

Student Number:.....

2022 Higher School Certificate Trial Examination

Chemistry

General Instructions

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

Total marks: 100

Section I – 20 marks (Pages 2-11)

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

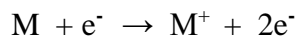
Section II – 80 marks (Pages 13-30)

- Attempt Questions 21-30
- Allow about 2 hours and 25 minutes for this section

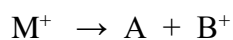
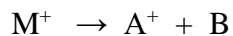
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- 3 A sample of compound M is analysed in a mass spectrometer where it forms the molecular ion M^+ according to



Some of the molecular ions fragment as follows:



The mass spectrum would show peaks due to the species

- A. M^+ , A, A^+ , B and B^+ only
- B. M^+ , A^+ and B^+ only
- C. A^+ and B^+ only
- D. A and B only
- 4 Which of the following statements would apply to compounds that belong to the same homologous series?
- I – They have similar physical properties.
II – They have similar chemical properties.
III – They contain the same functional group.
IV – They have the same molecular formula but different structures.
- A. III only
- B. IV only
- C. II and III only
- D. I, II, III and IV

- 5 Methanoic acid and ethanoic acid are both weak acids with the following acid dissociation constants K_a at 25°C:

- methanoic acid (HCOOH) = 1.82×10^{-4}
- ethanoic acid (CH_3COOH) = 1.74×10^{-5}

Two separate solutions were prepared, one of 0.1 M methanoic acid and the other of 0.1 M ethanoic acid. Which one of the following would be present in the lowest concentration at 25°C?

- A. CH_3COOH in the ethanoic acid solution
- B. CH_3COO^- in the ethanoic acid solution
- C. HCOOH in the methanoic acid solution
- D. HCOO^- in the methanoic acid solution

- 6 Some solid copper sulfate crystals were added to a beaker of water, stirred to dissolve the solid, covered to prevent evaporation and left to stand.

After 1 day, solid crystals were still present in the beaker. More solid copper sulfate, which contained radioactive atoms, was then added to the beaker. The beaker was then covered and left to stand for a second day. Assume that temperature has remained constant.

Which of the following statements is/are correct after the 2-day period?

I – none of the extra solid will dissolve as the solution was already saturated.

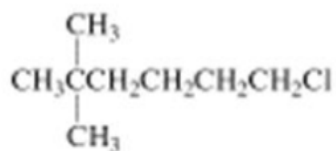
II – the solution will contain radioactive atoms as some of the radioactive solid will have dissolved.

III – there will be more solid remaining in the beaker than was present before the radioactive solid was added.

IV – the final solution of copper sulfate will be more concentrated than it was after 1 day.

- A. I only
- B. II only
- C. II and III only
- D. II, III and IV only

- 7 The correct IUPAC name for the compound shown below is



- A. 1-chloro-5,5-dimethylhexane
B. 5,5-dimethyl-1-chlorohexane
C. 2,2-dimethyl-6-chlorohexane
D. 6-chloro-2,2-dimethylhexane
- 8 A student, analysing an unknown solution (X) known to contain a salt or a mixture of salts, reacted samples of the solution, separately, with solutions of sodium sulfate and sodium carbonate.

A white solid was formed in both reactions.

The teacher said that the unknown solution contained one or more of the following cations.

- I – Ba^{2+}
II – Pb^{2+}
III – Mg^{2+}
IV – Ca^{2+}

The cation(s) present in solution X could be

- A. I and II only
B. II only
C. I, II and III only
D. I, II and IV only

9 Which one of the following lists contains only analytical techniques that can be used to determine the concentration of a substance?

- A. AAS and UV-visible spectroscopy
- B. ^{13}C NMR spectroscopy and IR spectroscopy
- C. IR spectroscopy and mass spectrometry
- D. Mass spectrometry and AAS

10 Which of the following organic compounds will react with a solution of sodium hydroxide?

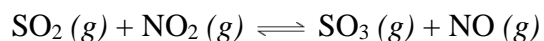
I – propanoic acid

II – propan-1-ol

III – 1-chloropropane

- A. I only
- B. I and II only
- C. I and III only
- D. II and III only

11 Consider this reaction, whose $K_{eq} = 33$.

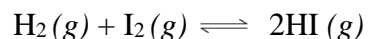


If 0.10 mol each of SO_2 and NO_2 are placed in a 1.0 L container, what is the concentration of SO_3 at equilibrium?

- A. 0.0030 M
- B. 0.015 M
- C. 0.085 M
- D. 0.097 M

- 12 When two moles of an organic compound are burnt in oxygen, eight moles of carbon dioxide gas are formed. In a second test, when a few drops of bromine are added to the compound and shaken, the bromine rapidly decolourises. The formula of the compound could be
- A. C_4H_8
 - B. C_4H_{10}
 - C. C_8H_{16}
 - D. C_8H_{18}
- 13 One litre of an aqueous solution of potassium hydroxide (KOH) has a pH of 12.0 at 25°C . The amount of pure HCl gas, in moles, that must be added to the solution to lower the pH from pH 12.0 to 2.0 would be
- A. 10
 - B. 2
 - C. 0.02
 - D. 0.01
- 14 In a titration, a 25.00 mL titre of 1.00 M hydrochloric acid neutralised a 20.00 mL aliquot of sodium hydroxide solution. If, in repeating the titration and washing the glassware involved, the titre would be
- A. equal to 25.00 mL if water was left in the titration flask after final rinsing.
 - B. less than 25.00 mL if the final rinsing of the burette was with water rather than the acid.
 - C. greater than 25.00 mL if the final rinsing of the 20.00 mL pipette was with water rather than the base.
 - D. greater than 25.00 mL if the titration flask had been rinsed with the acid prior to the addition of the aliquot.

- 15 Hydrogen iodide is produced by the reaction between hydrogen and iodine.

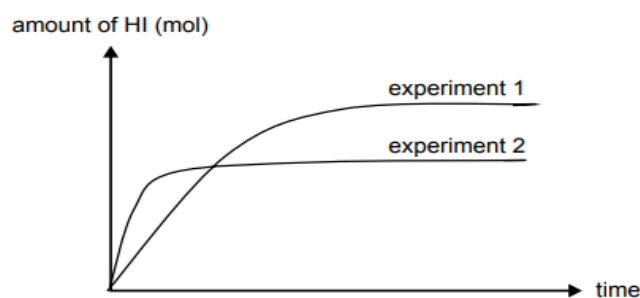


Two experiments were conducted.

Experiment 1: quantities of $\text{H}_2(\text{g})$ and $\text{I}_2(\text{g})$ were placed in a sealed vessel and the reaction allowed to proceed at constant temperature.

Experiment 2: experiment 1 was repeated, but at a different temperature.

The graph below shows the amount of hydrogen iodide produced over the course of experiments 1 and 2.



These results show that experiment 2 was conducted at a

- A. lower temperature than experiment 1 and the reaction is endothermic.
 - B. lower temperature than experiment 1 and the reaction is exothermic.
 - C. higher temperature than experiment 1 and the reaction is endothermic.
 - D. higher temperature than experiment 1 and the reaction is exothermic.
- 16 The molecule $\text{HOCH}_2\text{CH}_2\text{CH}_2\text{COOH}$ (molar mass = 104 g mol^{-1}) forms a condensation polymer in which the average polymer molecule contains 1000 monomer units. The approximate molar mass of the polymer, in g mol^{-1} , is
- A. 68000
 - B. 86000
 - C. 95000
 - D. 104000

- 17 A compound known to contain carbon, hydrogen and oxygen was analysed by ^{13}C NMR and ^1H NMR spectroscopy. The following numbers of peaks were detected on the spectrum.

- ^{13}C NMR – 2 peaks
- ^1H NMR – 1 peak

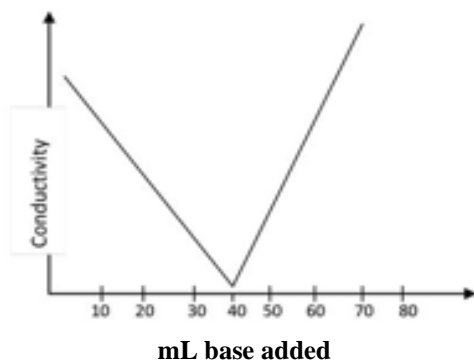
The compound could be

- A. Butan-1-ol
- B. Propanone
- C. Propan-2-ol
- D. Ethanol
- 18 A 0.10 M solution of fluoride ions is gradually added to a solution containing Ba^{2+} , Ca^{2+} and Pb^{2+} ions, each at a concentration of $1 \times 10^{-3} \text{ M}$. In what order, from first to last, will the precipitates of BaF_2 , CaF_2 and PbF_2 form?

Solubility Product, K_{sp}	
BaF_2	1.8×10^{-7}
CaF_2	1.5×10^{-10}
PbF_2	7.1×10^{-7}

- A. CaF_2 , PbF_2 , BaF_2
- B. BaF_2 , CaF_2 , PbF_2
- C. PbF_2 , BaF_2 , CaF_2
- D. CaF_2 , BaF_2 , PbF_2

- 19 A conductometric titration was carried out using an acid and a base of similar concentration and the graph below was recorded.

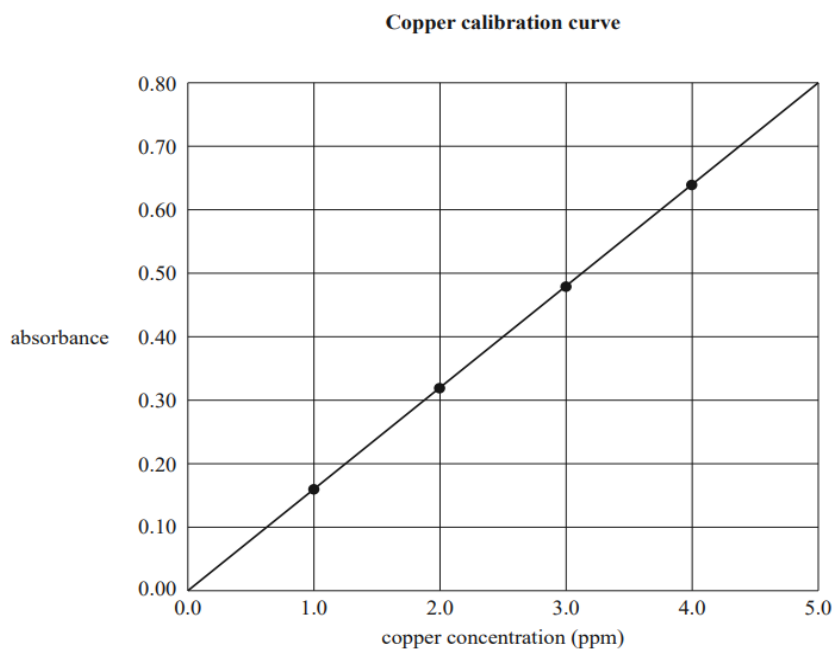


The acid and base used could have been

- A. H_2SO_4 and $\text{Ba}(\text{OH})_2$
- B. H_2SO_4 and NH_3
- C. CH_3COOH and NH_3
- D. CH_3COOH and $\text{Ba}(\text{OH})_2$

20

An atomic absorption spectrometer can be used to determine the level of copper in soils. The calibration curve below plots the absorbance of four standard copper solutions against the concentration of copper ions in ppm. The concentrations of copper ions in the standard solutions were 1.0, 2.0, 3.0 and 4.0 mg L^{-1} . ($1 \text{ mg L}^{-1} = 1 \text{ ppm}$)



If the test solution gave an absorbance reading of 0.40, what would be the concentration of copper ions in the solution in mol L^{-1} ?

- A. 2.5
- B. 3.9×10^{-2}
- C. 3.9×10^{-5}
- D. 2.5×10^{-6}

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Chemistry

Student Number:.....

Section II – 80 marks

Attempt Questions 21-30

Allow about 2 hours and 25 minutes for this section.

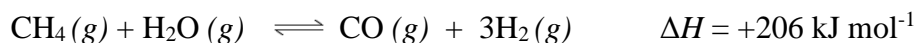
Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.

Show all relevant working in questions involving calculations.

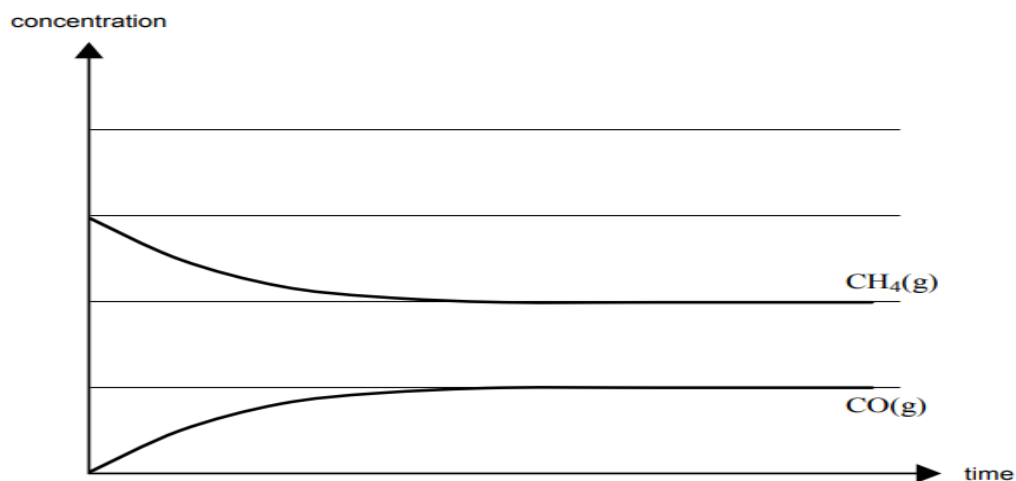
Extra writing space is provided on pages 31 and 32. If you use this space, clearly indicate which question you are answering.

Question 21 (8 marks)

Carbon monoxide and hydrogen can be produced from the reaction of methane with steam, according to the equation:



Some methane and steam were placed in a closed container and allowed to react at a fixed temperature. The following graph shows the changes in concentration of methane and carbon monoxide as the reaction progresses.



- (a) On the graph above, draw a line to predict the change in concentration of hydrogen gas as the reaction progresses. Label this line. 2

Explain why you have drawn the line in this position.

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- (b) On the graph above, draw a line to show how the formation of carbon monoxide would differ over time in the presence of a catalyst. Label this line. 2

Explain why you have drawn the line in this position.

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Question 21 continues on the next page

Question 21 (continued)

- (c) The rates of chemical reactions may be explained using the collision theory model. TWO of the following statements about rates and the collision theory model are INCORRECT.

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	Statement
I	All particles have the same kinetic energy at a fixed temperature.
II	Reactant particles need to collide with sufficient energy to react.
III	The rate of a reaction at a constant temperature increases as the reaction proceeds.
IV	Increasing the temperature increases the fraction of collisions with energy above the activation energy.

Indicate which of the four statements (I – IV) are INCORRECT.

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For each of the nominated INCORRECT statements, explain why it is incorrect.

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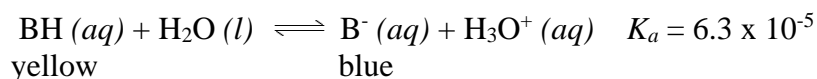
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Question 22 (5 marks)

Bromophenol blue is a weak acid (represented as BH) that acts as an acid-base indicator. In solution the following equilibrium is established.



At low pH, bromophenol blue exists mainly as the acid, BH, which is yellow in colour, while at high pH it exists mainly as its conjugate base, B⁻, which is blue. An intermediate colour is observed when the concentration of the acid and the concentration of the conjugate base are similar.

- (a) Write an expression for K_a in terms of the concentrations of BH, B⁻ and H⁺. **1**

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- (b) When [BH] = [B⁻], the mixture appears green. Calculate the pH at which [BH] = [B⁻]. **1**

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- (c) Calculate the ratio [B⁻]/[BH] when the pH of a solution of bromophenol blue is 7. **1**

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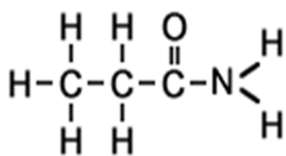
- (d) What colour will the indicator solution appear at pH 7? Justify your answer, based on your responses to parts (b) and (c) above. **2**

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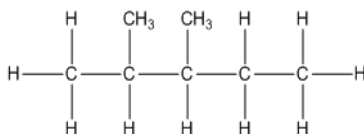
Question 23 (10 marks)

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

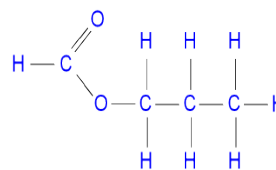
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Compound 1



Compound 2



Compound 3

Compound 1

Compound 2

Compound 3

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

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Question 23 continues on the next page

Question 23 (continued)

- (c) Compound 3 (in part (a) above) will react with a solution of sodium hydroxide. **3**
Compare this reaction with saponification of a fat. Include equations for both reactions.

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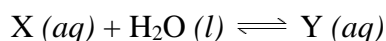
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Question 24 (13 marks)

- (a) When the substance CH_3CHO (substance X) is dissolved in water it reacts to form an equilibrium mixture with $\text{CH}_3\text{CH}(\text{OH})_2$ (substance Y) according to the equation **2**



The concentration of X can be determined using UV–Visible spectroscopy. X absorbs strongly at 290 nm. Y shows no absorbance at this wavelength.

In a particular experiment at 25°C, the relationship between absorbance at 290 nm and concentration of X (in mol L^{-1}) is given by:

$$\text{Absorbance} = 4.15 \times [\text{X}]$$

In the experiment, 0.110 mol of X is dissolved rapidly in 1.00 L of water at 25°C. The absorbance of the solution changes as some of the X is converted to Y. The table below shows the change in absorbance over time (measured in seconds).

Absorbance	0.430	0.303	0.270	0.255	0.250	0.250
Time (s)	6.00	60.0	90.0	120.0	240.0	480.0
[X] (mol L^{-1})						

Complete the table above by filling in the values for [X] for each absorbance reading.

- (b) What is the concentration of X, in mol L^{-1} , when the reaction reached equilibrium? **1**

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- (c) Calculate the percentage of the original 0.110 mol of X that has been converted into Y at equilibrium. **2**

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- (d) The average rate of a reaction can be determined by calculating the change in concentration of a reactant per second. Calculate the average rate, in M/s, at which the concentration of X changed during the first 6.00 s of the reaction. **2**

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Question 24 continues on the next page

Question 24 (continued)

- (e) Draw structural formulae for compounds X and Y and identify the functional groups in each of X and Y. **2**

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- (f) Summarise the process of UV–Visible spectroscopy and its relationship to Beer’s Law (given on the data sheet). Use substance X as an example in your response. **4**

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Question 25 (7 marks)

- (a) Using the data provided on the data pages, calculate the solubility in water of lead (II) carbonate at 25°C. **2**
Show your calculations and reasoning.

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- (b) Quantitatively compare the solubility of lead (II) carbonate in water with its solubility in a 0.10 mol/L solution of lead (II) nitrate, at 25°C. **2**

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- (c) 25 mL of 0.015 M lead (II) nitrate solution and 50 mL of 0.0030 M sodium carbonate solution are mixed. Does precipitation of lead (II) carbonate occur? **3**
Show your calculations and explain your reasoning.

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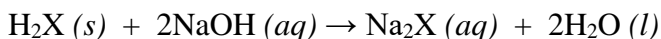
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Question 26 (5 marks)

0.415 g of a pure acid, $\text{H}_2\text{X}(s)$, is added to exactly 100 mL of 0.105 M $\text{NaOH}(aq)$.
A reaction occurs according to the equation:



The NaOH is in excess. This excess NaOH requires 25.21 mL of 0.197 M $\text{HCl}(aq)$ for neutralisation.

- (a) Calculate the amount, in moles, of NaOH that is added to the acid H_2X initially. **1**

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- (b) Calculate the amount, in moles, of NaOH that reacts with the acid H_2X . **2**

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- (c) Calculate the molar mass, in g mol^{-1} , of the acid H_2X . **2**

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Question 27 (10 marks)

The table shows acid dissociation constants at 25°C.

Acid	Formula	K_a
Nitrous	HNO_2	7.2×10^{-4}
Hydrofluoric	HF	6.6×10^{-4}
Hydrocyanic	HCN	6.2×10^{-10}
Propanoic	$\text{CH}_3\text{CH}_2\text{COOH}$	1.34×10^{-5}
Chlorous	HClO_2	1.1×10^{-2}

- (a) Identify the weakest acid in the table and determine the $\text{p}K_a$ value for this acid at 25°C. 2

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- (b) Identify the weakest base formed from these acids. What is the $\text{p}K_b$ for this base at 25°C? 2

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- (c) Calculate the pH of a 0.010 M solution of propanoic acid at 25°C. 2

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Question 27 continues on the next page

Question 27 (continued)

- (d) A buffer solution is prepared by combining 100 mL of 0.010 M nitrous acid and 80 mL of 0.010 M NaNO_2 . **4**

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

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Question 28 (10 marks)

(a) Draw structures for THREE isomers of C_4H_8O and name these compounds.

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(b) Describe the reactions which could be carried out in the laboratory to form each of these THREE compounds from the appropriate alkanols. Draw structural formulae for the alkanols used in each of the reactions.

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Question 28 continues on the next page

Question 28 (continued)

- (c) How could you distinguish between the THREE isomers drawn in part (a), using either chemical reactions or spectroscopy or a combination of both?

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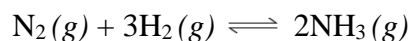
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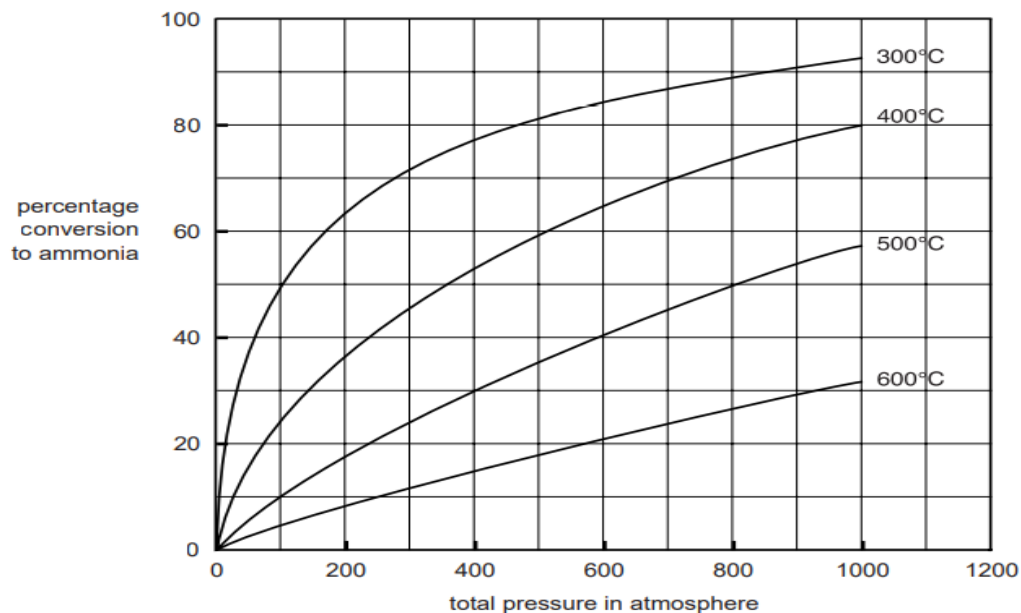
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Question 29 (5 marks)

Ammonia is prepared industrially from hydrogen and nitrogen in the presence of a suitable catalyst according to the equation:



The graph below shows the variation of the equilibrium yield of ammonia with pressure at different temperatures.



- (a) A particular industrial plant uses a pressure of 300 atm and a temperature of 500°C. From the graph, determine the percentage yield of ammonia under these conditions.

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- (b) Deduce from the graph whether the production of ammonia from hydrogen and nitrogen is an exothermic or an endothermic reaction. Explain your reasoning.

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Question 29 continues on the next page

Question 29 (continued)

- (c) Temperatures less than 400°C are not used for this industrial reaction. Give a possible reason why this is so. **1**

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- (d) Iron on the surface of iron oxide is used as a catalyst in this industrial process. Explain how this affects the economic viability of the industrial process. **1**

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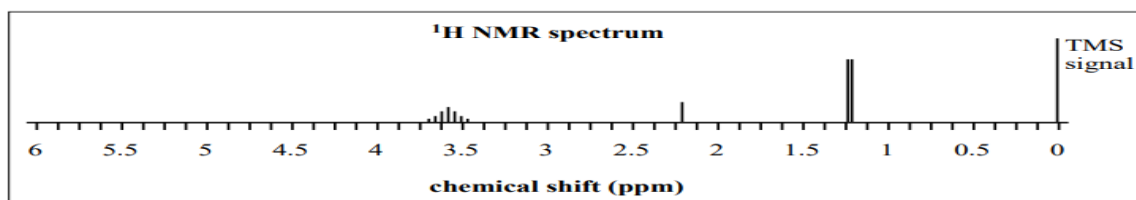
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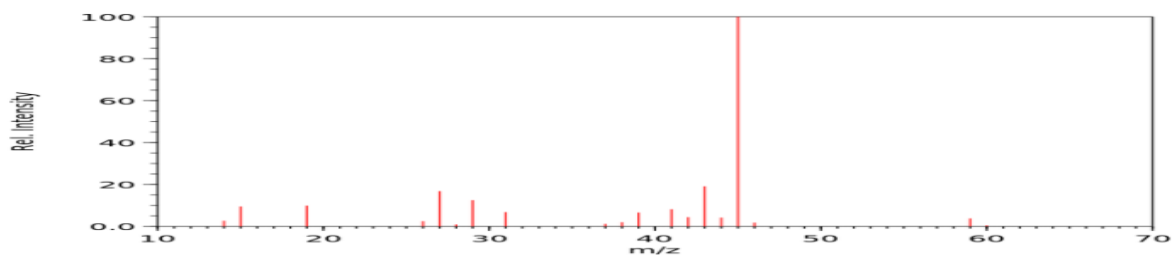
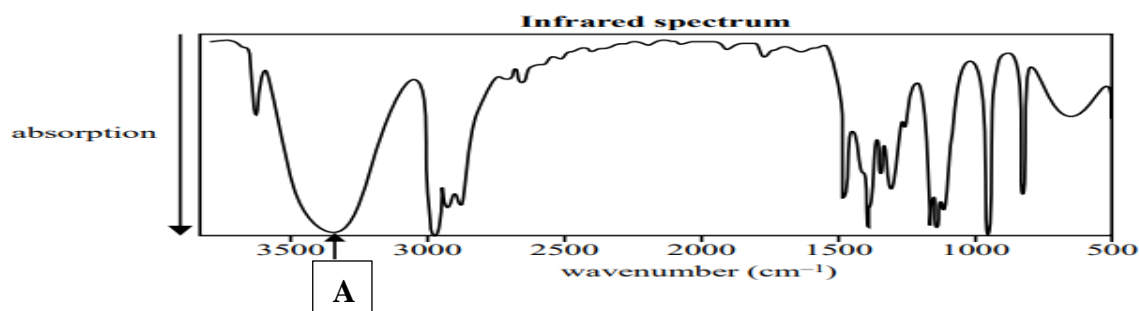
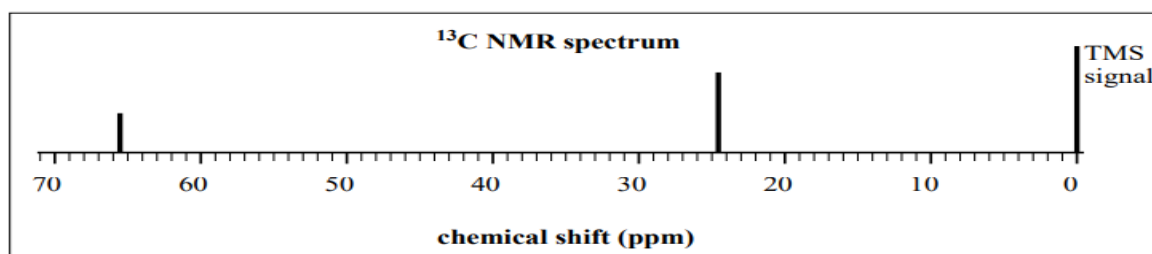
Question 30 (7 marks)

An organic chemist found a bottle in the laboratory that was labelled “organic cleaning fluid”. Chemical tests showed the empirical formula of the compound to be C_3H_8O .

The chemist obtained spectral data about the compound in the cleaning fluid. The 1H NMR and ^{13}C NMR spectra, the infrared spectrum and the mass spectrum are shown below. The 1H NMR data is summarised in the table below the spectrum.



Chemical shift (ppm)	Relative peak area	Peak splitting
1.2	6	doublet (2)
2.2	1	singlet (1)
3.6	1	septet (7)



Question 30 continues on the next page

Question 30 (continued)

- (a) How many different carbon environments are present in the compound? **1**

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- (b) How many different hydrogen environments are present in the compound? **1**

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- (c) In the ^1H NMR spectrum, the signal at 3.6 ppm is split into a septet (7 peaks). What is the number of equivalent protons that are bonded to the adjacent carbon atom(s)? **1**

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- (d) Using the Infrared absorption data on the data pages, identify the atoms that are associated with the absorption labelled A on the infrared spectrum. **1**

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- (e) What conclusions can you draw about the structure of the compound from your answers to parts (a) to (d)? **1**

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- (f) From the mass spectrum, what causes the small peak at $m/z = 59$? **1**

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- (g) Draw the most likely structure of the “cleaning fluid”. **1**

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Section II - Extra writing space

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Section II - Extra writing space

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Student Number:.....

HSC CHEMISTRY TRIAL EXAM – MULTIPLE-CHOICE ANSWER SHEET

ATTEMPT ALL QUESTIONS

Question	1	A <input type="radio"/>	B <input type="radio"/>	C <input type="radio"/>	D <input type="radio"/>
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	13	A <input type="radio"/>	B <input type="radio"/>	C <input type="radio"/>	D <input type="radio"/>
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	19	A <input type="radio"/>	B <input type="radio"/>	C <input type="radio"/>	D <input type="radio"/>
	20	A <input type="radio"/>	B <input type="radio"/>	C <input type="radio"/>	D <input type="radio"/>

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Chemistry

FORMULAE SHEET

$$n = \frac{m}{MM}$$

$$q = mc\Delta T$$

$$pK_a = -\log_{10}[K_a]$$

$$c = \frac{n}{V}$$

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

$$A = \epsilon lc = \log_{10} \frac{I_o}{I}$$

$$PV = nRT$$

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

Avogadro constant, N_A $6.022 \times 10^{23} \text{ mol}^{-1}$

Volume of 1 mole ideal gas: at 100 kPa and

at 0°C (273.15 K) 22.71 L

at 25°C (298.15 K) 24.79 L

Gas constant $8.314 \text{ J mol}^{-1} \text{ K}^{-1}$

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

Specific heat capacity of water $4.18 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

DATA SHEET

Solubility constants at 25°C


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

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

Infrared absorption data

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

¹³C NMR chemical shift data

Type of carbon	δ/ppm
$\begin{array}{c} \quad \\ -C-C- \\ \quad \end{array}$	5–40
$\begin{array}{c} \\ R-C-Cl \text{ or } Br \\ \end{array}$	10–70
$\begin{array}{c} \quad \\ R-C-C- \\ \quad \\ O \end{array}$	20–50
$\begin{array}{c} \\ R-C-N \\ \end{array}$	25–60
$\begin{array}{c} \\ -C-O- \\ \end{array}$ alcohols, ethers or esters	50–90
$\begin{array}{c} \diagup \quad \diagdown \\ C=C \\ \diagdown \quad \diagup \end{array}$	90–150
$R-C \equiv N$	110–125
	110–160
$\begin{array}{c} R-C- \\ \\ O \end{array}$ esters or acids	160–185
$\begin{array}{c} R-C- \\ \\ O \end{array}$ aldehydes or ketones	190–220

UV absorption

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

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

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

Some standard potentials

$\text{K}^+ + \text{e}^-$	\rightleftharpoons	$\text{K}(s)$	-2.94 V
$\text{Ba}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ba}(s)$	-2.91 V
$\text{Ca}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ca}(s)$	-2.87 V
$\text{Na}^+ + \text{e}^-$	\rightleftharpoons	$\text{Na}(s)$	-2.71 V
$\text{Mg}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Mg}(s)$	-2.36 V
$\text{Al}^{3+} + 3\text{e}^-$	\rightleftharpoons	$\text{Al}(s)$	-1.68 V
$\text{Mn}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Mn}(s)$	-1.18 V
$\text{H}_2\text{O} + \text{e}^-$	\rightleftharpoons	$\frac{1}{2}\text{H}_2(g) + \text{OH}^-$	-0.83 V
$\text{Zn}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Zn}(s)$	-0.76 V
$\text{Fe}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Fe}(s)$	-0.44 V
$\text{Ni}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Ni}(s)$	-0.24 V
$\text{Sn}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Sn}(s)$	-0.14 V
$\text{Pb}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Pb}(s)$	-0.13 V
$\text{H}^+ + \text{e}^-$	\rightleftharpoons	$\frac{1}{2}\text{H}_2(g)$	0.00 V
$\text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	$\text{SO}_2(aq) + 2\text{H}_2\text{O}$	0.16 V
$\text{Cu}^{2+} + 2\text{e}^-$	\rightleftharpoons	$\text{Cu}(s)$	0.34 V
$\frac{1}{2}\text{O}_2(g) + \text{H}_2\text{O} + 2\text{e}^-$	\rightleftharpoons	2OH^-	0.40 V
$\text{Cu}^+ + \text{e}^-$	\rightleftharpoons	$\text{Cu}(s)$	0.52 V
$\frac{1}{2}\text{I}_2(s) + \text{e}^-$	\rightleftharpoons	I^-	0.54 V
$\frac{1}{2}\text{I}_2(aq) + \text{e}^-$	\rightleftharpoons	I^-	0.62 V
$\text{Fe}^{3+} + \text{e}^-$	\rightleftharpoons	Fe^{2+}	0.77 V
$\text{Ag}^+ + \text{e}^-$	\rightleftharpoons	$\text{Ag}(s)$	0.80 V
$\frac{1}{2}\text{Br}_2(l) + \text{e}^-$	\rightleftharpoons	Br^-	1.08 V
$\frac{1}{2}\text{Br}_2(aq) + \text{e}^-$	\rightleftharpoons	Br^-	1.10 V
$\frac{1}{2}\text{O}_2(g) + 2\text{H}^+ + 2\text{e}^-$	\rightleftharpoons	H_2O	1.23 V
$\frac{1}{2}\text{Cl}_2(g) + \text{e}^-$	\rightleftharpoons	Cl^-	1.36 V
$\frac{1}{2}\text{Cr}_2\text{O}_7^{2-} + 7\text{H}^+ + 3\text{e}^-$	\rightleftharpoons	$\text{Cr}^{3+} + \frac{7}{2}\text{H}_2\text{O}$	1.36 V
$\frac{1}{2}\text{Cl}_2(aq) + \text{e}^-$	\rightleftharpoons	Cl^-	1.40 V
$\text{MnO}_4^- + 8\text{H}^+ + 5\text{e}^-$	\rightleftharpoons	$\text{Mn}^{2+} + 4\text{H}_2\text{O}$	1.51 V
$\frac{1}{2}\text{F}_2(g) + \text{e}^-$	\rightleftharpoons	F^-	2.89 V

PERIODIC TABLE OF THE ELEMENTS

PERIODIC TABLE OF THE ELEMENTS																	
KEY																	
Atomic Number Symbol Standard Atomic Weight Name																	
79 Au 197.0 Gold																	
4 Be 9.012 Beryllium																	
12 Mg 24.31 Magnesium																	
20 Ca 40.08 Calcium																	
21 Sc 44.96 Scandium																	
22 Ti 47.87 Titanium																	
23 V 50.94 Vanadium																	
24 Cr 52.00 Chromium																	
25 Mn 54.94 Manganese																	
26 Fe 55.85 Iron																	
27 Co 58.93 Cobalt																	
28 Ni 58.69 Nickel																	
29 Cu 63.55 Copper																	
30 Zn 65.38 Zinc																	
31 Ga 69.72 Gallium																	
32 Ge 72.64 Germanium																	
33 As 74.92 Arsenic																	
34 Se 78.96 Selenium																	
35 Br 79.90 Bromine																	
36 Kr 83.80 Krypton																	
37 Rb 85.47 Rubidium																	
38 Sr 87.61 Strontium																	
39 Y 88.91 Yttrium																	
40 Zr 91.22 Zirconium																	
41 Nb 92.91 Niobium																	
42 Mo 95.96 Molybdenum																	
43 Tc Technetium																	
44 Ru 101.1 Ruthenium																	
45 Rh 102.9 Rhodium																	
46 Pd 106.4 Palladium																	
47 Ag 107.9 Silver																	
48 Cd 112.4 Cadmium																	
49 In 114.8 Indium																	
50 Sn 118.7 Tin																	
51 Sb 121.8 Antimony																	
52 Te 127.6 Tellurium																	
53 I 126.9 Iodine																	
54 Xe 131.3 Xenon																	
55 Cs 132.9 Cesium																	
56 Ba 137.3 Barium																	
57-71 Lanthanoids																	
72 Hf 178.5 Hafnium																	
73 Ta 180.9 Tantalum																	
74 W 183.9 Tungsten																	
75 Re 186.2 Rhenium																	
76 Os 190.2 Osmium																	
77 Ir 192.2 Iridium																	
78 Pt 195.1 Platinum																	
79 Au 197.0 Gold																	
80 Hg 200.6 Mercury																	
81 Tl 204.4 Thallium																	
82 Pb 207.2 Lead																	
83 Bi 209.0 Bismuth																	
84 Po Astatine																	
85 At Polonium																	
86 Rn Radon																	
87 Fr Francium																	
88 Ra Radium																	
89-103 Actinoids																	
104 Rf Rutherfordium																	
105 Db Dubnium																	
106 Sg Seaborgium																	
107 Bh Bohrium																	
108 Hs Hassium																	
109 Mt Meitnerium																	
110 Ds Darmstadtium																	
111 Rg Roentgenium																	
112 Cn Copernicium																	
113 Uut Ununtrium																	
114 Fl Flerovium																	
115 Uup Ununpentium																	
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Lanthanoids

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

Actinoids

89	Ac	227.0	Actinium
90	Th	232.0	Thorium
91	Pa	231.0	Protactinium
92	U	238.0	Uranium
93	Np		Neptunium
94	Pu		Plutonium
95	Am		Americium
96	Cm		Curium
97	Bk		Berkelium
98	Cf		Californium
99	Es		Einsteinium
100	Fm		Fermium
101	Md		Mendelevium
102	No		Nobelium
103	Lr		Lawrencium

Standard atomic weights are abridged to four significant figures.

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

Information on elements with atomic numbers 113 and above is sourced from the International Union of Pure and Applied Chemistry Periodic Table of the Elements (January 2016 version). The International Union of Pure and Applied Chemistry Periodic Table of the Elements (February 2010 version) is the principal source of all other data. Some data may have been modified.

2022 Higher School Certificate Chemistry Trial Examination

Mapping Grid

Section I

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

Disclaimer

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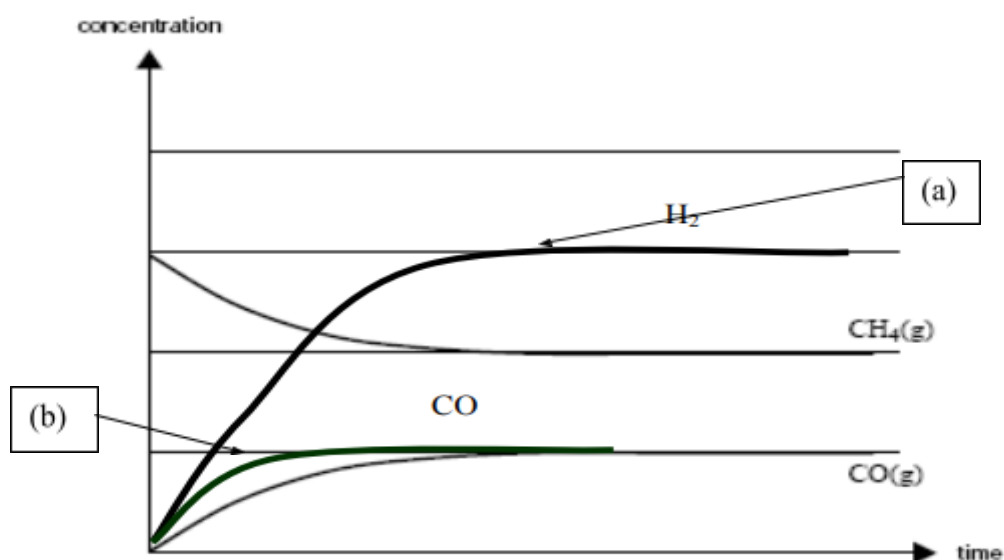
Explanations for Multiple-Choice	
1	B A catalyst lowers the activation energy both of the forward and reverse reactions by the same amount.
2	A NH_4^+ is acidic. KCl solution is neutral as neither K^+ nor Cl^- react with water so the pH of water stays at close to 7. NH_3 and $\text{Ba}(\text{OH})_2$ are bases so produce OH^- in solution and $\text{pH} > 7$.
3	B Peaks on a mass spectrum are associated with positive ions – both parent molecular and fragment. These are the species deflected and separated in the magnetic field.
4	C Members of the same homologous series have similar chemical properties because they have the same functional group and only differ in the length of carbon chain. Because they differ in length of chain and mass, they have different physical properties and different intermolecular forces.
5	B They are both weak acids, so the equilibria both lie to the left. Since methanoic acid is the stronger of the 2 acids, it will dissociate to a greater extent than ethanoic acid. Hence the species in lowest concentration will be ethanoate ions.
6	C Both statements II and III are correct. The dynamic equilibrium will mean the radioactive atoms will be both in solid and solution after time has elapsed. No more solid will dissolve than previously so after addition of additional solid, more will be present in the beaker. The solution will still be saturated so the concentration of ions will still be the same as previously if the temperature is constant.
7	A The chain is numbered from the RHS, to give the lowest number to the carbon where the first branch occurs. (Note the change in IUPAC rules over the past few decades.) The chlorine must be written before the methyl groups according to the alphabetical order rules.
8	D Ba^{2+} , Pb^{2+} and Ca^{2+} all form sulfate and carbonate precipitates. Mg^{2+} forms a precipitate with carbonate ions but not with sulfate ions.
9	A NMR spectroscopy determines numbers of atoms, not concentration. IR spectroscopy indicates functional groups present and mass spectrometry indicates the structure of the species. For both AAS and UV–visible spectroscopy the absorbance is proportional to concentration.
10	C

	Propan-1-ol will not react with sodium hydroxide (the –OH group is NOT basic). Propanoic acid undergoes neutralisation with sodium hydroxide and 1-chloropropane undergoes a substitution reaction with sodium hydroxide to form propan-1-ol.
11	<p>C</p> $K_{eq} = [\text{SO}_3] [\text{NO}] / [\text{SO}_2] [\text{NO}_2] = 33$ <p>If x mol SO₃ form, then</p> $K_{eq} = (x)(x) / (0.1 - x)(0.1 - x) = x^2 / (0.1 - x)^2$ <p>Taking the square root of each side</p> $\sqrt{33} = x / 0.1 - x$ $5.75 = x / 0.1 - x$ $x = 0.574 / 6.74 = 0.085 \text{ mol/L}$
12	<p>A</p> <p>The compound must be an alkene. It must contain 4 carbon atoms, as 2 moles of the compound form 8 moles of CO₂.</p>
13	<p>C</p> <p>Since pH = 12, the [OH⁻] = 0.01 mol/L</p> <p>Hence 0.01 moles HCl gas would be required to bring the pH to 7.</p> <p>To further drop the pH to 2, then the final acid concentration must be 0.01 mol/L.</p> <p>Hence a total of 0.02 moles HCl gas is needed.</p>
14	<p>A</p> <p>Water in the titration flask will not change the no. of moles of NaOH present. If the burette is rinsed with water, the concentration of the acid is reduced so the titre would need to be greater to neutralise the NaOH. If the pipette transferring the NaOH had been rinsed with water, there would have been a smaller no. of moles of NaOH in the 20.0 mL aliquot, so the titre required for neutralisation would have been less than 25.0 mL. If the titration flask had been rinsed with acid, some of the NaOH would have been already neutralised and hence the titre would be less than 25.0 mL.</p>
15	<p>D</p> <p>Experiment 2 has a higher initial rate of reaction and so occurs at the higher temperature. Experiment 1 produces more HI by the time equilibrium is established, so the forward reaction is favoured at lower temperatures, indicating that the reaction is exothermic.</p>
16	<p>B</p> <p>During polymerisation, the carboxyl (–COOH) group on one molecule will react with the hydroxyl (–OH) group on an adjacent molecule in a condensation reaction. For each <i>n</i> monomers that react to form the polymer chain, (<i>n</i>–1) ester groups are formed and (<i>n</i>–1) H₂O molecules are condensed out.</p> <p>The relative molecular mass of the polymer chain will be (1000 × 104) – (999 × 18) = 86018</p> <p>So the approximate molar mass of the polymer is 86000 g mol⁻¹.</p>

17	<p>B</p> $\begin{array}{c} \text{H} & & \text{O} & & \text{H} \\ & & & & \\ \text{H}-\text{C}- & \text{C}- & \text{C}-\text{H} \\ & & \\ \text{H} & & \text{H} \end{array}$ <p>Propanone</p> <p>It has 2 ^{13}C NMR peaks (2 identical CH_3 groups result in a single peak) and 1 ^1H NMR peak (all 6 H atoms in the same environment and hence only 1 peak).</p> <p>Butan-1-ol has 4 carbon environments (hence 4 peaks) and 5 hydrogen environments (5 peaks). Propan-2-ol has 2 different carbon environments and 3 hydrogen environments. Ethanol has 2 carbon environments and 3 hydrogen environments.</p>
18	<p>D</p> <p>The least soluble will precipitate first and the most soluble last. The smaller the K_{sp} value the less soluble the salt. All 3 salts have the same number of ions (1 cation to 2 fluoride ions). Hence the order is CaF_2, BaF_2, PbF_2.</p>
19	<p>A</p> <p>The strong conductance before and after the equivalence point indicates a strong acid and strong base. The almost zero conductance at the equivalence point is because the BaSO_4 precipitate will have removed the ions from solution.</p>
20	<p>C</p> <p>According to the calibration curve, absorbance of 0.40 corresponds to $[\text{Cu}]$ of $2.5 \text{ ppm} = 2.5 \text{ mg L}^{-1} = 2.5 \times 10^{-3} \text{ g L}^{-1}$ $= (2.5 \times 10^{-3}) / 63.5 \text{ mol L}^{-1} = 3.9 \times 10^{-5} \text{ mol L}^{-1}$</p>

Section II – 80 marks

Question 21 (8 marks)



21 (a) (2 marks)

Criteria	Marks
<ul style="list-style-type: none"> Draws a line labelled (a) above AND <ul style="list-style-type: none"> Explains that 3 moles of hydrogen are formed when 1 mole of CO forms 	2
<ul style="list-style-type: none"> Draws a line labelled (a) above OR <ul style="list-style-type: none"> Explains that 3 moles of hydrogen are formed when 1 mole of CO forms 	1

Sample answer

Because of the mole ratio in the equation, the amount of H_2 produced must be 3 x the amount of CO produced. The line should show the $[\text{H}_2]$ reaching equilibrium at the same elapsed time as CO and CH_4 gases.

21 (b) (2 marks)

Criteria	Marks
<ul style="list-style-type: none"> Draws a line labelled (b) above AND <ul style="list-style-type: none"> Explains that the rate of formation of CO is faster when a catalyst is present but the same amount of CO is formed 	2
<ul style="list-style-type: none"> Draws a line labelled (b) above OR <ul style="list-style-type: none"> Explains that the rate of formation of CO is faster when a catalyst is present but the same amount of CO is formed 	1

Sample answer

The line drawn (b) should show a steeper slope / faster rate of reaction when a catalyst is present but the same amount of CO should be formed as for the uncatalysed reaction. (Note that both backward and forward reaction rates would have increased – not just that of the CO production.)

21 (c) (4 marks)

Criteria	Marks
<ul style="list-style-type: none"> Indicates that BOTH statements I and III are INCORRECT For each of reactions I and III, explains clearly why the statement is incorrect 	4
<ul style="list-style-type: none"> Indicates that BOTH statements I and III are INCORRECT For ONE of reactions I and III, explains clearly why the statement is incorrect 	3
<ul style="list-style-type: none"> Indicates that ONE of statements I and III is INCORRECT Explains clearly why the statement is incorrect 	2
<ul style="list-style-type: none"> Indicates that ONE of statements I and III is INCORRECT but does not provide a clear explanation 	1

Sample answer (marks only to be awarded for correctly recognising incorrect statements).
 Statements I and III are incorrect.

Statement I is incorrect as not all particles have the same kinetic energy at a fixed temperature. All particles have the same average kinetic energy at a fixed temperature but there will be a wide range of speeds. The particles in a gas sample collide and hence change speed. At a given temperature, not all particles have the same kinetic energy nor will be moving at the same speed. It is the average kinetic energy which is proportional to temperature (K).

Statement III is incorrect as the rate of reaction decreases as the reaction proceeds. The rate of reaction depends on the concentration of the reactants. As the reactants are consumed the rate of combination decreases.

Question 22 (5 marks)

22 (a) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answer

$$K_a = \frac{[\text{B}^-][\text{H}_3\text{O}^+]}{[\text{BH}]}$$

22 (b) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answerSince $[\text{B}^-] = [\text{BH}]$ Then $K_a = [\text{H}_3\text{O}^+] = 6.3 \times 10^{-5}$ $\text{pH} = -\log_{10}(6.3 \times 10^{-5}) = 4.20$

22 (c) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answerWhen $\text{pH} = 7$ $[\text{H}_3\text{O}^+] = 1.0 \times 10^{-7}$ Then $K_a = \frac{[\text{B}^-](1.0 \times 10^{-7})}{[\text{BH}]} = 6.3 \times 10^{-5}$

$$\frac{[\text{B}^-]}{[\text{BH}]} = \frac{6.3 \times 10^{-5}}{1.0 \times 10^{-7}} = 6.3 \times 10^2$$

22 (d) (2 marks)

Criteria	Marks
<ul style="list-style-type: none">The indicator solution will be blue AND <ul style="list-style-type: none">Uses evidence from answers (b) and (c) to predict the blue colour	2
<ul style="list-style-type: none">Justifies the answer given, using some correct information from parts (b) and (c)	1

Sample answer

From part (c), at pH = 7, since $[B^-] = 630 \times [BH]$, the blue colour will dominate.

From part (b), at pH = 4.2, the transition from blue to yellow occurs.

Note that the question stated that “an intermediate colour is observed when the concentration of the acid and the concentration of the conjugate base are similar”; i.e. close to pH = 4.2. At this pH the solution would be green.

Question 23 (10 marks)

23 (a) (3 marks)

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

Sample answer

Compound 1 = propanamide

Compound 2 = 2,3-dimethylpentane

Compound 3 = 1-propyl methanoate

23 (b) (4 marks)

Criteria	Marks
<ul style="list-style-type: none"> Predicts the correct order of boiling points (Compound 2, Compound 3, Compound 1) Explains thoroughly the impact of the different intermolecular forces Identifies that Compound 1 has very strong hydrogen bonding Identifies that Compound 2 has dispersion (temporary dipole-dipole) forces only Identifies that Compound 3 has dipole-dipole bonding 	4
<ul style="list-style-type: none"> Predicts the correct order of boiling points Explains thoroughly the impact of the different intermolecular forces Identifies the intermolecular forces in 2 of the 3 compounds 	3
<ul style="list-style-type: none"> TWO of: <ul style="list-style-type: none"> Predicts the correct order of boiling points Explains the impact of the different intermolecular forces Identifies the intermolecular forces in 2 of the 3 compounds 	2
<ul style="list-style-type: none"> ONE of: <ul style="list-style-type: none"> Predicts the correct order of boiling points Explains the impact of the different intermolecular forces Identifies the intermolecular forces in 1 of the 3 compounds 	1

Sample answer

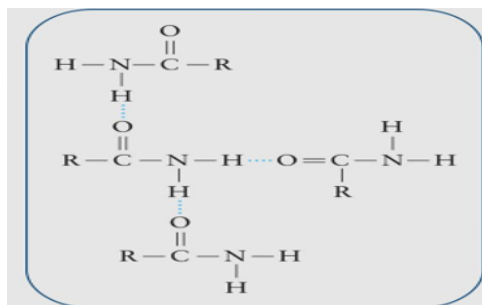
The order of increasing boiling points is Compound 2, Compound 3, Compound 1.

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

Compound 2 is non-polar and has only weak intermolecular forces (dispersion or temporary dipole-dipole forces) caused by the electrical interaction of molecules as they collide (protons from 1 molecule being attracted to electrons from the other as the molecules are temporarily distorted on collision). (Boiling point 58°C)

Compound 1 is polar and would experience very strong hydrogen bonding forces, as well as weaker temporary and permanent dipolar forces) as molecules interact. These are strong intermolecular forces as hydrogen bonds can also form between the oxygen of 1 molecule and the hydrogen of the -NH_2 group. The geometry of the molecules allows more than 1 H-bond

per molecule at any instant. Propanamide has a boiling point of 213°C and is a solid at room temperature. This boiling point is higher than that of Compound 3, an ester which does not exhibit hydrogen bonding between neighbouring molecules.



Compound 3 is an ester. It is a polar molecule with dipole-dipole interactions but has no hydrogen bonding. (Boiling point 102°C)

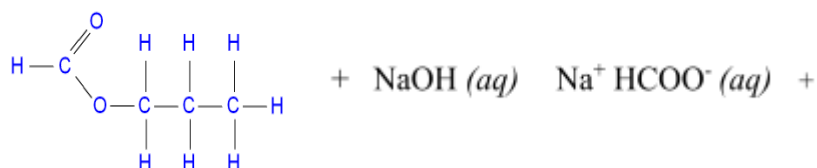
Hence the intermolecular forces and thus boiling points are highest in Compound 1 and lowest in Compound 2.

23 (c) (3 marks)

Criteria	Marks
<ul style="list-style-type: none"> Compares alkaline hydrolysis of 1-propyl methanoate with saponification Writes a correct equation for the alkaline hydrolysis of the ester Writes a correct equation for the saponification of a lipid 	3
<ul style="list-style-type: none"> TWO of the above 	2
<ul style="list-style-type: none"> ONE of the above 	1

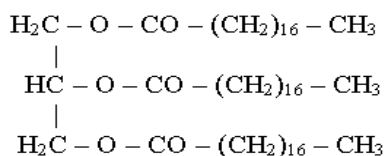
Sample answer

The 2 processes involve the same chemical reaction - the alkaline hydrolysis of esters. The alkaline hydrolysis of the ester 1-propyl methanoate produces sodium methanoate and propan-1-ol.

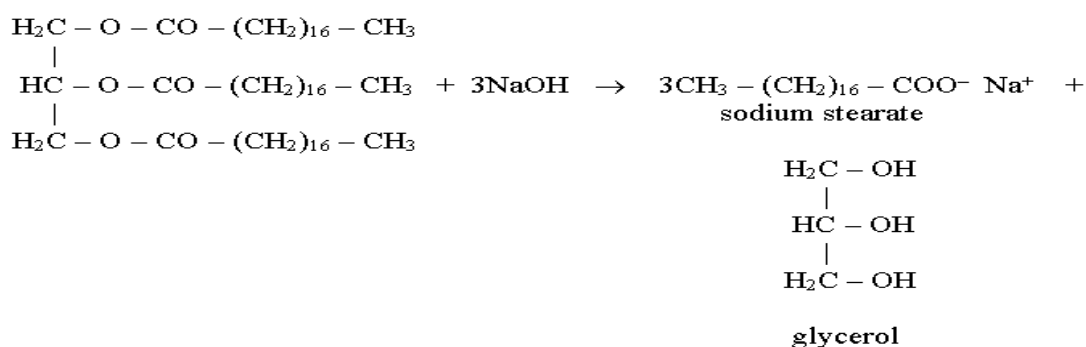


Hydrolysis of fats and oils produces glycerol and the sodium salt of the long-chain fatty acid, sodium stearate. The mixture is heated over a period of time and the solid soap formed is physically separated from the liquid glycerol. The soap must be separated from the by-product glycerol by adding salt (to separate the soap from the glycerol and water), filtering off the soap (or decanting the liquids).

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



The equation for the saponification of glyceryl tristearate,



Question 24 (13 marks)

24 (a) (2 marks)

Criteria	Marks
• Completes the table correctly	2
• Completes the table with at least 3 correct entries	1

Sample answer

Absorbance	0.430	0.303	0.270	0.255	0.250	0.250
Time (s)	6.00	60.0	90.0	120.0	240.0	480.0
[X] (mol L ⁻¹)	0.104	0.0730	0.0651	0.0614	0.0602	0.0602

24 (b) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answer

Equilibrium is reached when the concentration of X is constant, i.e. at 0.0602 mol L⁻¹.

24 (c) (2 marks)

Criteria	Marks
• Correct answer	2
• Calculates change in no. of moles of X	1

Sample answer

Moles of X at equilibrium = 0.0602

Moles of X initially = 0.110

Change in moles = 0.110 – 0.0602 = 0.0498 mol (the amount that has been converted into Y)

% original X converted into Y = (0.0498/0.110) x 100 = 45.3%

24 (d) (2 marks)

Criteria	Marks
• Correct answer	2
• Calculates change in no. of moles of X	1

Sample answer

[X] at 6.00 s = 0.104 mol L⁻¹

[X] initially = 0.110 mol L⁻¹

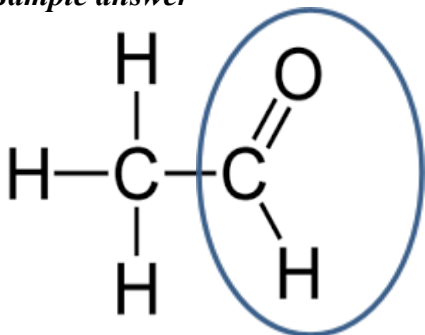
Change in concentration over 6.00 s = 0.110 – 0.104 = 0.006 mol L⁻¹

Hence average change in concentration of X per second = 0.006/6 = 0.001 M s⁻¹

24 (e) (2 marks)

Criteria	Marks
<ul style="list-style-type: none"> • Draws 2 correct formulae for X and Y AND <ul style="list-style-type: none"> • Identifies the functional groups both in X and Y 	2
<ul style="list-style-type: none"> • Draws 2 correct formulae OR <ul style="list-style-type: none"> • Identifies the functional groups both in X and Y OR <ul style="list-style-type: none"> • Draws 1 correct structure and identifies the functional group in that structure 	1

Sample answer



X Functional group = aldehyde

Y Functional group = alcohol

24 (f) (4 marks)

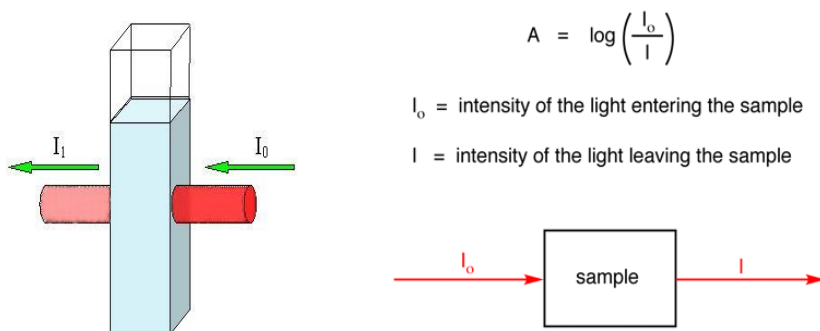
Criteria	Marks
<ul style="list-style-type: none"> Summarises a procedure to determine the concentration of X by use of UV-VIS spectroscopy Explains that the absorbance of light at a frequency of 290 nm (absorbed by the CHO functional group in X) is proportional to the concentration of X in the solution Includes reference to Beer's Law Includes some details of <ul style="list-style-type: none"> developing a calibration curve using solutions of known X concentration determination of the absorbance of the sample using the calibration curve 	4
<ul style="list-style-type: none"> Summarises a procedure to determine the concentration of X by use of UV-VIS spectroscopy Explains that the absorbance of light at a frequency of 290 nm (absorbed by the CHO functional group) is proportional to the concentration of X in the solution Includes reference to Beer's Law 	3
<ul style="list-style-type: none"> Explains that the absorbance of light at a frequency of 290 nm (absorbed by the CHO functional group) is proportional to the concentration of X in the solution Includes reference to Beer's Law 	2
<ul style="list-style-type: none"> Includes some correct information about UV-VIS spectroscopy 	1

Sample answer

A spectrophotometer is an instrument that can pass light of a single wavelength through a solution and measure the amount that passes through (is transmitted) and hence the amount of light absorbed (the absorbance).

Substance X containing a functional group ($-\text{CHO}$) is known to have a maximum absorbance at a particular wavelength of light (290 nm).

To measure absorbance, a beam of light at this frequency with intensity I_0 is aimed at the tested solution placed in a cuvette. The intensities of the entering beam (I_0) and the emerging beam (I) are measured, and the absorbance (A) is calculated from the ratio of the two.



The absorbance (A) is determined by Beer's Law (given on the data page)

$$A = \epsilon lc = \log_{10} \frac{I_0}{I}$$

The relationship tells us that the amount of light absorbed is:

- proportional to the concentration of the solution being tested (a linear relationship).
- proportional to the pathlength of light through the sample (the greater the distance the light moves through the sample, the greater the energy absorbed).

- a function of the difference in intensities of light entering (I_0) and leaving (I) the sample.

The spectrophotometer must be zeroed by passing light of the appropriate wavelength (290 nm for example) through a blank container (cuvette) containing only the solvent. Then, the same wavelength of light is passed through the solution in the same cuvette. The amount of light at 290 nm that is absorbed by the solution is called the absorbance at 290 nm and is abbreviated A_{290} .

A series of solutions containing known concentrations of X would then be placed in turn in the spectrometer and the absorbance measured.

A calibration curve would then be drawn. This would show a straight line, passing through zero. The straight line indicates that the absorbance is proportional to the concentration of X in the standards used for calibration.

The sample would then be tested using the same spectrometer and the absorbance measured. The calibration curve would then be used to determine the concentration of X in the unknown sample.

Question 25 (7 marks)

25 (a) (2 marks)

Criteria	Marks
• Correct answer, with correct units, showing correct working/reasoning	2
• Correct method and reasoning, with mathematical error	1

Sample answerLet the solubility of PbCO_3 be s .

$$K_{sp} \text{PbCO}_3 = 7.40 \times 10^{-14} = [\text{Pb}^{2+}] [\text{CO}_3^{2-}] = (s)^2$$

$$s^2 = 7.40 \times 10^{-14}$$

$$s = 2.72 \times 10^{-7} \text{ mol/L}$$

The solubility of PbCO_3 in water = $2.72 \times 10^{-7} \text{ mol/L}$

25 (b) (2 marks)

Criteria	Marks
• Correct conclusion based on correct calculations	2
• Correct calculation for the solubility of PbCO_3 in lead (II) nitrate solution	1

Sample answerLet the solubility of PbCO_3 in a 0.10 mol/L solution of lead (II) nitrate = x

$$K_{sp} \text{PbCO}_3 = [\text{Pb}^{2+}] [\text{CO}_3^{2-}] = (x + 0.10) (x) = 7.40 \times 10^{-14}$$

Since x is small by comparison with 0.10

$$K_{sp} \text{PbCO}_3 = [\text{Pb}^{2+}] [\text{CO}_3^{2-}] = (0.10) (x) = 7.40 \times 10^{-14}$$

$$x = 7.40 \times 10^{-14} / (0.10) = 7.4 \times 10^{-13} \text{ mol/L}$$

The solubility of PbCO_3 in 0.10 M Pb^{2+} = $7.4 \times 10^{-13} \text{ mol/L}$ The solubility of PbCO_3 in water = $2.72 \times 10^{-7} \text{ mol/L}$ (from part (a) above)Hence PbCO_3 is less soluble in a 0.10 mol/L solution of Pb^{2+} ion than in water.

25 (c) (3 marks)

Criteria	Marks
• Correct conclusion based on correct calculations	3
• Correct calculation for the $[\text{Pb}^{2+}] [\text{CO}_3^{2-}]$ after mixing	2
• Correct calculation of no. of moles of $\text{Pb}(\text{NO}_3)_2$ and Na_2CO_3	1

Sample answer

$$\text{No. of moles } \text{Pb}(\text{NO}_3)_2 = 0.015 \times (25/1000) = 3.75 \times 10^{-4}$$

$$\text{no. of moles } \text{Na}_2\text{CO}_3 = 0.0030 \times (50/1000) = 1.5 \times 10^{-4}$$

Total volume of solution = 75 mL

$$[\text{Pb}^{2+}] = 3.75 \times 10^{-4} / 0.075 = 5.0 \times 10^{-3} \text{ mol/L}$$

$$[\text{CO}_3^{2-}] = 1.5 \times 10^{-4} / 0.075 = 2.0 \times 10^{-3} \text{ mol/L}$$

The product of the concentration of the ions is

$$[\text{Pb}^{2+}] [\text{CO}_3^{2-}] = 5.0 \times 10^{-3} \times 2.0 \times 10^{-3} = 1.0 \times 10^{-5}$$

Since this product is greater than K_{sp} (7.40×10^{-14}), a precipitate will form.

Question 26 (5 marks)

26 (a) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answer

No. of moles of NaOH = $0.105 \times 100/1000 = 0.0105$ mol

26 (b) (2 marks)

Criteria	Marks
• Correct answer	2
• Correct no. of moles HCl reacted with excess NaOH	1

Sample answer

No. of moles of HCl reacting with excess NaOH = $0.197 \times 25.21/1000 = 0.004967$ mol

Hence no. of moles NaOH in excess = 0.004967 mol

Hence no. of moles of NaOH reacted with $H_2X = 0.0105 - 0.004967 = 0.005533$ mol NaOH

26 (c) (2 marks)

Criteria	Marks
• Correct molar mass of H_2X	2
• Correct no. of moles of H_2X	1

Sample answer

Since the pure acid H_2X is diprotic

No of moles of H_2X that reacted = $0.005533/2 = 0.0027665$

Hence 0.0027665 moles H_2X has a mass of 0.415 g

1 mole H_2X has a mass of $0.415/0.0027665$ g = 149.98 g

Molar mass to 3 s.f. = 150 g

Question 27 (10 marks)

27 (a) (2 marks)

Criteria	Marks
<ul style="list-style-type: none"> Identifies hydrocyanic acid as the weakest acid AND determines the pK_a value for hydrocyanic acid 	2
<ul style="list-style-type: none"> Identifies hydrocyanic acid as the weakest acid OR determines the pK_a value for the identified acid 	1

Sample answer

hydrocyanic acid

$pK_a = -\log_{10}(K_a) = -\log_{10}(6.2 \times 10^{-10}) = 9.21$ (2 s.f.) (same rule for s.f. in pK_a calculations as in pH; see below)

27 (b) (2 marks)

Criteria	Marks
<ul style="list-style-type: none"> Identifies the ClO_2^- (chlorite ion) as the weakest base AND determines the pK_b for this base 	2
<ul style="list-style-type: none"> Identifies the ClO_2^- (chlorite ion) as the weakest base OR determines the pK_b for the identified base 	1

Sample answer

HClO_2 (chlorous acid) forms the chlorite ion (ClO_2^-) as its conjugate base.

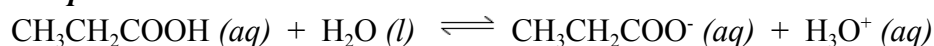
The strongest acid forms the weakest base.

For a conjugate acid-base pair:

$$pK_b = 14 - pK_a = 14.00 - 1.96 = 12.04$$

27 (c) (2 marks)

Criteria	Marks
<ul style="list-style-type: none"> Calculates the pH to 2 s.f. 	2
<ul style="list-style-type: none"> Shows some correct working and reasoning 	1

Sample answer

$$K_a \text{ CH}_3\text{CH}_2\text{COOH} = \frac{[\text{CH}_3\text{CH}_2\text{COO}^-][\text{H}_3\text{O}^+]}{[\text{CH}_3\text{CH}_2\text{COOH}]} = 1.34 \times 10^{-5}$$

Let x moles of $\text{CH}_3\text{CH}_2\text{COOH}$ ionise, forming x moles of H_3O^+

$$K_a \text{ CH}_3\text{CH}_2\text{COOH} = \frac{[x][x]}{[0.010 - x]} = 1.34 \times 10^{-5}$$

Assume x will be small by comparison with 0.010

$$\text{Hence } [x]^2 = 1.34 \times 10^{-5} \times 0.010 = 1.34 \times 10^{-7}$$

$$[\text{H}_3\text{O}^+] = \sqrt{(1.34 \times 10^{-7})} = 0.000366 \text{ mol/L}$$

$$\text{Hence pH} = -\log_{10}(0.000366) = 3.44 \text{ (2 s.f.)}$$

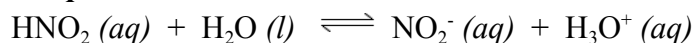
Note for teachers: In mathematical terms, the number to the left of the decimal point in a logarithm is called the characteristic and the number to the right of the decimal point is called

the mantissa. The mantissa has as many significant figures as the number from which the logarithm was determined. In this case there are 2 s.f. in the least accurate data given.
Hence $[\text{H}_3\text{O}^+] = 0.000366$ pH = 3.44

27 (d) (4 marks)

Criteria	Marks
<ul style="list-style-type: none"> Calculates the pH to 2 s.f. Explains why this mixture is classified as a buffer 	4
<ul style="list-style-type: none"> Calculates the pH with correct steps but mathematical error Explains why this mixture is classified as a buffer 	3
<ul style="list-style-type: none"> Determines the $[\text{H}_3\text{O}^+]$ in the buffer AND explains why this mixture is classified as a buffer 	2
<ul style="list-style-type: none"> Determines the $[\text{H}_3\text{O}^+]$ in the buffer OR explains why this mixture is classified as a buffer 	1

Sample answer



$$K_a \text{HNO}_2 = \frac{[\text{NO}_2^-][\text{H}_3\text{O}^+]}{[\text{HNO}_2]} = 7.2 \times 10^{-4}$$

$$\text{Initial } [\text{HNO}_2] = 0.010 \text{ mol/L}$$

$$\text{Initial } [\text{NO}_2^-] = 0.010 \text{ mol/L}$$

On mixing, the volume is increased to 180 mL

$$\text{After mixing, } [\text{HNO}_2] = 0.010 \times 100/180 = 0.00555 \text{ mol/L}$$

$$\text{After mixing, } [\text{NO}_2^-] = 0.010 \times 80/180 \text{ mol/L} = 0.00444 \text{ mol/L}$$

Let x mol/L HNO_2 ionise at equilibrium.

At equilibrium

$$[\text{HNO}_2] = (0.00555 - x) \text{ mol/L}$$

$$[\text{NO}_2^-] = (0.00444 + x) \text{ mol/L}$$

$$[\text{H}_3\text{O}^+] = x \text{ mol/L}$$

$$K_a \text{HNO}_2 = \frac{[\text{NO}_2^-][\text{H}_3\text{O}^+]}{[\text{HNO}_2]} = 7.2 \times 10^{-4} = \frac{(0.00444 + x)(x)}{(0.00555 - x)}$$

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

$$K_a \text{HNO}_2 = \frac{[\text{NO}_2^-][\text{H}_3\text{O}^+]}{[\text{HNO}_2]} = 7.2 \times 10^{-4} = \frac{(0.00444)(x)}{(0.00555)}$$

$$[\text{H}_3\text{O}^+] = x = 7.2 \times 10^{-4} \times 0.00555/0.00444 = 0.00090 \text{ mol/L}$$

$$\text{pH} = 3.05$$

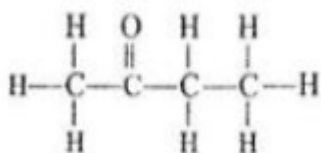
A buffer solution is one which will maintain an almost constant pH, even if small quantities of strong acid or base are added to it. As long as there are close to equal moles of equal concentration solutions making up the buffer mixture, and the acid and base are both only moderately strong as acids and bases, the solution will stay at close to the pH value 3.05, as calculated above. By Le Chatelier's Principle, if [x] is small by comparison with the

concentrations of the acid and base, if the concentration of H^+ in the buffer mixture changes slightly, the proportions of HNO_2 and NO_2^- will change to keep the pH close to 3.05.

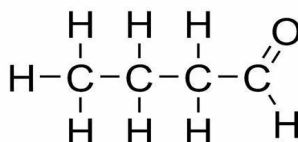
Question 28 (10 marks)

28 (a) (3 marks)

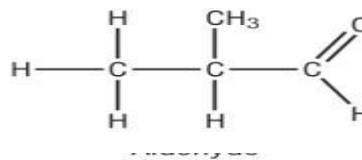
Criteria	Marks
• Draws THREE isomers of C_4H_8O and names them	3
• Draws TWO isomers of C_4H_8O and names them	2
• Draws ONE isomer of C_4H_8O and names it	1

Sample answer

butanone



butanal



2-methylpropanal

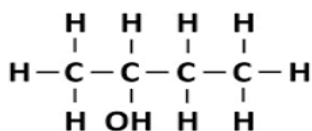
28 (b) (4 marks)

Criteria	Marks
<ul style="list-style-type: none"> Identifies oxidation reactions using an appropriate acidified oxidising agent Identifies butan-2-ol, butan-1-ol and 2-methylpropan-1-ol as the alcohols to be oxidised Draws correct structures for the 3 alcohols 	4
<ul style="list-style-type: none"> Identifies oxidation reactions using an appropriate acidified oxidising agent Identifies TWO of butan-2-ol, butan-1-ol and 2-methylpropan-1-ol as the alcohols to be oxidised Draws correct structures for the 2 alcohols 	3
<ul style="list-style-type: none"> Identifies oxidation reactions using an appropriate acidified oxidising agent Identifies ONE of butan-2-ol, butan-1-ol and 2-methylpropan-1-ol as the alcohol to be oxidised Draws a correct structure for 1 alcohol 	2
OR <ul style="list-style-type: none"> Identifies oxidation reactions using an appropriate acidified oxidising agent Identifies ONE of butan-2-ol, butan-1-ol and 2-methylpropan-1-ol as the alcohol to be oxidised and names the alcohol 	1

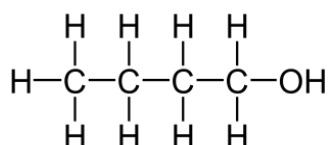
Sample answer

The 3 isomers can be produced by oxidising the appropriate alkanols using acidified potassium dichromate solution (orange). When the oxidation has occurred and the required product formed, the dichromate ions will have reacted to form green chromate ions.

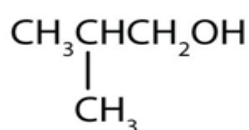
Butan-2-ol (a secondary alcohol) is oxidised to form butanone.



Butan-1-ol (a primary alcohol) is oxidised to form butanal. The reaction requires that the alkanal is removed from the reaction mixture as soon as possible otherwise the resulting alkanal can undergo further oxidation to a carboxylic acid. This is done by using an excess of alcohol and distilling off the alkanal as soon as it forms.



2-methylpropan-1-ol (a primary alcohol) is oxidised to form 2-methylpropanal (using an excess of the alcohol and distilling off the alkanal as soon as it forms).



28 (c) (3 marks)

Criteria	Marks
• Outlines a method which distinguishes between all THREE isomers	3
• Outlines a method which would distinguish TWO of the isomers	2
• Outlines a method which would identify ONE of the isomers	1

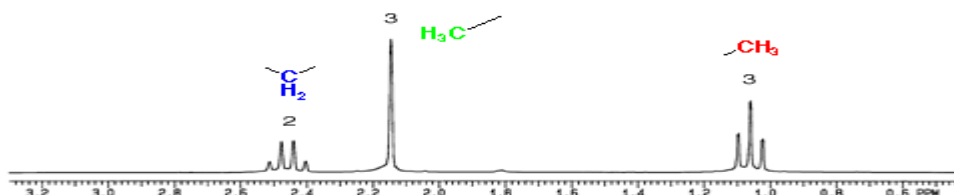
Sample answer

Obtain pure samples of the 3 isomers, butanone, butanal and 2-methylpropanal.

React each sample using an oxidising agent (such as acidified potassium dichromate). Warm the reaction mixture and use excess oxidising agent. The 2 alkanals should react (as shown by the orange colour turning green). If the organic product is separated by distillation and then tested by adding water and an acid-base indicator, it will identify the products as acids but will not distinguish between the alkanals.

However, if ^{13}C NMR spectroscopy is used with the 2 alkanals, they can be distinguished. The butanal spectrum will have 4 carbon peaks, but 2-methylpropanal will only have 3 peaks, due to the 3 different carbon environments (as the 2 CH_3 groups will have identical environments).

Butanone will not be oxidised, so can be identified as the orange colour of the potassium dichromate will remain. If it were tested by ^{13}C NMR spectroscopy, it would show 4 peaks. Using ^1H NMR spectroscopy would show 3 hydrogen environments.



Question 29 (5 marks)

29 (a) (1 mark)

Criteria	Mark
<ul style="list-style-type: none"> Correct answer 	1

Sample answer

24-25%

29 (b) (2 marks)

Criteria	Marks
<ul style="list-style-type: none"> Deduces that the production of ammonia is exothermic AND	2
<ul style="list-style-type: none"> Provides an appropriate explanation 	
<ul style="list-style-type: none"> States that the production of ammonia is exothermic 	1

Sample answer

The graph shows that the percentage of ammonia produced decreases as the temperature increases.

By Le Chatelier's Principle, a system at equilibrium will shift to minimise the effects of any change in external conditions imposed on it. Raising the temperature favours the endothermic reaction, so the backward reaction must be endothermic.

Hence the forward reaction as given in the equation must be exothermic.

29 (c) (1 mark)

Criteria	Mark
<ul style="list-style-type: none"> States an appropriate reason 	1

Sample answer

At temperatures less than 400°C, the reaction rate will be too slow for the process to be viable.

29 (d) (1 mark)

Criteria	Mark
<ul style="list-style-type: none"> Explains why the use of a catalyst affects the economic viability of the industrial process 	1

Sample answer

Even though the percentage of ammonia produced is greatest at low temperatures, the rate is too slow. The use of a catalyst increases the rate of reaction without raising the temperature. Hence the catalyst makes the reaction faster without temperature increase. Industrial processes need to be both yield and time efficient and require the minimum energy input for the same yield.

Question 30 (7 marks)

30 (a) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answerTWO (see the 2 lines on the ^{13}C NMR spectrum).

30 (b) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answerTHREE (see the 3 lines on the ^1H NMR spectrum).

30 (c) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answer

SIX (The septet at 3.6 ppm on the ^1H NMR spectrum implies the presence of six equivalent H atoms on neighbouring C atoms. This means three H atoms on each of two neighbouring C atoms.)

30 (d) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answer

The atoms are O and H in an O–H bond.

30 (e) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answer

It must be an alcohol that has 3 carbons, 2 of which are in $-\text{CH}_3$ groups. This means the C–O–H group must be on carbon-2. The 8 hydrogen atoms are in 2 groups of 3, 1 on the central C and 1 on the $-\text{OH}$ group. It must be propan-2-ol.

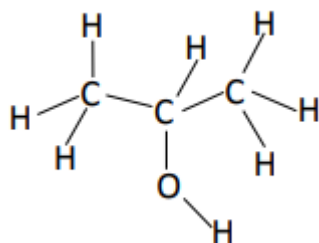
30 (f) (1 mark)

Criteria	Mark
• Correct answer	1

Sample answerIt is the parent ion less 1 H atom. ($\text{C}_3\text{H}_7\text{O}^+$) (The parent ion is $\text{C}_3\text{H}_8\text{O}^+$ with $m/z = 60$.)

30 (g) (1 mark)

Criteria	Mark
• Correct answer	1



Section I
Mapping Grid

Question	Marks	Content	Syllabus Outcomes
1	1	Mod 5: Factors that Affect Equilibrium	12-4, 12-12
2	1	Mod 6: Using Brønsted-Lowry Theory	12-5, 12-13
3	1	Mod 8: Analysis of Organic Substances	12-5, 12-6, 12-15
4	1	Mod 7: Nomenclature	12-7, 12-14
5	1	Mod 6: Quantitative Analysis	12-5, 12-13
6	1	Mod 5: Solution Equilibria	12-6, 12-12
7	1	Mod 7: Nomenclature	12-5, 12-14
8	1	Mod 8: Analysis of Inorganic Substances	12-5, 12-15
9	1	Mod 8: Analysis of Organic Substances Mod 8: Analysis of Inorganic Substances	12-7, 12-15
10	1	Mod 7: Reactions of Organic Acids and Bases	12-5, 12-14
11	1	Mod 5: Calculating the Equilibrium Constant	12-6, 12-12
12	1	Mod 7: Reactions Involving Hydrocarbons	12-6, 12-14
13	1	Mod 6: Quantitative Analysis	12-6, 12-13
14	1	Mod 6: Quantitative Analysis	12-2, 12-13
15	1	Mod 5: Factors that Affect Equilibrium	12-4, 12-12
16	1	Mod 7: Polymers	12-4, 12-14
17	1	Mod 8: Analysis of Organic Substances	12-6, 12-15
18	1	Mod 5: Solution Equilibria	12-5, 12-12
19	1	Mod 6: Quantitative Analysis	12-5, 12-13
20	1	Mod 8: Analysis of Inorganic Substances	12-6, 12-15

Section II

Mapping Grid

Question	Marks	Content	Syllabus Outcomes
21 (a)	2	Mod 5: Factors that Affect Equilibrium	12-4, 12-7, 12-12
21 (b)	2	Mod 5: Factors that Affect Equilibrium	12-4, 12-7, 12-12
21 (c)	4	Mod 5: Factors that Affect Equilibrium	12-4, 12-7, 12-12
22 (a)	1	Mod 6: Quantitative Analysis	12-4, 12-7, 12-13
22 (b)	1	Mod 6: Quantitative Analysis	12-4, 12-7, 12-13
22 (c)	1	Mod 6: Quantitative Analysis	12-4, 12-7, 12-13
22 (d)	2	Mod 6: Quantitative Analysis	12-7, 12-13
23 (a)	3	Mod 7: Nomenclature	12-5, 12-7, 12-14
23 (b)	4	Mod 7: Hydrocarbons, Reactions of Organic Acids and Bases	12-5, 12-7, 12-14
23 (c)	3	Mod 7: Reactions of Organic Acids and Bases	12-7, 12-14
24 (a)	2	Mod 8: Analysis of Organic Substances	12-2, 12-5, 12-15
24 (b)	1	Mod 8: Analysis of Organic Substances	12-2, 12-5, 12-15
24 (c)	2	Mod 8: Analysis of Organic Substances	12-2, 12-5, 12-15
24 (d)	2	Mod 8: Analysis of Organic Substances	12-2, 12-5, 12-15
24 (e)	2	Mod 8: Analysis of Organic Substances	12-7, 12-15
24 (f)	4	Mod 8: Analysis of Organic Substances	12-7, 12-15
25 (a)	2	Mod 5: Solution Equilibria	12-6, 12-12
25 (b)	2	Mod 5: Solution Equilibria	12-6, 12-12
25 (c)	3	Mod 5: Solution Equilibria	12-6, 12-7, 12-12
26 (a)	1	Mod 6: Quantitative Analysis	12-3, 12-4, 12-13
26 (b)	2	Mod 6: Quantitative Analysis	12-3, 12-4, 12-13
26 (c)	2	Mod 6: Quantitative Analysis	12-3, 12-4, 12-13
27 (a)	2	Mod 6: Quantitative Analysis	12-5, 12-13
27 (b)	2	Mod 6: Quantitative Analysis	12-5, 12-13
27 (c)	2	Mod 6: Quantitative Analysis	12-6, 12-13
27 (d)	4	Mod 6: Quantitative Analysis Mod 6: Using Brønsted-Lowry Theory	12-6, 12-7, 12-13
28 (a)	3	Mod 7: Nomenclature	12-5, 12-7, 12-14
28 (b)	4	Mod 7: Alcohols, Nomenclature	12-2, 12-7, 12-14
28 (c)	3	Mod 7: Alcohols, Nomenclature Mod 8: Analysis of Organic Substances	12-2, 12-7, 12-14, 12-15
29 (a)	1	Mod 5: Factors that Affect Equilibrium	12-5, 12-12
29 (b)	2	Mod 5: Factors that Affect Equilibrium	12-5, 12-7, 12-12
29 (c)	1	Mod 8: Chemical Synthesis and Design	12-5, 12-15
29 (d)	1	Mod 8: Chemical Synthesis and Design	12-7, 12-15
30 (a)	1	Mod 8: Analysis of Organic Substances	12-5, 12-15
30 (b)	1	Mod 8: Analysis of Organic Substances	12-5, 12-15
30 (c)	1	Mod 8: Analysis of Organic Substances	12-5, 12-15
30 (d)	1	Mod 8: Analysis of Organic Substances	12-5, 12-15
30 (e)	1	Mod 8: Analysis of Organic Substances	12-5, 12-15
30 (f)	1	Mod 8: Analysis of Organic Substances	12-5, 12-15
30 (g)	1	Mod 8: Analysis of Organic Substances	12-7, 12-15