Student Name:……………………………

2021 Higher School Certificate
Trial Examination

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- NESA-approved calculators may be used
- Three data sheets and a Periodic Table are provided at the back of this paper

Total marks: 100

Section I – 20 marks
- Attempt Questions 1-20
- Allow about 35 minutes for this section

Section II – 80 marks
- Attempt Questions 21-29
- Allow about 2 hours and 25 minutes for this section

CHEMTR21_EXAM

Section I – 20 marks
Attempt Questions 1-20
Allow about 35 minutes for this section

Use the multiple-choice answer sheet provided for Questions 1-20

Select the alternative A, B, C or D that best answers the question. Fill in the response oval completely.

Sample 2 + 4 = A. 2 B. 6 C. 8 D. 9

A B C D

If you think you have made a mistake, put a cross through the incorrect answer and fill in the new answer.

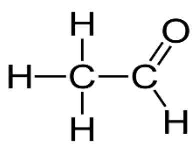
A B C D

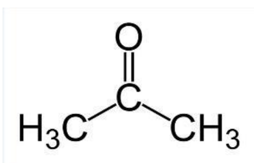
If you have changed your mind and have crossed out what you consider to be the correct answer, then indicate this by writing the word *correct* and drawing an arrow as follows:

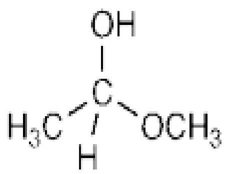
correct

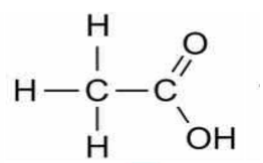
A B C D

1 Which of the following organic compounds is classified as a ketone?

A. 

B. 

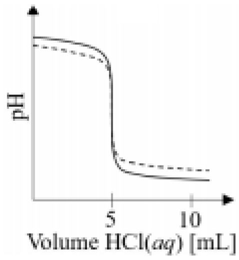
C. 

D. 

2 When 0.100 M HCl was added to a 10.0 mL sample of aqueous NaOH, it generated the titration curve shown as a solid line.

If the same number of moles of NaOH, but initially at a volume of 20.0 mL, were titrated with 0.100 M HCl, which of the dashed curves would best describe this new titration?

A.



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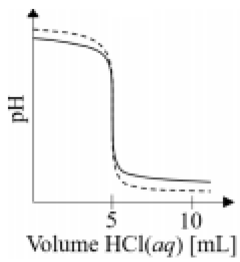
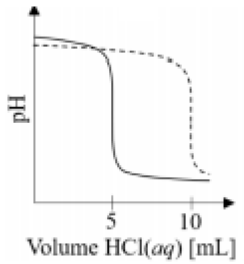
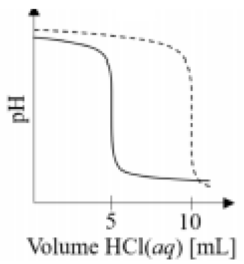


C.



D.



3 An understanding of Le Chatelier's Principle is useful in the chemical industry. The prediction that can be made using this principle is the effect of

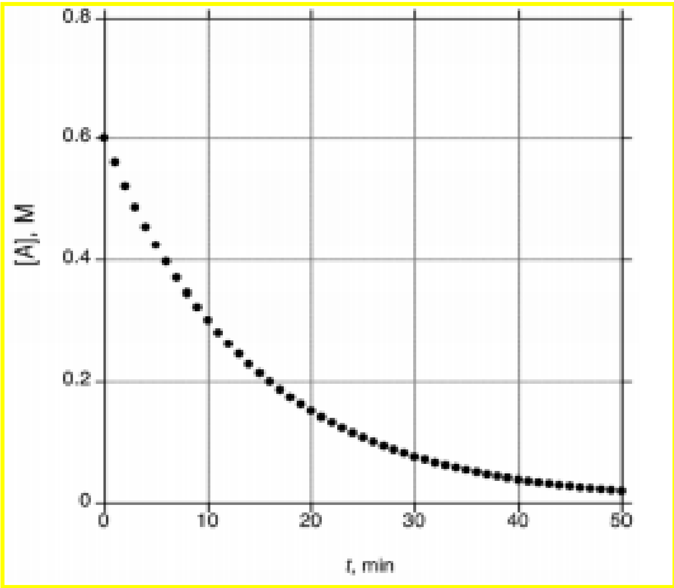
A. catalysts on the rate of reaction.

B. catalysts on the position of equilibrium.

C. changes in temperature on the rate of reaction.

D. changes in the concentration of reactants on the position of equilibrium.

4 A reaction A → 2 B was monitored over time.
What is the average rate of disappearance of A between t = 0 and t = 10 minutes?



A. 0.03 M min^{-1}

B. 0.04 M min^{-1}

C. 0.06 M min^{-1}

D. 0.07 M min^{-1}

5 What is the function of the beam of electrons in a mass spectrometer?

A. It detects the mass of the particles.

B. It deflects the stream of positively charged particles.

C. It bombards the sample causing ionisation to form positive particles.

D. It removes positive particles from within the spectrometer.

6 Identify the conjugate base of the hydronium ion.

A. H_2O

B. H_3O^+

C. OH^-

D. O^{2-}

7 Which of the following organic compounds will produce the aqueous solution which has the highest pH?

A. Propanoic acid

B. Propanol

C. Propanamide

D. Propanamine

8 and 9 Questions 8 and 9 both relate to the endothermic reaction shown below.

$$N_2O_4\,(g) \rightleftharpoons 2NO_2\,(g) \qquad K_{eq} \text{ is } 0.48 \text{ at } 100°C$$

8 In an experiment it was found that the concentration of N_2O_4*(g)* was 0.20 mol/L. Calculate the concentration of the NO_2*(g)* in this equilibrium mixture.

A. 0.10 mol/L

B. 0.31 mol/L

C. 0.096 mol/L

D. 3.23 mol/L

9 Which change will decrease the number of moles of N_2O_4 *(g)* present in this system at equilibrium?

A. Increasing the volume of the container

B. Increasing the pressure by injecting argon *(g)*

C. Increasing the pressure by injecting H_2 *(g)*

D. Increasing the temperature

10 Three solutions of equal concentration of KNO_3 *(aq)*, NH_4NO_3*(aq)* and KHCOO *(aq)* were prepared and their pH values measured using a pH meter.

In which of the following are these salt solutions listed from most acidic to least acidic?

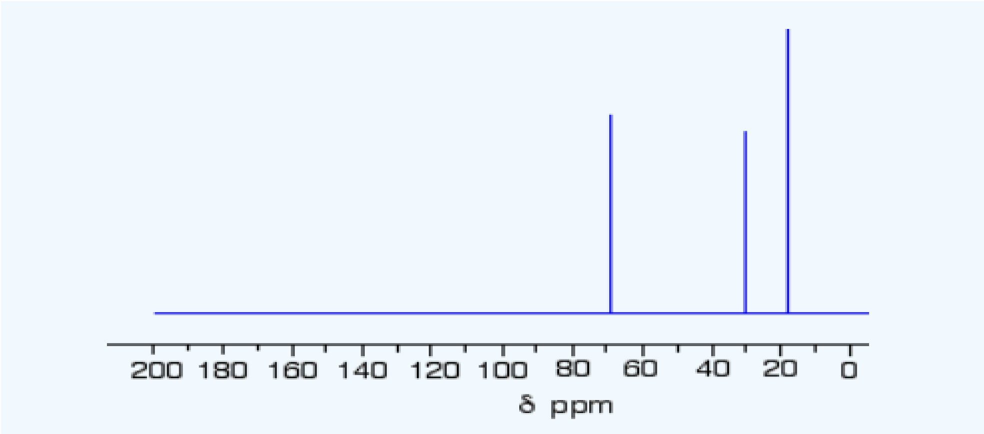
A. KNO_3, NH_4NO_3, KHCOO

B. NH_4NO_3, KNO_3, KHCOO

C. KHCOO, KNO_3, NH_4NO_3

D. NH_4NO_3, KHCOO, KNO_3

11



The ^{13}C NMR spectrum above corresponds to which one of the following compounds?

A. Butan-1-ol

B. Butan-2-ol

C. 2-methylpropan-1-ol

D. 2-methylpropan-2-ol

12 During a precipitation titration investigation, a 100.0 mL sample of a solution containing chloride ions was titrated with 11.75 mL of 0.250 mol/L $AgNO_3$ to reach the end-point. Calculate the mass of chloride ions present in the original sample.

A. 0.00294 g

B. 0.0520 g

C. 0.104 g

D. 0.208 g

13 What is the correct I.U.P.A.C. name for the compound with formula shown below?

```
         F   H   H   H   H
         |   |   |   |   |
    Cl – C – C – C – C – C – H
         |   |   |   |   |
         H   H   H   O   H
                     |
                     H
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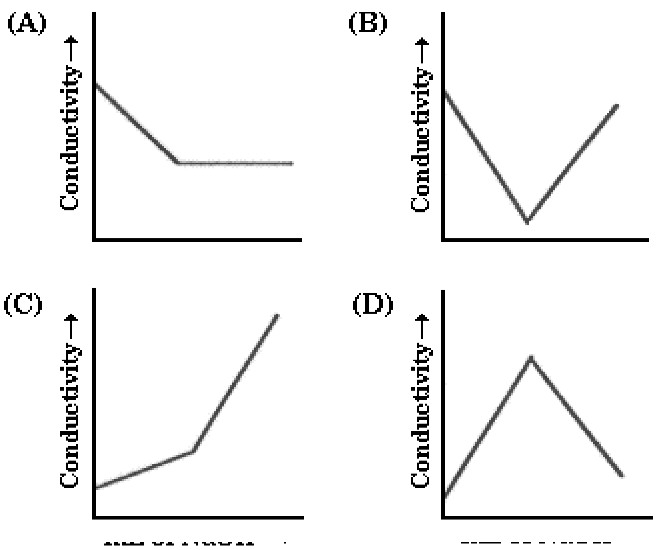
A. 1-chloro-1-fluoropentan-4-ol

B. 1-fluoro-1-chloropentan-4-ol

C. 5-chloro-5-fluoropentan-2-ol

D. 5-fluoro-5-chloropentan-2-ol

14 Which graph best represents the electrical conductivity changes that occur when an aqueous solution of sulfuric acid is titrated with an aqueous solution of ammonia?



15 A scientist wished to distinguish between propanoic acid and butanoic acid using laboratory reactions and spectroscopy.

Which of the following would be most useful in distinguishing between the 2 compounds?

A. Reacting the samples with sodium hydroxide and measuring the mass of water formed

B. Reacting the samples with sodium metal and measuring the volume of hydrogen formed

C. Using C-13 NMR spectroscopy

D. Using UV spectroscopy

16 A student wishes to distinguish between samples of pentane and pent-2-ene. Which of the following tests would allow the 2 compounds to be identified?

I – Adding bromine water to both

II – Adding acidified potassium permanganate solution to both

III – Testing the pH of both

IV – Reacting both with excess oxygen and measuring the volume of carbon dioxide formed

A. I and II

B. I, II and III

C. I only

D. IV only

17 The K_{sp} of $Sr(OH)_2$ is 2.0 x 10^{-3} mol L^{-1}.
What is the pH of a saturated solution of $Sr(OH)_2$?

A. 2 x 10^{-3}

B. 11.30

C. 12.65

D. 13.20

18 Consider the following reaction, at equilibrium, at 500 K.

$$SO_2\,(g) + \tfrac{1}{2}O_2\,(g) \rightleftharpoons SO_3\,(g) \quad \Delta H = -99 \text{ kJ mol}^{-1}$$

Which of the following statements is (are) correct?

I – the Gibbs free energy change, $\Delta G = 0$
II – the rates of the forward and reverse reactions are equal
III – ΔS is positive for the forward reaction
IV – ΔH is positive for the reverse reaction

A. I and II only

B. I, II and IV only

C. II and III only

D. II, III and IV only

19 An organic compound of formula C_4H_9O

I – could be formed by reaction of an alkene and water in the presence of an acid catalyst
II – could be an alkanol
III – could be formed by reduction of an alkanoic acid
IV – could react with an alkanoic acid to form an ester

Which of the above statements are correct?

A. I, II, III and IV

B. I, II and III only

C. II and III only

D. III and IV only

20 The ionisation constant of water at 60ºC is $K_w = 1.0 \times 10^{-13}$.

Which of the following statements are correct?

I – Autoionisation of water is exothermic.
II – A sample of pure water at 60ºC is slightly acidic

A. I only

B. II only

C. Both I and II

D. Neither I nor II

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Chemistry

Section II – 80 marks
Attempt Questions 21-29
Allow about 2 hours and 25 minutes for this section.

Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.

Show all relevant working in questions involving calculations.

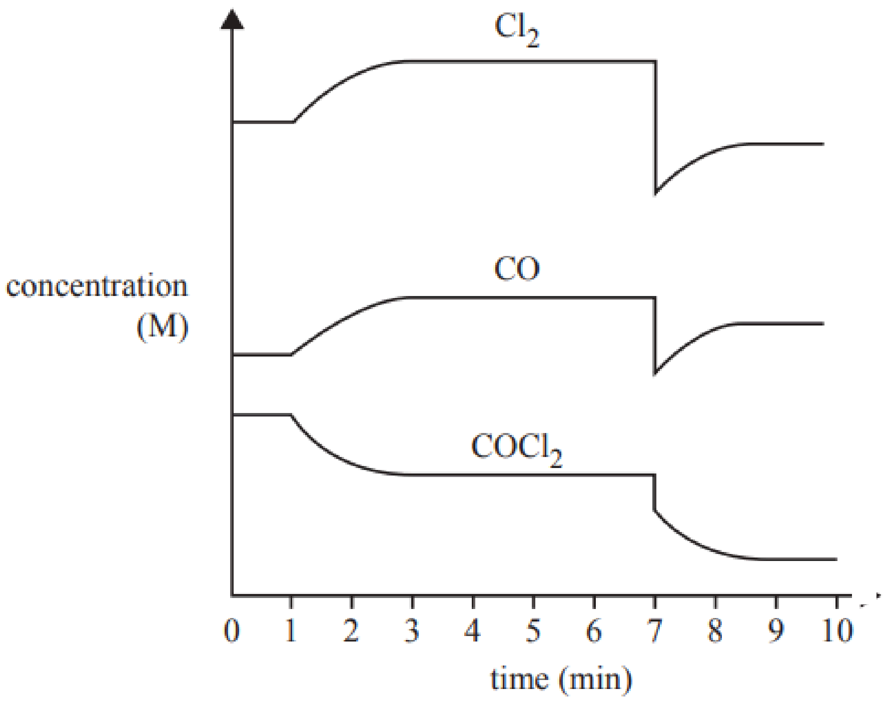
Extra writing space is provided on pages 33 to 36. If you use this space, clearly indicate which question you are answering.

Question 21 (8 marks)

The following equation represents the reaction between chlorine gas, Cl_2, and carbon monoxide gas, CO.

$$Cl_2\,(g) + CO\,(g) \rightleftharpoons COCl_2\,(g) \qquad \Delta H = -108 \text{ kJ mol}^{-1}$$

The concentration–time graph below represents changes to the system.



(a) Identify the changes imposed on the system at time = 1 min and time = 7 min. **2**

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(b) Extend the above graph to 15 minutes and draw lines to show the predicted changes if the temperature of the system were decreased at time = 10 minutes and no further changes were made up to the 15 minute mark. **2**

Question 21 continues on the next page

Question 21 (continued)

(c) Explain the changes you have predicted in part (b) above. **2**

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(d) The equilibrium involving chlorine and carbon monoxide is described as “dynamic”. Explain this classification. **2**

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Question 22 (6 marks)

Nitrogen dioxide, NO_2, and dinitrogen tetroxide, N_2O_4, form an equilibrium mixture represented by the following equation.

$$\underset{\text{brown}}{2NO_2(g)} \rightleftharpoons \underset{\text{colourless}}{N_2O_4\,(g)} \qquad \Delta H = -57.2 \text{ kJ mol}^{-1}$$

(a) Predict the change in colour of the mixture of gases if the temperature of the equilibrium mixture increased at constant pressure and explain your prediction. **2**

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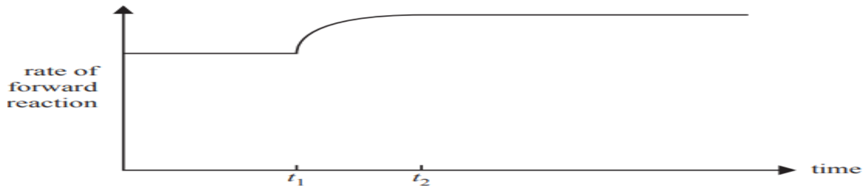
(b) A graph showing the rate of the **forward reaction only** is shown above. **2**

At time t_1, the temperature of the equilibrium mixture was increased. A new equilibrium was achieved at t_2.



Explain, using collision theory, why the rates of **both the forward and backward reactions** would increase at t_1 and compare the magnitude of the increase in the rate of backward reaction with that of the rate of the forward reaction.

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Question 22 continues on the next page

Question 22 (continued)

(c) Compare the rates of backward and forward reactions at time t_2 and explain your response. **2**

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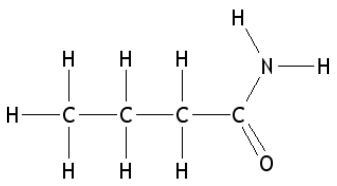
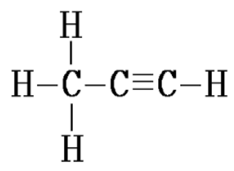
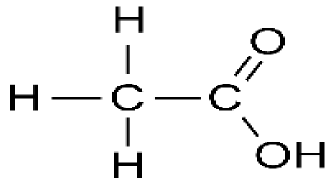
Question 23 (13 marks)

(a) Using IUPAC nomenclature, name the compounds shown below. **3**







Compound 1 Compound 2 Compound 3

Compound 1 ………………………………………………………………………………

Compound 2 ………………………………………………………………………………

Compound 3 ………………………………………………………………………………

(b) Compare the intermolecular forces in the above 3 molecules and predict the order of boiling points (lowest to highest) of these molecules. Explain your prediction. **4**

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Question 23 continues on the next page

Question 23 (continued)

(c) Compound 3 (in part (a) above) will react with a solution of sodium carbonate. Describe observations you would make that indicated that chemical reaction had occurred. Include an equation in your response. **2**

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(d) Compound 3 (in part (a) above) will react when refluxed with ethanol. Describe the process of reflux and the separation of the products from reactants, write an equation for the reaction. **4**

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Question 24 (10 marks)

(a) A student was asked to derive a method of distinguishing between 4 unlabelled bottles with samples of solutions of $Pb(NO_3)_2$, $BaCl_2$, $FeSO_4$ and $MgSO_4$ using chemical reactions. **4**

Draw a flow chart to show the steps that could be followed to confirm the identity of each of the solutions. Include observed results.

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Question 24 continues on the next page

Question 24 (continued)

(b) Write ionic equations for THREE of the chemical reactions involved in the flow chart in part (a). **3**

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(c) Many metal ions can be detected and identified by the formation of coloured complex ions. Identify a coloured complex ion by drawing its structure and explain the bonding structure of this complex ion. **3**

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Question 25 (6 marks)

(a) Using the data provided on the data pages, compare the solubility in water of silver carbonate and silver chloride at 25°C. **3**
Show your calculations and reasoning.

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(b) Quantitatively compare the solubility of silver chloride in water with its solubility in a 0.10 mol/L solution of sodium chloride, at 25°C. **3**

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Question 26 (13 marks)

(a) Explain why sodium hydroxide cannot be used as a primary standard for titrations. **2**

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(b) Sodium carbonate (anhydrous) is used as a primary standard for a titration to determine the concentration of a solution of sulfuric acid. **4**
Describe the procedure used to prepare the solutions and glassware needed for an accurate titration.

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Question 26 continues on the next page

Question 26 (continued)

(c) Determine the concentration of a sulfuric acid solution if 34.50 mL of the acid is required to neutralise 25.0 mL of a solution of 0.150 M sodium carbonate solution. **2**

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(d) Identify a suitable indicator for use with this titration and explain your response. **2**

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(e) Calculate the pH at 25°C after 240 mL of 0.50 mol L^{-1} sodium hydroxide is added to 60 mL of 0.20 mol L^{-1} sulfuric acid solution. **3**

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Question 27 (8 marks)

The table shows acid dissociation constants at 25ºC.

Acid	Formula	K_a
Nitrous	HNO_2	7.2×10^{-4}
Hydrofluoric	HF	6.6×10^{-4}
Hydrocyanic	HCN	6.2×10^{-10}
Formic	HCOOH	1.8×10^{-4}
Chlorous	$HClO_2$	$1.1.x10^{-2}$

(a) Identify the strongest acid in the table and determine the pK_a value for this acid. **2**

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(b) Calculate the pH of a 0.010 M solution of formic acid. **2**

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Question 27 continues on the next page

Question 27 (continued)

(c) A buffer solution is prepared by combining 100 mL of 0.010 M $HCOOH$ and 80 mL of 0.010 M $NaHCOO$. **4**

Calculate the pH of this buffer solution and explain the classification of the solution as a buffer.

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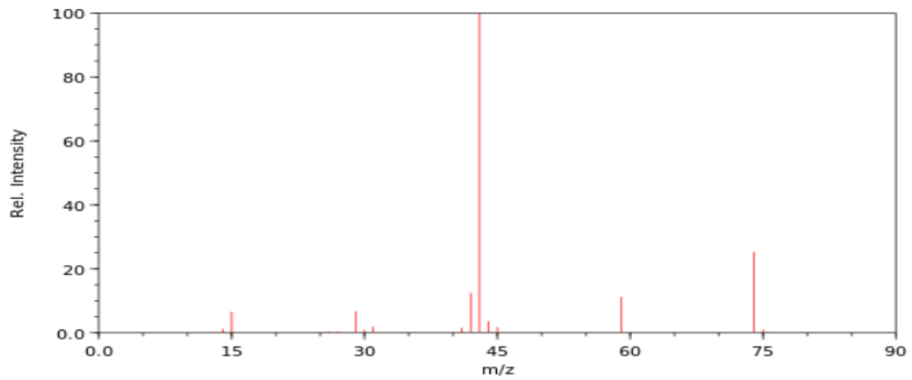
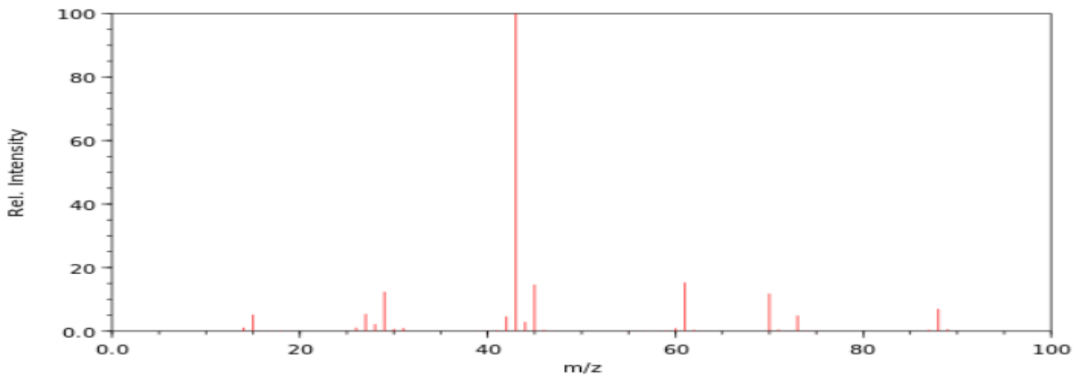
Question 28 (7 marks)

(a) A scientist wished to distinguish between samples of ethyl ethanoate and methyl ethanoate. He carried out an instrumental analysis. **3**
The spectra obtained are shown below.



Spectrum I



Spectrum II

Identify the type of spectroscopy used and match the spectra with the two samples. Justify your answer.

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Question 28 continues on the next page

Question 28 (continued)

(b) Name the homologous series into which ethyl ethanoate and methyl ethanoate are classified. **1**

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(c) Outline the processes which manufactures soaps from compounds containing the same functional group as ethyl ethanoate. **3**

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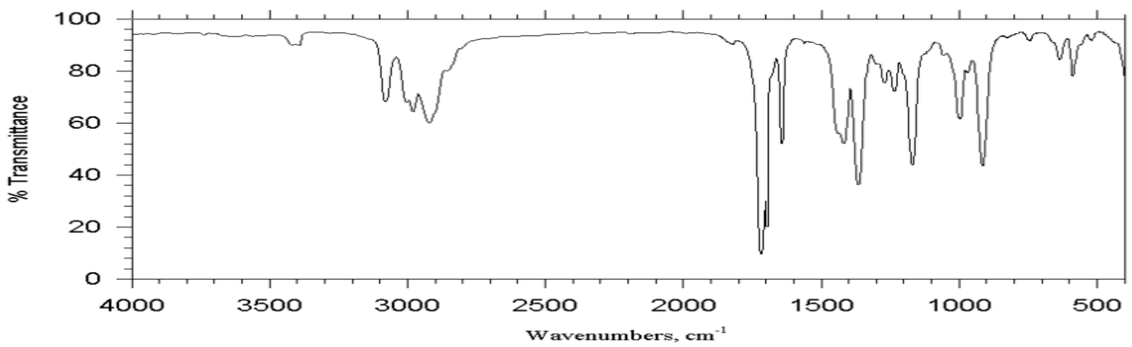
Question 29 (9 marks)

A scientist wished to identify an organic compound of formula C_4H_8O. The organic compound did not decolorise bromine water. She carried out instrumental analyses using 3 different types of spectroscopy.

(a) The IR spectrum is shown below. **2**



What do the regions 3100–4000 cm^{-1} and 1650–1700 cm^{-1} indicate about the bonds in C_4H_8O? Give your reasoning.

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(b) The ^{13}C-NMR spectrum of the unknown compound has four distinct peaks. Draw two possible structural formulas of the unknown compound using the information provided. **2**

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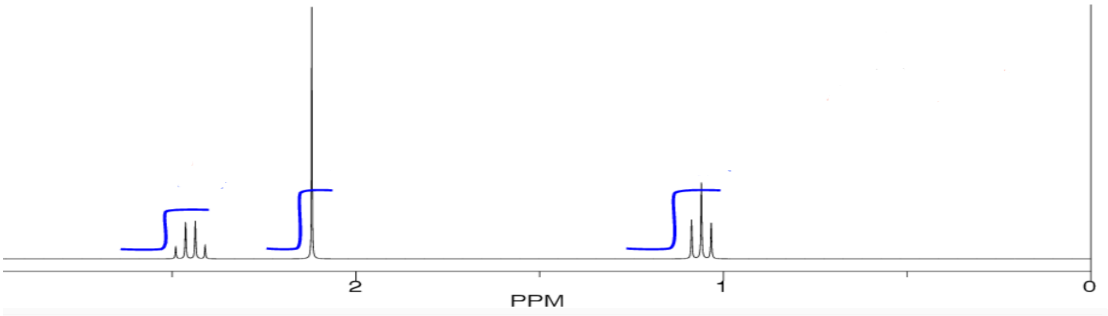
Question 29 continues on the next page

Question 29 (continued)

(c) The high-resolution ^{1}H NMR spectrum of the unknown compound has three peaks, as shown below. **3**



Use the high-resolution ^{1}H NMR spectrum to identify three pieces of information about the unknown compound and indicate how each would assist in determining its structure.

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Question 29 continues on the next page

Question 29 (continued)

(d) Describe a chemical test which could be used to distinguish between the 2 possible structures you have drawn in part (b) above. **2**

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Student Name:………..………………………

CHEMISTRY – MULTIPLE-CHOICE ANSWER SHEET

ATTEMPT ALL QUESTIONS

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

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FORMULAE SHEET

$n = \dfrac{m}{MM}$	$c = \dfrac{n}{V}$	$PV = nRT$
$q = mc\Delta T$	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$	$\text{pH} = -\log_{10}\left[\text{H}^+\right]$
$pK_a = -\log_{10}\left[K_a\right]$	$A = \varepsilon lc = \log_{10}\dfrac{I_o}{I}$	

Avogadro constant, N_A .... 6.022×10^{23} mol^{-1}

Volume of 1 mole ideal gas: at 100 kPa and
at 0°C (273.15 K) .... 22.71 L
at 25°C (298.15 K) .... 24.79 L

Gas constant .... 8.314 J mol^{-1} K^{-1}

Ionisation constant for water at 25°C (298.15 K), K_w .... 1.0×10^{-14}

Specific heat capacity of water .... 4.18×10^3 J kg^{-1} K^{-1}

DATA SHEET

Solubility constants at 25°C

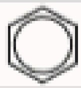
Compound	K_{sp}	*Compound*	K_{sp}
Barium carbonate	2.58×10^{-9}	Lead(II) bromide	6.60×10^{-6}
Barium hydroxide	2.55×10^{-4}	Lead(II) chloride	1.70×10^{-5}
Barium phosphate	1.3×10^{-29}	Lead(II) iodide	9.8×10^{-9}
Barium sulfate	1.08×10^{-10}	Lead(II) carbonate	7.40×10^{-14}
Calcium carbonate	3.36×10^{-9}	Lead(II) hydroxide	1.43×10^{-15}
Calcium hydroxide	5.02×10^{-6}	Lead(II) phosphate	8.0×10^{-43}
Calcium phosphate	2.07×10^{-29}	Lead(II) sulfate	2.53×10^{-8}
Calcium sulfate	4.93×10^{-5}	Magnesium carbonate	6.82×10^{-6}
Copper(II) carbonate	1.4×10^{-10}	Magnesium hydroxide	5.61×10^{-12}
Copper(II) hydroxide	2.2×10^{-20}	Magnesium phosphate	1.04×10^{-24}
Copper(II) phosphate	1.40×10^{-37}	Silver bromide	5.35×10^{-13}
Iron(II) carbonate	3.13×10^{-11}	Silver chloride	1.77×10^{-10}
Iron(II) hydroxide	4.87×10^{-17}	Silver carbonate	8.46×10^{-12}
Iron(III) hydroxide	2.79×10^{-39}	Silver hydroxide	2.0×10^{-8}
Iron(III) phosphate	9.91×10^{-16}	Silver iodide	8.52×10^{-17}
		Silver phosphate	8.89×10^{-17}
		Silver sulfate	1.20×10^{-5}

Aylward and Findlay, *SI Chemical Data* (5th Edition) is the principal source of data for this examination paper. Some data may have been modified for examination purposes.

Infrared absorption data

Bond	Wavenumber/cm^{-1}
N—H (amines)	3300–3500
O—H (alcohols)	3230–3550 (broad)
C—H	2850–3300
O—H (acids)	2500–3000 (very broad)
C≡N	2220–2260
C═O	1680–1750
C═C	1620–1680
C—O	1000–1300
C—C	750–1100

^{13}C NMR chemical shift data

Type of carbon		δ/ppm
$-\overset{\vert}{\underset{\vert}{C}}-\overset{\vert}{\underset{\vert}{C}}-$		5–40
$R-\overset{\vert}{\underset{\vert}{C}}-Cl$ or Br		10–70
$R-\underset{\underset{O}{\Vert}}{C}-\overset{\vert}{\underset{\vert}{C}}-$		20–50
$R-\overset{\vert}{\underset{\vert}{C}}-N\langle$		25–60
$-\overset{\vert}{\underset{\vert}{C}}-O-$	alcohols, ethers or esters	50–90
$\rangle C=C\langle$		90–150
$R-C\equiv N$		110–125
		110–160
$R-\underset{\underset{O}{\Vert}}{C}-$	esters or acids	160–185
$R-\underset{\underset{O}{\Vert}}{C}-$	aldehydes or ketones	190–220

UV absorption

(This is not a definitive list and is approximate.)

Chromophore	λ_{max} (nm)
C—H	122
C—C	135
C═C	162

Chromophore	λ_{max} (nm)
C≡C	173 178 196 222
C—Cl	173
C—Br	208

Some standard potentials

$K^+ + e^-$	$\rightleftharpoons$	$K(s)$	–2.94 V
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	$Ba(s)$	–2.91 V
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	$Ca(s)$	–2.87 V
$Na^+ + e^-$	$\rightleftharpoons$	$Na(s)$	–2.71 V
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	$Mg(s)$	–2.36 V
$Al^{3+} + 3e^-$	$\rightleftharpoons$	$Al(s)$	–1.68 V
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	$Mn(s)$	–1.18 V
$H_2O + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g) + OH^-$	–0.83 V
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	$Zn(s)$	–0.76 V
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	$Fe(s)$	–0.44 V
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	$Ni(s)$	–0.24 V
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	$Sn(s)$	–0.14 V
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	$Pb(s)$	–0.13 V
$H^+ + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g)$	0.00 V
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2(aq) + 2H_2O$	0.16 V
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	$Cu(s)$	0.34 V
$\frac{1}{2}O_2(g) + H_2O + 2e^-$	$\rightleftharpoons$	$2OH^-$	0.40 V
$Cu^+ + e^-$	$\rightleftharpoons$	$Cu(s)$	0.52 V
$\frac{1}{2}I_2(s) + e^-$	$\rightleftharpoons$	I^-	0.54 V
$\frac{1}{2}I_2(aq) + e^-$	$\rightleftharpoons$	I^-	0.62 V
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	0.77 V
$Ag^+ + e^-$	$\rightleftharpoons$	$Ag(s)$	0.80 V
$\frac{1}{2}Br_2(l) + e^-$	$\rightleftharpoons$	Br^-	1.08 V
$\frac{1}{2}Br_2(aq) + e^-$	$\rightleftharpoons$	Br^-	1.10 V
$\frac{1}{2}O_2(g) + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O	1.23 V
$\frac{1}{2}Cl_2(g) + e^-$	$\rightleftharpoons$	Cl^-	1.36 V
$\frac{1}{2}Cr_2O_7^{2-} + 7H^+ + 3e^-$	$\rightleftharpoons$	$Cr^{3+} + \frac{7}{2}H_2O$	1.36 V
$\frac{1}{2}Cl_2(aq) + e^-$	$\rightleftharpoons$	Cl^-	1.40 V
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	1.51 V
$\frac{1}{2}F_2(g) + e^-$	$\rightleftharpoons$	F^-	2.89 V

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number	79
Symbol	Au
Standard Atomic Weight	197.0
Name	Gold

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.941 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	20 Ca 40.08 Calcium	21 Sc 44.96 Scandium	22 Ti 47.87 Titanium	23 V 50.94 Vanadium	24 Cr 52.00 Chromium	25 Mn 54.94 Manganese	26 Fe 55.85 Iron	27 Co 58.93 Cobalt	28 Ni 58.69 Nickel	29 Cu 63.55 Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.64 Germanium	33 As 74.92 Arsenic	34 Se 78.96 Selenium	35 Br 79.90 Bromine	36 Kr 83.80 Krypton
37 Rb 85.47 Rubidium	38 Sr 87.61 Strontium	39 Y 88.91 Yttrium	40 Zr 91.22 Zirconium	41 Nb 92.91 Niobium	42 Mo 95.96 Molybdenum	43 Tc Technetium	44 Ru 101.1 Ruthenium	45 Rh 102.9 Rhodium	46 Pd 106.4 Palladium	47 Ag 107.9 Silver	48 Cd 112.4 Cadmium	49 In 114.8 Indium	50 Sn 118.7 Tin	51 Sb 121.8 Antimony	52 Te 127.6 Tellurium	53 I 126.9 Iodine	54 Xe 131.3 Xenon
55 Cs 132.9 Caesium	56 Ba 137.3 Barium	57–71 Lanthanoids	72 Hf 178.5 Hafnium	73 Ta 180.9 Tantalum	74 W 183.9 Tungsten	75 Re 186.2 Rhenium	76 Os 190.2 Osmium	77 Ir 192.2 Iridium	78 Pt 195.1 Platinum	79 Au 197.0 Gold	80 Hg 200.6 Mercury	81 Tl 204.4 Thallium	82 Pb 207.2 Lead	83 Bi 209.0 Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89–103 Actinoids	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Uut Ununtrium	114 Fl Flerovium	115 Uup Ununpentium	116 Lv Livermorium	117 Uus Ununseptium	118 Uuo Ununoctium

Lanthanoids

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm Promethium	62 Sm 150.4 Samarium	63 Eu 152.0 Europium	64 Gd 157.3 Gadolinium	65 Tb 158.9 Terbium	66 Dy 162.5 Dysprosium	67 Ho 164.9 Holmium	68 Er 167.3 Erbium	69 Tm 168.9 Thulium	70 Yb 173.1 Ytterbium	71 Lu 175.0 Lutetium

Actinoids

89 Ac Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium

Standard atomic weights are abridged to four significant figures.

Elements with no reported values in the table have no stable nuclides.

Information on elements with atomic numbers 113 and above is sourced from the International Union of Pure and Applied Chemistry Periodic Table of the Elements (January 2016 version).

The International Union of Pure and Applied Chemistry Periodic Table of the Elements (February 2010 version) is the principal source of all other data. Some data may have been modified.

2021 Higher School Certificate
Trial Examination

Mapping Grid

Section I

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

Section II – 80 marks

Question 21 (8 marks)
21 (a) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–12
Targeted Performance Bands: 2-4

Criteria	Marks
● Identifies the changes imposed BOTH at time = 1 min AND time = 7 min	2
● Identifies the change imposed at time = 1 min OR time = 7 min	1

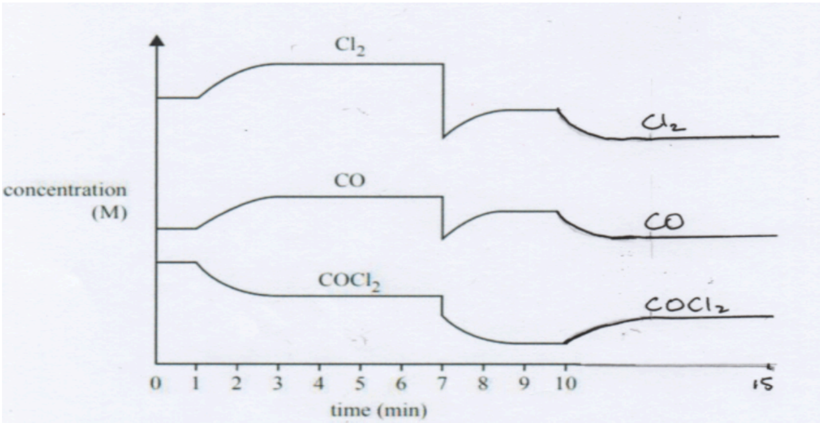
Sample answer
At time = 1 minute, the temperature of the system has increased.

At time = 7 minutes, the concentration of all 3 species has been reduced by a increase in volume of the system (and hence a decrease in pressure).

21 (b) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–12
Targeted Performance Bands: 3-5

Criteria	Marks
● Draws lines which indicate gradual changes in concentration of the 3 gases ● Indicates a new equilibrium being reached ● Indicates the lower concentrations of Cl_2 and CO and the higher concentration of $COCl_2$	2
● TWO of the above	1

Sample answer



21 (c) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–12
Targeted Performance Bands: 2-4

Criteria	Marks
● Explains the changes correctly in terms of the shift in equilibrium	2
● Outlines some correct information relating to the answer in part (b)	1

Sample answer
When the temperature decreases, the forward exothermic reaction is favoured. Hence the equilibrium shifts (by Le Chatelier's Principle) to counteract the change as the forward reaction releases heat. This lowers the concentration of the reactants Cl_2 and CO and increases the concentration of the product $COCl_2$.

21 (d) (2 marks)
Outcomes Assessed: CH12–7, CH12–12
Targeted Performance Bands: 2-3

Criteria	Marks
● Explains TWO features of a dynamic equilibrium	2
● Explains ONE feature of a dynamic equilibrium	1

Sample answer
In a dynamic equilibrium, externally it appears as if there is no change (macroscopic properties remain the same), but at a particle level the reaction is going at equal rates in opposite directions. Some of the reactants and products remain in the container.

Question 22 (6 marks)
22 (a) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–12
Targeted Performance Bands: 3-4

Criteria	Marks
• Predicts that the solution will become a darker brown AND • Explains the prediction	2
• Predicts that the solution will become a darker brown	1

Sample answer
The equilibrium will move to the left when temperature is increased, so the mixture will become a darker brown. In an equilibrium system, an increase in temperature will always favour the endothermic reaction, which has a higher activation energy and hence will take in more energy than the reverse exothermic reaction. In this example, the forward reaction is exothermic and the backward reaction endothermic, so an increase in temperature shifts the equilibrium to the left increasing the proportion of brown nitrogen dioxide in the equilibrium mixture.

22 (b) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–12
Targeted Performance Bands: 3-5

Criteria	Marks
• Explains, using collision theory, why the rates of the both the **forward and backward reactions** increase at t_1 AND • Correctly compares the magnitude of the increases in the rate of backward reaction with that of the rate of the forward reaction	2
• Explains, using collision theory, why the rates of the both the **forward and backward reactions** would increase at t_1 OR • Correctly compares the magnitude of the increases in the rate of backward reaction with that of the rate of the forward reaction	1

Sample answer
An increase in temperature has occurred which increases the reaction rate of both backward and forward reactions. Collision theory states that this increase in rate is the result of greater frequency of successful collisions (as the particles have greater kinetic energy), resulting in a greater rate of reaction.

The increase in rate of the backward reaction will be greater than the increase in rate of the forward reaction as the backward reaction is endothermic and has a greater activation energy than the forward exothermic reaction. The increase in temperature will have greater impact on the rate of the reaction which has the greater activation energy.

(It is the result of these differences in rate that the equilibrium shifts to favour the endothermic reaction when the temperature of an equilibrium system is increased.)

22 (c) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–12
Targeted Performance Bands: 3-5

Criteria	Marks
● Explains why the rates of backward and forward reactions are equal at time t_2	2
● Predicts that the rates of backward and forward reactions are equal at time t_2	1

Sample answer
When a system is in equilibrium, the rates of forward and backward reactions are always equal.
The rates of reverse and forward reactions will be the same as each other after t_2 because a new equilibrium has then been achieved at the higher temperature.
These rates will be higher than the rates at t_1.

Question 23 (13 marks)
23 (a) (3 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–14
Targeted Performance Bands: 3-5

Criteria	Marks
• Names THREE compounds correctly	3
• Names TWO compounds correctly	2
• Names ONE compound correctly	1

Sample answer
Compound 1 = butanamide
Compound 2 = propyne
Compound 3 = ethanoic acid

23 (b) (4 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–14
Targeted Performance Bands: 2-6

Criteria	Marks
• Predicts the correct order of boiling points (Compound 2, Compound 3, Compound 1) • Explains thoroughly the impact of the different intermolecular forces • Identifies that Compound 1 has very strong hydrogen bonding and greater mass and chain length than Compound 3 • Identifies that Compound 2 has dispersion (temporary dipole-dipole forces) only • Identifies that Compound 3 has hydrogen bonding (2 hydrogen bonds form between adjacent molecules)	4
• Predicts the correct order of boiling points • Explains thoroughly the impact of the different intermolecular forces • Identifies the intermolecular forces in 2 of the 3 compounds	3

• TWO of:
  • Predicts the correct order of boiling points
  • Explains thoroughly the impact of the different intermolecular forces
  • Identifies the intermolecular forces in 2 of the 3 compounds
	2

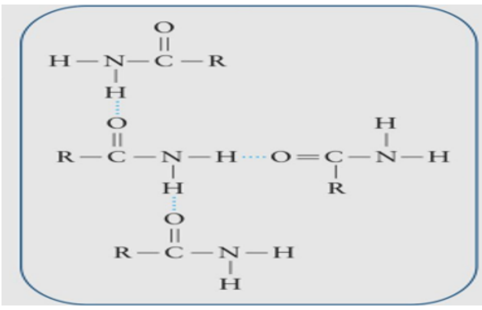
• ONE of:
  • Predicts the correct order of boiling points
  • Explains thoroughly the impact of the different intermolecular forces
  • Identifies the intermolecular forces in 1 of the 3 compounds
	1

Sample answer
The order of increasing boiling points is Compound 2, Compound 3, Compound 1.

The stronger the intermolecular forces, the higher the boiling point, as greater energy is needed to separate the liquid molecules to form a gas.

Compound 2 is non-polar and has only weak intermolecular forces (dispersion or temporary dipole-dipole forces) caused by the electrical interaction of molecules as they collide (protons from 1 molecule being attracted to electrons from the other as the molecules are temporarily distorted on collision).

Compound 1 is polar and would experience very strong hydrogen bonding forces, as well as weaker temporary and permanent dipolar forces) as molecules interact. These are strong intermolecular forces as hydrogen bonds can also form between the oxygen of 1 molecule and the hydrogen of the $-NH_2$ group. The geometry of the molecules allows more than 1 H-bond per molecule at any instant. Butanamide has a boiling point of 213°C and hence is a solid at room temperature. This boiling point is higher than that of Compound 3, as Compound 1 has greater mass and chain length than ethanoic acid. Both form hydrogen bonds between neighbouring molecules.



Compound 3 is an alkanoic acid and has the very polar –COOH functional group. The hydrogen atom of the –COOH can form a hydrogen bond with an oxygen of the neighbouring acid molecule. The planar nature of this –COOH group allows 2 H-bonds per pair of molecules.

Hence the intermolecular forces and thus boiling points are highest in Compound 1 and lowest in Compound 2.

23 (c) (2 marks)

Outcomes Assessed: CH12–4, CH12–7, CH12–14

Targeted Performance Bands: 3-4

Criteria	Marks
● Describes TWO observations AND ● Writes a correct equation	2
● Describes TWO observations OR ● Writes a correct equation	1

Sample answer

Ethanoic acid will react with sodium carbonate solution to produce bubbles of (carbon dioxide) gas. The temperature will rise.

$2CH_3COOH\ (aq) + CO_3^{2-}\ (aq) \rightarrow 2CH_3COO^-\ (aq) + CO_2\ (g) + H_2O\ (l)$

ethanoic acid ethanoate ions

23 (d) (4 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–14
Targeted Performance Bands: 2-5

Criteria	Marks
● Describes thoroughly the processes of reflux and separation of the products and reactants ● Writes a correct equation	4
● Describes thoroughly the processes of reflux and separation of the products and reactants OR ● Writes a correct equation AND describes some correct details of the reflux and separation processes	3
● Describes some correct details of the reflux and separation processes OR ● Writes a correct equation AND identifies some correct information about the reflux and separation processes	2
● Writes a correct equation OR identifies some correct information about the reflux and separation processes	1

Sample answer

Ethanol, ethanoic acid (glacial acetic acid) and the catalyst, concentrated sulfuric acid, are placed in a flask attached to a reflux condenser. The mixture is heated slowly, with the flame height and the water flow rate through the condenser controlled to ensure that no gases escape into the laboratory. Boiling chips in the flask ensure even boiling. The reaction to form the ester and water occurs in the gaseous phase; the vapour condenses in the condenser and returns to the reflux flask to be reheated.

After refluxing for an hour, the mixture is cooled, and the reaction stopped by addition of sodium carbonate (to remove the catalyst) and dried (to remove water) by addition of magnesium sulfate crystals (a drying agent). This removal of water prevents the backward reaction (hydrolysis of the ester) occurring. A separating funnel is used to separate the aqueous and non-aqueous layers. Esters are insoluble in water (apart from low molecular weight esters like methyl methanoate), so the ester will be in the upper layer in the separating funnel. The bottom layer is discarded. The upper layer is distilled (or fractionally distilled) and the fraction with the boiling point of the ester is collected.

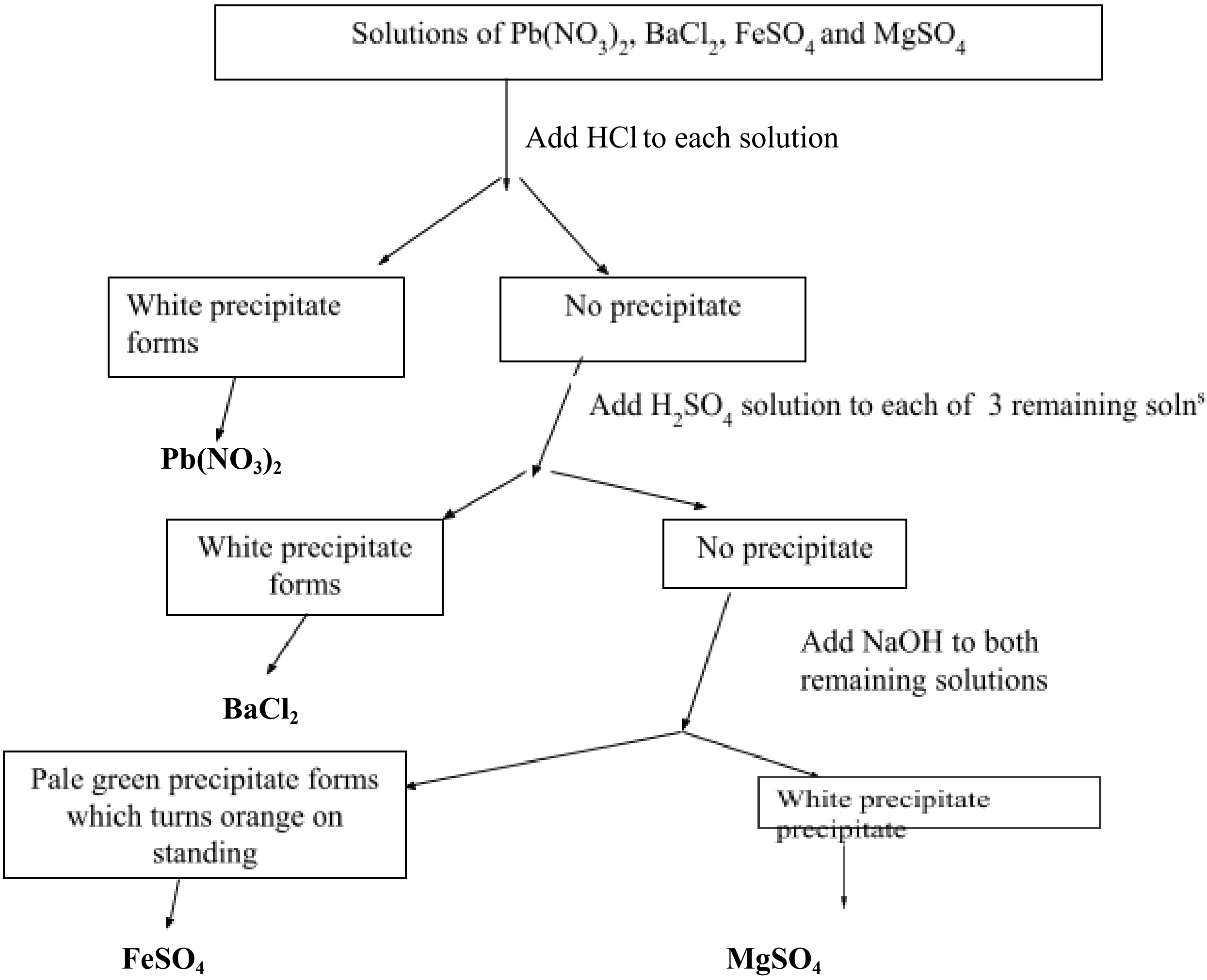
$$CH_3CH_2OH\,(l) + CH_3COOH\,(l) \xrightleftharpoons{\text{conc } H_2SO_4} CH_3COOCH_2CH_3\,(l) + H_2O\,(l)$$

The products are ethyl ethanoate and water.

Question 24 (10 marks)
24 (a) (4 marks)
Outcomes Assessed: CH12–2, CH12–7, CH12–15
Targeted Performance Bands: 2-5

Criteria	Marks
● Draws a flow chart to show a correct method of identification of ALL FOUR solutions ● Includes all observations	4
● Draws a flow chart to show a correct method of identification of THREE solutions ● Includes correct observations for the 3 correctly identified solutions	3
● Draws a flow chart to show a correct method of identification of TWO solution ● Includes correct observations for the 2 correctly identified solutions	2
● Draws a flow chart and includes some correct information	1

Sample answer (several possible answers)



24 (b) (3 marks)
Outcomes Assessed: CH12–7, CH12–15
Targeted Performance Bands: 2-4

Criteria	Marks
• Writes 3 correct ionic equations	3
• Writes 2 correct ionic equations	2
• Writes 1 correct ionic equation	1

Sample answer
Pb^{2+} *(aq)* + $2Cl^-$ *(aq)* → $PbCl_2$ *(s)*

Ba^{2+} *(aq)* + SO_4^{2-} *(aq)* → $BaSO_4$ *(s)*

Fe^{2+} *(aq)* + $2OH^-$ *(aq)* → $Fe(OH)_2$ *(s)*

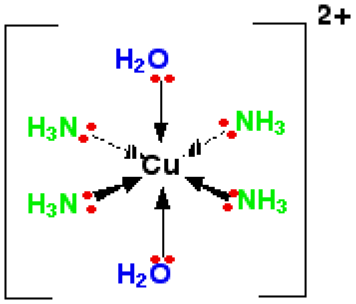
Mg^{2+} *(aq)* + $2OH^-$ *(aq)* → $Mg(OH)_2$ *(s)*

24 (c) (3 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–15
Targeted Performance Bands: 3-5

Criteria	Marks
• Gives an example of a coloured complex ion AND • Identifies the ligands AND • Explains how the ligands are bonded to the metal cation	3
• TWO of the above	2
• ONE of the above	1

Sample answer
$[Cu(NH_3)_4]^{2+}$ *(aq)*

This complex ion is the tetraammine copper (II) ion. Complex ions have a metal atom (here copper) at the centre of the ion and atoms or groups of atoms (called ligands), which bond by co-ordinate bonding onto the central atom. The ammonia (and water) molecules are the ligands, and each has a non-bonding pair of electrons which moves into empty orbitals of the copper ion to form the covalent bond.



the tetraamminediaquacopper(II) ion

Question 25 (6 marks)
25 (a) (3 marks)
Outcomes Assessed: CH12–6, CH12–12
Targeted Performance Bands: 3-6

Criteria	**Marks**
• Correct answers, with correct units, showing correct working/reasoning	3
• Correct calculations for solubility of Ag_2CO_3 and AgCl in water but no overall comparison made	2
• Correct calculation for solubility of Ag_2CO_{34} in water OR the solubility of AgC_2 in water	1

Sample answer
Let the solubility of Ag_2CO_3 be s.
K_{sp} $Ag_2CO_3 = 8.46 \times 10^{-12} = [Ag^+]^2 [CO_3^{2-}] = (2s)^2 (s) = 4s^3$
$s^3 = 2.115 \times 10^{-12}$
$s = 1.3 \times 10^{-4}$ mol/L

The solubility of Ag_2CO_3 in water = 1.3×10^{-4} mol/L

Let the solubility of AgCl be s.
K_{sp} AgCl = $1.77 \times 10^{-10} = [Ag^+] [Cl^-] = (s) (s) = s^2$
$s = \sqrt{(1.77 \times 10^{-10})} = 1.3 \times 10^{-5}$ mol/L

The solubility of AgCl in water = 1.3×10^{-5} mol/L

Hence Ag_2CO_3 is more soluble in water than AgCl at 25°C. (by a factor of 10)

25 (b) (3 marks)
Outcomes Assessed: CH12–6, CH12–12
Targeted Performance Bands: 3-6

Criteria	**Marks**
• Correct conclusion based on correct calculations	3
• Correct calculation for the solubility of AgCl in sodium chloride solution	2
• Incorrect calculation or conclusion but correct method /reasoning	1

Sample answer
Let the solubility of AgCl in a 0.10 mol/L solution of sodium chloride = x
K_{sp} AgCl = $[Ag^+] [Cl^-] = (x) (0.10 + x) = 1.77 \times 10^{-10}$
Since x is small by comparison with 0.10
K_{sp} AgCl = $[Ag^+] [Cl^-] = (x) (0.10) = 1.77 \times 10^{-10}$
$x = 1.77 \times 10^{-10} / (0.10) = 1.77 \times 10^{-10} / 1.0 \times 10^{-1} = 1.77 \times 10^{-9}$ mol/L

The solubility of AgCl in 0.10 M Cl^- = 1.8×10^{-9} mol/L
The solubility of AgCl in water = 1.3×10^{-5} mol/L (from part (a) above)

Hence AgCl is less soluble (by almost a factor of 10^4) in a 0.10 mol/L solution of chloride ion than in water.

Question 26 (13 marks)

26(a) (2 marks)

Outcomes Assessed: CH12–3, CH12–7, CH12–13

Targeted Performance Bands: 2-4

Criteria	Marks
• Explains thoroughly the reasons why sodium hydroxide cannot be used as a primary standard	2
• Outlines at least 1 significant reason why the concentration of sodium hydroxide is inaccurate unless it has been standardised	1

Sample answer

Sodium hydroxide, if solid or in an open container as a solution, will react with carbon dioxide from air and absorb water from air. Therefore its mass and concentration are not accurately known. Titration is a technique which is very accurate if the concentrations of the reactants used are accurate.

Standards used in titrations must be able to be weighed out accurately, not contain impurities, not gain or lose mass as they are being weighed or used and be of high molar mass so that errors in measurements involve only small fractions of a mole.

Sodium hydroxide is standardised just before use by reacting a solution with an acid of known concentration. Sodium hydroxide is standardised by reacting it with an acid which meets the criteria of a primary standard. Oxalic acid is often used for this standardisation step.

26 (b) (4 marks)
Outcomes Assessed: CH12–3, CH12–7, CH12–13
Targeted Performance Bands: 2-5

Criteria	Marks
● Describes the steps in weighing out the primary standard, identifies the glassware and describes the techniques in preparing the solution of known concentration ● Describes the steps in preparing a burette and transferring the sulfuric acid of known concentration into it ● Describes the steps in preparing the conical flask and cleaning the pipette for transfer of the sodium carbonate into the flask ● Describes the technique of titrating, measuring the titre and use of a suitable indicator	4
● THREE of the above	3
● TWO of the above	2
● ONE of the above	1

Sample answer
To make a standard solution of a base:

- Weigh out accurately the required mass of the basic primary standard (anhydrous sodium carbonate).
- Transfer the mass exactly to a volumetric flask (previously cleaned with water). Use a funnel; wash into the volumetric flask with wash bottle of de-ionised water. Make up to calibration mark.

The unknown solution of sulfuric acid needs to be measured out using a burette. This burette after cleaning with water needs to be washed out with some of the sulfuric acid solution.

To use the sodium carbonate base in a titration:

- A pipette (say 25.0 mL) should be cleaned with water and rinsed with the solution it will transfer to the conical flask.
- Pipette out of the volumetric flask an exact volume (say 25.0 mL) of known concentration base into a clean, rinsed with de-ionised water, conical flask.
- Fill a 50.00 mL burette with the unknown acidic solution (burette should have been rinsed with a small quantity of this acidic solution).
- Add 3 drops of suitable indicator (probably methyl orange) to the conical flask.
- Titrate known base (sodium carbonate) with unknown acid until the indicator just changes (from yellow to pink if methyl orange is used).
- Calculate moles of sodium carbonate in conical flask and hence (from balanced equation) calculate moles of acidic solution transferred from burette (from a known volume).
- Calculate the concentration of acidic solution.

26 (c) (2 marks)
Outcomes Assessed: CH12–4, CH12–13
Targeted Performance Bands: 2-4

Criteria	Marks
● Calculates correctly the concentration of sulfuric acid solution	2
● Writes a correct equation for the reaction OR ● Determines the correct no. of moles of sodium carbonate used	1

Sample answer
Na_2CO_3 + H_2SO_4 → Na_2SO_4 + H_2O + CO_2
1 mole 1 mole

Moles sodium carbonate = (25.0/1000) x 0.150 = 0.00375 mol

Hence moles sulfuric acid needed = 0.00375 mol

Concentration sulfuric acid = n/V = 0.00375/0.0345 = 0.109 mol/L

26 (d) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–13
Targeted Performance Bands: 2-4

Criteria	Marks
● Identifies a suitable indicator AND ● Explains correctly the reason for the choice	2
● Identifies a suitable indicator OR ● Explains correctly the reason for the choice	1

Sample answer
Methyl orange is the best indicator, as it changes from red to yellow in the pH range 3-5. The salt formed at the equivalence point of this titration is sodium sulfate which will NOT affect the pH of the resultant solution. However, since carbon dioxide is produced the resultant solution will be slightly acidic because of the reaction of carbon dioxide with water to form carbonic acid.

26 (e) (3 marks)
Outcomes Assessed: CH12–6, CH12–13
Targeted Performance Bands: 4-5

Criteria	Marks
• Calculates pH correctly	3
• Makes 1 error only in calculations	2
• Show some correct calculations	1

Sample answer
Moles NaOH added = (240/1000) x 0.50 = 0.120 mol
Moles H_2SO_4 added = (60/1000) x 0.20 = 0.012 mol
Moles H^+ added = 2 x 0.012 = 0.024 mol
Excess moles OH^- after neutralisation = 0.120 – 0.024 = 0.096 mol

Volume of final solution = 300 mL
Conc NaOH in final mixture = 0.096/0.300 = 0.320 mol/L
pOH = 0.495

pH = 14.000 – 0.495 = 13.51

Question 27 (8 marks)
27 (a) (2 marks)
Outcomes Assessed: CH12–5, CH12–13
Targeted Performance Bands: 2-4

Criteria	Marks
● Identifies chlorous acid as the strongest acid AND determines the pK_a value for chlorous acid	2
● Identifies chlorous acid as the strongest acid OR determines the pK_a value for the identified acid	1

Sample answer
Chlorous acid
$pK_a = -\log(K_a) = -\log(1.1 \times 10^{-2}) = 1.96$ (2 s.f.) (same rule for s.f. in pK_a calculations as in pH; see below)

27 (b) (2 marks)
Outcomes Assessed: CH12–5, CH12–13
Targeted Performance Bands: 3-6

Criteria	Marks
● Calculates the pH to 2 s.f.	2
● Shows some correct working and reasoning	1

Sample answer
$HCOOH\ (aq) + H_2O\ (l) \rightleftharpoons HCOO^-\ (aq) + H_3O^+\ (aq)$

$$K_a\ HCOOH = \frac{[HCOO^-][H_3O^+]}{[HCOOH]} = 1.8 \times 10^{-4}$$

Let x moles of HCOOH ionise, forming x moles of H_3O^+

$$K_a\ HCOOH = \frac{[x][x]}{[0.010 - x]} = 1.8 \times 10^{-4}$$

Assume x will be small by comparison with 0.010
Hence $[x]^2 = 1.8 \times 10^{-4} \times 0.010 = 1.8 \times 10^{-6}$
$[H_3O^+] = \sqrt{(1.8 \times 10^{-6})} = 0.0013416$ mol/L
Hence pH $= -\log_{10}(0.0013416) = 2.87$ (2 s.f.)

Note for teachers: In mathematical terms, the number to the left of the decimal point in a logarithm is called the characteristic and the number to the right of the decimal point is called the mantissa. The mantissa has as many significant figures as the number from which the logarithm was determined. In this case there are 2 s.f. in the data given.
Hence $[H_3O^+] = 0.0013416$ pH = 2.87

27 (c) (4 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–13
Targeted Performance Bands: 3-6

Criteria	Marks
● Calculates the pH to 2 s.f. ● Explains why this mixture is classified as a buffer	4
● Calculates the pH with correct steps but mathematical error ● Explains why this mixture is classified as a buffer	3
● Determines the $[H_3O^+]$ in the buffer AND explains why this mixture is classified as a buffer	2
● Determines the $[H_3O^+]$ in the buffer OR explains why this mixture is classified as a buffer	1

Sample answer

$HCOOH\ (aq) + H_2O\ (l) \rightleftharpoons HCOO^-\ (aq) + H_3O^+\ (aq)$

$$K_a\ HCOOH = \frac{[HCOO^-][H_3O^+]}{[HCOOH]} = 1.8 \times 10^{-4}$$

Initial [HCOOH] = 0.010 mol/L
Initial $[HCOO^-]$ = 0.010 mol/L
On mixing, the volume is increased to 180 mL
After mixing, [HCOOH] = 0.010 x 100/180 = 0.00555 mol/L
After mixing, $[HCOO^-]$ = 0.010 x 80/180 mol/L = 0.00444 mol/L

Let x mol/L HCOOH ionise at equilibrium.

At equilibrium
[HCOOH] = (0.00555 – x) mol/L
$HCOO^-]$ = (0.00444 + x) mol/L
$[H_3O^+]$ = x mol/L

$$K_a\ HCOOH = \frac{[HCOO^-][H_3O^+]}{[HCOOH]} = 1.8 \times 10^{-4} = \frac{(0.00444 + x)(x)}{(0.00555 - x)}$$

Assume x is small by comparison with 0.00555 and with 0.00444 mol/L

$$K_a\ HCOOH = \frac{[HCOO^-][H_3O^+]}{[HCOOH]} = 1.8 \times 10^{-4} = \frac{(0.00444)(x)}{(0.00555)}$$

$[H_3O^+] = x = 1.8 \times 10^{-4} \times 0.00555/0.00444 = 0.000225$ mol/L

pH = 3.65

A buffer solution is one which will maintain an almost constant pH, even if small quantities of strong acid or base are added to it. As long as there are close to equal moles of equal concentration solutions making up the buffer mixture, and the acid and base are both only moderately strong as acids and bases, the solution will stay at close to the pH value 3.65, as calculated above. By Le Chatelier's Principle, if [x] is small by comparison with the concentrations of the acid and base, if the concentration of H^+ in the buffer mixture changes slightly, the proportions of HCOOH and $HCOO^-$ will change to keep the pH close to 3.65.

Question 28 (7 marks)
28 (a) (3 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–15
Targeted Performance Bands: 3-5

Criteria	Marks
● Identifies mass spectrometry AND ● Identifies Spectrum 1 as methyl ethanoate and Spectrum 2 as ethyl ethanoate AND ● Justifies the identification by analysing the fragmentation patterns	3
● TWO of the above	2
● ONE of the above	1

Sample answer
The instrumental analysis used is mass spectrometry.

The 2 compounds have similar structure but different chain length and hence different molecular weight. The parent ion in Spectrum 1 is at 74 and in Spectrum 2 at 88. These m/z ratios correspond to the positive ions formed from methyl ethanoate (molecular weight = 74) and ethyl ethanoate (molecular weight 88) respectively, when 1 electron has been removed to form a +1 ion.

28 (b) (1 mark)
Outcomes Assessed: CH12–7, CH12–14
Targeted Performance Bands: 3-5

Criteria	Mark
● Identifies the homologous series as esters	1

Sample answer
Ethyl ethanoate and methyl ethanoate are both esters

28 (c) (3 marks)

Outcomes Assessed: CH12–7, CH12–14

Targeted Performance Bands: 2-5

Criteria	Marks
• Identifies that soaps are manufactured from long-chain esters in fats and oils AND • Outlines the process of saponification including details of the chemical reaction AND • Outlines the process of separation of soap from by-products	3
• TWO of the ABOVE	2
• ONE of the ABOVE	1

Sample answer

Methyl ethanoate and ethyl ethanoate are esters.

Fats and oils are esters of glycerol. Three molecules of a long-chain acid (such as stearic acid, $CH_3 - (CH_2)_{16} - COOH$) combine with one molecule of glycerol (a tri-alcohol) to form the tri-ester.

The structure of the ester, glyceryl tristearate, is shown below

$$\begin{array}{l} H_2C - O - CO - (CH_2)_{16} - CH_3 \\ \quad | \\ HC - O - CO - (CH_2)_{16} - CH_3 \\ \quad | \\ H_2C - O - CO - (CH_2)_{16} - CH_3 \end{array}$$

This fat is hydrolysed by the reaction with a strong base, such as sodium hydroxide. The mixture is heated over a period of time and the solid soap formed is physically separated from the liquid glycerol.

The equation for the saponification of glyceryl tristearate.

$$\begin{array}{l} H_2C - O - CO - (CH_2)_{16} - CH_3 \\ \quad | \\ HC - O - CO - (CH_2)_{16} - CH_3 \\ \quad | \\ H_2C - O - CO - (CH_2)_{16} - CH_3 \end{array} + 3NaOH \rightarrow \underset{\text{sodium stearate}}{3CH_3 - (CH_2)_{16} - COO^- \ Na^+} + \underset{\text{glycerol}}{\begin{array}{l} H_2C - OH \\ \quad | \\ HC - OH \\ \quad | \\ H_2C - OH \end{array}}$$

The soap is sodium stearate, the sodium salt of the long-chain acid. Glycerol is the useful by-product of the industrial reaction process.

The soap must be separated from the by-product glycerol by adding salt (to separate the soap from the glycerol and water), filtering off the soap (or decanting the liquids).

Question 29 (9 marks)
29 (a) (2 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–15
Targeted Performance Bands: 3-5

Criteria	Marks

● From the 3100-4000 cm^{-1} region:
  ● Identifies that there are no –OH bonds in the molecule so the compound is not an alcohol or acid
● From the 1650-1700 cm^{-1} region:
  ● Identifies that a carbonyl group is in the molecule so the molecule is likely to be an aldehyde or ketone
	2

● Identifies that the molecule is NOT an alcohol OR ● Identifies that the compound is not an acid OR ● Identifies that the compound contains a carbonyl group	1

Sample answer
The compound contains carbon, hydrogen and oxygen (given in question). We know from the absence of characteristic absorption in the 3100-4000 cm^{-1} region, that the compound is not an acid or an alcohol as there is no evidence of –OH functional group in acids or alcohols in the 3100-4000 cm^{-1} range as the broad absorption region characteristic of acids or alcohols is absent.

It is likely to be an alkanal or an alkanone, given that it has only 1 oxygen and is not an ester, (as has only 1 oxygen).

There is positive indication of a carbonyl group (as evidenced by the absorption in the 1650-1700 cm^{-1} region.

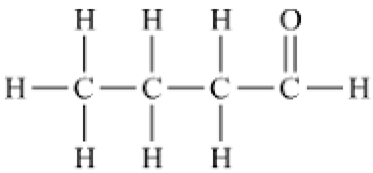
It does not contain carbon-carbon double or triple bonds as it does not react with bromine water.

29 (b) (2 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–14, CH12–15
Targeted Performance Bands: 3-5

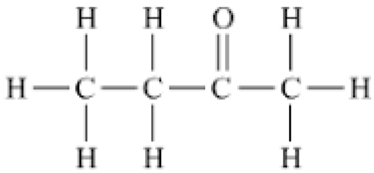
Criteria	Marks
● Draws 2 possible structures	2
● Draws 1 possible structure	1

Sample answer

Butanal



Butanone



Both structures would result in 4 distinct peaks on a ^{13}C-NMR spectrum. Note: butanal can have a branched carbon chain but that would only have 3 distinct peaks.

29 (c) (3 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–15
Targeted Performance Bands: 3-6

Criteria	Marks
● Identifies THREE pieces of information from the ^{1}H-NMR spectrum	3
● Identifies TWO pieces of information from the ^{1}H-NMR spectrum	2
● Identifies ONE piece of information from the ^{1}H-NMR spectrum	1

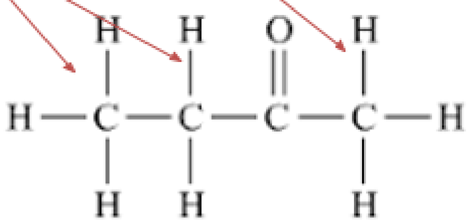
Sample answer
The spectrum shows that the compound has the 8 hydrogen atoms in 3 different environments.

There are 3 hydrogens which do not have another hydrogen atom on an adjacent atom. This corresponds to a CH_3–CO– structure as seen in butanone.

There are 3 hydrogens which have 2 hydrogens on an adjacent atom. This corresponds to a molecule with an ethyl group, –CH_2CH_3.

There are 2 hydrogens which have 3 hydrogen on adjacent atoms.

Butanone



Hence the unknown is butanone.

29 (d) (2 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–14
Targeted Performance Bands: 3-4

Criteria	Marks
● Describes a chemical test including method and observations, which could be used to distinguish between the 2 possible structures	2
● Identifies a chemical test which could be used to distinguish between the 2 possible structures	1

Sample answer
The sample could be reacted in a test tube with acidified potassium dichromate solution, which is orange. If, on heating and shaking, the orange colour changes to green, then the unknown would have been oxidised. This would have indicated that the unknown was butanal.

If no colour change occurs, the unknown is butanone.

Section 1

Question	Marks	Content	Syllabus Outcomes	Targeted Performance Bands
1	1	Mod 7: Nomenclature	CH12–7, CH12–14	2-3
2	1	Mod 6: Quantitative Analysis	CH12–6, CH12–13	3-4
3	1	Mod 8: Chemical Synthesis and Design	CH12–5, CH12–15	3-4
4	1	Mod 5: Factors that Affect Equilibrium	CH12–4, CH12–12	3-4
5	1	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	3-4
6	1	Mod 6: Using the Br□nsted-Lowry Theory	CH12–7, CH12–13	3-4
7	1	Mod 7: Analysis of Organic Acids and Bases	CH12–4, CH12–14	3-4
8	1	Mod 5: Calculating the Equilibrium Constant	CH12–6, CH12–12	3-4
9	1	Mod 5: Factors that Affect Equilibrium	CH12–5, CH12–12	3-4
10	1	Mod 6: Using the Br□nsted-Lowry Theory	CH12–6, CH12–13	3-4
11	1	Mod 8: Analysis of Organic Substances	CH12–6, CH12–15	3-4
12	1	Mod 8: Analysis of Inorganic Substances	CH12–6, CH12–15	3-4
13	1	Mod 7: Nomenclature	CH12–7, CH12–14	3-4
14	1	Mod 6: Quantitative Analysis	CH12–5, CH12–13	3-4
15	1	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	3-4
16	1	Mod 7: Reactions Involving Hydrocarbons	CH12–5, CH12–14	4-5
17	1	Mod 5: Solution Equilibria	CH12–6, CH12–12	5-6
18	1	Mod 5: Factors that Affect Equilibrium	CH12–5, CH12–12	5-6
19	1	Mod 7: Alcohols	CH12–4, CH12–14	5-6
20	1	Mod 6: Quantitative Analysis	CH12–6, CH12–13	5-6

Section II

Question	Marks	Content	Syllabus Outcomes	Targeted Performance Bands
21 (a)	2	Mod 5: Factors that Affect Equilibrium	CH12–4, CH12–7, CH12–12	2-4
21 (b)	2	Mod 5: Factors that Affect Equilibrium	CH12–4, CH12–7, CH12–12	3-5
21 (c)	2	Mod 5: Factors that Affect Equilibrium	CH12–4, CH12–7, CH12–12	2-4
21 (d)	2	Mod 5: Static and Dynamic Equilibrium	CH12–7, CH12–12,	2-3
22 (a)	2	Mod 5: Factors that Affect Equilibrium	CH12–4, CH12–7, CH12–12	3-5
22 (b)	2	Mod 5: Factors that Affect Equilibrium	CH12–4, CH12–7, CH12–12	3-4
22 (c)	2	Mod 5: Factors that Affect Equilibrium	CH12–4, CH12–7, CH12–12	3-5
23 (a)	3	Mod 7: Nomenclature	CH12–4, CH12–7, CH12–14	3-5
23 (b)	4	Mod 7: Hydrocarbons, Reactions of Organic Acids and Bases	CH12–5, CH12–7, CH12–14	2-6
23 (c)	2	Mod 7: Reactions of Organic Acids and Bases	CH12–4, CH12–7, CH12–14	3-4
23 (d)	4	Mod 7: Reactions of Organic Acids and Bases	CH12–4, CH12–7, CH12–14	2-5
24 (a)	4	Mod 8: Analysis of Inorganic Substances	CH12–2, CH12–7, CH12–15	2-5
24 (b)	3	Mod 8: Analysis of Inorganic Substances	CH12–7, CH12–15	2-4
24 (c)	3	Mod 8: Analysis of Inorganic Substances	CH12–4, CH12–7, CH12–15	3-5
25 (a)	3	Mod 5: Solution Equilibria	CH12–6, CH12–12	3-6
25 (b)	3	Mod 5: Solution Equilibria	CH12–6, CH12–12	3-6
26 (a)	2	Mod 6: Quantitative Analysis	CH12–3, CH12–7, CH12–13	2-4
26 (b)	4	Mod 6: Quantitative Analysis	CH12–3, CH12–7, CH12–13	2-5
26 (c)	2	Mod 6: Quantitative Analysis	CH12–4, CH12–13	2-4
26 (d)	2	Mod 6: Quantitative Analysis	CH12–4, CH12–7, CH12–13	2-4
26 (e)	3	Mod 6: Quantitative Analysis	CH12–6, CH12–13	2-5

Question	Marks	Content	Syllabus Outcomes	Targeted Performance Bands
27 (a)	2	Mod 6: Quantitative Analysis	CH12–5, CH12–13	2-4
27 (b)	2	Mod 6: Quantitative Analysis	CH12–5, CH12–13	3-6
27 (c)	4	Mod 6: Quantitative Analysis	CH12–5, CH12–7, CH12–13	3-6
28 (a)	3	Mod 8: Analysis of Organic Substances	CH12–5, CH12–7, CH12–15	3-5
28 (b)	1	Mod 7: Reactions of Organic Acids and Bases	CH12–7, CH12–14	2-3
28 (c)	3	Mod 7: Reactions of Organic Acids and Bases	CH12–7, CH12–14	2-5
29 (a)	2	Mod 8: Analysis of Organic Substances	CH12–5, CH12–7, CH12–15	3-5
29 (b)	2	Mod 7: Nomenclature Mod 8: Analysis of Organic Substances	CH12–5, CH12–7, CH12–14, CH12–15,	3-5
29 (c)	3	Mod 7: Products of Reactions Involving Hydrocarbons Mod 8: Analysis of Organic Substances	CH12–5, CH12–7, CH12–14, CH12–15	3-6
29 (d)	2	Mod 7: Reactions of Organic Acids and Bases	CH12–5, CH12–7, CH12–14	3-4