2
Centre Number

Student Number

ABBOTSLEIGH

2022 **TRIAL HIGHER SCHOOL CERTIFICATE EXAMINATION**

Chemistry

General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- A formulae sheet, data sheet and Periodic Table are provided at the back of this paper

Total marks: 100

Section I – **20 marks** (pages 2–8)

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

Section II – **80 marks** (pages 9–36)

- Attempt Questions 21–33
- Allow about 2 hours and 25 minutes for this section

Section I

20 marks
Attempt Questions 1–20
Allow about 35 minutes for this part.

Use the multiple-choice answer sheet at the back of this paper for Questions 1–20.

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1 Which of the following analyses is qualitative only?

A. Analysis of the blood alcohol content of a motorist.

B. Measurement of the acid content of orange juice.

C. Detection of strontium ions in polluted water.

D. Use of gravimetric analysis to determine the molar mass of an organic compound.

2 Bromine water can be used in the school laboratory to distinguish between which of the following types of organic compounds.

A. alkene and alkyne

B. alkane and alkene

C. carboxylic acid and alcohol

D. primary alcohol and tertiary alcohol

3 How can dynamic chemical equilibrium best be described?

A. An open system in which the rate of the forward reaction equals the rate of the reverse reaction.

B. A closed system in which the rate of the forward reaction equals the rate of the reverse reaction.

C. A closed system in which all reactions have ceased and so concentrations of all species remain constant.

D. An open system in which all reactions have ceased and so concentrations of all species remain constant.

4 Which of the following is a limitation of the Brønsted-Lowry theory of acids?

A. The theory did not classify HCl as an acid.

B. The theory cannot explain non-neutral salt solutions.

C. The theory cannot explain neutralisation reactions in non-aqueous solvents.

D. The theory cannot explain neutralisation reactions where proton transfer does not occur.

5 The basic principle behind the analysis of compounds using infrared spectroscopy is the

A. movement of electrons in the molecule.

B. movement of electrons between different energy levels.

C. absorption of radiation by nuclei placed in a magnetic field.

D. bending or stretching vibrations of covalent bonds in molecules.

6 To prepare a series of standards for the calibration of an atomic absorption spectrometer a stock solution of 0.100 M nickel (II) sulfate was required.

To prepare the stock solution

A. 15.5 g of $NiSO_4$ should be dissolved in 500.0 mL of distilled water in a beaker.

B. 7.74 g of $NiSO_4$ should be added to 500.0 mL of distilled water in a volumetric flask.

C. 7.74 g of $NiSO_4$ should be transferred to a 500.0 mL volumetric flask, the solid dissolved in a small volume of distilled water and the volume made up to the calibration mark with distilled water.

D. 15.5 g of $NiSO_4$ should be transferred to a 500.0 mL volumetric flask, the solid dissolved in a small volume of distilled water and the volume made up to the calibration mark with distilled water.

7 Which of the following is NOT a conjugate acid-base pair?

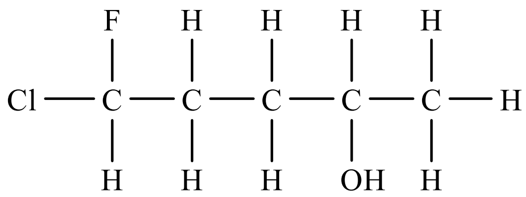
A. NH_3 and NH_4^+

B. H_3O^+ and OH^-

C. HS^- and H_2S

D. H_2O and OH^-

8 What is the correct IUPAC name for the compound with formula shown below?



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

9 Which of the following does NOT have an isomer?

A. ethene

B. pentane

C. but-1-ene

D. cyclopropane

10 20.00 mL of 0.10 $molL^{-1}$ of a strong diprotic acid was diluted to 250.0 mL with distilled water.

What was the pH of the final solution?

A. 8.0×10^{-3}

B. 1.6×10^{-2}

C. 1.8

D. 2.1

11 In which solution will PbI_2 have the lowest molar solubility?

$$PbI_2(s) \rightleftharpoons Pb^{2+}(aq) + 2I^-(aq) \qquad K_{sp} = 9.8 \times 10^{-9}$$

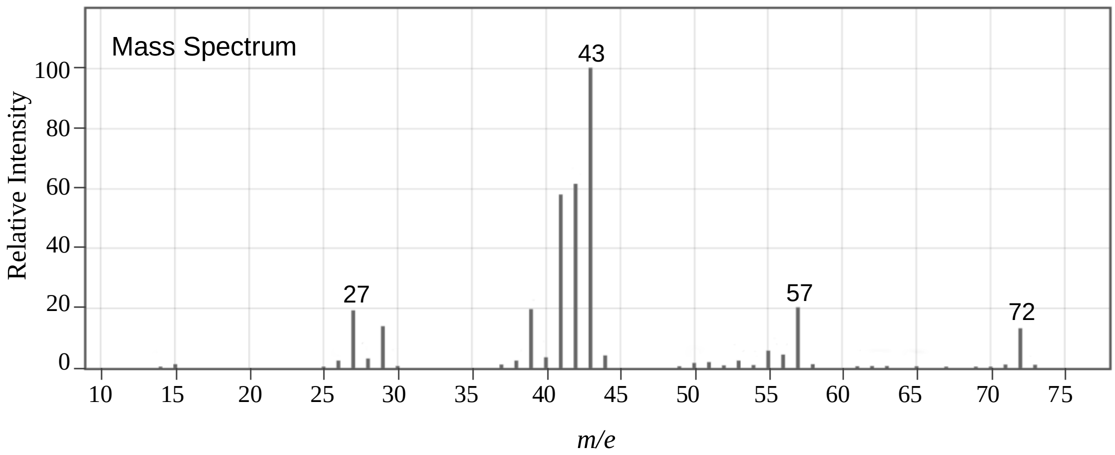
A. 0.02 M $KI(aq)$

B. 0.02 M $CaI_2(aq)$

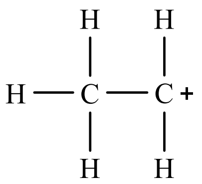
C. 0.02 M $Pb(NO_3)_2(aq)$

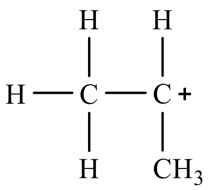
D. 0.02 M $Pb(ClO_4)_2(aq)$

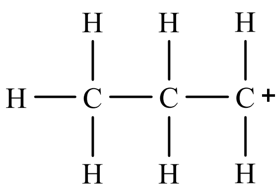
12 The mass spectrum for pentane is shown below.



Which of the following ions would most likely give rise to the base peak in this spectrum?

A. 

B. 

C. 

D. $[CH_3CH_2CH_2CH_2CH_3]^{+}$

13 A student weighed out 2.5 g of fertiliser, dissolved it in water and added 150.0 mL of 0.25 M barium chloride solution. The precipitate of barium sulfate, after being filtered off and dried to constant mass, weighed 3.8 g.

What was the percentage by mass of sulfate in the fertiliser?

A. 63

B. 66

C. 69

D. 95

14 Which of the following alcohols have been classified correctly?

	Names of alcohols and their classification		
	Primary	*Secondary*	*Tertiary*
A.	butan-1-ol	2-methylpropan-1-ol	2-methylpropan-2-ol
B.	propan-1-ol	pentan-3-ol	2-methylpropan-2-ol
C.	2,2-dimethylpropan-1-ol	butan-2-ol	ethanol
D.	propan-2-ol	butan-2-ol	pentan-3-ol

15 Which is the INCORRECT statement about the reaction when solid magnesium burns in air?

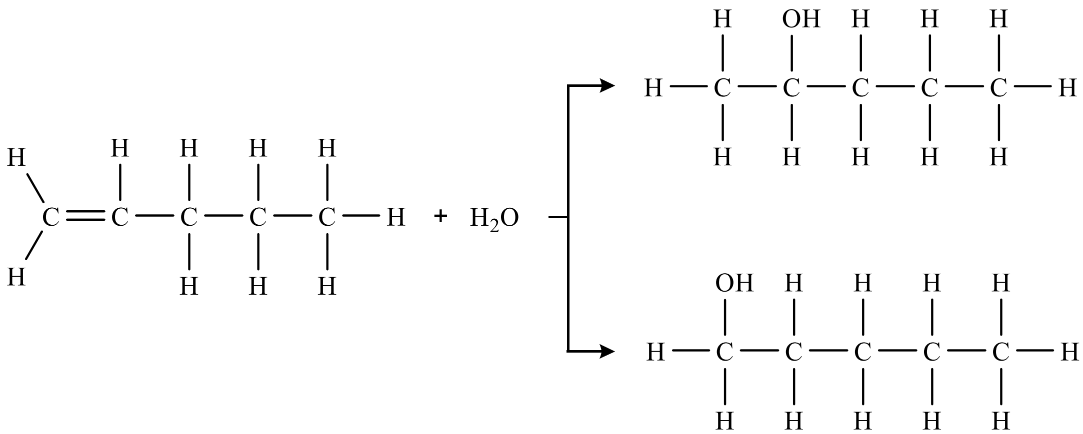
A. The reaction is described as combustion.

B. The enthalpy and entropy changes for the reaction are both negative.

C. The enthalpy change is negative while the change in entropy is positive.

D. The reaction does not reach equilibrium and the system is classified as open.

16 When pent-1-ene undergoes an addition reaction water, two products are formed:



Which of the following alkenes will also produce two products when they undergo an addition reaction with water?

A. ethene

B. but-2-ene

C. oct-2-ene

D. hex-3-ene

17 Sulfur trioxide is produced by the reaction of sulfur dioxide with oxygen:

$$2SO_2(g) + O_2(g) \longrightarrow 2SO_3(g)$$

8.0 mol of $SO_2(g)$ was placed in a 2.0 L container with 4.0 mol of $O_2(g)$ and allowed to reach equilibrium. At equilibrium, the concentration of $SO_3(g)$ was 2.0 mol L^{-1}.

What is the value of K_{eq} under these conditions?

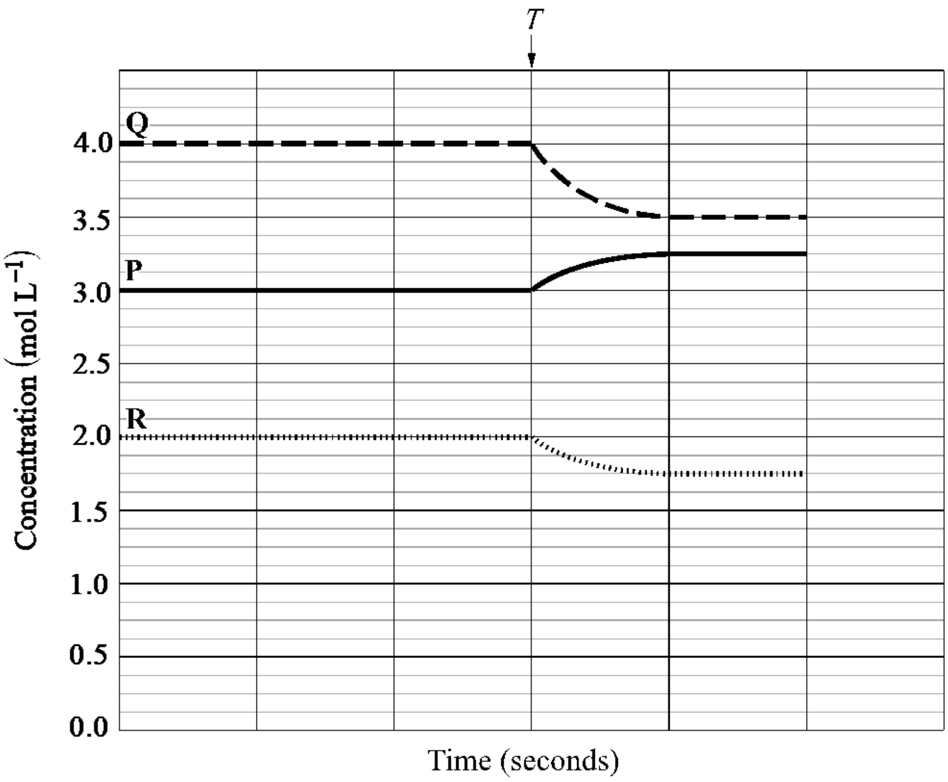
A. 0.037

B. 0.11

C. 1.0

D. 2.0

18 The following concentration–time graph refers to a mixture of three gases, **P**, **Q** and **R**, in an enclosed 5.0 L container. At time *T* the mixture is heated.



The equilibrium system that represents the graph is

A. $P(g) \rightarrow 2Q(g) + R(g)$ and the forward reaction is exothermic.

B. $2Q(g) \rightarrow P(g) + R(g)$ and the forward reaction is endothermic.

C. $2Q(g) + R(g) \rightarrow P(g)$ and the forward reaction is exothermic.

D. $P(g) + 2Q(g) \rightarrow R(g)$ and the forward reaction is endothermic.

19 An aqueous solution of sodium dihydrogen phosphate (NaH_2PO_4) has a pH less than 7 due to the following equilibrium being established in solution:

$$H_2PO_4^-(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^+(aq)$$

Which statement best explains this observation?

A. $H_2PO_4^-(aq)$ is a strong acid.

B. $H_2O(l)$ is a stronger base than $H_2PO_4^-(aq)$.

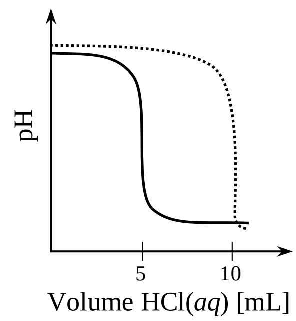
C. $H_2PO_4^-(aq)$ is a weaker base than $HPO_4^{2-}(aq)$.

D. The conjugate base of $H_2PO_4^-(aq)$ is a stronger base than $H_2O(l)$.

20 When 0.150 M HCl(*aq*) was added to a 20.0 mL sample of aqueous $Ba(OH)_2(aq)$, it generated the titration curve shown as a **solid line**.

If the same number of moles of $Ba(OH)_2$, but initially at a volume of 10.0 mL, were titrated with 0.150 M HCl, which of the **dotted line** curves would best describe this new titration?

A.



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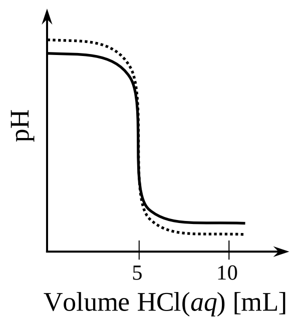

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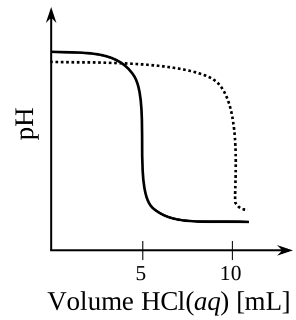
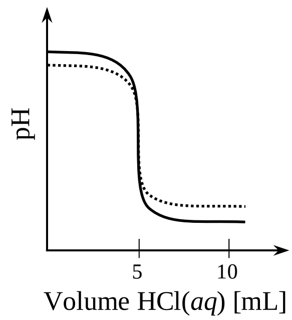


D.



2022 TRIAL HSC EXAMINATION

2

Centre Number

Student Number

Chemistry

Section II Answer Booklet

80 marks
Attempt Questions 21–33
Allow about 2 hours and 25 minutes for this section

Instructions

- Write your Student Number at the top of this page.
- 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 at the back of this booklet. If you use this space, clearly indicate which question you are answering.

Please turn over

Question 21 (5 marks)

Consider the following equilibrium system.

$$\underset{\text{yellow}}{Fe^{3+}(aq)} + \underset{\text{colourless}}{SCN^{-}(aq)} \rightleftharpoons \underset{\text{blood-red}}{[FeNCS]^{2+}(aq)} \qquad \Delta H < 0$$

The solution is blood-red.

(a) On addition of 1.0 M KOH(*aq*) to the equilibrium system, the blood-red colour of the solution faded and $Fe(OH)_3(s)$ formed as a brown precipitate. **3**

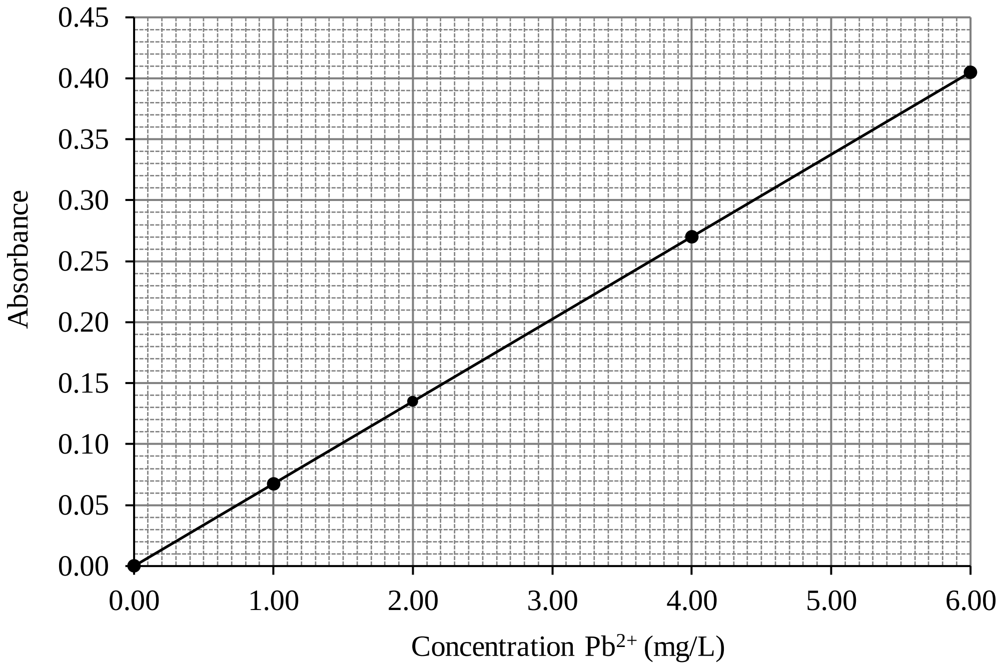
Explain the colour change of the solution in terms of collision theory and rate of reaction.

(b) Justify ONE way to shift the equilibrium to the right, without adding any further reagents to the equilibrium system. **2**

Question 22 (3 marks)

The Australian health guideline for lead in garden soil is no more than 300 mg/kg. Lead is a neurotoxin that affects childhood development. A sample of soil was suspected of containing high levels of lead, which is a hazardous heavy metal. **3**

To determine the concentration of lead in the soil atomic absorption spectroscopy (AAS) was used using an appropriate lamp with a wavelength of 218 nm.



A 2.00 g sample of the soil was taken and dissolved in acid and diluted to a total volume of 50.0 mL. The absorbance of the sample was determined to be 0.25.

Using the graph, calculate the concentration of lead in the soil and determine if it is safe to grow vegetables.

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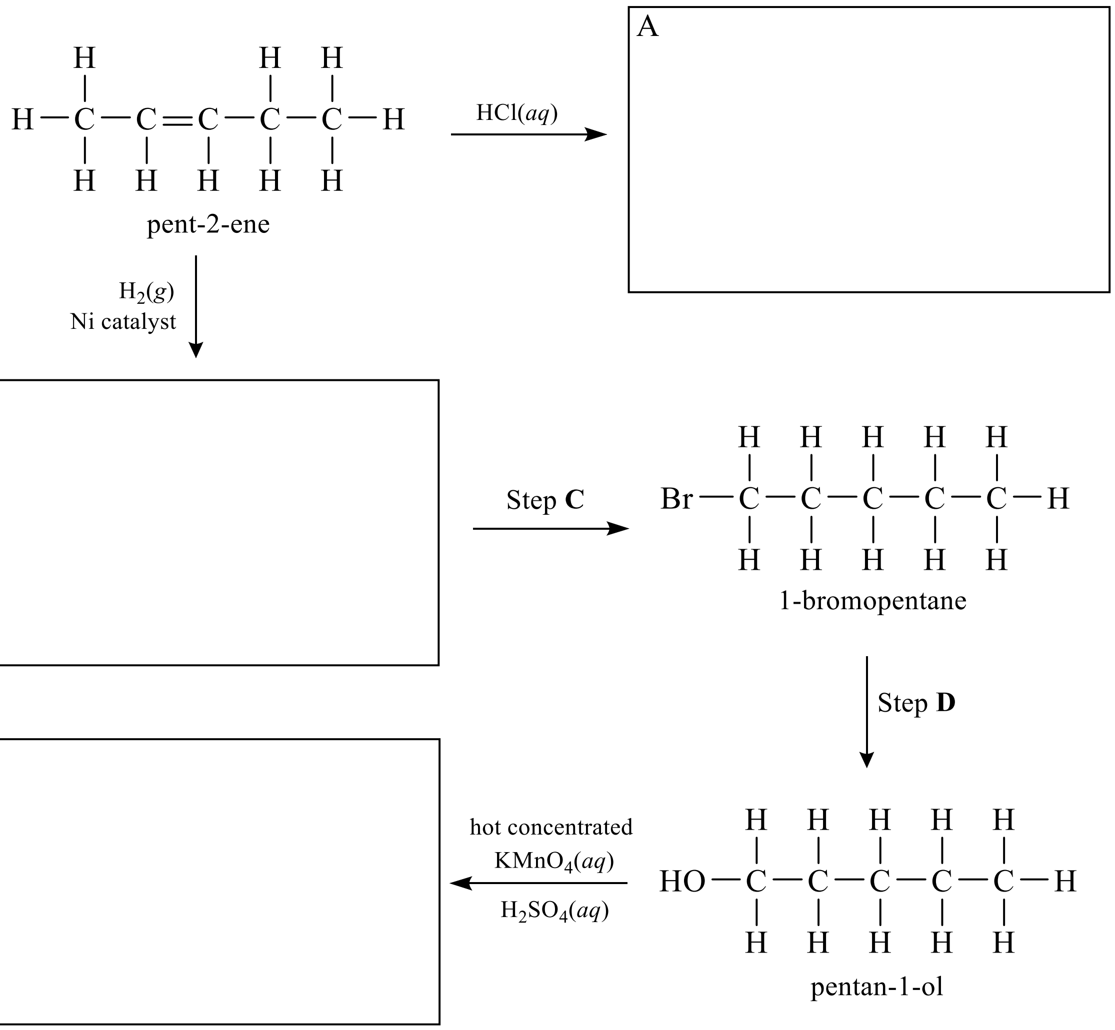
Question 23 (7 marks)

A sequence of chemical reactions, starting with pent-2-ene, is shown in the flow chart.

(a) Complete the flow chart by drawing structural formulae for compounds A, B and E. **3**



(b) Complete the table to identify the reagent and conditions required at Steps **C** and **D** in the flow chart above. **2**

Step	*Reagent and Conditions*
C	
D	

Question 23 continues on page 13

(c) If these reactions were carried out in the school laboratory, justify ONE precaution that would be needed. **2**

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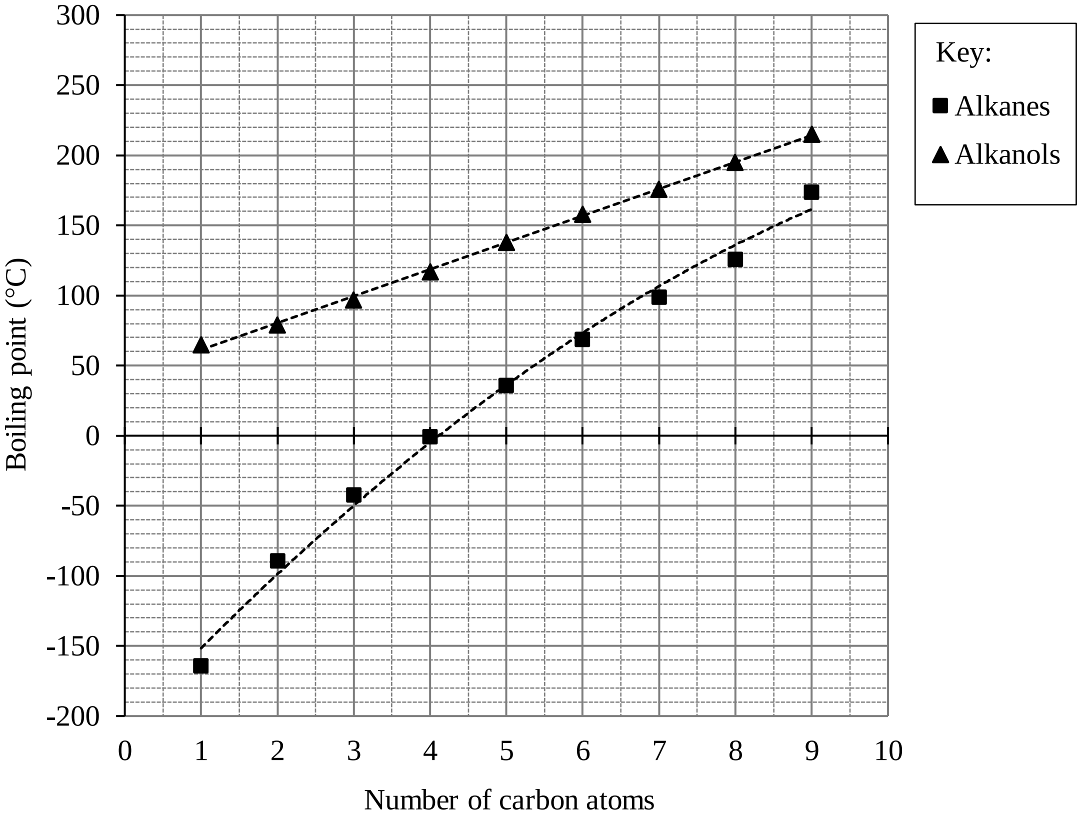
End of Question 23

Please turn over

Question 24 (8 marks)

The graph below shows how the boiling point of two different straight chain homologous series, alkanes and alkanols, vary with number of carbon atoms.



(a) State and explain the trends in boiling point shown in the graph for both alkanes and alkanols. **4**

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Question 24 continues on page 15

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(b) The boiling points of various straight chain alkanoic acids are given in the table below: **2**

Carbon atoms	*Boiling point* (°C)
1	101
2	118
3	141
4	164
5	186
6	205
7	223
8	239
9	259

Graph this data on the grid on page **14** to show how the boiling points of alkanoic acids compare with the other two homologous series.

(c) Explain why your graph for alkanoic acids sits above that of alkanols. **2**

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End of Question 24

Question 25 (6 marks)

During an outdoor school camp, a group of students used a cooking stove that is fuelled with liquid butane cylinders. The cooking stove was used to heat a kettle containing 950 mL of water at 12°C.

(a) Calculate the mass of butane required to heat the water to its boiling point given that only 40% of the energy provided by the combustion reaction of butane actually goes to heating the water. **4**

The enthalpy of combustion of butane is -2878 kJ mol^{-1}.

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Question 25 continues on page 17

Question 25 (continued)

(b) Describe TWO environmental implications of using hydrocarbons like butane. **2**

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End of Question 25

Question 26 (4 marks)

Three solutions of equal concentration of sodium nitrate, ammonium nitrate and sodium propanoate were prepared, and their pH values were measured.

(a) List the solutions in order from lowest to highest pH. **1**

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(b) Using your knowledge of acids and bases, justify the order given in (a). **3**

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Question 27 (5 marks)

On her first day in the *AbbSure* testing facility a trainee analytical chemist was given a single sample of river water for analysis. The river is known to be contaminated with a single metal ion. The supervisor told the trainee to carry out tests to determine which one of the following ions are present in the river from barium, calcium, magnesium, lead or silver. **5**

This is the process she followed:

1. She gently boiled 500 mL of the river water until the volume had reduced to 10 mL to increase the concentration of the ion present.
2. She measured three separate 1 mL samples of the water into micro test tubes.
3. She carried out the tests in the order shown below, adding 3 drops of the test reagent to the concentrated river water and recorded her observation for each test.

Test number	*Reagent added*	*Observation*
1	1 M $NaOH$	White precipitate
2	1 M H_2SO_4	White precipitate
3	1 M $NaCl$	No reaction

Based on her observations from these tests, the trainee reported to her supervisor that the water was contaminated with calcium ions.

Question 27 continues on page 19

Question 27 (continued)

Evaluate the validity of the procedure AND the conclusion made by the trainee analytical chemist.

Include a net ionic equation for the formation of one of the possible precipitates.

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End of Question 27

Question 28 (10 marks)

The parietal cells in the stomach secrete hydrochloric acid (HCl). The flow of acid increases when food enters the stomach which means if you eat or drink too much you can develop heartburn or indigestion. Antacids, such as TUMS are used to neutralise this excess acid.

The active ingredient in TUMS is calcium carbonate, $CaCO_3$, a base. There are also other ingredients, such as binders present in each tablet.

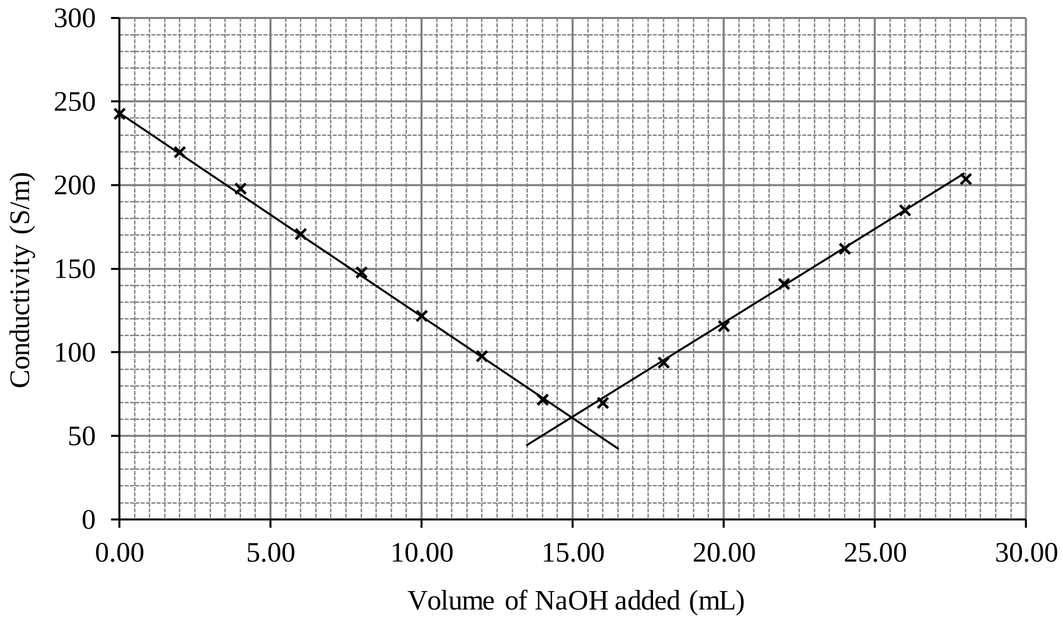
The following ***back titration*** procedure is used by quality control chemists to check the composition of every batch of TUMS tablets before they can be shipped from the manufacturer:

1. Add 1.30 g of finely ground tablet into a conical flask.
2. Pipette 25.00 mL of 1.073 M hydrochloric acid to the conical flask.
3. Stir for 5 minutes.
4. Add 10 mL of 1M sodium phosphate to the flask.
5. Heat gently with stirring for 10 minutes.
6. Titrate with 1.102 M sodium hydroxide using a conductivity probe.

Sodium phosphate is used to remove calcium ions from the solution so they do not interfere during Step 6.

The average data from the conductometric titration for one batch of TUMS tablets is shown below:

Conductometric Titration – HCl / NaOH



Question 28 continues on page 21

(a) The manufacturer of TUMS states that the quantity of calcium carbonate in each tablet should be between 38 – 40% by mass. **7**

This can be calculated using the formula:

$$\%\ \text{mass } CaCO_3 = \frac{\text{mass } CaCO_3}{\text{mass tablet}} \times 100\%$$

Assess whether this batch of TUMS tablets is within the specified range.

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Question 28 continues on page 22

(b) When calcium carbonate is neutralised by hydrochloric acid some of the carbon dioxide gas produced dissolves in the solution. This results in the formation of carbonic acid, $H_2CO_3(aq)$, as shown below: **3**

$$CO_2(g) \rightleftharpoons CO_2(aq) \qquad \Delta H < 0$$

$$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) \qquad \Delta H < 0 \qquad K_{eq} = 3.1 \times 10^{-5} \text{ at } 25°C$$

Using this information and your knowledge of equilibrium and titration, evaluate the importance of *Step 5* in terms of the accuracy of the quality control analysis.

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End of Question 28

Question 29 (4 marks)

Carbon, as graphite, burns to form gaseous carbon dioxide.

Thermodynamic data (at 298 K) for the complete combustion of graphite is given below.

$$\Delta_c H^\circ = -393.5 \text{ kJ mol}^{-1}$$

$$\Delta_c S^\circ = 2.9 \text{ J K}^{-1} \text{ mol}^{-1}$$

(a) Calculate $\Delta_c G^\circ$ in kJ mol^{-1}. **2**

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(b) Use this data to explain why the combustion of graphite does not come to equilibrium but instead will always proceed to completion irrespective of the temperature at which the reaction takes place. **2**

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Question 30 (11 marks)

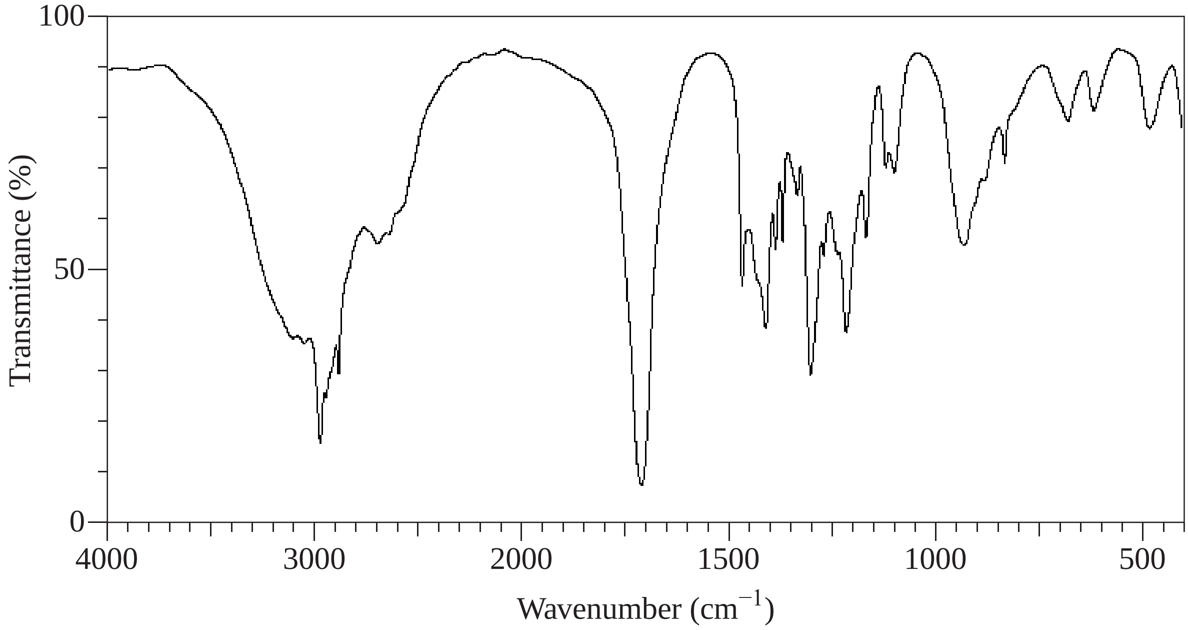
During a long overdue cleaning of the organic chemical storeroom a chemist finds a bottle of a clear colourless liquid simply labelled '$C_5H_{10}O_2$'.

Organic compounds are expensive, so she decides to have a sample of the liquid analysed to determine the molecular structure of the compound so the bottle can then be correctly labelled. The results of this analysis are shown.

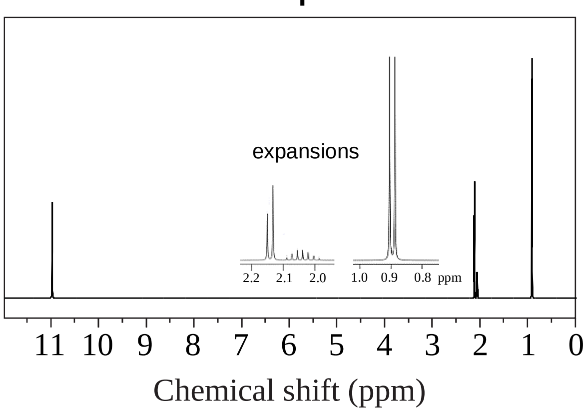
Chemical Tests

Reagent	*Observation*
Bromine water	No reaction
Acidified potassium permanganate	No reaction
Addition of sodium hydrogen carbonate	Bubbles of gas produced

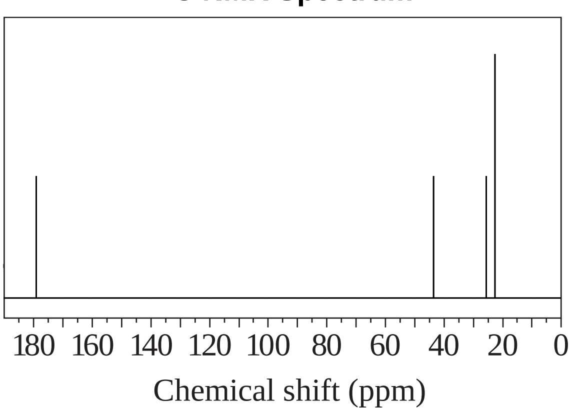
Infrared Spectrum



^{1}H NMR Spectrum



^{13}C NMR Spectrum



Question 30 continues on page 25

Question 30 (continued)

Data from ^{1}H NMR spectrum

Chemical Shift	*Relative peak area*	*Splitting pattern*
0.9	6	doublet
2.05	1	complex multiplet
2.15	2	doublet
11.0	1	singlet

^{1}H NMR chemical shift data

Type of proton		δ/ppm
$Si(C\mathbf{H}_3)_4$	(TMS)	0
$R-C\mathbf{H}_3$		0.7–1.3
$R-C\mathbf{H}_2-R$		1.2–1.5
$R-C\mathbf{H}R_2$		1.5–2.0
$\mathbf{H}_3C-CO-$	(aldehydes, ketones or esters)	2.0–2.5
$-C\mathbf{H}-CO-$	(aldehydes, ketones or esters)	2.1–2.6
$\mathbf{H}_3C-O-$	(alcohols or esters)	3.2–4.0
$-C\mathbf{H}-O-$	(alcohols or esters)	3.3–5.1
$R_2-C\mathbf{H}_2-O-$	(alcohols or esters)	3.5–5.0
$R-O\mathbf{H}$		1–6
$R_2C=C\mathbf{H}R$	(alkene)	4.5–7.0
$R-C\mathbf{H}O$	(aldehyde)	9.4–10.0
$R-COO\mathbf{H}$		9.0–13.0

Question 30 continues on page 26

Question 30 (continued)

(a) In the space provided, draw a structural formula for the organic compound, name the compound and justify your answer using relevant information from the chemical tests and each of the spectra. **7**

IUPAC Name : ....

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Question 30 continues on page 27

Question 30 (continued)

Question 30 continues on page 28

Question 30 (continued)

(b) Draw and name a straight chain isomer of the organic compound you have identified in part (a) and compare the infrared spectrum for the isomer with that of the organic compound from the storeroom. **4**

IUPAC Name : ....

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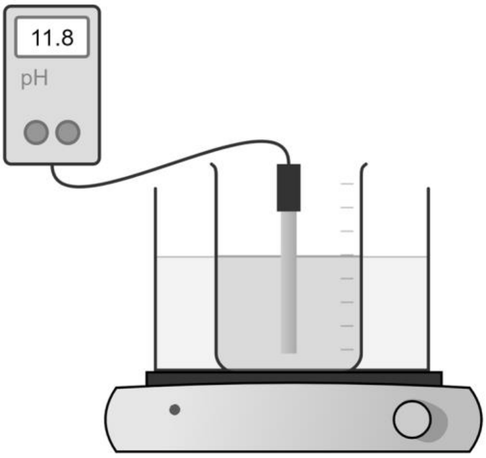
End of Question 30

Question 31 (3 marks)

A student slowly added a small mass of solid barium hydroxide to 100 mL of distilled water in a beaker placed in a water bath of temperature 25°C. The solution was stirred continuously and the pH of the solution constantly measured with a probe and data logger. **3**



60 seconds after the addition, the student thought they observed a slight cloudiness in the solution and assumed the solution was saturated. The pH of the mixture at this time was measured at 11.8 on the data logger as shown in the diagram above.

Use the data recorded by the student to determine if the solution was saturated at 60 seconds. Show your working.

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Question 32 (6 marks)

A student has four solutions:

Solution A	50 mL 1.0 M sodium acetate
Solution B	50 mL 1.0 M acetic acid
Solution C	50 mL 0.5 M hydrochloric acid
Solution D	50 mL 0.5 M sodium hydroxide

(a) When *Solution A* is mixed with *Solution B* a buffer is formed that has a pH of 4.74. **3**

Explain, without the use of calculations, why the pH only increases to 4.75 when 0.5 mL of 0.1 M sodium hydroxide is added to this buffer.

Include a chemical equation in your answer.

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Question 32 continues on page 31

Question 32 (continued)

(b) Justify why a buffer can be prepared from a mixture of *Solution B* and *Solution D* but not from a mixture of *Solution B* and *Solution C.* **3**

Support your answer with a chemical equation.

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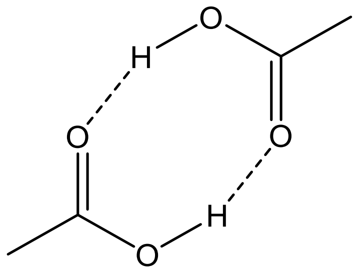
End of Question 32

Question 33 (8 marks)

Acetic acid, CH_3COOH, can exist as a dimer, $(CH_3COOH)_2$, in the gas phase. The dimer is a cyclic molecule that consists of two CH_3COOH monomers linked through hydrogen bonds, as in the diagram:



Dimer of acetic acid

The dimer decomposes to produce gaseous acetic acid according to the reaction:

$$(CH_3COOH)_2(g) \rightleftharpoons 2CH_3COOH(g) \qquad K_{eq} = 3.2 \times 10^{-4} \text{ at } 25°C$$

Acetic acid dimer, $(CH_3COOH)_2(g)$, is added to an empty sealed 1.0 L vessel at a concentration of 1.5×10^{-3} mol L^{-1} and this system is allowed to reach equilibrium at 25°C.

(a) Calculate the concentration of gaseous acetic acid $CH_3COOH(g)$ in the resulting gas mixture. **3**

Question 33 continues on page 33

Question 33 (continued)

(b) Calculate the percentage of the dimer that is converted into gaseous acetic acid at room temperature. **2**

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(c) If the pressure of the reaction system increased, explain whether formation of the monomer or dimer would be favoured. **3**

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End of Paper

Section II Extra writing space

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HSC CHEMISTRY

Assessment Task 4 Trial Examination

Marking Guidelines and Sample Responses

Section I: 20 marks

Multiple-choice Answer Key

Question	Answer	KU/WS
1	C	KU
2	B	KU
3	B	KU
4	D	KU
5	D	KU
6	C	WS
7	B	KU
8	C	KU
9	A	KU
10	C	WS

Question	Answer	KU/WS
11	B	KU
12	C	KU
13	A	WS
14	B	KU
15	C	KU
16	C	KU
17	C	WS
18	A	WS
19	B	KU
20	B	WS

Section II: 80 marks

Question 21(a) (3 marks) KU

Criteria	Marks
• Identifies that $[Fe^{3+}]$ decreases and so the frequency of collisions between reactant particles decreases and the rate of the forward reaction decreases. • Identifies the rate of the reverse reaction initially remains constant. • Identifies that the rate of the reverse reaction is proportionally greater than the forward reaction. • Links change in colour of solution to the shift in equilibrium and the decrease in the concentration of $[FeNCS]^{2-}$(*aq*)	3
• TWO of the above	2
• ONE of the above	1

Sample response:

The formation of the brown $Fe(OH)_3$(*s*) precipitate removes Fe^{3+} ions from solution. As a result, the frequency of collisions between reactant particles decreases and the rate of the forward reaction decreases.

The removal of Fe^{3+} ions from solution doesn't alter the frequency of collisions between products, so the rate of the reverse reaction initially remains constant. However, the rate of the reverse reaction is now proportionally greater than the rate of the forward reaction.

As a result, the equilibrium shifts left and so the concentration of $[FeNCS]^{2+}$(*aq*) decreases in solution, leading to the fading of the blood-red colour that was observed.

Explain is the verb so students should be sure to link the cause and effect

Cause: Decrease in Fe^{3+}(*aq*) sees rate of reverse reaction increases proportionally to the rate of the forward reaction.

Effect: Decrease in concentration of $[FeNCS]^{2+}$(*aq*) – leads to dissipation of the blood red colour.

Identifies that the frequency of collisions between product particles remains constant initially and so

Question 21(b) (2 marks) KU

Criteria	Marks
• Identifies a change that could be imposed on the equilibrium system to shift the equilibrium to the right. • Uses Le Châtelier's principle to justify the proposed change.	2
• Identifies a change that could be imposed on the equilibrium system to shift the equilibrium to the right.	1

Sample response:

If the temperature of the solution decreased by cooling the reaction system, this would see the equilibrium shift to the right.

This is because the reaction is exothermic ($\Delta H < 0$) in the forward direction, and so produces heat. A decrease in the temperature of the solution will see the reaction proceed in the forward direction, generating heat to counteract the change that was imposed on the system (LCP).

Question 22 (3 marks) Skills

Criteria	Marks
• Calculates the concentration of lead in the soil • Determines that the soil is safe to use	3
• Makes a mistake in the calculation that is traceable such as incorrect conversion of g to kg. • Determination of soil safety based on the incorrect calculation OR • Correctly calculates the concentration of lead AND does not determine the safety of the soil	2
• Provides some relevant information	1

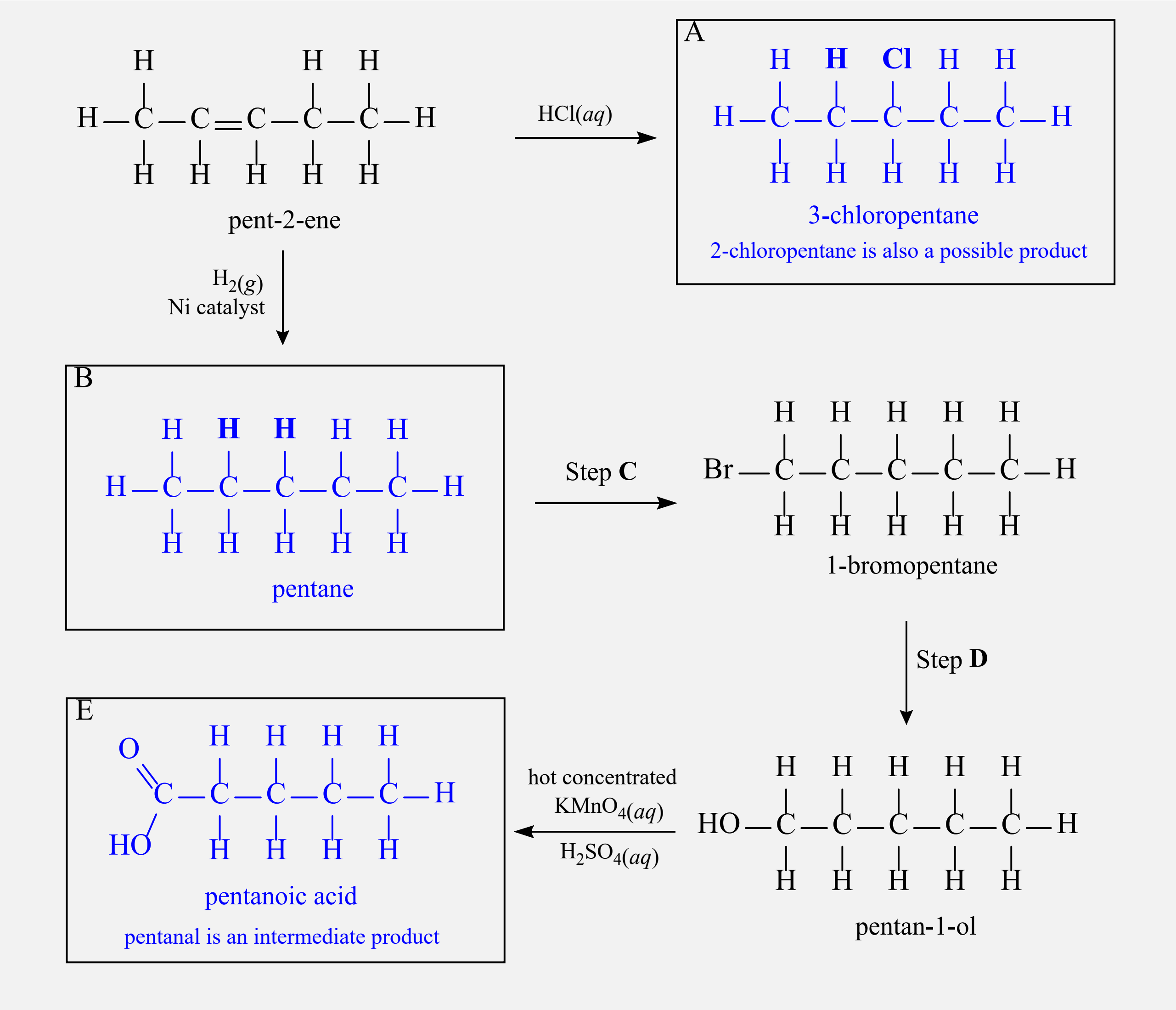
Sample response

Absorbance at 0.25 corresponds to concentration in mg/L of 3.7
3.7 * 0.05 = 0.185mg in 50 mL
2.0 g = 0.0020 kg
0.185 / 0.0020 = 92.5 mg/kg which is less than 300mg so the soil is safe

Question 23(a) (3 marks) KU

Criteria	Marks
• Correct structural formulae for all 3 compounds	3
• One error	2
• Two errors in structural formulae	1

Sample response:



Question 23(b) (2 marks) KU

Criteria	Marks
• 3 Correct reagents and conditions for C and D	2
• 2 Correct reagent and conditions for C or D	1
• 1 correct condition or reagent	0

Sample response

Step	*Reagent*	*Conditions*
C	Br-Br or Br_2	UV light
D	H_2O or NaOH(aq)	Ethanol (solvent) + heat

Question 23(c) (2 marks) Skills **Marker: SN**

Criteria	Marks
• One correct precaution AND related justification given	2
• Only precaution without justification	1

Sample response

- Keep organic chemicals away from open flame or sparks as it is highly flammable
- Store/use organic chemicals in a well-ventilated area as fumes are toxic/harmful

Question 24(a) (4 marks) KU

Criteria	Marks
• Identifies/states the trend of BOTH the alkanes and alkanols AND provides explanation for the difference in BP between them ○ BP of both alkanes and alkanols increase with the increasing number of C atoms ○ the alkanols have higher BP compared to alkanes with the same number of C atoms ○ lower BP of alkanes due to dispersion forces-less energy required to break IMF ○ higher BP of alkanols due to stronger hydrogen bond (more energy required to break) and dispersion forces	4
• One trend OR one explanation missing (3 of the above)	3
• Trends not mentioned OR explanation of bonds missing (only 2 of the above)	2
• Some relevant information	1

Sample response

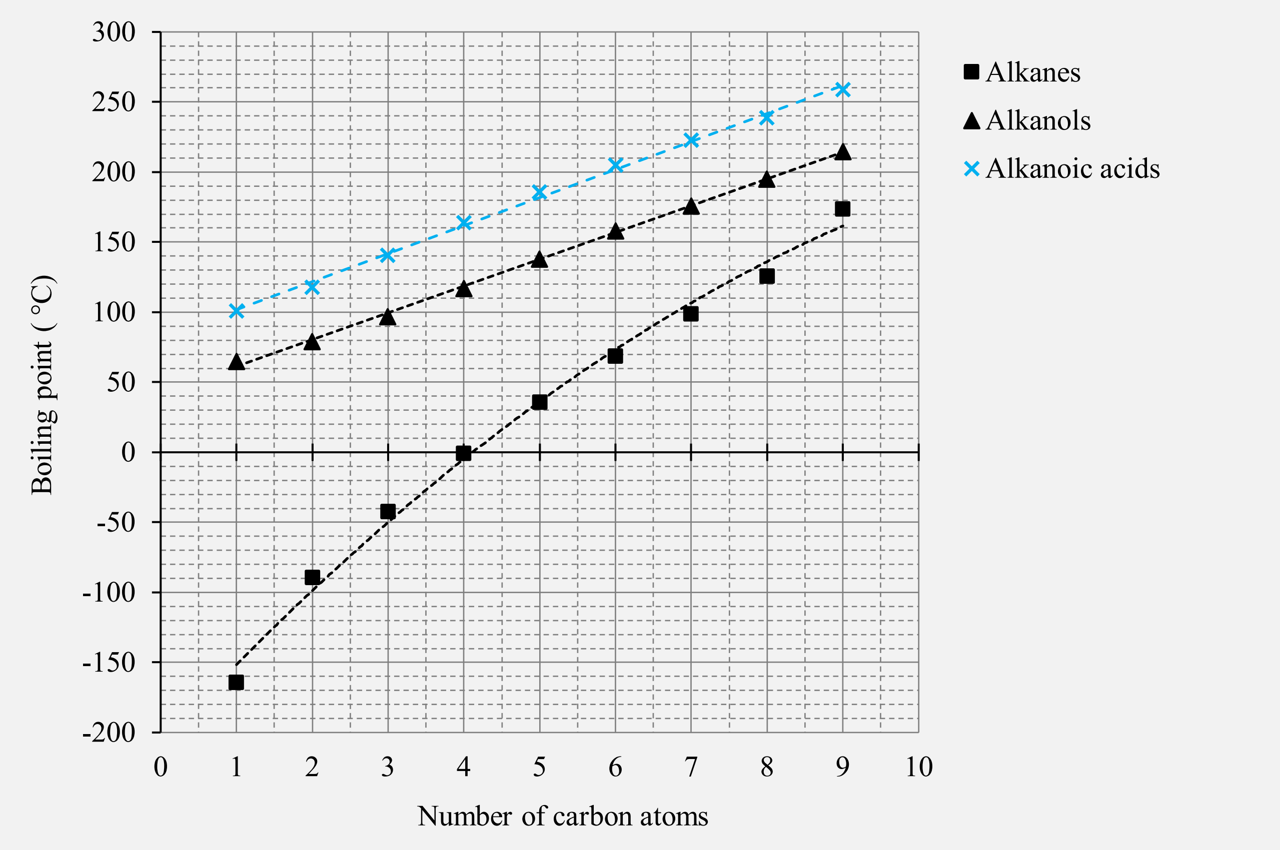
From the graph, the boiling points of both the alkanes and alkanols show a similar trend ie. as the number of carbon atoms increases, boiling point also increases in both groups (as the number of dispersion forces increases). Between the two, the alkanols have a higher boiling point compared to the alkanes. This is because in alkanes, dispersion forces are the main intermolecular forces present (less energy required to break). In alkanols, in addition to the dispersion forces, strong hydrogen bonds can be formed and these bonds require more energy to break them. As a result, alkanols have higher BP than alkanes.

Question 24(b) (2 marks) Skills

Criteria	Marks
• Correctly plotting boiling points and drawing a line of best fit/trendline	2
• Incorrect plots or trendline not drawn	1

Sample response

See graph below



Question 23(c) (2 marks) KU **Marker: SN**

Criteria	Marks
• Provides explanation for higher BP of alkanoic acid ○ Alkanoic acids have dipole-dipole forces in addition to H bonds and dispersion forces requiring higher energy to break bonds	2
• Incomplete answer with some relevant detail	1

Sample response

In alkanoic acids, in addition to dispersion forces, there are hydrogen bonds in the carboxyl end and dipole-dipole forces in the carbonyl end which gives alkanoic acids very strong intermolecular forces that require higher energy to break. As a result, they have a higher BP compared to the other two.,

Question 25(a) (4 marks) Skills – units marked for.

Criteria	Marks
• Correctly calculates mass of butane showing ALL working and reasoning. Correct unit needed, g (grams). ○ Heat of reaction correctly calculated ○ Calculations to show 40% of the heat of combustion ○ Calculating number of moles of butane ○ Correct calculation of mass of butane	4
• ONE incorrect calculation OR correct calculation without correct unit for mass	3
• TWO incorrect steps/calculations	2
• At least ONE correct working or calculation/reasoning shown	1

Sample response

$q = mC\Delta T$ $m = 950mL/g$, $\Delta T = 100-12 = 88$ C, $C = 4.18$ J/g/K
$= 950 \times 4.18 \times 88$
$= 349448$ J /1000 = 349.44 kJ. This is only 40%

Energy from combustion = 349.44/40 x 100 = 873.62 kJ

Number of moles of butane = $q/\Delta Hc$ = 873.kJ/2878 $kJmol^{-1}$ = 0.303 moles

Mass = n x MM = 0.303 x 58.08 = 17.6 g = 18 g (2 sig fig)

Question 25(b) (2 marks). KU

Criteria	Marks
• Two environmental impacts of using hydrocarbons like butane identified and described (give features)	2
• Environmental impacts named/identified but not described • Only one environmental impact described	1

Sample response

Any TWO of the following:

- Mining for/of hydrocarbons damages land, soil erosion and loss of habitats of organisms living around the mine. It can cause pollution or environmental accidents
- Hydrocarbons are a non-renewable resource
- Combustion of hydrocarbons releases carbon dioxide into the atmosphere- pollution producing large amounts of NO, NO_2, SO_2
- Burning of fossil fuels -greenhouse gases, global temperature rise, acidification of ocean- affecting coral reefs

- Plastic products produced from hydrocarbons causing environmental pollution due to non-biodegradability

Question 26(a) (1 mark) KU

Criteria	Marks
• Correct order provided.	1

Sample response

Lowest to highest pH = ammonium nitrate, sodium nitrate, sodium propanoate.

Question 26(b) (3 marks) KU **Marker: RT**

Criteria	Marks
• Justification provided for each substance based on the effect of each ion on the pH (or acidic/basic/neutral nature) of the solution via EITHER the production of H_3O^+/OH^-/neither OR the ion being the conjugate of the relevant strong/weak acid/base.	3
• Partial justification provided.	2
• One piece of relevant information provided.	1

Sample response

Sodium nitrate will have a neutral pH as both ions are the conjugate of a strong base/acid so have no tendency to react with water and produce H_3O^+/OH^-, and hence the pH remains neutral.
Ammonium nitrate will have the lowest pH as it is an acidic salt. The ammonium ion is the conjugate acid of the weak base NH_3, so produces H_3O^+ in solution which gives an acidic (<7) pH.
Sodium propanoate will have the highest pH as it is a basic salt. The propanoate ion is the conjugate base of the weak acid propanoic acid, so produces OH^- in solution which gives a basic (>7) pH.

Question 27 (4 marks) KU – mark for states in ionic equation

Criteria	Mark
• Shows a comprehensive understanding of the process for ion testing and that reducing the volume is appropriate to increase concentration with the correct results for the tests • Gives + and – of the process used • Correct ionic equation with state symbols • Makes judgement that the procedure does not work. • Makes the judgement that the conclusion is incorrect	5
• Shows thorough understanding of the results for ion testing and the ppt formed when tests are performed • Gives some + and – of the process used • Correct ionic equation • Makes a judgement on the conclusion that it is incorrect	4
• Sound understanding of ion testing • Outlines some + and – of the process in terms of identifying the ion present • A judgement on the procedure OR the conclusion	3
• Covers either + or – of the procedure OR • Makes an incorrect judgement using information provided OR • Provides relevant information AND an equation	2
• Provides some relevant information	1

Sample response

Reducing the volume is appropriate and a valid step as some test results will result in no precipitate if the concentration of an ion is too low. E.g. calcium will not precipitate as a sulfate if the concentration is too low.
Test with hydroxide: silver is eliminated in the test with sodium hydroxide as the precipitate would be a milky brown in colour. Calcium, magnesium and lead all produce a white precipitate with hydroxide so at the end of this test the ion is indicated as one of these four.
Possible equations are for Ca, Mg, Pb or Ba with OH^-
Test with sulfuric acid: magnesium is eliminated as the metal ion as no precipitate would be formed. Calcium, barium, silver and lead sulfate are all white precipitatea so not yet identified the ion.
Possible equations are for Ca or Ba or Ag or Pb with SO_4^{2-}
Test with chloride last: getting no ppt eliminates Pb as it would give a white ppt. [Ag also eliminated even if not considered earlier as AgCl is insoluble]. Ca and Ba chloride are soluble so the identification of the ion is gets to either Ca or Ba.
Judgements – the procedure does not lead to an identification of ion **and** the conclusion is potentially wrong. The results of the three tests eliminates Ag and Pb and Mg but not Ca and Ba. A flame test is then needed to distinguish. Order is not relevant as using the cumulative tests but cannot reach the conclusion of Ca. Even if did in the order chloride, sulfate then hydroxide would still not confirm that the ion is calcium.

Question 28(a) (7 marks) Skills

Criteria	Marks
• Correctly calculates the %mass of $CaCO_3$ showing all working: ○ volume NaOH from graph and n(NaOH) calculated using n=cV ○ n(HCl excess) using molar ratio from titration ○ n(HCl total) calculated using n=cV ○ n(HCl reacted with $CaCO_3$) calculated using (HCl total) - n(HCl excess) ○ n($CaCO_3$) calculated using molar ratio from reaction ○ m($CaCO_3$) calculated using n=m/MM and %mass $CaCO_3$ calculated using formula given AND assesses whether the batch is within the specified range.	7
• Mark deducted for each error or omission (including providing an assessment and showing sufficient working)	6-4
• 2-3 correct steps in the calculation with sufficient working OR 3-4 correct steps in the calculation without sufficient working	2-3
• One relevant piece of information provided.	1

Sample response

Total n(HCl) added to tablet = cV = 1.073 *x* 25.00/1000 = 0.026825 mol

Total n(HCl) added = n(HCl reacted with $CaCO_3$) + n(HCl excess)

HCl – NaOH titration:

$HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

From graph V(NaOH) = 15.00 mL (working shown on graph)

$\therefore$ n(NaOH) = cV = 1.102 *x* 15.00/1000 = 0.01653 mol

$\therefore$ n(HCl excess) = 0.01653 mol (1:1 molar ratio NaOH:HCl from equation)

$\therefore$ n(HCl reacted with $CaCO_3$) = 0.026825 – 0.01653 = 0.010295 mol

$CaCO_3$ – HCl reaction:

$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$

$\therefore n(CaCO_3) = \frac{n(HCl\ reacted)}{2} = \frac{0.010295}{2} = 5.1475 \times 10^{-3}$ mol (1:2 molar ratio $CaCO_3$:HCl from equation)

$\therefore m(CaCO_3) = n \times MM = 5.1475 \times 10^{-3} \times (40.08 + 12.01 + 3 \times 16.00)$

$= 5.1475 \times 10^{-3} \times 100.09$

$= 0.515$ g

$\therefore$ %mass $CaCO_3$ in TUMS = $\frac{0.515}{1.30} \times 100 = 39.8$ %

Assessment:

As the %mass $CaCO_3$ is between 38-40 %, this batch of TUMS tablets is within the specified range.

Question 28(b) (3 marks) KU

Criteria	Marks
• Provides an evaluation of Step 5 in terms of accuracy considering: o the purpose of Step 5 = heating shifts both exothermic equilibria left which minimises carbonic acid in solution o the effect of carbonic acid in the solution = increase in $[H^+]$ o the effect of carbonic acid on the analysis = one of increases V(NaOH) for titration, inaccurate equivalence point, underestimate of %mass (or similar)	3
• Two pieces of relevant information provided with no/incorrect judgement OR One piece of relevant information provided with a corresponding judgement	2
• One piece of relevant information provided.	1

Sample response

The heating in Step 5 shifts both equilibria left as they are both exothermic. This removes carbonic acid from the solution which is needed so that the correct %mass is determined by the analysis. If there is carbonic acid in the solution this will increase the [H+] present after the reaction of HCl with the $CaCO_3$ in TUMS and give a higher volume of NaOH needed in the titration and therefore a higher n(HCl) excess. This in turn gives a lower value for n(HCl reacted with $CaCO_3$) and m($CaCO_3$) and so the %mass will be underestimated. Therefore, Step 5 is **very important** in maintaining the accuracy of the quality control analysis.

Question 29(a) (2 marks) Skills

Criteria	Marks
• Correctly calculates $\Delta_c G^\circ$.	2
• Provides ONE correct step in calculation.	1

Sample response

$$\begin{aligned}\Delta_c G^\circ &= \Delta_c H^\circ - T\Delta_c S^\circ \\ &= -393.5 \text{ kJ mol}^{-1} - (298 \text{ K})(2.9 \times 10^{-3} \text{ kJ K}^{-1}\text{ mol}^{-1}) \\ &= -394.36 \text{ kJ mol}^{-1} \\ &= \underline{\underline{-390 \text{ kJ mol}^{-1}}} \text{ (2 sf)}\end{aligned}$$

Question 29(b) (2 marks) KU

Criteria	Marks
• States that the reaction does not come to equilibrium with reference to the value of ΔG being large (or non-zero). • Compares both enthalpic and entropic contributions to ΔG to show ΔG will always be negative and thus always proceeds to completion.	2
• ONE of the above.	1

Sample response

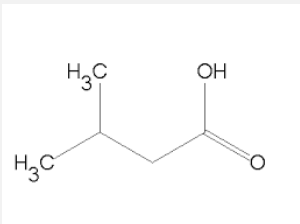
For a reaction to establish equilibrium, ΔG must be close to zero. In this case ΔG is large and non-zero so the reaction does not come to equilibrium.

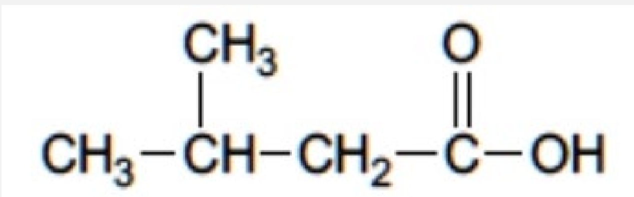
Given $\Delta_c H^\circ$ and $-T\Delta_c S^\circ$ will always be negative, $\Delta_c G^\circ = \Delta_c H^\circ - T\Delta_c S^\circ$ will always be large and negative regardless of the temperature. Therefore the reaction will always proceed to completion, regardless of T.

Question 30(a) (7 marks) KU

Criteria	Marks
• Draws the correct structural formula of 3-methylbutanoic acid AND names correctly. • Justifies the correct structure showing an extensive understanding of the interpretation of the spectroscopic data. • Refers explicitly to the spectroscopic data AND the chemical tests.	7
• Draws the correct structural formula but names incorrectly. • Draws the structure with a minor error and names correctly. • Justifies the structure showing a thorough understanding of the interpretation of the spectroscopic data. • Refers to relevant spectroscopic data AND the chemical tests to clearly link the data to the structure.	6
• Shows a sound understanding of the interpretation of spectroscopic data and the chemical tests. • Uses relevant information provided to justify the structure drawn and named • Provides a structural formula that is consistent with data provided	4-5
• Provides some understanding of the interpretation of spectroscopic data. • Correctly identifies an acid using the results from the chemical tests.	2-3
• One relevant piece of information using either the spectroscopic data or the chemical tests	1

Sample response





Chemical tests indicate that the compound is not an alkene (no reaction with bromine water) nor a primary or secondary alkanol (no reaction with acidified permanganate). Reaction with sodium hydrogen carbonate infers an alkanoic acid.

IR spectrum:
The IR spectrum shows a strong absorption at $1750 cm^{-1}$ which is consistent with a carbonyl group. The broad O-H (acid) absorption band (stretch) is present at $2500\text{-}3300 cm^{-1}$. The IR therefore indicates the unknown is an acid and the structure shows an acid.

C-13 NMR:

4 peaks in the C-13 NMR indicate the presence of 4 C environments. (The given formula indicates that there are 5 C so 2 must be in identical/very similar environments)
One is at a chemical shift of 180 ppm, indicating C=O group which is present in the structure.
C atom adjacent to the carboxylic acid group is consistent with the chemical shift at 45 ppm.
The remaining two peaks with chemical shifts approximately 23-25 ppm are consistent with C in alkyl groups.

H-1 NMR:
Singlet with a chemical shift at 11.0 ppm is consistent with the H on the O-H group of the COOH.
A doublet with the shift at 2.15 and relative peak area of 2 is consistent of a CH_2 group with one neighbouring H atom.
A complex multiplet at 2.05 ppm and the doublet at 0.9 ppm combination are consistent with the presence of the $-CH(CH_3)_2$ group.

The combination of the C-NMR and H-NMR suggest a $CH(CH_3)_2$ group attached to a CH_2 group adjacent to the carboxylic acid.

Combination of the spectra provide the correct identification.

Question 30(b) (4 marks) KU

Criteria	Marks
• Draws the straight chain pentanoic acid isomer of the acid named in part (a) and correctly names the structure. • Shows an extensive understanding of IR spectra	4
• Draws an isomer but of the incorrect functional group and names it correctly OR draws correct isomer and names incorrectly OR draws a branched isomer and names correctly • Shows thorough understanding of IR	2-3
• A relevant piece of information relating to either structure or IR	1

Sample response

The straight chain isomer is pentanoic acid

IR similarity:
The isomer and the unknown will have the same absorptions for the -OH and the C=O.
IR difference:
The IR would vary in the fingerprint region of 1500 – 100 cm^{-1}.

Question 31 (3 marks) Skills **Marker: LT**

Criteria	Marks
• Correctly uses pH to calculate $[OH^-](aq)$. • Correctly calculates Q_{sp}. • Compares Q_{sp} and K_{sp} to make a correct judgement on whether the solution is saturated.	3
• TWO of the above.	2
• ONE correct step in calculation.	1

Sample response(s)

The dissolution of $Ba(OH)_2$ proceeds as follows:

$$Ba(OH)_2(s) \rightleftharpoons Ba^{2+}(aq) + 2OH^-(aq) \qquad K_{sp} = \underset{\text{(from data sheet)}}{2.55 \times 10^{-4}}$$

We use the pH of the solution to calculate $[OH^-]$.

$$\begin{aligned} pOH &= 14.0 - pH \\ &= 14.0 - 11.8 \\ &= 2.2 \end{aligned}$$

Then $[OH^-] = 10^{-pOH} = 10^{-2.2} = 6.3 \times 10^{-3}$ M.

From the balanced chemical equation for the dissolution reaction, we know that when 6.3×10^{-3} mol of OH^- is produced, half as much Ba^{2+} will be produced, so $[Ba^{2+}] = 3.2 \times 10^{-3}$ M.

Inserting these values into the ion-product expression and comparing Q_{sp} with K_{sp}:

$$\begin{aligned} Q_{sp} &= [Ba^{2+}][OH^-]^2 \\ &= (3.2 \times 10^{-3})(6.3 \times 10^{-3})^2 \\ &= 1.2 \times 10^{-7} \end{aligned}$$

Because $Q_{sp} < K_{sp}$, the solution is not saturated and $Ba(OH)_2$ will not precipitate.

Question 32(a) (3 marks) KU

Criteria	Marks

• Small increase in pH explained by providing:
  ○ how the added OH^- is neutralised/removed by the buffer
  ○ how pH change is minimised by the buffer
• Relevant chemical equation included.
	3

• Incomplete explanation with relevant chemical equation. OR Sound explanation without a relevant chemical equation.	2
• One piece of relevant information provided.	1

Sample response(s)

The buffer system has relatively large and equal concentrations of acetic acid molecules and acetate ions. When the NaOH is added the hydroxide ions combine with acetic acid molecules to form acetate ions and water: $CH_3COOH(aq) + OH^-(aq) \rightarrow CH_3COO^-(aq) + H_2O(l)$
Although this reaction is reversible, since the $[CH_3COOH]$ is much greater than that of the added $[OH^-]$, most of the hydroxide ions are neutralised and so the $[H_3O^+]$ and therefore pH remain near their original level.

OR

Buffer equation: $CH_3COOH(aq) + H_2O(l) \rightleftharpoons CH_3COO^-(aq) + H_3O^+(aq)$
When the NaOH is added the $[H_3O^+]$ decreases due to $H_3O^+ + OH^- \rightarrow 2H_2O$. This causes the equilibrium to shift right to counteract the change and increase the $[H_3O^+]$. Because the buffer contains relatively large and equal concentrations of CH_3COOH and CH_3COO^- the shift right returns the $[H_3O^+]$ and hence pH to close to the original value (only slightly higher).

Question 32(b) (3 marks) KU

Criteria	Marks
• Provides a reason for B+D forming a buffer AND a reason B+C doesn't form a buffer AND a relevant chemical equation.	3
• Two of the above.	2
• One piece of relevant information provided.	1

Sample response

Solution B + D forms a buffer because the reaction:
$CH_3COOH + OH^- \rightarrow CH_3COO^- + H_2O$
occurs which converts half the acetic acid molecules to acetate ions which gives a solution with relatively large and equal concentrations of an acid (acetic acid) and its conjugate base (acetate ion).

Solution B + C doesn't form a buffer solution as it is just the mixing of two acids. When the strong acid, HCl, ionises no equilibrium forms so it can't buffer. When acetic acid ionises an equilibrium forms but the [conjugate base/acetate ion] isn't high enough to create a buffer.

Question 33(a) (3 marks) Skills – marked for sig figs

Criteria	Marks
• Provides correct expression for K_{eq} • Calculates the correct equilibrium concentration of gaseous acetic acid • Expresses answer to correct number of significant figures (2sf)	3
• Any TWO of the above	2
• Any ONE correct step in the calculation.	1

Sample response

The initial concentration of acetic acid dimer acid, $(CH_3COOH)_2(g)$ is 1.5×10^{-3} M and the vessel is initially empty so the initial concentration of gaseous acetic acid is 0 M. The concentration of $(CH_3COOH)_2$ will change by $-x$ and $CH_3COOH(g)$ will increase by $+2x$ as the reaction proceeds to equilibrium.

	$(CH_3COOH)_2$	$\rightleftharpoons$	$2CH_3COOH$
Initial concentration (mol L^{-1})	1.5×10^{-3}		0
Change in concentration (mol L^{-1})	$-x$		$+2x$
Equilibrium concentration (mol L^{-1})	$1.5 \times 10^{-3} - x$		$+2x$

Since $K_a = 3.2 \times 10^{-4}$, decomposition of the dimer only occurs to a small extent, and thus x is very small. We can then make the simplifying approximation that $[(CH_3COOH)_2(g)] = 1.5 \times 10^{-3}$.

Substituting these quantities into the K_{eq} expression gives:

$$K_{eq} = \frac{[CH_3COOH]^2}{[(CH_3COOH)_2]} = \frac{(2x)^2}{1.5\times10^{-3} - x} \approx \frac{4x^2}{1.5\times10^{-3}} = 3.2\times10^{-4}$$

We can now solve this for x:

$$x^2 = \frac{(3.2\times10^{-4})(1.5\times10^{-3})}{4} = 1.2\times10^{-7}$$

$$x = 3.5\times10^{-4}$$

We know that the equilibrium concentration of gaseous acetic acid is $2x$, therefore

$$\begin{aligned}[CH_3COOH(g)] &= 2x \\ &= 2\times(3.5\times10^{-4})\text{ M} \\ &= \underline{\underline{6.9\times10^{-4}\text{ M}}}\text{ (2 sf)}\end{aligned}$$

Question 33(b) (2 marks) Skills

Criteria	Marks
• Provides rationale to calculate the percentage of dimer converted to monomer. • Calculates the correct percentage.	2
• ONE of the above.	1

Sample response

From part (a), x is defined as the change in the concentration of dimer that has converted into gaseous acetic acid. Therefore:

$$\begin{aligned}\text{\% dimer converted to monomer} &= \frac{x}{[(CH_3COOH)_2]_{\text{initial}}} \times 100\% \\ &= \frac{3.5\times10^{-4}}{1.5\times10^{-3}} \times 100\% \\ &= \underline{\underline{23\%}}\end{aligned}$$

Question 33(c) (3 marks) KU

Criteria	Marks
• States that formation of the dimer would be favoured. • Provides explanation using LCP to show the system counteracting the imposed change in pressure. • Makes reference to the number of moles on both sides of the reaction.	3
• TWO of the above	2
• ONE of the above	1

Sample response

If the pressure of the reaction system increased by decreasing the volume of the container, the reaction system would favour the side of the reaction with the fewer number of moles to counteract the change in pressure imposed on the system (LCP). In this instance the equilibrium position would shift to favour production of the dimer. This is because the reverse reaction produces 1 mol of $(CH_3COOH)_2(g)$ compared to the forward reaction which produces 2 mol of $CH_3COOH(g)$.