



Name: .....

Class: .....

Section I	/20
Section II	/80
Total	/100

MOCK HSC EXAMINATION

# Chemistry

## General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using blue or black pen
- Black pen is preferred
- Draw diagrams using pencil
- Board-approved calculators may be used
- A data sheet and a Periodic Table are provided at the back of this paper
- Write your name and class at the top of this page

Total marks – 100

**Section I** Pages 2 – 11

### 20 marks

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

**Section II** Pages 12 – 31

### 80 marks

- Attempt Questions 21 – 32
- Allow about 2 hours and 25 minutes for this section

**Section I: Multiple Choice Questions (20 marks)**

**Attempt Questions 1 – 20**

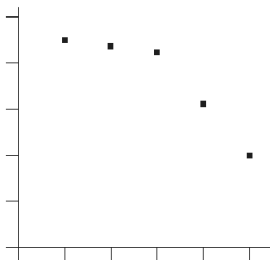
**Allow about 35 minutes for this section**

Use the multiple choice answer sheet for Questions 1 – 20.

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|-----|-----|-----|-----|-----|
| 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) |

1. Which of the following is a pair of chain isomers where the boiling point of the first compound is higher than that of the second compound?
- (A) 2,2-dimethylbutane and hexane  
(B) Butan-1-ol and 2-methylpropan-1-ol  
(C) Hexan-1-amine and pentan-1-amine  
(D) Butanoic acid and ethyl ethanoate
2. The graph below shows how the acid ionisation constant ( $K_a$ ) of acetic acid varies with temperature.



From the graph, it can be concluded that the ionisation of acetic acid in water is:

- (A) Endothermic and the pH of acetic acid will decrease as temperature increases  
(B) Endothermic and the pH of acetic acid will increase as temperature increases  
(C) Exothermic and the pH of acetic acid will decrease as temperature increases  
(D) Exothermic and the pH of acetic acid will increase as temperature increases
3. An unknown salt dissolves in water to give a solution that causes red litmus to turn blue. When sulfuric acid is added to this solution, no bubbling is observed but a white precipitate does form. Furthermore, when this solution is vaporised into a flame, an apple green flame colour is observed.

What is a possible identity for the unknown salt?

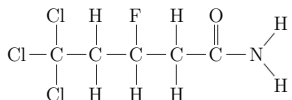
- (A) Barium acetate  
(B) Barium chloride  
(C) Barium carbonate  
(D) Calcium carbonate

4. When solid calcium hydroxide is added to water, only some of the calcium hydroxide dissolves.

What is the solubility of calcium hydroxide in water?

- (A) 0.0800 g/100 mL  
 (B) 0.800 g/100 mL  
 (C) 0.0108 g L<sup>-1</sup>  
 (D) 0.108 g L<sup>-1</sup>

5. Consider the following compound:



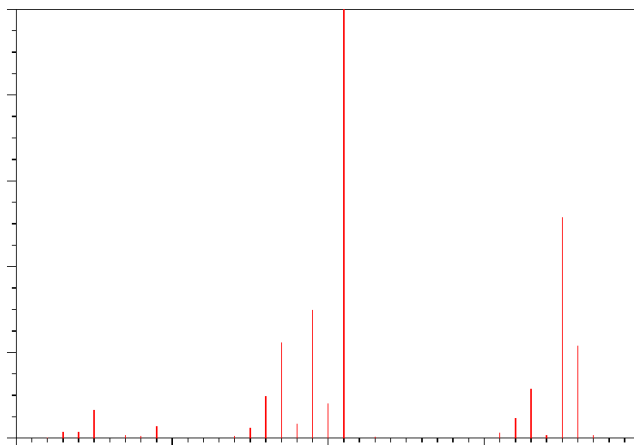
What is the systematic name of this compound?

- (A) 1-amino-5,5,5-trichloro-3-fluoropentanal  
 (B) 3-fluoro-5,5,5-trichloropentanamide  
 (C) 5,5,5-trichloro-3-fluoropentanamine  
 (D) 5,5,5-trichloro-3-fluoropentanamide
6. A laboratory contains solutions of hydrochloric acid and methanoic acid, both at the same volume and concentration.
- Which of the following statements regarding these two solutions is correct?
- (A) Both acids have the same pH  
 (B) Both solutions would be neutralised by the same volume of 0.10 mol L<sup>-1</sup> NaOH  
 (C) The hydrochloric acid has a lower electrical conductivity than the methanoic acid  
 (D) The methanoic acid contains a higher number of anion particles than the hydrochloric acid
7. Ammonium nitrate is a highly water soluble salt. When it is dissolved in water, the temperature of the water decreases.

Which row of the following table correctly describes the thermodynamics of the dissolution of ammonium nitrate in water under standard conditions?

	Enthalpy change	Entropy change	Gibbs free energy change
(A)	$\Delta H^\ominus < 0$	$\Delta S^\ominus < 0$	$\Delta G^\ominus < 0$ since $\Delta H^\ominus < T\Delta S^\ominus$
(B)	$\Delta H^\ominus > 0$	$\Delta S^\ominus < 0$	$\Delta G^\ominus < 0$ since $\Delta H^\ominus > T\Delta S^\ominus$
(C)	$\Delta H^\ominus > 0$	$\Delta S^\ominus > 0$	$\Delta G^\ominus < 0$ since $\Delta H^\ominus < T\Delta S^\ominus$
(C)	$\Delta H^\ominus > 0$	$\Delta S^\ominus > 0$	$\Delta G^\ominus < 0$ since $\Delta H^\ominus > T\Delta S^\ominus$

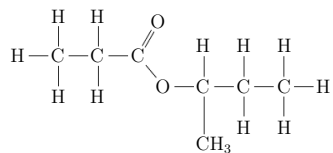
8. The mass spectrum of a compound is shown below.



What is the most likely identity of the compound?

- (A)  $\text{NO}_2$
  - (B)  $\text{CO}_2$
  - (C)  $\text{C}_3\text{H}_8$
  - (D)  $\text{C}_2\text{H}_5\text{OH}$
9. The conjugate base of a Brønsted-Lowry acid must always have:
- (A) A hydroxide ion
  - (B) A negative charge
  - (C) An unpaired electron
  - (D) A lone pair of electrons

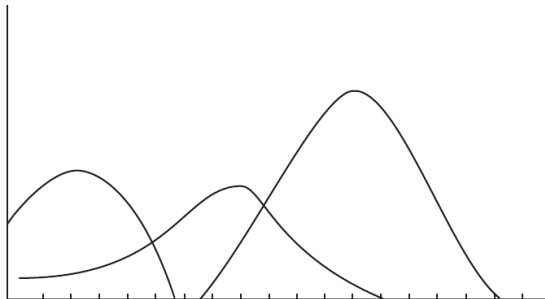
10. The following compound can be produced from a reaction between two reagents, **P** and **Q**.



If the boiling points of **P** and **Q** are 99°C and 141°C respectively, which row of the following table correctly identifies the reagents?

	<b>P</b>	<b>Q</b>
(A)	Butan-2-ol	Propanoic acid
(B)	2-methylpropan-1-ol	Propanoic acid
(C)	Propanoic acid	Butan-2-ol
(D)	Propanoic acid	2-methylpropan-1-ol

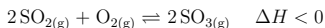
11. Ultraviolet-visible (UV-vis) spectroscopy was used to measure the absorbance of three dyes over a range of wavelengths. The absorbance spectra produced are shown below.



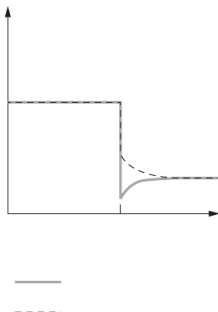
Which of the following is the most suitable wavelength to use to determine the concentration of the red dye in a mixture containing all three dyes?

- (A) 430 nm  
 (B) 500 nm  
 (C) 540 nm  
 (D) 620 nm

12. Consider the following reaction:

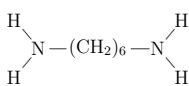


The following graph shows how the rate of the forward and reverse reactions for this system varies with time.

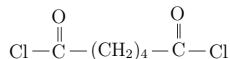


Which of the following disturbances may have been applied at time  $t$ ?

- (A)  $\text{SO}_2$  was removed from the reaction vessel
  - (B)  $\text{SO}_3$  was removed into the reaction vessel
  - (C) The temperature of the reaction vessel was decreased
  - (D) The volume of the reaction vessel was increased
13. The monomers below combine together to form nylon-6,6 and hydrogen chloride.



Hexane-1,6-diamine



Hexanedioyl dichloride

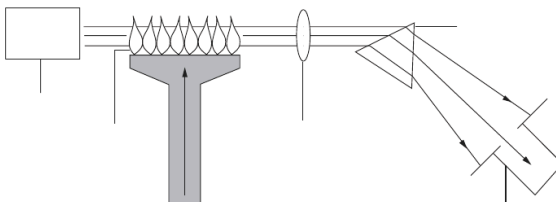
The table below shows the approximate molar mass of these monomers and hydrogen chloride.

Compound	Approximate molar mass ( $\text{g mol}^{-1}$ )
Hexane-1,6-diamine	116
Hexanedioyl dichloride	183
Hydrogen chloride	36

What is the approximate molar mass of the nylon-6,6 molecule formed when 20 molecules of hexane-1,6-diamine combines with 20 molecules of hexanedioyl dichloride?

- (A)  $4540 \text{ g mol}^{-1}$
- (B)  $4576 \text{ g mol}^{-1}$
- (C)  $4612 \text{ g mol}^{-1}$
- (D)  $5980 \text{ g mol}^{-1}$

14. The diagram below shows a spectrometer that is being used to analyse a sample solution for a particular metal cation.



A group of high school students made the following statements regarding this instrument:

- (i) The intensity of light emitted by the lamp is higher than the intensity of light that exits from the flame
- (ii) The lamp produces a continuous spectrum and only some wavelengths are absorbed by the element being tested
- (iii) The flame vaporises and atomises the sample being tested
- (iv) The flame vaporises and ionises the sample being tested

Which of the above statements are correct?

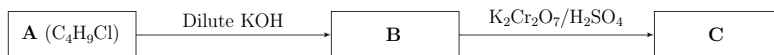
- (A) (i) and (iii)
  - (B) (i) and (iv)
  - (C) (ii) and (iii)
  - (D) (ii) and (iv)
15. A 25.0 mL solution of  $0.15 \text{ mol L}^{-1}$  hydrochloric acid was mixed with a 20.0 mL solution of  $0.10 \text{ mol L}^{-1}$  potassium hydroxide.

What is the pH of the resultant solution?

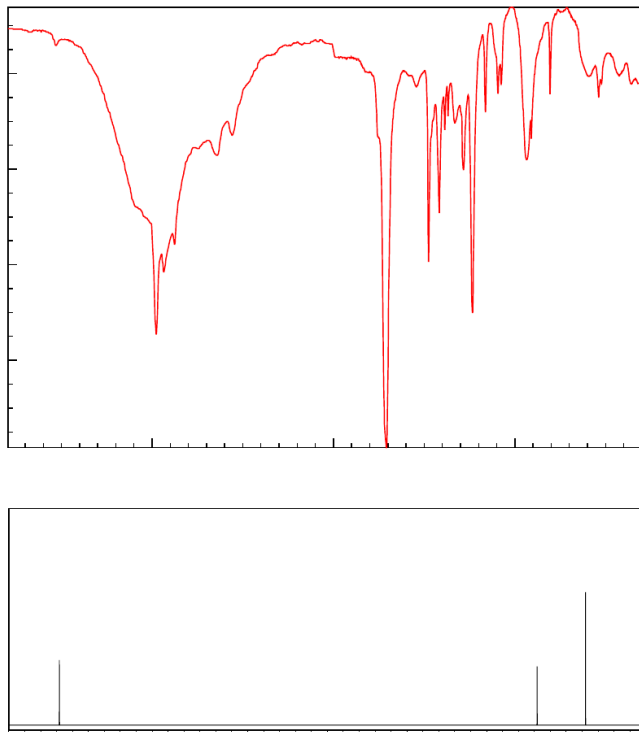
- (A) 1.06
- (B) 1.15
- (C) 1.41
- (D) 2.76



16. Consider the following series of reactions where **A**, **B** and **C** are different organic compounds.



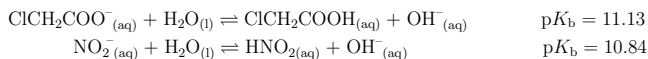
The infrared (IR) spectrum and  $^{13}\text{C}$  nuclear magnetic resonance (NMR) spectrum of compound **C** is shown below:



Based on the above information, what is the identity of compound **A**?

- (A) 1-chlorobutane
- (B) 2-chlorobutane
- (C) 1-chloro-2-methylpropane
- (D) 2-chloro-2-methylpropane

17. Consider the following reactions:

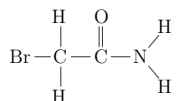


Equimolar solutions of  $\text{ClCH}_2\text{COONa}$ ,  $\text{ClCH}_2\text{COOH}$ ,  $\text{NaNO}_2$  and  $\text{HNO}_2$  were prepared.

Which row of the following table identifies the solutions that would have the lowest and highest pH value?

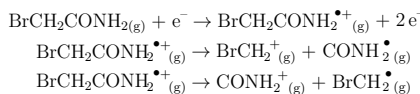
	Lowest pH	Highest pH
(A)	$\text{ClCH}_2\text{COOH}$	$\text{ClCH}_2\text{COONa}$
(B)	$\text{ClCH}_2\text{COOH}$	$\text{NaNO}_2$
(C)	$\text{HNO}_2$	$\text{ClCH}_2\text{COONa}$
(D)	$\text{HNO}_2$	$\text{NaNO}_2$

18. The structural formula of an organic compound is shown below:



The common isotopes of bromine are  $^{79}\text{Br}$  and  $^{81}\text{Br}$  which both have a natural abundance of approximately 50%.

When this organic compound is analysed with a mass spectrometer, the following processes occur:

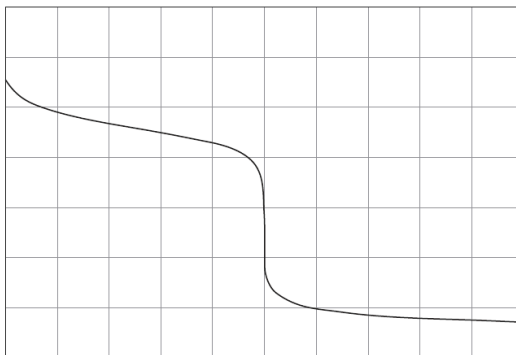


Which row of the following table shows the number of appreciable peaks that these processes would produce on the mass spectrum and the species directly responsible for these peaks?

	Number of peaks	Species directly responsible
(A)	3	$\text{BrCH}_2\text{CONH}_2^{\bullet+}$ , $\text{BrCH}_2^+$ , $\text{CONH}_2^+$
(B)	3	$\text{BrCH}_2\text{CONH}_2^{\bullet+}$ , $\text{CONH}_2^{\bullet}$ , $\text{BrCH}_2^{\bullet}$
(C)	5	$\text{BrCH}_2\text{CONH}_2^{\bullet+}$ , $\text{BrCH}_2^+$ , $\text{CONH}_2^+$
(D)	5	$\text{BrCH}_2\text{CONH}_2^{\bullet+}$ , $\text{BrCH}_2^+$ , $\text{CONH}_2^{\bullet}$ , $\text{CONH}_2^+$ , $\text{BrCH}_2^{\bullet}$

19. Which of the following combinations of acid and base would produce the largest temperature change for the resultant mixture?
- (A) 100 mL of  $0.05 \text{ mol L}^{-1}$  nitric acid and 100 mL of  $0.50 \text{ mol L}^{-1}$  sodium hydroxide
- (B) 100 mL of  $0.20 \text{ mol L}^{-1}$  sulfuric acid and 100 mL of  $0.10 \text{ mol L}^{-1}$  potassium hydroxide
- (C) 100 mL of  $0.20 \text{ mol L}^{-1}$  hydrochloric acid and 100 mL of  $0.10 \text{ mol L}^{-1}$  barium hydroxide
- (D) 200 mL of  $0.10 \text{ mol L}^{-1}$  nitric acid and 200 mL of  $0.40 \text{ mol L}^{-1}$  potassium hydroxide
20. An aqueous solution of bromocresol green contains a yellow molecule (HInd) and a blue anion ( $\text{Ind}^-$ ). The  $\text{p}K_{\text{a}}$  of bromocresol green is 4.90.

A few drops of bromocresol green is added to a base and the mixture is then titrated against an acid. The corresponding titration curve is shown below:



Which row of the following table shows the colour change that will be observed and the relative concentration ratio of HInd to  $\text{Ind}^-$  at the equivalence point?

	Colour change at equivalence point	$\frac{[\text{HInd}]}{[\text{Ind}^-]}$ at equivalence point
(A)	Blue to green	0.79
(B)	Yellow to green	0.79
(C)	Blue to green	1.26
(D)	Yellow to green	1.26

**Section II: Short Answer Questions (80 marks)**  
**Attempt Questions 21 – 32**  
**Allow about 2 hours and 25 minutes for this part**

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

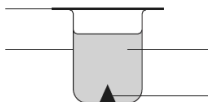
Show all relevant working in questions involving calculations.

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**Question 21** (4 marks)

The following equilibrium mixture was set up in a laboratory.

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Some solid sodium sulfate is then dissolved into the solution and the mixture is maintained at a constant temperature for several days.

With reference to collision theory and the solubility product ( $K_{sp}$ ), explain how the final equilibrium mixture would compare with the initial equilibrium mixture with respect to:

- The mass of solid  $\text{CuSO}_4$  present
- The concentration of  $\text{Cu}^{2+}$  and  $\text{SO}_4^{2-}$  ions in the solution

Include a relevant chemical equation in your answer.

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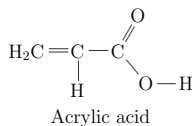
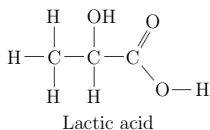
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**Question 22** (9 marks)

The structure of two monomers which can be used to make different polymers are shown below.



A polymer chemist carried out two different polymerisation reactions to convert lactic acid into poly(lactic acid) and acrylic acid into poly(acrylic acid).

- (a) Compare the process of polymerisation that the monomers above undergo. Include relevant chemical equations using structural formulae in your answer. 4

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- (b) Describe a simple chemical test that could be used to confirm if all of the acrylic acid has been completely converted into poly(acrylic acid). Include a relevant chemical equation using structural formulae in your answer. 2

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(c) Polyethylene is a commonly used commercial polymer that is very versatile.

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Explain why polyethylene is such a versatile polymer with reference to the structure, properties and uses of TWO different forms of polyethylene.

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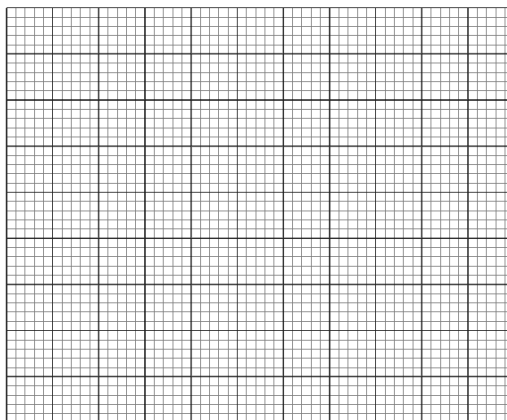
**Question 23** (10 marks)

A student carried out a conductometric titration between a standardised hydrochloric acid solution and an unknown ethanamine solution. The table below shows how the electrical conductivity of the reaction mixture varied as ethanamine was added from a burette to a conical flask containing 25.0 mL of  $0.12 \text{ mol L}^{-1}$  hydrochloric acid.

Volume of ethanamine added (mL)	Conductivity ( $\text{mS cm}^{-1}$ )
0.00	24.00
2.00	23.47
4.00	23.00
6.00	22.80
8.00	22.00
10.00	21.55
12.00	21.00
14.00	20.70
16.00	20.69
18.00	20.71
20.00	20.70

- (a) Construct an appropriate graph of the data.

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- (b) Calculate the pH of the unknown ethanamine solution given that the  $pK_b$  of ethanamine is 3.35. 4

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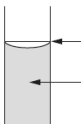
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- (c) Prior to the conductometric titration, the hydrochloric acid was standardised by titrating it against a sodium carbonate primary standard solution. During the preparation of the primary standard, the student filled a volumetric flask to the level shown below: 3



A burette was then rinsed with the sodium carbonate solution and filled, while a conical flask was rinsed with the hydrochloric acid solution and filled. The student then carried out the titration and calculated the concentration of hydrochloric acid to be  $0.12 \text{ mol L}^{-1}$ .

Explain the effect that each individual mistake made by the student would have on the calculated concentration of hydrochloric acid.

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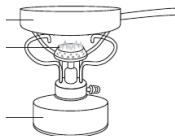
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**Question 24** (5 marks)

A camp stove using butane as a fuel is used to heat water in an aluminium pot as shown below.



The table below shows some information regarding this set up.

Mass of the aluminium pot	250.00 g
Mass of the aluminium pot and water	650.00 g
Initial temperature of the aluminium pot and water	18.5°C
Specific heat capacity of aluminium	0.900 J g <sup>-1</sup> K <sup>-1</sup>
Molar heat of combustion of butane	2877 kJ mol <sup>-1</sup>
Total heat lost to the surroundings	60.0%

- (a) Using all of the data above, calculate the minimum mass of butane that needs to be combusted to heat both the aluminium pot and water to 100.0°C. 4

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- (b) It was found that to achieve the required temperature change for the aluminium pot and water, a larger mass of butane was required than the value calculated in part (a). 1

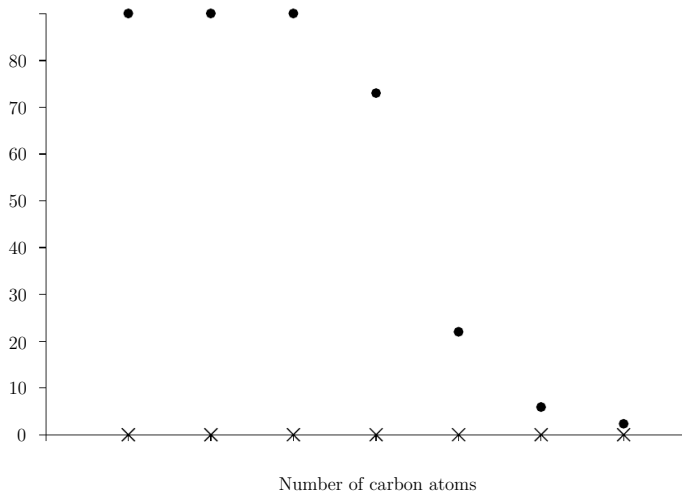
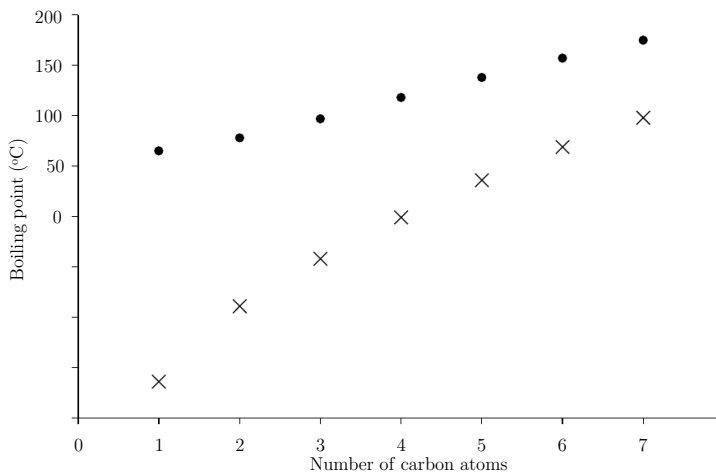
Propose a chemical reason, other than heat loss, for this difference.

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**Question 25** (9 marks)

The graphs below shows how the boiling point and water solubility of straight chain alkanes and primary alcohols varies with the number of carbon atoms in the molecule.



●  
x Alkanes

- (a) Explain the trends shown on the graphs. Include relevant diagrams in your answer.

- (b) On the boiling point graph, draw a line to roughly show how the boiling points of straight chain primary amines will compare with the other compounds and explain your answer.

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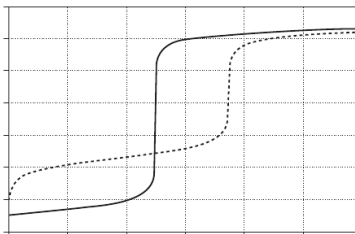
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**Question 26** (7 marks)

The graph shows the changes in pH for the titrations of equal volumes of two monoprotic acids, HX and HY, against a potassium hydroxide solution.



- (a) A chemistry student made the following statement:

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“Since a greater volume of potassium hydroxide is required to completely neutralise HY compared to HX, HY is a stronger acid than HX.”

Critically assess this statement with reference to TWO different pieces of evidence from the graph.

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- (b) Account for the difference in shape between the two titration curves in the pH range of 4 – 6, and describe the importance of the effect responsible for this difference in a specific natural system. **3**

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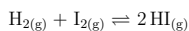
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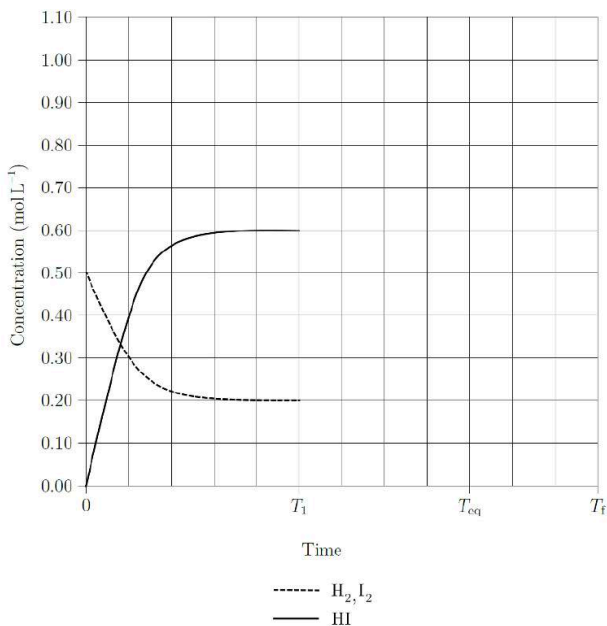
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**Question 27** (6 marks)

Hydrogen and iodine can react to produce hydrogen iodide according to the following equation:



A 2.0 L reaction vessel initially contained  $0.50 \text{ mol L}^{-1}$  hydrogen gas and  $0.50 \text{ mol L}^{-1}$  iodine gas which were allowed to react. The graph below shows the variation in concentration of reactants and products as a function of time for this system.



- (a) Calculate the equilibrium constant for the reaction.

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- (b) At time  $T_1$ , 0.80 mol of hydrogen iodide gas was rapidly added into the 2.0 L reaction vessel, and the system was then allowed to reach equilibrium at  $T_{\text{eq}}$ . The reaction vessel was maintained at a constant temperature throughout this time.

Calculate the equilibrium concentration of all the gases at  $T_{\text{eq}}$  and hence sketch two curves on the provided graph to show how the concentrations of the reactants and products change between  $T_1$  and  $T_f$ .

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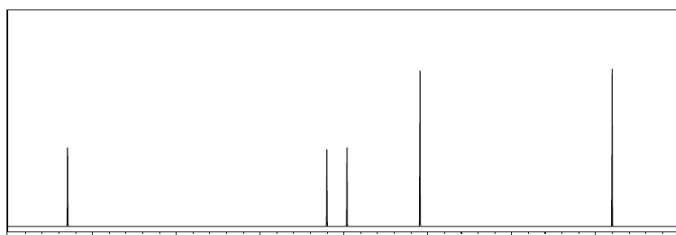
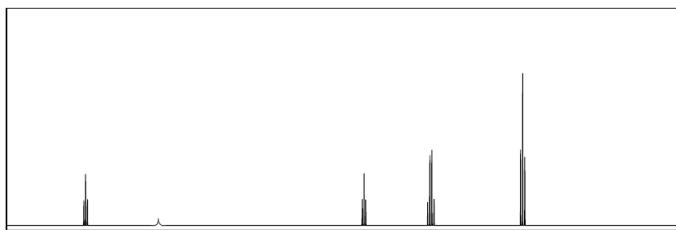
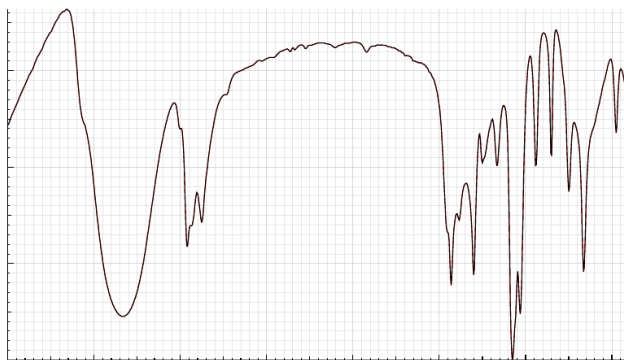
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**Question 28** (7 marks)

An unknown organic compound with a molecular formula of  $C_7H_{15}OCl$  was analysed with infrared (IR) spectroscopy and nuclear magnetic resonance (NMR) spectroscopy. The following spectra were obtained from these techniques.

7



Analyse the spectra above to determine the structural formula of the organic compound.

Note:  $^1H$  NMR chemical shift data has been included on your data sheet.



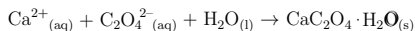


**Question 29** (6 marks)

Ammonium oxalate is a common reagent used to determine the concentration of metal ions in water samples since the oxalate ion ( $\text{C}_2\text{O}_4^{2-}$ ) readily reacts with group 2 metal ions to form insoluble precipitates.

The most common metal ions in sea water are sodium, potassium, calcium and magnesium. A student used the following procedure to analyse a sea water sample for its calcium ion content.

- A 200.0 mL sample of sea water was placed into a beaker.
- Excess ammonium oxalate solution was added to the sample. All of the calcium ions in the sample was completely precipitated out according to the following equation:



- The mixture was then filtered using a pre-weighed 13.637 g sintered glass crucible and the residue collected. The residue was washed with distilled water and ethanol, and then dried to constant mass at room temperature.
- The mass of the sintered glass crucible with the dried residue was found to be 15.154 g.

- (a) Calculate the concentration of calcium ions in the sea water sample that would be directly obtained from the student's experimental results in ppm. **3**

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- (b) For comparison, the student also used atomic absorption spectroscopy (AAS) to determine the concentration of calcium ions in the sea water sample. **3**

Predict how the calcium ion concentration obtained by AAS would compare with the value calculated in part (a), and explain which result is more accurate.

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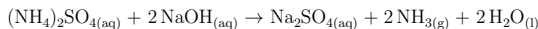
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**Question 30** (5 marks)

Fertiliser contains nitrogen in the form of ammonium sulfate. The following procedure was used to determine the nitrogen content of a lawn fertiliser.

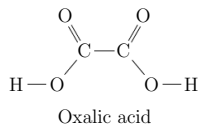
**5**

- A 1.758 g sample of the fertiliser was dissolved in 250.0 mL of distilled water.
- A 20.0 mL aliquot of the fertiliser solution was mixed with 50.0 mL of  $0.160 \text{ mol L}^{-1}$  sodium hydroxide. The reaction mixture was heated and all of the ammonium sulfate was neutralised according to the following equation:



- The reaction mixture was heated for a further 10 minutes to remove any residual ammonia.
- The excess sodium hydroxide in the final mixture was then titrated against a  $0.120 \text{ mol L}^{-1}$  oxalic acid primary standard solution to the phenolphthalein end point.
- The procedure was repeated three times. The results of the titration and the structural formula of oxalic acid are given below.

Titration	Volume of oxalic acid (mL)
1	26.90
2	26.50
3	26.45
4	26.55



Calculate the percentage by mass of nitrogen in the lawn fertiliser.

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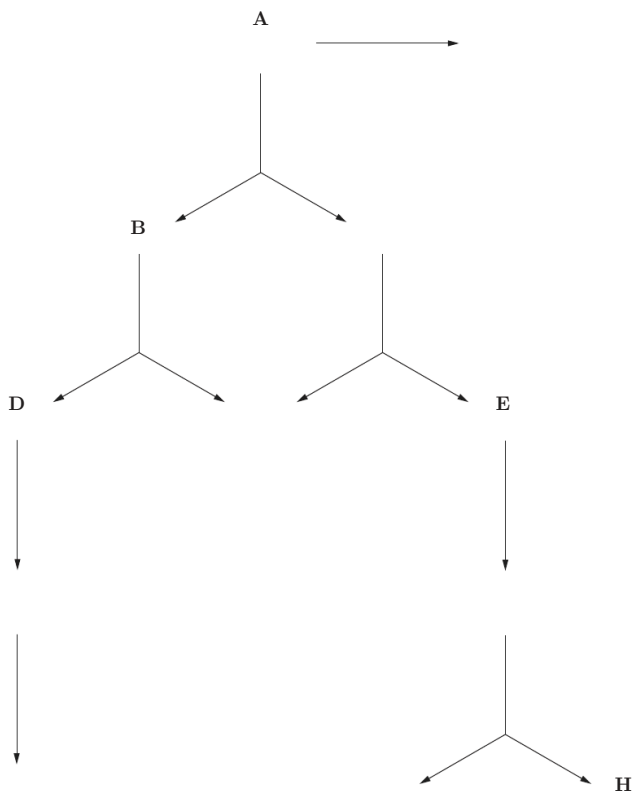
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**Question 31** (8 marks)

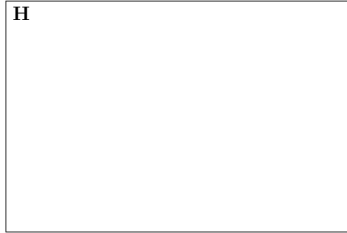
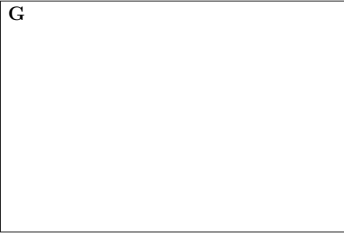
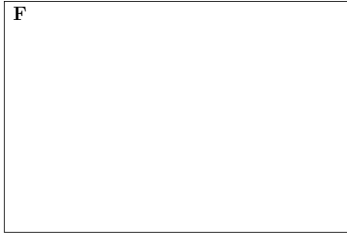
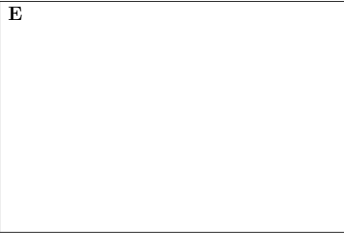
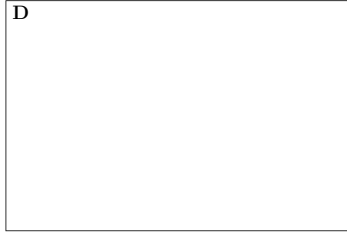
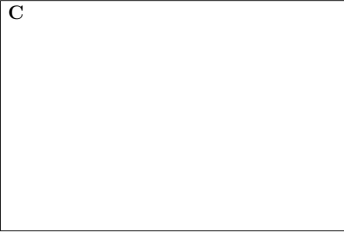
The flowchart below shows reactions involving different organic compounds (**A** to **H**).

8



Draw the structural formula of compounds **A** to **H** in the corresponding space provided.

<b>A</b>	<b>B</b>
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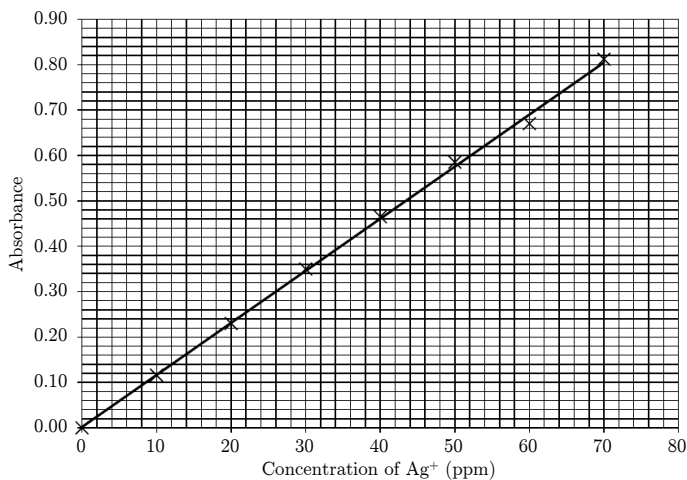


**Question 32** (4 marks)

The following procedure was used to determine the solubility product ( $K_{sp}$ ) of silver sulfate.

4

- 25.0 mL of  $1.0 \text{ mol L}^{-1}$  silver nitrate was mixed with 75.0 mL of  $1.0 \text{ mol L}^{-1}$  sodium sulfate and a precipitate formed.
- The precipitate was filtered off and a 10.0 mL aliquot of the filtrate was diluted to 100.0 mL with distilled water in a volumetric flask.
- The diluted filtrate was analysed with atomic absorption spectroscopy (AAS) for its silver ion content and it was found to have an absorbance of 0.60.
- A series of standard solutions was used to construct the calibration curve below.



Calculate the value of  $K_{sp}$  for silver sulfate.

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**End of paper**

## Section II extra writing space

If you use this space, clearly indicate which question you are answering.

**2023 HSC Chemistry Exam Solutions**  
**Section I: Multiple Choice Questions**

1. D.

Hydrocarbons are toxic so they should be disposed of in a separate waste container.

2. C.

The diagram shows an AAS instrument.

3. B.

The compound contains a  $\text{C}\equiv\text{C}$  triple bond, so it is an alkyne. The longest C chain contains 5 C atoms and numbering from right to left to give the  $\text{C}\equiv\text{C}$  functional group the lowest number yields pent-2-yne.

4. D.

$$\begin{aligned}K_{\text{sp}} &= [\text{Na}^+][\text{Cl}^-] \\&= 6.13 \times 6.13 \\&= 37.6\end{aligned}$$

5. D.

This model contains an equilibrium mixture of the unionised acid molecule and its ions which represents a weak acid. It also has a large number of dissolved acid solute particles per unit volume so it is concentrated.

6. C.

pH is a logarithmic scale given by  $\text{pH} = -\log_{10}[\text{H}^+]$ , so when pH decreases by 3, the  $[\text{H}^+]$  will increase by  $10 \times 10 \times 10 = 1000$  fold.



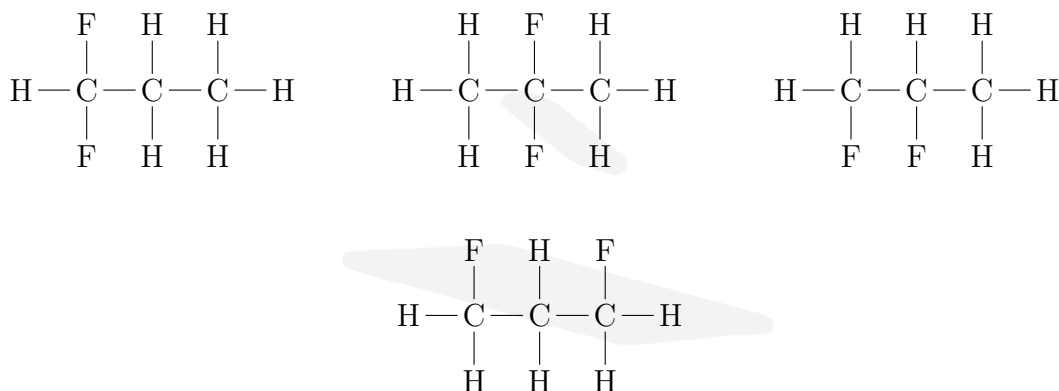
7. A.

Using a mole ICE table:

	CO	H <sub>2</sub>	CH <sub>3</sub> OH
Initial (mol)	0.8	0.8	0
Change (mol)	-0.3	-0.6	+0.3
Equilibrium (mol)	0.5	0.2	0.3

8. C.

The isomers are:



9. C.

The titration curve starts at a basic pH, so there must be a base in the conical flask and an acid in the burette. The equivalence point is at  $\text{pH} < 7$  which indicates this is a strong acid-weak base titration.

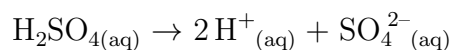
10. A.

This order is consistent with the strength of the intermolecular forces formed by each compound:

- Heptane is non-polar so it only forms weak dispersion forces.
- Heptan-2-one is polar and contains a C=O group that allows it to form dipole-dipole forces.
- Heptan-1-ol is polar and contains a -OH group that allows it to form strong hydrogen bonds.
- Heptanoic acid is polar and contains a -COOH group that allows it to form more extensive hydrogen bonds.

11. C.

Assuming that both ionisation steps of  $\text{H}_2\text{SO}_4$  are complete,



$$\begin{aligned}[\text{H}^+] &= 2 \times 1 \times 10^{-5} \text{ mol L}^{-1} \\ &= 2 \times 10^{-5} \text{ mol L}^{-1} \\ \text{pH} &= -\log_{10}(2 \times 10^{-5}) \\ &= 4.7\end{aligned}$$

For NaOH,

$$\begin{aligned}\text{pOH} &= -\log_{10}(5 \times 10^{-5}) \\ &= 4.3 \\ \text{pH} &= 14.00 - 4.3 \\ &= 9.7\end{aligned}$$

Therefore, the indicator would turn purple in  $\text{H}_2\text{SO}_4$  and blue-green in NaOH.

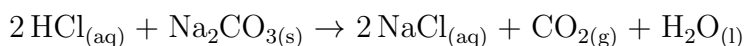
12. B.

When pressure is increased, Le Chatelier's principle predicts the equilibrium will shift right towards the side with less moles of gas (4 : 2) in an attempt to decrease the pressure. This causes more  $\text{NH}_3$  to get produced, increasing yield.

13. A.

$\text{Ag}^+$  forms a brown precipitate ( $\text{AgOH}$ ) and a white precipitate ( $\text{AgCl}$ ) in tests 3 and 4. The  $\text{SO}_4^{2-}$  ion forms a white precipitate ( $\text{BaSO}_4$ ) in test 2.  $\text{Ag}_2\text{SO}_4$  is also a neutral salt so it causes red litmus to remain red in test 1.

14. D.



$$\begin{aligned}n(\text{Na}_2\text{CO}_3) &= \frac{1.34 \text{ g}}{2(22.99) + 12.01 + 3(16.00) \text{ g mol}^{-1}} \\ &= 0.0126 \text{ mol} \\ n(\text{HCl}) &= 2 \times 0.0126 \text{ mol} \\ &= 0.0253 \text{ mol} \\ V(\text{HCl}) &= \frac{0.0253 \text{ mol}}{0.540 \text{ mol L}^{-1}} \\ &= 0.0468 \text{ L} \\ &= 46.8 \text{ mL}\end{aligned}$$

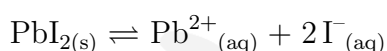
15. B.

By linear interpolation of the data, propan-1-ol ( $\text{C}_3\text{H}_7\text{OH}$ ) should have a heat of combustion between that of ethanol ( $\text{C}_2\text{H}_5\text{OH}$ ) and butan-1-ol ( $\text{C}_4\text{H}_9\text{OH}$ ).

16. B.

From the data sheet,  $K_{\text{sp}}(\text{AgI}) = 8.52 \times 10^{-17}$  and  $K_{\text{sp}}(\text{AgCl}) = 1.77 \times 10^{-10}$ . Since the  $K_{\text{sp}}$  of AgI is lower than AgCl by several orders of magnitude, the AgI will preferentially precipitate out first (the precipitation of AgI reaches completion at the first equivalence point) and AgCl precipitates out afterwards (the precipitation of AgCl reaches completion at the second equivalence point).

17. A.



$$K_{\text{sp}} = [\text{Pb}^{2+}][\text{I}^{-}]^2$$

$$9.8 \times 10^{-9} = (s)(2s)^2$$

$$= 4s^3$$

$$\Rightarrow s = 1.3 \times 10^{-3} \text{ mol L}^{-1}$$

$$n(\text{PbI}_2) = 1.3 \times 10^{-3} \text{ mol L}^{-1} \times 0.375 \text{ L}$$

$$= 5.1 \times 10^{-4} \text{ mol}$$

$$m(\text{PbI}_2) = 5.1 \times 10^{-4} \text{ mol} \times 461 \text{ g mol}^{-1}$$

$$= 0.23 \text{ g}$$

18. A.

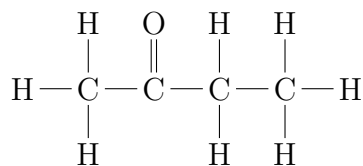
At time  $t$ , the temperature must have decreased since the rate of both the forward and reverse reactions decreased. The answer must therefore be (A) or (B).

Le Chatelier's principle predicts that when temperature is decreased, the equilibrium will favour the exothermic reaction to increase temperature. From the graph, after time  $t$ , the reverse reaction rate is higher than the forward reaction rate which means the equilibrium is shifting left due to a net reverse reaction. Therefore, the reverse reaction must be exothermic and the forward reaction must be endothermic ( $\Delta H > 0$ ).

**Note:** To the PEAK students, please compare this question to Question 18 of the 2023 PEAK trial exam (held in July).

19. B.

The structural formula of butan-2-one is shown below:



The peak at  $m/z = 43$  is caused by the  $\text{CH}_3\text{CO}^+$  fragment ion that fragmented off the unstable molecular ion.

A. is incorrect since the  $\text{CH}_3\text{CO}$  product is neutral in charge and would not produce a signal on the mass spectrum. D. is also incorrect since the  $\text{CH}_3\text{CH}_2\text{CH}_2^+$  fragment ion is unlikely to be formed from the fragmentation of butan-2-one (which doesn't contain that fragment in its structural formula).

20. D.

$$\begin{aligned}
 [\text{NO}_2]_{\text{i}} &= \frac{1.80 \text{ mol}}{2.00 \text{ L}} \\
 &= 0.90 \text{ mol L}^{-1}
 \end{aligned}$$

	NO	O <sub>2</sub>	NO <sub>2</sub>
<b>Initial (mol)</b>	0	0	0.90
<b>Change (mol)</b>	+2 <i>x</i>	+ <i>x</i>	-2 <i>x</i>
<b>Equilibrium (mol)</b>	2 <i>x</i>	<i>x</i>	0.90 - 2 <i>x</i>

$$\begin{aligned}
 K &= \frac{[\text{NO}_2]^2}{[\text{NO}]^2[\text{O}_2]} \\
 2.47 \times 10^{12} &= \frac{(0.90 - 2x)^2}{(2x)^2(x)}
 \end{aligned}$$

Note that  $2x$  is a measure of how much product is converted into reactants. Since  $K$  is very large, the equilibrium position lies well to the right, so very little product is converted into the reactants. Therefore, assume that  $0.90 - 2x \doteq 0.90$ .

$$\begin{aligned}
 2.47 \times 10^{12} &= \frac{(0.90)^2}{(2x)^2(x)} \\
 \implies x &= 4.34 \times 10^{-5} \text{ mol L}^{-1} \\
 [\text{NO}] &= 2 \times 4.34 \times 10^{-5} \text{ mol L}^{-1} \\
 &= 8.69 \times 10^{-5} \text{ mol L}^{-1}
 \end{aligned}$$

## Section II: Short Answer Questions

### Question 21

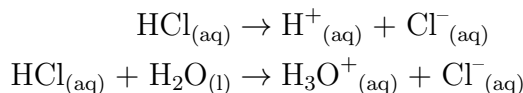
Functional group isomers: Butanal and butan-2-one (OR 2-methylpropanal and butan-2-one)

Chain isomers: Butanal and 2-methylpropanal

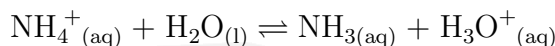
### Question 22

Arrhenius defined an acid as a substance that ionises to produce  $\text{H}^+$  ions in aqueous solution, whereas Brønsted/Lowry defined acids as proton donors.

HCl would be classified as both an Arrhenius acid and a Brønsted/Lowry acid since it produces  $\text{H}^+$  ions in aqueous solution and can also act as a proton donor as shown below.



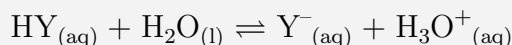
$\text{NH}_4\text{Cl}$  is a salt that dissociates into the  $\text{NH}_4^+$  and  $\text{Cl}^-$  ions. Arrhenius would not classify  $\text{NH}_4\text{Cl}$  as an acid as it does not produce any  $\text{H}^+$  ions when it dissociates. However, Brønsted/Lowry would classify  $\text{NH}_4\text{Cl}$  as an acidic salt since the  $\text{NH}_4^+$  ion is the weak conjugate acid of a weak base ( $\text{NH}_3$ ) and can donate a proton to water to form  $\text{H}_3\text{O}^+$  ions.



Note that the  $\text{Cl}^-$  ion is the extremely weak conjugate base of a strong acid (HCl) so it does not react with water to any significant extent.

### Question 23

Both solutions X and Y are neutral since they start with a pH of 7.00. When concentrated NaOH is added to solution Y, the pH increases by a minimal amount because Y is a buffer solution that can resist changes in pH when a small amount of acid/base is added to it. Solution Y would contain similar amounts of a weak acid (say HY) and its conjugate base ( $\text{Y}^-$ ).

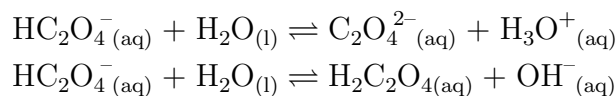


When NaOH is added, the  $\text{OH}^-$  reacts with  $\text{H}_3\text{O}^+$  to form water which effectively causes  $[\text{H}_3\text{O}^+]$  to decrease. Le Chatelier's principle predicts the equilibrium will shift right in an attempt to increase  $[\text{H}_3\text{O}^+]$  which minimises the increase in pH.

When NaOH is added to solution X, the pH rapidly increases because X is not a buffer solution. The  $[\text{OH}^-]$  will simply increase rapidly (and the  $[\text{H}_3\text{O}^+]$  will decrease), causing the pH to increase significantly to 12.00.

### Question 24

$\text{HC}_2\text{O}_4^-$  is amphiprotic because it can act as both a proton donor and a proton acceptor as shown below.



Note: Answers may also include reactions of  $\text{HC}_2\text{O}_4^-$  with  $\text{H}_3\text{O}^+$  or  $\text{OH}^-$ .

**Question 25**

$$\begin{aligned}
 \text{(a)} \quad q_w &= mc\Delta T \\
 &= (205 \text{ g})(4.18 \text{ J g}^{-1} \text{ K}^{-1})(60.4 - 23.7) \text{ K} \\
 &= 3.14 \times 10^4 \text{ J}
 \end{aligned}$$

Assuming no heat loss,

$$\begin{aligned}
 q(\text{C}_8\text{H}_{17}\text{OH}) &= -3.14 \times 10^4 \text{ J} \\
 n(\text{C}_8\text{H}_{17}\text{OH}) &= \frac{q}{\Delta H} \\
 &= \frac{-3.14 \times 10^4 \text{ J}}{-5294 \times 10^3 \text{ J mol}^{-1}} \\
 &= 5.94 \times 10^{-3} \text{ mol} \\
 n(\text{C}_8\text{H}_{17}\text{OH}) &= 5.94 \times 10^{-3} \text{ mol} \times 130.23 \text{ g mol}^{-1} \\
 &= 0.774 \text{ g}
 \end{aligned}$$

- (b) One advantage of biofuels is that they are renewable fuels. Ethanol, for example, can be produced by fermentation of sugars from crops like sugar cane. Using biofuels will help reduce our reliance on non-renewable fossil fuels like petrol.

**Question 26**

- (a) When  $\text{NO}_2$  is consumed by the water,  $[\text{NO}_2]$  decreases. Le Chatelier's principle predicts the equilibrium between  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$  (given in reactor 2) will shift towards the left in an attempt to increase  $[\text{NO}_2]$ . This causes the  $\text{N}_2\text{O}_4$  to get converted into  $\text{NO}_2$ .
- (b) The water that is disposed from Separator 1 can be recycled into Reactor 3. This makes the process more economical since less reactants will need to be purchased. A catalyst can also be used in all the reactors to increase the reaction rate by providing an alternative reaction pathway with a lower activation energy. This would allow the products to be produced more quickly.

**Question 27**

$$\begin{aligned}
 m(\text{C}_2\text{H}_5\text{OH}) &= 0.789 \text{ g mL}^{-1} \times 185 \text{ mL} \\
 &= 146 \text{ g} \\
 n(\text{C}_2\text{H}_5\text{OH}) &= \frac{146 \text{ g}}{(2(12.01) + 6(1.008) + 16.00) \text{ g mol}^{-1}} \\
 &= 3.17 \text{ mol} \\
 n(\text{CO}_2) &= 3.17 \text{ mol}
 \end{aligned}$$

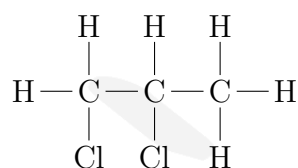
$$\begin{aligned}
 PV &= nRT \\
 (100 \text{ kPa})V &= 3.17 \text{ mol} \times 8.314 \text{ J mol}^{-1} \text{ K}^{-1} \times 310 \text{ K} \\
 \implies V &= 81.7 \text{ L}
 \end{aligned}$$

**Question 28**

- (a) Bromine water can be added to Q. If the bromine water is decolourised from brown to colourless, then Q is an alkene that undergoes an addition reaction due to its reactive C=C double bond.
- (b) There is a molecular ion peak at  $m/z = 112$ , so the molecular mass of R is 112 amu (note that the peak at  $m/z = 114$  is due to the Cl-37 isotope).

$$\begin{aligned}M(\text{C})_{\text{total}} &= 0.32 \times 112 \text{ amu} \\&= 35.84 \text{ amu} \\N(\text{C}) &= \frac{35.84 \text{ amu}}{12 \text{ amu}} \\&\approx 3\end{aligned}$$

Therefore, R has 3 C atoms and 2 Cl atoms (on different C atoms due to the addition reaction). Assuming the remaining atoms are H yields:



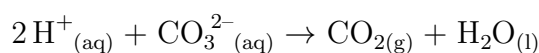
The molecular mass of this compound ( $\text{C}_3\text{H}_6\text{Cl}_2$ ) is  $M = (3 \times 12 + 6 \times 1 + 2 \times 35) \text{ amu} = 112 \text{ amu}$  which is consistent with the mass spectrum.

**Question 29**

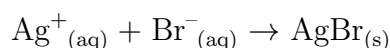
Alcohols are polar molecules that contain a polar  $-\text{OH}$  group which allows them to form strong hydrogen bonds with water which is also polar. This allows smaller alcohols to be soluble in water. However, as the molar mass of the alcohols increase, their hydrophobic, non-polar hydrocarbon chains increase in size and begin to outweigh the effects of the polar  $-\text{OH}$  group. There will be stronger dispersion forces between the larger alcohols that are more difficult for water to overcome. This causes alcohol's water solubility to decrease as molar mass increases as shown on the graph.

**Question 30**

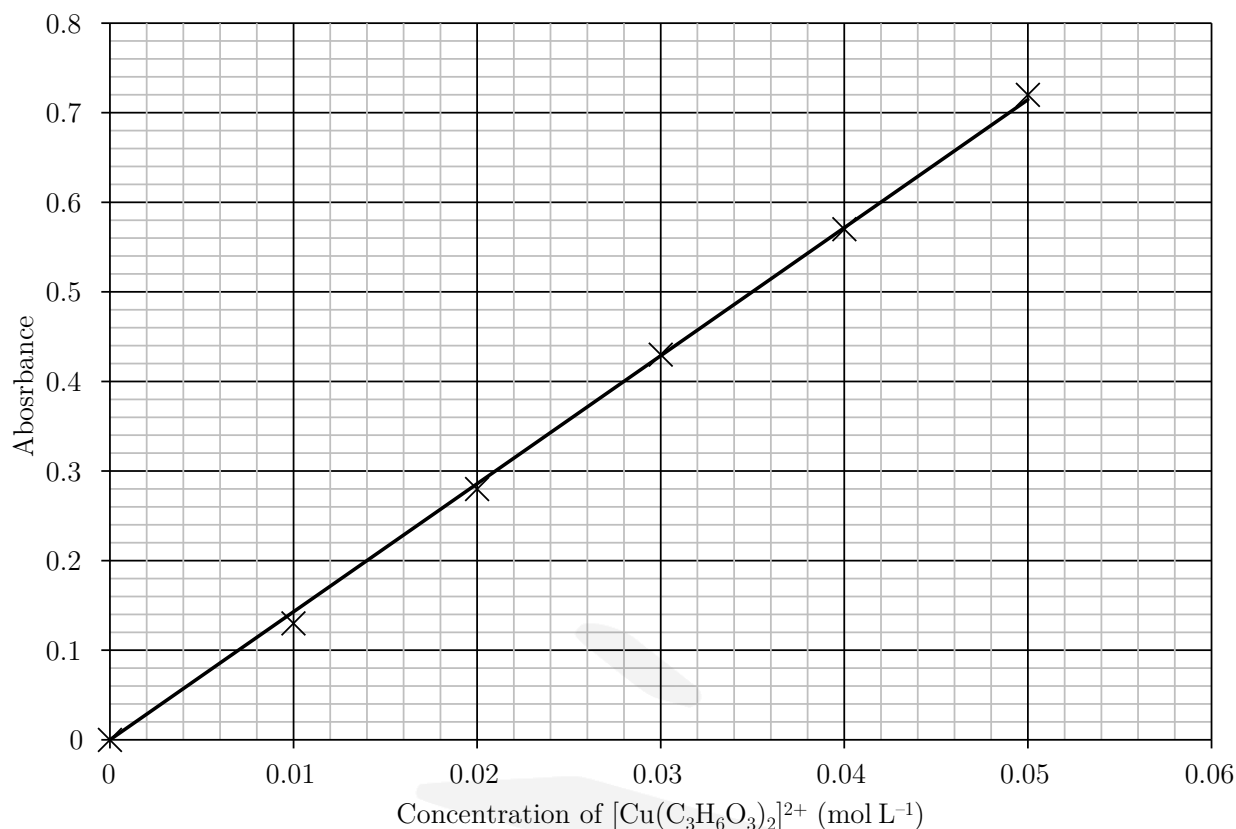
Excess  $\text{HNO}_3$  can be added to the mixture and if effervescence (bubbling) is observed, then the solution contains  $\text{CO}_3^{2-}$  ions. If no bubbling is observed, then the sample does not contain  $\text{CO}_3^{2-}$  ions.



$\text{AgNO}_3$  can then be added to the acidified sample and if a pale yellow precipitate forms, then  $\text{Br}^-$  ions are present. If no pale yellow precipitate forms, then no  $\text{Br}^-$  ions are present.



## Question 31

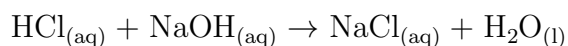


Interpolating from the calibration curve, when  $A = 0.66$ ,  $[\text{Cu}(\text{C}_3\text{H}_6\text{O}_3)_2]^{2+} = 0.046 \text{ mol L}^{-1}$

	$\text{Cu}^{2+}$	$\text{C}_3\text{H}_6\text{O}_3$	$[\text{Cu}(\text{C}_3\text{H}_6\text{O}_3)_2]^{2+}$
<b>Initial</b>	0.056	0.111	0
<b>Change</b>	-0.046	-0.092	+0.046
<b>Equilibrium</b>	0.010	0.019	0.046

$$\begin{aligned}
 K &= \frac{[\text{Cu}(\text{C}_3\text{H}_6\text{O}_3)_2]^{2+}}{[\text{Cu}^{2+}][\text{C}_3\text{H}_6\text{O}_3]^2} \\
 &= \frac{0.046}{0.010 \times 0.019^2} \\
 &= 1.3 \times 10^4
 \end{aligned}$$

## Question 32



Discarding the 1<sup>st</sup> rough titre,

$$\begin{aligned}
 V(\text{HCl}) &= \frac{(0.02205 + 0.02200 + 0.02195) \text{ L}}{3} \\
 &= 0.02200 \text{ L}
 \end{aligned}$$

$$\begin{aligned}
 n(\text{HCl}) &= 0.1102 \text{ mol L}^{-1} \times 0.02200 \text{ L} \\
 &= 2.424 \times 10^{-3} \text{ mol}
 \end{aligned}$$

$$n(\text{NaOH}) \text{ titrated} = 2.424 \times 10^{-3} \text{ mol}$$



These moles of NaOH came from a 20.0 mL aliquot of the diluted resultant solution. Therefore, the moles of NaOH in the 250.0 mL diluted resultant solution is given by:

$$\begin{aligned}n(\text{NaOH}) \text{ leftover} &= \frac{250.0 \text{ mL}}{20.0 \text{ mL}} \times 2.424 \times 10^{-3} \text{ mol} \\&= 0.03031 \text{ mol} \\n(\text{NaOH}) \text{ added} &= 1.124 \text{ mol L}^{-1} \times 0.05000 \text{ L} \\&= 0.05620 \text{ mol} \\n(\text{NaOH}) \text{ reacted} &= n(\text{NaOH}) \text{ added} - n(\text{NaOH}) \text{ leftover} \\&= 0.05620 \text{ mol} - 0.03031 \text{ mol} \\&= 0.02590 \text{ mol} \\n(\text{NH}_4^+) &= 0.02590 \text{ mol} \\m(\text{NH}_4^+) &= 0.02590 \text{ mol} \times (14.01 + 4(1.008)) \text{ g mol}^{-1} \\&= 0.4672 \text{ g}\end{aligned}$$

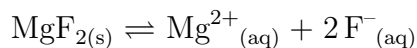
### Question 33

- (a) The system is at equilibrium between 6 minutes and 8 minutes. During this time, the rate of the forward and reverse reactions are equal and there is a continuous interchange between the reactants and the products, so the concentration of all species remain constant.
- (b) The temperature or volume of the system was increased.

When temperature is increased, Le Chatelier's principle predicts the equilibrium will shift left towards the heat absorbing endothermic reaction to decrease temperature. When the volume is increased, pressure decreases. Le Chatelier's principle predicts the equilibrium will shift left, towards the side with more moles of gas (3 : 2) to increase the pressure.

In both cases, the reverse reaction is favoured which causes  $[\text{A}_2]$  and  $[\text{B}_2]$  to increase while  $[\text{AB}_2]$  decreases until equilibrium is re-established at  $t = 12$  minutes.

**Note:** The  $y$ -axis plots moles and not concentration, so the increase in volume won't result in vertical spikes on the graph.

**Question 34**

$$\begin{aligned} n(\text{F}^{-})_{\text{i}} &= 1.50 \text{ mol L}^{-1} \times 0.175 \text{ L} \\ &= 0.263 \text{ mol} \end{aligned}$$

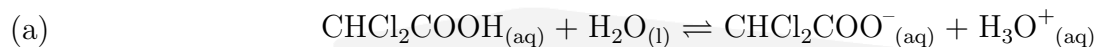
$$\begin{aligned} n(\text{MgF}_2)_{\text{ppted}} &= \frac{0.6231 \text{ g}}{62.31 \text{ g mol}^{-1}} \\ &= 0.01000 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{F}^{-})_{\text{ppted}} &= 2 \times 0.01000 \text{ mol} \\ &= 0.02000 \text{ mol} \end{aligned}$$

$$\begin{aligned} n(\text{F}^{-})_{\text{eq}} &= 0.263 \text{ mol} - 0.02000 \text{ mol} \\ &= 0.243 \text{ mol} \end{aligned}$$

$$\begin{aligned} [\text{F}^{-}]_{\text{eq}} &= \frac{0.243 \text{ mol}}{(0.125 + 0.175) \text{ L}} \\ &= 0.808 \text{ mol L}^{-1} \end{aligned}$$

$$\begin{aligned} K_{\text{sp}} &= [\text{Mg}^{2+}]_{\text{eq}} [\text{F}^{-}]_{\text{eq}}^2 \\ 5.16 \times 10^{-11} &= [\text{Mg}^{2+}]_{\text{eq}} \times 0.808^2 \\ \Rightarrow [\text{Mg}^{2+}]_{\text{eq}} &= 7.90 \times 10^{-11} \text{ mol L}^{-1} \end{aligned}$$

**Question 35**

$$\begin{aligned} [\text{H}^{+}]_{\text{eq}} &= 10^{-1.107} \text{ mol L}^{-1} \\ &= 0.0782 \text{ mol L}^{-1} \end{aligned}$$

	$\text{CHCl}_2\text{COOH}$	$\text{CHCl}_2\text{COO}^{-}$	$\text{H}_3\text{O}^{+}$
<b>Initial</b>	0.2000	0	0
<b>Change</b>	-0.0782	+0.0782	+0.0782
<b>Equilibrium</b>	0.122	0.0782	0.0782

$$\begin{aligned} K_{\text{a}} &= \frac{[\text{CHCl}_2\text{COO}^{-}][\text{H}_3\text{O}^{+}]}{[\text{CHCl}_2\text{COOH}]} \\ &= \frac{0.0782 \times 0.0782}{0.122} \\ &= 0.0501 \end{aligned}$$

Note: The final answer should be reported to 3 significant figures since the pH value given has 3 decimal places.

- (b) For the ionisation of both acids,  $\Delta S^\ominus < 0$  which is thermodynamically unfavourable as it leads to less disorder. However, for  $\text{CH}_3\text{COOH}$ ,  $\Delta H^\ominus < 0$  (exothermic) which is thermodynamically favourable while for  $\text{CCl}_3\text{COOH}$ ,  $\Delta H^\ominus > 0$  (endothermic) which is unfavourable.

For  $\text{CH}_3\text{COOH}$ , the unfavourable  $T\Delta S^\ominus$  term greatly outweighs the favourable  $\Delta H^\ominus$  term, leading to  $\Delta G^\ominus = \Delta H^\ominus - T\Delta S^\ominus > 0$ , so the ionisation of  $\text{CH}_3\text{COOH}$  is not spontaneous (under standard state conditions).

For  $\text{CCl}_3\text{COOH}$ , both the enthalpy and entropy terms are unfavourable so  $\Delta G^\ominus > 0$  and the ionisation of  $\text{CCl}_3\text{COOH}$  is also not spontaneous. However, the unfavourable  $T\Delta S^\ominus$  term is a lot smaller in magnitude for  $\text{CCl}_3\text{COOH}$  compared to  $\text{CH}_3\text{COOH}$ , leading to a much lower magnitude of  $\Delta G^\ominus$ . The smaller positive  $\Delta G^\ominus$  for the ionisation of  $\text{CCl}_3\text{COOH}$  is equivalent to a higher  $K_a$  (via the relationship  $\Delta G^\ominus = -RT \ln K$ ) and a smaller  $\text{p}K_a$  compared to  $\text{CH}_3\text{COOH}$ . This means  $\text{CCl}_3\text{COOH}$  is a stronger acid (has a higher degree of ionisation) than  $\text{CH}_3\text{COOH}$ .

**Note:** The reference to  $\Delta G^\ominus = -RT \ln K$  is NOT required for full marks to be obtained and has only been included for completion.

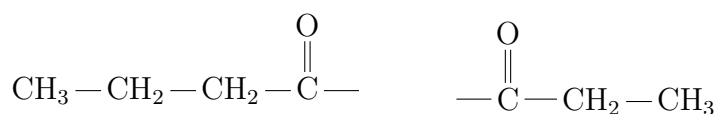
**Question 36**

**A** is an alkene that is hydrated with  $\text{H}_2\text{O}$ /dilute  $\text{H}^+$  to an alcohol **B**. This is supported by the IR spectrum of **B** showing a broad absorption at  $3230 - 3550 \text{ cm}^{-1}$ , indicating that a  $\text{O}-\text{H}$  (alcohol) group is present. Alcohol **B** is oxidised by  $\text{MnO}_4^-/\text{H}^+$  to either a ketone or a carboxylic acid.

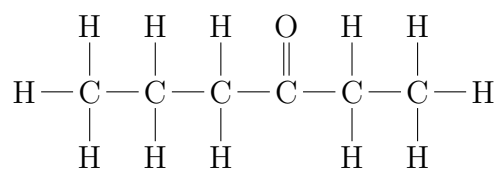
From the  $^1\text{H}$  NMR data, **C** cannot be a carboxylic acid or aldehyde since there are no signals between  $9.0 - 13.0 \text{ ppm}$ . Therefore, **C** must be a ketone produced from the oxidation of a secondary alcohol. There are 5 signals on the  $^1\text{H}$  NMR spectrum, so there are 5  $^1\text{H}$  environments which are summarised in the table below:

$\delta$ (ppm)	Integration	Multiplicity	$^1\text{H}$ Neighbours ( $n + 1$ rule)	Conclusion
1.01	3H	Triplet (3)	2	A $\text{CH}_3-$ group next to a $-\text{CH}_2-$ group  $\text{CH}_3-\text{CH}_2-$
1.05	3H	Triplet (3)	2	Another $\text{CH}_3-$ group next to a $-\text{CH}_2-$ group  $\text{CH}_3-\text{CH}_2-$
1.65	2H	Multiplet	—	A $-\text{CH}_2-$ group with multiple H neighbours  $-\text{CH}_2-$
2.42	2H	Triplet (3)	2	A $-\text{CH}_2-$ group deshielded by a $\text{C}=\text{O}$ group  $-\text{CH}_2-\text{CH}_2-\overset{\text{O}}{\parallel}{\text{C}}-$
2.46	2H	Quartet (4)	3	Another deshielded $-\text{CH}_2-$ group  $\overset{\text{O}}{\parallel}{\text{C}}-\text{CH}_2-\text{CH}_3$

From the information above, the fragments that make up the molecule are:

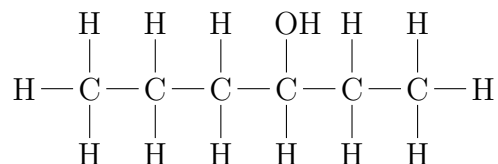


A possible structure is therefore:



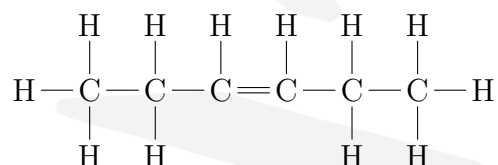
**C** contains the carbonyl ( $\text{C}=\text{O}$ ) functional group of a ketone

Therefore, **B** must be:



**B** contains a hydroxyl ( $-\text{OH}$ ) functional group

Noting that **A** only has 3 signals on the  $^{13}\text{C}$  NMR spectrum and thus 3 C environments, **A** must be a symmetrical alkene.



**A** contains a  $\text{C}=\text{C}$  functional group

The molar mass of **A** ( $\text{C}_6\text{H}_{12}$ ) is  $M = (6 \times 12.01 + 12 \times 1.008) \text{ g mol}^{-1} = 84.156 \text{ g mol}^{-1}$  which is consistent with the data given.

### Question 37

(a)

$$\begin{aligned}
 Q &= \frac{[\text{CO}_2]}{[\text{CO}]^2} \\
 &= \frac{1.21 \times 10^{-3}}{(1.10 \times 10^{-2})^2} \\
 &= 10.0 \\
 &= K
 \end{aligned}$$

$\therefore$  The system is at equilibrium.

(b) After  $\text{CO}_2$  is added, the equilibrium will shift left.

	<b>CO</b>	<b>CO<sub>2</sub></b>
<b>Initial</b>	$1.10 \times 10^{-2}$	$1.21 \times 10^{-3} + x$
<b>Change</b>	$+2y$	$-y$
<b>Equilibrium</b>	$1.10 \times 10^{-2} + 2y$	$1.21 \times 10^{-3} + x - y$

At equilibrium,  $[\text{CO}] = [\text{CO}_2]$ , so:

$$\begin{aligned} K &= \frac{[\text{CO}_2]}{[\text{CO}]^2} \\ &= \frac{[\text{CO}]}{[\text{CO}]^2} \\ &= \frac{1}{[\text{CO}]} \\ \therefore 10.00 &= \frac{1}{1.10 \times 10^{-2} + 2y} \\ \implies y &= 0.0445 \text{ mol L}^{-1} \end{aligned}$$

Using the fact that  $[\text{CO}_2] = [\text{CO}]$  to re-write the  $K$  expression gives:

$$\begin{aligned} K &= \frac{1}{[\text{CO}_2]} \\ 10.00 &= \frac{1}{1.21 \times 10^{-3} + x - 0.0445} \\ \implies x &= 0.143 \text{ mol L}^{-1} \\ n(\text{CO}_2)_{\text{added}} &= 0.143 \text{ mol L}^{-1} \times 1.00 \text{ L} \\ &= 0.143 \text{ mol} \end{aligned}$$