Section I

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

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

Place your student number and teacher's name on the sheet.

Select the alternative A, B, C or D that best answers the question.

Fill in the response oval completely using a **PENCIL**.

Sample Question $2 + 4 = ?$

(A) 2 (B) 6 (C) 8 (D) 9

A ○ B ○ C ● D ○

If you think you have made a mistake, **fully erase** your incorrect selection, ensuring no marks are left, and then fill in the new answer:

A ○ B ● C ○ D ○

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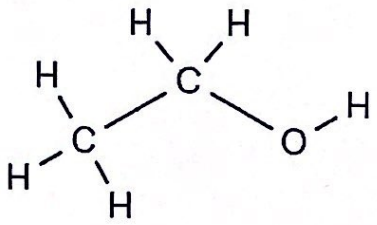
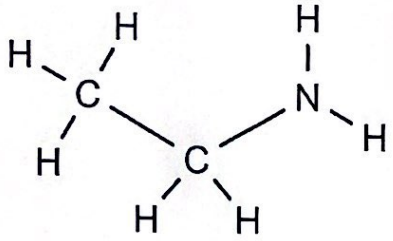
1 Which of the following organic compounds is an amide?

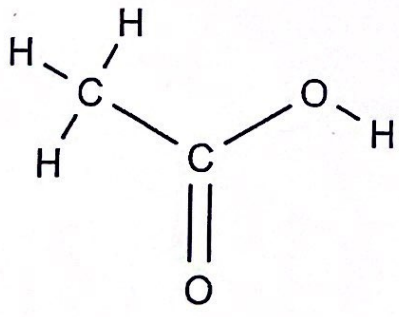
A.



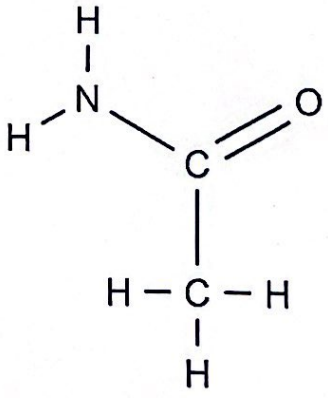
B.



C.



D.



2 The conjugate acid of HCO_3^- is:

A. H_3O^+

B. CO_3^{2-}

C. H_2CO_3

D. H_2O

3 How many chain isomers are there for the chemical formula C_5H_{12}?

A. 1

B. 2

C. 3

D. 4

4 Which of the following compounds has the highest molar solubility in water at 25°C?

A. $BaCO_3$

B. $Mg_3(PO_4)_2$

C. $Pb(OH)_2$

D. $CaSO_4$

5 Stomach (gastric) acid is a solution of mainly hydrochloric acid. The concentration of the acid can vary between 0.01 - 0.1 mol L^{-1}. Occasionally, excess acid is secreted into the stomach and this can cause significant discomfort. Medications are available which contain substances that neutralise this surplus acid.

Which substance would be best suited to safely neutralise the stomach acid?

A. A dilute solution of sodium chloride.

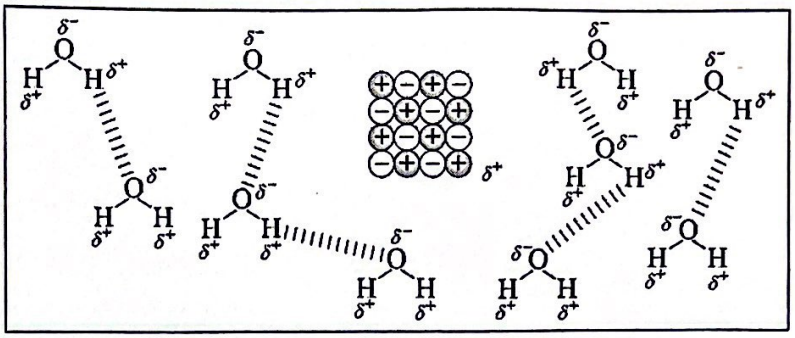
B. A dilute suspension of sodium hydrogen carbonate.

C. A concentrated solution of sodium hydroxide.

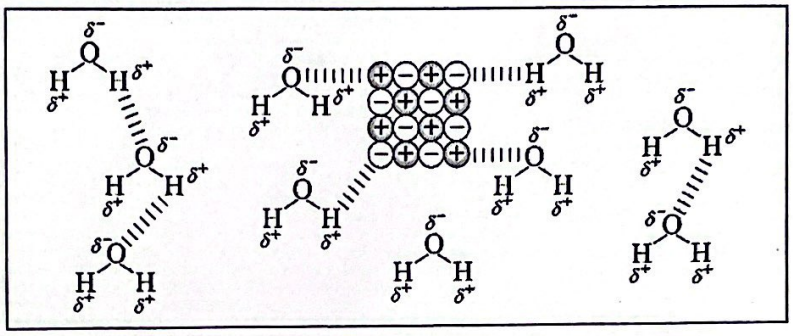
D. Large quantities of distilled water.

6 The diagram below shows three stages of a chemical process.

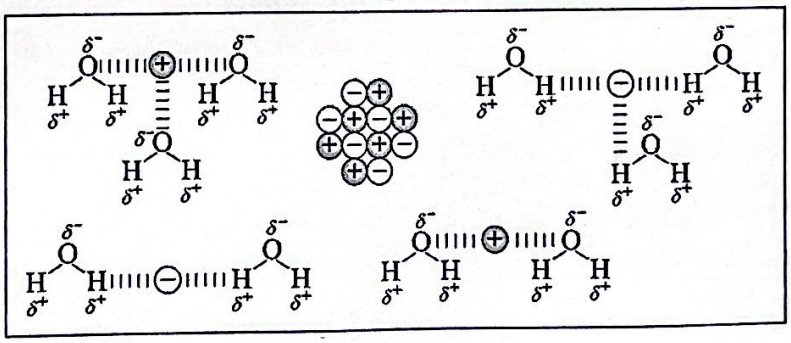
Stage I



Stage II



Stage III



Identify the chemical process that is shown in the diagram.

A. The dissociation of an ionic compound.

B. The dissociation of an acid.

C. The dissociation of a base.

D. The precipitation of an ionic compound.

Use the following information to answer Questions 7 and 8.

Nitrogen dioxide (a brown gas) and dinitrogen tetroxide (a colourless gas) are both forms of oxides of nitrogen. They form an equilibrium according to the chemical equation:

$$2NO_2(g) \rightleftharpoons N_2O_4(g)$$

At room temperature, an equilibrium mixture of the two gases has a light brown colour; however, at higher temperatures, the colour of the mixture is deep brown.

7 What conclusion can be drawn from this observation?

A. The reverse reaction in the equation is endothermic.

B. The forward reaction in the equation is endothermic.

C. The brown colour is due to the strong nitrogen-oxygen bonds in NO_2.

D. The equilibrium concentration of N_2O_4 is not dependent on temperature.

8 A student filled a sealed container with NO_2 and then left it until the colour remained constant. The teacher asked the student to describe the reaction process in terms of Gibbs free energy. Which of the following statements about the reaction progression is correct?

	Gibbs free energy when the container was first filled with NO_2	*Gibbs free energy when the colour remained constant*
A.	$\Delta G < 0$	$\Delta G = 0$
B.	$\Delta G > 0$	$\Delta G = 0$
C.	$\Delta G = 0$	$\Delta G < 0$
D.	$\Delta G = 0$	$\Delta G > 0$

9 How many peaks (excluding the TMS control peak) will be observed on the ^{13}C NMR spectrum of 3-ethylpentane?

A. 3

B. 4

C. 5

D. 7

10 Citric acid ($H_3C_6H_5O_7$) is a triprotic acid. It is often used as a flavouring and preservative in food and drinks. A solution of citric acid is neutralised by a solution of sodium hydroxide.

Identify the chemical equation that correctly represents the reaction between citric acid and sodium hydroxide.

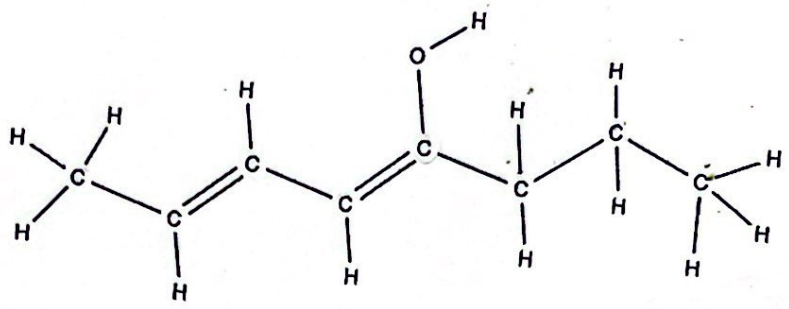
A. $3NaOH(s) + H_3C_6H_5O_{7(aq)} \rightarrow Na_3C_6H_5O_7(aq) + 3H_2O(l)$

B. $3NaOH(aq) + H_3C_6H_5O_7(aq) \rightarrow 3NaC_6H_5O_7(aq) + 3H_2O(l)$

C. $NaOH(aq) + 3H_3C_6H_5O_7(aq) \rightarrow Na_3C_6H_5O_7(aq) + 3H_2O(l)$

D. $3NaOH(aq) + H_3C_6H_5O_7(aq) \rightarrow Na_3C_6H_5O_7(aq) + 3H_2O(l)$

11 The systematic name for the organic compound below is:



A. Octa-4,5-dien-4-ol

B. Octa-4,6-dien-4-ol

C. Octa-2,4-dien-5-ol

D. Octa-2,3-dien-5-ol

12 Which one of the following **empirical formulae** could be that of a linear molecule?

A. CH

B. CH_2

C. CH_3

D. CH_4

13 A student was given a solution of methanoic acid of unknown concentration. To determine the concentration of the methanoic acid, they planned to titrate a standardised solution of sodium hydroxide with aliquots of the acid. The student thought phenolphthalein would be an appropriate indicator for this titration.

Which statement about their choice of indicator is correct?

Phenolphthalein is:

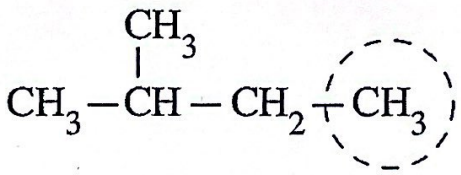
A. an appropriate indicator because at the equivalence point, the methanoate ion raises the pH of the solution above 7.

B. an appropriate indicator because it has a distinct colour change at a pH below 7.

C. not an appropriate indicator because its colour change does not match the equivalence point for this reaction.

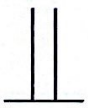
D. not an appropriate indicator because at the equivalence point the solution will have a pH of 7 as it is a neutralisation reaction.

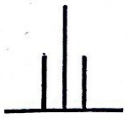
14 The structure of 2-methylbutane is shown below.

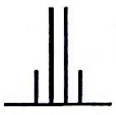


Which of the following splitting patterns would be observed in the ^1H NMR spectrum for the CH_3 group circled?

A. 

B. 

C. 

D. 

15 A 2.0 L container was used to heat 0.40 moles of phosphorus pentachloride to 200°C in the presence of a vanadium catalyst. The chemical equation for the reaction is:

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

At equilibrium, the mixture was found to contain 0.32 moles of chlorine.

The equilibrium constant for this reaction at this temperature is:

A. 0.64
B. 0.8
C. 0.256
D. 1.28

16 Which of the following ionic compounds would produce hydroxide ions when dissolved in water?

A. NaF
B. NaCl
C. NaBr
D. NaI

17 The pH of a buffer solution can be calculated using the following equation:

$$pH = pKa + \log \frac{[A^-]}{[HA]}$$

Where:
HA = the molecular acid
A^- = the conjugate base

Calculate the pH of a solution with equimolar concentrations of carbonic acid and hydrogen carbonate ions. The dissociation constant for the first ionisation of carbonic acid is Ka = 4.5×10^{-7}.

A. 7
B. 1
C. 6.35
D. 7.65

18 When detergents form an emulsion between oil and water, they bond with the oil through dispersion forces. Select the correct intermolecular force for each detergent that bonds it with water molecules.

	Anionic Detergent	*Cationic Detergent*	*Non-ionic Detergent*
A	Ion-dipole forces	Ion-dipole forces	Dispersion forces
B	Dipole-dipole forces	Dipole-dipole forces	Dipole-dipole forces
C	Hydrogen bonding	Hydrogen bonding	Dipole-dipole forces
D	Ion-dipole forces	Ion-dipole forces	Dipole-dipole forces

19 One of the advantages of using ethanol as a fuel is that it produces less carbon monoxide than petrol under the same conditions. Assuming complete combustion, calculate the volume of carbon dioxide produced if 10.0 g of ethanol is combusted at 200.0° C and at 100 kPa.

A. 3.6 L
B. 3.6 m^3
C. 8.5 L
D. 8.5 m^3

Answer should be ≈ 17.07L

20 An experiment is conducted in which 4-aminobutanoic acid, $H_2N(CH_2)_3COOH$, forms a condensation polymer containing 1000 monomer units.

What is the molar mass of this polymer?

A. 8.5×10^4 g mol^{-1}
B. 1.0×10^5 g mol^{-1}
C. 1.0×10^3 g mol^{-1}
D. 6.7×10^4 g mol^{-1}

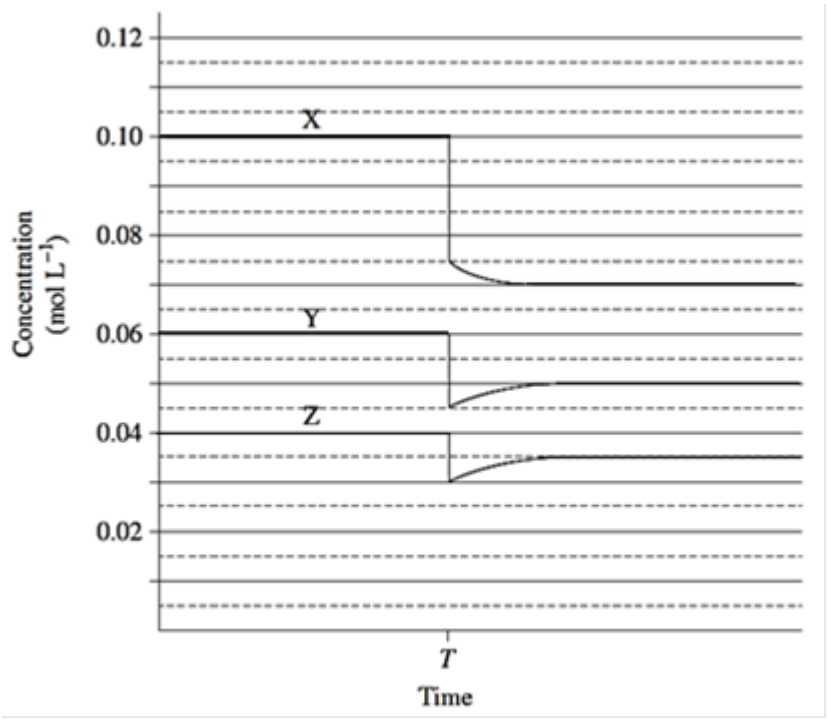
Question 21 (9 marks)

Phosgene ($COCl_2$) is a colourless gas that has an odour of freshly cut grass. It decomposes into chlorine gas and carbon monoxide through an endothermic reaction that establishes an equilibrium.

a) Write a chemical equation for this reaction including an appropriate scientific representation that it is endothermic. (2 marks)

b) Write an equilibrium expression for this reaction. (1 mark)

Phosgene, chlorine and carbon monoxide were mixed in a sealed container and allowed to reach equilibrium. A change was imposed at time T and the equilibrium re-established. The concentration of each gas was plotted against time and are represented with the letters X, Y and Z.



c) Identify the gas that is represented by the letter X on the graph. (1 mark)

d) Identify the change that occurred at time T and explain using Le Chatelier's Principle why the equilibrium re-established as shown in the graph. (4 marks)

e) Use the graph to calculate the equilibrium constant for the reaction before time T. (1 mark)

Question 22 (4 marks)

The heat of neutralisation for a reaction between a strong acid and a strong base is:

$$\Delta H = -57.62 \text{ kJ/mol.}$$

A student mixed 50.0 mL of 0.100 M hydrochloric acid with 50.0 mL of 0.200 M sodium hydroxide. They determined the mass of the final solution was 98.03 g. The teacher instructed the student to assume that the specific heat capacity of the solution would be the same as pure water.

Calculate the theoretical change in temperature of the reaction mixture. (4 marks)

Question 23 (5 marks)

Magnesium chloride is an ionic compound which is highly soluble in water.

a) Write the equation, including state symbols, for the process of forming a saturated solution of magnesium chloride in water (1 mark)

b) The table below shows some thermochemical data related to the dissolving of magnesium chloride solid in water.

Energy Required to Overcome the lattice forces to form free Mg2+ and Cl- ions.	+2493kJ/mol
Energy released upon hydration of Mg2+ ions.	-1920kJ/mol
Energy released upon hydration of Cl- ions.	-364kJ/mol

Use these data to calculate the standard enthalpy of solution of magnesium chloride. (2 marks)

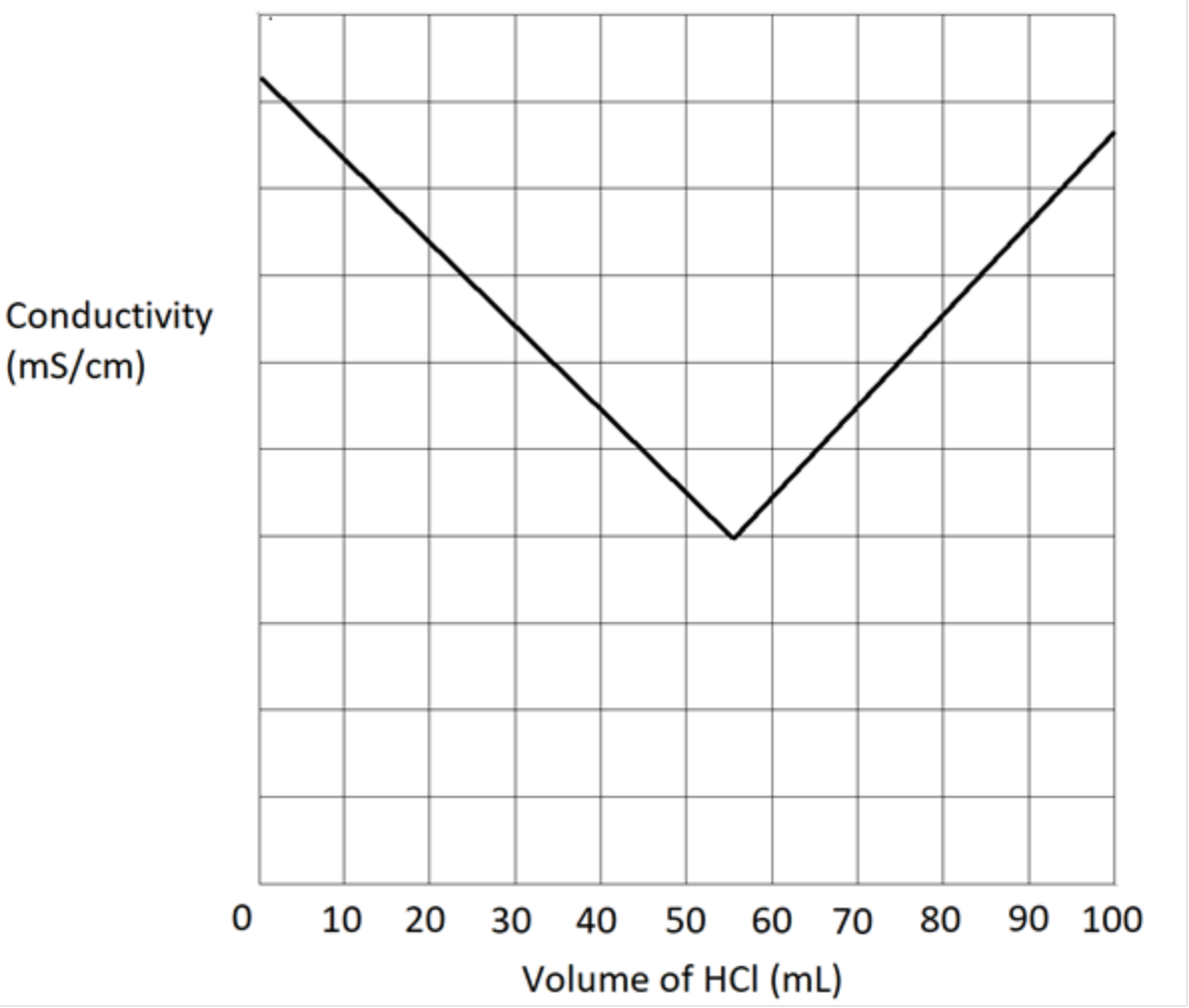
c) Use your answer to part (b) to deduce how the solubility of MgCl2 changes as the temperature is increased. Justify your answer. (2 marks)

Question 24 (5 marks)

Propan-1-amine has a boiling point of 47º C while N,N-dimethylmethanamine has a boiling point of just 3º C. Draw the structural formula for each compound and explain why there is a difference in boiling point. (5 marks)

Question 25 (6 marks)

A student wanted to determine the concentration of a solution of potassium hydroxide. They did this by reacting a 25 mL aliquot with a standard solution of hydrochloric acid while measuring the conductivity of the solution. 10.00 mL volumes of 0.1012 M hydrochloric acid were incrementally added using a burette and the conductivity was measured after each addition. The student recorded the following data.

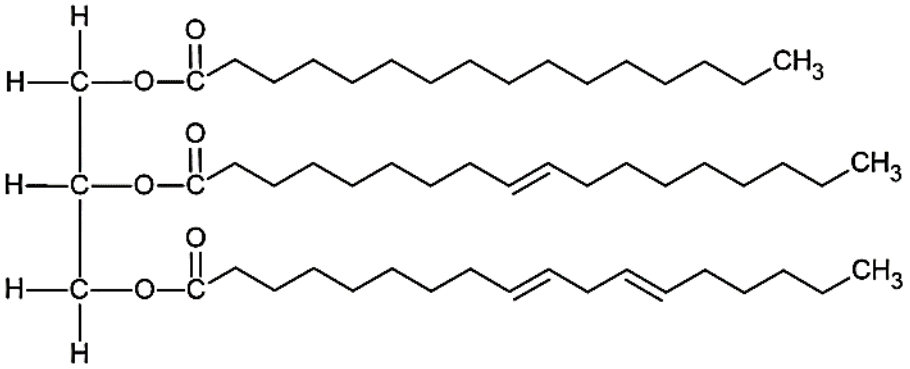


a) Explain the trend shown in the graph. (3 marks)

b) Calculate the concentration of the potassium hydroxide solution. (3 marks)

Question 26 (8 marks)

Linseed oil is a mixture of triesters. It is used for many purposes including as a protective layer for wooden furniture and as an ingredient in some cuisines. The diagram below shows the structure of a typical triester found in linseed oil.



When the triester shown above undergoes the process of de-esterification (this process is the opposite of esterification), three fatty acids are produced:

- palmitic acid
- linoleic acid
- oleic acid

which correspond to the three long chains in the diagram listed from top to bottom.

a) Why are compounds like the one depicted above called triesters? (1 mark)

b) In addition to the three acids listed above, ONE other product will form, and ONE other reactant will be consumed when the compound undergoes de-esterification. Identify the product and reactant and state the number of moles that would be produced/consumed from the complete de-esterification of one mole of the compound shown. (2 marks)

c) Castor oil is another natural product that may find a use as a component in biofuel. It releases 39.5 MJ kg−1 of energy when fully combusted. When 2.00 L of castor oil was combusted in a home-made engine 59.3 MJ of energy was released. Given that the density of castor oil is 0.96 g mL−1, calculate percentage efficiency of the home-made engine. (3 marks)

d) The picture below shows a laboratory reflux apparatus using a heating mantle.

e) Explain how TWO risks associated with heating volatile organic compounds are reduced by using a reflux apparatus with a heating mantle. (2 marks)

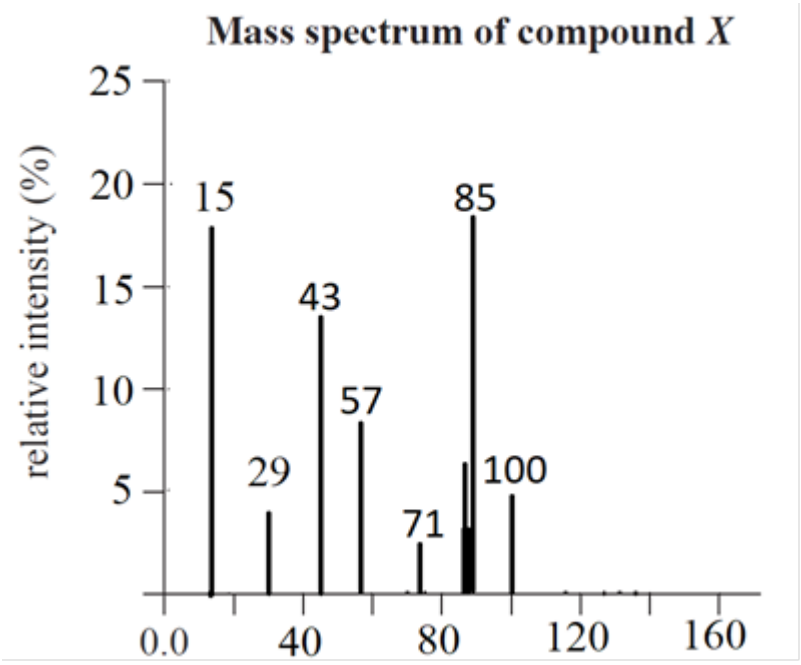
Question 27 (3 marks)

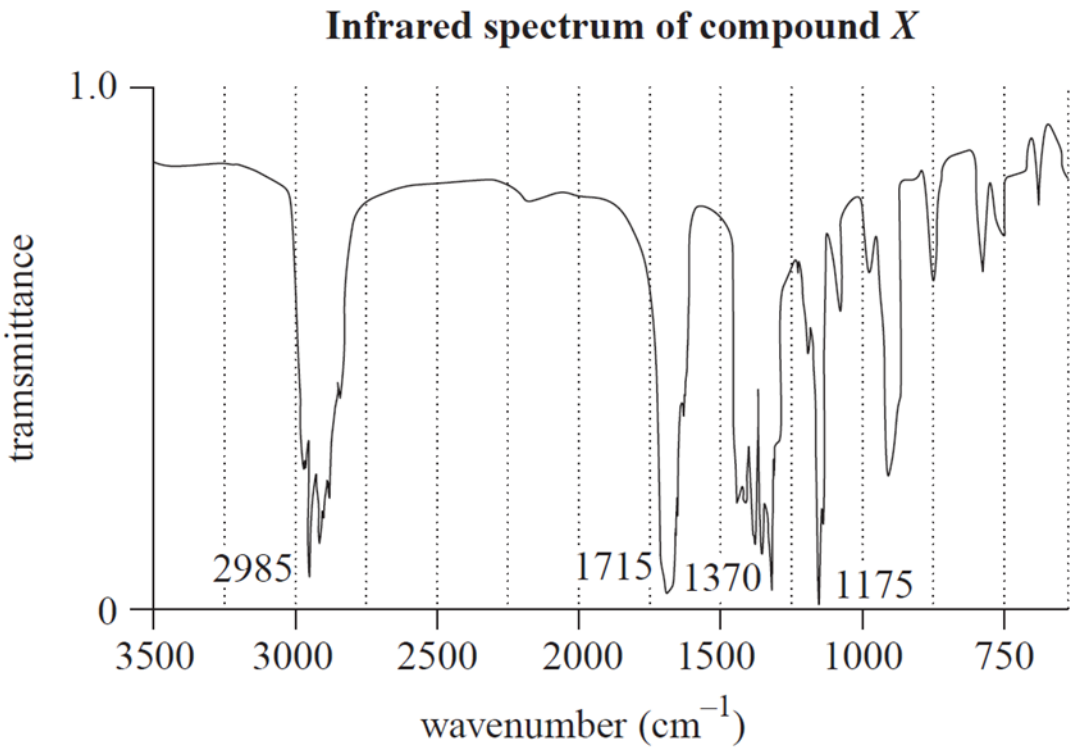
Sodium dihydrogen phosphate is an amphiprotic salt.

Explain what is meant by the term 'amphiprotic'. Support your answer with chemical equations. (3 marks)

Question 28 (5 marks)

A student obtained the following spectroscopic data to help to identify an unknown organic compound, labelled Compound X.





Identify Compound X, using BOTH spectra to justify your identification. (5 marks)

Question 29 (8 marks)

A solution of 4-chlorobutanoic acid was titrated against standardised sodium hydroxide solution. Small volumes of sodium hydroxide solution were added, and the pH was measured after each addition. The data collected are shown in the table below.

Volume of NaOH added (mL)	0	5	10	15	18	19	20	21	22	25	30
pH	3.8	4.3	4.6	4.5	4.7	5.0	12.1	12.5	13.3	13.0	13.0

a) Draw the structural formula of 4-chlorobutanoic acid. (1 mark)

b) Plot the values of the pH of the solution against the volume of NaOH and draw a smooth curve of best fit, ignoring possible outliers. (4 marks) **Use own graph paper…**

c) Estimate the pH at the equivalence point in this titration. (1 mark)

d) Use your graph to estimate a value of Ka for 4-chlorobutanoic acid. (2 marks)

Question 30 (8 marks)

The following table shows four acids which were tested for relative conductivity and pH:

Acid tested	*Relative Conductivity*	*pH*
Concentrated CH_3COOH (100% pure) known as glacial acetic acid	Does not conduct	Unable to measure
0.1 mol L^{-1} HCl solution	high	1.0
0.1 mol L^{-1} CH_3COOH solution	moderate	3.3
0.1 mol L^{-1} H_2SO_4 solution	high	0.7

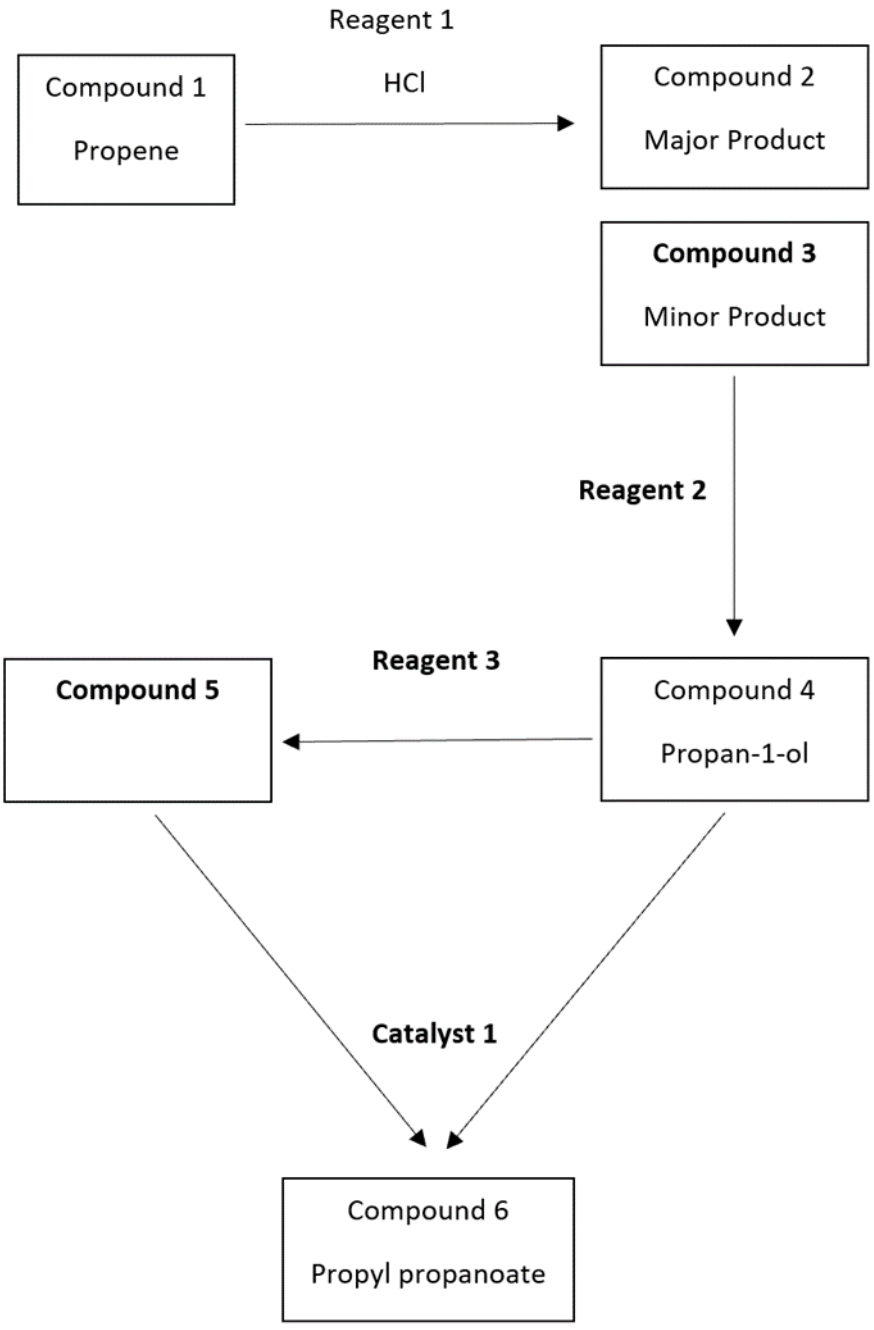
a) Explain why the pH for glacial acetic acid is unable to be measured. (2 marks)

b) Explain the differences in the pH values for the 0.1 mol L-1 acids that were tested. **Include relevant calculations.** (6 marks)

Exam continues on next page

Question 31 (7 marks)

The flow chart shows a series of reactions that would allow a chemist to synthesise propyl propanoate from propene.



a) Identify reagent 1, reagent 2, reagent 3, compound 3, compound 5 and catalyst 1 (5 marks)

b) Identify the following reaction types: (2 marks)
i) Compound 1 → Compound 2
ii)Compound 3 → Compound 4
iii)Compound 4 + Compound 5 → Compound 6

Question 32 (5 marks)

a) Given the molar solubility of MnCO3 is 4.20 x 10-6 M, calculate the solubility product for MnCO3. (2 marks)

b) A 0.200g sample of solid barium sulfate was added to 500mL of 0.010M sodium sulfate. Will all the barium sulfate sample dissolve? Justify your answer. (3 marks)

Question 33 (7 marks)

100.0 mL of 0.200 M hydrochloric acid was combined with 100.0 mL of 0.200 M ammonia solution. Calculate the pH of the final solution once the reaction has gone through to completion. (7 marks)

Ammonium pKa = 9.25
Hydrochloric acid pKa = -5.9

Multiple Choice Answers

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

Question 21 (9 marks) **Marks**

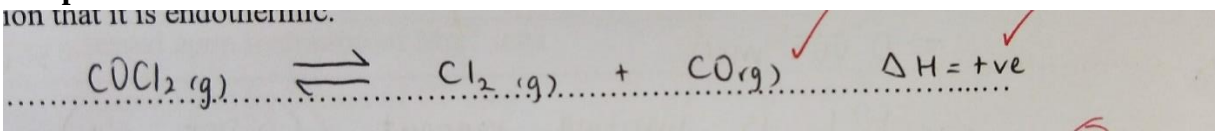
Phosgene ($COCl_2$) is a colourless gas that has an odour of freshly cut grass. It decomposes into chlorine gas and carbon monoxide through an endothermic reaction that establishes an equilibrium.

a) Write a chemical equation for this reaction including an appropriate scientific representation that it is endothermic. **2**

Marking Criteria	Marks
● Correct chemical equation including states ● Indicates that the enthalpy change is positive	1

1

Sample Answer



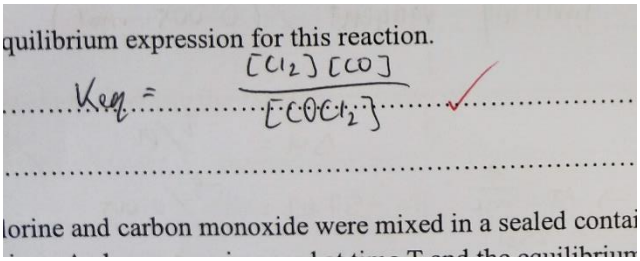
Markers Comments

Generally well done. Common mistakes were to leave out states and to include heat as a reactant. Also, some students had $+\Delta H$ along with the other products which represents it as a product. This is not how you represent an endothermic reaction. You should have $\Delta H =$ or $\Delta H > 0$ separate to the equation as it is not made of atoms, it is a representation of the energy change.

b) Write an equilibrium expression for this reaction.

Marking Criteria	Marks
● Correct equilibrium expression	1

Sample Answer



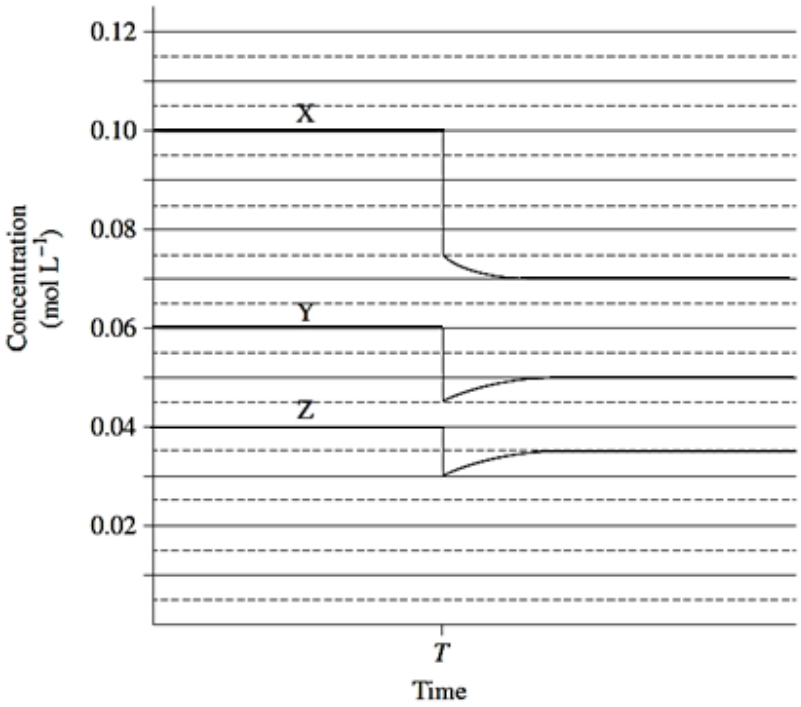
Markers Comments

Well done by most students. A very small number of student had it upside down (the reactant on top) and some did not include K=. This is an important part of the equilibrium expression.

1

Phosgene, chlorine and carbon monoxide were mixed in a sealed container and allowed to reach equilibrium. A change was imposed at time T and the equilibrium re-established. The concentration of each gas was plotted against time and are represented with the letters X, Y and Z.

4



Question 21 continued

c) Identify the gas that is represented by the letter X on the graph.

1

Marking Criteria	Marks
● Correctly identifies phosgene ($COCl_2$)	1

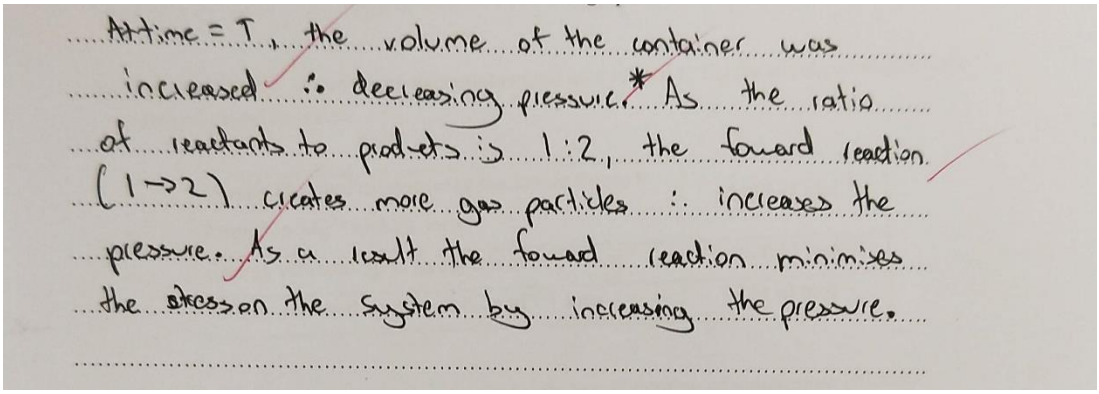
Markers Comments

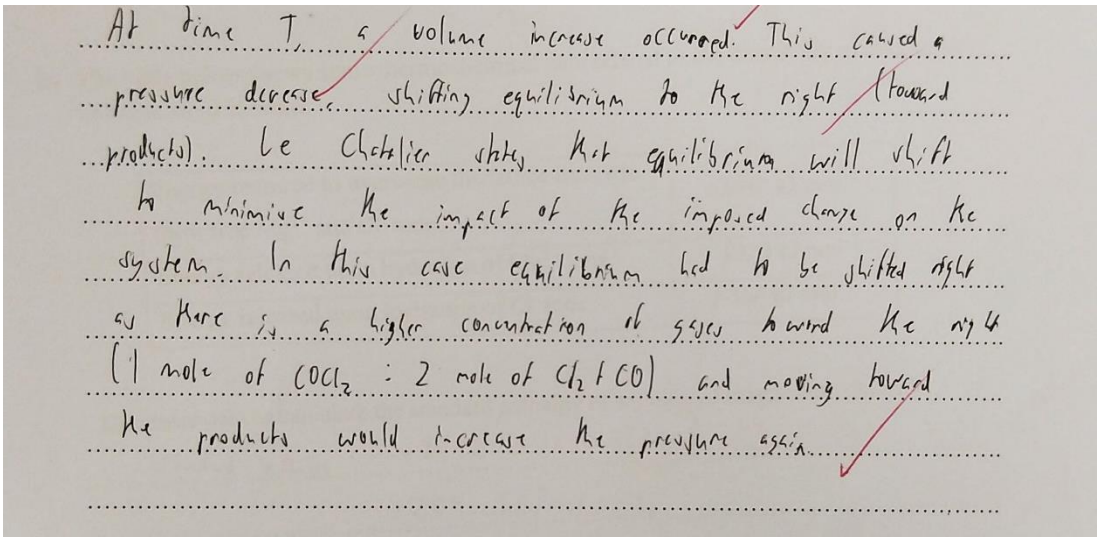
d) Identify the change that occurred at time T and explain using Le Chatelier's Principle why the equilibrium re-established as shown in the graph.

Marking Criteria	Marks
• Identifies the change as an increase in volume or that gas had been removed. • States that this results in a decrease in pressure • Explains that the equilibrium position shifts to the products to counteract the change • Because this increases the number of gas particles, therefore increase pressure	4
• One mistake or step missing from above	3
• Explains why the shift in equilibrium position counteracts an identified change (does not have to be pressure)	2
• States a change and predicts a shift in equilibrium position	1

Markers Comments

Sample Answer

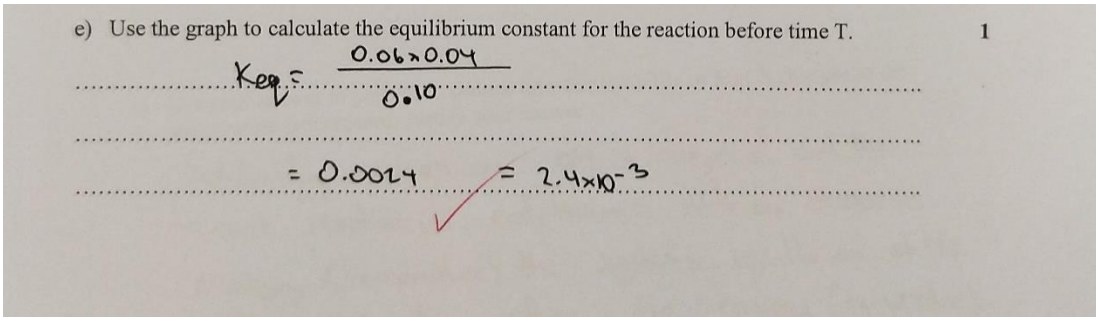

At time = T, the volume of the container was increased ∴ decreasing pressure. As the ratio of reactants to products is 1:2, the foward reaction (1→2) creates more gas particles ∴ increases the pressure. As a result the foward reaction minimises the stress on the system by increasing the pressure.


At time T, a volume increase occurred. This caused a pressure decrease, shifting equilibrium to the right (toward products). Le Chatelier states that equilibrium will shift to minimise the impact of the imposed change on the system. In this case equilibrium had to be shifted right as there is a higher concentration of gases toward the right (1 mole of $COCl_2$: 2 mole of Cl_2 / CO) and moving toward the products would increase the pressure again.

e) Use the graph to calculate the equilibrium constant for the reaction before time T.

Marking Criteria	Marks
• Calculates the equilibrium constant (0.024)	1

Sample Answer



Marks

Markers Comments

Question 22 (4 marks)

The heat of neutralisation for a reaction between a strong acid and a strong base is:

$$\Delta H = -57.62 \text{ kJ/mol.}$$

A student mixed 50.0 mL of 0.100 M hydrochloric acid with 50.0 mL of 0.200 M sodium hydroxide. They determined the mass of the final solution was 98.03 g. The teacher instructed the student to assume that the specific heat capacity of the solution would be the same as pure water.

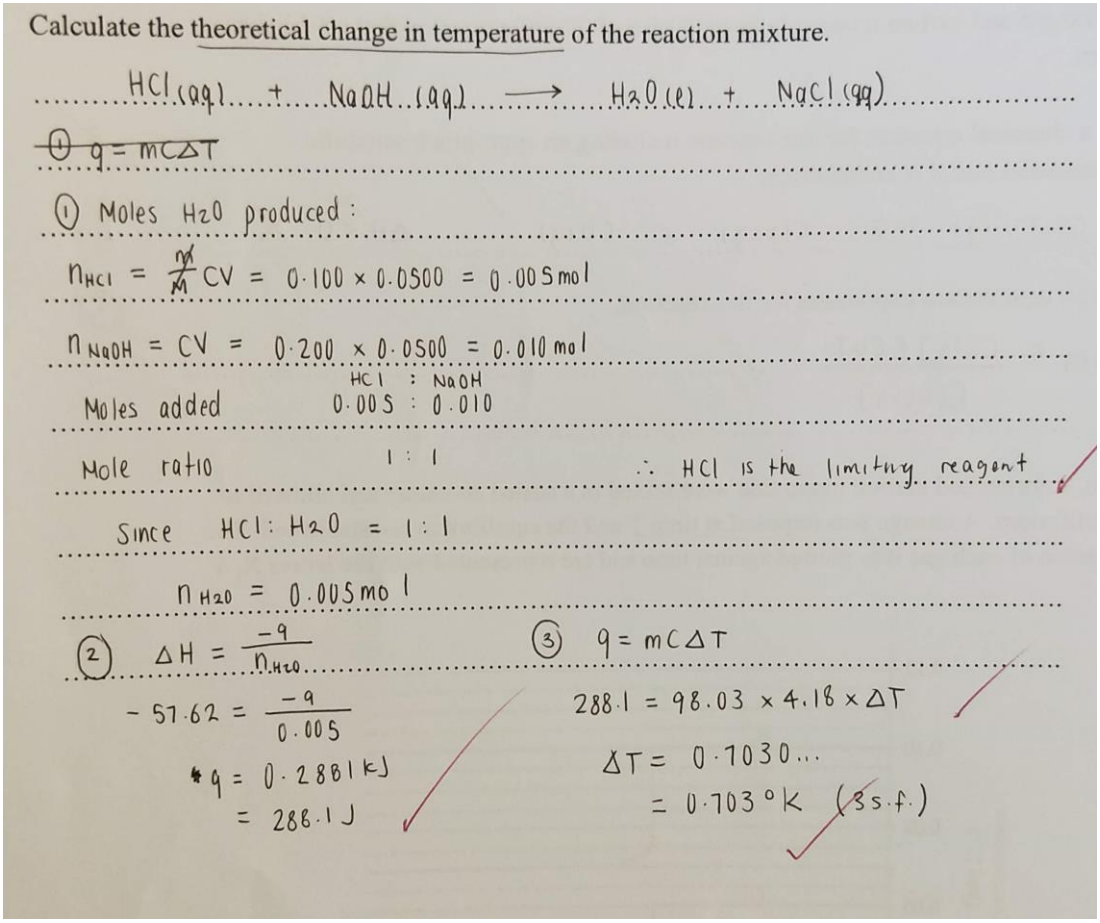
Calculate the theoretical change in temperature of the reaction mixture.

4

Marking Criteria	Marks
• Justifies HCl as the limiting reagent • Calculates q (288.1 J) with working • Calculates the change in temperature (0.703° C) with working and units • Give the final answer to 3 significant figures	4
• One mistake or step missing from above	3
• Two mistakes or steps missing from above	2
• Attempts at least one of the above step	1

Markers Comments

Sample Answer



Marks

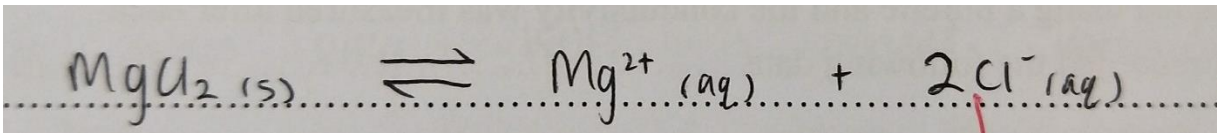
Question 23 (5 marks)

Magnesium chloride is an ionic compound which is highly soluble in water.

a) Write the equation, including state symbols, for the process of forming a saturated solution of magnesium chloride in water. **1**

Marking Criteria	Marks
● Correct chemical equation with states	1

Sample Answer



Markers Comments

b) The table below shows some thermochemical data related to the dissolving of magnesium chloride solid in water. **2**

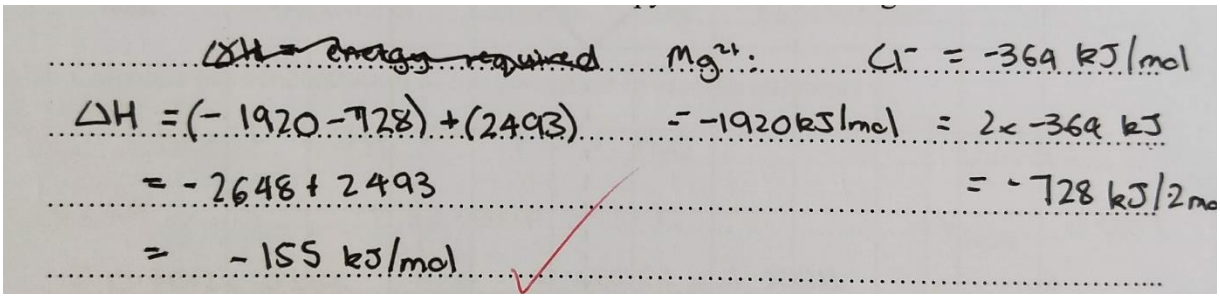
Energy required to overcome the lattice forces to form free Mg^{2+} and Cl^- ions.	+2493 kJ mol^{-1}
Energy released upon hydration of Mg^{2+} ions	–1920 kJ mol^{-1}
Energy released upon hydration of Cl^- ions	–364 kJ mol^{-1}

Use these data to calculate the standard enthalpy of solution of magnesium chloride. **2**

Marking Criteria	Marks
● Calculates the standard enthalpy ● Including units and working	2
● Attempts to combine standard energies	1

Markers Comments

Sample Answer

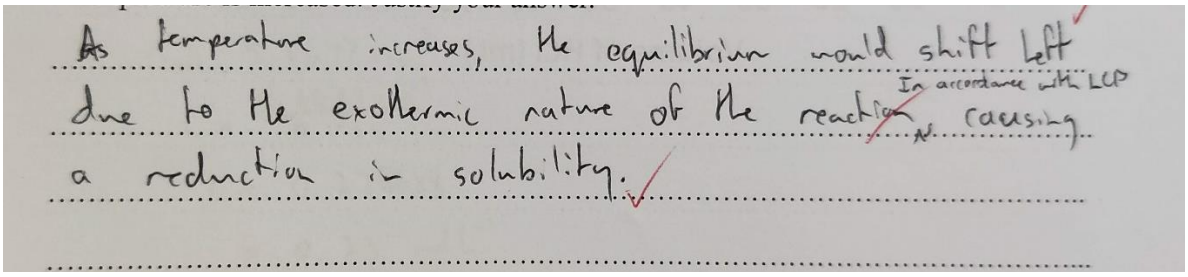


c) Use your answer to part (b) to deduce how the solubility of $MgCl_2$ changes as the temperature is increased. Justify your answer.

Marking Criteria	Marks
• Explains that an increase in temperature will cause the equilibrium position to shift to the reactant. • Links the shift left to reduced solubility If the previous question was a positive enthalpy, the opposite relationship was required.	2
• Explains how an increase in temperature will cause equilibrium position to shift.	1

Markers Comments

Sample Answer



Marks

Question 24 (5 marks)

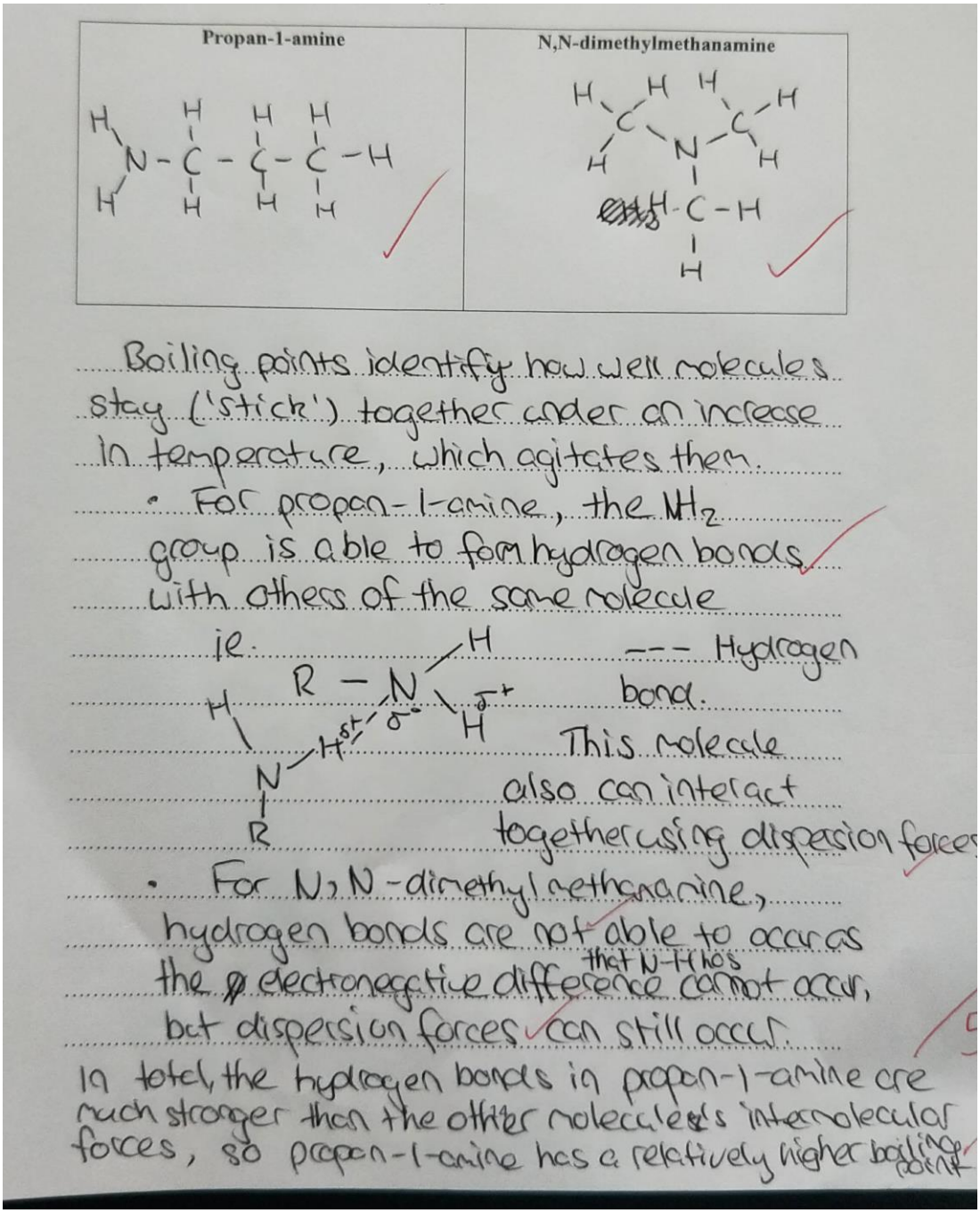
Propan-1-amine has a boiling point of 47º C while N,N-dimethylmethanamine has a boiling point of just 3º C. Draw the structural formula for each compound in the space provided and explain why there is a difference in boiling point. **5**

Marking Criteria	Marks
• Correct structures (one mark each)	2

Marks

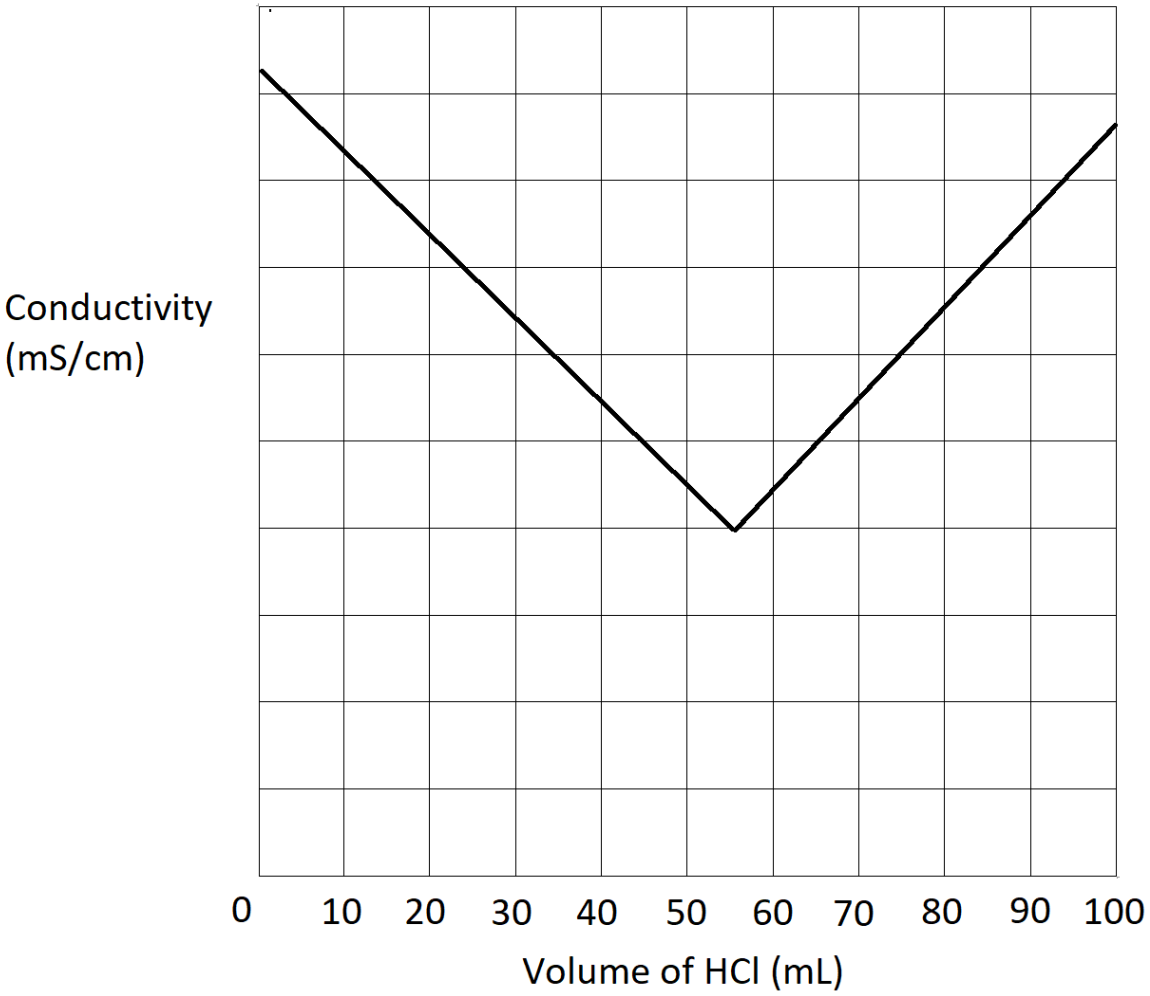
Marking Criteria	Marks
● Identifies the major intermolecular force for Propan-1-amine as hydrogen bonding ● Identifies the only intermolecular force for N,N-dimethylmethanamine as dispersion forces ● Explains that hydrogen bond require more energy to over come than dispersion forces, therefore, Propan-1-amine has a higher boiling point	3
● Correctly identifies the major intermolecular force one of the compounds. ● Relates the strength of intermolecular forces to boiling point	2
● Links intermolecular forces to boiling point	1

Sample Answer



Question 25 (6 marks)

A student wanted to determine the concentration of a solution of potassium hydroxide. They did this by reacting a 25 mL aliquot with a standard solution of hydrochloric acid while measuring the conductivity of the solution. 10.00 mL volumes of 0.1012 M hydrochloric acid were incrementally added using a burette and the conductivity was measured after each addition. The student recorded the following data.



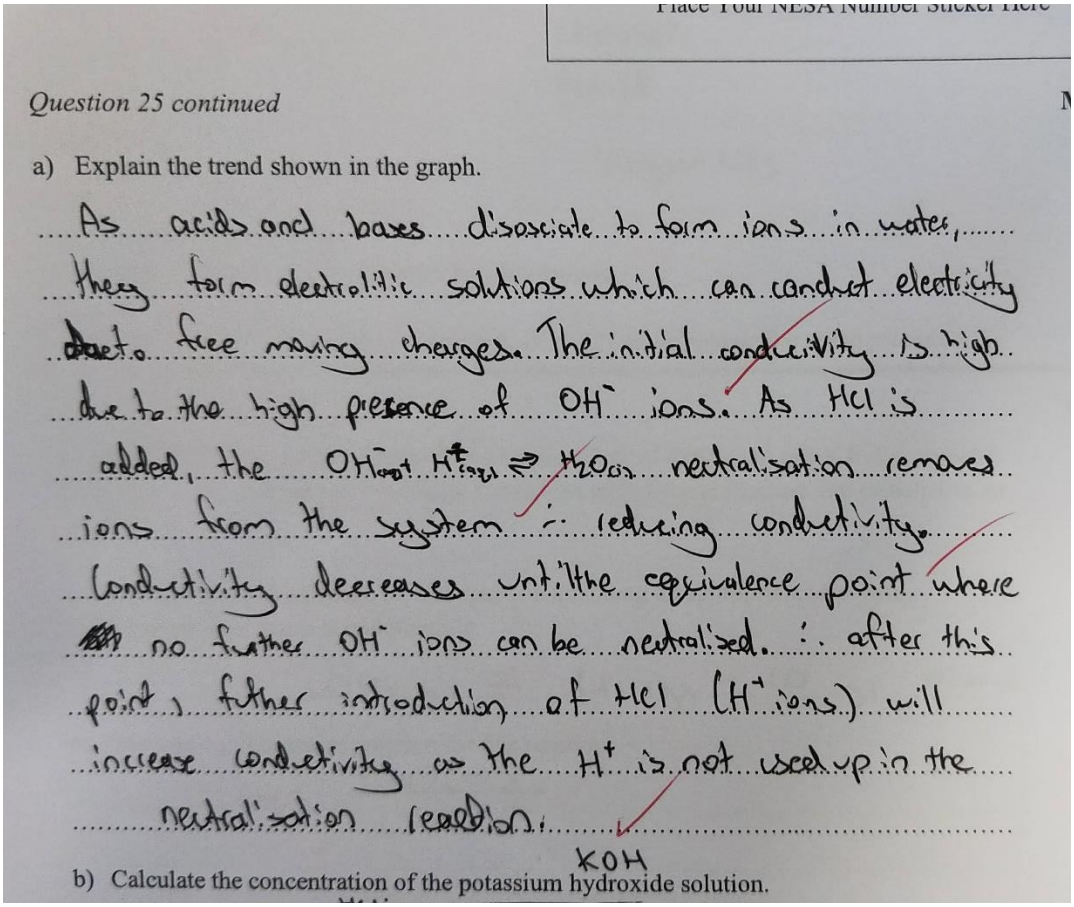
Question 25 continued **Marks**

a) Explain the trend shown in the graph. **3**

Marking Criteria	Marks
● Explains that the decrease in conductivity it because of the hydroxide ions concentration decreasing. ● Identifies the lowest point of conductivity as the equivalence point. ● Explains that the increase in conductivity is because of the hydrogen ion concentration increasing	3
● Correctly links either the decrease or increase in conductivity to the increase or decrease of hydrogen or hydroxide ions ● Identifies the lowest point of conductivity as the equivalence point.	2

● Links conductivity to the concentration ions in solution	1

Sample Answer



Question 25 continued

a) Explain the trend shown in the graph.

As acids and bases dissociate to form ions in water, they form electrolytic solutions which can conduct electricity due to free moving charges. The initial conductivity is high due to the high presence of OH^- ions. As HCl is added, the $OH^-_{(aq)} + H^+_{(aq)} \rightleftharpoons H_2O_{(l)}$ neutralisation removes ions from the system ∴ reducing conductivity. (conductivity decreases until the equivalence point where no further OH^- ions can be neutralised. ∴ after this point, futher introduction of HCl (H^+ ions) will increase conductivity as the H^+ is not used up in the neutralisation reaction.

KOH

b) Calculate the concentration of the potassium hydroxide solution.

3

b) Calculate the concentration of the potassium hydroxide solution.

Marking Criteria	Marks
● Selects the correct volume of HCl (54-56 mL) ● Calculates the number of moles of HCl ● Calculates the concentration of KOH	3
● One mistake of the above	2
● Attempts of the above steps	1

Sample Answer

$KOH(aq) + HCl(aq) \longrightarrow KCl(aq) + H_2O(l)$

1 : 1

$v = 25\ mL = 0.025\ L$ $\quad v = 55\ mL$ (from graph) $= 0.055\ L$

$c = ?$ $\quad c = 0.1012\ M$

$n = cV$

$= 0.1012 \times 0.055$

$= 0.005566\ mol$ (unrounded)

$n(HCl) = n(KOH)$ (1:1 ratio)

$\therefore n(KOH) = 0.005566\ mol$

$v = 0.025\ L$

$c = \frac{n}{v} = \frac{0.005566}{0.025} = 0.22264\ M = 2.2 \times 10^{-1}\ M$ (2 sig figs)

16

At equivalence point:

$n(HCl\ delivered) = cV$

$= 0.1012 \times 0.056$ (from graph)

$= 0.00566\ 72\ mol \Rightarrow$ (A) in cal.

$\therefore n(KOH) =$ (A) (1:1 molar ratio)

$[KOH] = \frac{n}{V}$

$= \frac{(A)}{0.025\ L}$

$= 0.23\ mol\ L^{-1}$ (2 s.f.)

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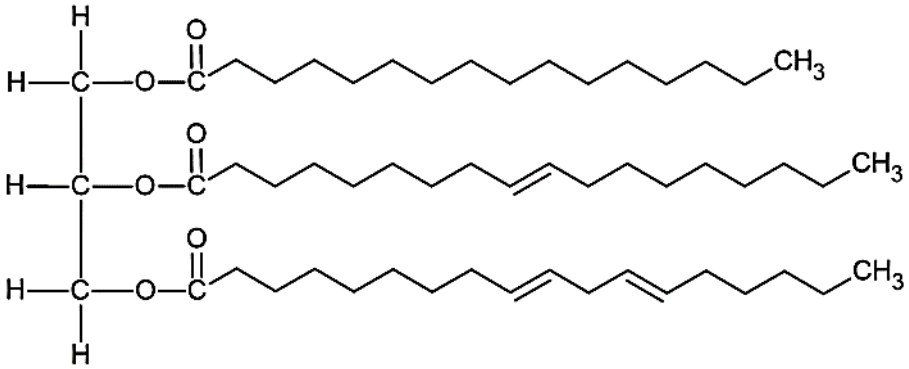
Question 26 (8 marks) **Marks**

Linseed oil is a mixture of triesters. It is used for many purposes including as a protective layer for wooden furniture and as an ingredient in some cuisines. The diagram below shows the structure of a typical triester found in linseed oil.



When the triester shown above undergoes the process of *de-esterification* (this process is the opposite of esterification), three fatty acids are produced:

- palmitic acid
- linoleic acid
- oleic acid

which correspond to the three long chains in the diagram listed from top to bottom.

a) Why are compounds like the one depicted above called triesters? **1**

Marking Criteria	Marks
● Identifies that there are three ester functional groups	1

2

b) In addition to the three acids listed above, ONE other product will form, and ONE other reactant will be consumed when the compound undergoes de-esterification.

Identify the product and reactant and state the number of moles that would be produced/consumed from the complete de-esterification of one mole of the compound shown.

Marking Criteria	Marks
● Identifies the reactant as water and the product as propane-1,2,3-triol ● States that 3 moles of water are consumed and 1 mole of propane-1,2,3-triol is produced	2

● Correctly identifies one product or reactant	1	**Marks**

Question 26 continues over the page

Question 26 continued

3

c) Castor oil is another natural product that may find a use as a component in biofuel. It releases 39.5 MJ kg^{-1} of energy when fully combusted.When 2.00 L of castor oil was combusted in a home-made engine 59.3 MJ of energy was released.

Given that the density of castor oil is 0.96 g mL^{-1}, calculate percentage efficiency of the home-made engine.

Marking Criteria	Marks
● Calculates the mass of 2 L as 1.920 Kg ● Calculates the theoretical energy release as 75.84 MJ ● Calculates 78.19… % efficiency	3
● One mistake or step missing from above	2
● Two mistakes or steps missing from above	1

d) The picture below shows a laboratory reflux apparatus using a heating mantle.

2

Explain how TWO risks associated with heating volatile organic compounds are reduced by using a reflux apparatus with a heating mantle.

Marking Criteria	Marks
● Identifies two specific risks of using a naked flame to heat a reflux apparatus and explain how these are reduced using a heating mantle	

● Identifies one specific risk	2

Marks

3

Question 27 (3 marks)

Sodium dihydrogen phosphate is an *amphiprotic* salt.

Explain what is meant by the term '*amphiprotic*'. Support your answer with chemical equations.

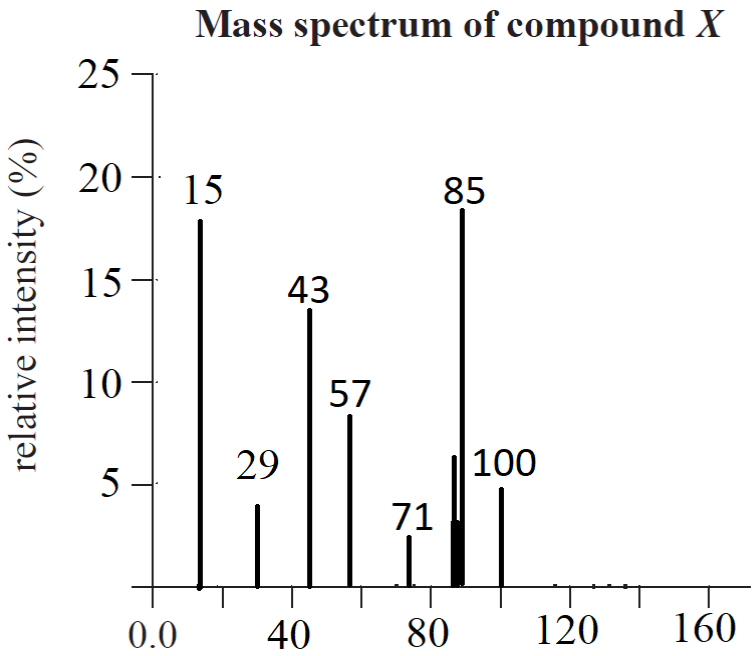
Marking Criteria	Marks
● Explains that amphiprotic compounds can donate and accept a proton. ● Correct equation showing Sodium dihydrogen phosphate donating a proton. ● Correct equation showing Sodium dihydrogen phosphate accepting a proton.	3
● One mistake or step missing from above	2
● Two mistakes or steps missing from above	1

.

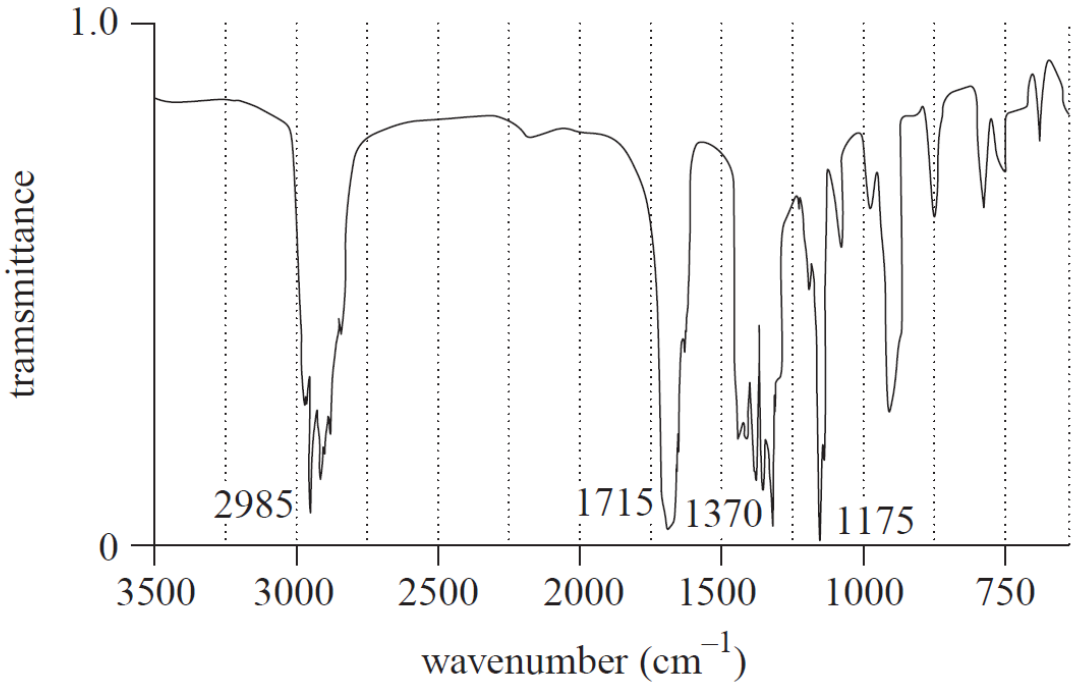
Marks

Question 28 (5 marks)

A student obtained the following spectroscopic data to help to identify an unknown organic compound, labeled Compound X.



Infrared spectrum of compound *X*



Question 28 continues over the page

Question 28 continued

Marks

5

Identify Compound X, using BOTH spectra to justify your identification.

Marking Criteria	Marks
• Identifies the compound as hexan-3-one (structure or name) • Identifies the peak at around 1650 cm^{-1} from the IR and links this to the presence of a carbonyl group • Identifies the molecular ion peak at 100 from the mass spec and links this to the molar mass of the compound • Identifies at least one mass spec peak that corresponds to a fragment that could only be from hexan-3-one. E.g. 57 for $CH_3CH_2CO^+$ • Uses this data to justify the identification of hexan-3-one	5
• All of the above with one mistake or the fragment selected does not conclusively identifies hexan-3-one	4
• Identifies the compound any of the possible chain isomers of hexan-3-one (structure or name) • Identifies the peak at around 1650 cm^{-1} from the IR and links this to the presence of a carbonyl group • Identifies the molecular ion peak at 100 from the mass spec and links this to the molar mass of the compound	3

● Identifies the peak at around 1650 cm^{-1} from the IR and links this to the presence of a carbonyl group ● Identifies the molecular ion peak at 100 from the mass spec and links this to the molar mass of the compound	2
● A relevant reference to either of the spectra	1

Question 29 (8 marks)

Marks

A solution of 4-chlorobutanoic acid was titrated against standardised sodium hydroxide solution. Small volumes of sodium hydroxide solution were added, and the pH was measured after each addition. The data collected are shown in the table below.

Volume of NaOH added (mL)	0	5	10	15	18	19	20	21	22	25	30
pH	3.8	4.3	4.6	4.5	4.7	5.0	12.1	12.5	13.3	13.0	13.0

a) Draw the structural formula of 4-chlorobutanoic acid. **1**

Marking Criteria	Marks
● Correct structural formula	1

4

b) Plot the values of the pH of the solution against the volume of NaOH and draw a smooth curve of best fit, ignoring possible outliers.

Marking Criteria	Marks
● Correct labels with units ● Linear scales that use more than half the graph ● Correct data marked with X ● Smooth LOBF	4
● One mistake or step missing from above	3
● Two mistakes or steps missing from above	2
● Attempt at graphing data	1

Marks

1

Question 29 continues over the page

Question 29 continued

c) Estimate the pH at the equivalence point in this titration.

Marking Criteria	Marks
● Selects the pH that is in the middle of the vertical increase on their graph. Around pH = 8.5 (I think)	1

2

d) The pK_a of a weak acid is equal to the pH of the solution in which half of the weak acid has been neutralised.

Use your graph to estimate a value of Ka for 4-chlorobutanoic acid.

Marking Criteria	Marks

• Uses the graph to select the volume of base that is half of the volume at the equivalence point (around 10 mL) • Selects the pH at this volume and states that this is equal to the pKa. (roughly pH = 4.5 therfore pKa = 4.5)	2
• Selects a pH and states that this is equal to the pKa	1

Marks

Question 30 (8 marks)

The following table shows four acids which were tested for relative conductivity and pH:

Acid tested	*Relative Conductivity*	*pH*
Concentrated CH_3COOH (100% pure) known as glacial acetic acid	Does not conduct	Unable to measure
0.1 mol L^{-1} HCl solution	high	1.0
0.1 mol L^{-1} CH_3COOH solution	moderate	3.3
0.1 mol L^{-1} H_2SO_4 solution	high	0.7

a) Explain why the pH for glacial acetic acid is unable to be measured. **2**

……

……

……

……

6

b) Explain the differences in the pH values for the 0.1 mol L^{-1} acids that were tested. Include relevant calculations.

……

……

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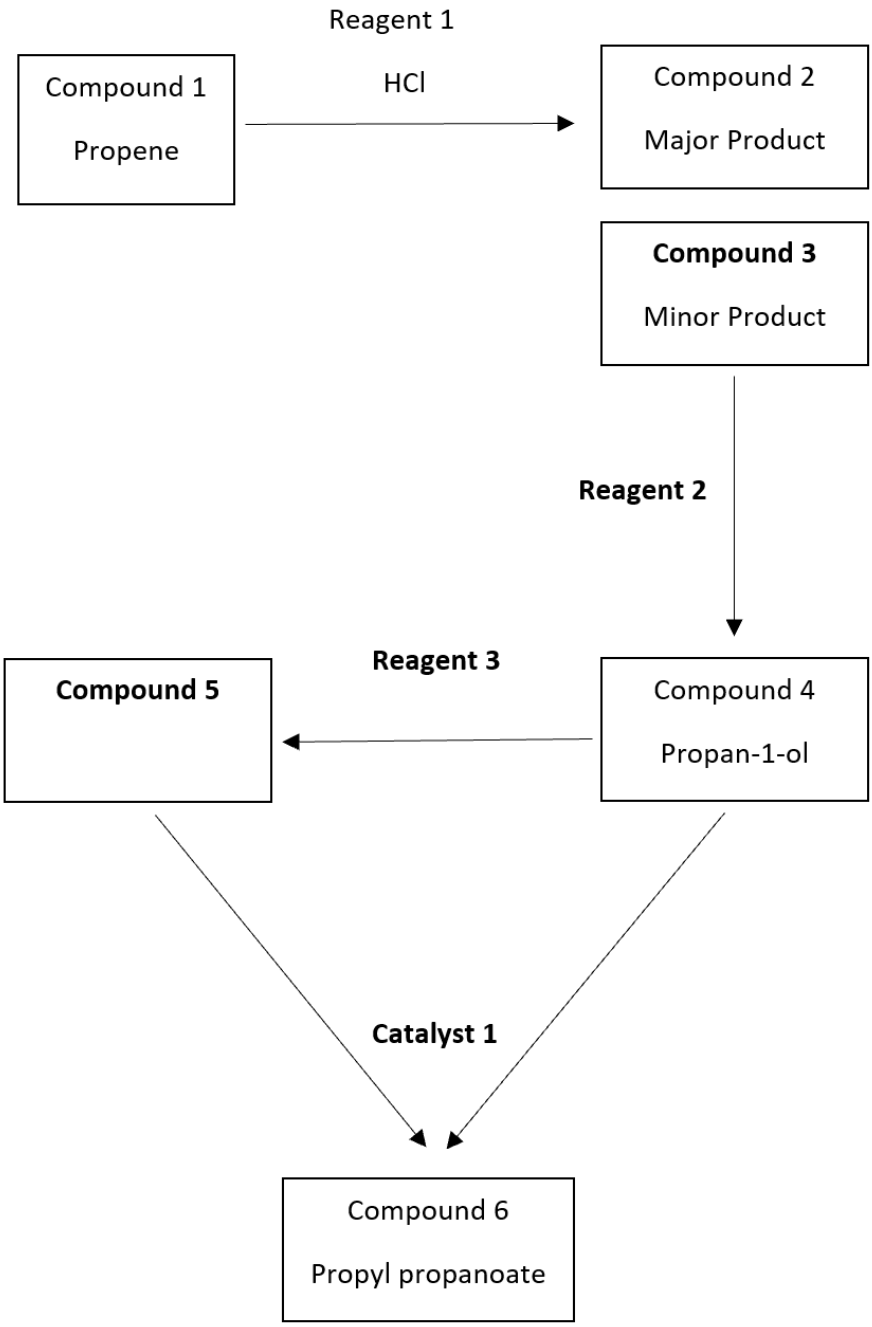
Marks

Question 31 (7 marks)

The flow chart shows a series of reactions that would allow a chemist to synthesise propyl propanoate from propene.



Question 31 continues over the page

Question 31 continued **Marks**

a) Identify the following substances from the flow chart. **5**

Marking Criteria	**Marks**
Five completely correct identifications	5
Four completely correct identifications, OR Three completely correct and two substantially correct identifications	4
Three completely correct identifications, OR Two completely correct and two substantially correct identifications	3
Two completely correct identifications, OR One completely correct and two substantially correct identifications	2
One completely correct identification	1

Marker's Comments

It was apparent that many students had not revised organic reactions sufficiently. Common errors include:

- Leaving out 'concentrated' for Catalyst 1
- Leaving out 'dilute' for Reagent 2
- Misinterpreting "reagent" as "reactant" – especially for Reagent 2. Many students identified the reactant, H_2O, when the reagent (substance necessary for the reaction to occur) is <u>dilute</u> NaOH or KOH (which includes the water).
- Including heat / reflux as a catalyst. Only substances can be catalysts, not energy or conditions. This did not cost marks this time.

2

Sample Answer

Compound 3

1-chloropropane

Reagent 2

dilute NaOH

Compound 5

propanoic acid

Reagent 3

H^+/MnO_4^- or acidified potatassium permanganate)

Catalyst 1

concentrated sulfuric acid (H_2SO_4)

b) Identify each of the following reaction types.

Marking Criteria	**Marks**
Three correct reaction types	2
One correct reaction type	1

Marker's Comments

Answers accepted were:

- Addition, hydrohalogenation, hydrochlorination, hydrogen halide addition
  - Better answers identified the specific type of addition reaction.
  - Halogenation was not accepted, as this is the addition of X_2 not HX.
- Substitution, nucleophilic substitution, substitution (hydration), substitution with HX
  - Note that 'hydration' alone was not accepted here, as this is a term used for addition of water to unsaturated hydrocarbons.
- Esterification
  - Condensation was not accepted; although this is a condensation reaction, esterification is the term for this specific reaction.

Sample Answer

Compound 1 → Compound 2

Reaction Type:...hydrohalogenation✓.....

Compound 3 → Compound 4

Reaction Type:...substitution✓.....

Compound 4 + Compound 5 → Compound 6

Reaction Type:...esterification✓.....

Question 32 (5 marks)

Marks

a) Given the molar solubility of $MnCO_3$ is 4.20×10^{-6} M, calculate the solubility product for $MnCO_3$. **2**

Marking Criteria	Marks
Writes correct K_{sp} expression AND calculates K_{sp} as 1.76×10^{-11}	2
Writes correct K_{sp} expression OR calculates K_{sp} as 1.76×10^{-11}	1

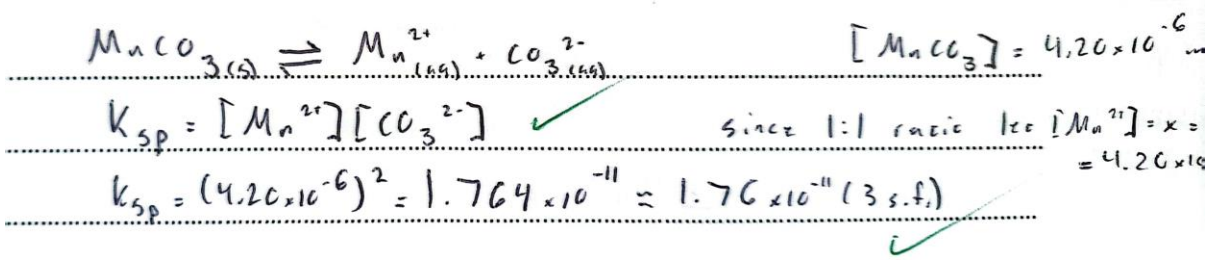
Marker's Comments

Mostly well answered, but some simple errors cost students marks: **3**

- Not recognising that *solubility product* meant K_{sp}, and attempting to calculate something else.
- Including the solid $MnCO_3$ in the K_{sp} expression. As the solid compound is pure, a "concentration" of it is a meaningless expression. You should not include it and then justify getting rid of it; just don't put it in.
- Using incorrect formulae for the manganese and carbonate ions. This was a common reason for getting ½ marks despite a mathematically correct answer.
- Considering 4.20×10^{-6} as K_{sp} then using it to calculate a molar solubility (x).

Better answers included an equation for the dissolution of manganese (II) carbonate and justified $x = [Mn^{2+}] = [CO_3^{2-}]$ using a mole ratio.

Sample Answer



b) A 0.200g sample of solid barium sulfate was added to 500mL of 0.010M sodium sulfate. Will all the barium sulfate sample dissolve? Justify your answer.

Marking Criteria	Marks
States that it will not dissolve or most will not dissolve, AND Justifies this by: • Calculating the molar solubility of $BaSO_4$ AND • Calculating the concentration of $BaSO_4$ required OR n_{BaSO4} present	3
Calculates the molar solubility of $BaSO_4$ (1.08×10^{-8}), OR Calculates the concentration of $BaSO_4$ required (1.7×10^{-3} M)	2
Writes a K_{sp} expression in terms of molar solubility (x), OR Calculates n_{BaSO4} present, OR Explains the common ion effect in general terms	1

Marker's Comments

Many students really struggled to get to grips with what to do in this question, and this was evidenced by a lot of poor setting out and attempts to create a chemical reaction or identify a limiting reagent in the mixed solution. The first challenge is to recognise that this is a common ion effect scenario, as both salts contain sulfate ions. Note that the only way to justify your conclusion for a question like this is <u>via calculations</u> which demonstrate (not just assert) that the quantity of barium sulfate provided cannot dissolve in the volume of sodium sulfate solution present; words are not enough. It was also critical to recall that a list of K_{sp} (solubility product) values are given on the Data Sheet, and barium sulfate is one of them.

Several suitable approaches were used by students:

- Calculating the number of moles of $BaSO_4$ in 0.200g and comparing it to the calculated number of moles (or mass) of $BaSO_4$ that could be dissolved in 500mL of Na_2SO_4 solution.

- Calculating the molar solubility (x) of $BaSO_4$ in Na_2SO_4 solution and comparing it to the concentration that a solution of $BaSO_4$ would have if 0.200g could be fully dissolved in 500mL.
- Calculating a Q_{sp} (assuming all the $BaSO_4$ could dissolve in the Na_2SO_4 solution) and comparing it to K_{sp} for $BaSO_4$.

Sample Answers

$Na_2SO_{4(aq)} \rightleftharpoons 2Na^+_{(aq)} + SO_4^{2-}{}_{(aq)}$ $\therefore [SO_4^{2-}] = 0.01M$

$K_{sp}(BaSO_4) = 1.08 \times 10^{-10}$

$BaSO_{4(s)} \rightleftharpoons Ba^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)}$

$\therefore 1.08 \times 10^{-10} = [Ba^{2+}][SO_4^{2-}]$

$[SO_4^{2-}] >> [Ba^{2+}]$, so using inital,

$[Ba^{2+}] = \frac{1.08 \times 10^{-10}}{0.01} = 1.08 \times 10^{-8}$ ✓

saturated = $[BaSO_4]$. (molar solubility)

$n(BaSO_4) = \frac{0.2\,g}{233.37\,g\,mol^{-1}} = 8.57 \times 10^{-4}$ mol

$c = 1.71 \times 10^{-3}$ M ✓

$> 1.08 \times 10^{-8}$

so the barium sulfate sample will not dissolve ✓

let x be molar solubility of $BaSO_4$

$K_{sp} = [Ba^{2+}][SO_4^{2-}]$

$K_{sp} = 1.08 \times 10^{-10}$

$1.08 \times 10^{-10} = x \times 0.01$

$x = \frac{1.08 \times 10^{-10}}{0.01}$

$= 1.08 \times 10^{-8}$ M ✓

$\therefore [BaSO_4] = 1.08 \times 10^{-8}$ M

$V = 0.5$ L

$[Ba^{2+}] = x$ as $Ba^{2+} : BaSO_4 = 1:1$

$[SO_4^{2-}] = x +$ preexisting SO_4^{2-}

$= x + 0.01$

$\doteq 0.01$ as $x \ll 0.01$ as $BaSO_4$ is sparingly soluble ✓

$\therefore$ as $n = c \times V$

$= 1.08 \times 10^{-8} \times 0.5$

$= 5.4 \times 10^{-9}$ mol

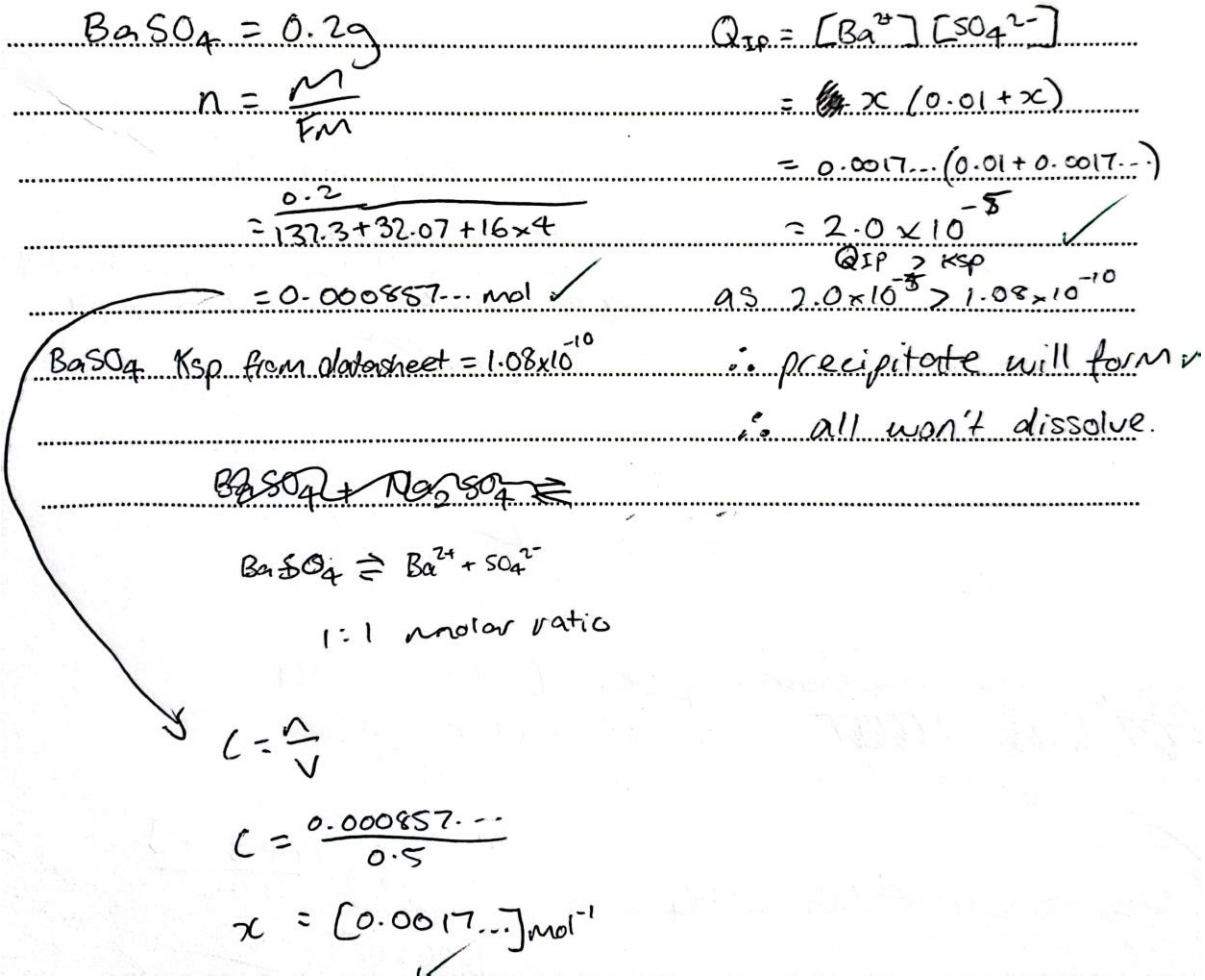
$m = n \times MM$

$= 5.4 \times 10^{-9} \times (137.3 + 32.07 + 4 \times 16$

$= 1.26019... \times 10^{-6}$ g

$\doteq 1.3 \times 10^{-6}$ g ✓

$\therefore$ not all the $BaSO_4$ will dissolve in 500mL of 0.01 M Na_2SO_4 as common ion effect occurs & only 1.3×10^{-6} g will dissolve. ✓



Marks

Question 33 (7 marks)

100.0 mL of 0.200 M hydrochloric acid was combined with 100.0 mL of 0.200 M ammonia solution. Calculate the pH of the final solution once the reaction has gone through to completion. **7**

Ammonium pKa = 9.25 Hydrochloric acid pKa = -5.9

Marking Criteria	*Marks*
Justifies the correct answer with full working shown	7
Calculates the correct answer with incomplete working, OR Calculates the incorrect answer (one error allowed) with correct complete working	6
Provides two relevant pieces of information, AND Calculates n(NH_4^+), AND Calculates K_a(NH_4^+), AND Writes the K_a expression for the dissociation of NH_4^+	5
Provides two relevant pieces of information, AND Calculates n(NH_4^+), AND Calculates K_a(NH_4^+)	4
Provides two relevant pieces of information, AND Calculates n(NH_4^+) OR calculates K_a(NH_4^+)	3
Provides two relevant pieces of information	2
Provides some *relevant* information	1

Marker's Comments

Unsurprisingly, this question was not well answered by most students, who spent a lot of valuable time and pen ink wandering in a chemical wilderness. Five students in the cohort scored full marks. I marked this question quite generously in the 1 – 4mk range to give access to many students.

This was definitely not a question to just start plugging numbers into likely-looking equations! To successfully approach this question, it was most important to recognise that:

- the reaction described was a neutralisation that had already gone to completion
- the stoichiometric ratios of the acid (HCl) and base (NH_3) involved meant that ONLY A SALT AND WATER WERE PRESENT at this point.

This was at its heart, therefore, an acidic/basic/neutral salt question, as only ammonium chloride and water are present when the neutralisation reaction has finished.

The K_a value provided for HCl was a distractor, as HCl is not only a strong acid, but no longer present after neutralisation. Its conjugate base (Cl^-) does not react with water and therefore did not influence the solution pH; in this situation, only the ammonium ion reacts with water.

Disappointingly many students are still not distinguishing ammonia (NH_3, a weak base) from ammonium (NH_4^+, its conjugate, and weak, acid). This impacted on the capacity to write correct equilibrium expressions. K_a is an acid dissociation constant, therefore *the acid in question is going to be a reactant* in the equilibrium expression:

$$NH_4^+ + H_2O \leftrightarrow NH_3 + H_3O^+$$

$$K_a = \frac{[NH_3][H_3O^+]}{[NH_4^+]}$$

It was necessary to take into account the dilution factor of the solution (50:50 when mixed), which halved $[NH_4^+]_i$ to 0.100M.

An ICE table was required to calculate $[NH_4^+]_{eq}$ before substitution into the K_a expression. This necessitated a quadratic solution, OR a clearly stated justification for using $[NH_4^+]_i$ instead ($x << 0.100$ for a weak acid with $K_a = 5.62 \times 10^{-10}$).

This was not the significant figures question, but the answer should correctly be quoted to 2sf (note that the logarithmic function changes the way sig figs are applied and thus K_a for NH_4^+ has 2sf; also note that K_a for HCl was not used, and thus the answer is not limited by its 1sf.

Sample Answer

$HCl_{(aq)} + NH_{3(aq)} \rightarrow NH_4Cl_{(aq)}$ ✓

$= 0.1\,L \times 0.2\,mol\,L^{-1} = 0.02\,mol = n_{NH_3} = n_{HCl}$

$\therefore$ no excess reactants once reaction is at completion $\left(1:1 \text{ molar ratio}\right)$

$\therefore$ pH of solution is only dependent on the acidic salt product: NH_4Cl

$n_{NH_4Cl} = 0.02\,mol$ ✓ $\therefore [NH_4Cl] = \dfrac{0.02\,mol}{0.2\,L} = 0.1\,mol\,L^{-1}$ ✓

$NH_4Cl_{(aq)} \rightleftharpoons NH_4^+{}_{(aq)} + Cl^-{}_{(aq)}$

$NH_4^+{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + NH_{3(aq)}$

Conc (mol L^{-1})	NH_4^+	H_3O^+	NH_3
Initial	0.1	0	0
change	$-x$	$+x$	$+x$
equilibrium	$0.1-x$	x	x
	≈ 0.1 as K_a very small		

$K_a = 10^{-pK_a} = 10^{-9.25}$ ✓

$K_a = \dfrac{[NH_3][H_3O^+]}{[NH_4^+]} = 10^{-9.25}$

$\dfrac{x^2}{0.1} = 10^{-9.25}$

$\therefore x = 7.5 \times 10^{-6}\,mol\,L^{-1} = [H_3O^+]$ ✓

$\therefore pH = -\log_{10}[H^+]$

$= -\log_{10}(7.5 \times 10^{-6})$

$\therefore pH = 5.125$ ✓ (3.sf)

excellent – you made it look easy!

End of paper