STUDENT NUMBER: ……..

# PENRITH SELECTIVE HIGH SCHOOL

# HSC CHEMISTRY 2022

# TRIAL EXAMINATION

**General Instructions**

- Reading time – 5 minutes
- Exam time – 3 hrs
- Board-approved calculators may be used
- Write using **blue or black** pen
- Chemistry Data Sheet is provided with this examination
- Answers written in pencil may be disqualified from review

**PART A**

***Multiple Choice (20)***

- Attempt Questions 1 – 20
- Allow about 30 minutes
- Provide responses on the Multiple Choice Answer Sheet

**PART B**

***Written response (80)***

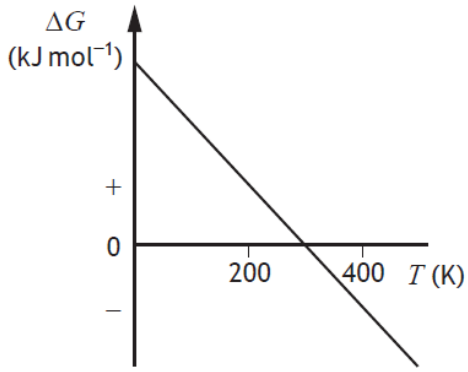
- Attempt Questions 21 – 32
- Allow 2 hrs and 30 minutes

TOTAL: / 100

**THIS EXAM PAPER MUST BE SUBMITTED AT THE END OF THE EXAMINATION**

## PART A – MULTIPLE CHOICE QUESTIONS

1. The following graph shows the variation in $\Delta G$ with temperature ($T$ ) for a reaction.




Which of the following statements is true?

A) The reaction is never feasible
B) The reaction is always feasible
C) The reaction is feasible above 300K
D) The reaction is feasible below 300K

2. In which ONE of the following reactions at equilibrium will the YIELD of the product increase when the VOLUME of the container is increased at constant temperature?

A) $N_2O_4(g) \rightleftharpoons 2NO_2(g)$
B) $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$
C) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
D) $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$

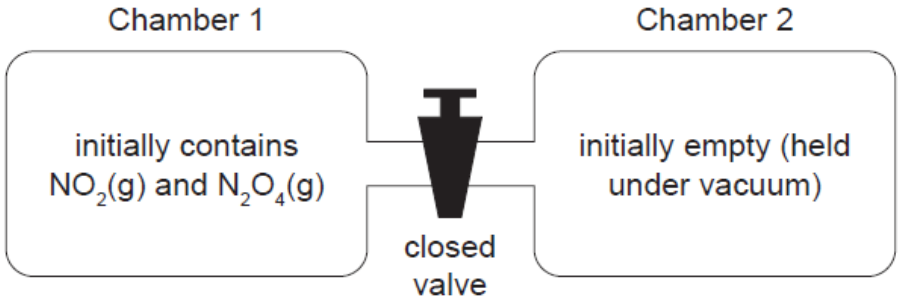
3. Which statement best describes the use of the equilibrium constant in relation to the solubility of ionic substances?

The equilibrium constant:

A) can only be determined for soluble substances.
B) can be used to determine the solubility of ionic substances.
C) does not give any useful information about the solubility of ionic substances.
D) cannot be used for partially soluble substances, as they are not a homogenous system.

**Refer to the following to answer Question 4 and 5**

Equal moles of nitrogen dioxide gas ($NO_2$) and dinitrogen tetroxide gas ($N_2O_4$) are sealed inside one half of a two-chamber reactor as shown below. The temperature inside both chambers is $25^0$C.




After a while, the following equilibrium is established inside Chamber 1.

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \quad \Delta H^0 = -58 \text{ kJ mol}^{-1}$$

reddish brown colourless

4. More $N_2O_4(g)$ is added to Chamber 1.

   What observations would be made about the colour of the gas mixture and its temperature after a new equilibrium is established?

| | Gas mixture colour | Temperature |
|---|---|---|
| A) | darker brown | higher |
| B) | darker brown | lower |
| C) | paler brown | higher |
| D) | paler brown | lower |

5. This scenario follows on from question 4.
   The valve between the chambers is opened, allowing the gas mixture in Chamber 1 to fill both chambers.

   Which statement describes the initial and final observations of the gas mixtures colour in chamber 1 as a new equilibrium is established?

| | Initial observation in chamber 1 | Observation as equilibrium is re-established |
|---|---|---|
| A) | Paler brown | Became darker |
| B) | Paler brown | Became even paler |
| C) | Darker brown | Became even darker |
| D) | Darker brown | Became paler |

6. Photosynthesis occurs in plants. Its chemical reaction is represented as follows:

$$6CO_{2\,(g)} + 6H_2O_{(l)} \xrightarrow[\text{Sunlight}]{\text{chlorophyll}} C_6H_{12}O_{6\,(aq)} + 6O_{2\,(g)}$$

Which row of the table correctly identifies the links between changes in entropy and enthalpy for combustion reactions and photosynthesis?

| | **Entropy change** | | **Enthalpy change** | |
|---|---|---|---|---|
| | **Photosynthesis** | **Combustion** | **Photosynthesis** | **Combustion** |
| A) | decreases | increases | exothermic | endothermic |
| B) | increases | decreases | endothermic | exothermic |
| C) | decreases | increases | endothermic | exothermic |
| D) | increases | decreases | exothermic | endothermic |

7. Which alternative most correctly represents the equilibrium expression for the following reaction?

$$Fe_2O_{3\,(s)} + 3CO_{(g)} \rightleftharpoons 2Fe_{(s)} + 3CO_{2\,(g)}$$

A) $\dfrac{[CO_2]^3}{[CO]^3}$

B) $\dfrac{[CO_2]^3}{[Fe_2O_3]\,[CO]^3}$

C) $\dfrac{[Fe_2O_3]\,[CO]^3}{[Fe]^2\,[CO]^3}$

D) $\dfrac{[Fe]^2\,[CO_2]^3}{[Fe_2O_3]\,[CO]^3}$

8. 50.00 mL of a 0.020 M solution of $Ba(OH)_2$ is added to 50.00 mL of a 0.060 M solution of $HNO_3$. The hydrogen ion concentration in the resultant solution, in mole per litre, is

A) 0.010

B) 0.020

C) 0.030

D) 0.040

9. Use the following acid ionization constants to identify the correct decreasing order of base strengths.

| | |
|---|---|
| HF | $Ka = 7.2 \times 10^{-4}$ |
| $HNO_2$ | $Ka = 4.5 \times 10^{-4}$ |
| HCN | $Ka = 6.2 \times 10^{-10}$ |

A) $CN^- > NO_2^- > F^-$

B) $NO_2^- > F^- > CN^-$

C) $F^- > CN^- > NO_2^-$

D) $F^- > NO_2^- > CN^-$

10. Which statement best represents Davy's definition of an acid?

A) Acids contain oxygen.
B) Acids are proton donors.
C) Acids contain replaceable hydrogen.
D) Acids ionise in solution to form hydrogen ions.

11. NaOCl is completely dissociated in water to form $Na^+(aq)$ and $OCl^-(aq)$. In solution, $OCl^-$ hydrolyses according to the equation

$$OCl^-_{(aq)} + H_2O_{(l)} \leftrightharpoons HOCl_{(aq)} + OH^-_{(aq)}$$

1.0 L of pure water at constant temperature is added to a 1.0 L solution of 0.10 M NaOCl.

When the solution reaches equilibrium again, the:

A) [H+] has decreased.
B) pH of the solution has decreased.
C) concentration of HOCl has increased.
D) value of the equilibrium constant has halved.

**Refer to the following information to answer Question 12 and 13.**

One litre of an aqueous solution of potassium hydroxide (KOH) has a pH of 12.0 at 25°C.

12. The amount of solid KOH, in mol, that must be added to the solution to raise the pH to 13.0 would be:

    A) $10^{-13}$
    B) $10^{-12}$
    C) 0.09
    D) 0.10

13. The amount of pure HCl gas, in mol, that must be added to the solution to lower the pH from pH 12.0 to 2.0 would be:

    A) 10
    B) 2.0
    C) 0.02
    D) 0.01

14. Potassium hydroxide and hydrochloric acid react in aqueous solution according to the following equation.

$$KOH_{(aq)} + HCl_{(aq)} \rightarrow KCl_{(aq)} + H_2O_{(l)}$$

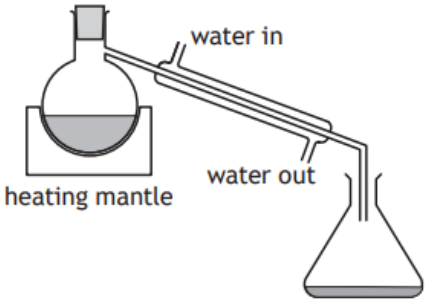
    A 50 mL solution containing 0.025 mol of KOH was mixed rapidly in an insulated vessel with a 50 mL solution containing 0.025 mol of HCl. The temperature increased by 3.5°C.

    Assuming that the specific heat capacity of the solution is the same as that of water, the enthalpy change, ΔH, of this reaction, in kJ mol−1, is closest to:

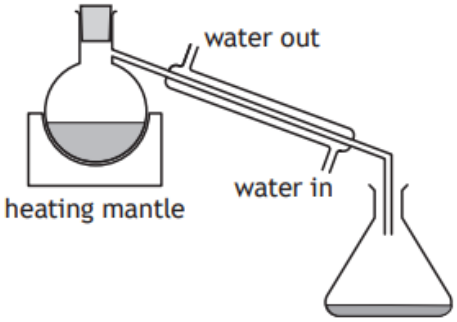
    A) –29
    B) –59
    C) $-2.9 \times 10^4$
    D) $-5.9 \times 10^4$

15. Which of the following diagrams shows the apparatus correctly set up for heating under reflux?

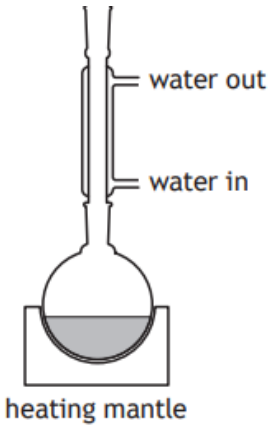
A)



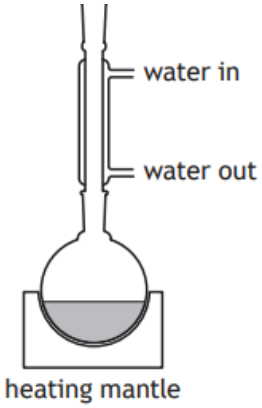

B)



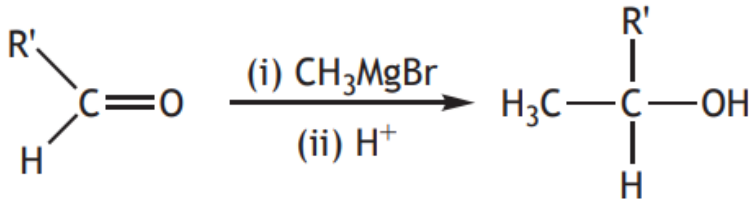

C)




D)



16. Aldehydes can be converted into alcohols by the following reaction:



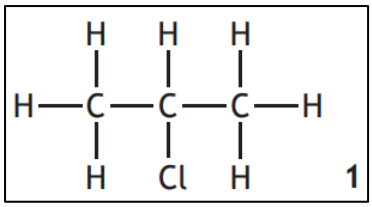

Which of the following aldehyde would produce a primary alcohol?

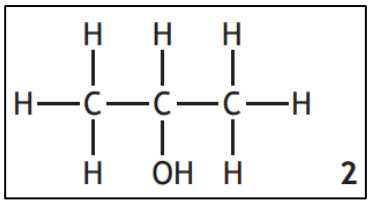
A) Methanal
B) Ethanal
C) Propanal
D) Butanal

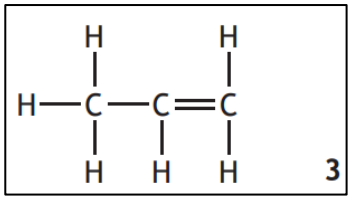
17. When but-1-ene reacts with hydrogen chloride, 1-chlorobutane and 2-chlorobutane are formed. According to Markovnikov's rule

A) There will be more 1-chlorobutane than 2-chlorobutane
B) There will be more 2-chlorobutane than 1-chlorobutane
C) There will be equal proportions of both products
D) It is impossible to tell the relative proportions of each product

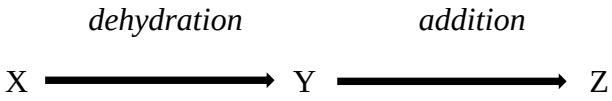
18. Consider the following chemical compounds.



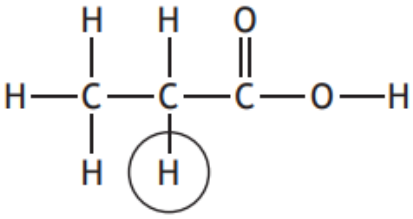




Which of the following correctly identifies X, Y and Z in the reaction sequence?



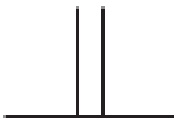

| | X | Y | Z |
|---|---|---|---|
| A) | 1 | 2 | 3 |
| B) | 2 | 1 | 3 |
| C) | 3 | 2 | 1 |
| D) | 2 | 3 | 1 |

19. The following structure shows propanoic acid.

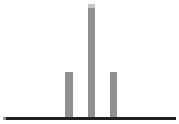



Which of the following shows the splitting pattern for the circled **H** atom above, in a high resolution proton NMR spectrum?

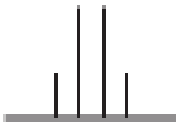
A)



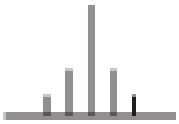
B)



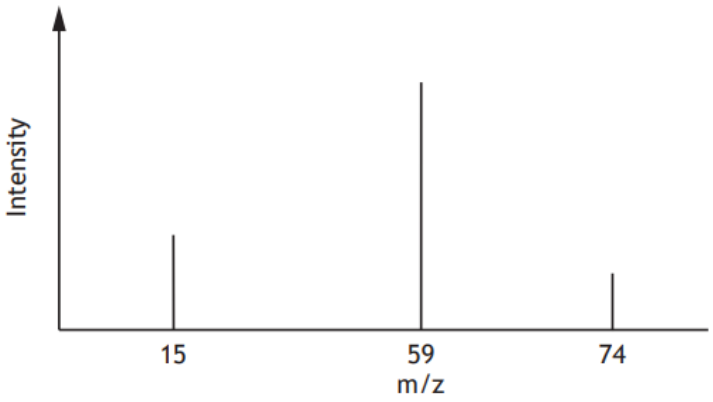
C)



D)



20. A simplified mass spectrum of an organic compound is shown below.




Which of the following compounds could NOT have produced the spectrum above?

A) $CH_3OCOCH_3$
B) $CH_3CH_2COOH$
C) $CH_3CH_2CH_2CH_2NH_2$
D) $CH_3CH(OH)CH_2CH_3$

**PART B**

**Question 21** **11 marks**

a) Construct an equation for the equilibrium that occurs in a saturated solution of $Mg(OH)_2$. 1m

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b) Construct an expression for the Ksp of $Mg(OH)_2$. 1m

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c) Calculate the molar solubility of $Mg(OH)_2$ in water at 25 °C, and give $[Mg^{2+}]$ and $[OH^-]$. Using the solubility constant given on the data sheet. 3m

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When dilute sodium hydroxide, NaOH, is added to a saturated solution of $Mg(OH)_2$ , the concentration of $Mg^{2+}$ ions in the saturated solution decreases.

d) Explain why the concentration of $Mg^{2+}$ ions in the saturated solution decreases upon the addition of NaOH. 3m

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e) Calculate the concentration of $Mg^{2+}$ ions in a solution after 30.0 mL of 0.120 mol $L^{-1}$ NaOH is added to 20.0 mL of a saturated $Mg(OH)_2$ solution. State any assumptions that have been made. 3m

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**Question 22** **3 marks**

Boron trichloride ($BCl_3$) is a gas that reacts with Hydrogen gas to produce solid Boron and Hydrogen chloride gas.

a) Construct a balanced equation for this reaction 1m

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b) The reaction is endothermic with $\Delta H^0$= + 127kJ mol $^{-1}$. The standard entropy change ($\Delta S^0$) for the reaction is 79.4 $JK^{-1}mol^{-1}$.

Calculate the $\Delta G^0$ for this reaction at 298K. State if the reaction is spontaneous at this temperature. 2m

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**Question 23** **4 marks**

A 1.00 L vessel contains, at equilibrium, 0.300 mol of $N_2$, 0.400 mol $H_2$ and 0.100 mol $NH_3$.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

If the temperature of the vessel is kept constant, how many moles of $H_2$ (g) must be introduced into the vessel in order to double the equilibrium concentration of $NH_3$(g)? 4m

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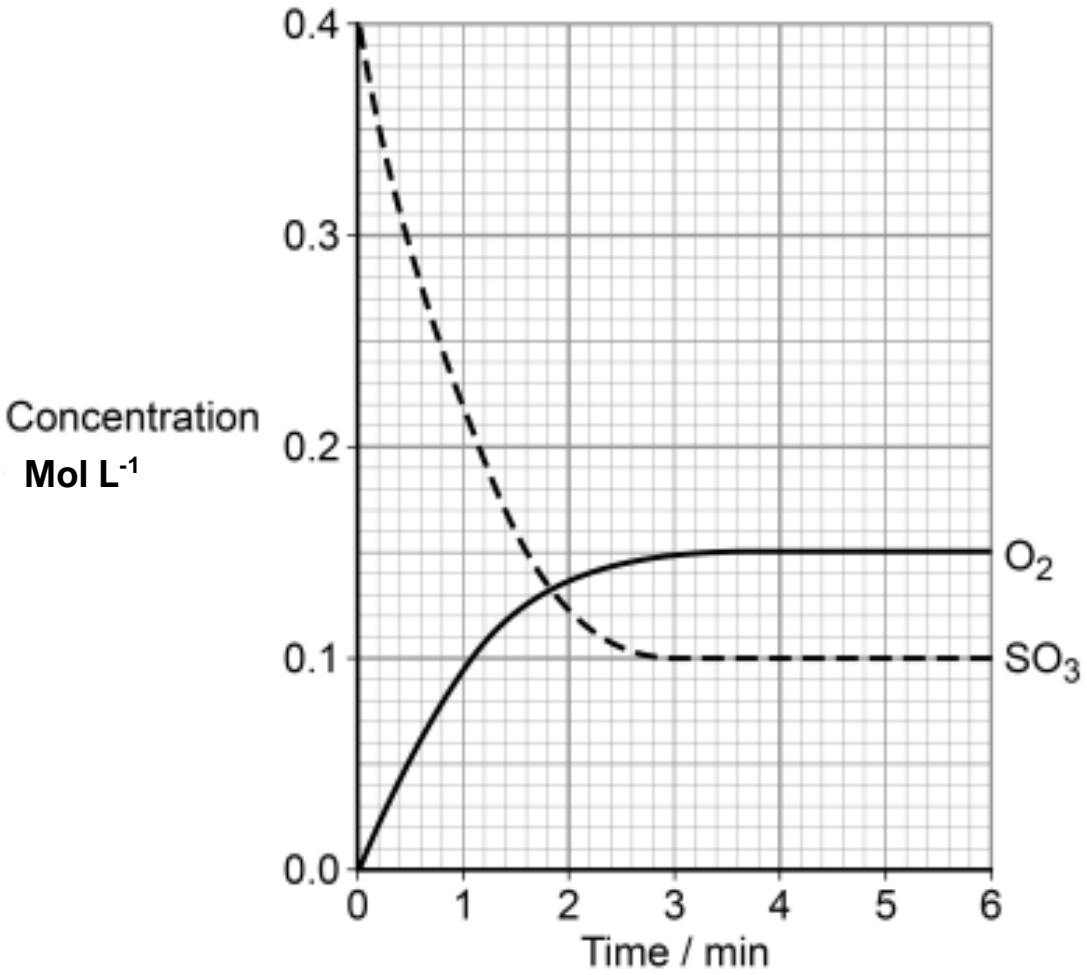
**Question 24** **7 marks**

Sulfur trioxide decomposes to form sulfur dioxide and oxygen at temperature $T_1$ according to the equilibrium shown.

$$2SO_{3\,(g)} \rightleftharpoons 2SO_{2\,(g)} + O_{2\,(g)} \qquad \Delta H = +196 \text{ kJ mol}^{-1}$$

The graph below shows the concentrations of sulfur trioxide and of oxygen over a period of 6 minutes at temperature $T_1$.




a) Sketch on the graph how the concentration of sulfur dioxide changes over these 6 minutes at temperature $T_1$. 2m

b) Calculate $K_{eq}$ for the equilibrium reaction. 2m

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c) The temperature of the mixture was changed to $T_2$ (not shown in the graph) and the mixture left to establish a new equilibrium.

In the new equilibrium mixture the concentration of sulfur trioxide was found to be 0.07 mol $L^{-1}$.

Deduce which of $T_1$ and $T_2$ is the higher temperature. Explain your deduction. 3m

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**Question 25** **6 marks**

Two chemistry students carried out a project on the chemistry of bleach. The bleach contained a solution of sodium hypochlorite, NaClO (aq). The students determined experimentally the concentration of hypochlorite ions, $ClO^-$, in the bleach.

Experimental procedure:

- The bleach solution was first diluted by adding 25.00 mL of the bleach to a 250.0 mL volumetric flask. The solution was filled to the graduation mark with deionized water.
- 25.00 mL of this solution was then reacted with excess iodide in acid

$$ClO^-_{(aq)} + 2I^-_{(aq)} + 2H^+_{(aq)} \rightarrow Cl^-_{(aq)} + I_{2\,(aq)} + H_2O_{(l)}$$

- The iodine formed was titrated with 0.100 mol $L^{-1}$ sodium thiosulfate solution, $Na_2S_2O_{3\,(aq)}$, using starch indicator.

$$I_{2\,(aq)} + 2S_2O_3^{2-}{}_{(aq)} \rightarrow 2I^-_{(aq)} + S_4O_6^{2-}{}_{(aq)}$$

The following data were recorded for the titration:

| | **Titre volumes (mL)** | | |
|---|---|---|---|
| | **1** | **2** | **3** |
| Final burette reading of 0.100 M $Na_2S_2O_3$ | 22.35 | 46.00 | 22.15 |
| Initial burette reading of 0.100 M $Na_2S_2O_3$ | 0.00 | 23.95 | 0.00 |

a) Calculate the volume (mL) of 0.100 M $Na_2S_2O_3$ required to reach the end point. 2m

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b) Determine the concentration of hypochlorite ions, $ClO^-$, present in the bleach. 4m

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**Question 26** **4 marks**

The Ka values of two salts are given below.

| | |
|---|---|
| $NaHCO_3$ | Ka= $4.7 \times 10^{-11}$ |
| $NaHSO_4$ | Ka= $1.3 \times 10^{-2}$ |

When the sodium hydrogen carbonate salt dissolves in water, the solution is found to be slightly alkaline (pH 8-9).

When the sodium hydrogen sulfate salt dissolves in water, the solution is found to be strongly acidic (pH 1-2).

a) Use appropriate equations to explain why aqueous solutions of sodium hydrogen carbonate and sodium hydrogen sulfate have such different pH values. 3m

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b) $NaHCO_3$ can be used to neutralise both acidic spills and basic spills. Provide one reason as to why this is the case. 1m

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**Question 27** **5 marks**

The pH ranges of a number of acid-base indicators are shown below:

| ***Indicator*** | ***pH range*** | ***Colour*** |
|---|---|---|
| Congo red | 3.0 – 5.0 | Blue - red |
| Methyl orange | 3.2 – 4.4 | Red - yellow |
| Phenol red | 6.8 – 8.0 | Yellow - red |

a) Which of the above indicators could be used to distinguish between solutions of $1 \times 10^{-5}$ mol $L^{-1}$ sodium hydroxide and $1 \times 10^{-5}$ mol $L^{-1}$ hydrochloric acid? Justify your answer. 2m

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b) A solution of hydrochloric acid was titrated with sodium bicarbonate. Explain which indicator would work best for determining the endpoint of the titration. 3m

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**Question 28** **6 marks**

The amount of iron in a newly developed, heat-resistant aluminium alloy is to be determined. An 80.50 g sample of alloy is dissolved in concentrated hydrochloric acid and the iron is converted to Fe2+(aq) ions. This solution is accurately transferred to a 250.0 mL volumetric flask and made up to the mark. 20.00 mL aliquots of this solution are then titrated against a standard 0.0400 M potassium permanganate solution.

$$5Fe^{2+}_{(aq)} + MnO_4{}^-_{(aq)} + 8H^+_{(aq)} \rightarrow 5Fe^{3+}_{(aq)} + Mn^{2+}_{(aq)} + 4H_2O_{(l)}$$

Four titrations were carried out and the volumes of potassium permanganate solution used were recorded in the table below.

| Titration Trial | Volume of $KMnO_4$ (mL) |
|---|---|
| 1 | 22.03 |
| 2 | 20.25 |
| 3 | 21.97 |
| 4 | 21.99 |

a) Calculate the average volume, in mL, of the concordant titres of the potassium permanganate solution. 1m

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b) Calculate the percentage, by mass, of iron in the 80.50 g sample of alloy. Express your answer to the correct number of significant figures. 5m

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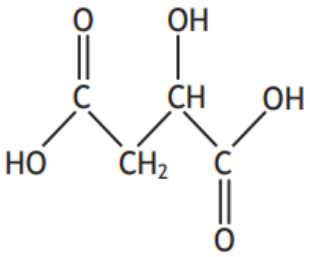
**Question 29** **5 marks**

Apple jam contains malic acid.




malic acid

Malic acid dissociates in TWO stages. The equation for the first stage of dissociation of malic acid is:

$$HOOCCH_2CH(OH)COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons HOOCCH_2CH(OH)COO^-_{(aq)} + H_3O^+_{(aq)}$$

a) Write an expression for the first stage dissociation constant, Ka, for malic acid. 1m

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b) Write the equation to show the second stage dissociation of malic acid. 1m

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While making apple, the jam will only thicken if the pH is between 2.7 and 3.3. The pH of the apple jam is determined by the first stage dissociation of malic acid ($K_a = 3.2 \times 10^{-4}$).

c) If the concentration of malic acid in the jam is 0.0052 mol $L^{-1}$, determine whether the jam will thicken at this concentration of malic acid. 3m

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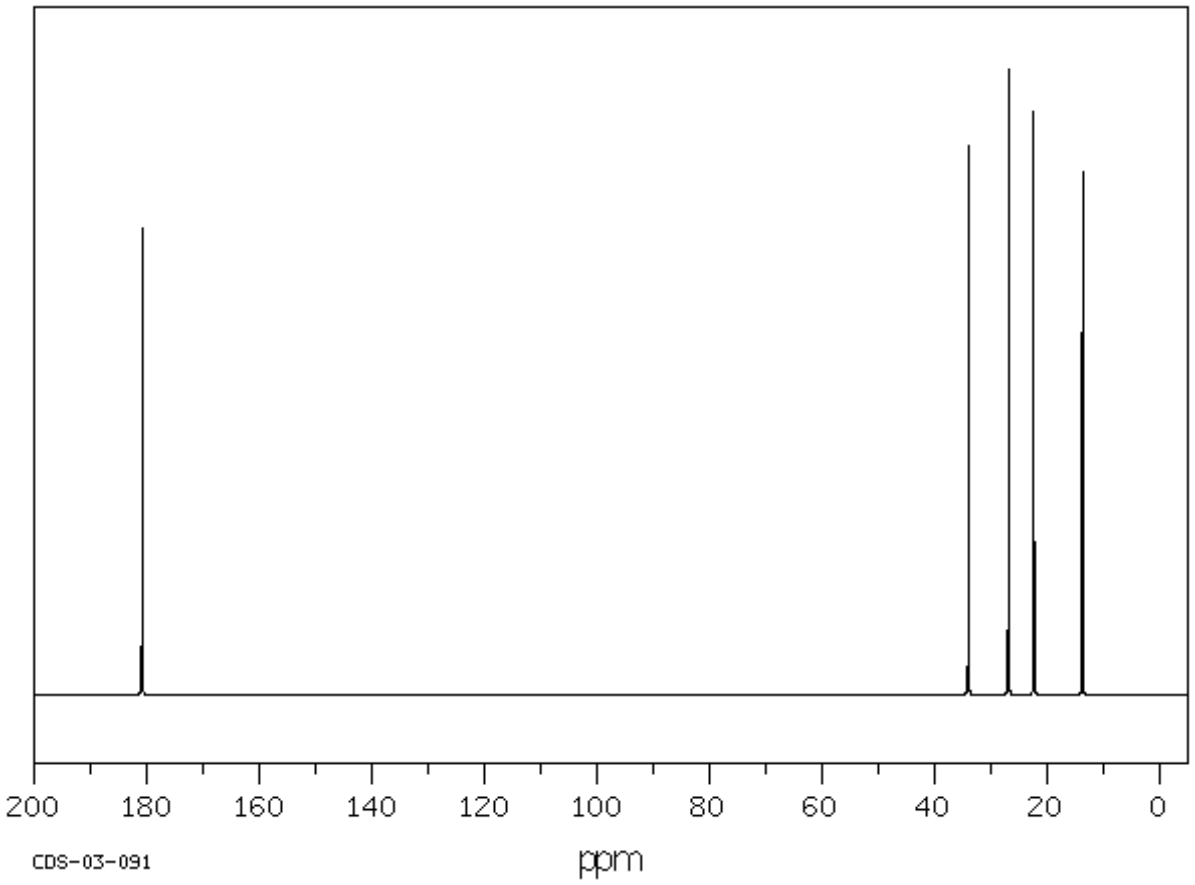
**Question 30** **14 marks**

An organic liquid compound containing carbon, hydrogen and oxygen has a molar mass of 102.13 g $mol^{-1}$.

When a small amount of sodium carbonate powder was added to a sample of the organic liquid, bubbles was observed rising in the test tube.

The organic liquid was analysed and was observed to display the following $C^{13}$-NMR spectrum.

**Image A. $C^{13}$ NMR**




a) Based on the information provided thus far, name and provide the possible structural formulae for the organic compound. 2m

b) Name and provide the structural formulae for the isomers of the organic compound identified in part a). Be sure to provide ONE of each of the following: 3m

| Structural Isomer | Structural formulae | Name |
|---|---|---|
| Chain | | |
| Functional | | |

c) Which isomer CANNOT be the organic liquid compound. Provide a reason based on the information provided thus far. 2m

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Further analysis provided the following spectral information of the organic liquid compound.

**Image B. Infrared spectrum**

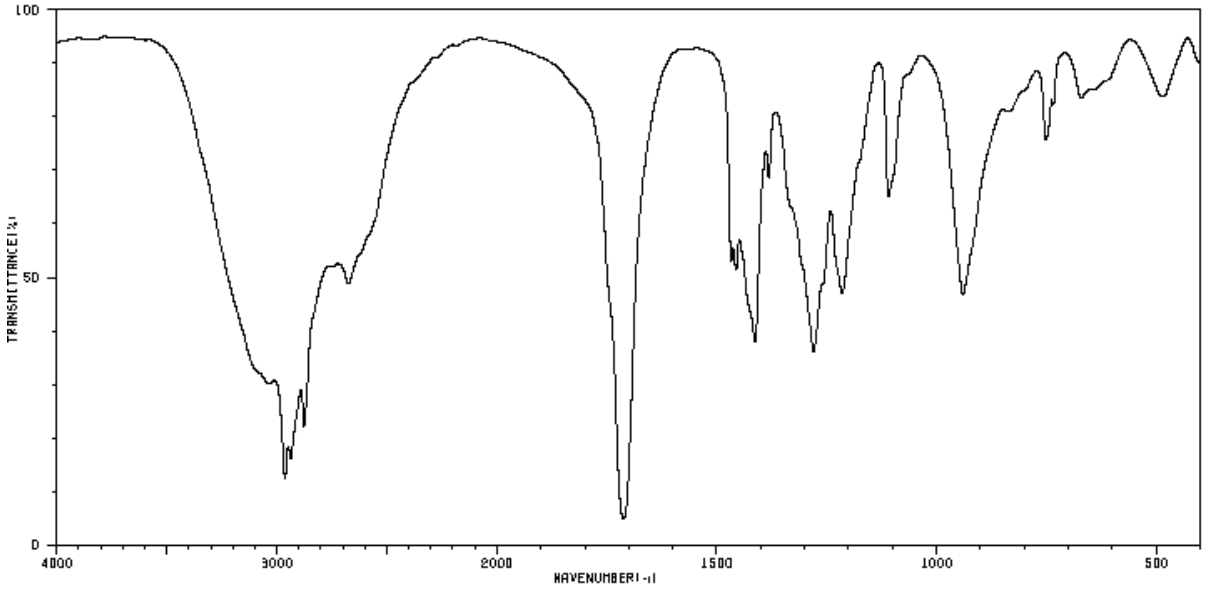


**Figure 1. Proton NMR peak data**

| Shift (ppm) | Number of peaks | Peak area ratio |
|---|---|---|
| **11.96** | 1 | 1 |
| **2.35** | 3 | 2 |
| **1.62** | 5 | 2 |
| **1.39** | 6 | 2 |
| **0.93** | 3 | 3 |

d) Mason claims that there is not enough information to definitively identify the organic liquid compound as it should also be analysed through the mass spectroscope.

Based on the spectral data and information provided, identify of the organic liquid compound and assess the validity of Mason's claim by analysing the range of spectral information provided and consider the usefulness of a mass spectrum. 7m

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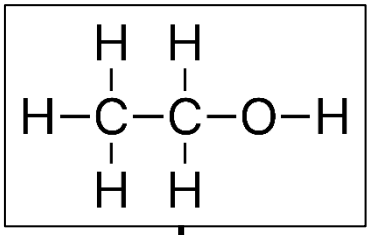
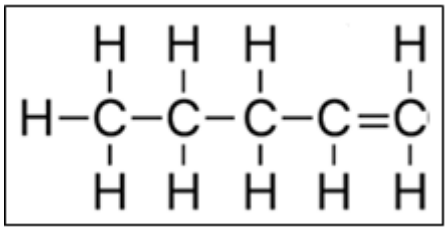
**Question 31** **7 marks**

Ramayan wants to make a banana-like ester of pentyl ethanoate. He is provided stock bottles of ethanol and pent-1-ene. Ramayan will need to conduct a number of chemical reactions in order to produce the ester from the two chemicals provided.

a) Complete the flow chart to show the reagents and conditions required for each step and draw the structural formulae of the main products (A, B and C) formed. 5m





X: ……

Y: ……..

A

B

Z: ……

C

b) Process X and Z are conducted using the same technique. Provide ONE reason to explain why the same technique is utilised in process X and Z. 2m

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**Question 32** **8 marks**

Brass is a useful alloy of copper and zinc.

To determine the percentage of copper in a brass screw, a student dissolved the screw in 20mL of concentrated nitric acid and made the resulting solution up to 250mL in a volumetric flask.

Five standard solutions were prepared by diluting a 0.10 mol $L^{-1}$ stock solution of copper (II) nitrate with distilled water.

a) One of the standard solutions had a concentration of 0.010 mol $L^{-1}$.

Describe, in detail, how this 0.010 mol $L^{-1}$ solution should be prepared in a 50mL volumetric flask from the 0.10 mol $L^{-1}$ stock solution. 3m

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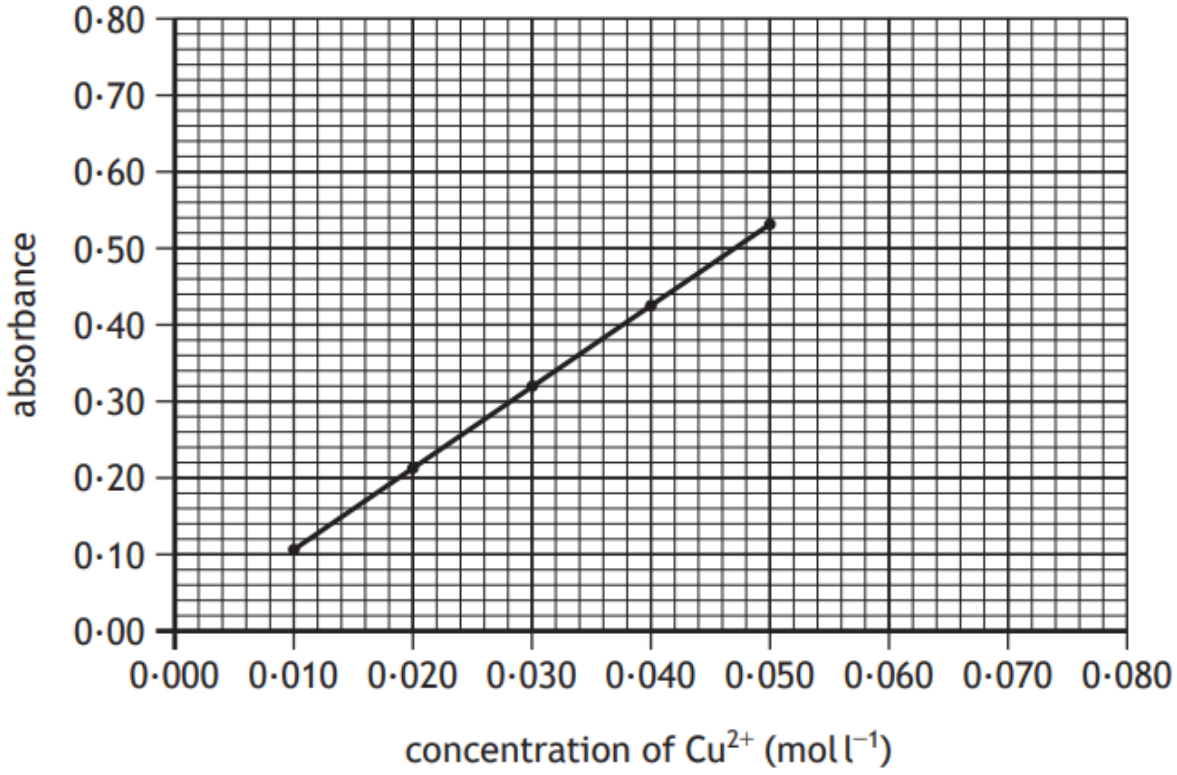
b) The colorimeter was fitted with a suitable filter and set to zero using a reference sample. The absorbance of the five standard solutions was determined and a calibration graph was drawn.



i) Name the substance that should be used to set the colorimeter to zero. 1m

……..

ii) The absorbance of the sample solution was 0.71. The sample solution was then diluted to decrease the concentration by half. The absorbance of this diluted solution was then measured.

Provide a reason for why the sample solution must be diluted. 1m

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iii) The mass of the screw was 1.43 g. The absorbance of the diluted solution was 0.34. Calculate the percentage by mass of copper in the screw. 3m

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**END OF EXAMINATION**

**PENRITH SELECTIVE HIGH SCHOOL**
**2022 HSC CHEMISTRY TRIAL – MARKING CRITERIA**

## PART A – MULTIPLE CHOICE

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

***MCQ explained***

**Question 1**

For a reaction to occur spontaneously Gibbs Free Energy must be negative, this occurs at a temperature of above 300K – as seen on the graph.

**Question 2**

An increase in volume will cause the equilibrium to shift in the direction that maximises the number of moles of gas.

**Question 3**

The solubility equilibrium constant indicates how much of a slightly soluble/ partially soluble ionic substance will dissolve in water.

**Question 4**

If $N_2O_4$ is added to the system  this will cause a shift in equilibrium and increase the concentration of $NO_2$ – the vessel will become darker brown in colour due to this. As equilibrium shifts to the left the temperature will initially increase but then will decrease to return the system to equilibrium.

**Question 5**

As volume increases due to the opening of the tap, the equilibrium will shift to the side with less moles of gas – the colourless $N_2O_4$.Then, as equilibrium is re-established the mixture will become darker in colour.

**Question 6**

In photosynthesis the number of molecules produced decreases, so entropy decreases. In combustion the number of molecules produced increases, so entropy increases. Photosynthesis is an endothermic reaction; it requires the input of energy. Combustion is exothermic as it releases energy.

**Question 7**

Solids are not included in the Keq expression, as all answers except for A include a solid substance they are not correct.

**Question 8**

$Ba(OH)_2$ (aq) + $2HNO_3$ (aq) → $Ba(NO_3)_2$ (aq) + $H_2O$ (l)

$n(HNO_3)$= c x v

= 0.060M x 0.05L

= 0.003 moles= $n(H^+)$ initially

$n(Ba(OH)_2)$ = 0.020 M x 0.05L

= 0.001 moles

$n(OH^-)$ initially = 2 x $n(Ba(OH)_2)$

= 2 x 0.001

= 0.0020 mol

Since the reaction is $OH^-$(aq) + $H^+$ (aq) → $H_2O$ (l)

$n(H^+)$ in resultant solution = 0.0030 - 0.0020

= 0.0010 mol

$[H^+]$ in resultant solution = 0.0010 mol/0.10L

= 0.010 mol $L^{-1}$

**Question 9**

Kw = Ka x Kb

Kb=Kw/Ka

Therefore Kb values for each compound:

HF= 1.39 x $10^{-11}$

$HNO_2$= 2.22 x $10^{-11}$

HCN = 1.61 x $10^{-5}$

Higher Kb value indicates stronger base. Therefore, the order of decreasing base strength would be $CN^- > NO_2^- > F^-$

**Question 10**

Davy electrolysed samples of hydrochloric acid and showed that it produced hydrogen gas and chlorine gas, but not oxygen gas. This experiment helped to disprove Lavoisier's oxygen theory of acids.

- Later experiments by other chemists showed that other acids e.g. hydrocyanic acid (HCN), also contained no oxygen but did contain hydrogen. As a result, Davy proposed that the **presence** of hydrogen in acids gave them their acidic properties

**Question 11**

The addition of water leads to the formation of a more dilute solution and thus a decrease in the concentration of $OCl^-$. This causes the reaction to shift to the left to increase the $[OCl^-]$. *A* would be incorrect as there would be no change in $[H^+]$. *C* would be incorrect as the concentration of HOCl would decrease due to the equilibrium shifting left. *D* is incorrect as we did not alter the temperature, therefore the Keq would not have been affected. *B* is the correct answer due to a decrease in $[OH^-]$, thus decreasing the pH.

e.g. pOH = -log[0.1] = 1 so pH is 13. If pOH = -log[0.0001] = 4, then pH is 10. There is a decrease in pH.

**Question 12**

pOH of KOH initially = 14 - 12

= 2

$[OH^-] = 10^{-2} = 0.01$

pOH of KOH at desired pH = 14 - 13
= 1
$[OH^-] = 10^{-1} = 0.1$
0.1-0.01= 0.09 mols of KOH needed to raise the pH to 13

**Question 13**
$[H^+] = 10^{-2}$
= 0.01
Enough HCl must be added to neutralise the $OH^-$ initially present and to then increase the amount of $H_3O^+$ present to 0.01 mol.
Thus mol of HCl needed would be 0.01 + 0.01 = 0.02 mol

**Question 14**
$\Delta H = -q/n$
$q = mc\Delta T$
= 100 x 4.18 x 3.5
= 1463 J
= 1.463 kJ

$\Delta H$ = -1.463kJ/0.025 mol
= -59

**Question 15**

Option A and B shows simple distillation. Option C and D both show the reflux apparatus. However, Option D shows the incorrect connection of the water tubes because the water must enter the leibig condenser from the bottom and leave from the top to ensure the temperature of the condenser is able to sustain a cool temperature to successfully condense gaseous particles.

**Question 16**

This particular reaction was not specifically taught in the syllabus but the point is that students carefully observe the generic equation provided, can apply their understanding of organic compound structures and can distinguish between primary, secondary and tertiary alcohols.

Option B through to D will ALL produce a secondary alcohol as

- The C=O bond will break leaving the C available to form another bond
- The methyl group in $CH_3MgBr$ will attach to the C atom
- The central carbon will now have 2 carbons attached to it

Methanal is the only option.

**Question 17**

When but-1-ene reacts with HCl, the double bond is broken and the H will bond to the C-atom that has the most H-atoms already present, following Markovnikov's rule. The Cl-atom will bond to the 2$^{nd}$ C atom. This structure is 2-chlorobutane. This is the MAJOR product.

The minor product is the other alternate position between H and Cl, 1-chlorobutane. Hence, the answer is B

**Question 18**

To convert X to Y dehydration is taking place, which means X must be an alcohol compound in order to have 1 H atom and the O-H bond removed to form water. Y must be an alkene as the product formed by the dehydration of alcohol.

To convert Y to Z, an addition reaction takes place. This means the double bond in the alkene must be broken to allow the addition of HCl to the compound.

Hence 2, 3, 1 is the only option (D)

**Question 19**

The circled H atom is attached to a neighbouring C-atom which holds 3 H atoms. Following the proton NMR splitting, the signal is n+1, therefore a quartet will be shown.

**Question 20**

The parent molecular ion has a mass of 74. By checking each of the options only C will add up to 73.138 which is NOT 74 and is therefore the answer.

## PART B – SHORT TO LONG RESPONSES

### Question 21

a) Construct an equation for the equilibrium that occurs in a saturated solution of $Mg(OH)_2$.

| Criteria | Marks |
|---|---|
| • Constructs a correctly balanced equation with correct states | **1** |

**Sample Answer:**

$Mg(OH)_2\ (s) \rightleftharpoons Mg^{2+}\ (aq) + 2OH^-\ (aq)$

**Marker Comment:**

Most students answered this question correctly – some included $H_20$ in their equation, this is not required.

b) Construct an expression for the Ksp of $Mg(OH)_2$.

| Criteria | Marks |
|---|---|
| • Constructs correct Ksp expression | **1** |

**Sample Answer:**

$Ksp = [Mg^{2+}][OH^-]^2$

**Marker Comment:**

Most students correctly derived the Ksp expression from the equilibrium equation. $Mg(OH)_2$ is not included as it is a solid.

c) Calculate the molar solubility of $Mg(OH)_2$ in water at 25 °C, and give $[Mg^{2+}]$ and $[OH^-]$. Using the solubility constant given on the data sheet.

| Criteria | Marks |
|---|---|
| • Correctly calculates value for $[Mg(OH)_2]$, $[Mg^{2+}]$ and $[OH^-]$<br>• Uses correct units in response | **3** |
| • Calculates value for $[Mg(OH)_2]$ OR$[Mg^{2+}]$ OR $[OH^-]$ | **2** |
| • Some relevant information | **1** |

**Sample Answer:**

Ratio of $Mg^{2+}$: $OH^-$ in $Mg(OH)_2$ is 1:2 as so let this equal x:2x
$Ksp = [Mg^{2+}][OH^-]^2$
From the data sheet $Ksp = 5.61x\ 10^{-12}$
$5.61 \times 10^{-12} = [x][2x]^2$
$5.61 \times 10^{-12} = 4x^3$
$x = \sqrt[3]{5.61x\ 10^{-12}/4} = 1.19 \times 10^{-4}M$
$[Mg(OH)_2] = [Mg^{2+}] = 1.19 \times 10^{-4}M \quad [OH^-] = 2.38 \times 10^{-4}M$

**Marker Comment:**

A number of students incorrectly stated that $[2x]^2 = 2x^2$ or did not double the concentration of $OH^-$ in this question. Students need to ensure that they include units in their answers and read the entire question – students were asked to state the $[Mg^{2+}]$ AND $[OH^-]$ and number of students did not do this.

d) When dilute sodium hydroxide, NaOH, is added to a saturated solution of $Mg(OH)_2$ , the concentration of $Mg^{2+}$ ions in the saturated solution decreases. Explain why the concentration of $Mg^{2+}$ ions in the saturated solution decreases upon the addition of NaOH.

| Criteria | Marks |
|---|---|
| • Correctly calculates value for $[Mg(OH)_2]$, $[Mg^{2+}]$ and $[OH^-]$<br>• Uses correct units in response | **3** |
| • Calculates value for $[Mg(OH)_2]$ OR $[Mg^{2+}]$ OR $[OH^-]$ | **2** |
| • Some relevant information | **1** |

**Sample Answer:**

When sodium hydroxide is added to water it dissociates into $Na^+$ and $OH^-$, the addition of this to the solution of $Mg(OH)_2$ means that there will be an increase in the overall concentration of $OH^-$ in the solution. This is called the common ion effect as NaOH and $Mg(OH)_2$ both contain the common ion $OH^-$.

$Mg(OH)_2$ (s) $\rightleftharpoons$ $Mg^{2+}$ (aq) + $2OH^-$ (aq)(amount of $OH^-$ increases in solution)

As this is an equilibrium reaction, a change in the concentration of a product will disturb the equilibrium. Le Chaterlier's Principle explains how if a system is disturbed it will move in such a way to minimise the disturbance. An increase in the concentration of a product will cause the equilibrium to shift to the reactants side to reduce the overall concentration of $OH^-$ in the solution. When the equilibrium shifts to the left (reactants side) the concentration of solid $Mg(OH)_2$ will increase and form more precipitate.

**Marker Comment:**

Students need to recognise that this is the common ion effect. Many students discussed equilibrium and how this relates to Le Chatelier's Principle – specifically stating the principle itself is very helpful. Just stating that more $Mg(OH)_2$ is produced is too generic, students need to state that this amount of solid or precipitate increases.

e) Calculate the concentration of $Mg^{2+}$ ions in a solution after 30.0 mL of 0.120 mol $L^{-1}$ NaOH is added to 20.0 mL of a saturated $Mg(OH)_2$ solution. State any assumptions that have been made

| Criteria | Marks |
|---|---|
| • Correctly calculates concentration of $Mg^{2+}$ in solution.<br>• States correct units in answer | **3** |
| • Utilise Ksp equation to attempt to find a correct answer to the question | **2** |
| • Some relevant information | **1** |

**Sample Answer:**

Number of moles of $OH^-$ present in added solution as NaOH

$c=n/V \ \therefore n=cxV$ n= 0.120M x 0.0300L = 0.0036 moles.

This number of moles is now in 50.0 mL of solution (added volume of NaOH and $Mg(OH)_2$solutions)

$c=n/V \therefore c=0.0036$ moles/0.0500L = 0.072M

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

| | | | |
|---|---|---|---|
| R | 1 | 1 | 2 |
| I | | s | 2s |
| C | | 0 | +0.072M |
| E | | s | 2s + 0.072M |

As s is a small value we will assume that 2s + 0.072M = 0.072M

Substituting into equation from expression for question 21b

$5.61x\ 10^{-12}$= s x $(0.072M)^2$ = $1.08 \times 10^{-9}$M

**Marker Comment:** Many students had difficulty with this calculation and did not understand that it was essentially a question about whether or not a precipitate would form. Students need to revise these more difficult concepts and understand the concentration of the final solution depends on the number of moles present and the final volume.

**Question 22**

a) Construct a balanced equation for this reaction

| Criteria | Marks |
|---|---|
| • Constructs a correctly balanced equation with correct states | **1** |

**Sample Answer:**

$2BCl_3$ (g) + $3H_2$ (g) → 2B(s) + 6HCl(g)

**Marker Comment:**

The majority of students correctly answered this question.

b) The reaction is endothermic with $\Delta H^0$= + 127kJ $mol^{-1}$. The standard entropy change ($\Delta S^0$) for the reaction is 79.4 $JK^{-1}mol^{-1}$. Calculate the $\Delta G^0$ for this reaction at 298K. State if the reaction is spontaneous at this temperature.

| Criteria | Marks |
|---|---|
| • Correctly calculates $\Delta G^0$<br>• Correct comment on spontaneity | **2** |
| • Some relevant information | **1** |

**Sample Answer:**

$\Delta G^0 = \Delta H^0 - T\Delta S^0$

$\Delta G^0$ = 127 kJ/mol – (298K x 0.0794 kJ/K/mol) = 127 kJ/mol – (23.6612 kJ/mol)

= 103.3388 kJ/mol = 103 kJ/mol

As the value for Gibbs Free Energy is greater than zero, this indicates that the reaction is not spontaneous.

**Marker Comment:**

Students need to ensure that they convert $\Delta H^0$ and $\Delta S^0$ to the same units – both as kJ OR J. Most students know that a negative value for Gibbs Free Energy indicates that the reaction is not spontaneous.

**Question 23**

A 1.00 L vessel contains, at equilibrium, 0.300 mol of $N_2$, 0.400 mol $H_2$ and 0.100 mol $NH_3$.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

If the temperature of the vessel is kept constant, how many moles of $H_2$ (g) must be introduced into the vessel in order to double the equilibrium concentration of $NH_3$(g)?

| Criteria | Marks |
|---|---|
| • Utilises a RICE/ICE table<br>• Determines Keq for system at equilibrium<br>• Calculates the amount of $H_2$ at new equilibrium<br>• Calculates the amount of $H_2$ added to vessel | **4** |
| • Utilises a RICE/ICE table<br>• Determines Keq for system at equilibrium<br>• Calculates the amount of $H_2$ at new equilibrium | **3** |
| • Determines the Keq value for the system | **2** |
| • Some relevant information | **1** |

**Sample Answer:**

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$

| | | | | |
|---|---|---|---|---|
| R | 1 | 3 | 2 | |
| I | 0.300 | 0.400+s | 0.100 | The change in concentration would d be 0.100 M |
| C | -0.050 | -0.150 | +0.100 | which is equal to a change of 2x – so we can determine |
| E | 0.250 | 0.250+s | 0.200 | the change that will occur in the other two gases. |

$$Keq = \frac{[NH_3]^2}{[N_2][H_2]^3}$$

Initial equilibrium constant $Keq = \frac{[0.100]^2}{[0.300][0.400]^3} = 0.521$

At new equilibrium Keq will remain the same

$$Keq = \frac{[0.200]^2}{[0.250][0.250 + s]^3} = 0.521$$

$s = (\sqrt[3]{(0.2002)/(.250x,52083)}) - 0.25$

$s = 0.425$

Therefore amount of $H_2$ gas that was added is 0.425 moles.

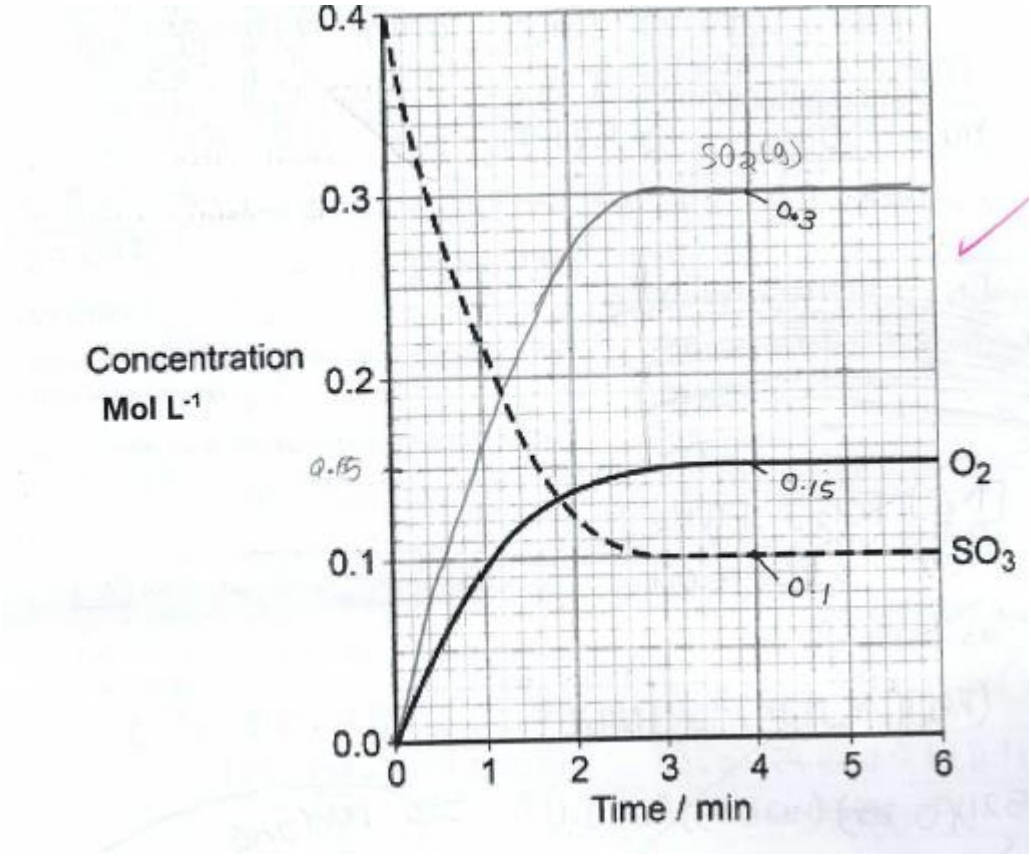
**Marker Comment:** Most students could determine the value for Keq for the initial mixture. Many students had difficulty in completing the second part of this question. This question is very similar to a question from the 2021 HSC – it is important that students revise past exam papers and understand how to complete these more difficult questions.

**Question 24**

a) Sketch on the graph how the concentration of sulfur dioxide changes over these 6 minutes at temperature $T_1$.

| Criteria | Marks |
|---|---|
| • Correctly draws and labels line | **2** |
| • Correctly draws line OR labels line | **1** |

**Sample Answer:**




**Marker Comment:** The majority of the cohort answered this question correctly, remember to label the line.

b) Calculate $K_{eq}$ for the equilibrium reaction.

| Criteria | Marks |
|---|---|
| • Correct Keq expression written<br>• Correct answer is calculated | **2** |
| • Correct Keq expression written | **1** |

**Sample Answer:**

$$K_{eq} = \frac{[O_2][SO_2]^2}{[SO_3]^2} = \frac{[0.15][0.30]^2}{[0.10]^3} = 14$$

**Marker Comment:**

Most students answered this question correctly.

c) Deduce which of $T_1$ and $T_2$ is the higher temperature. Explain your deduction.

| Criteria | Marks |
|---|---|
| • Identifies reaction as endothermic<br>• States that $T_2$ is higher than $T_1$.<br>• Explains that heat energy is absorbed and why | |
| • Identifies reaction as endothermic<br>• States that $T_2$ is higher than $T_1$. | |
| • Some relevant information | |

**Sample Answer:**

The given reaction is an endothermic reaction as ΔH is positive. The concentration of the reactant has decreased which means the concentration of the products has increased. As this is an equilibrium reaction, by Le Chatelier's Principle if a disturbance has occurred and then system will move in such a was as to minimise the change induced. The system must have experienced an increase in temperature, as it has moved toward the right hand side (endothermic) to absorb heat, thus $T_2$ is higher than $T_1$.

**Marker Comment:**

Most students achieved 2 or 3 marks in this question – it is important to state that heat is absorbed and this is what causes the equilibrium to shift – cause and effect is required – just stating that it moves to the right hand side is not and explanation.

**Question 25**

a) Calculate the volume (mL) of 0.100M $Na_2S_2O_3$ required to react with the iodine to reach the end point.

| Criteria | Marks |
|---|---|
| Student:<br>• Correctly calculates the average volume using volumes 2 and 3 (concordant values)<br>OR<br>• Correctly calculates the average volume using all three volumes | 2 |
| • Provides the correct average volume but does not show working | 1 |

**Sample answer:**
Volume 2: 46.00 mL - 23.95 mL= 22.05 mL

Average volume: (22.05 mL + 22.15 mL)/2 = 22.1 mL

**Marker's comment:**
Completed well, though a few students did not show their working out. I was hoping that students would pick up on the fact that only volumes 2 and 3 were concordant and use them for their calculations only, however this was not done by many students. This may have been because only 3 values were provided, and students felt they had to use all three. I ended up awarding marks for either type of calculation as long as working out was shown.

b) Determine the concentration of hypochlorite, $ClO^-$, present in the bleach.

| Criteria | Marks |
|---|---|
| Student:<br>• Correctly calculates moles of $S_2O_3^{2-}$<br>• Correctly calculates moles of $I_2$ using correct molar ratio (thus calculates moles of $ClO^-$ in 25 mL aliquot)<br>• Uses correct dilution factor to calculate moles of $ClO^-$ in 250 mL of sample<br>• Gives correct final value in mol $L^{-1}$ | 4 |
| Missing one of the above components | 3 |
| Missing two of the above components | 2 |
| Provides some relevant calculations | 1 |

**Sample answer:**

n ($S_2O_3^{2-}$) = CV

= 0.100 M x 0.0221 mL

= 0.00221 moles

n ($I_2$) = ½ x n ($S_2O_3^{2-}$)

=0.001109 moles = n ($ClO^-$) in 25mL (1:1 ratio)

25mL/250mL = 0.001109moles/x

x= 0.4436 mol $L^{-1}$

**Marker's comment:**

Note: no carry forward error from part a. Many students correctly calculated the amount of moles in 25mL but did not use the correct dilution factor to convert to 250mL. Some students did not use the correct stoichiometric ratio to calculate moles of iodine. A few students used n=m/mm to calculate moles instead of n= c x v.

**Question 26**

a) Use appropriate equations to explain why aqueous solutions of sodium hydrogen carbonate and sodium hydrogen sulfate have such different pH values.

| Criteria | Marks |
|---|---|
| Student:<br>- Makes reference to the Ka values in the stimulus<br>- Provides two or more relevant equations<br>- Relates the equations to the pH levels of the solutions | 3 |
| Missing one of the above components | 2 |
| Provides something relevant | 1 |

**Sample answer:**

$NaHCO_3$ has a low Ka value, indicating a low degree of acid dissociation. Thus, in water it can act as a base by accepting a proton from water as shown in the equation below:

$$HCO_3^-(aq) + H_2O(l) \leftrightharpoons H_2CO_3(aq) + OH^-(aq)$$

Due to the production of $OH^-$ ions, the resulting solution has a more alkaline pH.

$NaHSO_4$ has a high Ka value, indicating a high degree of acid dissociation. Thus, in water it can act as an acid by donating a proton to water as shown in the equation below:

$$HSO_4^-(aq) + H_2O(l) \leftrightharpoons SO_4^{2-}(aq) + H_3O^+(aq)$$

Due to the production of $H^+$ ions, the resulting solution has a more acidic pH.

**Marker's comment:**
Many students did not refer to the Ka values given in the stimulus. Some students focused a lot on conjugate pairs instead of using the stimulus information provided to them. Again, we remind you to ALWAYS refer to the stimulus as there is a reason it is given to you. Many students correctly identified that sodium hydrogen carbonate acts as a base and sodium hydrogen sulfate acts as an acid but did not use the Ka values to explain HOW you know this. Some students provided one or no equations even though the question specifically asks for more than one.

b) $NaHCO_3$ can be used to neutralise both acidic spills and basic spills. Provide one reason as to why this is the case.

| Criteria | Marks |
|---|---|
| Student identifies that $NaHCO_3$ is amphiprotic or amphoteric meaning it can act as both an acid and a base | 1 |

**Sample answer:**
$NaHCO_3$ is amphiprotic meaning it can act as both an acid and a base.

**Marker's comment:**
Answered well by the whole cohort. Since this is worth 1 mark, not a lot of detail was needed but it was great to see students giving thorough explanations.

**Question 27**

a) Which of the above indicators could be used to distinguish between solutions of $1 \times 10^{-5}$ mol $L^{-1}$ sodium hydroxide and $1 \times 10^{-5}$ mol $L^{-1}$ hydrochloric acid? Justify your answer.

| Criteria | Marks |
|---|---|
| Student:<br>- Calculates the pH of each solution using the concentration given<br>- Identifies that phenol red is the best indicator to use and justifies why by identifying the colour of the indicator at each pH | 2 |
| Missing one of the above components | 1 |

**Sample answer:**
pH (HCl) = $-\log(1 \times 10^{-5})$

= 5

pOH (NaOH) = $-\log(1 \times 10^{-5})$

= 14-5
= 9

Phenol red is red at a pH of 9 and yellow at a pH of 5, therefore it is the best indicator to use.

**Marker's comment:**
Generally answered well by students. Some provided two indicators even though the question asked for one that distinguishes between the two solutions. Some students didn't read the question properly and started talking about equivalence points.

b) A solution of hydrochloric acid was titrated with sodium bicarbonate. Explain which indicator would work best for determining the endpoint of the titration.

| Criteria | Marks |
|---|---|
| Student:<br>- Identifies that the reaction is between a strong acid and weak base, therefore the pH would be around 4.<br>- Explains that methyl orange would be the best indicator to use as it has a smaller pH range | 3 |
| - Identifies that the reaction is between a strong acid and weak base, therefore the pH would be around 4.<br>- Explains that Congo red would be the best indicator to use as the equivalence point falls in the pH range<br>OR<br>- Explains that methyl orange would be the best indicator to use as it has a smaller pH range but does not identify that the reaction is between a strong acid and weak base.<br>OR<br>- Identifies that the reaction is between a strong acid and weak base, therefore the pH would be around 4.<br>- Identifies that methyl orange would be the best indicator to use but does not explain why | 2 |
| Some relevant information provided | 1 |

**Sample answer:**
Hydrochloric acid is a strong acid while sodium bicarbonate is a weak base, thus a reaction between the two would result in an equivalence point of around 4. This pH falls into the pH range of both Congo red and methyl orange, however the best indicator choice would be methyl orange as it has a smaller pH range and would thus be more accurate.

**Marker's comment:**
Mixed performance across the cohort. Stronger students identified that methyl orange would be the best choice due to having a smaller pH range. Many students had the misunderstanding that a wider pH range would be better to ensure that the desired pH falls into the range or claimed that Congo red should be chosen as it has a more distinct colour change compared to methyl orange. Students are asked to revisit their understanding of indicators.

**Question 28**

a) Calculate the average volume, in mL, of the concordant titres of the potassium permanganate solution.

| Criteria | Marks |
|---|---|
| Student uses the correct concordant values to calculate the average volume of the solution | 1 |

**Sample answer:**

(22.03 + 21.97 + 21.99)/3= 22.00mL

**Marker's comment:**
Some students disregarded the first trial by saying it is a rough titre. This was unnecessary as it would have been specified that the first titre is rough. Some students used the second titre in their calculations which is incorrect as it does not fall within 0.1mL of any of the other values.

b) Calculate the percentage, by mass, of iron in the 80.50 g sample of alloy. Express your answer to the correct number of significant figures

| Criteria | Marks |
|---|---|
| Student:<br>- Correctly calculates n($MnO_4$) using n=C x V<br>- Correctly calculates n($Fe^{3+}$) in 20mL using the stoichiometric ratio (1:5)<br>- Correctly calculates n($Fe^{3+}$) in 250mL using the correct dilution factor<br>- Correctly calculates the mass of iron using m=n x mm<br>- Correctly calculates the % composition of iron in the alloy to the correct number of significant figures | 5 |
| Missing one of the above steps | 4 |
| Missing two of the above steps | 3 |
| Missing three of the above steps | 2 |
| Provides some relevant calculations | 1 |

**Sample answer:**

$n(MnO_4^-) = 0.0400M \times 22.00 \times 10^{-3}$ L

$= 8.80 \times 10^{-4}$ mol

n ($Fe^{3+}$) in 20 mL = $5 \times 8.80 \times 10^{-4}$ mol (1 $MnO_4^-$: 5 $Fe^{3+}$ ratio)

$= 4.40 \times 10^{-3}$ mol

n ($Fe^{3+}$) in 250mL = $4.40 \times 10^{-3}$ mol x 250/20

$= 5.50 \times 10^{-2}$ mol

m (Fe) = $5.50 \times 10^{-2}$ mol x 55.85 g/mol

=3.07175 g

% Fe in alloy = (3.07175 g/80.50g) x 100 = 3.82 (3 s.f.)

**Marker's comment:**
Note: no carry forward error from part a. Generally completed satisfactorily across the cohort. Some students forgot to calculate the amount in 250mL or did not use the correct dilution factor. Some students reached incorrect values along the way, however some marks were still awarded for showing the correct process. The question specified significant figures, however some students rounded their answer to the incorrect number of significant figures.

**Question 29**

a) Write an expression for the first stage dissociation constant, Ka, for malic acid.

| Criteria | Marks |
|---|---|
| Student writes the correct Ka expression for malic acid | 1 |

**Sample answer:**

$Ka = [HOOCCH_2CH(OH)COO^-][H_3O^+]/[HOOCCH_2CH(OH)COOH]$

**Marker's comment:**

Overall answered well across the cohort.

b) Write the equation to show the second stage dissociation of malic acid.

| Criteria | Marks |
|---|---|
| Student writes the correct second stage dissociation of malic acid | 1 |

**Sample answer:**

$HOOCCH_2CH(OH)COO^-(aq) + H_2O(l) \leftrightharpoons OOCCH_2CH(OH)COO^{2-}(aq) + H_3O^+(aq)$

**Marker's comment:**

A few students were confused by this question indicating they need to revisit some of their terminology. Most students answered well, however there were a few slight mistakes such as not writing the correct superscript ($^{2-}$). Students also had to make sure that the $H^+$ came off one of the OH groups.

c) If the concentration of malic acid in the jam is 0.0052 mol $L^{-1}$, determine whether the jam will thicken at this concentration of malic acid.

| Criteria | Marks |
|---|---|
| Student<br>- Correctly substitutes values into the Ka expression for malic acid and calculates $[H_3O^+]$<br>- Correctly calculates pH using $pH=-\log[H^+]$<br>- Correctly determines that the jam will thicken due to it falling in the pH range | 3 |
| Missing one of the above components | 2 |
| Provides some relevant calculations | 1 |

**Sample answer:**

$Ka = [x][x]/[0.0052]$

$3.2 \times 10^{-4} = [x^2]/[0.0052]$

$X^2 = 1.664 \times 10^{-6}$

$X = 0.00128996124\ M = [H_3O^+]$

$pH = -\log [H^+]$

$= 2.889423339$

$= 2.9$

The pH of the jam falls into the pH range, therefore it will thicken.

**Marker's comment:**

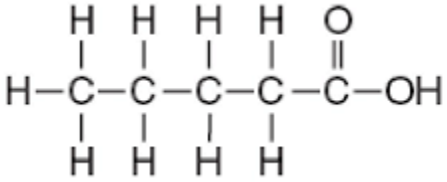
Many students used the Henderson Hasselbach equation, even though this question had nothing to do with buffers. These students were awarded one mark due to showing that they needed to calculate pH to answer the question. Some students did not use the Ka value provided in the question to calculate the $H^+$ ion concentration. Since Ka was small, it was fine to assume that x was negligible. Generally, this question was answered satisfactorily amongst the cohort.

**Question 30**

a) Based on the information provided thus far, name and provide the possible structural formulae for the organic compound.

| Criteria | Marks |
|---|---|
| Provides correct name AND structural formula | 2 |
| Provides correct name OR structural formula | 1 |

**Answer**

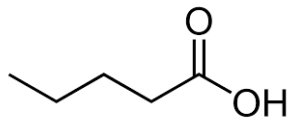


Pentanoic acid

**Markers comments**

The compound must be an acid due to bubbles forming when reacting with a metal carbonate.

Students who provided the structural formula with incomplete H-atoms would have lost a mark. The only time the H-atoms may be excluded is if it was in the following format:

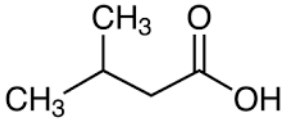
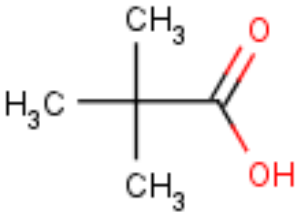
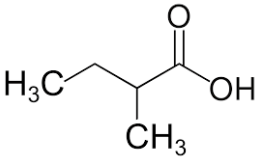


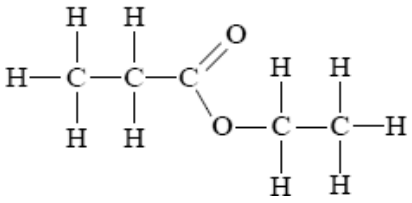
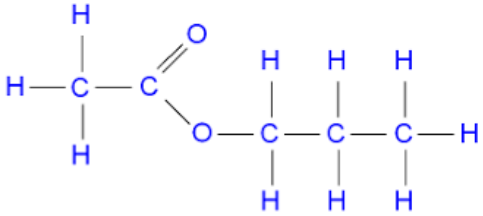
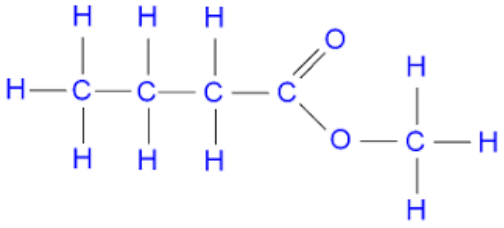

This was the only compound that could be possible which would fit the C-NMR and mass number provided. A number of students drew an acid, albeit the wrong one. The compound must be an acid with 5 carbon environments.

b) Name and provide the structural formulae for the isomers of the organic compound identified in part a). Be sure to provide ONE of each of the following:

| Criteria | Marks |
|---|---|
| TWO correct diagrams AND nomenclature provided for each | 3 |
| 1 – 2 diagrams correctly drawn AND only 1 correctly named | 2 |
| 1 diagram correctly drawn | 1 |

**Answer:**

| Structural Isomer | Structural formulae | Name |
|---|---|---|
| Chain | Option 1   | 3-methylbutanoic acid |
| | Option 2   | 2,2-dimethylpropanoic acid |
| | Option 3   | 2-methylbutanoic acid |

| | | |
|---|---|---|
| Functional | Option 1<br>  | Ethyl propanoate |
| | Option 2<br>  | Propyl ethanoate |
| | Option 3<br>  | Methyl butanoate |

**Markers comment**

Students must draw complete structures, with appropriate number of H's as well as write the correct nomenclature, including all the dashes and commas as required.

If students did not get part a) correct, they could still score marks here as carried forward error. As long as they drew a BRANCHED/CHAIN ester and an acid as the functional isomer.

c) Which isomer CANNOT be the organic liquid compound. Provide a reason based on the information provided thus far.

| Criteria | Marks |
|---|---|
| Correctly identifies the functional isomer as being impossible with supporting evidence | 2 |
| Identifies the functional isomer | 1 |

**Answer**

The functional isomer, which is an ester, cannot be the organic liquid compound as it will not react with metal carbonates to produce bubbles.

**Markers comment**

Students who drew and identified the correct organic compound in part a) generally answered this one well. However, those that chose the incorrect compound or drew wrong structures in part b) limited their ability to score marks here.

d) Mason claims that there is not enough information to definitively identify the organic liquid compound as it should also be analysed through the mass spectroscope. Based on the spectral data and information provided, identify of the organic liquid compound and assess the validity of Mason's claim by analysing the range of spectral information provided and consider the usefulness of a mass spectrum

| Criteria | Marks |
|---|---|
| • Extensive analysis of the 3 spectral data (C-NMR, H-NMR, IR) to confirm the identity of the organic liquid based on the possible isomers.<br>• Provides arguments for and against mason's claims.<br>• Makes a valid assessment. | 6-7 |
| • Thorough analysis and interpretation of the spectral data<br>• Provides arguments for and/or against mason's claims.<br>• Makes a valid assessment. | 4-5 |
| • Sound analysis and interpretation of the spectral data including mass spec<br>• Makes a valid assessment | 3 |
| • Basic interpretation of the spectral data | 2 |
| • Provided 1 piece of relevant information | 1 |

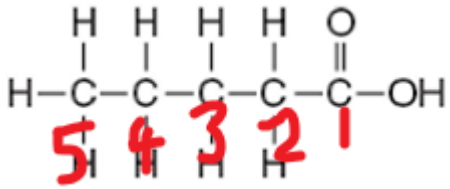
**Sample Answer**

Criteria for judgement: The validity of Mason's claim depends on whether all the information and spectral data (C-NMR, H-NMR, mass spec and IR) supports and can confirm, without a doubt, the identity of the compound.

The proposed compound is **pentanoic acid**.

Evidence:

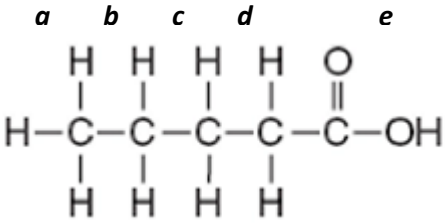
- The organic compound was reacted with metal carbonate where bubbles were observed. This suggests the compound is an acid so as to produce carbon dioxide.
- The molar mass of the compound is 102.13 g/mol. Pentanoic acid has a chemical formula of $C_4H_9COOH$. Mol weight = 5(12.01) + 10(1.008) + 2(16) = 102.13 g/mol.
- The C-NMR indicates 5 carbon environments. Given the asymmetric nature of the compound there are 5 carbon environment as labelled below.




- The chemical shift at 180ppm coincides with the C=O group for acids and esters. We know from its reactivity that it is an acid but it is confirmed by the C-NMR as there is NO additional chemical shift between 50-90 ppm to support an ester.
- The 4 other chemical shifts between 5-40 represents the C-C bonds in the compound.
- The infrared spectrum has a very broad peak that starts at 2500 $cm^{-1}$ towards 3000$cm^{-1}$ which represents the O-H group in acids. The additional long trough at 1700 $cm^{-1}$

represents the carbonyl C=O group. Together, the C=O and O-H, represents the carboxylate group (COOH), further cementing the acid aspect.

- The H-NMR provides the structural arrangement of the compound. It has 5 H-environments and the spectral data coincides with each of the environments perfectly:




Following the n+1 rule, where n is the number of H on the neighbouring carbon

***a*** = peak at 0.93 is a triplet with the peak area ratio of 3 – denoted by the 3 hydrogens in that environment

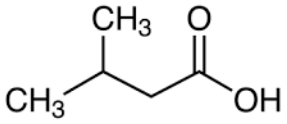
***b*** = peak at 1.39 with the peak area ratio of 2 – the neighbouring C has 5 H-atoms equating to a sextet signal

***c*** = peak at 1.62 with a quintet – the neighbouring C has 4 H-atoms

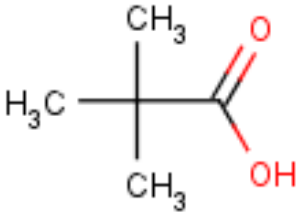
***d*** = peak at 2.35 with a triplet with a peak area ratio of 2 – the neighbouring C has 2 hydrogens allowing for a triplet signal. The chemical shift is larger due to being near a highly electronegative O atom.

***e*** = peak at 11.96. A single peak due to the neighbouring C not having any H attached.

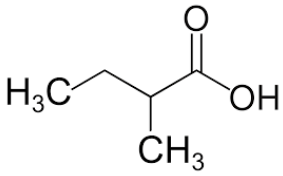
- The possible isomers, as identified in part b) cannot be possible.




3-methylbutanoic acid has 4 carbon environments




2,2-dimethylpropanoic acid does not match the CNMR spectrum as it has 3 carbon environments.



2-methylbutanoic acid has 5 carbon environment so it is possible BUT it does not coincide with the H-NMR. The methyl group in position 2 is next to a carbon that has only 1 H-atom, resulting in a doublet signal. This is not given in the H-NMR spectral data and is therefore NOT the organic compound.

- Information obtained from a mass spec includes the molecular mass of the parent molecular ion and the molecular mass of a range of fragments, including the base peak. This will mean the structure can be further confirmed in terms of the fragments however, Mason's claim is invalid as with each of the information obtained and the reactivity of the compound its structure is definitively confirmed and the mass spec is NOT required.

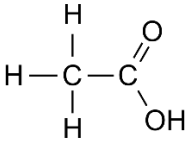
**Question 31**

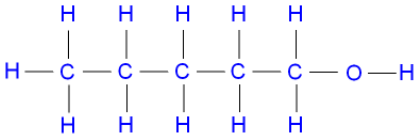
a) Complete the flow chart to show the reagents and conditions required for each step and draw the structural formulae of the main products (A, B and C) formed.

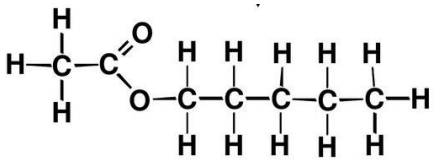
| Criteria | Marks |
|---|---|
| Provides THREE correct conditions and reagents for X – Z AND THREE correct structural formulae for A-C.<br>*(3 conditions + 3 diagrams)* | 5 |
| Provides THREE correct conditions and reagents AND TWO correct structural formulae.<br>OR<br>Provides TWO correct conditions and reagents AND THREE correct structural formulae. | 4 |
| Provides ONE - TWO correct conditions and reagents AND TWO correct structural formulae.<br>OR<br>Provides ONE-TWO correct structural formulae AND TWO correct conditions and reagents. | 3 |
| Provides ONE correct condition and reagent AND ONE correct structural formulae.<br>OR<br>Provides TWO correct structural formulae<br>OR<br>Provides TWO correct conditions and reagent | 2 |
| Provides 1 correct structural formula<br>OR<br>Provides ½ - 1 whole correct condition / reagent for either Z/X/Y | 1 |

**Answer:**

X: H+ / $Cr_2O_7^-$ and reflux (acidified dichromate or permanganate)
Y: Water and dilute sulfuric acid
Z: concentrated sulfuric acid and reflux

A: 

B: 

C: 

**Markers comments**

If students did not write down reflux for both X and Y, they were only penalised ONCE so that you were not penalised TWICE. It was necessary for the oxidation process that the oxidising agent says 'acidified' or is denoted by H+.

b) Process X and Z are conducted using the same technique. Provide ONE reason to explain why the same technique is utilised in process X and Z.

| Criteria | Marks |
|---|---|
| • Identifies the process<br>• Provides a reason with an explanation | 2 |
| • Provides something relevant | 1 |

**Answer**

Reflux is used in both processes to prevent the loss of volatile reactants and products so as to increase the yield.

**Markers comment**

Whilst heat is required to increase the rate of reaction, the purpose of the reflux apparatus specifically is to ensure there is no loss of volatile substances. Unfortunately, students appeared to be unsure of the technique.

**Question 32**

a) One of the standard solutions had a concentration of 0.010 mol $L^{-1}$. Describe, in detail, how this 0.010 mol $L^{-1}$ solution should be prepared in a 50mL volumetric flask from the 0.10 mol $L^{-1}$ stock solution.

| Criteria | Marks |
|---|---|
| • Correct volume<br>• Key equipment<br>• Logical and sequential steps | 3 |
| 2 key points provided | 2 |
| 1 key point provided | 1 |

**Answer**

C1 x V1 = C2 x V2

0.10 M x V1 = 0.010 M x 0.050 L
V1 = 0.005L or 5ml

Pipette 5ml of 0.10M solution and transfer to the 50ml volumetric flask. Add distilled water until the 50ml calibrated mark, just sitting on the meniscus. Stopper and invert at least 3 times.

**Markers comments**

This is from the preliminary course. Students need to make sure they review the preliminary content and skills.

b) i) Name the substance that should be used to set the colorimeter to zero.

| Criteria | Marks |
|---|---|
| Provides the correct substance | 1 |

**Answer:** distilled water

**Markers comments:**
Some students wrote copper nitrate solution or blank cuvette. These are both incorrect. If students gave TWO solutions they would not be able to gain the 1 mark as it shows the students does not know WHICH one is correct.

ii) The absorbance of the sample solution was 0.71. The sample solution was then diluted to decrease the concentration by half. The absorbance of this diluted solution was then measured. Provide a reason for why the sample solution must be diluted.

| Criteria | Marks |
|---|---|
| Provides valid and logical reason linked to the accuracy of data | 1 |

**Answer:** The concentration would be outside the calibrated curve provided which would be inaccurate.

**Markers comments:** Generally well done.

iii) The mass of the screw was 1.43 g. The absorbance of the diluted solution was 0.34. Calculate the percentage by mass of copper in the screw.

| Criteria | Marks |
|---|---|
| Show all relevant steps and provides correct percentage | 3 |
| Shows some form of manipulation of data | 2 |
| Provides concentration interpolated from the calibration curve | 1 |

**Answer**
At 0.34 absorbance, the concentration of $Cu^{2+}$ is 0.032 M (from graph).
$[Cu^{2+}] = 0.032 \times 2$ (due to dilution mentioned in part bii)
$= 0.064$ M

In 1L there are 0.064 moles, so in 250ml there are 0.016 moles of $Cu^{2+}$.

m(Cu2+) = n x MM
= 0.016 moles x 63.55 g/mol
= 1.0168 g

Percentage = 1.0168 g x 100
1.43g
= 71%

**Markers comment:** Students earned 2 marks if they multiped the concentration extrapolated from the graph x2 = this shows manipulation of the data. No further marks earned as the answer would be incorrect.