![QATs logo - Quality Assessment Tasks]

2019 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 21-32
- Allow about 2 hours and 25 minutes for this section

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   An anion which forms precipitates with solutions of barium ions, calcium ions, silver ions and lead (II) ions is

   A. Cl^-

   B. NO_3^-

   C. CH_3COO^-

   D. SO_4^{2-}

2   Which of the following compounds can be derived both from fossil fuels and from biomass materials?

   A.   Ethanol

   B.   Octane

   C.   Glucose

   D.   Cellulose

3 Three solutions of acids, HX, HY and HZ, are represented by the following diagrams. For clarity, water molecules have not been shown.
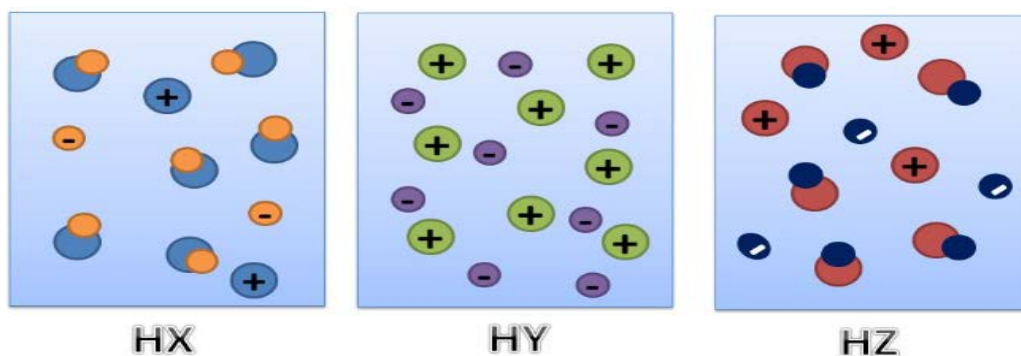
The acids, in order of increasing acid strength, are

A. HX, HY, HZ

B. HZ, HX, HY

C. HX, HZ, HY

D. HY, HZ, HX

4 Consider the following organic compounds:

I – CH_3CH_2COOH

II – CH_3COCH_3

III – CH_3CH_2CHO

Which of the following statements is correct?

A. Compounds I, II and III belong to the same homologous series.

B. Compound I has the lowest boiling point.

C. Compounds II and III have the same molecular formula.

D. Compounds I and III would combine to form an ester and water in the presence of concentrated sulfuric acid.

5   Which of the following shows the product(s) of reaction of but-1-ene with water, in the presence of an acid catalyst?

    A.   Butan-1-ol only.

    B.   Butan-2-ol only.

    C.   A mixture of butan-1-ol and butan-2-ol.

    D.   A mixture of butan-1-ol and butan-4-ol.

6   The pH of a 0.0001 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.   4%

    C.   96%

    D.   100%

7
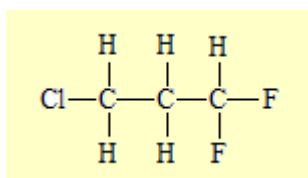
    The compound shown above is

    A.   2-chloro-3,3-difluoropropane

    B.   3-chloro-1-fluoropropane

    C.   3,3-difluoro-1-chloropropane

    D.   3-chloro-1,1-difluoropropane

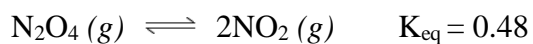**8**   Which of the following organic compounds is most basic?

    A.   Ethane

    B.   Ethanol

    C.   Ethanamide

    D.   Ethanamine

9   At 100°C, the equilibrium constant for the reaction below is 0.48.

    $N_2O_4\ (g) \rightleftharpoons 2NO_2\ (g)$ $K_{eq} = 0.48$

    In an experiment it was found that the concentration of $N_2O_4\ (g)$ was 0.20 mol/L.
    Calculate the concentration of $NO_2\ (g)$ in this equilibrium mixture, in mol/L.

    A.   0.096

    B.   0.31

    C.   0.24

    D.   0.48

10   Which is the INCORRECT statement about the reaction when liquid ethanol burns in
    air?

    A.   The enthalpy and entropy changes for the reaction are both negative.

    B.   The reaction is described as combustion.

    C.   The reaction does not reach equilibrium and the system is classified as open.

    D.   The enthalpy change is negative and gases form.

11   During a spectrophotometric analysis, a chemical of concentration 0.85 M was found to have an absorbance of 0.63. The path length of the cell was 1.5 cm.

What is the molar absorptivity constant of this chemical (in $M^{-1}cm^{-1}$)?

A.   0.36

B.   0.49

C.   2.0

D.   2.8

12   During a precipitation titration using the Mohr method, a 20.0 mL sample of a solution containing chloride ions was titrated with 31.5 mL of 0.150 mol/L $AgNO_3$ to reach the end-point.
Calculate the mass of chloride ions present in the original sample.

A.   0.00473 g

B.   0.0315 g

C.   0.168 g

D.   0.236 g

13 The diagram below represents the titration curve for the reaction between an acid and a base.
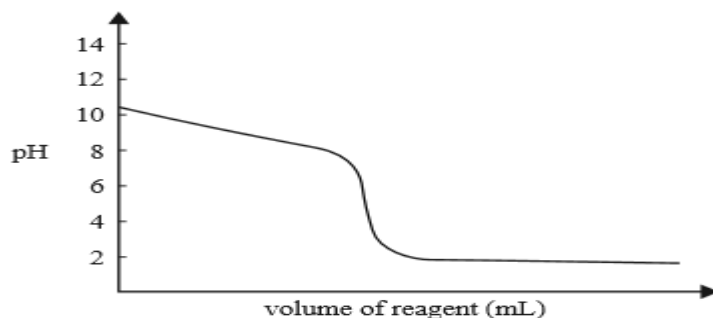
The equation that best represents the reaction described by the titration curve is

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

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

C. $CH_3COOH\ (aq) + NH_3\ (aq) \rightarrow CH_3COONH_4\ (aq)$

D. $CH_3COOH\ (aq) + NaOH\ (aq) \rightarrow CH_3COONa\ (aq) + H_2O\ (l)$

14 Which graph best represents the electrical conductivity changes that occur when an aqueous solution of acetic acid is titrated with an aqueous solution of sodium hydroxide, NaOH?
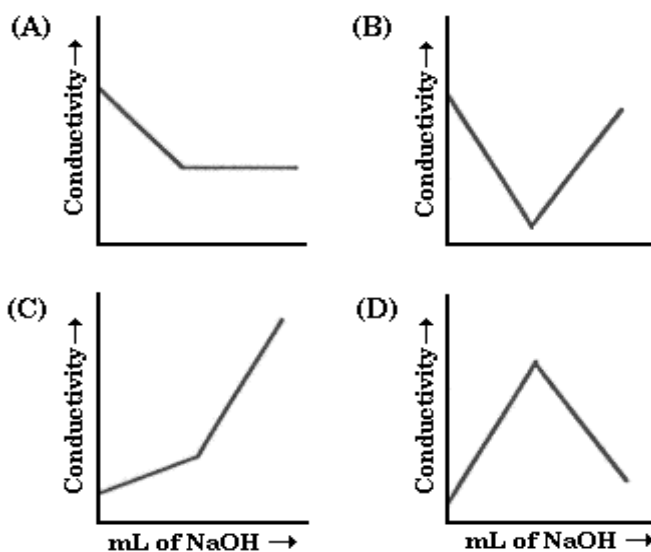
15   What is the pOH of the solution formed when 20.00 mL of 0.250 mol/L HCl is mixed with 80.00 mL of 0.350 mol/L NaOH solution at 25°C?

    A.   0.638

    B.   1.638

    C.   12.362

    D.   13.362

16   The diagram below shows a mass spectrum for an alkane.
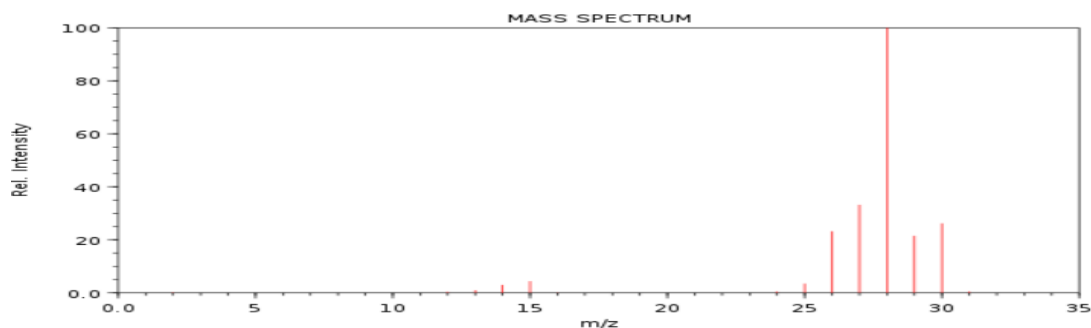
Which alternative correctly summarises the information from this spectrum?

	Parent ion	*Base peak*	*Formula of alkane*
A.	30	14	CH_4
B.	28	30	C_2H_6
C.	30	28	C_2H_6
D.	28	14	CH_4

17 The diagram below shows an infrared spectrum of an organic compound.

INFRARED SPECTRUM
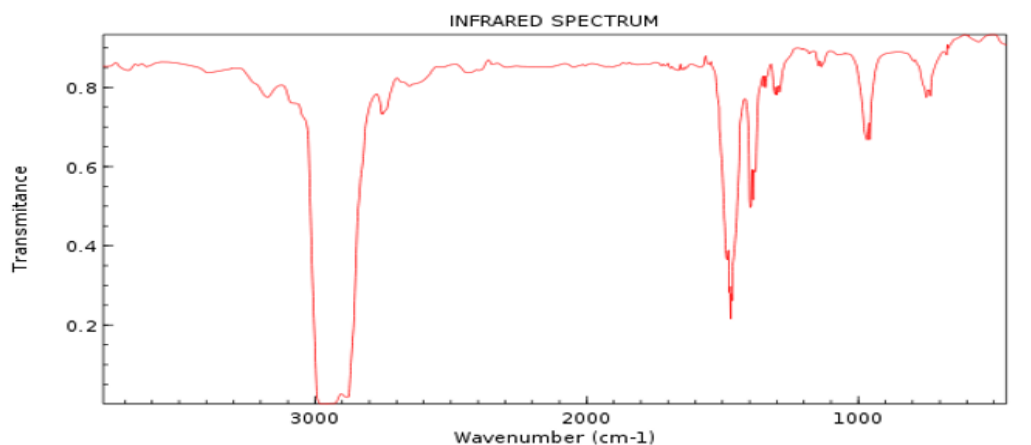
The compound analysed was

A.   butane

B.   butan-1-ol

C.   butan-2-ol

D.   butanoic acid

18 The equilibrium constant for the reaction below has an equilibrium constant K_1.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad K_1 = 159 \text{ at } 500K$$

At the same conditions of temperature and pressure, what is the equilibrium constant for the reaction:

$$HI(g) \rightleftharpoons \tfrac{1}{2}H_2(g) + \tfrac{1}{2}I_2(g)$$
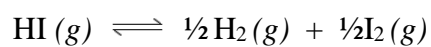
A.   0.00629

B.   0.0793

C.   12.6

D.   79.5

19   When a sample of NO_2 (g) is placed in a container, the following equilibrium is rapidly established:

$$2NO_2 (g) \rightleftharpoons N_2O_4 (g)$$
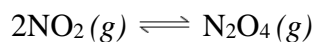
If this equilibrium mixture is a darker colour at high temperatures and at low pressures, which of these statements about the reaction is correct?

A.   The reaction is exothermic and NO_2 is darker in colour than N_2O_4.

B.   The reaction is exothermic and N_2O_4 is darker in colour than NO_2.

C.   The reaction is endothermic and NO_2 is darker in colour than N_2O_4.

D.   The reaction is endothermic and N_2O_4 is darker in colour than NO_2.

20   The K_{sp} of $Ca(OH)_2$ at 25°C is 5.02×10^{-6}.

What is the molar solubility of calcium hydroxide at this temperature?

A. 1.71×10^{-2}

B. 1.08×10^{-2}

C. 2.24×10^{-3}

D. 5.06×10^{-4}

Chemistry

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 34 to 37. If you use this space, clearly indicate which question you are answering.

Question 21 (7 marks)

A student carried out an experiment to compare the energy changes when solid ionic compounds dissolve in water.

(a)   The student observed that the temperature fell when potassium chloride dissolved but rose   **3**
      when sodium hydroxide dissolved.

      Explain these observations, by discussing the processes involved in the dissolution of
      ionic substances in water.

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Question 21 continues on the next page

Question 21 (continued)

(b) "The dissolution both of potassium chloride and of sodium hydroxide occur
     spontaneously."   **2**

     Justify the spontaneity of these physical processes in terms of the changes in enthalpy,
     entropy and Gibbs free energy.

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(c) Some small crystals of copper sulfate solid were observed in a beaker which contained a   **2**
     saturated solution of copper sulfate. The beaker was covered (so that water could not
     evaporate) and the beaker and cover were weighed. Over a period of time, the shape of
     the crystals changed but the weight of the beaker and its contents did not change.

     Explain these observations.

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Question 22 (7 marks)

Nitrogen monoxide, chlorine and NOCl form an equilibrium gaseous mixture:

$$Cl_2\,(g)\ +\ 2NO\,(g)\ \rightleftharpoons\ 2NOCl\,(g)$$
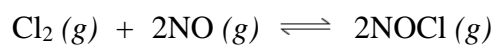
The graph below shows the changes in concentration of the three species over time.

$$Cl_2\,(g)\ +\ 2NO\,(g)\ \rightleftharpoons\ 2NOCl$$
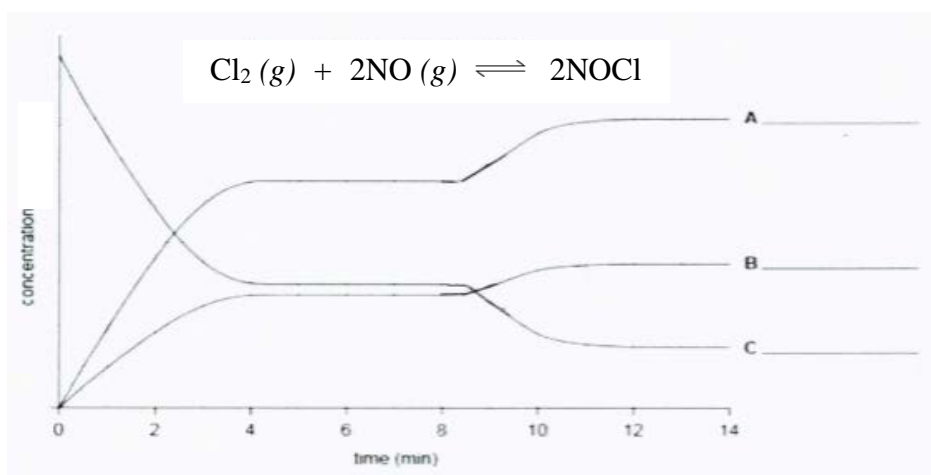
(a)   On the graph above, identify A, B and C as Cl_2, NO and NOCl.   **1**

(b)   Explain the change that was made to the reaction conditions at time $t = 8.5$ min.   **1**

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Question 22 (continued)

(c) Use data from the graph to calculate the equilibrium constant for the reaction (as written in the given equation) at time t = 6 min. **2**

Assume that the initial concentration of reactant C at t = 0 min is 8.5×10^{-2} mol L^{-1}.

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(d) Will the equilibrium constant at t = 12 min be the same as at t = 6 min? Explain your response. **2**

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(e) Will the presence of a catalyst impact on the equilibrium in any way? Explain your response. **1**

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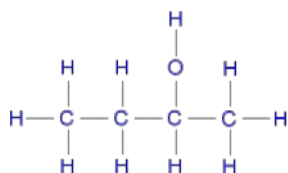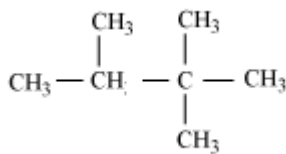**Question 23** (7 marks)

(a) Using IUPAC nomenclature, name the compounds shown below.   **3**
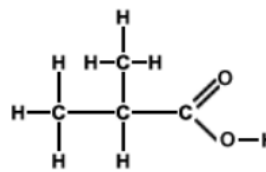
Compound 1   Compound 2   Compound 3

Compound 1 …………………………………………………………………………

Compound 2 …………………………………………………………………………

Compound 3 …………………………………………………………………………

(b) Compare the intermolecular forces in the above 3 molecules and predict the order of   **4**
boiling points (lowest to highest) of these molecules. Explain your prediction.

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Question 24 (4 marks)

A student was asked to distinguish between colourless organic liquids known to be
- butan-1-ol
- butan-2-ol
- 2-methylpropan-2-ol

(a)   Explain how the 3 isomers differ in their structures and how these differences allow   **2**
      them to be distinguished.

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(b)   Outline the observations which would be made to allow the 3 liquids to be identified.   **2**

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Question 25 (6 marks)

(a) Explain how Aboriginal and Torres Strait Islander Peoples have used the principles of solubility equilibria, when removing toxicity from foods such as cycad fruit. **2**

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(b) Calculate and compare the solubilities of $PbCl_2$ in water and in a 0.10 mol/L solution of sodium chloride, at 25°C. **3**

K_{sp} $PbCl_2 = 1.70$ x 10^{-5}

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Question 25 (continued)

(c)   Explain why your 2 answers in part (b) above differ.   **1**
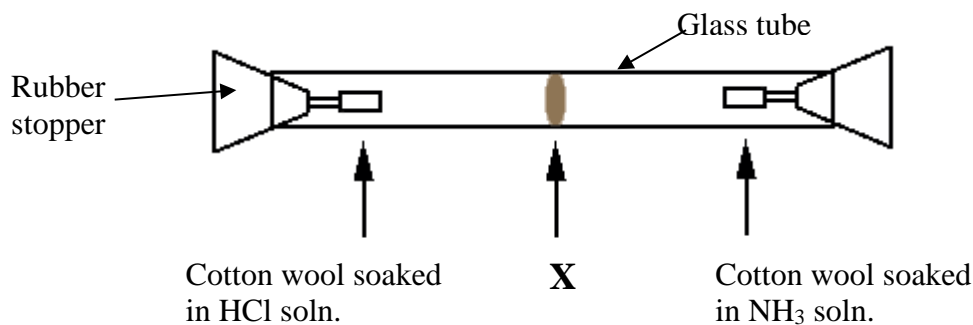
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Question 26 (3 marks)

The diagram shows an experiment related to acid-base reactions.

Glass tube

Rubber stopper

Cotton wool soaked
in HCl soln.

X

Cotton wool soaked
in NH_3 soln.

(a)   Write an equation for the reaction between the gases ammonia and hydrogen chloride   **1**
and hence identify the solid product **X**.

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(b)   Explain why the reaction of ammonia (gas) and hydrogen chloride (gas) can be classed   **2**
as an acid-base reaction by the Brønsted-Lowry theory, but not by the Arrhenius theory.

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Question 27 (9 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 strongest 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 nitrous acid.   **3**

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Question 27 continues on the next page

Question 27 (continued)

(c)   A buffer solution is prepared by combining 100 mL of 0.10 M HNO_2 and 100 mL of   **4**
0.10 M $NaNO_2$.

Calculate the pH of this buffer solution and explain why this solution is classified as a buffer.

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Question 28 (9 marks)

To determine the percentage by mass of calcium carbonate ($CaCO_3$) in an antacid tablet which had a mass of 0.250 g, the following procedure was used:

- The tablet was crushed and then placed in a beaker.

- A pipette was used to add 25.0 mL of 0.120 mol L^{-1} hydrochloric acid to the crushed tablet in the beaker.

- Once the reaction between the calcium carbonate and hydrochloric acid had stopped, phenolphthalein indicator was added to the reaction mixture.

- A burette was then used to add 0.0560 mol L^{-1} sodium hydroxide to the beaker to neutralise the excess hydrochloric acid.

- The phenolphthalein changed from colourless to pink after 27.4 mL of the sodium hydroxide solution had been added.

(a) Write a balanced equation for the reaction between calcium carbonate and hydrochloric acid.

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(b) Determine the percentage by mass of calcium carbonate in the tablet. Show all working and reasoning.

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Question 28 continues on the next page

Question 28 (continued)

(c) Explain the purpose of the indicator used in this experiment. **1**

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(d) Justify the use of phenolphthalein (rather than other indicators) for this titration, even though it changes colour between pH 8.3 and 10.00. **2**

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Question 28 continues on the next page

Question 28 (continued)

(e) Identify an instrumental technique which could be used to determine the concentration **2**
     of calcium ions in a solution and outline the principles of this technique.

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Question 29 (10 marks)

(a) Complete the diagram below by inserting: **8**

- structural formulae for compounds A, C, D, E and F
- the IUPAC names for compounds B, D and F

Compounds B and F may be synthesised as follows.

Compound A Structural formula:		Compound C Structural formula:

H_2O | catalyst

HCl

Compound B
Name:

NH_3

Mixture formed.

Use only 1-chloropropane

$Cr_2O_7^{2-}$
H^+

NaOH

Compound D
Structural formula:

Name:

Compound E
Structural formula:

H_2SO_4

Compound F
Structural formula:

Name:
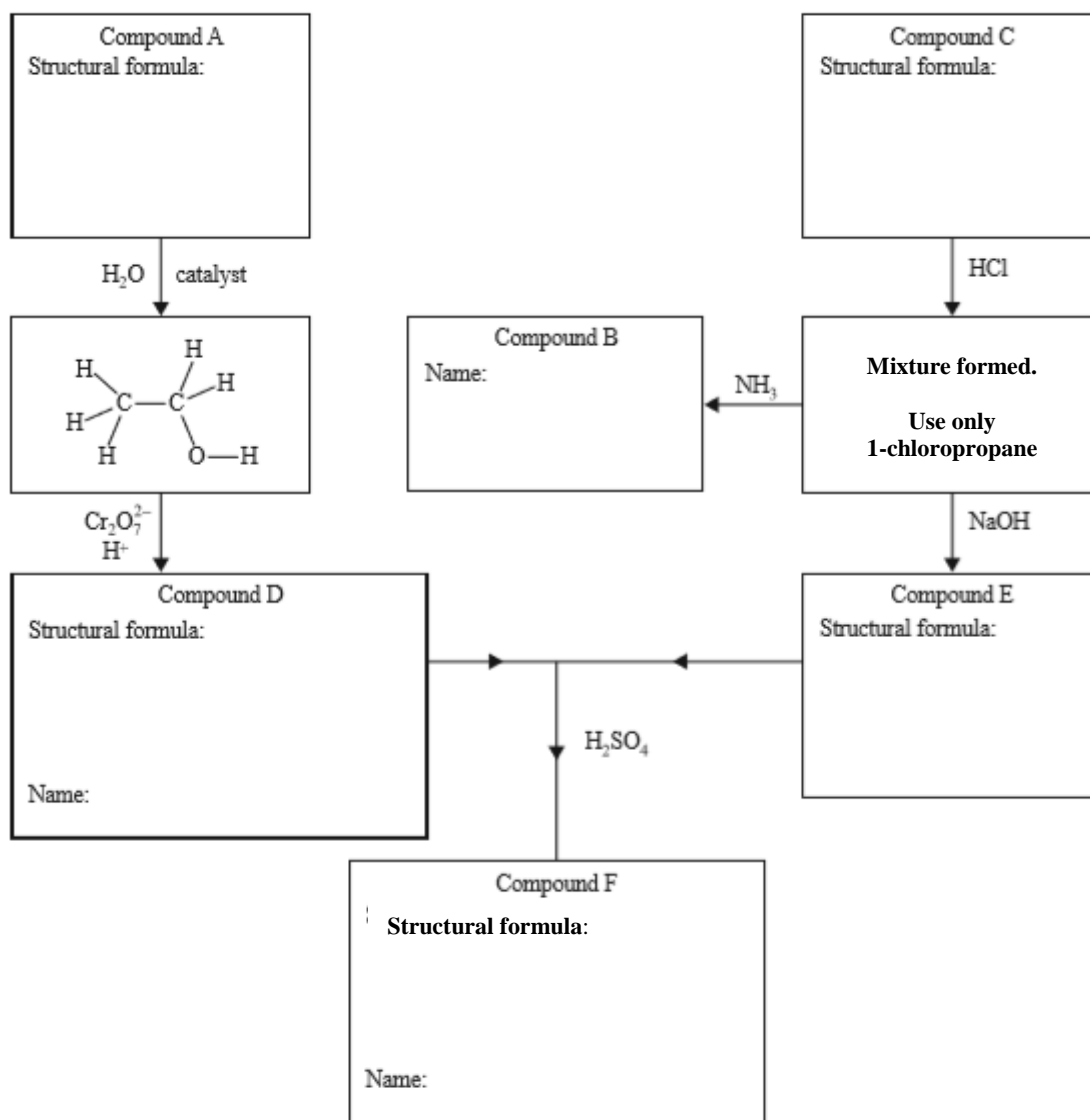
(b) Identify the types of reactions which occur when: **2**

- Compound C is converted to 1-chloropropane ……………………………………..

- 1-chloropropane is converted to Compound E ……………………………………..

Question 30 (3 marks)

Compare the structures, methods of formation and uses of polyvinyl chloride and a polyester.

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Question 31 (11 marks)

An organic compound has a formula $C_xH_yO_2Cl$.

A dilute solution of this compound has a pH of 4.5 at 25°C.

The infrared spectrum, mass spectrum, ^{13}C NMR spectrum and ^1H NMR spectrum for this organic compound are provided on pages 31 and 32.

(a) On the infrared spectrum on page 31, identify and label the 2 peaks that correspond to the 2 functional groups, other than a C–Cl group, in the compound. The C–Cl peak has already been identified on the infrared spectrum for you. **2**

(b) What information about the structure of the compound can be deduced from the pH of the solution of this compound? **1**

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(c) What information about the molecular mass was provided by the mass spectrum? **1**

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(d) Explain why there are 2 (rather than 1) parent ion peaks on the mass spectrum. **1**

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(e) What specific information about the compound was provided by the ^{13}C NMR spectrum? **2**

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Question 31 continues on the next page

Question 31 (continued)

(f) What specific information about the compound was provided by the ^{1}H NMR spectrum **2**
and the splitting patterns.

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(g) Write the molecular formula for the compound and hence identify **x** and **y** in the **1**
formula $\mathbf{C_xH_yO_2Cl.}$

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(h) Draw a structural formula for the compound. **1**

The data for Question 31 are on the next 2 pages.
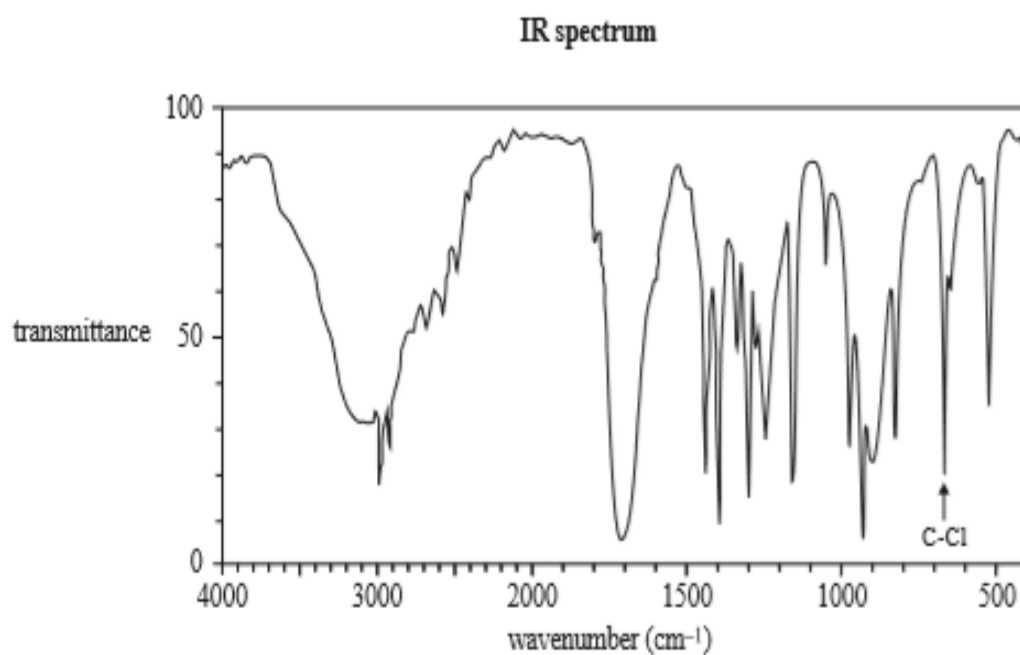
IR spectrum

Data: National Institute of Advanced Industrial Science and Technology

$C_xH_yO_2Cl$ mass spectrum

Isotope data
$^1H : ^2H = 99.99 : 0.01$
$^{12}C : ^{13}C = 98.93 : 1.07$
$^{35}Cl : ^{37}Cl = 75.78 : 24.22$
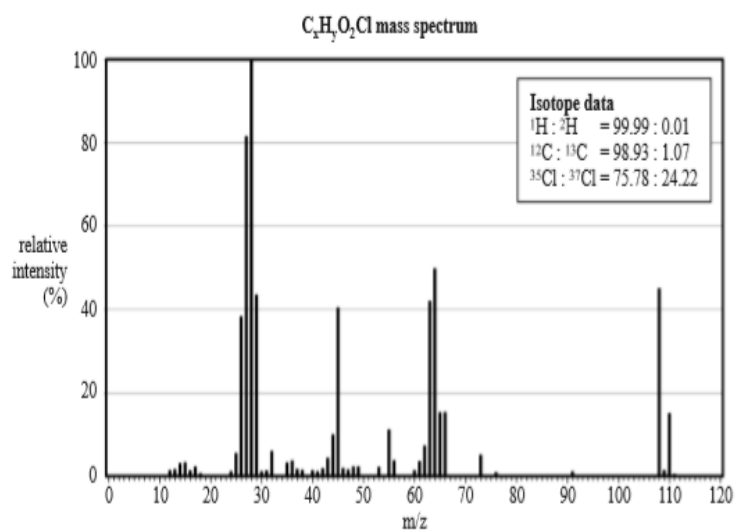
Data: National Institute of Advanced Industrial Science and Technology

^{13}C NMR spectrum
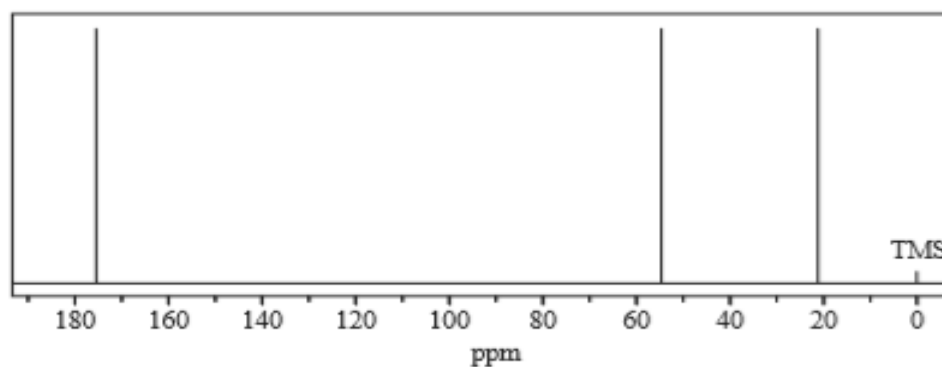
Data: National Institute of Advanced Industrial Science and Technology

^{1}H NMR spectrum
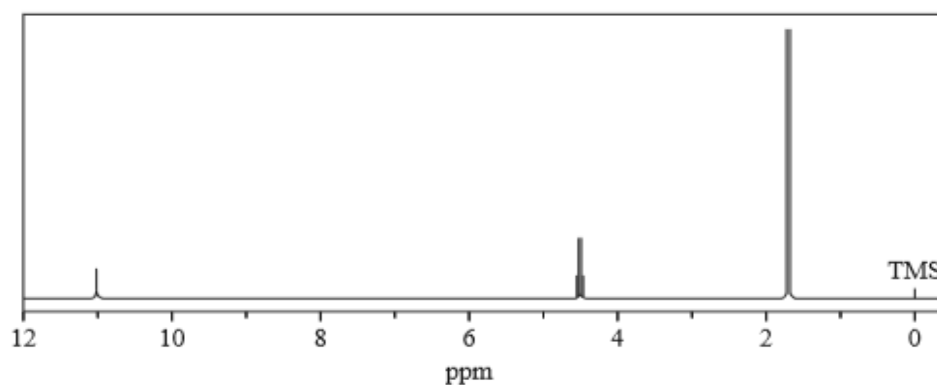
Data: National Institute of Advanced Industrial Science and Technology

^{1}H NMR data

Chemical shift (ppm)	Peak splitting	Relative peak area
1.7	doublet (2 peaks)	3
4.5	quartet (4 peaks)	1
11.2	singlet (1 peak)	1

Question 32 (4 marks)

Using precipitation reactions and the formation of a complex ion, you were able to distinguish between 2 aqueous solutions, one containing lead (II) ions and the other containing silver ions.

(a)   Outline your method. **1**

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(b)   Write an ionic equation for one of the precipitation reactions you describe. **1**

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(c)   Explain the structure and bonding of the complex ion formed when one of the two precipitates dissolves. Include a diagram of the structure of the complex ion in your response. **2**

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End of Paper

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Section II - Extra writing space

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Section II - Extra writing space

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CHEMISTRY – MULTIPLE-CHOICE ANSWER SHEET

ATTEMPT ALL QUESTIONS

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

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Chemistry

FORMULAE SHEET

$$n = \frac{m}{MM} \qquad\qquad c = \frac{n}{V} \qquad\qquad PV = nRT$$

$$q = mc\Delta T \qquad\qquad \Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \qquad\qquad pH = -\log_{10}[H^+]$$

$$pK_a = -\log_{10}[K_a] \qquad\qquad A = \varepsilon lc = \log_{10}\frac{I_o}{I}$$

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—C— ‖O	20–50
R—C—N	25–60
—C—O— alcohols, ethers or esters	50–90
C=C	90–150
R—C≡N	110–125
(benzene ring)	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

79
Au
197.0
Gold

Atomic Number / Symbol / Standard Atomic Weight / Name

Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
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.

2019 Higher School Certificate
Trial Examination

Mapping Grid

Section I

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

Question 21 (7 marks)
21 (a) (3 marks)
Outcomes Assessed: CH12–7, CH12–12
Targeted Performance Bands: 2-5

Criteria	Marks
• Explains the observations fully, by discussing the steps in the dissolution of ionic substances in water	3
• Partially explains the observations, by discussing some aspects of the steps in the dissolution of ionic substances in water	2
• Identifies some correct information about the observations OR the steps in dissolution	1

Sample answer
The dissolution process of an ionic solid in water involves 3 steps. The steps are described below.
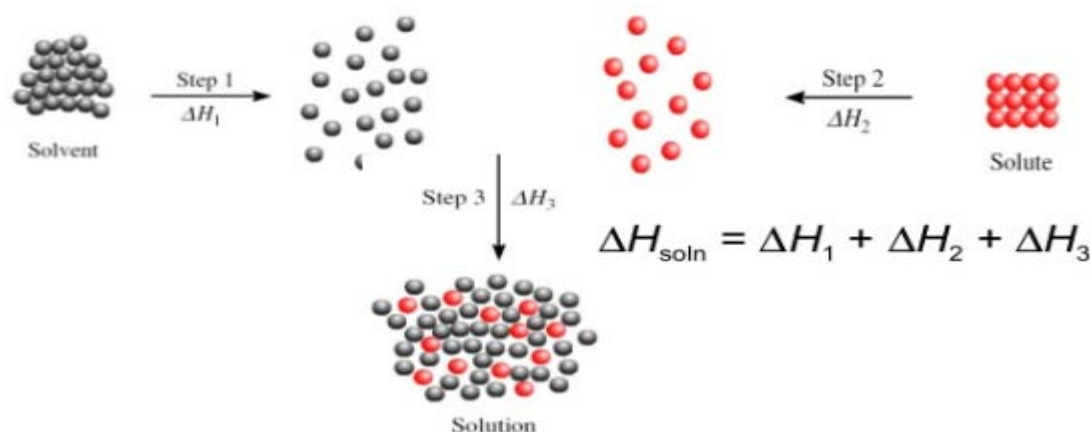
Step 1 involves the separation of molecules of the solvent. This step is **endothermic**, as energy is required to separate the solvent molecules from each other. Water molecules are strongly held together by hydrogen bonds.

Step 2 involves the separation of the ions in the solid. This is called **dissociation**. The dissociation step is endothermic, as the electrostatic forces in the ionic crystal need to be overcome.

Step 3 involves the mixing of the solvent and solute molecules. The ions from the solid are surrounded by the water molecules in a process called **hydration**. Hydration releases energy and hence is exothermic.

As the temperature fell during the dissolution of potassium chloride, the heat required for the endothermic steps (1 and 2) must be greater than that released in step 3. Net energy is taken from the surroundings so the temperature of the water falls.

Conversely, for the dissolution of sodium hydroxide, the energy released in the exothermic step 3 must be greater than that required for the sum of steps 1 and 2. Since net energy is released to the surroundings, the temperature rises.

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

Criteria	Marks
• Justifies the spontaneity of the dissolution processes, in terms of enthalpy, entropy and Gibbs free energy	2
• Explains some correct information about changes in terms of enthalpy, entropy and Gibbs free energy when dissolution occurs	1

Sample answer
Since both dissolution reactions occur spontaneously, the Gibbs energy must be negative.

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

In the case of potassium chloride, even though the reaction is not favoured by enthalpy considerations (ΔH is +ve), it must be favoured by entropy changes (ΔS is +ve) or the dissolution would not occur spontaneously. Since during dissolution the particles of the solid separate from each other and are spread through the solution, the particles move to a more random arrangement – hence entropy increases. Since a solid has dissolved to form a solution – a more random arrangement of particles and hence an increase in entropy – then the net effect is still an overall spontaneous reaction.

During dissolution of sodium hydroxide, the process is exothermic (ΔH is -ve), and the particles move to a more random state (ΔS is +ve), then both enthalpy and entropy are driving forces. The Gibbs energy is negative, and the reaction occurs spontaneously.

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

Criteria	Marks
• Correctly explains the change in shape and the constancy of mass in terms of the dynamic equilibrium	2
• Correctly explains the change in shape or the constancy of mass in terms of particles	1

Sample answer

Equilibrium exists between a saturated aqueous solution of copper sulfate and solid crystals of copper sulfate. The forward and backward reactions for the dissociation and formation of solid $CuSO_4$ are occurring in the beaker at the same rate. Hence no matter is leaving the system (the beaker is covered) so the mass remains constant. The processes of dissolution (ions leaving the crystal surface) and crystallisation (ions returning to the crystal surface) occur at the same rate but do not necessarily leave and return at the same location on the crystal surface. Hence the system can remain in equilibrium even though the shape of the crystal changes.

Question 22 (7 marks)
22 (a) (1 mark)
Outcomes Assessed: CH12–5, CH12–12
Targeted Performance Bands: 3-4

Criteria	Mark
• Correctly identifies A, B and C	1

Sample answer
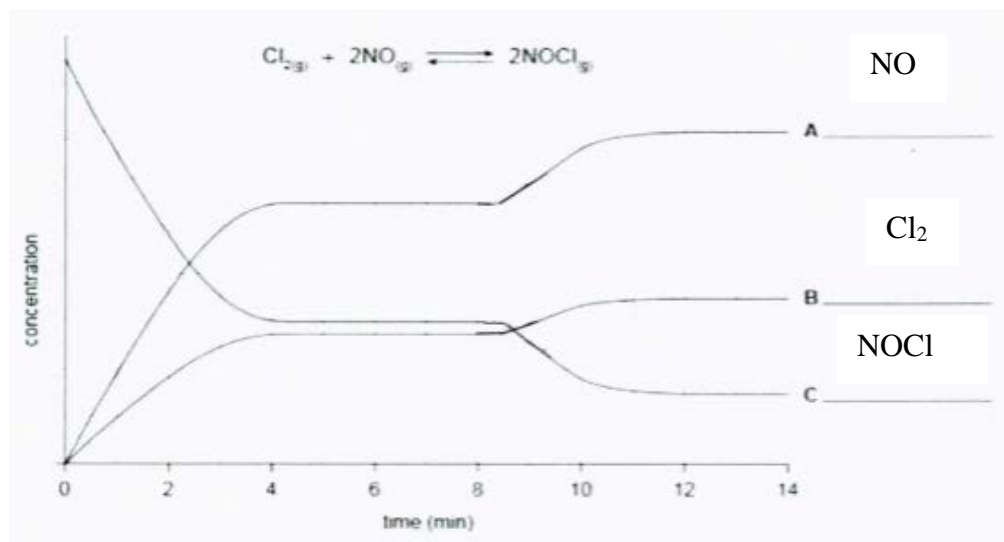
22 (b) (1 mark)
Outcomes Assessed: CH12–7, CH12–12
Targeted Performance Bands: 3-5

Criteria	Mark
• Explains that a temperature change has occurred (which could be an increase or decrease in temperature)	1

Sample answer
A change in temperature has occurred.
As no data has been given as to whether the forward reaction is exothermic or endothermic, it is not possible to state whether the temperature has increased or decreased. The change in temperature has caused a shift in the equilibrium towards the left (as the equation is written in the question paper) – producing higher concentrations of chlorine and nitrogen monoxide and a lower concentration of NOCl. If the forward reaction is exothermic, then an increase in temperature has occurred. Conversely, if the forward reaction (as written in the question paper) is endothermic, a decrease in temperature has occurred. Le Chatelier's Principle predicts that, if an equilibrium is disturbed, an increase in temperature favours the endothermic reaction.

22 (c) (2 marks)
Outcomes Assessed: CH12–4, CH12–7, CH12–12
Targeted Performance Bands: 3-5

Criteria	Marks
• Correctly calculates the equilibrium constant at 6 minutes, using the correct data from the graph	2
• Uses the correct equilibrium constant expression OR uses correct data from the graph	1

Sample answer
At t = 6 min
$[NOCl] = 3.0 \times 10^{-2}$ mol/L
$[Cl_2] = 2.75 \times 10^{-2}$ mol/L
$[NO] = 5.5 \times 10^{-2}$ mol/L

$$K_{eq} = \frac{[NOCl]^2}{[Cl_2][NO]^2} = \frac{(3.0 \times 10^{-2})^2}{(2.75 \times 10^{-2})(5.5 \times 10^{-2})^2} = \frac{9.0 \times 10^{-4}}{8.3 \times 10^{-5}}$$

$$= 11 \text{ (to 2 s.f.)}$$

22 (d) (2 marks)
Outcomes Assessed: CH12–6, CH12–7, CH12–12
Targeted Performance Bands: 2-3

Criteria	Marks
• Identifies that the equilibrium constants at t = 6 min and at t = 12 min differ because the temperature has changed	2
• Identifies that the equilibrium constants are different	1

Sample answer
Equilibrium constants depend on temperature.
Since the temperature changed at t = 8 min but did not change again, the equilibrium constant at t = 6 min will differ from the equilibrium constant t = 12 min.

22 (e) (1 mark)
Outcomes Assessed: CH12–7, CH12–12
Targeted Performance Bands: 3-4

Criteria	Mark
• Correct answer in terms of rates and yield	1

Sample answer
A catalyst will increase the rate both of the backward and forward reactions equally and will hence decrease the time taken for a new equilibrium to be achieved after an imposed change. However, it will not alter the concentrations of the species at equilibrium. Hence the presence of a catalyst will not alter the equilibrium constants.

Question 23 (7 marks)
23 (a) (3 marks)
Outcomes Assessed: 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 = butan-2-ol
Compound 2 = 2,2,3-trimethylbutane
Compound 3 = 2-methylpropanoic acid

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

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 point 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 oxygen results in a very polar bond with hydrogen in the O–H group. This hydrogen is attracted to the oxygen of a neighbouring alcohol molecule. The geometry of the molecule only allows 1 H-bond per pair of molecules at any instant.

Compound 3 is an acid and has the very polar – COOH functional group. The hydrogen atom of the –COOH can form a hydrogen bond with an oxygen of the neighbouring acid molecule. The planar nature of this –COOH 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.

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

Criteria	Marks
• Identifies the isomers as primary, secondary or tertiary alcohols and hence 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	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 butan-1-ol is a primary alcohol, butan-2-ol is a secondary alcohol and 2-methylpropan-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; e.g. butan-1-ol.
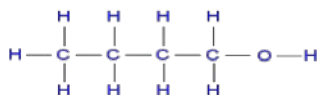
Secondary alcohol: the –OH group is attached to a carbon which is attached to 2 other carbons; e.g. butan-2-ol.
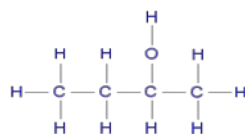
Tertiary alcohol: the –OH group is attached to a carbon which is attached to 3 other carbons; e.g. 2-methylpropan-2-ol.
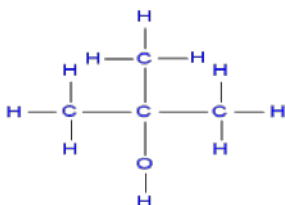
The 3 types of alcohols are distinguished between by reaction of a sample of each alcohol with acidified potassium dichromate solution, followed by testing of any products to distinguish between the primary and secondary alcohols. The 3 alcohols react differently (see below).

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

Criteria	Marks
• Outlines the observations (being colour changes from orange to green) for the oxidation reactions of primary and secondary alcohols AND outlines that no colour change is observed for the tertiary alcohol AND outlines that the product of oxidation of a primary alcohol is acidic and hence can be distinguished from the product of oxidation of a secondary alcohol	2
• ONE of the above	1

Sample answer

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, butan-1-ol is converted to butanal and then butanoic acid.

Secondary alcohols react with acidified potassium dichromate solution but form ketones/alkanones, not acids. Here butan-2-ol reacts to form propanone (acetone). 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.

Question 25 (6 marks)
25 (a) (2 marks)
Outcomes Assessed: CH12–7, CH12–12
Targeted Performance Bands: 2-4

Criteria	Marks
• Explains thoroughly how Aboriginal and Torres Strait Islander Peoples use the principles of solubility equilibria to remove toxins from foods	2
• Explains some aspects of removal of toxicity by leaching	1

Sample answer
Aboriginal and Torres Strait Islander Peoples remove soluble toxic substances from foods by leaching.

For example, cycad seeds are used in making breads, but these breads are poisonous if the seeds are not crushed and leaching used to remove the poisons.

The paste formed is left in water until the solubility of the poison in water is reached. This is achieved when the solubility equilibrium between the solid poison and the solution of poison has been achieved. The solution has then become saturated with the toxin. The equilibrium is then destroyed by removing the saturated solution containing the toxin, adding new pure water and waiting until equilibrium is again reached. The saturated solution is removed, fresh water added and the process repeated. Each step drives the equilibrium to the right and reduces the amount of toxin remaining in the seed.

The seed is then roasted to remove any residual toxin, before being used in cooking.

25 (b) (3 marks)
Outcomes Assessed: 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 $PbCl_2$ in water AND in sodium chloride solution but no overall comparison made	2
• Correct calculation for solubility of $PbCl_2$ in water OR in sodium chloride solution	1

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

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

Let the solubility of $PbCl_2$ in a 0.10 mol/L solution of sodium chloride = z
$K_{sp} PbCl_2 = [Pb^{2+}] [Cl^-]^2 = (z) (0.10 + 2z)^2 = 1.70 \times 10^{-5}$
Since z is small by comparison with 0.10
$K_{sp} PbCl_2 = [Pb^{2+}] [Cl^-]^2 = (z) (0.10)^2 = 1.70 \times 10^{-5}$
$z = 1.70 \times 10^{-5} / (0.10)^2 = 1.70 \times 10^{-5} / 1.0 \times 10^{-2} = 1.7 \times 10^{-3} mol/L$

The solubility of $PbCl_2$ in 0.10 M $Cl^- = 1.7 \times 10^{-3} mol/L$

Hence $PbCl_2$ is less soluble (by almost a factor of 10) in a 0.10 mol/L solution of chloride ion than in water.

25 (c) (1 mark)
Outcomes Assessed: CH12–7, CH12–12
Targeted Performance Bands: 4-5

Criteria	Mark
• Explains why the 2 answers in part (b) above differ	1

Sample answer
In a chemical solution in which several species are in equilibrium, increasing the concentration of any one of the ions by adding another chemical that also contains this ion will cause an increased amount of solid to form. This result is a consequence of Le Chatelier's Principle. The effect is seen (as here, in the result in part (b) above) as an effect on the solubility of salts. Adding an additional amount of one of the ions of the salt generally leads to increased precipitation of the salt, which reduces the product of the concentration of ions of the salt until the solubility equilibrium (K_{sp}) is reached.

Question 26 (3 marks)
26 (a) (1 mark)
Outcomes Assessed: CH12–7, CH12–13
Targeted Performance Bands: 2-3

Criteria	Mark
• Writes a correct, balanced equation and identifies ammonium chloride	1

Sample answer
$NH_3 (g) + HCl (g) \rightarrow NH_4Cl (s)$
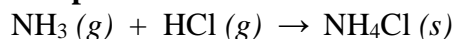
The solid formed on the inside of the tube is ammonium chloride.

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

Criteria	Marks
• Explains why the reaction in part (a) is classified as an acid-base reaction by the Brønsted-Lowry theory AND explains why the reaction is NOT classified as an acid-base reaction by the Arrhenius theory	2
• Explains why the reaction in part (a) is classified as an acid-base reaction by the Brønsted-Lowry theory OR explains why the reaction is NOT classified as an acid-base reaction by the Arrhenius theory	1

Sample answer
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.

Question 27 (9 marks)

27 (a) (2 marks)

Outcomes Assessed: CH12–5, CH12–13

Targeted Performance Bands: 2-4

| Criteria	Marks
• Identifies chlorous acid as the strongest acid AND determines the pK_a value for the identified acid	2
• Identifies chlorous acid as the strongest acid OR determines the pK_a value for the identified acid	1

Sample answer

Chlorous acid, $HClO_2$

$pK_a = -\log(K_a) = -\log(1.1 \times 10^{-2}) = 1.96$ (2 s.f.) (same rule for s.f. in pK_a calculations as in pH)

27 (b) (3 marks)

Outcomes Assessed: CH12–5, CH–6, CH12–13

Targeted Performance Bands: 3-6

Criteria	Marks
• Calculates the pH to 2 s.f. • Correctly determines the $[H_3O^+]$ • Shows correct working and reasoning	3
• Correctly determines the $[H_3O^+]$ • Shows correct working and reasoning	2
• Shows some correct working and reasoning	1

Sample answer

HNO_2 *(aq)* $+$ H_2O *(l)* $\rightleftharpoons$ NO_2^- *(aq)* $+$ H_3O^+ *(aq)*
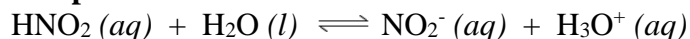
$K_a\ HNO_2 = \dfrac{[NO_2^-]\,[H_3O^+]}{[HNO_2]} = 7.2 \times 10^{-4}$

Let x moles of HNO_2 ionise, forming x moles of H_3O^+

$K_a\ HNO_2 = \dfrac{[x]\,[x]}{[0.10 - x]} = 7.2 \times 10^{-4}$

Since x will be small by comparison with 0.10

Hence $[x]^2 = 7.2 \times 10^{-4} \times 0.10 = 7.2 \times 10^{-5}$

$[H_3O^+] = \sqrt{(7.2 \times 10^{-5})} = 8.5 \times 10^{-3}$ mol/L

Hence pH $= -\log_{10}(8.5 \times 10^{-3}) = 2.07$ (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 $[H_3O^+] = 8.5 \times 10^{-4}$, pH $= 2.07$.
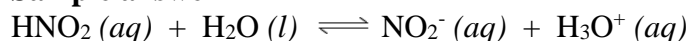
27 (c) (4 marks)
Outcomes Assessed: CH12–5, CH–6, CH12–7, CH12–13
Targeted Performance Bands: 3-6

Criteria	Marks
- Calculates the pH to 2 s.f. - Correctly determines the $[H_3O^+]$ - Shows correct working and reasoning - Explains why this mixture is classified as a buffer	4
• THREE of the above	3
• TWO of the above	2
• ONE of the above	1

Sample answer
HNO_2 *(aq)* + H_2O *(l)* $\rightleftharpoons$ NO_2^- *(aq)* + H_3O^+ *(aq)*

K_a HNO_2 = $\dfrac{[NO_2^-][H_3O^+]}{[HNO_2]}$ = 7.2 x 10^{-4}

Initial $[HNO_2]$ = 0.10 mol/L
Initial $[NO_2^-]$ = 0.10 mol/L

On mixing, the volume is doubled.
So the concentration of each is halved.

After mixing, $[HNO_2]$ = 0.050 mol/L
After mixing, $[NO_2^-]$ = 0.050 mol/L

Let x mol/L HNO_2 ionise at equilibrium.

At equilibrium
$[HNO_2]$ = (0.05 – x) mol/L
$[NO_2^-]$ = (0.05 + x) mol/L
$[H_3O^+]$ = x mol/L

K_a HNO_2 = $\dfrac{[NO_2^-][H_3O^+]}{[HNO_2]}$ = 7.2 x 10^{-4} = $\dfrac{(0.05 + x)(x)}{(0.05 – x)}$
Since x is small by comparison with 0.05 mol/L

$[H_3O^+]$ = x = 7.2 x 10^{-4} mol/L

pH = 3.14

This solution is classified as a buffer as the pH of the solution will not change significantly if small additions of acid or base are added.
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 3.14.

Question 28 (9 marks)

28 (a) (1 mark)
Outcomes Assessed: CH12–7, CH12–13
Targeted Performance Bands: 2-3

Criteria	Mark
• Writes a correct balanced equation	1

Sample answer

$CaCO_3$ *(s)* + $2HCl$ *(aq)* → $CaCl_2$ *(aq)* + CO_2 *(g)* + H_2O *(l)*

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

Criteria	Marks
• Calculates correctly the percentage by mass of $CaCO_3$ in the tablet	3
• Determines the moles of HCl in excess	2
• Determines the moles of HCl added to the flask	1

Sample answer

There were 3 steps in the process:
• A tablet was crushed and placed in a beaker
• 25.0 mL of 0.120 M hydrochloric acid was pipetted into the beaker
• The excess HCl was titrated with NaOH to determine the no. of moles of HCl in excess and hence the no. of moles of $CaCO_3$

Moles HCl added initially to react and dissolve $CaCO_3$ = cV = 0.120 x 0.025 = 0.00300 mol

Moles NaOH required for titration excess HCl = 0.0274 x 0.0560 = 0.00153 mol

Hence moles of excess HCl = 0.00153 (as NaOH and HCl react in 1:1 ratio)

Moles of HCl which had reacted with tablet = 0.00300 – 0.00153 = 0.00147 mol

Moles $CaCO_3$ = ½ moles HCl (from balanced equation)

Hence moles $CaCO_3$ in tablet = 0.000735 mol

Mass of $CaCO_3$ in tablet = n x M = 0.000735 x 100.1 = 0.0736 g (3 s.f.)

% $CaCO_3$ in tablet = 0.0736/0.250 x 100 = 29.4%

28 (c) (1 mark)
Outcomes Assessed: CH12–7, CH12–13
Targeted Performance Bands: 2-4

Criteria	Mark
• Explains the purpose of the indicator	1

Sample answer
Phenolphthalein is added after the reaction with the tablet had stopped to show that the solution still had excess acid in it. It would then have been colourless. (The reaction could have stopped because not enough HCl had been added.) When the phenolphthalein changed to pink, it showed all the excess acid had been neutralised and a drop of NaOH, which turns phenolphthalein pink, was now in the mixture.

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

Criteria	Marks
• Justifies the use of phenolphthalein rather than a different indicator for this titration AND explains the relevance of the pH of the colour change in titrations	2
• Justifies the use of phenolphthalein rather than a different indicator for this titration OR explains the relevance of the pH of the colour change in titrations	1

Sample answer
The titration involved in this experiment involved a strong acid, HCl, and a strong base, NaOH.

Indicators for a titration are chosen so that the colour change occurs at the same pH as the pH at the equivalence point.

The equivalence point for strong acid/strong base titrations is close to pH 7. Indicators such as litmus and bromothymol blue do change colour at pH 7, so might have been more suitable for the titration.

However, the use of phenolphthalein is justified, as the colour change for phenolphthalein is easy to detect (colourless to pink) and does not go through a gradation in colours, as do bromothymol blue and litmus solution.

Of greater significance is the fact that the pH changes so rapidly around the equivalence point in a strong acid/strong base titration. The pH changes in only 1 drop of base from pH 7 to 10. As a result, very little error (1 drop) will have occurred in the measurement of the volume of titrant added.

28 (e) (2 marks)
Outcomes Assessed: CH12–7, CH12–15
Targeted Performance Bands: 3-5

Criteria	Marks
• Identifies an instrumental technique which could be used to determine the concentration of calcium ions in solution AND outlines the principles of this technique	2
• Identifies an instrumental technique which could be used to determine the concentration of calcium ions in solution	1

Sample answer (many possible answers)

AAS could be used to determine the concentration of calcium ions in solution. This instrumental technique involves passing light of a frequency known to be absorbed by calcium ions through a sample. The intensities of light incident on the sample and after passing through the sample are compared. The absorbance measures the proportion of light of that frequency absorbed by the sample. The absorbance is proportional to the concentration of ions in the solution. The spectrometer would need calibrating before the sample was tested. This would involve using standards of known concentration and measuring their absorbance, using the same spectrometer under the same conditions. A calibration curve could be drawn for determination of the concentration of the unknown solution.

Question 29 (10 marks)
29 (a) (8 marks)
Outcomes Assessed: CH12–5, CH12–7, CH12–14
Targeted Performance Bands: 3-6

Criteria	Marks
• Completes 8 structural formulae or names	8
• Completes 7 structural formulae or names	7
• Completes 6 structural formulae or names	6
• Completes 5 structural formulae or names	5
• Completes 4 structural formulae or names	4
• Completes 3 structural formulae or names	3
• Completes 2 structural formulae or names	2
• Completes 1 structural formula or name	1

Sample answer

Compounds B and F may be synthesised as follows.
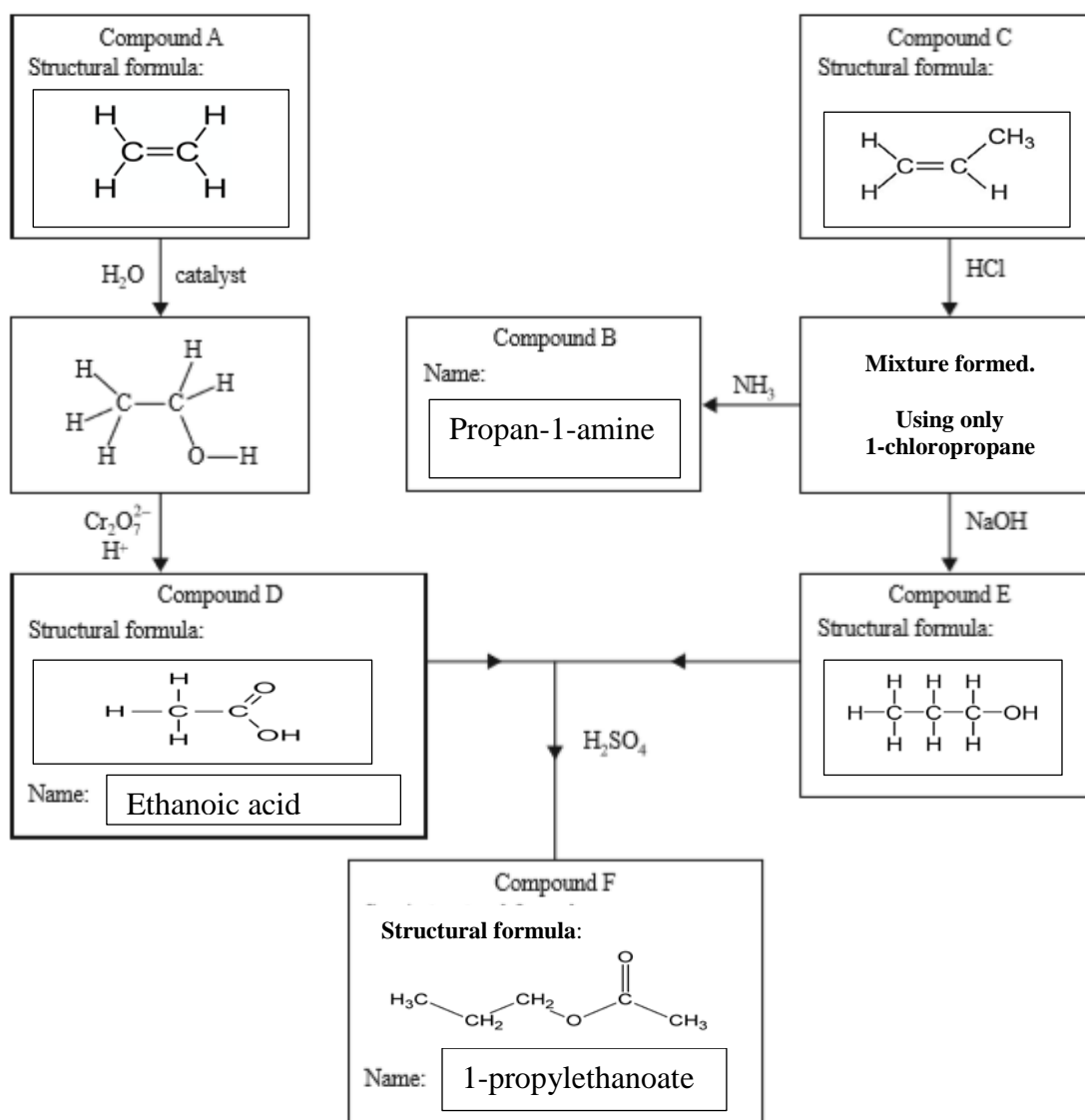
29 (b) (2 marks)
Outcomes Assessed: CH12–7, CH12–14
*Targeted Performance Bands: 4-5*

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

Sample answer
- Compound C is converted to 1-chloropropane in an **addition** reaction   (Note for teachers: the addition reaction produces a mixture of 1-chloropropane and 2-chloropropane. 1-chloropropane is the minor product (see Markovnikoff's Rule).)
- 1-chloropropane is converted to Compound E in a **substitution** reaction.

Question 30 (3 marks)
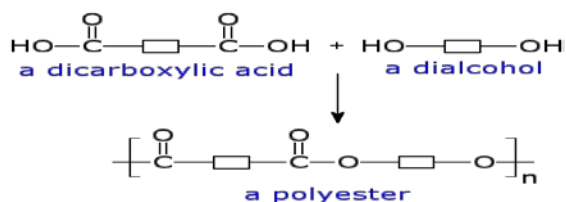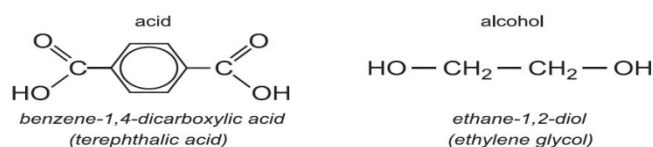*Outcomes Assessed: CH12–7, CH12–14*
Targeted Performance Bands: 3-5

Criteria	Marks
• Thoroughly compares polyvinyl chloride and a polyester, in terms of structures, methods of formation and uses	3
• Soundly compares polyvinyl chloride and a polyester, in terms of TWO of their structures, methods of formation and uses	2
• Outlines some correct information about polyvinyl chloride or a polyester	1

Sample answer

Polyvinyl chloride (PVC)

Chloroethene
(vinyl chloride)

Poly(chloroethene)
poly(vinyl chloride), PVC
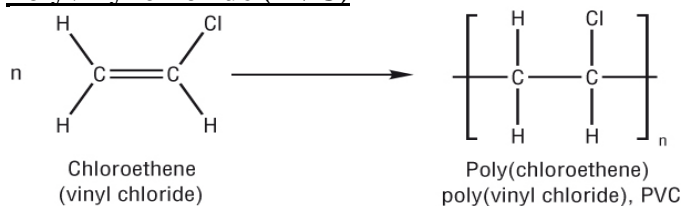
This is an **addition** polymer and is manufactured by a catalytic process that joins monomer chloroalkene monomers together by using the electrons from the double bonds to link the monomers into a long chain. PVC is used to make plumbing pipes as well as other structural plastic for building or domestic use.

Polyesters
These are **condensation** polymers made by the reaction of monomers. The monomers have reacting functional groups at both ends of the molecules, allowing ester links to form and water to be split out as monomers react to form the long-chain polymer.


benzene-1,4-dicarboxylic acid
(terephthalic acid)

ethane-1,2-diol
(ethylene glycol)

a dicarboxylic acid   a dialcohol

a polyester

Question 31 (11 marks)
31 (a) (2 marks)
Outcomes Assessed: CH12–5, CH12–15
Targeted Performance Bands: 3-4

Criteria	Marks
• Identifies correctly 2 peaks on the infrared spectrum as an –OH from an acid AND a carbonyl group (C=O)	2
• Identifies correctly 1 of the 2 peaks on the infrared spectrum as an –OH from an acid OR a carbonyl group (C=O)	1

Sample answer

IR spectrum
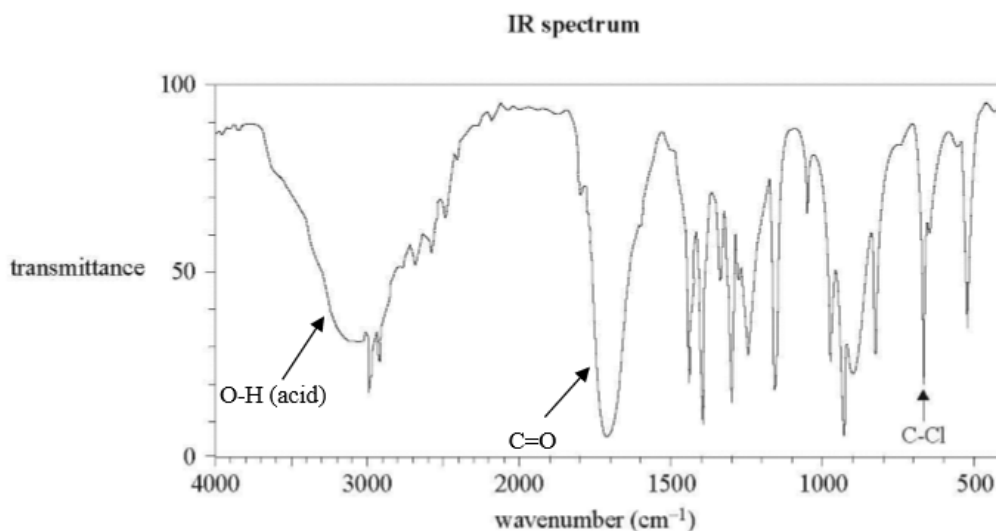
Data: National Institute of Advanced Industrial Science and Technology

31 (b) (1 mark)
Outcomes Assessed: CH12–5, CH12–15
Targeted Performance Bands: 3-4

Criteria	Mark
• Identifies the compound as acidic OR concludes that the compound contains a –COOH group	1

Sample answer
The compound forms an acidic solution, so probably contains a –COOH group.

31 (c) (1 mark)
Outcomes Assessed: CH12–5, CH12–15
Targeted Performance Bands: 3-5

Criteria	Mark
• Identifies that the molecular mass is approximately 110 because of the m/z ratio of the parent peak(s)	1

Sample answer
The mass spectrum indicates that there are 2 parent peaks, at m/z ratios of 108 and 110 – hence the molecular mass will be 108 or 110 depending on which chlorine isotope is present.

31 (d) (1 mark)
Outcomes Assessed: CH12–5, CH12–15
Targeted Performance Bands: 3-5

Criteria	Mark
• Explains the 2 parent peaks, by relating the different masses to the existence of 2 different chlorine isotopes of different mass	1

Sample answer
The mass spectrum indicates that there are 2 parent peaks, at m/z ratios of 108 and 110 – hence the molecular mass will be 108 or 110. This is because chlorine exists as 2 isotopes, chlorine-35 (75%) and chlorine-37 (25%). Depending on which chlorine isotope is present, the molecular mass and hence the parent ion peak can be at 108 or 110. If there were only 1 chlorine isotope, only 1 parent ion peak would exist.

31 (e) (2 marks)
Outcomes Assessed: CH12–5, CH12–15
Targeted Performance Bands: 3-5

Criteria	Marks
• Indicates that there are 3 carbons in different environments AND indicates that 1 of these carbons will be in a CH_3- group, one will be attached to a chlorine atom and the 3rd will be in a –COOH group	2
• Indicates that there are 3 carbons in different environments	1

Sample answer
The ^{13}C NMR spectrum shows 3 carbon environments. One of these indicates a carbon in an alkane environment, with a shift of 21 ppm, another carbon at 54 ppm (typical of a carbon attached to a halogen), and a third carbon at 175 ppm, typical of a carbon in an acid –COOH group.

31 (f) (2 marks)
Outcomes Assessed: CH12–5, CH12–15
Targeted Performance Bands: 3-5

Criteria	Marks
• Indicates there are three hydrogen environments in the molecule AND indicates (from the splitting patterns) that • one hydrogen environment has three neighbouring H atoms, • one hydrogen environment has one neighbouring H atom, and • one hydrogen environment has no neighbouring H atoms	2
• Indicates there are three hydrogen environments in the molecule	1

Sample answer
There are 3 different hydrogen environments on the molecule – one with three neighbouring H, one with one neighbouring H and one with no neighbouring H atoms.

NMR provides information on how many hydrogen neighbours exist for a particular hydrogen or group of equivalent hydrogens. In general, an NMR resonance will be split into **N + 1** peaks where **N** = number of hydrogens on the adjacent atom or atoms.

If there are **no hydrogens** on the adjacent atoms, then the resonance will remain a single peak, a *singlet*.
If there is **one hydrogen** on the adjacent atoms, the resonance will be split into two peaks of **equal size**, a *doublet*.
Two hydrogens on the adjacent atoms will split the resonance into three peaks with an area in the ratio of **1:2:1**, a *triplet*.
If there are **3 hydrogens** on the adjacent atoms, the resonance will be split into four peaks with an area in the ratio of **1:3:3:1**, a *quartet*.

Two of the three hydrogen environments are CH_3 and CH; the third is COOH.
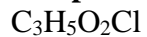
31 (g) (1 mark)
Outcomes Assessed: CH12–7, CH12–15
Targeted Performance Bands: 3-4

Criteria	Mark
• Writes the molecular formula for the compound and hence identifies **x** and **y**	1

Sample answer
$C_3H_5O_2Cl$

Hence in the formula $\mathbf{C_xH_yO_2Cl}$

$\mathbf{x} = 3$ and $\mathbf{y} = 5$

31 (h) (1 mark)
Outcomes Assessed: CH12–7, CH12–15
Targeted Performance Bands: 3-4

Criteria	Mark
• Draws a structural formula for the compound	1

Sample answer
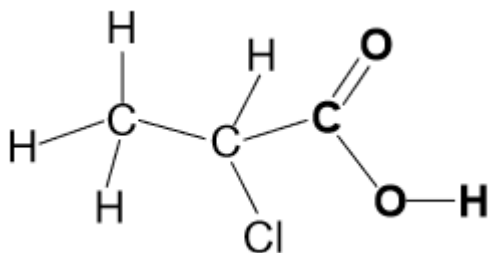
Question 32 (4 marks)
32 (a) (1 mark)
Outcomes Assessed: CH12–2, CH12–7, CH12–15
Targeted Performance Bands: 3-4

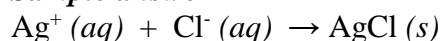| Criteria	Mark
• Outlines a suitable method	1

Sample answer
1 mL of a dilute solution of sodium chloride was added to each of 2 test tubes containing solutions of lead (II) nitrate and silver nitrate. The white precipitates that formed in each test tube were left to stand for a few minutes, then an aqueous solution of ammonia, NH_3, was added to each. The test tubes were shaken and then left to stand. The precipitate dissolved in the test tube containing silver ions but not in the test tube containing lead (II) ions. Hence it was possible, using this method, to distinguish between the 2 solutions.

32 (b) (1 mark)
Outcomes Assessed: CH12–7, CH12–15
Targeted Performance Bands: 2-3

Criteria	Mark
• Writes ONE correct ionic equation (including states)	1

Sample answer
$Ag^+ (aq) + Cl^- (aq) \rightarrow AgCl (s)$

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

Criteria	Marks
• Explains the structure and bonding in the complex ion formed when silver chloride dissolves AND includes a diagram of the structure of the complex ion	2
• Gives some correct information about the structure or bonding of any complex ion	1

Sample answer
$AgCl (s) + 2NH_3 (aq) \rightarrow [Ag(NH_3)_2]^+ (aq) + Cl^- (aq)$

The complex ion formed 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 molecule has a non-bonding pair of electrons which move into empty orbitals of the silver ion to form the covalent bond.
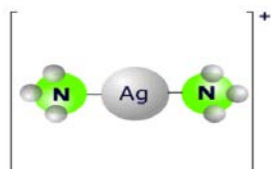
Section I

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

Section II

Question	Marks	Content	Syllabus Outcomes	Targeted Performance Bands
21 (a)	3	Mod 5: Solution Equilibria	CH12–7, CH12–12	2-5
21 (b)	2	Mod 5: Solution Equilibria	CH12–7, CH12–12	3-5
21 (c)	2	Mod 5: Solution Equilibria	CH12–7, CH12–12	3-5
22 (a)	1	Mod 5: Factors that Affect Equilibrium	CH12–5, CH12–12	3-4
22 (b)	1	Mod 5: Factors that Affect Equilibrium	CH12–7, CH12–12	3-5
22 (c)	2	Mod 5: Calculating the Equilibrium Constant	CH12–4, CH12–7, CH12–12	3-5
22 (d)	2	Mod 5: Calculating the Equilibrium Constant	CH12–6, CH12–7, CH12–12	2-3
22 (e)	1	Mod 5: Factors that Affect Equilibrium	CH12–7, CH12–12	3-4
23 (a)	3	Mod 7: Nomenclature	CH12–7, CH12–14	3-5
23 (b)	4	Mod 7 Hydrocarbons, Alcohols, Reactions of Organic Acids and Bases	CH12–7, CH12–14	3-5
24 (a)	2	Mod 8: Analysis of Organic Substances	CH12–7, CH12–15	2-5
24 (b)	2	Mod 8: Analysis of Organic Substances	CH12–7, CH12–15	2-4
25 (a)	2	Mod 5: Solution Equilibria	CH12–7, CH12–12	2-4
25 (b)	3	Mod 5: Solution Equilibria	CH12–6, CH12–12	3-6
25 (c)	1	Mod 5: Solution Equilibria	CH12–7, CH12–12	4-5
26 (a)	1	Mod 6: Properties of Acids and Bases	CH12–7, CH12–13	2-3
26 (b)	2	Mod 6: Properties of Acids and Bases	CH12–7, CH12–13	2-4
27 (a)	2	Mod 6: Quantitative Analysis	CH12–5, CH12–13	2-4
27 (b)	3	Mod 6: Quantitative Analysis	CH12–5, CH12–6, CH12–13	3-6
27 (c)	4	Mod 6: Quantitative Analysis	CH12–5, CH–6, CH12–7, CH12–13	3-6

Question	Marks	Content	Syllabus Outcomes	Targeted Performance Bands
28 (a)	1	Mod 6: Using the Brønsted-Lowry Theory	CH12–6, CH12–7, CH12–13	2-3
28 (b)	3	Mod 6: Quantitative Analysis	CH12–5, CH12–13	2-5
28 (c)	1	Mod 6: Quantitative Analysis	CH12–7, CH12–13	2-4
28 (d)	2	Mod 6: Quantitative Analysis	CH12–7, CH12–13	4-6
28 (e)	2	Mod 8: Analysis of Inorganic Substances	CH12–7, CH12–15	3-5
29 (a)	8	Mod 7: Reactions of Organic Acids and Bases	CH12–5, CH12–7, CH12–14	3-6
29 (b)	2	Mod 7: Reactions of Organic Acids and Bases	CH12–7, CH12–14	4-5
30	3	Mod 7: Reactions of Organic Acids and Bases	CH12–7, CH12–14	3-5
31 (a)	2	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	3-4
31 (b)	1	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	3-4
31 (c)	1	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	3-5
31 (d)	1	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	3-5
31 (e)	2	Mod 8: Analysis of Organic Substances	CH12–5, CH12–15	3-5
31 (f)	2	Mod 8: Analysis of Organic Substances	CH12–7, CH12–15	3-5
31 (g)	1	Mod 8: Analysis of Organic Substances	CH12–7, CH12–15	3-4
31 (h)	1	Mod 8: Analysis of Organic Substances	CH12–7, CH12–15	3-4
32 (a)	1	Mod 8: Analysis of Inorganic Substances	CH12–2, CH12–7, CH12–15	3-4
32 (b)	1	Mod 8: Analysis of Inorganic Substances	CH12–7, CH12–15	2-3
32 (c)	2	Mod 8: Analysis of Inorganic Substances	CH12–7, CH12–15	3-5