Student Name:……………………………

2020 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

Total marks: 100

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

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

CHEMTR20_EXAM

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

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

Select the alternative A, B, C or D that best answers the question. Fill in the response oval completely.

Sample 2 + 4 = A. 2 B. 6 C. 8 D. 9

A B C D

If you think you have made a mistake, put a cross through the incorrect answer and fill in the new answer.

A B C D

If you have changed your mind and have crossed out what you consider to be the correct answer, then indicate this by writing the word *correct* and drawing an arrow as follows:

correct

A B C D

1 When a solution of zinc chloride is added to a solution containing silver nitrate, a precipitate of silver chloride forms, according to the following chemical equation:

$2AgNO_3\ (aq) + ZnCl_2\ (aq) \rightarrow Zn(NO_3)_2\ (aq) + 2AgCl\ (s)$

Which of the following shows the relative changes in the number of moles of each species over time?

	Ag^+ *(aq)*	NO_3^- *(aq)*
A.	decreases	no change
B.	increases	decreases
C.	no change	no change
D.	decreases	increases

2 Consider the reaction:

$Br_2\,(g) + I_2\,(g) \rightleftharpoons 2IBr\,(g)$ $\quad K_c = 1.2 \times 10^2$ at 150°C

What is the K_c for the reaction shown below, at 150°C?

$4IBr\,(g) \rightleftharpoons 2Br_2\,(g) + 2I_2\,(g)$

A. 1.6×10^{-2}

B. 4.1×10^{-3}

C. 6.9×10^{-5}

D. 8.03×10^{-5}

3 An isomer of butanoic acid is

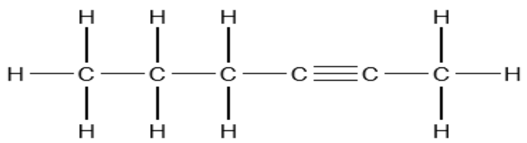
A. CH_3CH_2COOH

B. $CH_3CH_2COOCH_3$

C. $CH_3COCH_2CH_3$

D. $CH_3CH_2CH_2CHO$

4



The correct name of the compound above is

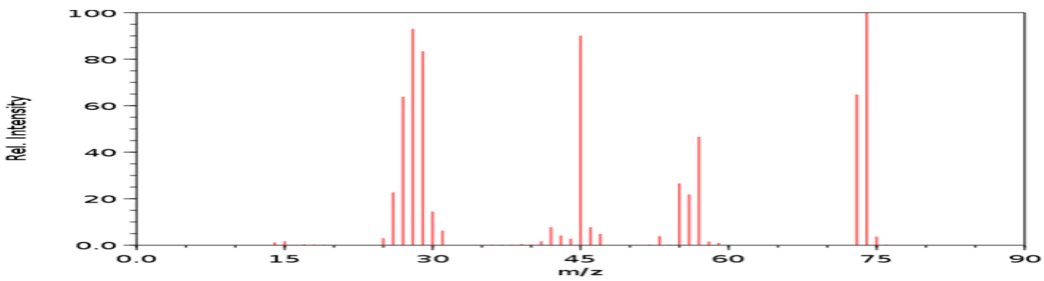
A. hex-4-yne

B. hex-2-yne

C. hex-2-ene

D. hept-2-yne

5 The diagram below shows the mass spectrum for an organic compound.



The compound is

A. ethanoic acid

B. ethanol

C. propanol

D. propanoic acid

6 The pH of a 0.01 mol L^{-1} solution of a monoprotic acid was measured by a student and found to be 4.

What proportion of the acid molecules has been converted to ions?

A. 0%

B. 1%

C. 90%

D. 100%

7 Identify the conjugate acid/base pair.

A. CH_3COOH / CH_3COO^-

B. H_3PO_4 / HPO_4^{2-}

C. H_3O^+ / OH^-

D. H_2CrO_4 / CrO_4^{2-}

8 Which of the following organic compounds is classified as an organic base?

A. Propane

B. Propanol

C. Propanamide

D. Propanamine

9 and 10 Questions 9 and 10 both relate to the endothermic dissociation of phosphorus pentachloride into chlorine and phosphorus trichloride.

$PCl_5\ (g) \rightleftharpoons PCl_3\ (g) + Cl_2\ (g)$ $K_p = 0.015$ at 450 K

9 A closed container at 450 K initially contains only PCl_5 *(g)* and PCl_3 *(g)*, each at a partial pressure of 2.7 atm. After the system reaches equilibrium, what is the partial pressure of Cl_2 *(g)*?

A. 0.015 atm

B. 0.12 atm

C. 0.20 atm

D. 2.7 atm

10 Which change will decrease the number of moles of Cl_2 *(g)* present in this system at equilibrium?

A. Increasing the volume of the container

B. Increasing the pressure by injecting argon *(g)*

C. Increasing the pressure by injecting PCl_5 *(g)*

D. Decreasing the temperature

11 The molar solubility of PbF_2 is 2.1×10^{-3} mol L^{-1}. What is its K_{sp}?

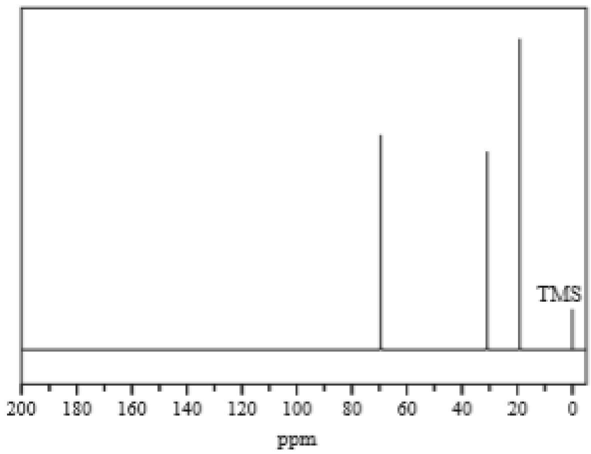
A. 4.4×10^{-6}

B. 8.8×10^{-6}

C. 3.7×10^{-8}

D. 9.3×10^{-9}

12



The ^{13}C NMR spectrum above corresponds to which one of the following compounds?

A. Propane

B. 2-methylbutane

C. 2-methylpropan-2-ol

D. 2-methylpropan-1-ol

13 During a precipitation titration investigation, a 10.0 mL sample of a solution containing chloride ions was titrated with 23.5 mL of 0.125 mol/L $AgNO_3$ to reach the end-point. Calculate the mass of chloride ions present in the original sample.

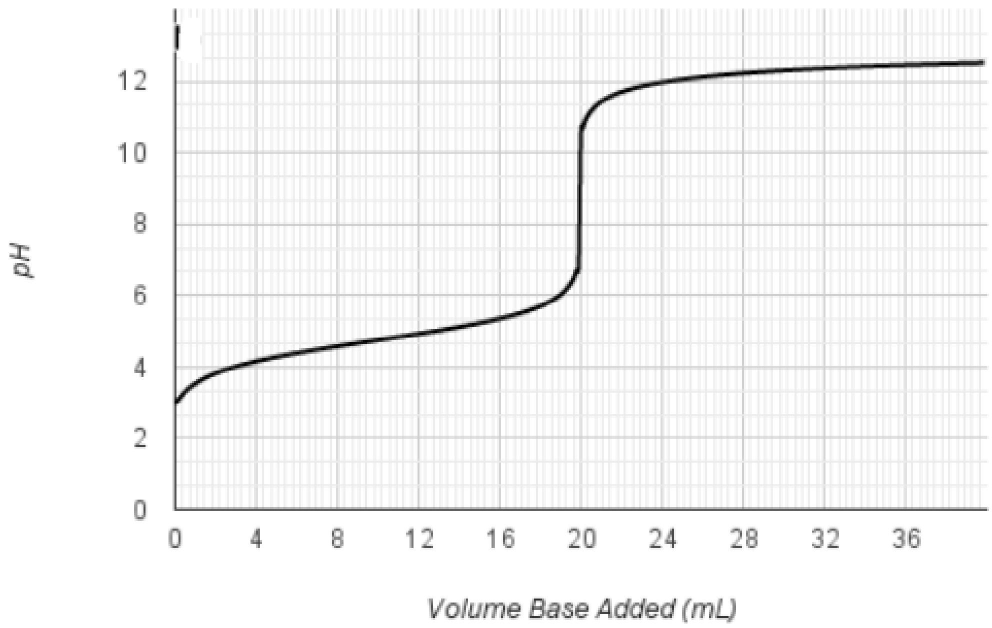
A. 0.00294 g

B. 0.0520 g

C. 0.104 g

D. 0.208 g

14 The diagram below represents the titration curve for the reaction between an acid and a base.



The equation that best represents the reaction described by the titration curve is

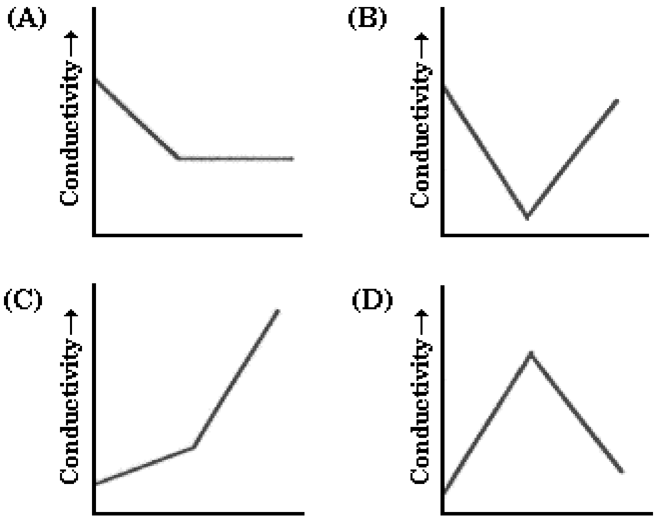
A. HCl *(aq)* + NH_3 *(aq)* → NH_4Cl *(aq)*

B. HCl *(aq)* + $NaOH$ *(aq)* → $NaCl$ *(aq)* + H_2O *(l)*

C. CH_3COOH *(aq)* + NH_3 *(aq)* → CH_3COONH_4 *(aq)*

D. CH_3COOH *(aq)* + $NaOH$ *(aq)* → CH_3COONa *(aq)* + H_2O *(l)*

15 Which graph best represents the electrical conductivity changes that occur when an aqueous solution of sulfuric acid is titrated with an aqueous solution of barium hydroxide?



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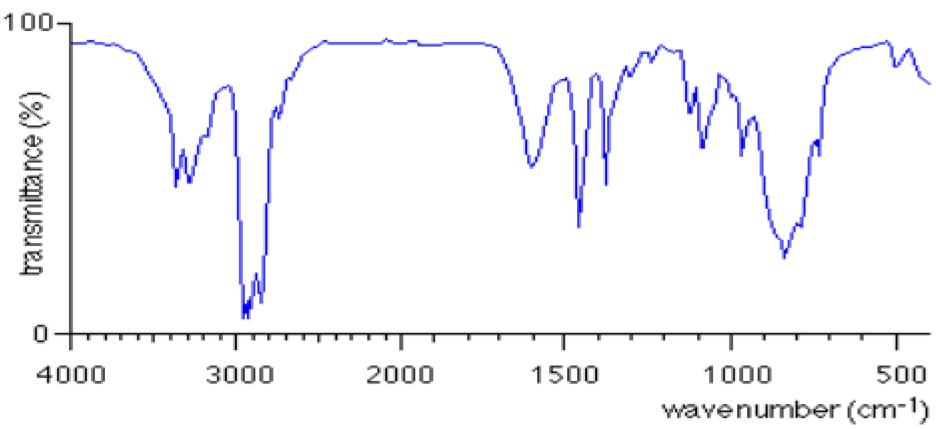


The diagram above shows the IR spectrum for a common organic molecule. The molecule is likely to be an

A. alkanoic acid.

B. alkene.

C. amine.

D. alcohol.

17 A student wishes to distinguish between samples of pentan-1-ol and pentanoic acid. Which of the following tests would NOT allow the 2 compounds to be identified?

A. Adding bromine water to both

B. Adding an acidified solution of potassium permanganate to both

C. Testing the pH of solutions of both

D. Adding sodium carbonate solution to both

18 Ammonia can be produced by the reaction of hydrogen and nitrogen. When this reaction takes place in a sealed container of fixed volume, an equilibrium system is established.

The equation for the reaction is:

$$N_2\,(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g) \qquad \Delta H = -92 \text{ kJ per mole of nitrogen}$$

If the pressure and volume remain constant when the temperature is increased, the forward reaction rate will

A. increase and the $[NH_3]$ will decrease.

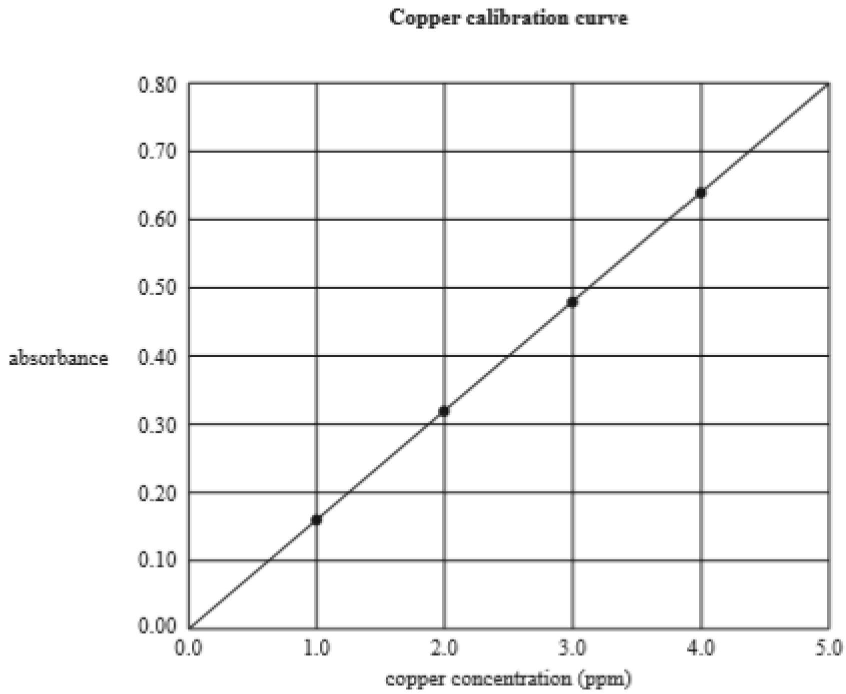
B. increase and the $[NH_3]$ will increase.

C. decrease and the $[NH_3]$ will decrease.

D. decrease and the $[NH_3]$ will remain the same.

19 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 mg L^{-1} = 1 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}

20 An organic compound of formula C_4H_8O

I – could be an alkanal or an alkanone
II – could be formed by oxidation of an alkanol
III – could be formed by reduction of an alkanoic acid
IV – could react with an alkanoic acid to form an ester

Which of the above statements are correct?

A. I, II, III and IV

B. I, II and III only

C. I and II only

D. III and IV only

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Chemistry

Section II – 80 marks
Attempt Questions 21-33
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 35 to 38. If you use this space, clearly indicate which question you are answering.

Question 21 (9 marks)

Consider the 4 equilibria represented by the equations below:

I	$H_2O\ (l) \rightleftharpoons H_2O\ (g)$
II	$H_2CO_3\ (aq) + H_2O\ (l) \rightleftharpoons HCO_3^-\ (aq) + H_3O^+\ (aq)$
III	$PCl_5\ (g) \rightleftharpoons PCl_3\ (g) + Cl_2\ (g)$
IV	$Mg(OH)_2\ (s) \rightleftharpoons Mg^{2+}\ (aq) + 2OH^-\ (aq)$

(a) Using all of the above examples of equilibria, explain the difference between homogeneous and heterogeneous equilibria. **2**

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Question 21 continues on the next page

Question 21 (continued)

(b) Identify which of the above 4 equilibria will change, when an increase in pressure is applied to the equilibrium system. Predict and explain the direction of the change(s). **2**

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(c) Some solid magnesium hydroxide was placed in a beaker and 100 mL water added. The beaker was covered so that water could not evaporate. After a period of time, solid remained in the beaker. Assume the temperature is at 25°C and that equilibrium has been reached. **3**

The solution was tested to determine the pH.

Calculate the pH of the solution.

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Question 21 continues on the next page

Question 21 (continued)

(d) 0.050 g of the solid remaining in the beaker from part (c) above was filtered and placed in a new beaker, containing 1000 mL of water. Assume the temperature is at 25°C. Determine whether all this solid will dissolve and hence determine the pH of the resulting solution. **2**

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Question 22 (8 marks)

A solution of hydrochloric acid was standardised by titration against a sodium carbonate solution using the following procedure.

- All glassware was rinsed correctly to remove possible contaminants.
- Hydrochloric acid was placed in the burette.
- 25.0 mL of sodium carbonate solution was pipetted into the conical flask.

The titration was performed and the hydrochloric acid was found to be 0.200 mol L^{-1}.

(a) Identify the substance used to rinse the conical flask and justify your answer. **2**

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(b) Explain why sodium carbonate solution, rather than sodium hydroxide solution, is used to standardise the hydrochloric acid solution. **2**

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Question 22 continues on the next page

Question 22 (continued)

(c) Seashells contain a mixture of carbonate compounds. **4**

The standardised hydrochloric acid was used to determine the percentage by mass of carbonate ions in a seashell using the following procedure.

- A 0.145 g sample of the seashell was placed in a conical flask.
- 50.0 mL of the standardised hydrochloric acid was added to the conical flask.
- At the completion of the reaction, the mixture in the conical flask was titrated with 0.250 mol L^{-1} sodium hydroxide.

The volume of sodium hydroxide used in the titration was 29.5 mL.

Calculate the percentage by mass of carbonate ions in the sample of the seashell.

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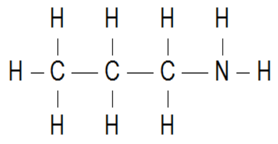
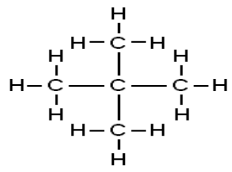
Question 23 (9 marks)

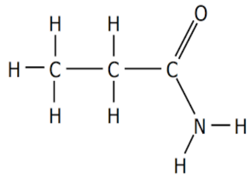
(a) Using IUPAC nomenclature, name the compounds shown below. **3**



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. **4**

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Question 23 continues on the next page

Question 23 (continued)

(c) Identify how compound 3 (in part (a) above) could be produced by a chemical reaction. Include an equation in your response. **2**

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Question 24 (9 marks)

(a) A bottle of solution is missing its label. It is known to be ONE of $AgNO_3$, $Ba(NO_3)_2$, $NaNO_3$ or $Fe(NO_3)_2$. **4**

Draw a flow chart to show the steps that could be followed to confirm the identity of the solution in the bottle. Include observed results.

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Question 24 continues on the next page

Question 24 (continued)

(b) Write ionic equations for the chemical reactions involved in the flow chart in part (a). **3**

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(c) Give an example of a complex ion you have studied. Identify the ligands is this complex ion and explain how they are bonded to the metal cation. **2**

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Question 25 (5 marks)

A student was asked to distinguish between colourless organic liquids known to be

- pentan-1-ol
- pentan-2-ol
- 2-methylbutan-2-ol

(a) Draw structural formulae for the 3 alcohols. Explain how the 3 isomers differ in their structures and how these differences allow them to be distinguished. **3**

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(b) Identify the organic products of any reactions you have described in part (a) above. **2**

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Question 26 (6 marks)

(a) Compare the solubility in water of lead (II) sulfate and lead (II) chloride at 25°C. Show your calculations and reasoning. **3**

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(b) Quantitatively compare the solubility of lead (II) sulfate in water with its solubility in a 0.10 mol/L solution of sodium sulfate, at 25°C. **3**

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Question 27 (7 marks)

(a) Identify a substance which can be classified as a Brønsted-Lowry acid but not as an acid by the Arrhenius theory. Explain your reasoning. Use equations in your response. **3**

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Question 27 continues on the next page

Question 27 (continued)

(b) When a base reacts with an acid, the salt solution formed is not necessarily neutral at 25°C. **4**
Discuss this statement, using appropriate examples and equations. Predict the pH of solutions resulting from a range of acid/base reactions.

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Question 28 (7 marks)

The table shows the acid dissociation constants at 25ºC.

Acid	Formula	K_a
Acetic acid	CH_3COOH	1.8×10^{-5}
Chlorous acid	$HClO_2$	1.1×10^{-2}
Formic acid	$HCOOH$	1.8×10^{-4}
Hydrocyanic acid	HCN	6.2×10^{-10}
Hydrofluoric acid	HF	6.6×10^{-4}
Water	H_2O	1.0×10^{-14}
Lactic acid	$CH_3CHOHCOOH$	1.4×10^{-4}
Nitrous acid	HNO_2	7.2×10^{-4}
Phenol	C_6H_5OH	1.3×10^{-10}

(a) Identify the weakest acid in the table and determine the pK_a value for this acid. **2**

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(b) Calculate the pH of a 0.10 M solution of hydrocyanic acid. **2**

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Question 28 continues on the next page

Question 28 (continued)

(c) A buffer solution is prepared by combining 100 mL of 0.10 M HCN and 100 mL of 0.10 M NaCN. **3**

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

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Question 29 (5 marks)

Sulfur trioxide is an unstable gas that can decompose according to the equation:

$$2SO_3\,(g) \rightleftharpoons 2SO_2\,(g) + O_2\,(g) \qquad \Delta H > 0$$

(a) A mixture of the three gases was added to a gas syringe and the contents allowed sufficient time to reach equilibrium. The volume of the syringe was then halved and the temperature was held constant. **2**

Identify the impact of this volume change on

- the value of the equilibrium constant

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- the amount of SO_2 gas

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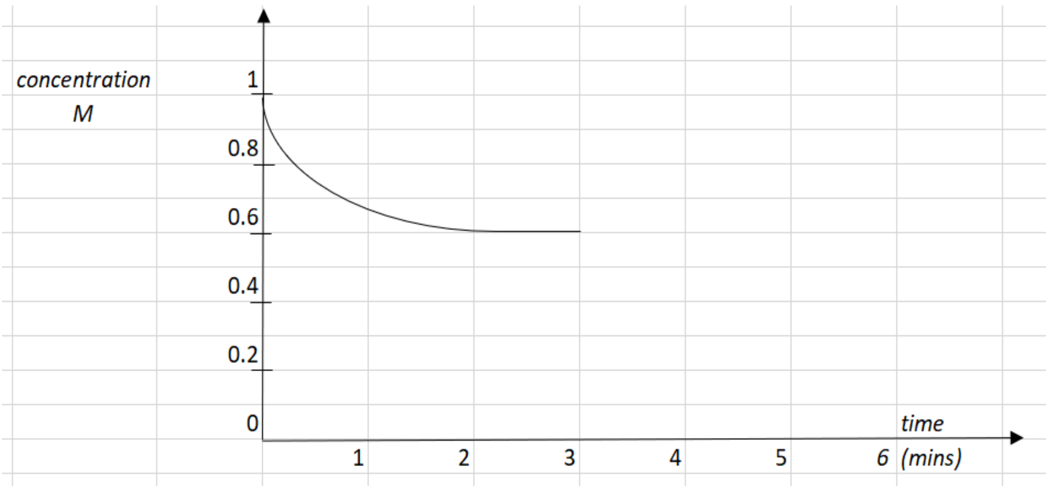
(b) A sample of sulfur trioxide gas was added to an empty sealed flask and its concentration was measured over the next 3 minutes. **2**

The SO_3 concentration is plotted on the graph below.

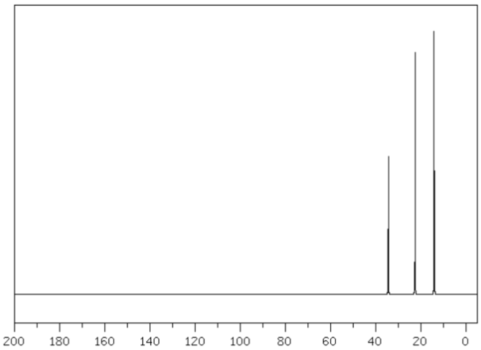


Draw on the graph the corresponding concentrations for the sulfur dioxide and oxygen gases during the first 3 minutes.

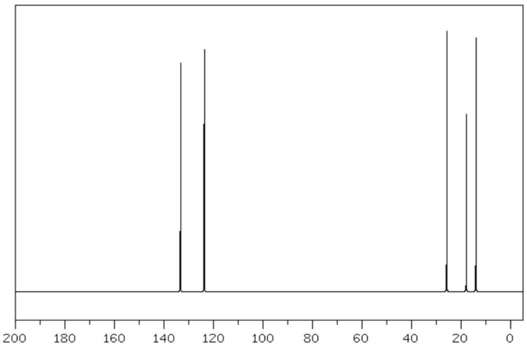
(c) At the 3-minute mark the temperature of the system is increased. On the graph provided in part (b), show the impact of this change on the SO_3 concentration. **1**

Question 30 (5 marks)

(a) A scientist wished to distinguish between samples of pent-2-ene and pentane. He carried out an instrumental analysis using ^{13}C NMR. **2**
The spectra obtained are shown below.



Spectrum I



Spectrum II

Match the spectra with the two hydrocarbon samples. Justify your answer.

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(b) Explain how the two samples, pent-2-ene and pentane, could be distinguished between by a chemical test. Include an appropriate equation for a reaction you describe and name the organic product formed. **3**

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Question 31 (3 marks)

Soaps are able to remove fats and oils from the skin because of their structure. **3**

Discuss this statement.

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Question 32 (3 marks)

Identify an instrumental technique used to determine the concentration of cations in a coloured solution. For this technique, outline the impact of Beer's Law in the determination of the cation determination. **3**

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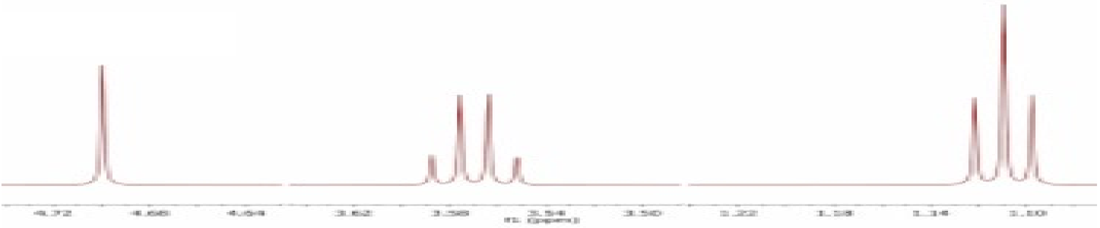
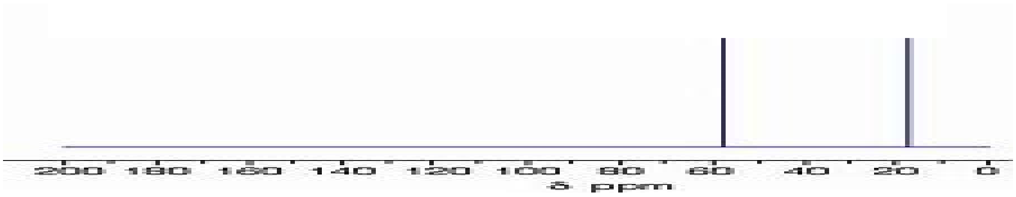
Question 33 (4 marks)

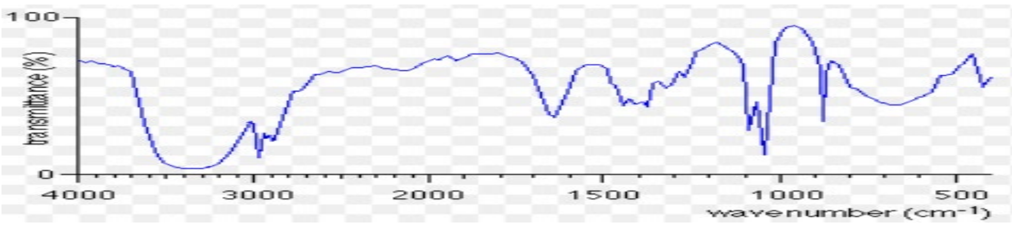
A scientist wished to identify an organic compound. She carried out instrumental analyses using 3 different types of spectroscopy. The spectra obtained are shown below. **4**



Spectrum I



Spectrum II



Spectrum III

Predict the identity of the unknown compound and justify your prediction, relating your answer to the spectra shown above.

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Student Name:……………………………

CHEMISTRY – MULTIPLE-CHOICE ANSWER SHEET

ATTEMPT ALL QUESTIONS

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

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FORMULAE SHEET

$n = \dfrac{m}{MM}$	$c = \dfrac{n}{V}$	$PV = nRT$
$q = mc\Delta T$	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$	$\mathrm{pH} = -\log_{10}\left[\mathrm{H^+}\right]$
$pK_a = -\log_{10}\left[K_a\right]$	$A = \varepsilon lc = \log_{10}\dfrac{I_o}{I}$	

Avogadro constant, N_A .... 6.022×10^{23} 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 J mol^{-1} K^{-1}

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

Specific heat capacity of water .... 4.18×10^3 J kg^{-1} K^{-1}

DATA SHEET

Solubility constants at 25°C

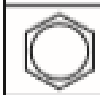
Compound	K_{sp}	*Compound*	K_{sp}
Barium carbonate	2.58×10^{-9}	Lead(II) bromide	6.60×10^{-6}
Barium hydroxide	2.55×10^{-4}	Lead(II) chloride	1.70×10^{-5}
Barium phosphate	1.3×10^{-29}	Lead(II) iodide	9.8×10^{-9}
Barium sulfate	1.08×10^{-10}	Lead(II) carbonate	7.40×10^{-14}
Calcium carbonate	3.36×10^{-9}	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

^{13}C NMR chemical shift data

Type of carbon		δ/ppm
—C—C—		5–40
R—C—Cl or Br		10–70
R—C(=O)—C—		20–50
R—C—N		25–60
—C—O—	alcohols, ethers or esters	50–90
C=C		90–150
R—C≡N		110–125
		110–160
R—C(=O)—	esters or acids	160–185
R—C(=O)—	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

$K^+ + e^-$	$\rightleftharpoons$	$K(s)$	–2.94 V
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	$Ba(s)$	–2.91 V
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	$Ca(s)$	–2.87 V
$Na^+ + e^-$	$\rightleftharpoons$	$Na(s)$	–2.71 V
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	$Mg(s)$	–2.36 V
$Al^{3+} + 3e^-$	$\rightleftharpoons$	$Al(s)$	–1.68 V
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	$Mn(s)$	–1.18 V
$H_2O + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g) + OH^-$	–0.83 V
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	$Zn(s)$	–0.76 V
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	$Fe(s)$	–0.44 V
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	$Ni(s)$	–0.24 V
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	$Sn(s)$	–0.14 V
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	$Pb(s)$	–0.13 V
$H^+ + e^-$	$\rightleftharpoons$	$\frac{1}{2}H_2(g)$	0.00 V
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2(aq) + 2H_2O$	0.16 V
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	$Cu(s)$	0.34 V
$\frac{1}{2}O_2(g) + H_2O + 2e^-$	$\rightleftharpoons$	$2OH^-$	0.40 V
$Cu^+ + e^-$	$\rightleftharpoons$	$Cu(s)$	0.52 V
$\frac{1}{2}I_2(s) + e^-$	$\rightleftharpoons$	I^-	0.54 V
$\frac{1}{2}I_2(aq) + e^-$	$\rightleftharpoons$	I^-	0.62 V
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	0.77 V
$Ag^+ + e^-$	$\rightleftharpoons$	$Ag(s)$	0.80 V
$\frac{1}{2}Br_2(l) + e^-$	$\rightleftharpoons$	Br^-	1.08 V
$\frac{1}{2}Br_2(aq) + e^-$	$\rightleftharpoons$	Br^-	1.10 V
$\frac{1}{2}O_2(g) + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O	1.23 V
$\frac{1}{2}Cl_2(g) + e^-$	$\rightleftharpoons$	Cl^-	1.36 V
$\frac{1}{2}Cr_2O_7^{2-} + 7H^+ + 3e^-$	$\rightleftharpoons$	$Cr^{3+} + \frac{7}{2}H_2O$	1.36 V
$\frac{1}{2}Cl_2(aq) + e^-$	$\rightleftharpoons$	Cl^-	1.40 V
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	1.51 V
$\frac{1}{2}F_2(g) + e^-$	$\rightleftharpoons$	F^-	2.89 V

PERIODIC TABLE OF THE ELEMENTS

KEY

Atomic Number	79
Symbol	Au
Standard Atomic Weight	197.0
Name	Gold

1 H 1.008 Hydrogen																	2 He 4.003 Helium
3 Li 6.941 Lithium	4 Be 9.012 Beryllium											5 B 10.81 Boron	6 C 12.01 Carbon	7 N 14.01 Nitrogen	8 O 16.00 Oxygen	9 F 19.00 Fluorine	10 Ne 20.18 Neon
11 Na 22.99 Sodium	12 Mg 24.31 Magnesium											13 Al 26.98 Aluminium	14 Si 28.09 Silicon	15 P 30.97 Phosphorus	16 S 32.07 Sulfur	17 Cl 35.45 Chlorine	18 Ar 39.95 Argon
19 K 39.10 Potassium	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 Caesium	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 Polonium	85 At Astatine	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	116 Lv Livermorium	117 Uus Ununseptium	118 Uuo Ununoctium

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 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.

2020 Higher School Certificate Trial Examination

Mapping Grid

Section I

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

Section II – 80 marks

Question 21 (9 marks)
21 (a) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–12
Targeted Performance Bands: 2-4

Criteria	Marks
• Explains clearly the difference between homogeneous and heterogeneous equilibria AND correctly assigns the 4 equilibria as homogeneous or heterogeneous	2
• Explains clearly the difference between homogeneous and heterogeneous equilibria OR correctly assigns the 4 equilibria as homogeneous or heterogeneous	1

Sample answer

In a homogeneous equilibrium, all species involved in the reaction are in the same phase/state. In a heterogeneuos equilibrium, the reacting species are in more than 1 state.

The only equilibrium which is classified as homogeneous is reaction III (all species in the gaseous state). The other 3 equilibria are classified as heterogeneous (species in more than 1 state).

21 (b) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–12
Targeted Performance Bands: 2-4

Criteria	Marks
• Identifies the TWO equilibria which will change when pressure is increased AND correctly predicts and explains the direction of the changes	2
• Identifies ONE equilibrium which will change when pressure is increased AND correctly predicts and explains the direction of the change	1

Sample answer

Only the 2 equilibria which involve gases (I and III) will change when pressure is applied.

Equilibrium I will move to the left to convert some gas to liquid water.

Equilibrium III will move to the left, to make more molecules of $PCl_5(g)$.

By Le Chatelier's Principle, an increase in pressure moves the equilibrium to the side with the smaller number of gas molecules, counteracting the applied change.

21 (c) (3 marks)
Outcomes Assessed: CH12–4, CH12–6, CH12–12, CH12–13
Targeted Performance Bands: 2-5

Criteria	Marks
• Correctly calculates the pH of the solution	3
• Correctly calculates the $[OH^-]$ of the solution	2
• Some correct reasoning or calculation steps	1

Sample answer

From the data pages, K_{sp} $Mg(OH)_2 = 5.61 \times 10^{-12}$
Let s moles/litre $Mg(OH)_2$ dissolve to form a saturated solution
$K_{sp} = [s]\,[2s]^2 = 4s^3 = 5.61 \times 10^{-12}$
$s^3 = 1.4025 \times 10^{-12}$
$s = 1.119 \times 10^{-4}$

Hence $[OH^-] = 2 \times 1.119 \times 10^{-4} = 2.238 \times 10^{-4}$ mol L^{-1}
pOH = 3.650
pH = 10.350

(Note that the volume of solution is not taken into consideration here as the solubility and pH depend on the concentration (not the number of moles) at equilibrium.)

21 (d) (2 marks)
Outcomes Assessed: CH12–4, CH12–6, CH12–12, CH12–13
Targeted Performance Bands: 3-5

Criteria	Marks
• Correctly determines whether all the solid will dissolve AND correctly determines the pH of the solution	2
• Correctly determines whether all the solid will dissolve	1

Sample answer

Moles of $Mg(OH)_2$ added to 1000 mL water
= 0.050/(24.31 + 32.00 + 2.016)
= 0.050/58.326
= 0.000857 mol/L
= 8.6×10^{-4} mol/L

Since this is greater than the solubility of $Mg(OH)_2$, the $[OH^-]$ and the pH will be the same as in the previous question – as it will be in any saturated solution at 25°C.

Hence pH = 10.350.

Question 22 (8 marks)
22 (a) (2 marks)
Outcomes Assessed: CH12–2, CH12–3, CH12–7, CH12–13
Targeted Performance Bands: 3-4

Criteria	Marks
• Identifies deionised water as the substance used to rinse the conical flask AND justifies the answer	2
• Identifies deionised water as the substance used to rinse the conical flask	1

Sample answer

Standard sodium carbonate is the solution to be placed in the flask. The flask must be cleaned and then rinsed with deionised water. If water remains in the flask, it will not change the number of moles of sodium carbonate in the flask. If either hydrochloric acid or sodium carbonate were used, the moles of the wash remaining in the flask would alter the titration results and hence make the calculation invalid.

22 (b) (2 marks)
Outcomes Assessed: CH12–2, CH12–3, CH12–7, CH12–13
Targeted Performance Bands: 3-4

Criteria	Marks
• Explains, giving at least 2 valid reasons, why sodium carbonate is used rather than sodium hydroxide as a standard	2
• Outlines one valid reason	1

Sample answer

A primary standard solution is one that can be used as the starting point in a series of titrations to determine the concentration of other solutions. The primary standard used to make the primary standard solution is normally a crystalline solid, which can be weighed out accurately (will not absorb water or carbon dioxide from the atmosphere) and has a relatively high molar mass (so that errors in transferring the solid are minimised in terms of moles). Sodium carbonate is suitable as it can be obtained pure, as crystals, can be weighed out accurately without absorbing water or reacting with carbon dioxide from the air and has a higher molar mass (106 g/mol) than NaOH (40 g/mol). Sodium hydroxide is not obtainable as pure crystals (lumps, which absorb water and react with CO_2).

22 (c) (4 marks)
Outcomes Assessed: CH12–5, CH12–6, CH12–13
Targeted Performance Bands: 2-5

Criteria	Marks
• Calculates correctly the percentage by mass of carbonate ions in the seashell	4
• Determines the mass of carbonate ions in the seashell	3
• Determines the moles of HCl in excess	2
• Determines the moles of HCl added to the flask	1

Sample answer

There were 4 steps in the process:

- The sample (0.145 g) was placed in a conical flask.
- 50.0 mL of standard hydrochloric acid (0.200 mol/L) was pipetted into the flask
- The excess HCl was titrated with NaOH to determine the no. of moles of HCl in excess and hence the no. of moles and mass of carbonate ions
- The percentage of carbonate ions, by mass, was determined

CO_3^{2-} (in the seashell) + 2HCl (aq) $\rightarrow$ $2Cl^-$ (aq) + CO_2 (g) + H_2O (l)

Moles HCl added initially to react and dissolve carbonate ions
= cV = 0.200 x 0.050 = 0.0100 mol

Moles NaOH required for titration excess HCl = 0.0295 x 0.250 = 0.007375 mol

Hence moles of excess HCl = 0.007375 (as NaOH and HCl react in 1:1 ratio)

Moles of HCl which had reacted with seashell = 0.0100 – 0.00738 = 0.00262 mol

Moles CO_3^{2-} = ½ moles HCl (from balanced equation)

Hence moles CO_3^{2-} in seashell = 0.00131 mol

Mass of CO_3^{2-} in seashell = n x M = 0.00131 x 60.01 = 0.0786 g (3 s.f.)

% CO_3^{2-} in seashell = 0.0786/0.145 x 100 = 54.2%

Question 23 (9 marks)
23 (a) (3 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–14
Targeted Performance Bands: 3-5

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

Sample answer

Compound 1 = propan-1-amine
Compound 2 = 2,2-dimethylpropane
Compound 3 = propanamide

23 (b) (4 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–14
Targeted Performance Bands: 3-6

Criteria	Marks
• Predicts the correct order of boiling points • Explains thoroughly the impact of the different intermolecular forces • Identifies that Compound 1 has hydrogen bonding as the strongest intermolecular force • Identifies that Compound 2 has dispersion (temporary dipole-dipole forces) only • Identifies that Compound 3 has hydrogen bonding (2 hydrogen bonds form between adjacent molecules)	4
• 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

• TWO of:
  • 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
	2

• ONE of:
  • Predicts the correct order of boiling points
  • Explains thoroughly the impact of the different intermolecular forces
  • Identifies the intermolecular forces in 1 of the 3 compounds
	1

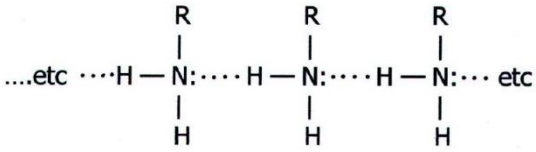
Sample answer

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

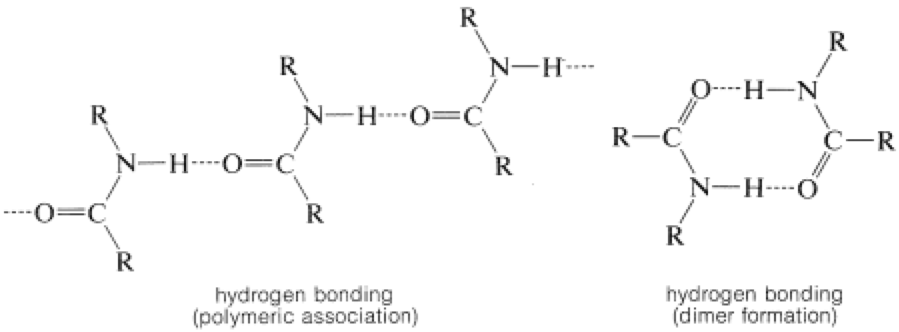
The stronger the intermolecular forces, the higher the boiling point, as greater energy is needed to separate the liquid molecules to form a gas.

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).

Compound 1 is polar and would experience hydrogen bonding forces, as well as weaker temporary and permanent dipolar forces) as molecules interact. These are strong intermolecular forces where the electronegativity of the nitrogen results in a very polar bond with hydrogen in the N–H group. This hydrogen is attracted to the nitrogen of a neighbouring amine molecule. The geometry of the molecule only allows 1 H-bond per pair of molecules at any instant.



Compound 3 is an amide and has the very polar – CONH functional group. The hydrogen atom of the –CONH can form a hydrogen bond with an oxygen of the neighbouring amide molecule. The planar nature of this –CONH group allows 2 H-bonds per pair of molecules. Hence the intermolecular forces and thus boiling points are highest in Compound 3 and lowest in Compound 2.



23 (c) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–14
Targeted Performance Bands: 4-5

Criteria	Marks
• Identifies a chemical reaction that produces compound 3 AND writes an appropriate equation	2
• Identifies a chemical reaction that produces compound 3	1

Sample answer

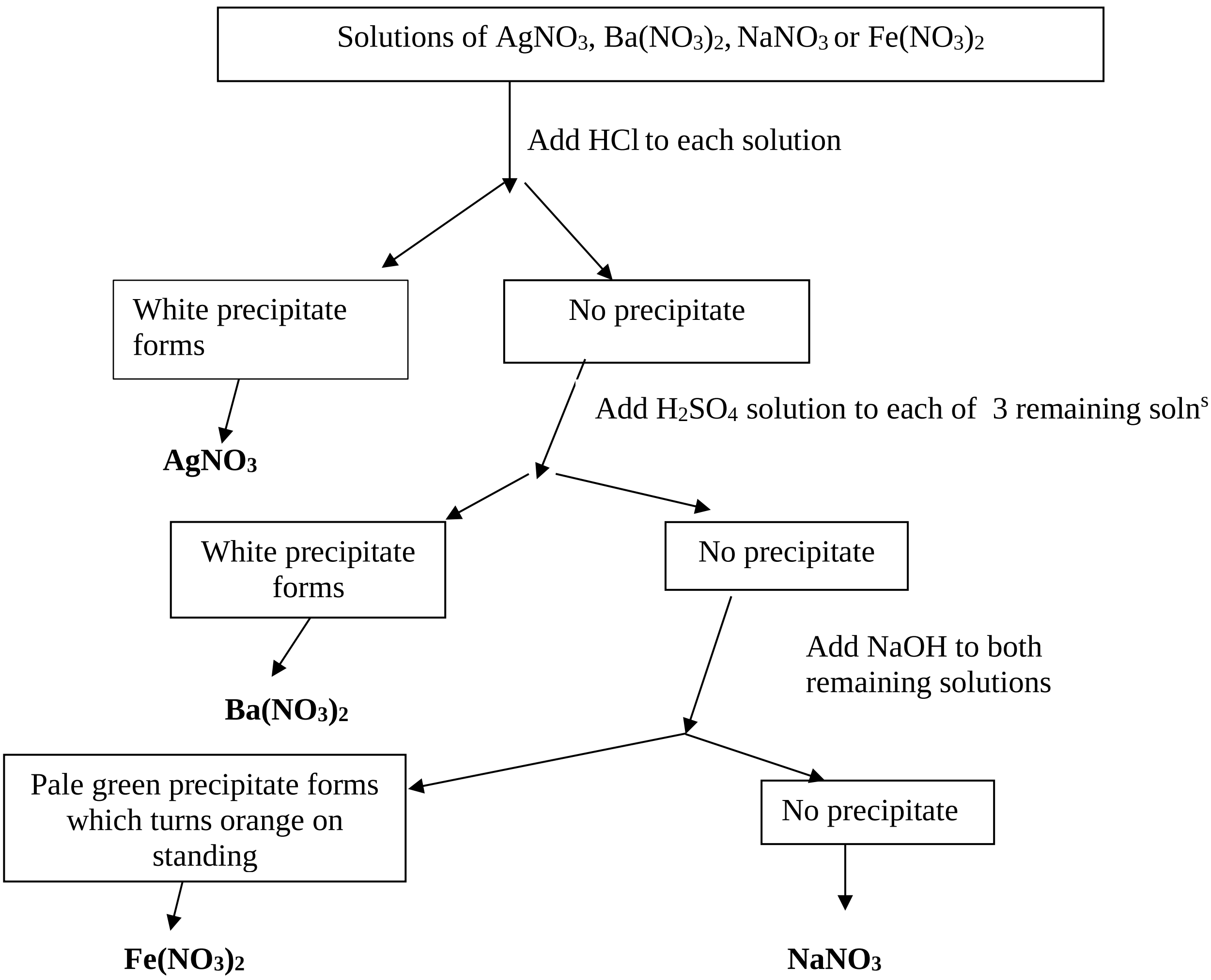
An alkanoic acid will react with ammonia to form an amide. Heat must be applied.

$CH_3CH_2COOH\ (aq)\ +\ NH_3\ (aq)\ \rightarrow\ CH_3CH_2CONH_2\ (aq)\ +\ H_2O\ (l)$
propanoic acid propanamide

Question 24 (9 marks)
24 (a) (4 marks)
Outcomes Assessed: CH12–2, CH12–3, CH12–7, CH12–15
Targeted Performance Bands: 2-5

Criteria	Marks
• Draws a flow chart to show a correct method of identification of ALL FOUR solutions • Includes all observations	4
• Draws a flow chart to show a correct method of identification of THREE solutions • Includes correct observations for the 3 correctly identified solutions	3
• Draws a flow chart to show a correct method of identification of TWO solutions • Includes correct observations for the 2 correctly identified solutions	2
• Includes some correct information	1

Sample answer



24 (b) (3 marks)
Outcomes Assessed: CH12–7, CH12–15
Targeted Performance Bands: 3-5

Criteria	Marks
• Writes 3 correct ionic equations	3
• Writes 2 correct ionic equations	2
• Writes 1 correct ionic equation	1

Sample answer

Ag^{+} (aq) + Cl^{-} (aq) → AgCl (s)

Ba^{2+} (aq) + SO_4^{2-} (aq) → $BaSO_4$ (s)

Fe^{2+} (aq) + $2OH^{-}$ (aq) → $Fe(OH)_2$ (s)

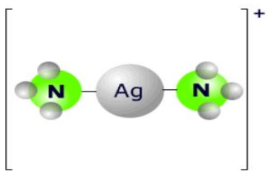
24 (c) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–15
Targeted Performance Bands: 3-5

Criteria	Marks
• Gives an example of a complex ion AND identifies the ligands and explains how the ligands are bonded to the metal cation	2
• Gives some correct information about the structure or bonding of any complex ion	1

Sample answer

$[Ag(NH_3)_2]^{+}$ (aq)

This complex ion is the diamminesilver ion. Complex ions have a metal atom (here silver) at the centre of the ion and atoms or groups of atoms (called ligands), which bond by co-ordinate bonding onto the central atom. The ammonia molecules are the ligands, and each has a non-bonding pair of electrons which moves into empty orbitals of the silver ion to form the covalent bond.



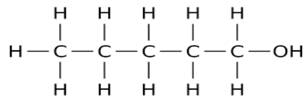
Question 25 (5 marks)
25 (a) (3 marks)
Outcomes Assessed: CH12–3, CH12–7, CH12–14
Targeted Performance Bands: 2-5

Criteria	Marks
• Correctly draws the structures of the 3 alcohols • Identifies the isomers as primary, secondary or tertiary alcohols and explains the difference in structures of the 3 isomers • Outlines the method of distinguishing between the 3 alcohols, which depends on the difference in structures	3
• TWO of the above	2
• ONE of the above	1

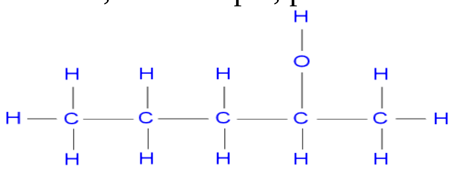
Sample answer

The 3 chemicals listed are isomers (all have the same molecular formula) and are all alcohols. They differ, in that pentan-1-ol is a primary alcohol, pentan-2-ol is a secondary alcohol and 2-methylbutan-2-ol is a tertiary alcohol.

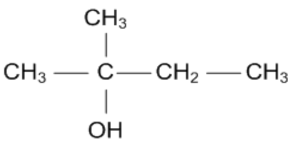
Primary alcohol: the –OH group is attached to a terminal carbon. The –OH group is attached to a carbon which is attached to only 1 other carbon, for example, pentan-1-ol.



Secondary alcohol: the –OH group is attached to a carbon which is attached to 2 other carbons, for example, pentan-2-ol.



Tertiary alcohol: the –OH group is attached to a carbon which is attached to 3 other carbons. for example, 2-methylbutan-2-ol.



The 3 types of alcohols are distinguished between by reaction of a sample of each alcohol with acidified potassium dichromate solution, followed by testing of any products to distinguish between the primary and secondary alcohols. The 3 alcohols react differently (see below).

Primary alcohols react with excess acidified potassium dichromate solution to form a carboxylic acid. The oxidising agent is converted into green chromate ions. The presence of the acid in solution could be tested by separating the product and testing a sample of the product with sodium carbonate solution; carbon dioxide bubbles would be produced. In this reaction, pentan-1-ol is converted to pentanal and then pentanoic acid.

Secondary alcohols react with acidified potassium dichromate solution but form ketones/alkanones, not acids. Here pentan-2-ol reacts to form pentanone. There is a colour change but no acid is formed.

Tertiary alcohols are not oxidised by acidified potassium dichromate solution, so no colour change occurs when the reagents are mixed.

25 (b) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–14
Targeted Performance Bands: 2-4

Criteria	Marks
• TWO correct answers	2
• ONE correct answer	1

Sample answer

The products are:
- pentanal and pentanoic acid (from the reaction of pentan-1-ol)
- pentan-2-one (from the reaction of pentan-2-ol)

Question 26 (6 marks)
26 (a) (3 marks)
Outcomes Assessed: CH12–4, CH12–6, CH12–12
Targeted Performance Bands: 3-6

Criteria	Marks
• Correct answers, with correct units, showing correct working/reasoning	3
• Correct calculations for solubility of $PbSO_4$ and $PbCl_2$ in water but no overall comparison made	2
• Correct calculation for solubility of $PbSO_4$ in water OR the solubility of $PbCl_2$ in water	1

Sample answer

Let the solubility of $PbSO_4$ be s.
$K_{sp}\ PbSO_4 = 2.53 \times 10^{-8} = [Pb^{2+}]\ [SO_4^{2-}] = (s)\ (s) = s^2$
$s = 1.59 \times 10^{-4}$ mol/L

The solubility of $PbSO_4$ in water = 1.59×10^{-4} mol/L

Let the solubility of $PbCl_2$ be s.
$K_{sp}\ PbCl_2 = 1.70 \times 10^{-5} = [Pb^{2+}]\ [Cl^-]^2 = (s)\ (2s)^2 = 4s^3$
$s^3 = 4.25 \times 10^{-6}$ mol/L
$s = (4.25 \times 10^{-6})^{1/3} = 1.62 \times 10^{-2}$ mol/L

The solubility of $PbCl_2$ in water = 1.62×10^{-2} mol/L

Hence $PbCl_2$ is more soluble in water than $PbSO_4$ at 25°C.

26 (b) (3 marks)
Outcomes Assessed: CH12–4, CH12–6, CH12–12
Targeted Performance Bands: 3-6

Criteria	Marks
• Correct conclusion based on correct calculations	3
• Correct calculation for the solubility of $PbSO_4$ in sodium sulfate solution	2
• Incorrect calculation or conclusion but correct method /reasoning	1

Sample answer

Let the solubility of $PbSO_4$ in a 0.10 mol/L solution of sodium sulfate = z
$K_{sp}\ PbSO_4 = [Pb^{2+}]\ [SO_4^{2-}] = (z)\ (0.10 + z) = 1.59 \times 10^{-8}$
Since z is small by comparison with 0.10
$K_{sp}\ PbSO_4 = [Pb^{2+}]\ [SO_4^{2-}] = (z)\ (0.10) = 1.59 \times 10^{-8}$
$z = 1.59 \times 10^{-8} / (0.10) = 1.59 \times 10^{-8} / 1.0 \times 10^{-1} = 1.59 \times 10^{-7}$ mol/L

The solubility of $PbSO_4$ in 0.10 M SO_4^{2-} = 1.59×10^{-7} mol/L
The solubility of $PbSO_4$ in water = 1.59×10^{-4} mol/L (from part (a) above)

Hence $PbSO_4$ is less soluble (by almost a factor of 10^3) in a 0.10 mol/L solution of sulfate ion than in water.

Question 27 (7 marks)
27 (a) (3 marks)
Outcomes Assessed: CH12–7, CH12–13
Targeted Performance Bands: 2-5

Criteria	Marks
• Identifies a substance which is classified as a Brønsted-Lowry acid but not as an acid by the Arrhenius theory • Explains the classification of an acid by both theories • Writes an appropriate equation	3
• TWO of the above	2
• ONE of the above	1

Sample answer

HCl (g) is classified as an acid by the Brønsted-Lowry theory but not by the Arrhenius theory.

NH_3 (g) + HCl (g) $\rightarrow$ NH_4Cl (s)

The Brønsted-Lowry theory classifies an acid as a proton donor and a base as a proton acceptor. In the reaction above, the proton is lost from the acid HCl (g) and gained by the base ammonia. The Brønsted-Lowry theory classification is irrespective of the state of the reactants, so the reaction can occur in the gaseous state.

Arrhenius described acid-base reactions as reactions which took place only in aqueous solution. An acid produced H^+ (now H_3O^+) as the only positive ion in solution. A base was an oxide or hydroxide that produced hydroxide ions in aqueous solution.

The reaction above is not occurring in aqueous solution, so would not have been classified as acid/base by Arrhenius.

27 (b) (4 marks)
Outcomes Assessed: CH12–6, CH12–7, CH12–13
Targeted Performance Bands: 2-6

Criteria	Marks
• Discusses this statement • Predicts the pH of solutions resulting from at least 3 acid/base reactions which produce salt solutions of different pH values • Explains why the pH values of these salt solutions differ • Writes appropriate equations	4
• Predicts the pH of solutions resulting from at least 3 acid/base reactions which produce salt solutions of different pH values • Explains why the pH values of these salt solutions differ • Writes appropriate equations	3
• Predicts the pH of solutions resulting from at least 2 acid/base reactions which produce salt solutions of different pH values • Explains why the pH values of these salt solutions differ • Writes appropriate equations	2
• Outlines some correct information about why salt solutions are not necessarily neutral	1

Sample answer

The pH of the salt solution resulting from the reaction of an acid and a base depends on the acid/base properties of the salt produced. This, in turn, depends on the strengths of the acids and bases used to make the salt.

Salts produced from a combination of strong acids and strong bases form neutral solutions with pH close to 7. For the reaction of sodium hydroxide with hydrochloric acid, the pH of the resulting solution is 7. The salt formed in this reaction is sodium chloride. As neither the sodium ion nor the chloride ion can act as an acid or base with water, the solution remains neutral.

$NaOH\ (aq) + HCl\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)$

For a strong base – weak acid reaction, such as sodium hydroxide reacting with acetic acid, the pH of the resulting solution is close to 9. The pH is 9 because the salt, sodium acetate, produces an alkaline solution. The acetate ion is a base and reacts with water to form hydroxide ions. These hydroxide ions forming from the reaction of the salt with water mean that the resultant solution is in the basic range, not at 7.

$NaOH\ (aq) + CH_3COOH\ (aq) \rightarrow NaCH_3COO\ (aq) + H_2O\ (l)$

$CH_3COO^-\ (aq) + H_2O\ (l) \rightleftharpoons OH^-\ (aq) + CH_3COOH\ (aq)$

For a strong acid – weak base reaction, such as HCl with ammonia solution, the pH at the equivalence point is in the pH 3-5 range. The solution after this reaction is at pH 3-5 because the salt, ammonium chloride, produces an acidic solution. The ammonium ion is a weak acid and reacts with water to form hydronium ions. These hydronium ions forming during the reaction mean that the pH is below 7, and thus the solution is slightly acidic.

NH_3 (aq) + HCl (aq) $\rightarrow$ NH_4Cl (aq)

NH_4^+ (aq) + H_2O (l) $\rightleftharpoons$ H_3O^+ (aq) + NH_3 (aq)

Hence the statement in the question is correct. The salt formed from an acid/base reaction may be neutral but may also be basic or acidic, depending on the acid/base properties of the salt formed.

Question 28 (7 marks)
28 (a) (2 marks)
Outcomes Assessed: CH12–5, CH12–13
Targeted Performance Bands: 2-4

Criteria	Marks
• Identifies water as the weakest acid AND determines the pK_a value for water	2
• Identifies water as the weakest acid OR determines the pK_a value for the identified acid	1

Sample answer

Water. H_2O
$pK_a = -\log(K_a) = -\log(1.0 \times 10^{-14}) = 14.00$ (2 s.f.) (same rule for s.f. in pK_a calculations as in pH; see below)

28 (b) (2 marks)
Outcomes Assessed: CH12–5, CH12–13
Targeted Performance Bands: 3-6

Criteria	Marks
• Calculates the pH to 2 s.f.	2
• Shows some correct working and reasoning	1

Sample answer

$$HCN\ (aq) + H_2O\ (l) \rightleftharpoons CN^-\ (aq) + H_3O^+\ (aq)$$

$$K_a\ HCN = \frac{[CN^-][H_3O^+]}{[HCN]} = 6.2 \times 10^{-10}$$

Let x moles of HCN ionise, forming x moles of H_3O^+

$$K_a\ HCN = \frac{[x][x]}{[0.10 - x]} = 6.2 \times 10^{-10}$$

Since x will be small by comparison with 0.10
Hence $[x]^2 = 6.2 \times 10^{-10} \times 0.10 = 6.2 \times 10^{-11}$
$[H_3O^+] = \sqrt{(6.2 \times 10^{-11})} = 7.87 \times 10^{-6}$ mol/L
Hence pH $= -\log_{10}(7.87 \times 10^{-6}) = 5.10$ (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. Hence $[H_3O^+] = 7.9 \times 10^{-6}$, pH = 5.10.

28 (c) (3 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–13
Targeted Performance Bands: 3-6

Criteria	Marks
• Calculates the pH to 2 s.f. • Explains why this mixture is classified as a buffer	3
• Determines the $[H_3O^+]$ in the buffer AND explains why this mixture is classified as a buffer	2
• Determines the $[H_3O^+]$ in the buffer OR explains why this mixture is classified as a buffer	1

Sample answer

$HCN\ (aq) + H_2O\ (l) \rightleftharpoons CN^-\ (aq) + H_3O^+\ (aq)$

$$K_a\ HCN = \frac{[CN^-][H_3O^+]}{[HCN]} = 6.2 \times 10^{-10}$$

Initial [HCN] = 0.10 mol/L
Initial $[CN^-]$ = 0.10 mol/L
On mixing, the volume is doubled.
So the concentration of each is halved.
After mixing, [HCN] = 0.050 mol/L
After mixing, $[CN^-]$ = 0.050 mol/L

Let x mol/L HCN ionise at equilibrium.

At equilibrium
[HCN] = (0.050 – x) mol/L
$[CN^-]$ = (0.050 + x) mol/L
$[H_3O^+]$ = x mol/L

$$K_a\ HCN = \frac{[CN^-][H_3O^+]}{[HCN]} = 6.2 \times 10^{-10} = \frac{(0.05 + x)(x)}{(0.05 - x)}$$

Since x is small by comparison with 0.05 mol/L

$[H_3O^+] = x = 6.2 \times 10^{-10}$ mol/L

pH = 9.21

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 9.21, 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 HCN and CN^- will change to keep the pH close to 9.21.

Question 29 (5 marks)
29 (a) (2 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–12
Targeted Performance Bands: 3-5

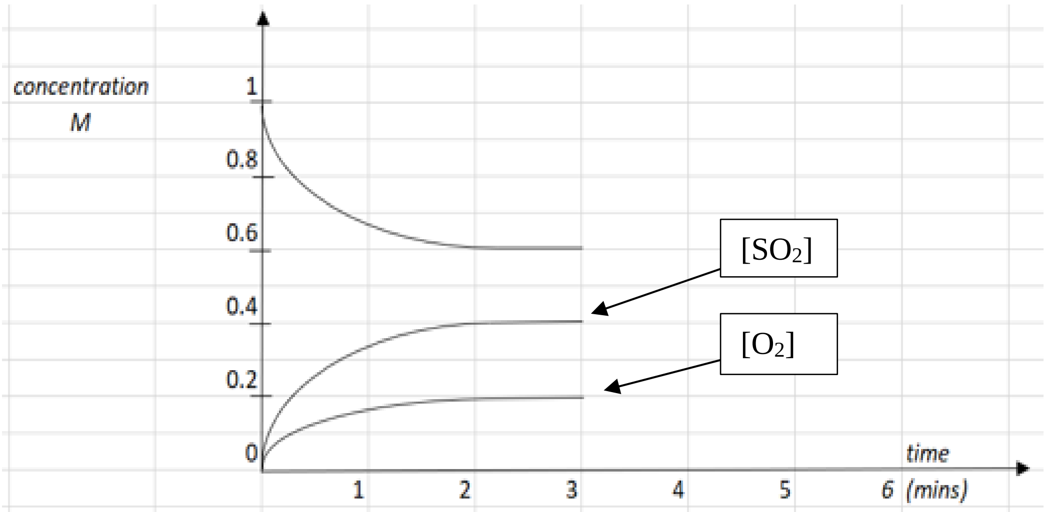
Criteria	Marks
• TWO correct answers	2
• ONE correct answer	1

Sample answer
- No change (as the temperature has not changed).
- The amount (no. of moles) of SO_2 will decrease (as the equilibrium will shift to left).

29 (b) (2 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–12
Targeted Performance Bands: 3-5

Criteria	Marks
• Shows the correct plots BOTH for sulfur dioxide and oxygen	2
• Shows the correct plot for ONE of sulfur dioxide and oxygen	1

Sample answer



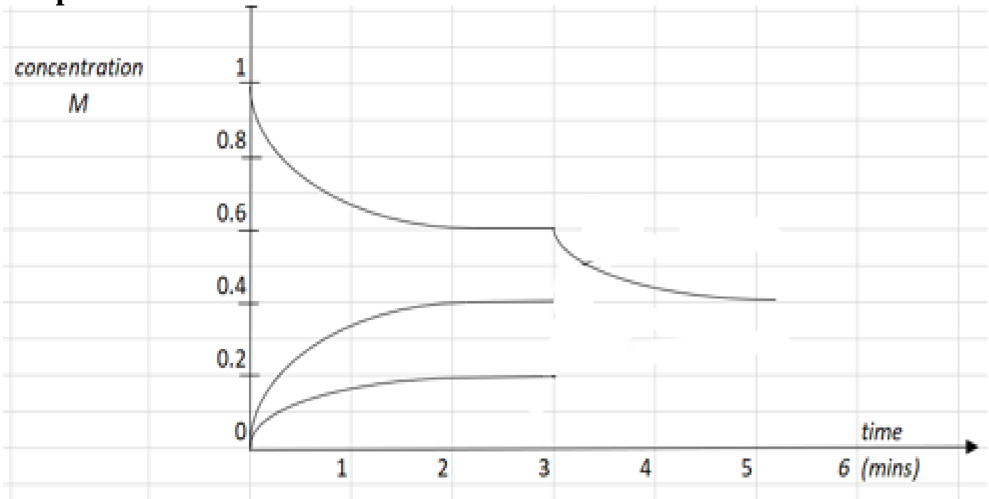
29 (c) (1 mark)

Outcomes Assessed: CH12–5, CH12–7, CH12–12

Targeted Performance Bands: 3-5

Criteria	Mark
• Shows the impact on the $[SO_3]$ after the 3-minute mark	1

Sample answer



(A smooth decline is all that is needed!)

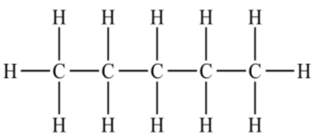
Question 30 (5 marks)
30 (a) (2 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–15
Targeted Performance Bands: 3-6

Criteria	Marks
• Correctly identifies the spectra AND justifies the choice in terms of no. of environments OR the values of the shifts	2
• Correctly identifies the spectra	1

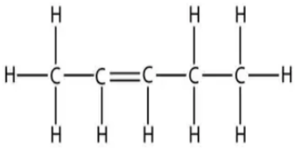
Sample answer

Spectrum 1 is pentane and spectrum 2 is pent-2-ene.

Spectrum 1 shows only 3 different carbon environments, all in the low shift range. These correspond to 3 different carbon environments in pentane.



pentane



pent-2-ene

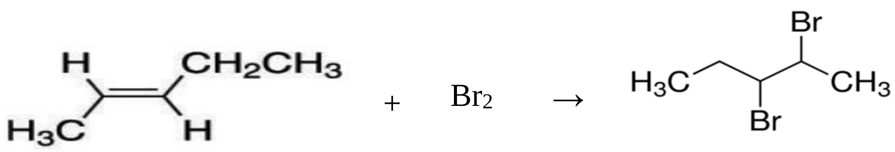
Spectrum 2 shows 5 different carbon environments. This corresponds to the 5 different carbon environments in pent-2-ene. The shift corresponding to 2 of the carbons is significantly higher than the other 3. This corresponds to the 2 carbons in pent-2-ene connected by the double bond.

30 (b) (3 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–14, CH12–15
Targeted Performance Bands: 3-6

Criteria	Marks
• Explains a chemical test to distinguish between the samples of pent-2-ene and pentane AND writes an appropriate equation AND names the organic product formed	3
• Identifies a chemical test to distinguish between the samples of pent-2-ene and pentane AND writes an appropriate equation OR names the organic product formed	2
• Identifies a chemical test to distinguish between the samples of pent-2-ene and pentane	1

Sample answer

The two samples can be distinguished by the addition of bromine water. The alkene, pent-2-ene, will react rapidly, with the yellow-brown bromine being decolourised. The pentane will only react slowly, when heated or if UV light is present. Hence the 2 hydrocarbons can be distinguished by the rate of reaction.



yellow/brown **colourless**

The product is 2,3-dibromopentane.

Question 31 (3 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–14
Targeted Performance Bands: 3-5

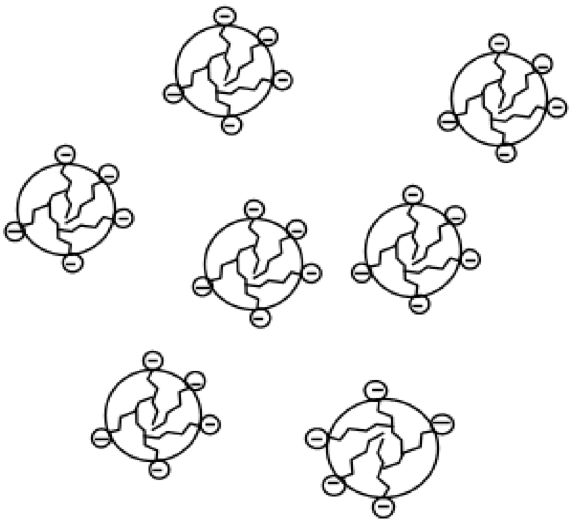
Criteria	Marks
• Discusses the statement • Explains clearly the structure of soap • Links the structure to the removal of fats and oils	3
• Explains clearly the structure of soap • Links the structure to the removal of fats and oils	2
• Outlines some correct information of the structure or cleaning action of soap	1

Sample answer

Soap is the sodium or potassium salt of a long-chain fatty acid. It has a hydrophobic, hydrocarbon tail – which is attracted to the oil or grease – and a negatively charged hydrophilic head – which is attracted to water. The dual nature of the molecule allows the tail to be attracted to (and hence remove) the oil and the head to be attracted to the water. The dirty soap, with oily dirt attached, goes down the drain with the water.

Soap is a surfactant. A surfactant is a substance which disperses dirt and grease as small particles throughout water.

In water, the soap and the dirt form spherical units called micelles.



The dirt is represented by the circle. The hydrophobic tails are attracted to the fat or oil (the dirt), while the anionic heads are on the outer surface of the "micelle" (the dispersed particle), closest to the water. Surfactants also decrease the surface tension of water (they get between the water particles and reduce the force of attraction between them). This reduction in surface tension allows the water particles to wet (spread out over) the surface of a dirty object rather than stay together as a drop of water.

Hence soap, because of its structure and ability to form micelles, is able to remove fats and oils from the skin when the soap is rubbed over the skin with water present.

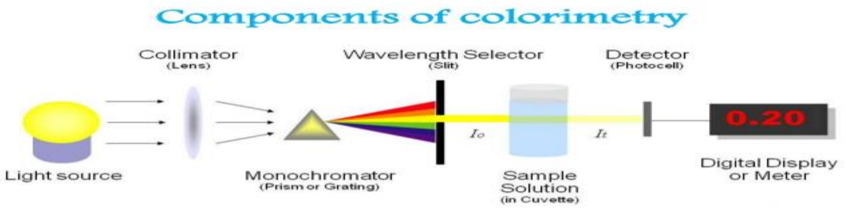
Question 32 (3 marks)

Outcomes Assessed: CH12–6, CH12–7, CH12–15

Targeted Performance Bands: 3-6

Criteria	Marks
• Identifies colorimetry • Outlines the principles of this technique • Identifies Beer's Law and how it impacts on determination of the concentration of a cation	3
• TWO of the above	2
• ONE of the above	1

Sample answer



Colorimetry is a technique used to determine the concentration of coloured compounds in solution. A colorimeter is a device used to test the concentration of a solution by measuring its absorbance of a specific wavelength of light.

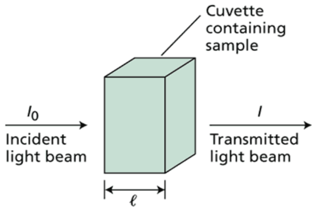
To use the colorimeter, different solutions must be made, including controls or references of known concentration to calibrate the instrument. The colorimeter is set to a specific frequency/wavelength or light may be filtered to achieve this wavelength. The colour or wavelength of the filter chosen for the colorimeter is extremely important, as the wavelength of light that is transmitted by the colorimeter has to be the same as that absorbed by the substance being measured. For example, the filter on a colorimeter might be set to red if the liquid is blue.

The digital output from the colorimeter is the absorbance of light. The absorbance of the unknown sample is determined by using the calibration curve achieved using standards of known concentration. Beer's Law is shown below.

$$A = \varepsilon l c = \log_{10}\frac{I_o}{I}$$

Beer's Law indicates that the absorbance of light (A) is proportional to the concentration (c) of the ion in solution.

The absorbance is also a function of the particular chemical compound (its absorptivity constant, (Ɛ)), the length of the beam of light (l) as it passes through the sample tube and the intensity of the light after passing through the tube by comparison with the intensity of the incident beam.



Question 33 (4 marks)
Outcomes Assessed: CH12–6, CH12–7, CH12–15
Targeted Performance Bands: 3-6

Criteria	Marks
• Correctly predicts the compound as ethanol • Justifies the prediction by outlining the information gained from each of the THREE spectra	4
• Outlines some information gained from each of the THREE spectra	3
• Outlines some information gained from TWO spectra	2
• Outlines some information gained from ONE spectrum	1

Sample answer

The unknown is ethanol.

Spectrum I – ^{1}H NMR spectrum.
This shows that the unknown has hydrogen atoms in 3 different environments. One of these hydrogens does not have another hydrogen on an adjacent atom. This would apply to the hydrogen in an –OH group in ethanol. The splitting pattern shows there are 3 hydrogens attached to a carbon in one environment and 2 in another. This corresponds to a molecule with an ethyl group, $–CH_2CH_3$.

Spectrum II – ^{13}C NMR spectrum.
This spectrum shows only 2 carbon environments. This corresponds to the 2 carbons in ethanol.

Spectrum III – IR spectrum.
The very broad absorption region in the 3500-3000 cm^{-1} range indicates that this is an alcohol and supports the prediction based on Spectra I and II.

Section I

Question	Marks	Content	Syllabus Outcomes	Targeted Performance Bands
1	1	Mod 8: Analysis of Inorganic Substances	CH12–4, CH12–15	2-3
2	1	Mod 5: Calculating the Equilibrium Constant	CH12–4, CH12–12	3-4
3	1	Mod 7: Nomenclature	CH12–4, CH12–14	3-4
4	1	Mod 7: Nomenclature	CH12–4, CH12–14	3-4
5	1	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	3-4
6	1	Mod 6: Quantitative Analysis	CH12–5, CH12–13	3-4
7	1	Mod 6: Using the Brønsted-Lowry Theory	CH12–4, CH12–14	3-4
8	1	Mod 7: Analysis of Organic Acids and Bases	CH12–5, CH12–14	3-4
9	1	Mod 5: Calculating the Equilibrium Constant	CH12–6, CH12–12	3-4
10	1	Mod 6: Using the Brønsted-Lowry Theory	CH12–4, CH12–14	3-4
11	1	Mod 5: Solution Equilibria	CH12–5, CH12–12	3-4
12	1	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	3-4
13	1	Mod 8: Analysis of Inorganic Substances	CH12–6, CH12–15	3-4
14	1	Mod 6: Quantitative Analysis	CH12–5, CH12–13	3-4
15	1	Mod 6: Quantitative Analysis	CH12–5, CH12–13	3-4
16	1	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	4-5
17	1	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	4-5
18	1	Mod 5: Factors that Affect Equilibrium	CH12–5, CH12–12	4-5
19	1	Mod 8: Analysis of Inorganic Substances	CH12–6, CH12–15	5-6
20	1	Mod 7: Nomenclature, Alcohols and Reactions of Organic Acids and Bases	CH12–6, CH12–14	5-6

Section II

Question	Marks	Content	Syllabus Outcomes	Targeted Performance Bands
21 (a)	2	Mod 5: Factors that Affect Equilibrium	CH12–4, CH12–7, CH12–12	2-4
21 (b)	2	Mod 5: Factors that Affect Equilibrium	CH12–4, CH12–7, CH12–12	2-4
21 (c)	3	Mod 5: Solution Equilibria Mod 6: Using the Brønsted-Lowry Theory	CH12–4, CH12– 6, CH12–12, CH12–13	2-5
21 (d)	2	Mod 5: Solution Equilibria	CH12–4, CH12– 6, CH12–12, CH12–13	3-5
22 (a)	2	Mod 6: Quantitative Analysis	CH12–2, CH12–3, CH12–7, CH12–13	3-4
22 (b)	2	Mod 6: Quantitative Analysis	CH12–2, CH12–3, CH12–7, CH12–13	3-4
22 (c)	4	Mod 6: Quantitative Analysis	CH12–5, CH12–6, CH12–13	2-5
23 (a)	3	Mod 7: Nomenclature	CH12–4, CH12–7, CH12–14	3-5
23 (b)	4	Mod 7: Hydrocarbons, Reactions of Organic Acids and Bases	CH12–5, CH12–7, CH12–14	3-6
23 (c)	2	Mod 7: Reactions of Organic Acids and Bases	CH12–4, CH12–7, CH12–14	4-5
24 (a)	4	Mod 8: Analysis of Inorganic Substances	CH12–2, CH12–3, CH12–7, CH12–15	2-5
24 (b)	3	Mod 8: Analysis of Inorganic Substances	CH12–7, CH12–15	3-5
24 (c)	2	Mod 8: Analysis of Inorganic Substances	CH12–4, CH12–7, CH12–15	3-5
25 (a)	3	Mod 7: Alcohols	CH12–3, CH12–7, CH12–14	2-5
25 (b)	2	Mod 7: Alcohols	CH12–4, CH12–7, CH12–14	2-4
26 (a)	3	Mod 5: Solution Equilibria	CH12–4, CH12–6, CH12–12	3-6
26 (b)	3	Mod 5: Solution Equilibria	CH12–4, CH12–6, CH12–12	3-6
27 (a)	3	Mod 6: Using the Brønsted-Lowry Theory	CH12–7, CH12–13	2-5
27 (b)	4	Mod 6: Using the Brønsted-Lowry Theory	CH12–6, CH12–7, CH12–13	2-6
28 (a)	2	Mod 6: Quantitative Analysis	CH12–5, CH12–13	2-4
28 (b)	2	Mod 6: Quantitative Analysis	CH12–5, CH12–13	3-6
28 (c)	3	Mod 6: Quantitative Analysis	CH12–5, CH12–7, CH12–13	3-6
29 (a)	2	Mod 5: Factors that Affect Equilibrium	CH12–5, CH12–7, CH12–12	3-5
29 (b)	2	Mod 5: Factors that Affect Equilibrium	CH12–5, CH12–7, CH12–12	3-5

Question	Marks	Content	Syllabus Outcomes	Targeted Performance Bands
29 (c)	1	Mod 5: Factors that Affect Equilibrium	CH12–5, CH12–7, CH12–12	3-5
30 (a)	2	Mod 8: Analysis of Organic Substances	CH12–5, CH12–7, CH12–15	3-6
30 (b)	3	Mod 7: Products of Reactions Involving Hydrocarbons Mod 8: Analysis of Organic Substances	CH12–5, CH12–7, CH12–14, CH12–15	3-6
31	3	Mod 7: Reactions of Organic Acids and Bases	CH12–5, CH12–7, CH12–14	3-5
32	3	Mod 8: Analysis of Inorganic Substances	CH12–6, CH12–7, CH12–15	3-6
33	4	Mod 8: Analysis of Organic Substances	CH12–6, CH12–7, CH12–15	2-6