbf{R}^-$(aq)	1,76 V

4.1 Write down THREE conditions needed for these cells to function as standard cells. (3)

4.2 For **Combination I**, identify:

4.2.1 The anode of the cell (1)

4.2.2 **Q** by using a calculation *(Answer: - 0,27 V; Ni / nickel)* (5)

4.3 For **Combination II**, write down the:

4.3.1 Oxidation half-reaction (2)

4.3.2 NAME or FORMULA of the metal used in the cathode compartment (1)

4.4 Arrange the following species in order of INCREASING oxidising ability: Q^{2+} ; R_2 ; Cd^{2+}
Explain fully how you arrived at the answer. A calculation is NOT required. (4)

[16]

QUESTION 5 (March 2016)

An electrochemical cell consisting of half-cells **A** and **B** is assembled under standard conditions as shown below.

Half-cell **A**	Pt, $Cℓ_2$ (101,3 kPa) | $Cℓ^-$ (1 mol·dm^{-3})
Half-cell **B**	Mg^{2+} (1 mol·dm^{-3}) | Mg(s)

5.1 At which half-cell, **A** or **B**, are electrons released into the external circuit? (1)

5.2 Write down the:

5.2.1 Reduction half-reaction that takes place in this cell (2)

5.2.2 NAME or FORMULA of the substance whose oxidation number DECREASES (1)

5.3 Calculate the initial cell potential of this cell when it is in operation. *(Answer: 3,72 V)* (4)

5.4 Write down an observation that will be made in half-cell **B** as the cell operates. Give a reason for the answer. (2)

[10]

QUESTION 6 (June 2016)

Magnesium (Mg) reacts with a dilute hydrochloric acid solution, HCℓ(aq), according to the following balanced equation: $Mg(s) + 2HC\ell(aq) \rightarrow MgC\ell_2(aq) + H_2(g)$

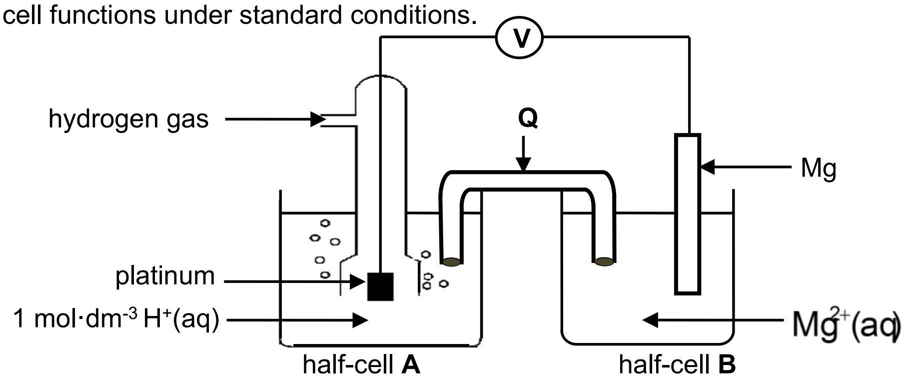
6.1 Give a reason why the reaction above is a redox reaction. (1)

6.2 Write down the FORMULA of the oxidising agent in the reaction above. (1)

It is found that silver does not react with the hydrochloric acid solution.

6.3 Refer to the relative strengths of reducing agents to explain this observation. (3)

The reaction of magnesium with hydrochloric acid is used in an electrochemical cell, as shown in the diagram below. The cell functions under standard conditions.



6.4 What is the function of platinum in the cell above? (1)

6.5 Write down the:

6.5.1 Energy conversion that takes place in this cell (1)

6.5.2 Function of **Q** (1)

6.5.3 Half-reaction that takes place at the cathode (2)

6.5.4 Cell notation of this cell (3)

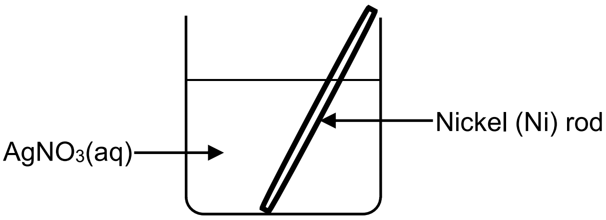
6.6 Calculate the initial emf of this cell. *(Answer: 2,36 V)* (4)

6.7 How will the addition of concentrated acid to half-cell **A** influence the answer to QUESTION 6.6? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

[18]

QUESTION 7 (November 2016)

7.1 A nickel (Ni) rod is placed in a beaker containing a silver nitrate solution, $AgNO_3(aq)$ and a reaction takes place.



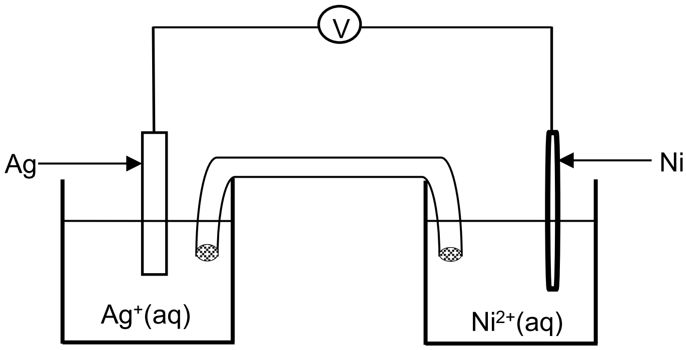
Write down the:

7.1.1 NAME or FORMULA of the electrolyte (1)

7.1.2 Oxidation half-reaction that takes place (2)

7.1.3 Balanced equation for the net (overall) redox reaction that takes place (3)

7.2 A galvanic cell is now set up using a nickel half-cell and a silver half-cell.



7.2.1 Which electrode (Ni or Ag) must be connected to the negative terminal of the voltmeter? Give a reason for the answer. (2)

7.2.2 Write down the cell notation for the galvanic cell above. (3)

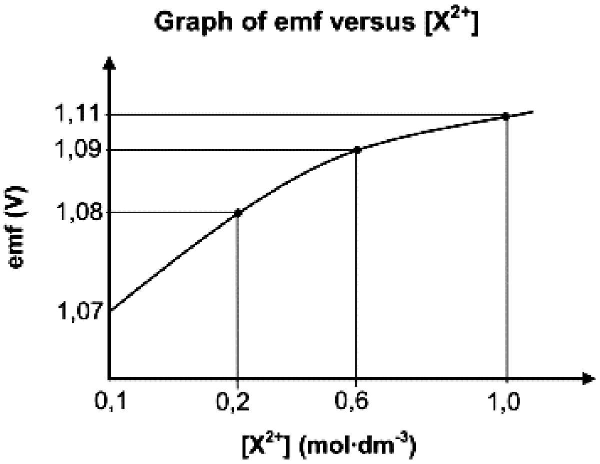
7.2.3 Calculate the initial reading on the voltmeter if the cell functions under standard conditions. (4)

7.2.4 How will the voltmeter reading in QUESTION 7.2.3 be affected if the concentration of the silver ions is increased? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

[16]

QUESTION 8 (June 2017)

The electrochemical cell represented by the cell notation below is used to investigate the relationship between the concentration of X^{2+}(aq) and the emf of the cell. The concentration of Zn^{2+}(aq) and the temperature are kept at standard conditions.



Zn(s) | Zn^{2+}(aq) || X^{2+}(aq) | X(s)

The graph shows the results obtained.

8.1 For this investigation, write down the:

8.1.1 Dependent variable (1)

8.1.2 Name of an instrument needed to measure the emf of the cell (1)

8.1.3 Name of the component of the cell that ensures electrical neutrality (1)

8.1.4 Values of TWO standard conditions needed to ensure that the standard emf is obtained (2)

8.2 Write down the conclusion that can be drawn from the results. (2)

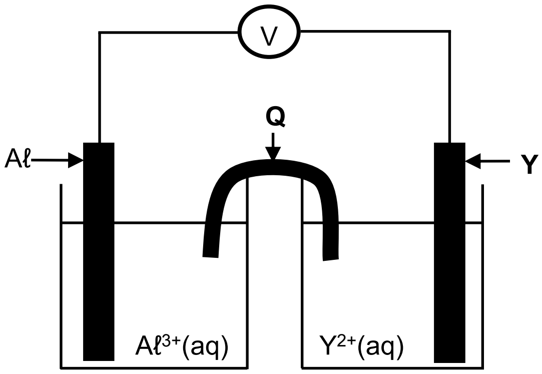
8.3 Identify electrode **X** with the aid of a calculation. (5)

8.4 Write down the overall (net) cell reaction that takes place when this cell is in operation. (3)

[15]

QUESTION 9 (Maart 2017)

In the electrochemical cell shown below an aluminium electrode and another metal electrode, **Y**, are used.



9.1 Write down the:

9.1.1 Name of component **Q** (1)

9.1.2 Type of electrochemical cell represented above (1)

It is found that the mass of the aluminium electrode increases whilst the cell is functioning.

9.2 How will EACH of the following change while the cell is functioning? Choose from INCREASES, DECREASES or REMAINS THE SAME.

9.2.1 The concentration of $A\ell^{3+}$(aq) (1)

9.2.2 The concentration of Y^{2+}(aq) (1)

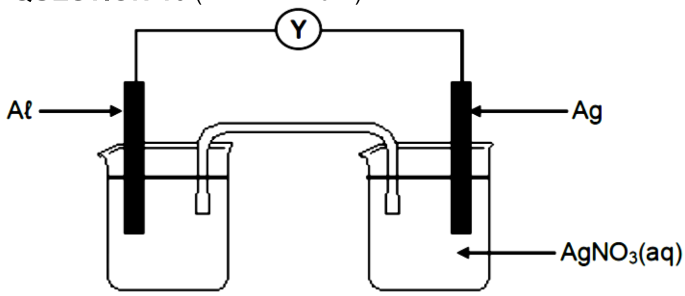
9.3 Write down the half-reaction that takes place at electrode **Y**. (2)

9.4 Write down the cell notation of the cell. (3)

9.5 The initial emf of this cell measured under standard conditions is 0,7 V. Identify metal **Y** by means of a calculation. (5)

[14]

QUESTION 10 (November 2017)



10.1 Learners set up a galvanic cell and measure its emf under standard conditions.

10.1.1 Write down the name of component **Y**. (1)

10.1.2 Is Aℓ the ANODE or the CATHODE? (1)

10.1.3 Write down the overall (net) cell reaction that takes place in this cell when it is working. (3)

10.1.4 Calculate the initial emf of this cell (4)

10.2 Consider the half-cells, **P**, **Q** and **R**, represented in the table below.

HALF-CELL P	HALF-CELL Q	HALF-CELL R
Zn | Zn^{2+}(aq)	Cℓ | $C\ell^{-}$(aq)	Cu | Cu^{2+}(aq)

Different combinations of the half-cells above are compared to determine the highest emf produced under standard conditions.

10.2.1 Write down the NAME of a suitable electrode for half-cell **Q**. (1)

10.2.2 State the standard conditions under which the half-cells should operate to ensure a fair comparison. (2)

10.2.3 Write down the NAME or FORMULA of the strongest reducing agent in the half-cells above. (1)

10.2.4 Which combination of half-cells will produce the highest emf? Choose from **PR**, **PQ** or **QR**. (NO calculation is required.) (1)

[14]

QUESTION 11 (March 2018)

11.1 A group of learners use the redox reaction below to construct an electrochemical cell.

$$Sn^{2+}(aq) + 2Ag^{+}(aq) \rightarrow 2Ag(s) + Sn^{4+}(aq)$$

11.1.1 Define a *reducing agent in terms of electron transfer*. (2)

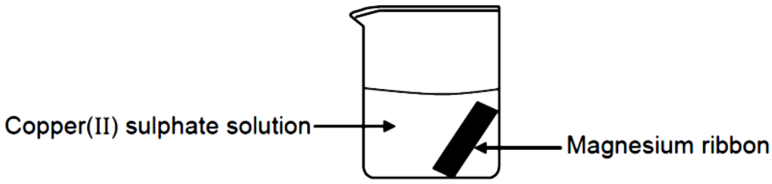
11.1.2 Name a substance that should be used as electrode in the anode half-cell. (1)

11.1.3 Write down the NAME or FORMULA of the reducing agent. (1)

11.1.4 Write down the cell notation of the cell. (3)

11.1.5 Calculate the initial emf of this cell under standard conditions. (4)

11.2 In a separate experiment, the learners place magnesium ribbon in a beaker containing a blue solution of copper(II) sulphate. After a while, the solution becomes colourless.



11.2.1 State ONE observable change in the beaker, besides a colour change of the solution, that the learners can make. (1)

11.2.2 Refer to the relative strengths of oxidising agents or reducing agents to explain why the solution becomes colourless. (3)

[15]

QUESTION 12 (June 2018)

12.1 Consider the electrochemical cell represented by the cell notation below, where **X** is an unknown metal:

$$Pt(s) \mid Fe^{2+}(aq), Fe^{3+}(aq) \parallel X^{+}(aq) \mid X(s)$$

The cell potential of this cell was found to be 0,03 V.

12.1.1 Write down the type of electrochemical cell illustrated above. (1)

12.1.2 What does the single line (|) in the above cell notation represent? (1)

12.1.3 Write down the half-reaction that takes place at the anode in the above cell. (2)

12.1.4 Identify **X** with the aid of a calculation. (5)

12.2 A $Pt(s) \mid Fe^{2+}(aq), Fe^{3+}(aq)$ half-cell is connected to a $Cu(s) \mid Cu^{2+}(aq)$ half-cell.

Write down the:

12.2.1 Chemical symbol for the electrode in the cathode half-cell (1)

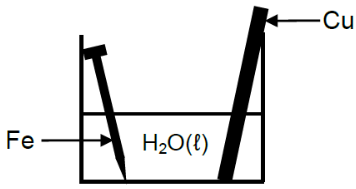
12.2.2 NAME of the oxidising agent (1)

12.2.3 Overall balanced cell reaction that takes place in this cell (3)

[14]

QUESTION 13 (November 2018)

13.1 Corrosion is a redox reaction that takes place in the presence of oxygen and water. Rusting is the corrosion of iron leading to the formation of iron(III) ions.



13.1.1 Define *oxidation* in terms of electron transfer. (2)

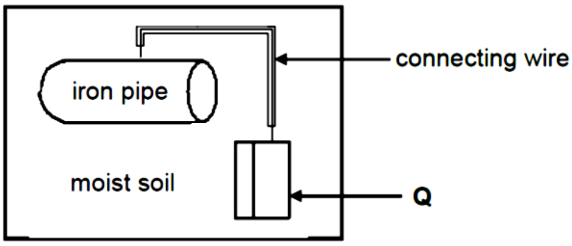
A cleaned copper rod and a cleaned iron nail are placed in a beaker containing water at 25 °C, as shown. After a while it was observed that the iron nail was coated with rust. The copper rod showed no visible signs of corrosion.

13.1.2 Write down the half-reaction for the iron nail. (2)

13.1.3 Does iron act as REDUCING AGENT or OXIDISING AGENT in the beaker? (1)

13.1.4 Explain the above observation by referring to the Table of Standard Reduction Potentials. (3)

To prevent rusting of an underground iron pipe, the pipe is connected to a metal (**Q**) that corrodes easily.



13.1.5 You are given two metals, Zn and Cu, to use as metal **Q**. Which metal would more suitable? Give a reason. (2)

13.2 A galvanic cell is constructed using a $Fe \mid Fe^{3+}$ half- cell and a $Cu \mid Cu^{2+}$ half-cell.

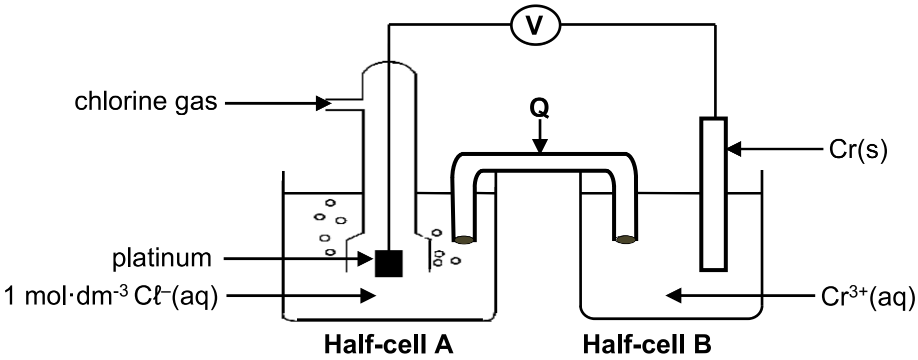
13.2.1 Write down the overall (net) cell reaction that takes place when the cell is functioning. (3)

13.2.2 Calculate the cell potential of this cell under standard conditions. *(Answer: 0,40 V)* (4)

[17]

QUESTION 14 (June 2019)

The electrochemical cell below functions under standard conditions.



14.1 Give a reason why platinum is used as the electrode in half-cell **A**. (1)

14.2 Write down the:

14.2.1 Energy conversion that takes place in this cell (1)

14.2.2 Half-reaction that takes place at the cathode (2)

14.2.3 Cell notation for this cell (3)

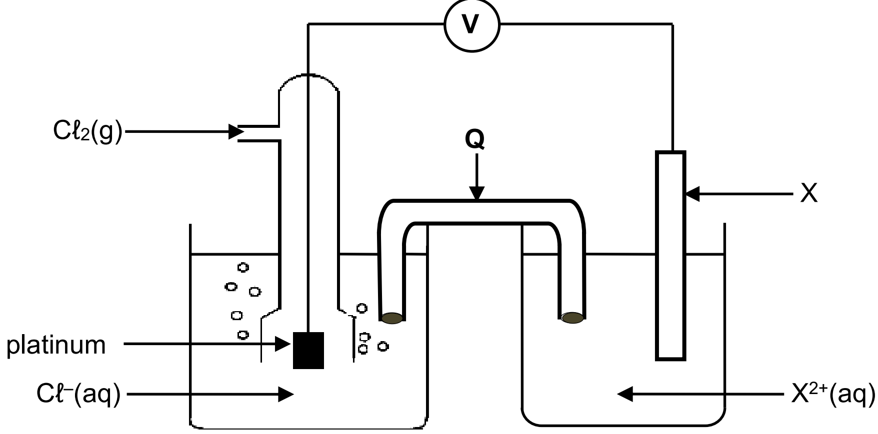
14.3 Calculate the initial emf of this cell. *(Answer: 2,10 V)* (4)

14.4 Silver chloride is an insoluble salt. What will be the effect on the cell potential when a small amount of silver nitrate solution, $AgNO_3$(aq), is added to half-cell **A**? Choose from INCREASES, DECREASES or REMAINS THE SAME. (2)

[13]

QUESTION 15 (November 2019)

A standard electrochemical cell is set up using two standard half-cells, as shown in the diagram below.



15.1 State the energy conversion that takes place in this cell. (1)

15.2 What is the function of component **Q**? (1)

X is a metal. A voltmeter connected across the cell initially registers 1,49 V.

15.3 Use a calculation to identify metal **X**.
(Answer: -0,13 V; Pb) (5)

15.4 Write down the NAME or FORMULA of the reducing agent. (1)

15.5 The reading on the voltmeter becomes ZERO after this cell operates for several hours.

15.5.1 Give a reason for this reading by referring to the rates of oxidation and reduction half-reactions taking place in the cell. (1)

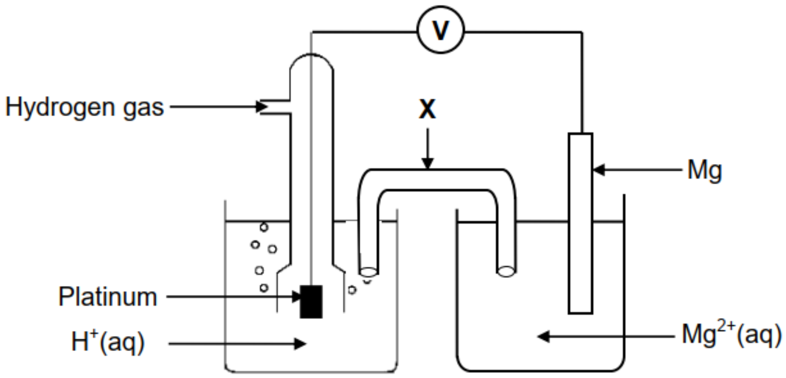
A silver nitrate solution, $AgNO_3$(aq), is NOW added to the chlorine half-cell and a precipitate forms.

15.5.2 How will the reading on the voltmeter be affected? (Choose from INCREASES, DECREASES or REMAINS the same) (1)

15.5.3 Use Le Chatelier's principle to explain the answer to QUESTION 15.5.2. (2)

[12]

QUESTION 16 (November 2020)
The electrochemical cell illustrated is set up under standard conditions.



16.1 Component **X** completes the circuit in the cell. State ONE other function of component **X**. (1)
16.2 Define the term *anode*. (2)
16.3 Identify the anode in this cell. (1)
16.4 Write down the:
16.4.1 Reduction half-reaction that takes place in this cell (2)
16.4.2 NAME or FORMULA of the reducing agent in this cell (1)
16.5 Calculate the initial voltmeter reading of this cell under standard conditions. *(Answer: 2,36 V)* (4)
16.6 The $Mg|Mg^{2+}$ half-cell is now replaced by a $Cu|Cu^{2+}$ half-cell. It is found that the direction of electron flow changes. Fully explain why there is a change in direction of electron flow by referring to the relative strengths of the reducing agents involved. (3)
[14]

QUESTION 17 (June 2021)
17.1 When a piece of sodium metal (Na) is added to water in a test tube, hydrogen gas is released. When phenolphthalein indicator is added to the test tube, the solution turns pink.
17.1.1 Define the term *reduction* in terms of electron transfer. (2)
17.1.2 Write down the reduction half-reaction. (2)
17.1.3 Write down the balanced equation for the reaction that takes place. (3)
17.1.4 Give a reason why the solution turns pink. (1)

When a piece of copper is added to water in a test tube, no reaction is observed.

17.1.5 Refer to the relative strengths of the REDUCING AGENTS to explain why no reaction is observed. (3)
17.2 Consider the cell notation below.

$$Pb(s) \mid Pb^{2+}(aq) \parallel Fe^{3+}(aq), Fe^{2+}(aq) \mid Pt(s)$$

17.2.1 What does the single line (|) in the cell notation above represent? (1)
17.2.2 State the energy conversion that takes place in this cell. (1)
17.1.3 Calculate the initial emf of the cell under standard conditions.
(Answer: 0,90 V) (4)
[17]

QUESTION 18 (September 2021)
A galvanic cell at standard conditions is represented by the cell notation below. **X** and **Y** are unknown electrodes.

$$X \mid Zn^{2+}(aq) \parallel Fe^{3+}(aq)\ ,\ Fe^{2+}(aq) \mid Y$$

18.1 Write down the NAME or FORMULA of:
18.1.1 Electrode **X** (1)
18.1.2 Electrode **Y** (1)
18.1.3 The oxidising agent (1)
18.2 Write down:
18.2.1 ONE function of electrode **Y** (1)
18.2.2 The half-reaction that takes place at electrode **Y** (2)
18.2.3 The net (overall) equation for the cell reaction that takes place in this cell (3)
18.3 Calculate the initial emf of this cell. *(Answer: 1,53 V)* (4)
18.4 How will the initial emf of the cell be affected when the concentration of the iron(III) ions is changed to 0,6 $mol{\cdot}dm^{-3}$? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)
[14]

QUESTION 19 (November 2021)
The table below shows two half-cells, **A** and **B**, used to assemble an electrochemical cell under STANDARD CONDITIONS.

Half-cell **A**	$Cu^{2+}(aq) \mid Cu(s)$
Half-cell **B**	$Ag^{+}(aq) \mid Ag(s)$

19.1 State the energy conversion that takes place in this cell. (1)
19.2 Calculate the mass of silver nitrate, $AgNO_3$, used to prepare 150 cm^3 of the electrolyte solution in half-cell **B**. *(Answer: 25,50 g)* (4)
19.3 Define the term *reducing agent*. (2)
19.4 Write down the:
19.4.1 NAME or FORMULA of the reducing agent (1)
19.4.2 Balanced equation for the reaction that takes place (3)
19.5 Calculate the initial emf of this cell. *(Answer: 0,46 V)* (4)
19.6 How will the emf of the cell be affected if the concentration of the copper ions in half-cell **A** increases? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)
[16]

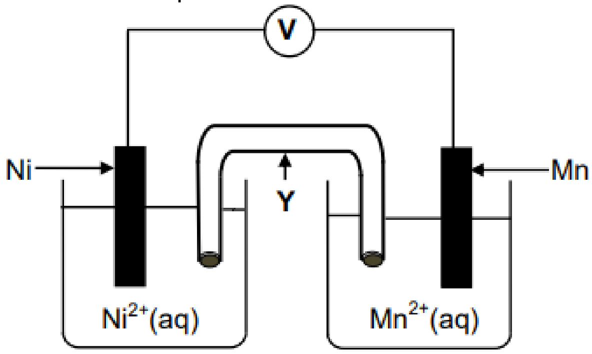
QUESTION 20 (June 2022)
20.1 An electrochemical cell is set up using an aluminium rod, Aℓ, and a gas **X**.
The initial emf measured under standard conditions is 2,89 V.

20.1.1 State the standard conditions under which this cell operates. (3)
20.1.2 Use a calculation to identify gas **X**.
(Answer: 1,23 V; Oxygen) (5)
20.1.3 Write down the FORMULA of the reducing agent in this cell. (1)
20.1.4 Write down the half-reaction that takes place at the cathode. (2)
20.1.5 Write down the cell notation for this cell. (3)
20.2 Which container, ZINC or COPPER, will be more suitable to store an aqueous solution of nickel ions, Ni^{2+}? Refer to the Table of Standard Reduction Potentials to fully explain the answer in terms of the relative strengths of reducing agents. (4)
[18]

QUESTION 21 (November 2022)
21.1 A piece of zinc (Zn) is placed in a test tube containing an acidified permanganate solution, $MnO^{-}(aq)$. After some time, it is found that a redox reaction has taken place.

Use the Table of Standard Reduction Potentials to answer the following questions:

21.1.1 Write down the NAME or FORMULA of the reducing agent. (1)
21.1.2 Refer to the relative strengths of the OXIDISING AGENTS to explain why a redox reaction has taken place. (3)
21.2 A standard electrochemical cell is set up as shown below.



21.2.1 Write down the function of component **Y**. (1)
21.2.2 In which direction will electrons flow in the external circuit? Choose from 'Ni to Mn' OR 'Mn to Ni'. (2)
21.2.3 Calculate the initial emf of this cell.
(Answer: 0,91 V) (4)
21.2.4 Write down the balanced equation for the net cell reaction taking place. (3)
21.2.5 The concentration of $Ni^{2+}(aq)$ is now increased.
Will the reading on the voltmeter INCREASE, DECREASE or REMAIN THE SAME? (1)
[15]

B ELECTROLYTIC CELLS

Electrolytic cells

TYPE OF ELECTROCHEMICAL CELL in which electrical energy is converted to chemical energy

Basic components:
- **Two electrodes**
- An **electrolyte** – solution/ melt that conducts electricity through the movement of ions
- A **source of direct current (DC)**

Electrolysis

PROCESS in which electrical energy is converted to chemical energy

Does not take part in reaction

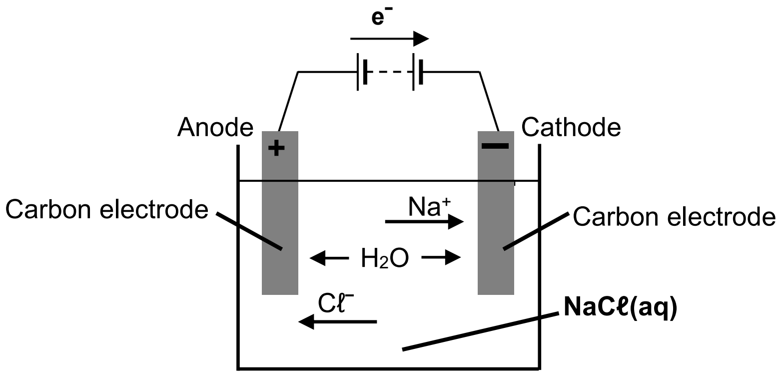
Using INERT electrodes

Takes part in reaction

Using ACTIVE electrodes

Electrolysis of a Concentrated Sodium Chloride Solution

1. Both electrodes are inert. (Pt or C)
2. Electrolyte: concentrated $NaC\ell(aq)$
3. H_2O is a stronger oxidising agent than Na^+ ions and will be reduced at the cathode.



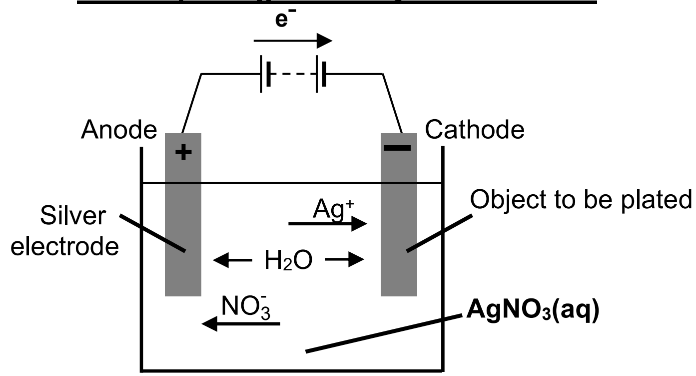
Oxidation: $2C\ell^- \rightarrow C\ell_2 + 2e^-$ Reduction: $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$

Cell reaction: $2H_2O(\ell) + 2C\ell^-(aq) \rightarrow H_2(g) + 2OH^-(aq) + C\ell_2(g)$

ELECTROPLATING

1. **Cathode:** Object to be plated (to be covered with another metal)
2. **Electrolyte:** Ions of metal used for plating (Solution must contain ions of the metal with which the object will be covered with.)
3. **Anode:** Metal with which object must be plated with (Anode made of same metal than the one the object will be covered with.)

Electroplating of an object with silver



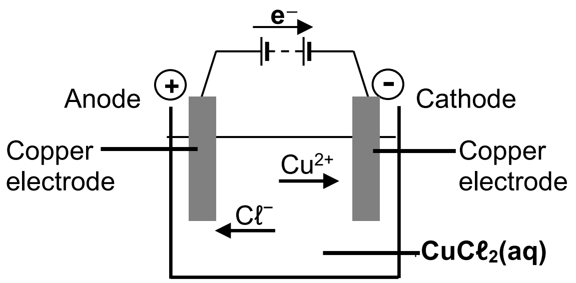
Oxidation: $Ag \rightarrow Ag^+ + e^-$ Reduction: $Ag^+ + e^- \rightarrow Ag$

Cell reaction: $Ag^+(aq) + Ag(s) \rightarrow Ag(s) + Ag^+(aq)$

Electrolysis of a concentrated copper(II) chloride solution

Using ACTIVE electrodes
Purification of copper

1. Both electrodes made of **copper (Cu)**
2. Electrolyte: Cu^{2+} solution



Oxidation: $Cu \rightarrow Cu^{2+} + 2e^-$ **Reduction:** $Cu^{2+} + 2e^- \rightarrow Cu$

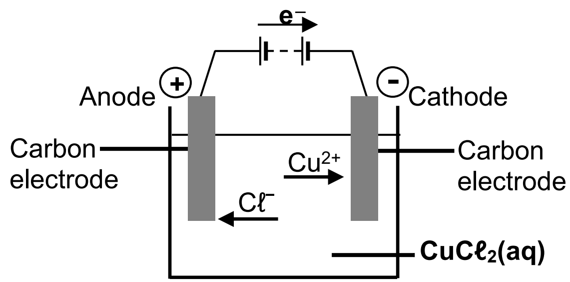
Cell reaction: $Cu(s) + Cu^{2+}(aq) \rightarrow Cu^{2+}(aq) + Cu(s)$

The positive Cu^{2+} ions move to cathode (**−** electrode) and gains electrons:
$Cu^{2+} + 2e^- \rightarrow Cu$ (reduction)

The negative $C\ell^-$ ions move to the anode (**+** electrode), an active Cu electrode.
Cu is a stronger reducing agent than $C\ell^-$ and therefore Cu will be oxidised to Cu^{2+}:
$Cu \rightarrow Cu^{2+} + 2e^-$ (oxidation)

Using INERT electrodes
Decomposition of $CuC\ell_2(aq)$

1. Both electrodes made of **carbon (C)**
2. Electrolyte: Cu^{2+} solution



Oxidation: $2C\ell^- \rightarrow C\ell_2 + 2e^-$ **Reduction:** $Cu^{2+} + 2e^- \rightarrow Cu$

Cell reaction: $2C\ell^-(aq) + Cu^{2+}(aq) \rightarrow C\ell_2(g) + Cu(s)$

The positive Cu^{2+} ions move to cathode (− electrode) and gains electrons: **$Cu^{2+} + 2e^- \rightarrow Cu$ (reduction)**

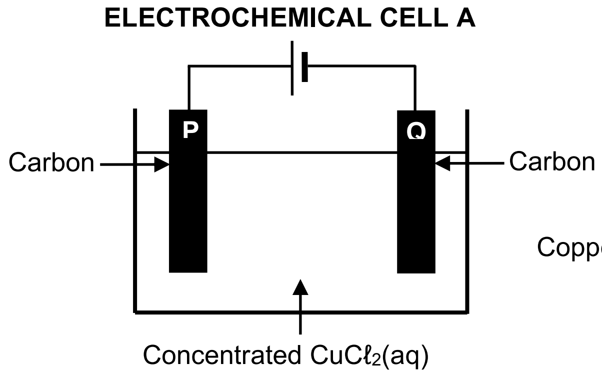
The negative $C\ell^-$ ions move to the anode (**+** electrode), an inactive carbon electrode, and loses electrons:
$2C\ell^- \rightarrow C\ell_2 + 2e^-$ (oxidation)

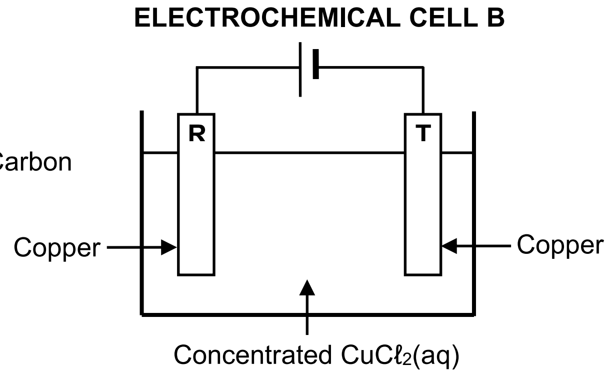
TERMS AND DEFINITIONS	
Electrolytic cell	A cell in which electrical energy is converted into chemical energy.
Anode	The electrode where oxidation takes place.
Cathode	The electrode where reduction takes place.
Electrolyte	A solution that conducts electricity through the movement of ions.
Electrolysis	The chemical process in which electrical energy is converted to chemical energy OR the use of electrical energy to produce a chemical change.
Electrodes	An electrical conductor used in a galvanic cell to make contact with a non-metallic part of the circuit e.g. the electrolyte.
Electroplating	The covering of an object with a metal by making it the cathode in an electrolytic cell.

TYPICAL QUESTIONS

QUESTION 1 (November 2014)

The simplified diagrams below represent two electrochemical cells, **A** and **B**.
A concentrated copper(**II**) chloride solution is used as electrolyte in both cells.





1.1 Are A and B ELECTROLYTIC or GALVANIC cells? (1)

1.2 Which of the electrodes (**P**, **Q**, **R** or **T**) will show a mass increase? Write down a half-reaction to motivate the answer. (4)

1.3 Write down the NAME or FORMULA of the product formed at:

1.3.1 Electrode **P** (1)

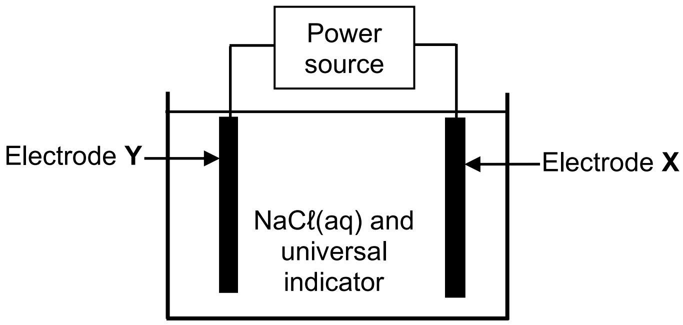
1.3.2 Electrode **R** (1)

1.4 Fully explain the answer to QUESTION 1.3.2 by referring to the relative strengths of the reducing agents involved. (3)

[10]

QUESTION 2 (March 2015)

The apparatus below is used to demonstrate the electrolysis of a concentrated sodium chloride solution. Both electrodes are made of carbon. A few drops of universal indicator are added to the electrolyte. The equation for the net cell reaction is: $2NaC\ell(aq) + 2H_2O(\ell) \rightarrow C\ell_2(g) + H_2(g) + 2NaOH(aq)$



Initially the solution has a green colour. Universal indicator becomes red in acidic solutions and purple in alkaline solutions.

2.1 Define the term *electrolyte*. (2)

When the power source is switched on, the colour of the electrolyte around electrode **Y** changes from green to purple.

2.2 Write down the half-reaction that takes place at electrode **Y**. (2)

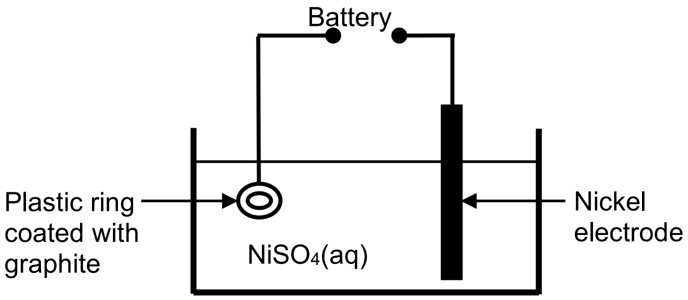
2.3 Write down the NAME or FORMULA of the gas released at electrode **X**. (1)

2.4 Refer to the Table of Standard Reduction Potentials to explain why hydrogen gas, and not sodium, is formed at the cathode of this cell. (2)

[7]

QUESTION 3 (June 2015)

The diagram shows a simplified electrolytic cell that can be used to electroplate a plastic ring with nickel.



Prior to electroplating the ring is covered with a graphite layer.

3.1 Define the term *electrolyte*. (2)

3.2 Give ONE reason why the plastic ring must be coated with graphite prior to electroplating. (1)

3.3 Write down the half-reaction that occurs at the plastic ring. (2)

3.4 Write down the NAME or FORMULA of the reducing agent in the cell. Give a reason for the answer. (2)

3.5 Which electrode, the RING or NICKEL, is the cathode? Give a reason for the answer. (2)

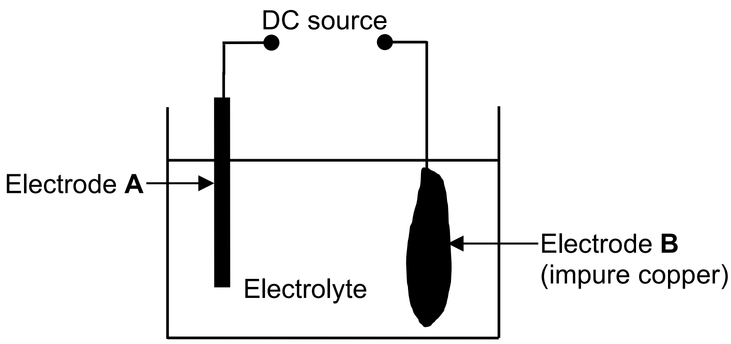
The nickel electrode is now replaced with a carbon rod.

3.6 How will the concentration of the electrolyte change during electroplating? Write down only INCREASES, DECREASES or NO CHANGE. Give a reason for the answer. (2)

[11]

QUESTION 4 (November 2015)

The simplified diagram represents an electrochemical cell used for the purification of copper.



4.1 Define the term *electrolysis*. (2)

4.2 Give a reason why a direct-current (DC) source is used in this experiment. (1)

4.3 Write down the half-reaction which takes place at electrode **A**. (2)

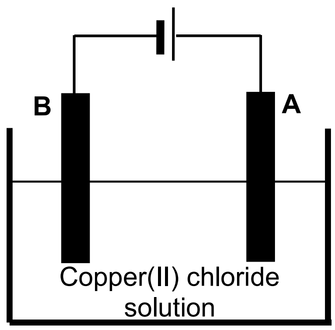
4.4 Due to small amounts of zinc impurities in the impure copper, the electrolyte becomes contaminated with Zn^{2+} ions. Refer to the attached Table of Standard Reduction Potentials to explain why the Zn^{2+} ions will not influence the purity of the copper obtained during this process. (3)

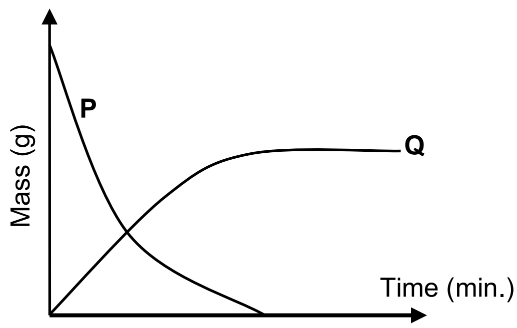
4.5 After the purification of the impure copper was completed, it was found that $2{,}85 \times 10^{-2}$ moles of copper were formed. The initial mass of electrode **B** was 2,0 g. Calculate the percentage of copper that was initially present in electrode **B**. *(Answer: 90,49%)* (4)

[12]

QUESTION 5 (March 2016)

The electrochemical cell below is set up to demonstrate the purification of copper. The graphs below show the change in mass of the electrodes whilst the cell is in operation.





5.1 Write down the type of electrochemical cell illustrated. (1)

5.2 Define a *reducing agent* in terms of electron transfer. (2)

5.3 Which graph represents the change in mass of electrode **A**? (1)

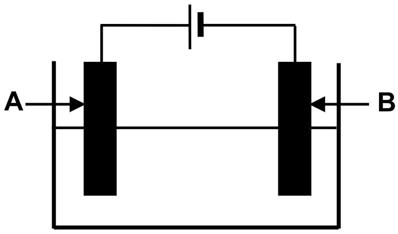
5.4 Write down the half-reaction that takes place at electrode **A**. (2)

5.5 Electrodes **A** and **B** are now replaced by graphite electrodes. It is observed that chlorine gas ($C\ell_2$) is released at one of the electrodes. At which electrode (**A** or **B**) is chlorine gas formed? Fully explain how it is formed. (3)

[9]

QUESTION 6 (June 2016)

The diagram below shows an electrochemical cell used to purify copper. <u>A solution that conducts electricity</u> is used in the cell.



6.1 Write down:

6.1.1 ONE word for the underlined phrase above the diagram (1)

6.1.2 The type of electrochemical cell illustrated above (1)

6.2 In which direction (from **A** to **B** or from **B** to **A**) will electrons flow in the external circuit? (1)

6.3 Which electrode (**A** or **B**) is the:

6.3.1 Cathode (1)

6.3.2 Impure copper (1)

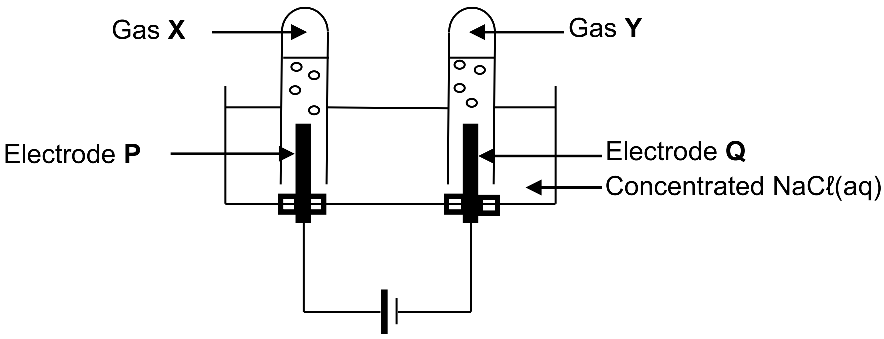
6.4 How will the mass of electrode A change as the reaction proceeds? Choose from INCREASES, DECREASES or REMAINS THE SAME. Give a reason for the answer. (2)

[7]

QUESTION 7 (November 2016)

In the electrochemical cell below, carbon electrodes are used during the electrolysis of a concentrated sodium chloride solution. The balanced equation for the net (overall) cell reaction is:

$$2H_2O(\ell) + 2C\ell^-(aq) \rightarrow C\ell_2(g) + H_2(g) + 2OH^-(aq)$$



7.1 Is the reaction EXOTHERMIC or ENDOTHERMIC? (1)

7.2 Is electrode **P** the ANODE or the CATHODE? Give a reason for the answer. (2)

7.3 Write down the NAME or FORMULA of:

7.3.1 Gas **X** (1)

7.3.2 Gas **Y** (1)

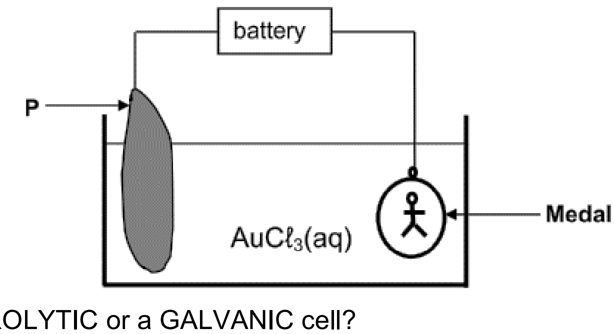
7.4 Write down the reduction half-reaction. (2)

7.5 Is the solution in the cell ACIDIC or ALKALINE (BASIC) after completion of the reaction? Give a reason for the answer. (2)

[9]

QUESTION 8 (June 2017)

The simplified diagram below represents a cell used to electroplate an iron medal with a thin layer of gold.



8.1 Is this an ELECTROLYTIC or a GALVANIC cell? (1)

8.2 Which electrode, **P** or the **Medal**, is the anode? (1)

8.3 Write down the:

8.3.1 Half-reaction that takes place at electrode **P** (2)

8.3.2 Oxidation number of gold (Au) in the electrolyte (1)

8.3.3 Energy change that takes place in this cell (1)

8.3.4 Visible change that occurs on electrode **P** after the cell functions for a while (1)

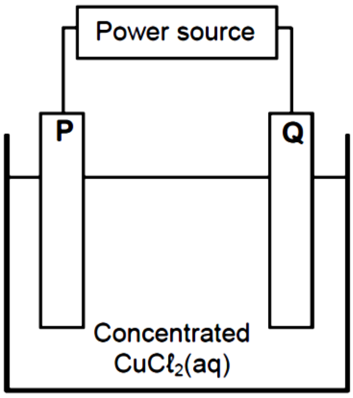
8.4 Besides improving appearance, state ONE other reason why the medal is electroplated. (1)

8.5 State ONE of the two possible changes that should be made to the cell above to electroplate the medal with silver instead of gold. (1)

[9]

QUESTION 9 (November 2017)

The simplified diagram represents an electrochemical cell used in the refining of copper. One of the electrodes consists of impure copper.



9.1 What type of power source, AC or DC, is used to drive the reaction in this cell? (1)

9.2 When an electric current passes through the $CuC\ell_2$(aq), the mass of electrode **P** increases. Is electrode **P** the CATHODE or the ANODE? Write down the relevant half-reaction to support the answer. (3)

9.3 The impure copper contains zinc impurities which are oxidised to zinc ions. Refer to the relative strengths of oxidising agents to explain why zinc ions will not influence the quality of the pure copper produced in this cell. (3)

9.4 Electrodes **P** and **Q** are now replaced by carbon electrodes.

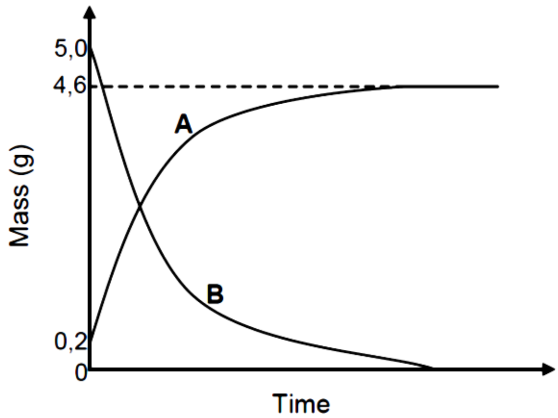
9.4.1 What will be observed at electrode **Q**? (1)

9.4.2 How will the concentration of the electrolyte change as the reaction proceeds? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

[9]

QUESTION 10 (March 2018)

The graph represents the changes in mass that occur at electrode **A** and electrode **B** in an electrolytic cell during the purification of copper.



10.1 Define *electrolysis*. (2)

10.2 Which graph, **A** or **B**, represents the change in mass of the anode during electrolysis? (1)

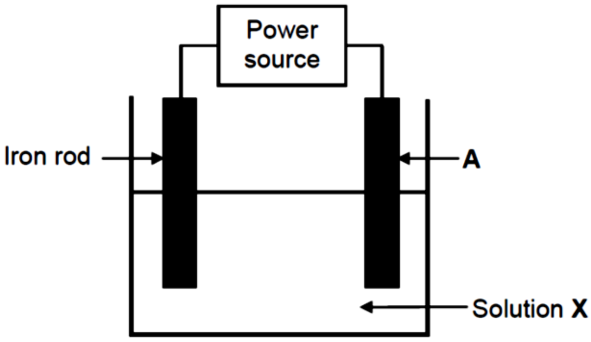
10.3 Write down the equation of the half-reaction which takes place at the cathode of this cell. (2)

10.4 Use the information in the graph and calculate the percentage purity of the impure copper.
(Answer: 88%) (4)

[9]

QUESTION 11 (June 2018)

The diagram below shows an electrolytic cell used to electroplate an iron rod with COPPER. Solution **X** is made up of an unknown NITRATE.



11.1 Solutions, such as solution **X**, are always used in electrochemical cells.

11.1.1 Write down the general term used to describe these solutions. (1)

11.1.2 What is the function of these solutions in electrochemical cells? (1)

11.2 Write down the FORMULA of solution **X**. (1)

11.3 Which electrode (**A** or **IRON ROD**) is the negative electrode? Give a reason for the answer. (2)

11.4 Write down the half-reaction that takes place at electrode **A**. (2)

11.5 Electrode **A** is now replaced by a silver rod without making any other changes to the cell. After a while, TWO metallic ions are found to be present in the solution.

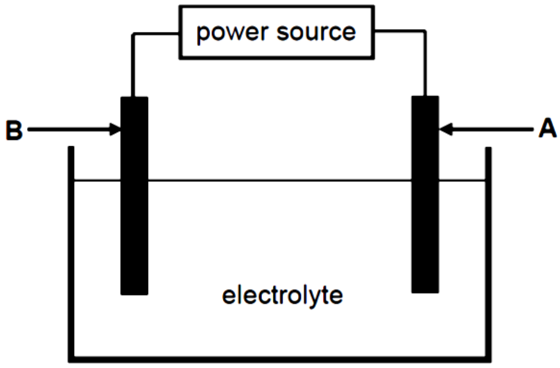
11.5.1 Name the TWO metallic ions present in the solution. (2)

11.5.2 Refer to the relative strengths of oxidising agents to explain which ONE of the two ions will preferably be involved in the plating process. (2)

[11]

QUESTION 12 (November 2018)

The electrolytic cell below is set up to obtain pure copper from a piece of impure copper. The impure copper contains other metals, such as platinum, iron, cobalt, silver and nickel. The cell potential of the power source is adjusted so that only copper is deposited on electrode **B**.



12.1 Define an *electrolytic cell*. (2)

12.2 Write down the FORMULA of a suitable electrolyte for this cell. (1)

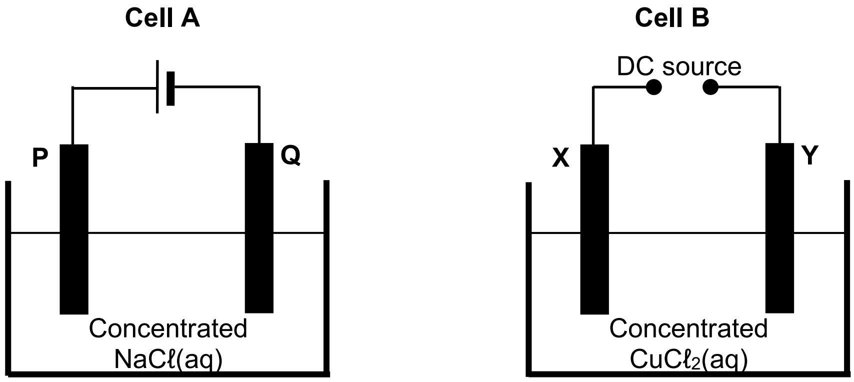
12.3 Which electrode (**A** or **B**) is the cathode? Write down the relevant half-reaction taking place at this electrode. (3)

12.4 Sludge forms below one of the electrodes while the cell above is in operation. Which of the metals, PLATINUM, IRON, COBALT, SILVER or NICKEL, will be present in the sludge? (2)

[8]

QUESTION 13 (June 2019)

The diagrams below represent two electrochemical cells. **P**, **Q**, **X** and **Y** are carbon electrodes.



When cell **B** is functioning, the mass of electrode **X** increases.

13.1 What type of electrochemical cell, GALVANIC or ELECTROLYTIC, is illustrated above? (1)

13.2 Write down the half-reaction that takes place at electrode **Q**. (2)

13.3 The products formed in the two cells are compared.

13.3.1 Name ONE substance that is produced in BOTH cells. (1)

13.3.2 Write down the LETTERS of the TWO electrodes where this product is formed. Choose from **P**, **Q**, **X** and **Y**. (2)

13.4 Is electrode **X** the CATHODE or the ANODE? Give a reason for the answer. (2)

13.5 Write down the net (overall) cell reaction that takes place in cell **B**. (3)

[11]

QUESTION 14 (November 2019)

Chlorine is produced industrially by the electrolysis of a concentrated sodium chloride solution, NaCℓ(aq). The balanced equation for the net (overall) cell reaction is as follows:

$$2NaC\ell(aq) + 2H_2O(\ell) \rightarrow H_2(g) + 2NaOH(aq) + C\ell_2(g)$$

14.1 Define the term electrolysis. (2)

14.2 For the above reaction, write down the:

14.2.1 Half-reaction that takes place at the cathode (2)

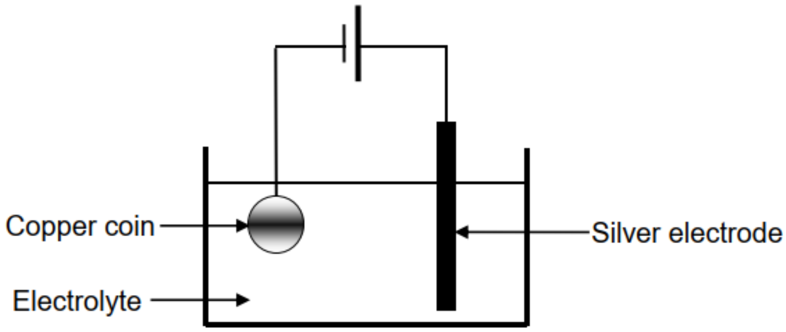
14.2.2 NAME or FORMULA of the oxidising agent (1)

14.3 Refer to the Table of Standard Reduction Potentials to explain why sodium ions are not reduced during this process. (3)

[8]

QUESTION 15 (November 2020)

The simplified diagram below represents an electrolytic cell used to electroplate a copper (Cu) coin with silver (Ag).



15.1 Define the term *electrolysis*. (2)

15.2 Which component in the diagram indicates that this is an electrolytic cell? (1)

15.3 Write down the NAME or FORMULA of the electrolyte. (1)

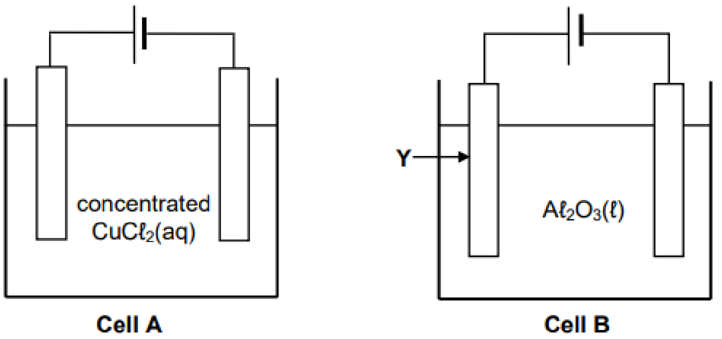
15.4 How will the concentration of the electrolyte change during electroplating? Choose from INCREASES, DECREASES or REMAINS THE SAME. Give a reason for the answer. (2)

15.5 Write down the balanced equation of the half-reaction that takes place at the silver electrode. (2)

[8]

QUESTION 16 (June 2021)

The diagrams below show two electrochemical cells in which carbon electrodes are used. In cell **A**, concentrated copper (II) chloride solution is used and in cell **B**, liquid aluminium oxide is used.



16.1 What type of electrochemical cell, ELECTROLYTIC or GALVANIC, is shown above? Give a reason for the answer. (2)

16.2 Write down the:

16.2.1 Half-reaction that takes place at the anode of cell **A** (2)

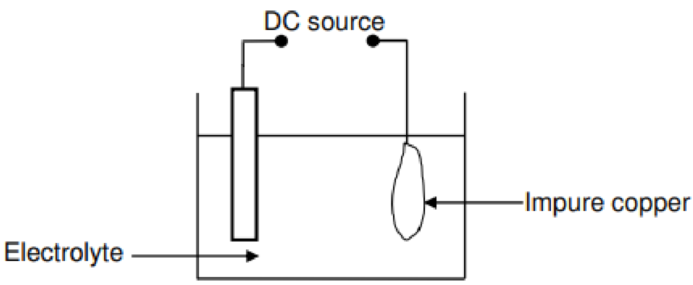
16.2.2 Half-reaction that takes place at the cathode of cell **B** (2)

16.2.3 NAME or FORMULA of the product formed at the cathode of cell **A** (1)

[7]

QUESTION 17 (September 2021)

The simplified diagram below represents an electrochemical cell used for the purification of copper. The impure copper contains small amounts of silver (Ag) and zinc (Zn) as the only impurities.



17.1 Define the term *electrolysis*. (2)

17.2 Write down the NAME or FORMULA of TWO positive ions present in the electrolyte. (2)

17.3 Write down the half-reaction that takes place at the cathode. (2)

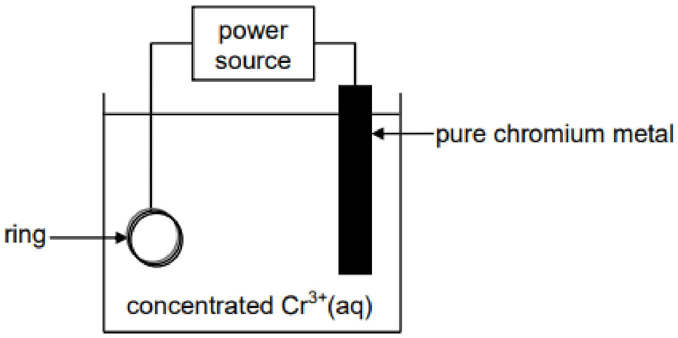
17.4 Refer to the Table of Standard Reduction Potentials and explain why the purified copper will NOT contain any zinc. (3)

17.5 Calculate the maximum mass of Cu formed if 0,6 moles of electrons are transferred.
(Answer: 19,05 g) (3)

[12]

QUESTION 18 (November 2021)

The diagram below shows a simplified electrolytic cell used to electroplate a ring.



18.1 Define the term electrolyte. (2)

18.2 Is the pure chromium metal the ANODE or the CATHODE of the cell? Give a reason for the answer. (2)

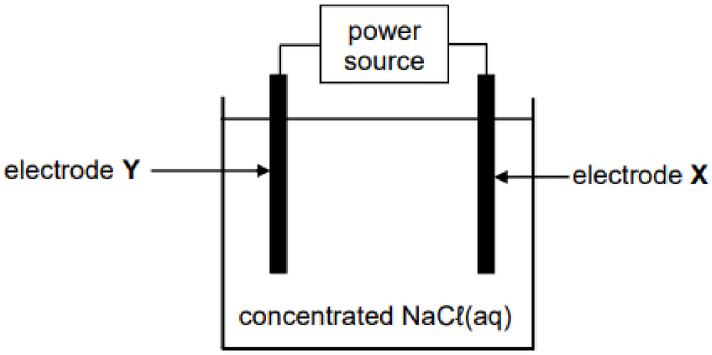
18.3 Write down the half-reaction that takes place at the ring. (2)

18.4 Calculate the total charge transferred when the mass of the pure chromium changes by 2 g.
(Answer: 11 076,8 to 11 580 C) (5)

[11]

QUESTION 19 (June 2022)

The simplified diagram on the right represents an electrochemical cell used for the electrolysis of a concentrated sodium chloride solution, NaCℓ(aq). **X** and **Y** are carbon electrodes.



19.1 Define the term *electrolysis*. (2)

19.2 Chlorine gas, $C\ell_2(g)$, is released at electrode **X**. Write down the:

19.2.1 Letter (**X** or **Y**) of the electrode where oxidation takes place (1)

19.2.2 Half-reaction that takes place at electrode **Y** (2)

19.2.3 Direction in which electrons flow in the external circuit. Choose from **X** to **Y** OR **Y** to **X**. (1)

19.2.4 Balanced equation for the net (overall) cell reaction that takes place in the cell (3)

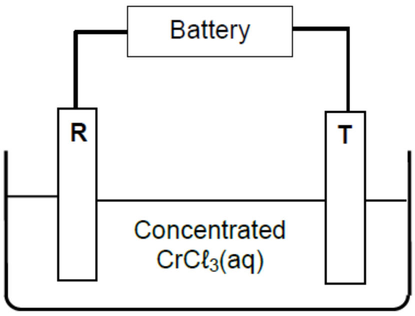
19.3 How will the pH of the electrolyte change during the reaction? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

19.4 Give a reason for the answer to QUESTION 19.3. (1)

[11]

QUESTION 20 (November 2022)

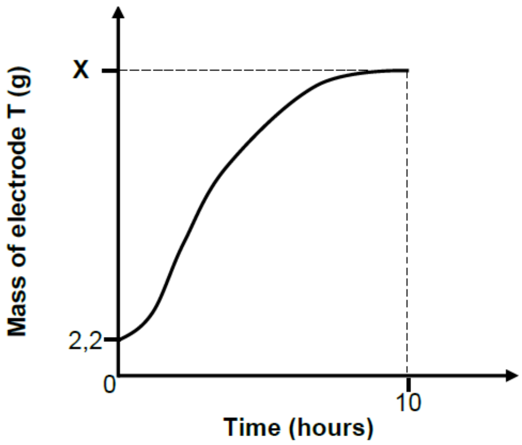
The diagram below represents a simplified cell used for the electrolysis of CONCENTRATED chromium(**III**) chloride, $CrC\ell_3(aq)$. Electrodes **R** and **T** are made of carbon.



The net cell reaction is: $2CrC\ell_3(aq) \rightarrow 2Cr(s) + 3C\ell_2(g)$

20.1 Define the term electrolysis. (2)

20.2 The graph below, NOT drawn to scale, represents the changes in the mass of electrode **T** during electrolysis.



20.2.1 Write down the half-reaction that takes place at electrode **T**. (2)

A current of 2,5 A passes through the cell for 10 hours. Calculate the:

20.2.2 Total charge that flows through the cell during this time *(Answer: 9 x 10^4 C)* (3)

20.2.3 Value of **X** as shown on the graph *(Answer: 18,32 to 18,40 g)* (6)

[13]