



**NAMIBIA UNIVERSITY
OF SCIENCE AND TECHNOLOGY**

FACULTY OF ENGINEERING AND THE BUILT ENVIRONMENT

InSTEM

QUALIFICATION: INTRODUCTION TO SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS	
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COURSE CODE: ICH402S	COURSE NAME: INTRODUCTION TO CHEMISTRY B
SESSION: JANUARY 2023	PAPER: N/A
DURATION: 3 HOURS	MARKS: 100

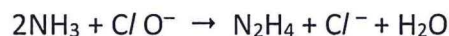
SECOND OPPORTUNITY/SUPPLEMENTARY EXAMINATION PAPER	
EXAMINER(S)	Ms Elvira van Wyk Mr Victor Nwagbara
MODERATOR:	Dr Kayini Chigayo

INSTRUCTIONS
<ol style="list-style-type: none">1. Answer all questions.2. Write all the answers in ink.3. No books, notes, correction fluid (Tippex) or cell phones allowed.4. Pocket calculators are allowed.5. You are not allowed to borrow or lend any equipment or stationary.6. Periodic Table on page 9

THIS EXAMINATION PAPER CONSISTS OF 10 PAGES (Excluding this front page)

Question 1**[10]**

1.1 Chlorate(I) ions undergo the following reaction under aqueous conditions.



A series of experiments was carried out at different concentrations of ClO^- and NH_3 .

The table below shows the results obtained.

experiment	$[\text{ClO}^-] / \text{mol dm}^{-3}$	$[\text{NH}_3] / \text{mol dm}^{-3}$	initial rate / $\text{mol dm}^{-3} \text{s}^{-1}$
1	0.200	0.200	1.025
2	0.400	0.200	2.05
3	0.400	0.400	8.20

1.1.1 Use the data in the table to determine the order with respect to each reactant, ClO^- and NH_3 .

Show your reasoning.

(2)

1.1.2 Write the rate equation for this reaction.

(1)

1.1.3 Use the results of experiment 1 to calculate the rate constant, k , for this reaction. Include the units of k .

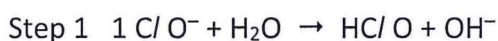
(2)

1.2 In another experiment, the reaction between chlorate(I) ions and iodide ions in aqueous alkali was investigated. A solution of iodide ions in aqueous alkali was added to a large excess of chlorate(I) ions and $[\text{I}^-]$ was measured at regular intervals.

1.2.1 Describe how the results of this experiment can be used to confirm that the reaction is first-order with respect to $[\text{I}^-]$

(2)

1.2.2 A three-step mechanism for this reaction is shown.



Use this mechanism to deduce the overall equation for this reaction.

(1)

1.2.3 In the three-step mechanism in 1.2.2, identify a step that involves a redox reaction. Explain your answer.

(2)

Question 2**[14]**

Entropy changes and free energy changes can be used to predict the feasibility of processes.

2.1 Three processes are given below.

For each process, predict and explain whether the entropy change, ΔS , would be positive or negative.

- The melting of iron.
- The reaction of magnesium with dilute sulfuric acid.
- The complete combustion of ethane: $2\text{C}_2\text{H}_6(\text{g}) + 7\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l})$ (3)

2.2 Ammonia can be oxidised as shown in the equation below.



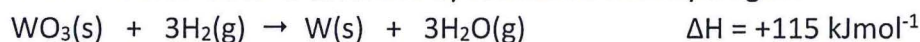
At 450°C , $\Delta H = -907 \text{ kJ mol}^{-1}$ and $\Delta G = -1041 \text{ kJ mol}^{-1}$. Calculate the standard entropy change, ΔS , in $\text{J K}^{-1} \text{ mol}^{-1}$, for this reaction.

Show all your working. (4)

2.3 A reaction is not feasible at low temperatures but is feasible at high temperatures. Deduce the signs of ΔH and ΔS for the reaction and explain why the feasibility changes with temperature. (3)

2.4 The metal tungsten is obtained on a large scale from its main ore, wolframite. Wolframite contains tungsten(VI) oxide, WO_3 .

Tungsten is extracted from wolframite by reduction with hydrogen:



Standard entropies are given in the table below.

Substance	$\text{WO}_3(\text{s})$	$\text{H}_2(\text{g})$	$\text{W}(\text{s})$	$\text{H}_2\text{O}(\text{g})$
$S^\ominus/\text{JK}^{-1}\text{mol}^{-1}$	76	131	33	189

2.4.1 Calculate the free energy change, ΔG , in kJ mol^{-1} , for this reaction at 25°C . (2)

2.4.2 Calculate the minimum temperature, in K, at which this reaction becomes feasible. (Show your working) (2)

Question 3**[21]**

This question is about acids, bases and buffers solutions.

- 3.1 Ethanoic acid, CH₃COOH, and propanoic acid, C₂H₅COOH, are weak Brønsted–Lowry acids.

The acid dissociation constants, K_a , of the two acids are shown below.

Acid	$K_a/\text{mol dm}^{-3}$
CH ₃ COOH	1.70×10^{-5}
C ₂ H ₅ COOH	1.30×10^{-5}

- 3.1.1 Explain the term *weak acid*. (1)

- 3.1.2 Write the expression for the acid dissociation constant, K_a , of ethanoic acid. (1)

- 3.1.3 Calculate the pH of a $2.85 \times 10^{-2} \text{ mol dm}^{-3}$ solution of C₂H₅COOH.

Give your answer to **two** decimal places. (2)

- 3.1.4 Ethanoic acid is mixed with propanoic acid. An acid-base equilibrium is set up.

Copy and complete the equation for the equilibrium.

Label the conjugate acid-base pairs using the labels **acid 1**, **base 1**, **acid 2**, **base 2**.



- 3.2 Barium hydroxide, Ba(OH)₂, is a strong Brønsted–Lowry base.

A student prepares 250.0 cm³ of 0.1250 mol dm⁻³ barium hydroxide.

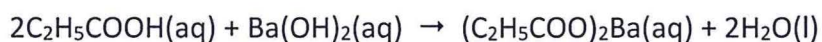
- 3.2.1 Explain what is meant by the term *Brønsted–Lowry base*. (1)

- 3.2.2 Calculate the mass of Ba(OH)₂ that the student would need to weigh to **two** decimal places to prepare 250.0 cm³ of 0.1250 mol dm⁻³ Ba(OH)₂. (3)

- 3.2.3 Calculate the pH of a 0.1250 mol dm⁻³ solution of Ba(OH)₂.
Give your answer to **two** decimal places. (3)

- 3.3 The student attempts to prepare a buffer solution by mixing 200 cm³ of 0.324 mol dm⁻³ C₂H₅COOH with 100 cm³ of the 0.1250 mol dm⁻³ Ba(OH)₂ prepared in 3.2.

The equation for the reaction that takes place is shown below.



Explain whether the student was successful in preparing a buffer solution.

Include all reasoning and any relevant calculations.

(3)

- 3.4 Blood contains a mixture of carbonic acid, H₂CO₃, and hydrogen carbonate ions, HCO₃⁻.

Explain how the carbonic acid–hydrogen carbonate mixture acts as a buffer.

In your answer include the equation for the equilibrium in this buffer solution and explain how this equilibrium system is able to control blood pH

(5)

Question 4

[12]

- 4.1 20.0 cm³ of 0.100 mol dm⁻³ NaOH were slowly added to a 10.0 cm³ sample of 0.100 mol dm⁻³ ethanoic acid, and the pH was measured throughout the addition.

4.1.1 Calculate the number of moles of NaOH remaining at the end of the addition.

(2)

4.1.2 Calculate the [OH⁻] at the end of the addition.

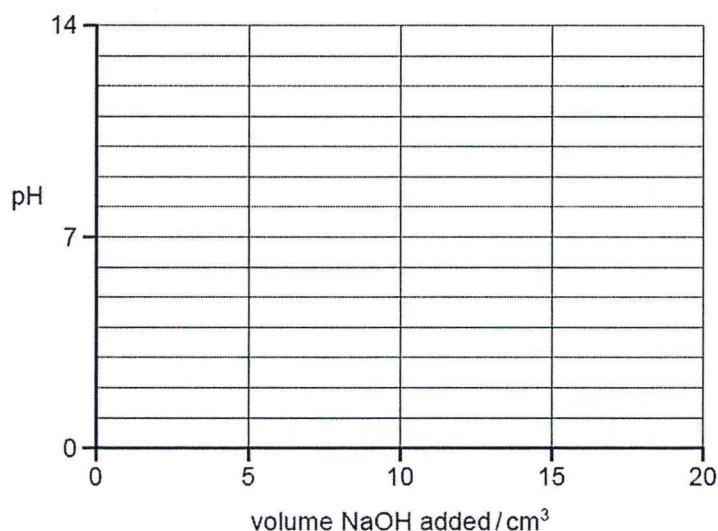
(3)

4.1.3 Using the expression $K_w = [\text{H}^+][\text{OH}^-]$ and your value in 4.1.2, calculate [H⁺] and the pH of the solution at the end of the addition.

(3)

- 4.2 Draw similar axes as below in your answer book, sketch how the pH will change during the addition of a total of 20.0 cm³ of 0.100 mol dm⁻³ NaOH. Mark clearly where the endpoint occurs.

(3)



4.3 From the following list of indicators, which one is most suitable for this titration

Indicator	pH
Malachite green	0 - 1
Thymol blue	1 - 2
Bromophenol blue	3 - 4
Phenolphthalein	9 - 10

(1)

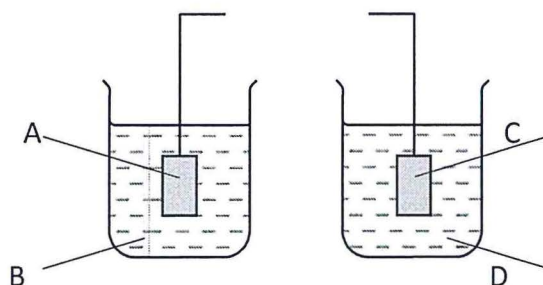
Question 5

[17]

5.1.1 Define the term standard cell potential, E_{cell}° .

(1)

The following incomplete diagram shows the apparatus that can be used to measure the E_{cell}° for a cell composed of the Fe^{3+} / Fe^{2+} and Ag^{+} / Ag half-cells.



5.1.2 Redraw and complete the diagram, labelling the components you add.

(1)

5.1.3 Identify the components A-D.

(4)

5.2.1 Use E° values provided to write an equation for the cell reaction that takes place if the two electrodes in 5.1.1 are connected by a wire and the circuit is completed.

(1)

Standard electrode potential and redox potentials, E° at 298 K (25 oC)	E° / V
$Ag^{+} + e^{-} \rightleftharpoons Ag$	+0.80
$Fe^{3+} + e^{-} \rightleftharpoons Fe^{2+}$	+0.77
$Fe^{2+} + 2e^{-} \rightleftharpoons Fe$	-0.44
$Fe^{3+} + 3e^{-} \rightleftharpoons Fe$	-0.04

5.2.2 Another electrochemical cell was set up using $0.31 \text{ mol dm}^{-3} \text{ Ag}^+(\text{aq})$ instead of the standard Ag solution.

Use the Nernst equation, $E = E^\circ + 0.059 \log [\text{Ag}^+(\text{aq})]$, and the relevant E° values to calculate the new E_{cell} in this experiment. (2)

5.3.1 Write an expression for the solubility product, K_{sp} , of PbCl_2 . (1)

5.3.2 Calculate the value of K_{sp} , including units. (2)

5.4 The behaviour of PbI_2 and SnCl_2 towards reducing agents are similar, but their behaviour towards oxidising agents are very different.

Table of some electrode potentials

Half-reaction	Electrode potential (V)
$\text{Zn}^{2+} + 2 \text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$\text{Fe}^{2+} + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
$\text{Pb}^{2+} + 2\text{e}^- \rightleftharpoons \text{Pb}$	-0.13
$\text{Sn}^{2+} + 2\text{e}^- \rightleftharpoons \text{Sn}$	-0.14
$2\text{H}^+ + 2\text{e}^- \rightleftharpoons \text{H}_2$	0.00
$\text{Sn}^{4+} + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}$	0.15
$2\text{I}^- + 2\text{e}^- \rightleftharpoons \text{I}_2$	0.54
$\text{Ag}^+ + \text{e}^- \rightleftharpoons \text{Ag}$	0.80
$\text{Br}_2(\text{l}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^-$	1.07
$2\text{Cl}^- + 2\text{e}^- \rightleftharpoons \text{Cl}_2$	1.36
$\text{Pb}^{4+} + 2\text{e}^- \rightleftharpoons \text{Pb}^{2+}$	1.69

5.4.1 Illustrate this comparison by quoting and comparing relevant E° values shown in the table above for the two metals and their ions. Explain what the relative E° values mean in terms of the ease of oxidation or reduction of these compounds. (3)

5.4.2 Writing a balanced molecular or ionic equation in each case, suggest a reagent to carry out each of the following reactions.

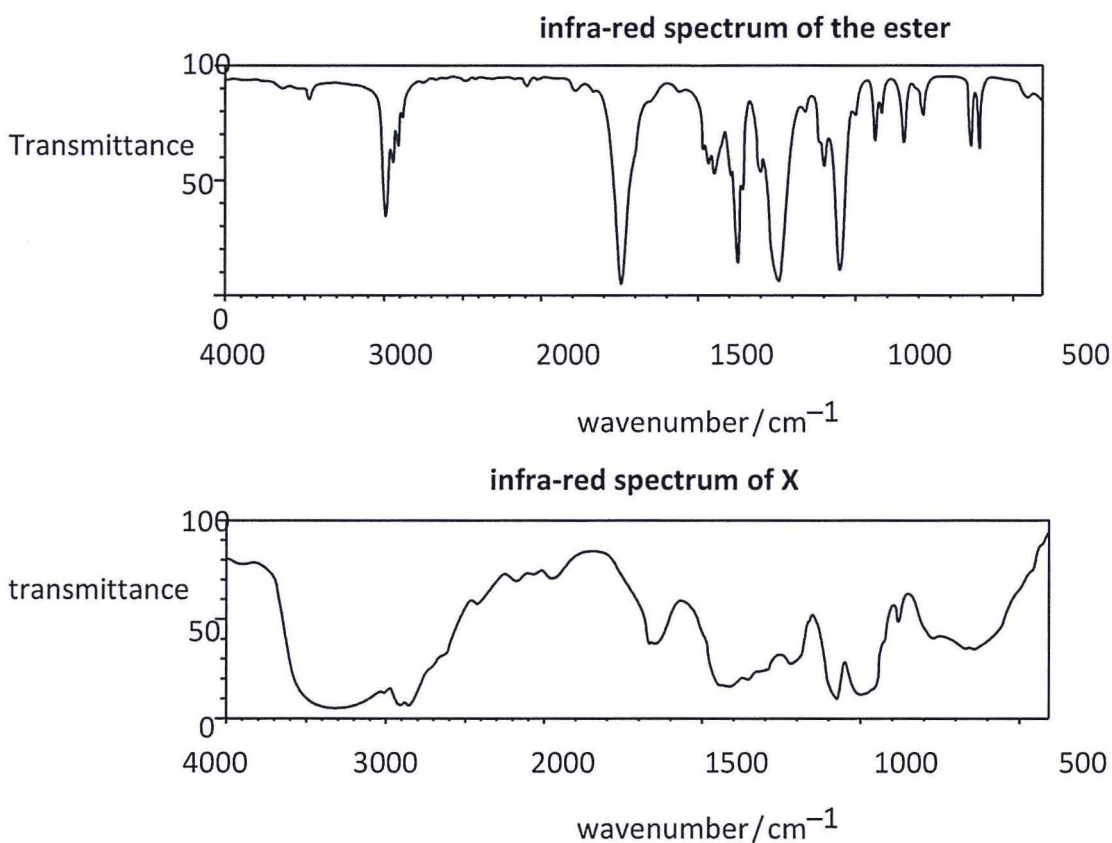
$\text{Pb}^{2+} \rightarrow \text{Pb}(\text{s})$ and $\text{Sn}^{4+} \rightarrow \text{Sn}^{2+}$ (2)

Question 6**[21]**

Allyl bromide, $\text{CH}_2=\text{CHCH}_2\text{Br}$, is used in the production of polymers.

- 6.1 Part of the C=C double bond in allyl bromide is called a π -bond. Draw a labelled diagram to show the formation of the π -bond. (2)
- 6.2 Allyl bromide is a member of a homologous series. Compounds in this series have the same general formula
- 6.2.1 What is meant by the term homologous series? (2)
- 6.2.2 What is the general formula of the homologous series that has allyl bromide as a member? (1)
- 6.2.3 Give the systematic name for allyl bromide. (1)
- 6.3 Reaction mechanisms use curly arrow and can involve electrophiles and nucleophiles.
- 6.3.1 What does a curly arrow represent in mechanisms? (1)
- 6.3.2 What is meant by the term nucleophile? (1)
- 6.4 Allyl bromide, $\text{CH}_2=\text{CHCH}_2\text{Br}$, reacts with bromine, Br_2 .
Outline the mechanism of this reaction.
Include curly arrows, relevant dipoles and the intermediate and final product(s). (4)
- 6.5 This part of the question is about molecules with molecular formula $\text{C}_4\text{H}_8\text{O}_2$.
- 6.5.1 Give the structural formulae of the pair of chain isomers with the formula $\text{C}_4\text{H}_8\text{O}_2$ that are carboxylic acids. (2)
- 6.5.2.1 Give the structural formulae of a pair of positional isomers with the formula $\text{C}_4\text{H}_8\text{O}_2$ that are esters. (2)
- 6.5.2.2 Give the reagents and conditions needed to produce one of your esters in 6.5.2.1 (2)

6.5.3 The infra-red spectra of one of the esters and of another isomer, X, are shown. X decolourises bromine water and is not an ester or an acid.



Explain the differences between these two spectra, with particular reference to the peaks with wavenumbers above 1500 cm^{-1} .

Absorption frequencies are given on the last page of this paper. (3)

Question 7 [5]

7.1 Write the equations for the following decay processes:

The beta decay of uranium -237 (1)

7.2 A chemist determines that a sample of petrified wood has a carbon-14 decay rate of 6.00 counts per minute per gram. What is the age of the piece of wood in years? The decay rate of carbon-14 in fresh wood today is 13.6 counts per minute per gram, and the half life of carbon-14 is 5730 years. (4)

The Periodic Table of the Elements

1	2											3	4	5	6	7	0		
																		(18)	
																		4.0 He helium 2	
(1)	(2)	Key										(13)	(14)	(15)	(16)	(17)			
6.9 Li lithium 3	9.0 Be beryllium 4	relative atomic mass symbol name atomic (proton) number										10.8 B boron 5	12.0 C carbon 6	14.0 N nitrogen 7	16.0 O oxygen 8	19.0 F fluorine 9	20.2 Ne neon 10		
23.0 Na sodium 11	24.3 Mg magnesium 12	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	27.0 Al aluminium 13	28.1 Si silicon 14	31.0 P phosphorus 15	32.1 S sulfur 16	35.5 Cl chlorine 17	39.9 Ar argon 18		
39.1 K potassium 19	40.1 Ca calcium 20	45.0 Sc scandium 21	47.9 Ti titanium 22	50.9 V vanadium 23	52.0 Cr chromium 24	54.9 Mn manganese 25	55.8 Fe iron 26	58.9 Co cobalt 27	58.7 Ni nickel 28	63.5 Cu copper 29	65.4 Zn zinc 30	69.7 Ga gallium 31	72.8 Ge germanium 32	74.9 As arsenic 33	79.0 Se selenium 34	79.9 Br bromine 35	83.8 Kr krypton 36		
85.5 Rb rubidium 37	87.6 Sr strontium 38	88.9 Y yttrium 39	91.2 Zr zirconium 40	92.9 Nb niobium 41	98.0 Mo molybdenum 42	[97] Tc technetium 43	101.1 Ru ruthenium 44	102.9 Rh rhodium 45	108.4 Pd palladium 46	107.9 Ag silver 47	112.4 Cd cadmium 48	114.8 In indium 49	118.7 Sn tin 50	121.8 Sb antimony 51	127.6 Te tellurium 52	128.9 I iodine 53	131.3 Xe xenon 54		
132.9 Cs caesium 55	137.3 Ba barium 56	138.9 La * lanthanum 57	178.5 Hf hafnium 72	180.9 Ta tantalum 73	183.8 W tungsten 74	186.2 Re rhenium 75	190.2 Os osmium 76	192.2 Ir iridium 77	195.1 Pt platinum 78	197.0 Au gold 79	200.6 Hg mercury 80	204.4 Tl thallium 81	207.2 Pb lead 82	209.0 Bi bismuth 83	[209] Po polonium 84	[210] At astatine 85	[222] Rn radon 86		
[223] Fr francium 87	[226] Ra radium 88	[227] Ac † actinium 89	[267] Rf rutherfordium 104	[270] Db dubnium 105	[269] Sg seaborgium 106	[270] Bh bohrium 107	[270] Hs hassium 108	[278] Mt meitnerium 109	[281] Ds darmstadtium 110	[281] Rg roentgenium 111	[285] Cn copernicium 112	[286] Nh nihonium 113	[289] Fl flerovium 114	[289] Mc moscovium 115	[293] Lv livermorium 116	[294] Ts tennessine 117	[294] Og oganesson 118		

* 58 – 71 Lanthanides

† 90 – 103 Actinides

140.1 Ce cerium 58	140.9 Pr praseodymium 59	144.2 Nd neodymium 60	[145] Pm promethium 61	150.4 Sm samarium 62	152.0 Eu europium 63	157.3 Gd gadolinium 64	158.9 Tb terbium 65	162.5 Dy dysprosium 66	164.9 Ho holmium 67	167.3 Er erbium 68	168.9 Tm thulium 69	173.0 Yb ytterbium 70	175.0 Lu lutetium 71
232.0 Th thorium 90	231.0 Pa protactinium 91	238.0 U uranium 92	[237] Np neptunium 93	[244] Pu plutonium 94	[243] Am americium 95	[247] Cm curium 96	[247] Bk berkelium 97	[251] Cf californium 98	[252] Es einsteinium 99	[257] Fm fermium 100	[258] Md mendelevium 101	[259] No nobelium 102	[262] Lr lawrencium 103

Characteristic infrared absorption frequencies for some selected bonds

Bond	Functional groups containing the bond	Characteristic IR absorption range (in wavenumbers)/ cm^{-1}
C-O	Hydroxy, ester	1040-1300
C=C	Aromatic compound, alkene	1500-1680
C=O	Amide Carbonyl, carboxyl ester	1640-1690 1670-1740 1710-1750
C≡N	nitrile	2200-2250
C-H	alkane	2850-2950
N-H	Amine	3300-3000
O-H	Carboxyl hydroxy	2500-3000 3200-3600

