SYDNEY GRAMMAR SCHOOL

TRIAL EXAMINATION 2025

FORM VI CHEMISTRY

General Instructions

- Reading Time: 5 minutes
- Working Time: 3 hours
- Write using black pen

Structure of Paper & Instructions

- Section 1: Multiple-choice (20 marks). Spend 35 minutes on this section.
- Section 2: Written answer (80 marks). Spend 2 hours 25 minutes on this section.

Exam Instructions

- Remove the centre staple and hand in all parts of the paper in a neat bundle.
- Show all relevant working.
- **Write your candidate number in the space provided on pages 1, 11, 17, 23 and 27.**

Total marks: 100

Friday 8 August

12:00 pm

Checklist

Each boy should have the following:

☐ 1 question paper

☐ 1 multiple-choice answer sheet

☐ 1 data sheet

JL Senczyszyn

Examiners: EJS, JAC, JLS, TW

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SECTION I: MULTIPLE CHOICE QUESTIONS
20 marks

Attempt ALL Questions
Use the Multiple-Choice Answer Sheet.

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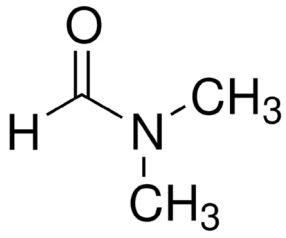
1 What is the IUPAC name for the structure shown?



(A) *N*-dimethylmethanal

(B) *N*-ethylmethanamide

(C) *N,N*-dimethylmethanamine

(D) *N,N*-dimethylmethanamide

2 Which of the following compounds is produced in the reaction between hydrochloric acid and calcium carbonate but **not** in the reaction between hydrochloric acid and calcium hydroxide?

(A) calcium chloride

(B) carbon dioxide

(C) hydrogen

(D) water

3 What is the equilibrium expression for the equilibrium system shown?

$$Fe_3O_4(s) + 4H_2(g) \rightleftharpoons 3Fe(s) + 4H_2O(g)$$

(A) $K_{eq} = \frac{1}{[H_2]^4}$

(B) $K_{eq} = \frac{[H_2O]}{[H_2]}$

(C) $K_{eq} = \frac{[H_2O]^4}{[H_2]^4}$

(D) $K_{eq} = \frac{[Fe]^3[H_2O]^4}{[Fe_3O_4][H_2]^4}$

4 Which of the following substances is an Arrhenius base?

(A) Li_2CO_3

(B) NH_3

(C) $NaHCO_3$

(D) $Sr(OH)_2$

5 Which compound listed below will react in the presence of concentrated sulfuric acid with the product of its own oxidation to produce an ester?

(A) propan-1-ol

(B) propan-2-ol

(C) propanal

(D) propanoic acid

6 Which compound will produce a peak at 210 ppm in ^{13}C NMR spectroscopy?

(A) pentan-1-ol

(B) pentan-1-amine

(C) pentanoic acid

(D) pentanal

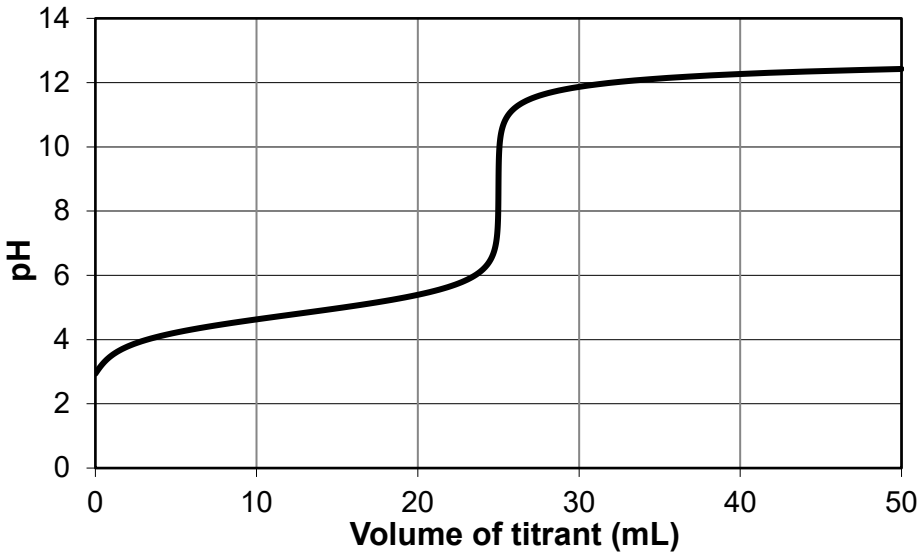
7 Consider the equilibrium system shown for the production of nitrosyl chloride (NOCl).

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \quad \Delta H = -75.5 \text{ kJ mol}^{-1}$$

Which of the following conditions will maximise the equilibrium yield of nitrosyl chloride?

	Pressure	*Temperature*
(A)	high	high
(B)	high	low
(C)	low	high
(D)	low	low

Use the information below to answer questions 8 and 9.



8 Which of the following titrations would result in this titration curve?

(A) 0.1 mol L^{-1} C_2H_5COOH with 0.1 mol L^{-1} NH_3

(B) 0.1 mol L^{-1} C_2H_5COOH with 0.1 mol L^{-1} NaOH

(C) 0.1 mol L^{-1} HCl with 0.1 mol L^{-1} NaOH

(D) 0.1 mol L^{-1} HCl with 0.1 mol L^{-1} NH_3

9 Which of the following indicators is most suitable for determining the endpoint of the titration above?

	Indicator	*Colour change pH range*
(A)	Methyl orange	3.1 – 4.4
(B)	Bromothymol blue	6.0 – 7.6
(C)	Phenolphthalein	8.2 – 10.0
(D)	Alizarin yellow R	10.1 – 12.0

10 An aqueous solution containing which substance is most likely to have a pH of 9?

(A) methanol

(B) propanoic acid

(C) ethanamine

(D) butanal

11 In proton NMR, what do the relative peak areas indicate about a pure substance?

(A) The number of protons in the molecule.

(B) The ratio of protons in different environments.

(C) The proximity of the proton to an electronegative element.

(D) The molecular weight of the molecule.

12 Infrared spectroscopy of a pure compound produces a broad peak centered at 3415 cm^{-1}. Which series of organic compounds is the unknown compound likely to belong to?

(A) alcohol

(B) carboxylic acid

(C) aldehyde

(D) alkene

13 Which of the following mixtures of aqueous species will form a buffer solution when both species have a concentration of approximately 0.1 mol L^{-1}.

(A) HCl / Cl^-

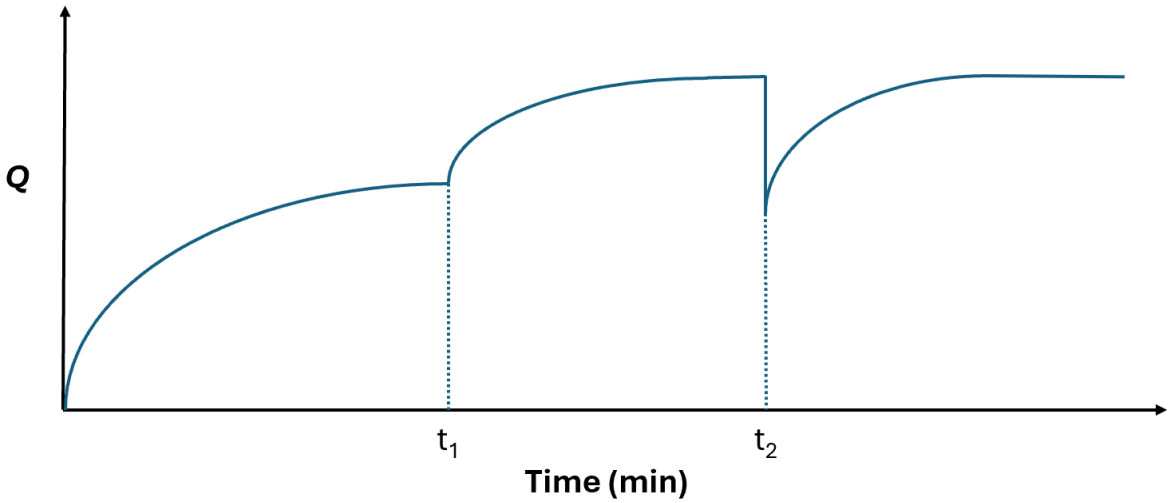
(B) $HCOOH$ / $HCOO^-$

(C) H_3O^+ / H_2O

(D) H_2O / OH^-

14 The graph shows changes in *Q* over time for the equilibrium system shown.

$$X(g) \rightleftharpoons Y(g) \qquad \Delta H > 0$$



Which of the following could be the changes made at t_1 and t_2?

	Change made at t_1	*Change made at t_2*
(A)	Decrease in temperature	Addition of X
(B)	Decrease in temperature	Removal of X
(C)	Increase in temperature	Addition of Y
(D)	Increase in temperature	Removal of Y

15 Which set of peaks would be likely found in the mass spectrum of 2,2-dimethylpropanal?

(A) *m/z* = 14, *m/z* =28, *m/z* = 57, *m/z* = 71 and *m/z* = 85

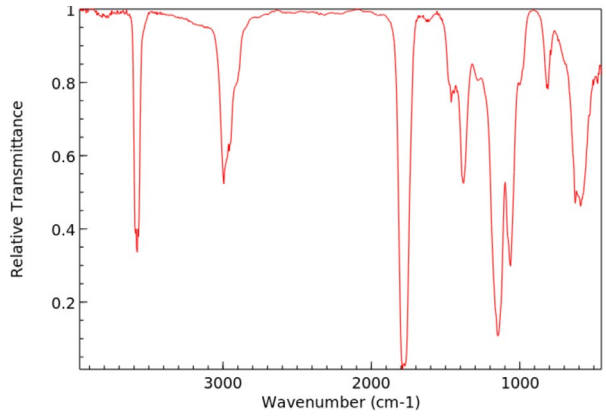
(B) *m/z* = 14, *m/z* = 29, *m/z* = 58, *m/z* = 73 and *m/z* = 87

(C) *m/z* = 15, *m/z* = 29, *m/z* = 57, *m/z* = 71 and *m/z* = 86

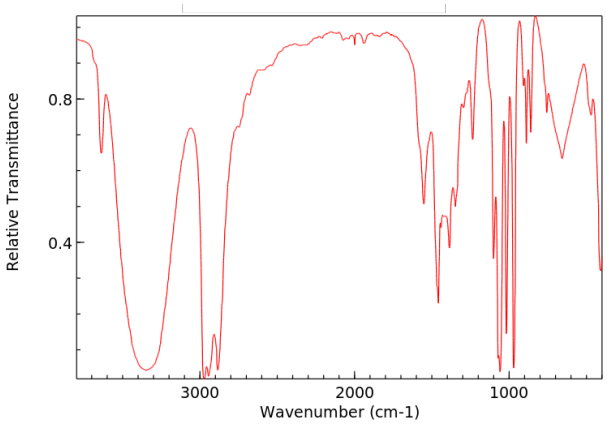
(D) *m/z* = 15, *m/z* = 28, *m/z* = 58, *m/z* = 73 and *m/z* = 86

16 Which infrared spectrum was most likely produced from a pure sample of propanone?

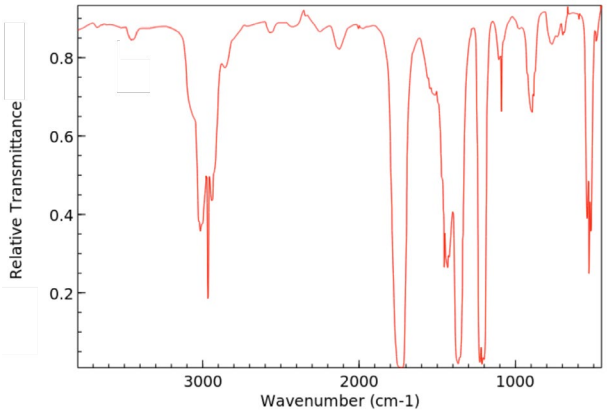
(A)



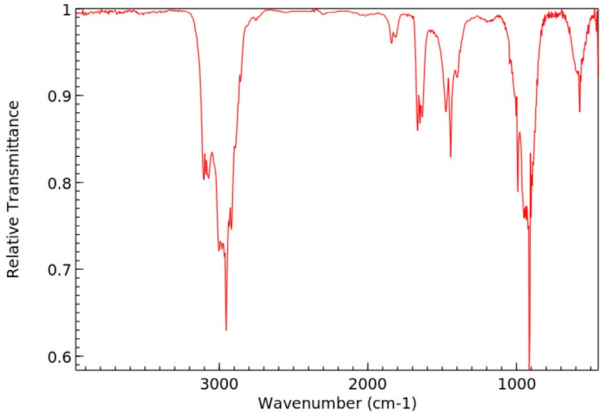
(B)



(C)



(D)



17 In an experiment to determine the K_{sp} value of barium fluoride, five 1.0 mL samples containing barium ions were prepared and each was added to a 1.0 mL solution containing fluoride ions. The results are given below.

Sample	*Barium ion solution*		*Fluoride ion solution*		*Observation*
	Initial concentration (mol L^{-1})	*Volume (mL)*	*Initial concentration (mol L^{-1})*	*Volume (mL)*	
1	0.010	1.0	0.026	1.0	No precipitate
2	0.010	1.0	0.028	1.0	No precipitate
3	0.010	1.0	0.030	1.0	Faint white precipitate
4	0.010	1.0	0.032	1.0	White precipitate

Which of the following could be the K_{sp} value of barium fluoride?

(A) 1.0×10^{-6}

(B) 1.2×10^{-6}

(C) 8.8×10^{-6}

(D) 7.2×10^{-5}

18 When ethene is reacted completely with hydrogen bromide, 7.27 L of the product is obtained at 25.0°C and 120 kPa. What is the mass of ethene that was reacted?

(A) 7.27 g

(B) 9.87 g

(C) 79.7 g

(D) 118 g

19 A salt has a K_{sp} value of 4.3×10^{-10} and a molar solubility of 2.0×10^{-3} mol L^{-1}. Which of the following represents the formula of this salt?

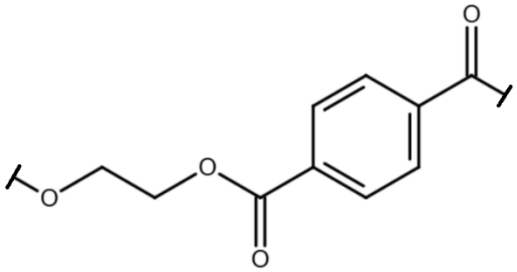
(A) XY

(B) XY_2

(C) XY_3

(D) X_2Y_3

20 1.242 kg of a single polymer with the repeating unit shown below was obtained after a polymerisation reaction.



What mass of water is released during this polymerisation reaction?

(A) 116 g

(B) 233 g

(C) 656 g

(D) 803 g

SECTION II: WRITTEN ANSWER QUESTIONS
80 marks
Attempt ALL Questions

CANDIDATE NUMBER							

Question 21 (2 marks) **Marks**

Using balanced chemical equations, show that the $H_2PO_4^-$ ion can react with both strong acids and strong bases.

2

Question 22 (3 marks)

Calculate the pH of 0.20 mol L^{-1} hydrazoic acid (HN_3, K_a 1.9×10^{-5}).

3

Question 23 (6 marks) **Marks**

Hydrogen iodide decomposes when heated to hydrogen and iodine as shown below.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

(a) Give the equilibrium expression for this reaction.

1

(b) In an experiment, 1.75 mol of hydrogen iodide was placed in a 1.00 L vessel at a constant temperature. At equilibrium, the concentration of iodine gas was 0.168 mol L^{-1}.

What is the K_{eq} value at this temperature?

3

(c) Explain what would happen to the value of K_{eq} if a catalyst was added at constant temperature.

2

Question 24 (4 marks) **Marks**

100.0 mL of 1.00 mol L^{-1} sodium hydroxide is mixed with 100.0 mL of 1.00 mol L^{-1} nitric acid in a cardboard cup. The initial temperature of each solution is 24.30 °C and the resulting solution has a temperature of 31.15 °C.

You can assume that there is no volume change upon reaction, and that the resulting solution has a density of 1.04 g mL^{-1} and a specific heat capacity of 4.03 J K^{-1} g^{-1}.

Calculate the enthalpy of neutralisation for this reaction.

4

Question 25 (10 marks) **Marks**

The synthesis of ammonia from its elements is an equilibrium process.

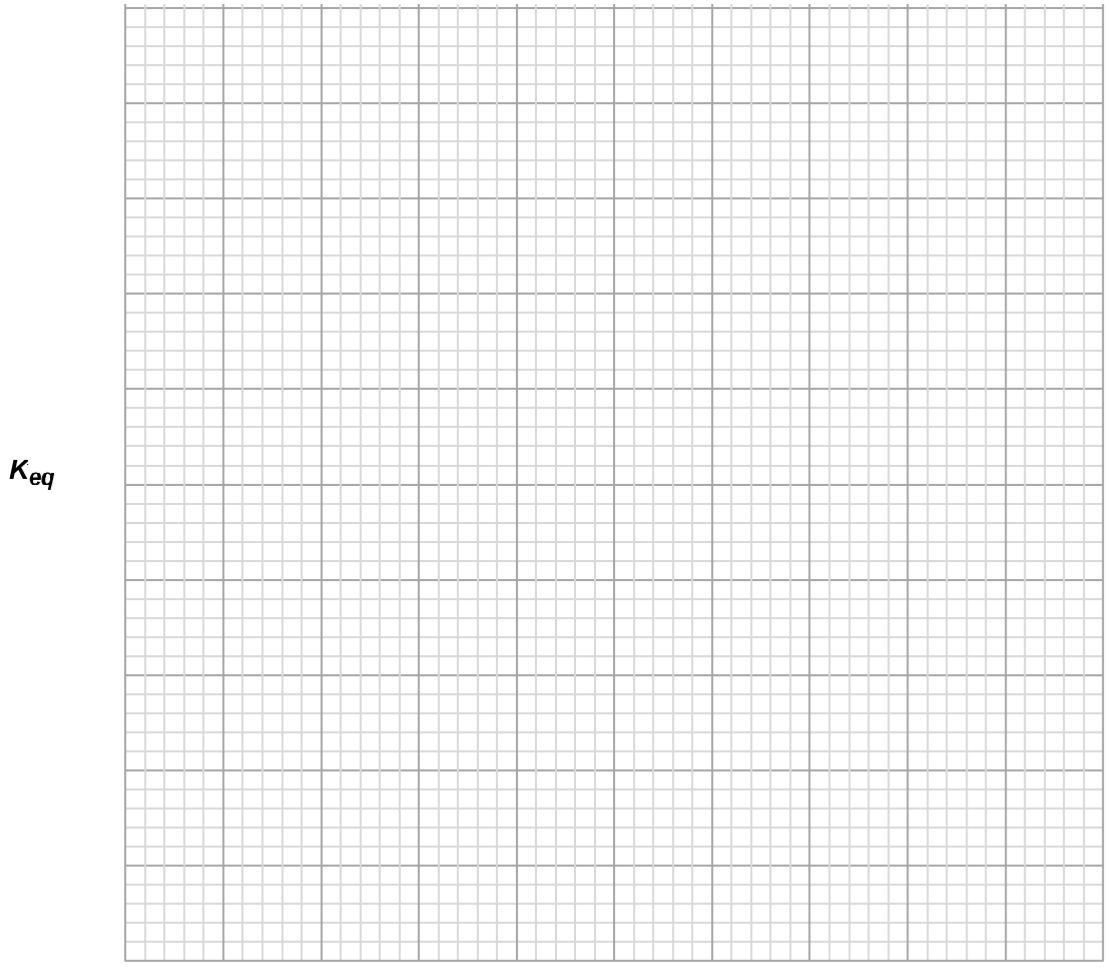
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The table shows the value of K_{eq} for this reaction at a range of different temperatures.

Temperature (K)	K_{eq}
390	90
400	44
420	12
430	6.4
440	3.6

(a) Plot this data, including a curved line of best fit.

3



Question 25 continued. **Marks**

(b) Using the graph, estimate K_{eq} at 410 K.

1

(c) A system at 410 K is found to have $[N_2]$ = 0.24 mol L^{-1}, $[H_2]$ = 1.1 mol L^{-1} and $[NH_3]$ = 1.6 mol L^{-1}.

Show that this system is not at equilibrium and use Q and K_{eq} to explain how the system will shift to reach equilibrium.

3

(d) Is the production of ammonia exothermic or endothermic? Justify your answer using Le Châtelier's Principle and the data provided.

3

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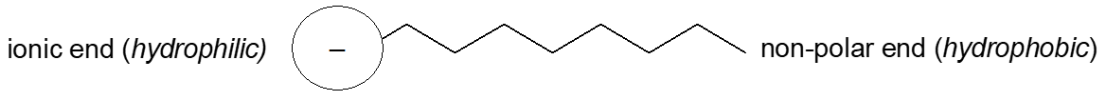
Question 26 (5 marks) **Marks**

Soap can be used as a cleaning agent due to its ability to stabilise emulsions.

(a) Draw a labelled diagram to show the structure of a soap molecule.



2

(b) Explain how soap can act as a cleaning agent.

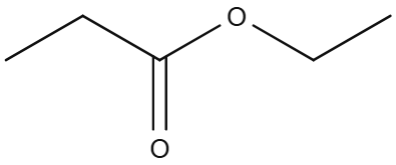
3

Question 27 (4 marks)

Two esters, A and B, have molecular formula $C_5H_{10}O_2$.

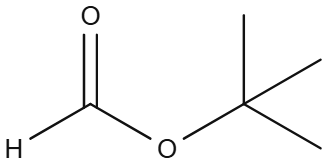
Proton NMR spectroscopy was performed on both compounds, and the following data was obtained.

Ester A



Chemical shift (ppm)	*Relative peak area*	*Peak splitting pattern*
1.05	3	triplet
1.16	3	triplet
2.26	2	quartet
4.11	2	quartet

Ester B



Chemical shift (ppm)	*Relative peak area*	*Peak splitting pattern*
1.42	9	singlet
9.60	1	singlet

Question continues on next page.

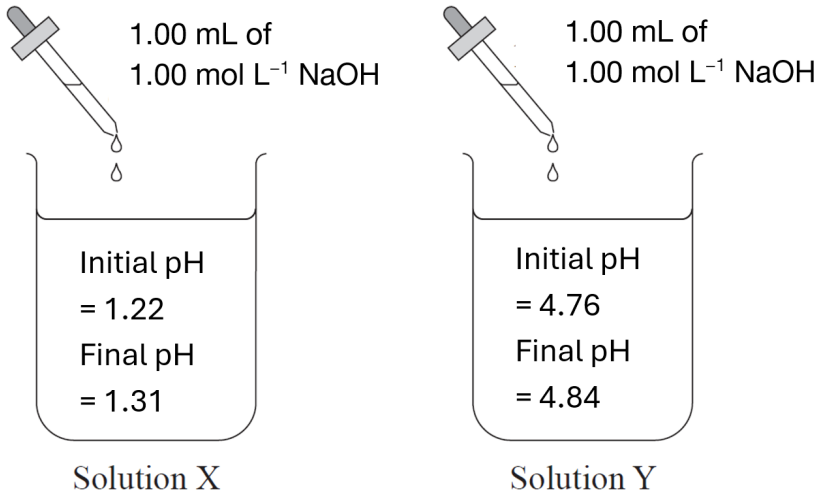
Question 27 continued. **Marks**

State **two** differences between the proton NMR data and relate these to the structure of the two esters.

4

Question 28 (7 marks) **Marks**

The pH of two 100 mL solutions, X and Y, were measured before and after 1.00 mL of 1.00 mol L^{-1} sodium hydroxide solution was added to each.



One of these solutions contains a solution of a weak acid and its conjugate base, both at a concentration of 0.10 mol L^{-1}; the other contains a 0.060 mol L^{-1} solution of hydrochloric acid.

(a) By performing a relevant calculation, show that Solution X is the 0.060 mol L^{-1} solution of hydrochloric acid. **2**

(b) Calculate the K_a of the weak acid. **1**

Question continues on next page.

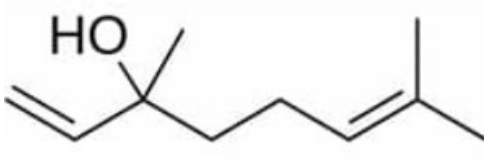
Question 28 continued. **Marks**

When 1.00 mL of 1.00 mol L^{-1} sodium hydroxide solution is added to 100 mL of water, the pH increases from 7.00 to 12.00.

(c) Explain why adding 1.00 mL of 1.00 mol L^{-1} sodium hydroxide solution to both solution X and solution Y does not change pH of either appreciably. **4**

Question 29 (5 marks) **Marks**

Linalool is a compound found in many flowers and spices. The structural formula is shown below.



(a) State the names of the **two** functional groups in linalool.

2

(b) Linalool undergoes many chemical reactions. Complete the table by identifying the product when the following reagents are added to a linalool solution under the stated conditions.

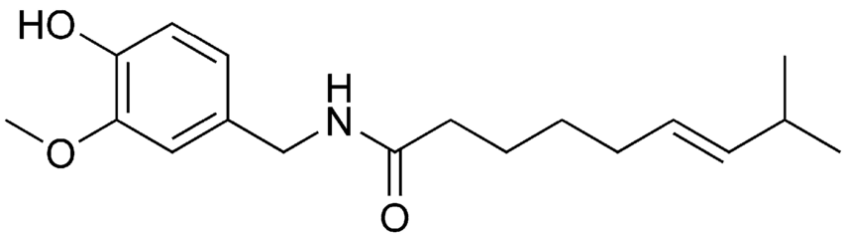
3

Reagent and conditions	*Structural formula of organic product*
$H_2(g)$ Pd catalyst	
$Br_2(aq)$	
HCOOH(*aq*) H_2SO_4 catalyst Heat under reflux	

Question 30 (3 marks) **Marks**

The compound responsible for the hot taste of chillies, capsaicin, is shown. Drinking full cream milk, which contains fat, is recommended after eating meals containing lots of chilli as it reduces the hot taste on the tongue.

Explain why milk is better than water in removing capsaicin from the tongue.



3

Question 31 (9 marks) **Marks**

Three bottles, known to contain pentan-1-ol, pentan-3-ol and 2-methylbutan-2-ol, are missing labels.

(a) Suggest how a student could distinguish between the three alcohols using one or more chemical tests.

3

Question continues on next page.

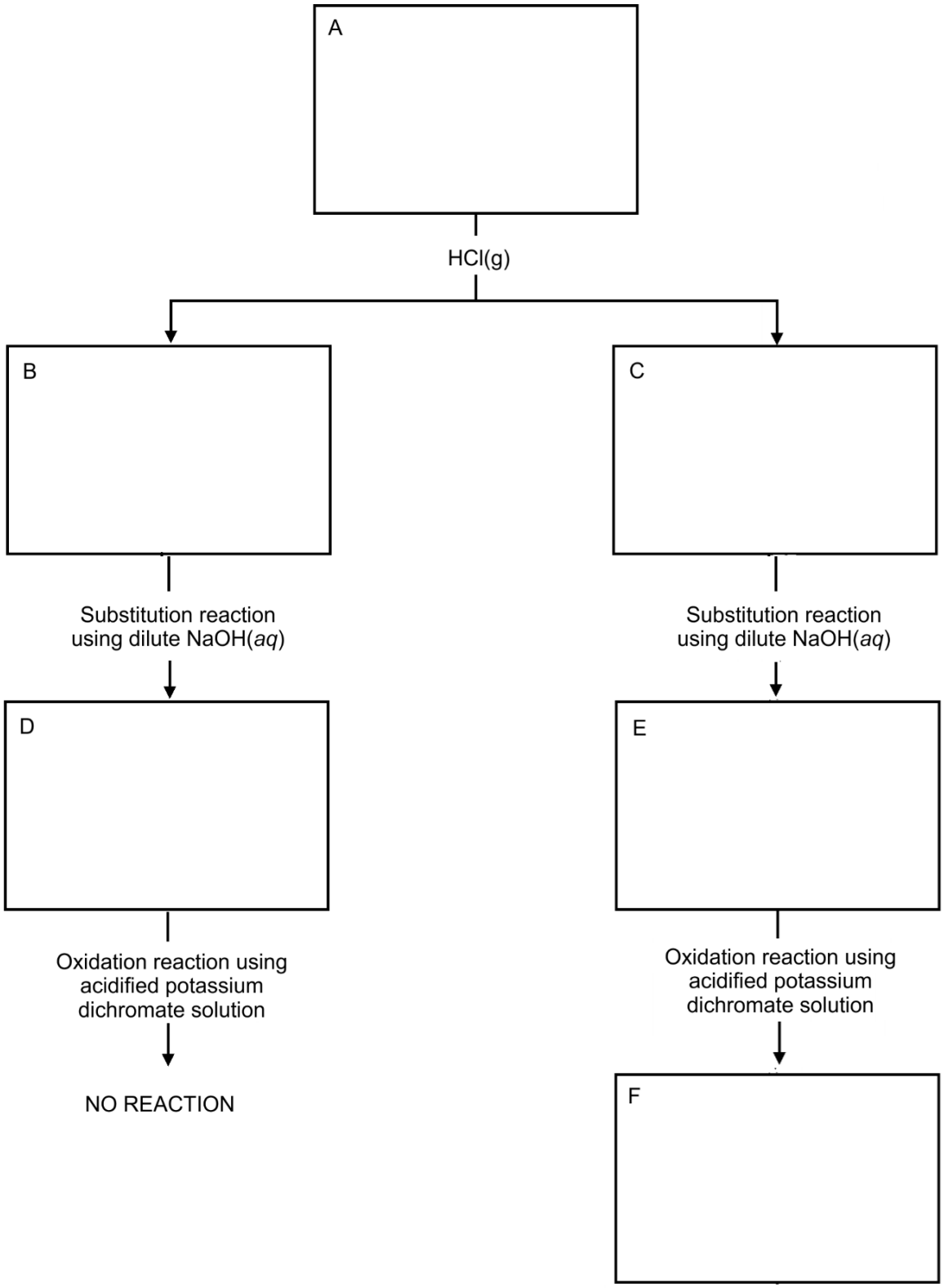
Question 31 continued. **Marks**

(b) The student can use a combination of infrared, mass spectrometry and ^{13}C NMR to confirm the contents of the three bottles. Evaluate the suitability of these techniques for this purpose.

6

Question 32 (5 marks) **Marks**

Alkene A reacts with gaseous hydrogen chloride to form two isomers, B and C, with molecular formula C_4H_9Cl. A sequence of reactions for each compound is shown below. Determine the structural formulae of the compounds A to F.



CANDIDATE NUMBER

Question 33 (5 marks) **Marks**

Periclase is a mineral composed of magnesium oxide (*MM* 40.31 g mol^{-1}). A 0.4802 g ore sample containing periclase is treated with 50.00 mL of 0.5020 mol L^{-1} hydrochloric acid. The acid reacts with the magnesium oxide, but not with the other components of the ore sample. After reaction and filtration, the solution is made up to 250.0 mL in a volumetric flask. 25.00 mL aliquots of this solution are titrated with 0.1034 mol L^{-1} sodium hydroxide (NaOH), requiring an average of 12.90 mL to reach the endpoint.

Calculate the percentage by mass of magnesium oxide in the periclase ore sample.

5

Question 34 (5 marks) **Mark**

Red iron(III) thiocyanate is produced in the following equilibrium reaction.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons [FeSCN]^{2+}(aq)$$

At equilibrium at 298 K there are 0.00540 mol of $Fe^{3+}(aq)$, 0.00823 mol of $SCN^{-}(aq)$ and 0.0631 mol of $[FeSCN]^{2+}(aq)$ in a 100.0 mL solution.

What mass of pure sodium hydroxide should be added to increase the amount of $SCN^{-}(aq)$ to 0.00944 mol at equilibrium?

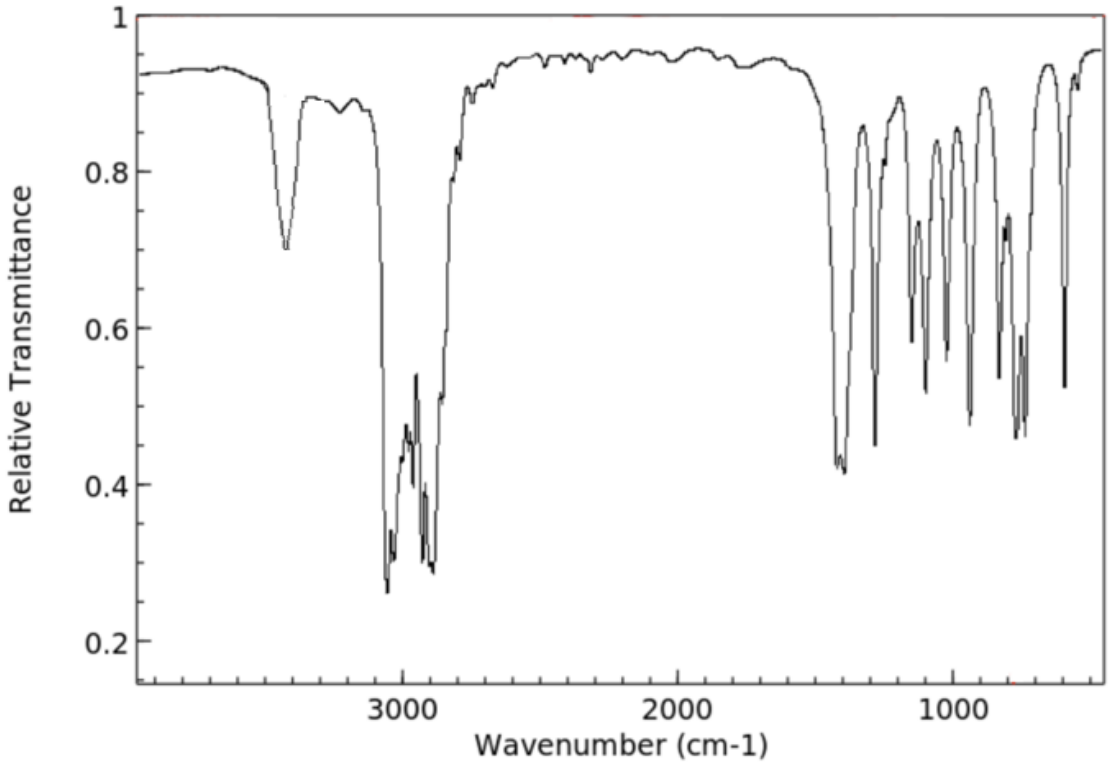
5

Question 35 (7 marks)

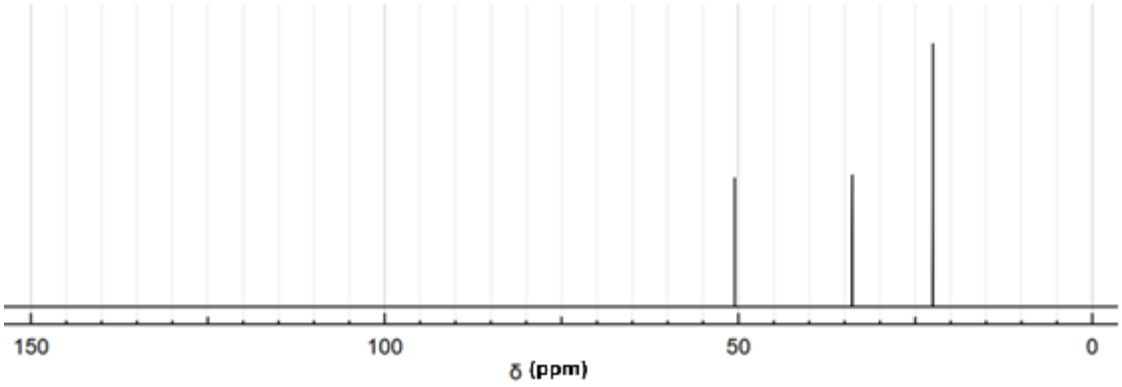
Compound Q is an organic compound which contains roughly 19% nitrogen by mass.

The infrared, ^{13}C NMR and ^{1}H NMR spectra of compound Q are shown below.

Chemical shift data for ^{1}H NMR is provided.



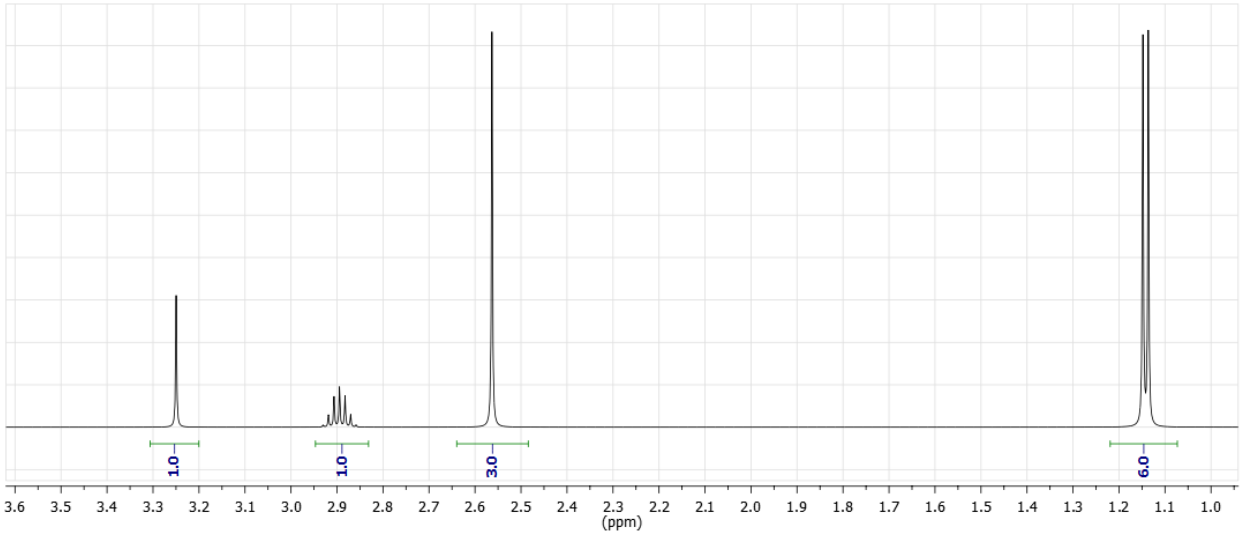
IR spectrum of compound Q



^{13}C NMR spectrum of compound Q

Question continues on next page.

Question 35 continued.



^{1}H NMR spectrum of compound Q

^{1}H NMR chemical shift data

Type of proton	δ/ppm
$Si(C\mathbf{H}_3)_4$ (TMS)	0
R–C$\mathbf{H}_3$	0.9–1.0
R–C$\mathbf{H}_2$–R	1.2–1.5
R–C$\mathbf{H}$R$_2$	1.5–2.0
R–C≡C–**H** (alkyne)	2.0–3.1
–CO–C$\mathbf{H}_2$– (aldehydes, ketones or esters)	2.1-2.7
R–C$\mathbf{H}_2$–NH$_2$ or C$\mathbf{H}$R–NH$_2$	2.4–3.0
R–C$\mathbf{H}_2$–NHR or C$\mathbf{H}$R–NHR	2.5–3.1
–C$\mathbf{H}_2$–O– (alcohols, ethers or esters)	3.3–4.8
R–O**H**	1–6
R–N$\mathbf{H}_2$	1–5
R–N**H**R	1–5
R$_2$C=C**H**R (alkene)	4.5–7.0
R–COON**H**–R (amide)	5–9
R–C**H**O (aldehyde)	9.4–10.0
R–COO**H**	9.0–13.0

Question 35 continued. **Marks**

Draw and name compound Q and justify your choice using all information provided.

7

Compound Q

Name:

Question 35 continued.

2019 | HIGHER SCHOOL CERTIFICATE EXAMINATION

Chemistry

FORMULAE SHEET

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

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

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

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

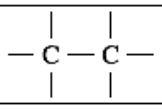
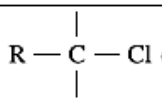
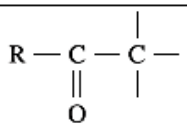
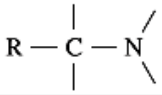
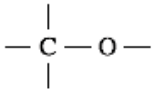
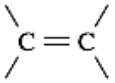
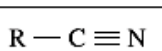
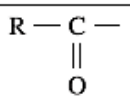
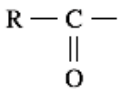
Compound	K_{sp}	*Compound*	K_{sp}
Barium carbonate	2.58×10^{-9}	Lead(II) bromide	6.60×10^{-6}
Barium hydroxide	2.55×10^{-4}	Lead(II) chloride	1.70×10^{-5}
Barium phosphate	1.3×10^{-29}	Lead(II) iodide	9.8×10^{-9}
Barium sulfate	1.08×10^{-10}	Lead(II) carbonate	7.40×10^{-14}
Calcium carbonate	3.36×10^{-9}	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
		5–40
		10–70
		20–50
		25–60
	alcohols, ethers or esters	50–90
		90–150
		110–125
		110–160
	esters or acids	160–185
	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

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 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

KEY

Atomic Number: 79
Symbol: Au
Standard Atomic Weight: 197.0
Name: Gold

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 (November 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.

SYDNEY GRAMMAR SCHOOL

TRIAL EXAMINATION 2025

FORM VI CHEMISTRY

CRIB

General Instructions

- Reading Time: 5 minutes
- Working Time: 3 hours
- Write using black pen

Structure of Paper & Instructions

- Section 1: Multiple-choice (20 marks). Spend 35 minutes on this section.
- Section 2: Written answer (80 marks). Spend 2 hours 25 minutes on this section.

Exam Instructions

- Remove the centre staple and hand in all parts of the paper in a neat bundle.
- Show all relevant working.
- **Write your candidate number in the space provided on pages 1, 11, 17, 23 and 27.**

Total marks: 100

Friday 8 August

12:00 pm

Checklist

Each boy should have the following:

☐ 1 question paper

☐ 1 multiple-choice answer sheet

☐ 1 data sheet

JL Senczyszyn

Examiners: EJS, JAC, JLS, TW

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SECTION I: MULTIPLE CHOICE QUESTIONS
20 marks

Attempt ALL Questions
Use the Multiple-Choice Answer Sheet.

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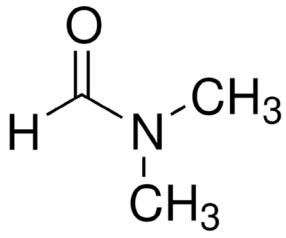
1 What is the IUPAC name for the structure shown?



(A) *N*-dimethylmethanal

(B) *N*-ethylmethanamide

(C) *N,N*-dimethylmethanamine

(D) *N,N*-dimethylmethanamide

2 Which of the following compounds is produced in the reaction between hydrochloric acid and calcium carbonate but **not** in the reaction between hydrochloric acid and calcium hydroxide?

(A) calcium chloride

(B) carbon dioxide

(C) hydrogen

(D) water

3 What is the equilibrium expression for the equilibrium system shown?

$$Fe_3O_4(s) + 4H_2(g) \rightleftharpoons 3Fe(s) + 4H_2O(g)$$

(A) $K_{eq} = \frac{1}{[H_2]^4}$

(B) $K_{eq} = \frac{[H_2O]}{[H_2]}$

(C) $K_{eq} = \frac{[H_2O]^4}{[H_2]^4}$

(D) $K_{eq} = \frac{[Fe]^3[H_2O]^4}{[Fe_3O_4][H_2]^4}$

4 Which of the following substances is an Arrhenius base?

(A) Li_2CO_3

(B) NH_3

(C) $NaHCO_3$

(D) $Sr(OH)_2$

5 Which compound listed below will react in the presence of concentrated sulfuric acid with the product of its own oxidation to produce an ester?

(A) propan-1-ol

(B) propan-2-ol

(C) propanal

(D) propanoic acid

6 Which compound will produce a peak at 210 ppm in ^{13}C NMR spectroscopy?

(A) pentan-1-ol

(B) pentan-1-amine

(C) pentanoic acid

(D) pentanal

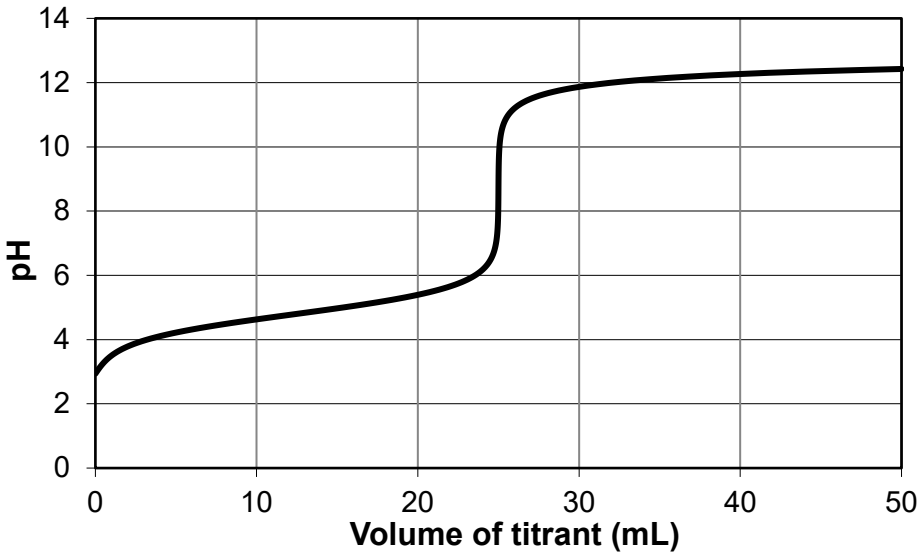
7 Consider the equilibrium system shown for the production of nitrosyl chloride (NOCl).

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \quad \Delta H = -75.5 \text{ kJ mol}^{-1}$$

Which of the following conditions will maximise the equilibrium yield of nitrosyl chloride?

	Pressure	*Temperature*
(A)	high	high
(B)	high	low
(C)	low	high
(D)	low	low

Use the information below to answer questions 8 and 9.



8 Which of the following titrations would result in this titration curve?

(A) 0.1 mol L^{-1} C_2H_5COOH with 0.1 mol L^{-1} NH_3

(B) 0.1 mol L^{-1} C_2H_5COOH with 0.1 mol L^{-1} NaOH

(C) 0.1 mol L^{-1} HCl with 0.1 mol L^{-1} NaOH

(D) 0.1 mol L^{-1} HCl with 0.1 mol L^{-1} NH_3

9 Which of the following indicators is most suitable for determining the endpoint of the titration above?

	Indicator	*Colour change pH range*
(A)	Methyl orange	3.1 – 4.4
(B)	Bromothymol blue	6.0 – 7.6
(C)	Phenolphthalein	8.2 – 10.0
(D)	Alizarin yellow R	10.1 – 12.0

10 An aqueous solution containing which substance is most likely to have a pH of 9?

(A) methanol

(B) propanoic acid

(C) ethanamine

(D) butanal

11 In proton NMR, what do the relative peak areas indicate about a pure substance?

(A) The number of protons in the molecule.

(B) The ratio of protons in different environments.

(C) The proximity of the proton to an electronegative element.

(D) The molecular weight of the molecule.

12 Infrared spectroscopy of a pure compound produces a broad peak centered at 3415 cm^{-1}. Which series of organic compounds is the unknown compound likely to belong to?

(A) alcohol

(B) carboxylic acid

(C) aldehyde

(D) alkene

13 Which of the following mixtures of aqueous species will form a buffer solution when both species have a concentration of approximately 0.1 mol L^{-1}.

(A) HCl / Cl^-

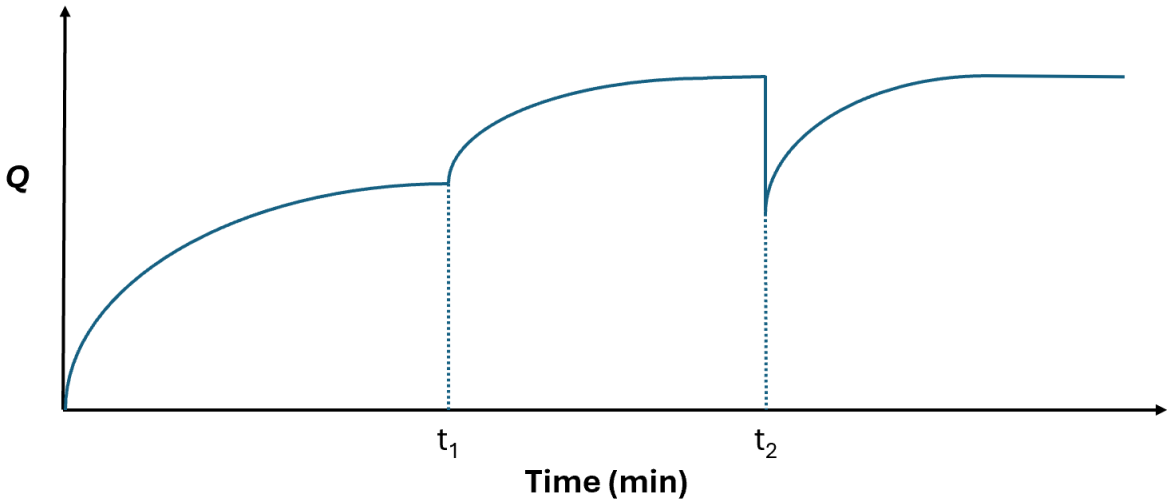
(B) $HCOOH$ / $HCOO^-$

(C) H_3O^+ / H_2O

(D) H_2O / OH^-

14 The graph shows changes in *Q* over time for the equilibrium system shown.

$$X(g) \rightleftharpoons Y(g) \qquad \Delta H > 0$$



Which of the following could be the changes made at t_1 and t_2?

	Change made at t_1	*Change made at t_2*
(A)	Decrease in temperature	Addition of X
(B)	Decrease in temperature	Removal of X
(C)	Increase in temperature	Addition of Y
(D)	Increase in temperature	Removal of Y

15 Which set of peaks would be likely found in the mass spectrum of 2,2-dimethylpropanal?

(A) *m/z* = 14, *m/z* =28, *m/z* = 57, *m/z* = 71 and *m/z* = 85

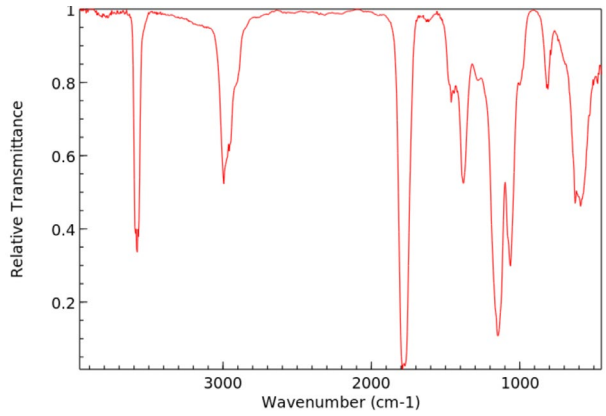
(B) *m/z* = 14, *m/z* = 29, *m/z* = 58, *m/z* = 73 and *m/z* = 87

(C) *m/z* = 15, *m/z* = 29, *m/z* = 57, *m/z* = 71 and *m/z* = 86

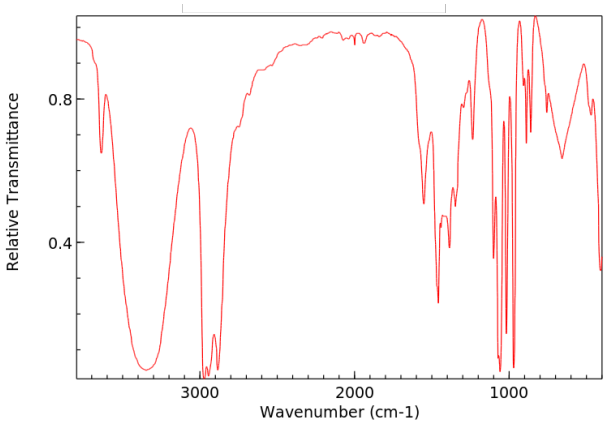
(D) *m/z* = 15, *m/z* = 28, *m/z* = 58, *m/z* = 73 and *m/z* = 86

16 Which infrared spectrum was most likely produced from a pure sample of propanone?

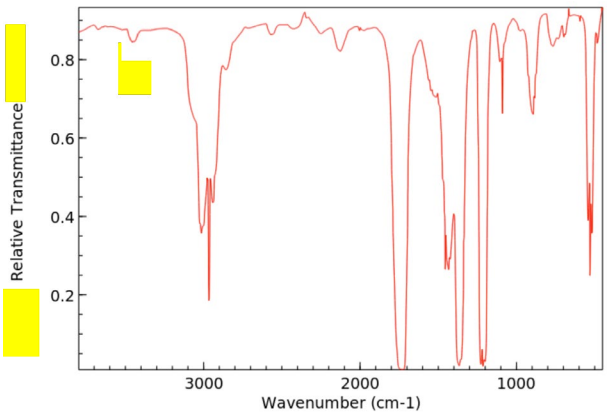
(A)



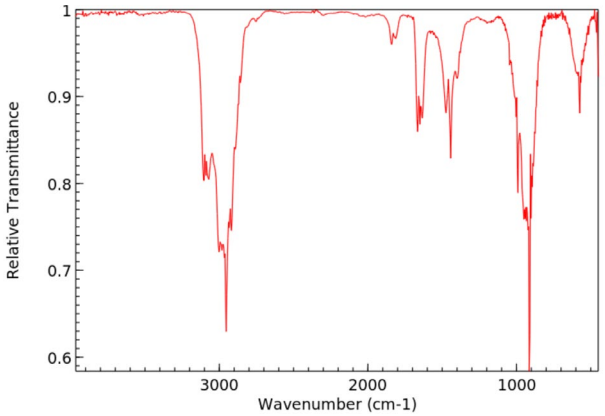
(B)



(C)



(D)



17 In an experiment to determine the K_{sp} value of barium fluoride, five 1.0 mL samples containing barium ions were prepared and each was added to a 1.0 mL solution containing fluoride ions. The results are given below.

Sample	*Barium ion solution*		*Fluoride ion solution*		*Observation*
	Initial concentration (mol L^{-1})	*Volume (mL)*	*Initial concentration (mol L^{-1})*	*Volume (mL)*	
1	0.010	1.0	0.026	1.0	No precipitate
2	0.010	1.0	0.028	1.0	No precipitate
3	0.010	1.0	0.030	1.0	Faint white precipitate
4	0.010	1.0	0.032	1.0	White precipitate

Which of the following could be the K_{sp} value of barium fluoride?

(A) 1.0×10^{-6}

(B) 1.2×10^{-6}

(C) 8.8×10^{-6}

(D) 7.2×10^{-5}

18 When ethene is reacted completely with hydrogen bromide, 7.27 L of the product is obtained at 25.0°C and 120 kPa. What is the mass of ethene that was reacted?

(A) 7.27 g

(B) 9.87 g

(C) 79.7 g

(D) 118 g

19 A salt has a K_{sp} value of 4.3×10^{-10} and a molar solubility of 2.0×10^{-3} mol L^{-1}. Which of the following represents the formula of this salt?

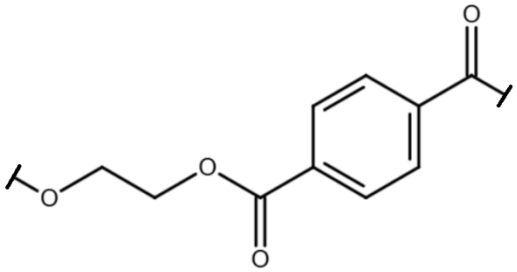
(A) XY

(B) XY_2

(C) XY_3

(D) X_2Y_3

20 1.242 kg of a single polymer with the repeating unit shown below was obtained after a polymerisation reaction.



What mass of water is released during this polymerisation reaction?

(A) 116 g

(B) 233 g

(C) 656 g

(D) 803 g

SECTION II: WRITTEN ANSWER QUESTIONS
80 marks
Attempt ALL Questions

CANDIDATE NUMBER							

Question 21 (2 marks) **Marks**

Using balanced chemical equations, show that the $H_2PO_4^-$ ion can react with both strong acids and strong bases.

2

1 mark $H_2PO_4^-(aq) + H^+(aq) \rightarrow H_3PO_4(aq)$

1 mark $H_2PO_4^-(aq) + OH^-(aq) \rightarrow HPO_4^{2-}(aq) + H_2O(l)$

Accepted H_3O^+ or H^+, any strong acid such as HCl, any reasonable metal hydroxide. Equations needed to clearly show the correct gain/loss of H^+, and have correct balancing.

Question 22 (3 marks)

Calculate the pH of 0.20 mol L^{-1} hydrazoic acid (HN_3, K_a 1.9×10^{-5}).

3

	$HN_3(aq) \rightleftharpoons$	$H^+(aq)$	$+ N_3^-(aq)$
I	0.20	0	0
C	$-x$	$+x$	$+x$
E	$0.20 - x$	x	x

$$K_a = \frac{[H^+(aq)][N_3^-(aq)]}{[HN_3(aq)]}$$

Assuming that $x << 0.20$,

$$\frac{x^2}{0.20} = 1.9 \times 10^{-5}$$

$x^2 = 3.8 \times 10^{-6}$
$x = 1.9 \times 10^{-3}$ mol L^{-1}
$pH = -\log_{10}(1.9 \times 10^{-3}) = 2.71$
(Same result if no assumption made)

Correct answer with working	*3 marks*
Overall method correct with error	*2 marks*
Some relevant information	*1 mark*

Question 23 (6 marks) **Marks**

Hydrogen iodide decomposes when heated to hydrogen and iodine as shown below.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

(a) Give the equilibrium expression for this reaction. **1**

$K_{eq} = \frac{[H_2][I_2]}{[HI]^2}$ (Must include K_{eq})

(b) In an experiment, 1.75 mol of hydrogen iodide was placed in a 1.00 L vessel at a constant temperature. At equilibrium, the concentration of iodine gas was 0.168 mol L^{-1}.

What is the K_{eq} value at this temperature? **3**

	$2HI(g) \rightleftharpoons$	$H_2(g)$ +	$I_2(g)$
I	1.75 M	0	0
C	-(2 x 0.168) M	+0.168	+0.168
E	1.414 M	0.168 M	0.168 M

$$K_{eq} = \frac{[H_2][I_2]}{[HI]^2} = \frac{[0.168][0.168]}{[1.414]^2} = 0.0141$$

Correct answer to 3 significant figures	*3 marks*
A value for K_{eq} calculated with an error	*2 marks*
Some relevant information	*1 mark*

(c) Explain what would happen to the value of K_{eq} if a catalyst was added at constant temperature. **2**

1- K_{eq} will be the same.

*1- catalyst increases the reaction rate of both the forward and reverse reaction **by the same amount** so the forward rate will be the same as the reverse rate and therefore K_{eq} remains the same*

OR

$[H_2]$, $[I_2]$, [HI] are not affected by addition of catalyst therefore K_{eq} remains the same.

Did not accept explanation by negative e.g. "only temperature changes K_{eq}".

Question 24 (4 marks) **Marks**

100.0 mL of 1.00 mol L^{-1} sodium hydroxide is mixed with 100.0 mL of 1.00 mol L^{-1} nitric acid in a cardboard cup. The initial temperature of each solution is 24.30 °C and the resulting solution has a temperature of 31.15 °C.

You can assume that there is no volume change upon reaction, and that the resulting solution has a density of 1.04 g mL^{-1} and a specific heat capacity of 4.03 J K^{-1} g^{-1}.

Calculate the enthalpy of neutralisation for this reaction.

4

m(solution after reaction) = 200.0 mL × 1.04 g mL^{-1} = 208 g

ΔT = 31.15 – 24.30 = 6.85 K

q =mcΔT = 208 g × 4.03 J K^{-1} g^{-1} × 6.85 K = 5740 J = 5.74 kJ

n(H_2O) = n(HNO_3) = n(NaOH) = 1.00 mol L^{-1} × 0.100 L = 0.100 mol

ΔH= –5.74 kJ / 0.100 mol = –57.4 kJ mol^{-1} (to 3 s.f.)

Correct answer with working	*4 marks*
Minor mistake(s) e.g. not using the given specific heat capacity, not using the density data.	*3 marks*
At least two of the major steps of the calculation included (moles/q/ ΔH)	*2 marks*
Some relevant information	*1 mark*

Question 25 (10 marks) **Marks**

The synthesis of ammonia from its elements is an equilibrium process.

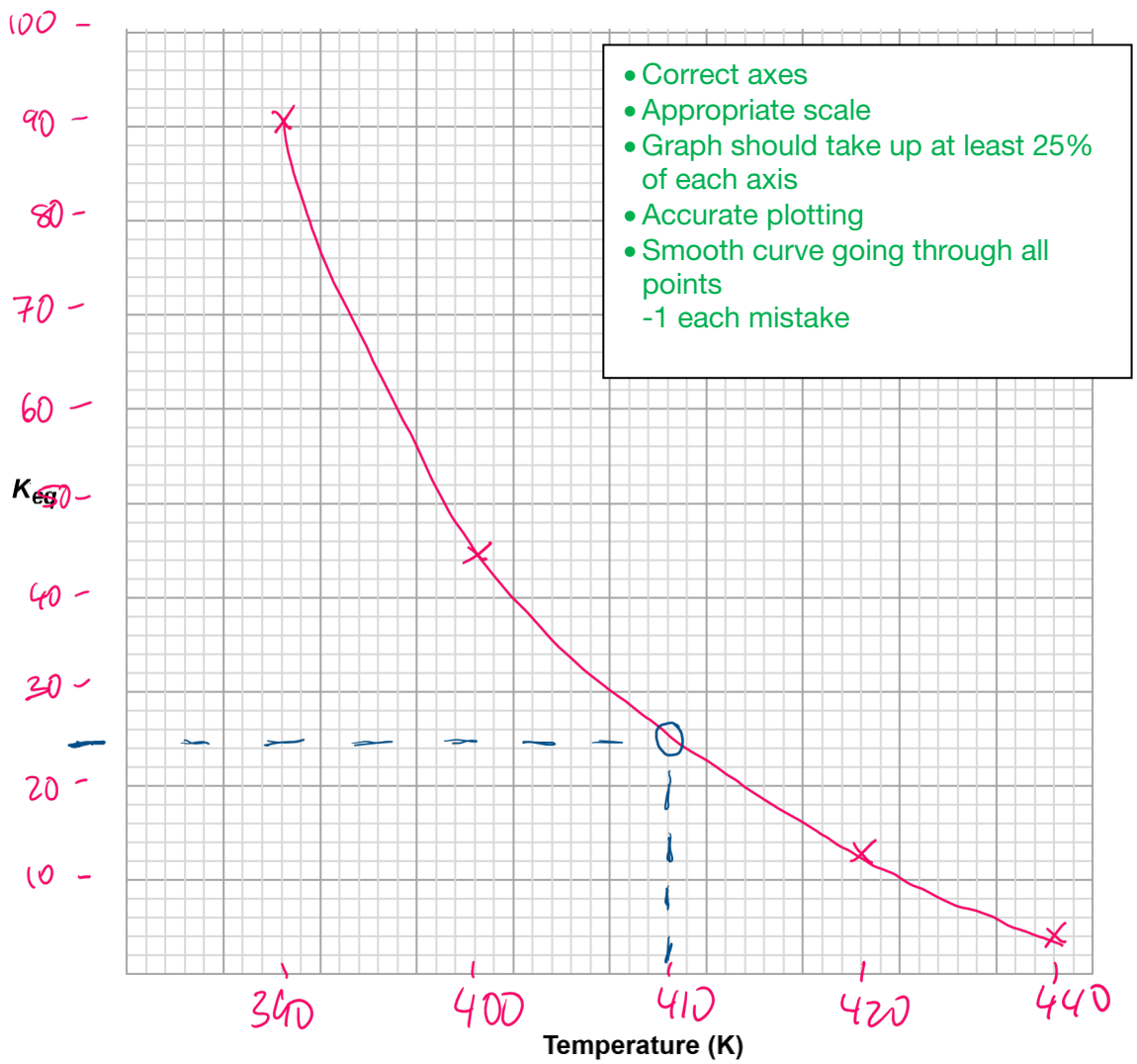
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The table shows the value of K_{eq} for this reaction at a range of different temperatures.

Temperature (K)	K_{eq}
390	90
400	44
420	12
430	6.4
440	3.6

(a) Plot this data, including a curved line of best fit.

3



Question 25 continued. **Marks**

(b) Using the graph, estimate K_{eq} at 410 K.

1

Correct value taken from their graph (generally K_{eq} = 22-27)

(c) A system at 410 K is found to have $[N_2]$ = 0.24 mol L^{-1}, $[H_2]$ = 1.1 mol L^{-1} and $[NH_3]$ = 1.6 mol L^{-1}.

Show that this system is not at equilibrium and use *Q* and K_{eq} to explain how the system will shift to reach equilibrium.

3

$$Q = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{[1.6]^2}{[0.24][1.1]^3} = 8$$

$Q < K_{eq}$, so system is not at equilibrium.

Q must increase so system will favour forward reaction, increasing $[NH_3]$ and decreasing $[N_2]$ and $[H_2]$ until $Q = K_{eq}$.

Correct calculation, explains shift in terms of concentration, Q, and K_{eq}.	*3 marks*
Missing one of the above	*2 marks*
Some relevant information	*1 mark*

(d) Is the production of ammonia exothermic or endothermic? Justify your answer using Le Châtelier's Principle and the data provided.

3

Forward reaction is exothermic.
As seen in graph, as temperature increases K_{eq} decreases. This means as temp increases $[N_2]$ and $[H_2]$ increases and $[NH_3]$ decreases and the reverse reaction is favoured.
According LCP, higher temperature will favour the endothermic direction, so the reverse reaction is endothermic, and the forward direction is exothermic.

Must refer to data/graph, related LCP specifically to the scenario, explicitly conclude that the production of ammonia is exothermic	*3 marks*
Missing part of the above	*2 marks*
Some relevant information	*1 mark*

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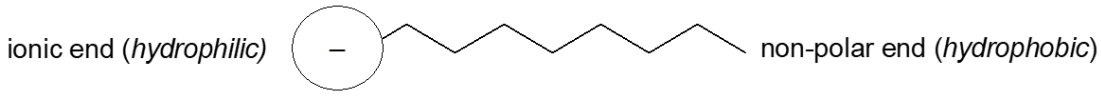
Question 26 (5 marks) **Marks**

Soap can be used as a cleaning agent due to its ability to stabilise emulsions.

(a) Draw a labelled diagram to show the structure of a soap molecule.



2

Criteria	*Marks*
Provides: A correct diagram with a negatively charged head and a hydrocarbon tail Correct labels identifying polar/hydrophillic head and non-polar/hydrophobic tail	*2*
Provides one of the above	*1*

(b) Explain how soap can act as a cleaning agent.

3

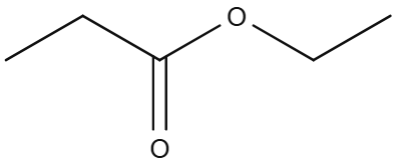
Criteria	*Marks*
Provides a thorough explanation in terms of intermolecular forces and the formation of an emulsion in final step: Must include: • The non-polar end of the soap ions bond to the grease via **dispersion forces AND** the ionic end bonds to water molecules via **H-bonding/ion-dipole**. • Formation of a **micelle** • Micelles suspended in water / washed away with water – refer to cleaning action • Must have some statement regarding keeping micelles separate • Must refer to cleaning action – being washed away	*3*
Provides a sound explanation Must have at least one intermolecular force identified or simply stated 'substance' instead of grease/oil	*2*
Provides some relevant information Any correct intermolecular force Identifies micelles are formed	*1*

Question 27 (4 marks)

Two esters, A and B, have molecular formula $C_5H_{10}O_2$.

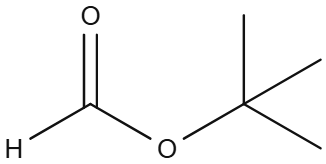
Proton NMR spectroscopy was performed on both compounds, and the following data was obtained.

Ester A



Chemical shift (ppm)	*Relative peak area*	*Peak splitting pattern*
1.05	3	triplet
1.16	3	triplet
2.26	2	quartet
4.11	2	quartet

Ester B



Chemical shift (ppm)	*Relative peak area*	*Peak splitting pattern*
1.42	9	singlet
9.60	1	singlet

Question continues on next page.

Question 27 continued. **Marks**

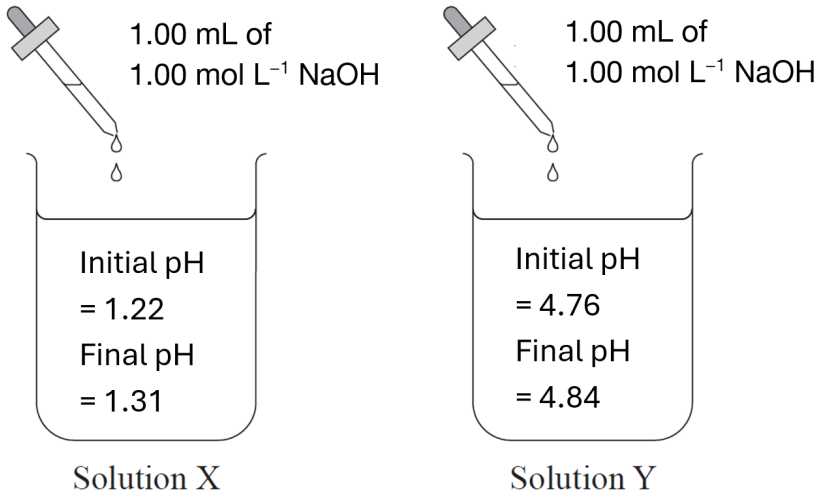
State **two** differences between the proton NMR data and relate these to the structure of the two esters.

4

Criteria	***Marks***
States **two differences** and relates these to the structure of the two esters. Must have explicit link to data and structures i.e. Ester A shows….. Ester B shows….. Difference 1: Number of peaks Ester A produces 4 peaks ester B produces 2 peaks Difference 2: Different splitting Ester A produces 2 triplets and 2 quartets, while ester B produces 2 singlets Ester A must contain CH_2 next to CH_3, whereas ester B contains two (sets of) isolated protons	***4***
States two differences and some link to the structure Must have explicit links to data and one of the structures General links to both structures eg 'A' has triplets and quartets because neighbouring carbons have hydrogen but B has singlets as no neighbouring carbon has hydrogen General statement – more/less peaks	***3***
States two differences from data with no explicit links OR states 1 difference with general link to structure	***2***
Provides some relevant information: States one/two differences	***1***

Question 28 (7 marks) **Marks**

The pH of two 100 mL solutions, X and Y, were measured before and after 1.00 mL of 1.00 mol L^{-1} sodium hydroxide solution was added to each.



One of these solutions contains a solution of a weak acid and its conjugate base, both at a concentration of 0.10 mol L^{-1}; the other contains a 0.060 mol L^{-1} solution of hydrochloric acid.

(a) By performing a relevant calculation, show that Solution X is the 0.060 mol L^{-1} solution of hydrochloric acid.

2

Any relevant calculation:

$pH = -\log_{10}[H_3O^+] = -\log_{10}(0.0600) = 1.22$
This is the same as the **initial** pH of solution X, so solution X is the 0.060 mol L^{-1} solution of hydrochloric acid.

OR

$[HCl] = [H_3O^+] = 10^{-1.22} = 0.060$ mol L^{-1}
The initial pH is 1.22, so the concentration of HCl must be 0.060 mol L^{-1}

OR

n(HCl) = 0.006 mol n(NaOH) = 0.001 mol
n(HCl) in excess after NaOH addition = 0.005 mol
$[HCl] = [H_3O^+] = 0.005 / 0.101 = 0.0495$ mol L^{-1}
Final pH = 1.31

(b) Calculate the K_a of the weak acid.

1

$pK_a = 4.76$ (when $[HA] = [A^-]$, pH = p*K*a)
$K_a = 10^{-4.76} = 1.7 \times 10^{-5}$

Question continues on next page.

Question 28 continued. **Marks**

When 1.00 mL of 1.00 mol L^{-1} sodium hydroxide solution is added to 100 mL of water, the pH increases from 7.00 to 12.00.

(c) Explain why adding 1.00 mL of 1.00 mol L^{-1} sodium hydroxide solution to both solution X and solution Y does not change pH of either appreciably.

4

Solution X

1.00 mL × 1.00 mol L^{-1} = 1.00 mmol of NaOH is being added to both solutions.
Solution X contains 100 mL × 0.0600 mol L^{-1} = 6.00 mmol HCl.
After reaction with the added NaOH, 5.00 mmol of HCl remains, **so it is still present in relatively large excess**, so the pH will not increase appreciably.

Criteria	Marks
Use data to show, AND state, that HCl is in large excess.	2
Use data to show, OR state, that HCl is in large excess	1

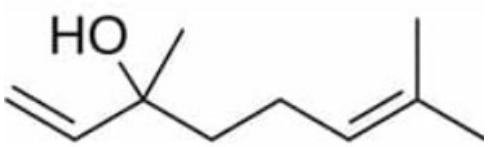
Solution Y

Contains 100 mL × 0.100 mol L^{-1} = 10.0 mmol of the weak acid and 10.0 mmol of its conjugate base. Adding 1.00 mmol of NaOH will turn 1.00 mmol of the acid form into the base form, leaving 9.00 mmol of the weak acid and 11.00 mmol of the conjugate base in the resulting solution. As the ratio of conjugate base to acid is still close to 1, the pH of the solution will be close to the p*K*a, so the pH will not increase appreciably. Or buffer explanation.

Criteria	Marks
Use data to show, AND state, that solution is acting as a buffer	2
Use data to show, OR state, that solution is acting as a buffer	1

Question 29 (5 marks) **Marks**

Linalool is a compound found in many flowers and spices. The structural formula is shown below.



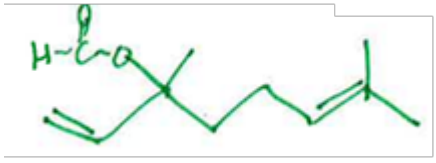
(a) State the names of the **two** functional groups in linalool.

2

1 mark: Alkene / carbon-carbon double bond
1 mark: alcohol / hydroxyl group

(b) Linalool undergoes many chemical reactions. Complete the table by identifying the product when the following reagents are added to a linalool solution under the stated conditions.

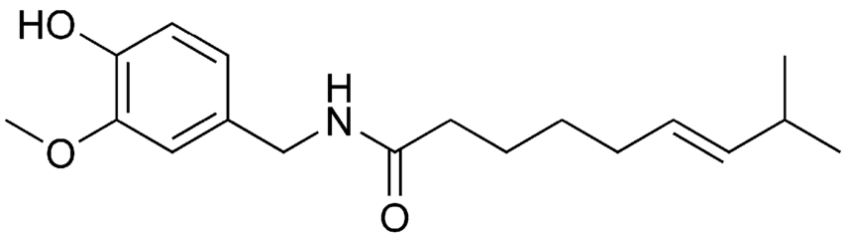
3

Reagent and conditions	*Structural formula of organic product*
$H_2(g)$ Pd catalyst	
$Br_2(aq)$	
HCOOH(aq) H_2SO_4 catalyst Heat under reflux	

Question 30 (3 marks) **Marks**

The compound responsible for the hot taste of chillies, capsaicin, is shown. Drinking full cream milk, which contains fat, is recommended after eating meals containing lots of chilli as it reduces the hot taste on the tongue.

Explain why milk is better than water in removing capsaicin from the tongue.



3

Criteria	*Marks*
Provides a thorough explanation in terms of intermolecular forces, including: • *ID capsaicin as non-polar molecule* • *ID dispersion forces between milk and capsaicin* • *Higher solubility in milk than water OR forms emulsion/micelles* • *Must include comparison with water* *A full explanation in terms of enthalpy/entropy changes was also awarded full marks*	*3*
Provides a sound explanation including: *-Includes 2 points from above*	*2*
Provides some relevant information including: *-Forms stronger bonds with milk*	*1*

Question 31 (9 marks) **Marks**

Three bottles, known to contain pentan-1-ol, pentan-3-ol and 2-methylbutan-2-ol, are missing labels.

(a) Suggest how a student could distinguish between the three alcohols using one or more chemical tests.

3

Criteria	*Marks*
Give a test or two tests AND expected results for pentan-1-ol, pentan-3-ol and 2-methylbutan-2-ol *For example:* *Add Lucas reagent to all three alcohols* *Tertiary alcohol turns cloudy immediately* *Secondary alcohol turns cloudy after some time* *Primary alcohol remains colourless solution*	*3*
Give test AND at least one correct result	*2*
Give test OR a correct result	*1*

Question continues on next page.

Question 31 continued. **Marks**

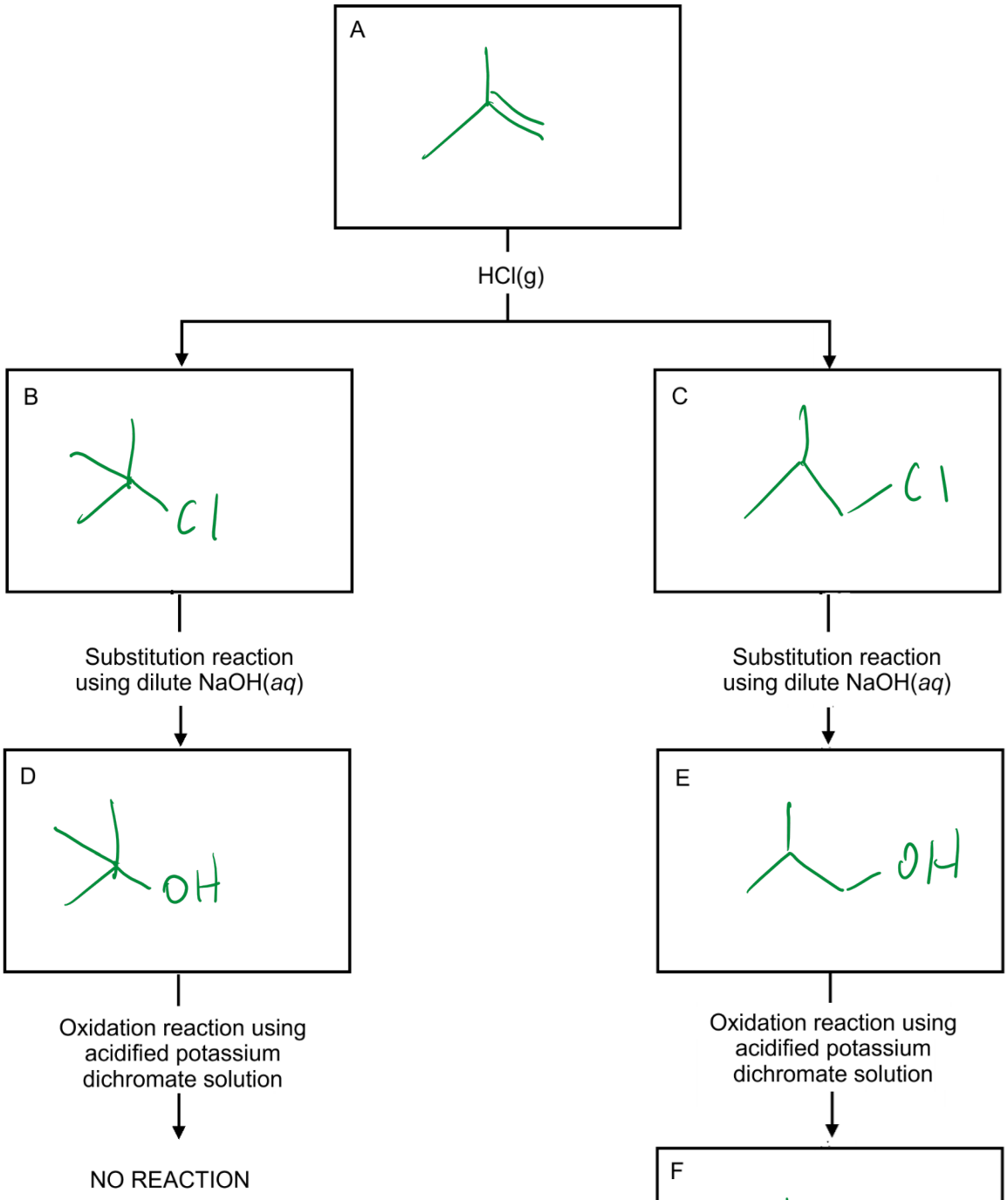
(b) The student can use a combination of infrared, mass spectrometry and ^{13}C NMR to confirm the contents of the three bottles. Evaluate the suitability of these techniques for this purpose.

6

Criteria	*Marks*
Evaluate the suitability of IR, MS and 13C NMR, by: *-Commenting on suitability of each method* *-Referring to the structure/formula of the molecule* *-Referring to the expected spectra.* *IR* • *Can not be used to confirm all three isomers* • *Alcohols all contain O-H* • *All molecules produce broad peak at 3230-3550 cm^{-1}.* *MS* • *Can not be used to confirm all three isomers* • *All molecules are isomers/have the same MM* • *They would all produce an M+ peak in same position/at m/z 88.* *13C NMR* • *Can confirm each individual alcohol* • *Each alcohol has a different number of unique carbon environments* • *Each alcohol will give a different number of peaks:* • *Pentan-1-ol will give 5 peaks* • *Pentan-3-ol will give 3 peaks* • *2-Methylbutan-2-ol will give 4 peaks*	*1) 6*
As above, but including: *- 1 incomplete evaluation (missing link to structure or spectra) OR* *- 1/2 small errors (including incorrect number of C-environments/peaks)*	*5*
As above, but including: *- 2/3 incomplete evaluations (missing reference to spectra or structure of alcohols) OR* *-2 full evaluations + 1 incorrect evaluation* *-Mostly correct terminology*	*4*
As above, but with: *- Vague evaluations, missing links to spectra and structure of the alcohols*	*3*
Two pieces of relevant information	*2*
One piece of relevant information	*1*

Question 32 (5 marks) **Marks**

Alkene A reacts with gaseous hydrogen chloride to form two isomers, B and C, with molecular formula C_4H_9Cl. A sequence of reactions for each compound is shown below. Determine the structural formulae of the compounds A to F.



3 marks for alkene A

2 marks for plus any error.

1 mark for any correct structure.

ACCEPT ALDEHYDE

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Question 33 (5 marks) **Marks**

Periclase is a mineral composed of magnesium oxide (*MM* 40.31 g mol^{-1}). A 0.4802 g ore sample containing periclase is treated with 50.00 mL of 0.5020 mol L^{-1} hydrochloric acid. The acid reacts with the magnesium oxide, but not with the other components of the ore sample. After reaction and filtration, the solution is made up to 250.0 mL in a volumetric flask. 25.00 mL aliquots of this solution are titrated with 0.1034 mol L^{-1} sodium hydroxide (NaOH), requiring an average of 12.90 mL to reach the endpoint.

Calculate the percentage by mass of magnesium oxide in the periclase ore sample.

5

n(HCl) = 50.00 mL × 0.5020 mol L^{-1} = 25.10 mmol

n(NaOH) = 12.90 mL × 0.1034 mol L^{-1} = 1.334 mmol

n(HCl in XS, in aliquot) = 1.334 mmol

n(HCl in XS, total) = 250.0 mL / 25.00 mL × 1.334 mmol = 13.34 mmol

n(HCl reacting with MgO) = 25.10 mmol – 13.34 mmol = 11.76 mmol

n(MgO) = 11.76 mmol / 2 = 5.881 mmol

m(MgO) = 5.881 × 10^{-3} mol × 40.31 g mol^{-1} = 0.2371 g

%(MgO) = 0.2371 g / 0.4802 g ×100 = 49.37%

Criteria	*Mark*
• Correctly calculates the percentage by mass of magnesium oxide in the periclase ore sample	5
• Calculates the percentage by mass of magnesium oxide in the periclase ore sample, but with one error, e.g. ○ Missing 1:2 mole ratio ○ Missing 25 in 250 sampling factor ○ Major rounding error: wrong value in 3rd s.f. (out of 4)	4
• Calculates the percentage by mass of magnesium oxide in the periclase ore sample, but with two minor errors, or one major conceptual error, e.g. ○ Calculation that ignores the excess reagent / back titration concept	3
• Performs two different steps of the calculation, e.g. ○ Writes a balanced chemical equation ○ Performs a concentration × volume calculation (n.b. performing two such calculations is not sufficient for 2 marks) ○ Excess/limiting reagent identification	2
• Provides some relevant information	1

Question 34 (5 marks) **Mark**

Red iron(III) thiocyanate is produced in the following equilibrium reaction.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons [FeSCN]^{2+}(aq)$$

At equilibrium at 298 K there are 0.00540 mol of $Fe^{3+}(aq)$, 0.00823 mol of $SCN^{-}(aq)$ and 0.0631 mol of $[FeSCN]^{2+}(aq)$ in a 100.0 mL solution.

What mass of pure sodium hydroxide should be added to increase the amount of $SCN^{-}(aq)$ to 0.00944 mol at equilibrium?

5

$$K_{eq} = \frac{[FeSCN^{2+}]}{[Fe^{3+}][SCN^{-}]} = \frac{\left[\frac{0.0631}{01}\right]}{\left[\frac{0.00540}{0.1}\right]\left[\frac{0.00823}{0.1}\right]} = 142.0$$

Let x = amount of Fe^{3+} removed by precipitation as $Fe(OH)_3(s)$.

	$Fe^{3+}(aq)$ +	$SCN^{-}(aq) \rightleftharpoons$	$FeSCN^{2+}(aq)$
I	0.00540 – x mol	0.00823 mol	0.0631 mol
C	+ 0.00121 mol	+ 0.00121 mol	– 0.00121 mol
E	0.00661 – x mol	0.00944 mol	0.06189 mol
Conc.	$\frac{0.00661 - x}{0.1}$ mol L^{-1}	0.0944 mol L^{-1}	0.6189 mol L^{-1}

$$K_{eq} = \frac{[FeSCN^{2+}]}{[Fe^{3+}][SCN^{-}]} = 142.0 = \frac{[0.6189]}{[Fe^{3+}][0.0944]}$$

$[Fe^{3+}] = 0.0462$ mol L^{-1}

$\frac{0.00661 - x}{0.1} = 0.0462$ mol L^{-1}, so $x = 0.00199$ mol

$Fe^{3+}(aq) + 3OH^{-}(aq) \rightarrow Fe(OH)_3(s)$

$n(OH^{-}$ added$) = 3 \times 0.00199$ mol $= 0.00598$ mol

$m(NaOH) = n \times MM = 0.00598$ mol $\times 39.998$ g $mol^{-1} = 0.239$ g (to 3 s. f.)

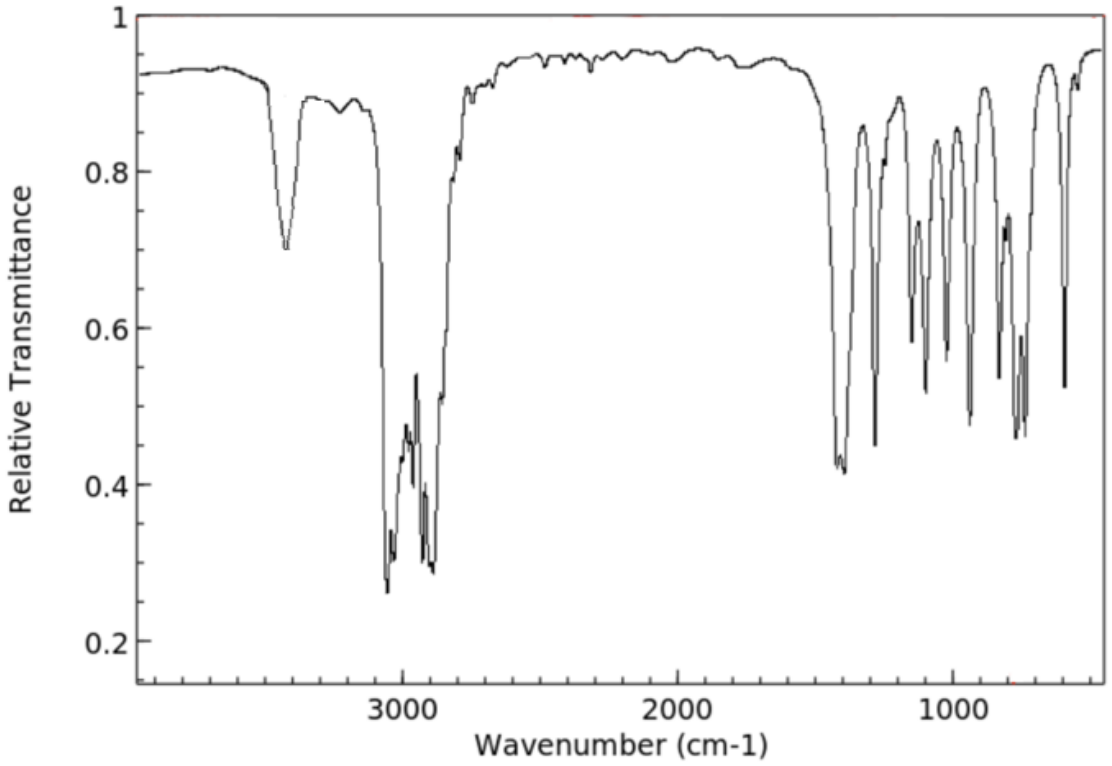
Criteria	*Mark*
• Correctly calculates the mass of sodium hydroxide added	5
• Performs the major steps of the calculation ○ e.g. calculates final $[Fe^{3+}]$ and/or $n(Fe^{3+})$ removed	4
• Performs some steps of the calculation ○ e.g. calculates K_{eq}, $\Delta n(SCN^{-})$ and substantially correct ICE box values	3
• Performs two steps of the calculation ○ e.g. calculates K_{eq}, AND ○ $\Delta n(SCN^{-})$ OR some correct ICE box values	2
• Provides some relevant information	1

Question 35 (7 marks)

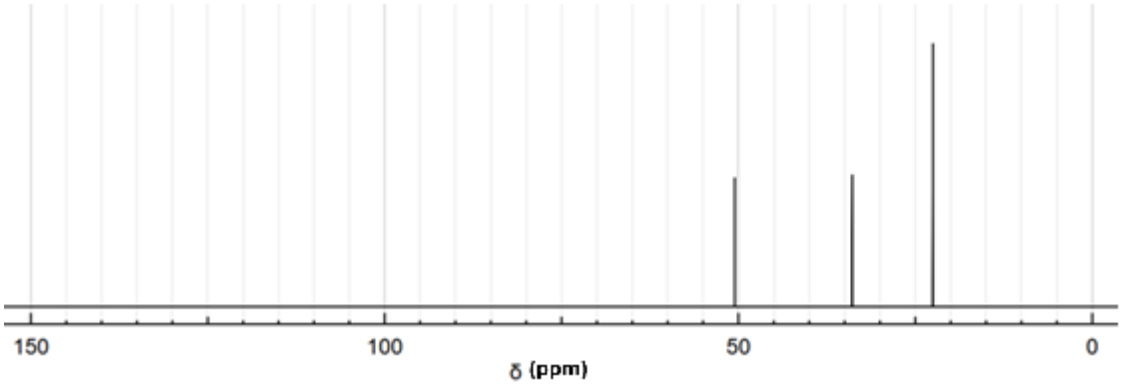
Compound Q is an organic compound which contains roughly 19% nitrogen by mass.

The infrared, ^{13}C NMR and ^{1}H NMR spectra of compound Q are shown below.

Chemical shift data for ^{1}H NMR is provided.



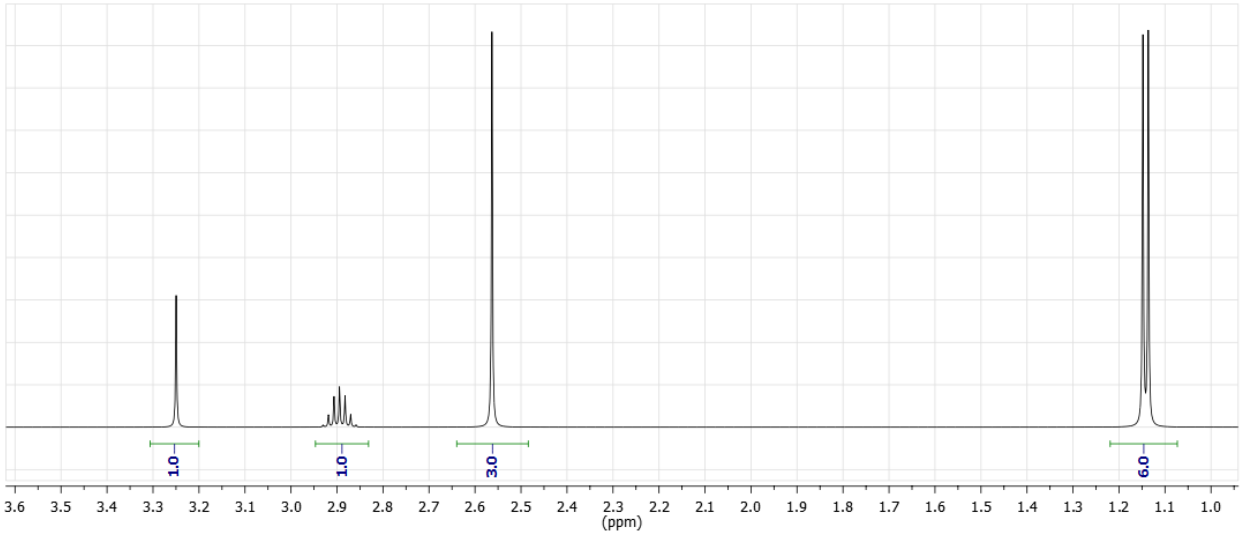
IR spectrum of compound Q



^{13}C NMR spectrum of compound Q

Question continues on next page.

Question 35 continued.



^{1}H NMR spectrum of compound Q

^{1}H NMR chemical shift data

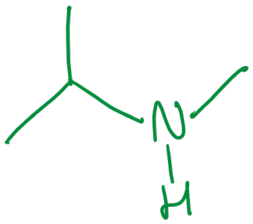
Type of proton	δ/ppm
$Si(C\mathbf{H}_3)_4$ (TMS)	0
R–C$\mathbf{H}_3$	0.9–1.0
R–C$\mathbf{H}_2$–R	1.2–1.5
R–C$\mathbf{H}$R$_2$	1.5–2.0
R–C≡C–**H** (alkyne)	2.0–3.1
–CO–C$\mathbf{H}_2$– (aldehydes, ketones or esters)	2.1-2.7
R–C$\mathbf{H}_2$–NH$_2$ or C$\mathbf{H}$R–NH$_2$	2.4–3.0
R–C$\mathbf{H}_2$–NHR or C$\mathbf{H}$R–NHR	2.5–3.1
–C$\mathbf{H}_2$–O– (alcohols, ethers or esters)	3.3–4.8
R–O**H**	1–6
R–N$\mathbf{H}_2$	1–5
R–N**H**R	1–5
R$_2$C=C**H**R (alkene)	4.5–7.0
R–COON**H**–R (amide)	5–9
R–C**H**O (aldehyde)	9.4–10.0
R–COO**H**	9.0–13.0

Question 35 continued. **Marks**

Draw and name compound Q and justify your choice using all information provided.

7

Compound Q



Name: ***N*-methylpropan-2-amine**

Marking Guidelines

Criteria	*Mark*
• Draws and names correct structure • Justifies structure with respect to all information provided	7
• Draws and names correct structure • Justifies structure with respect to most information provided OR • Draws correct structure • Justifies structure with respect to all information provided	6
• Draws structure with at least some correct parts • Relates some information provided to structure	4-5
• Draws structure with at least some correct parts AND/OR • Provides some analysis of relevant information	2-3
• Provides some relevant information	1

Sample Answer

% composition

If 1 × N, molar mass(Q) ≈ 100 / (19 / 14.01) ≈ 74 g mol^{-1}

Integration of 11 × H in ^{1}H NMR suggests 11 × H. Removing mass of NH_{11} (25) from 74 leaves 49, or approximately 4 × C.

This suggests that the formula is $C_4H_{11}N$, with molar mass 73.138 g mol^{-1}

IR

Peak at ~3400 cm^{-1} due to N-H (possibly secondary amine)

^{13}C NMR

3 peaks (at δ 23, 35 and 50 ppm) → some symmetry (fewer peaks than the number of carbon atoms in the molecule).

50 ppm peak definitely in C-N range (25 – 60 ppm) and 23 ppm peak must be C-C (5 – 40 ppm).

35 ppm peak is in both C-C and C-N ranges, so could be either.

^{1}H NMR

The 3H singlet must be a methyl group, and the chemical shift of 2.55 ppm indicates that it is attached to a nitrogen (given 2.5 – 3.1 ppm range for –N-CH_2-): N-C**H**$_3$.

Similarly, the 1H multiplet at 2.9 ppm indicates a CH group attached to a nitrogen, with many protons on adjacent carbon atoms. The protons in the 6H doublet are split by the 1H multiplet and vice versa, which is characteristic of an isopropyl group: -C**H**(C**H**$_3$)$_2$. This gives the structure: N-C**H**(C**H**$_3$)$_2$.

The 1H singlet at 3.25 ppm must be the remaining NH proton (no splitting and its chemical shift is not distinctive (1-5 ppm, which covers all peaks present!), so not of great diagnostic use).

2019 | HIGHER SCHOOL CERTIFICATE EXAMINATION

Chemistry

FORMULAE SHEET

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

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

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

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

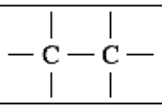
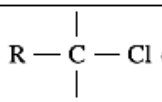
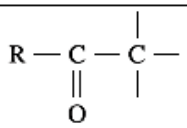
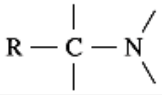
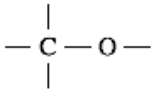
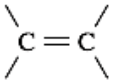
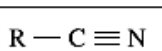
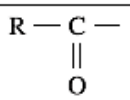
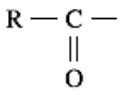
Compound	K_{sp}	*Compound*	K_{sp}
Barium carbonate	2.58×10^{-9}	Lead(II) bromide	6.60×10^{-6}
Barium hydroxide	2.55×10^{-4}	Lead(II) chloride	1.70×10^{-5}
Barium phosphate	1.3×10^{-29}	Lead(II) iodide	9.8×10^{-9}
Barium sulfate	1.08×10^{-10}	Lead(II) carbonate	7.40×10^{-14}
Calcium carbonate	3.36×10^{-9}	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
		5–40
		10–70
		20–50
		25–60
	alcohols, ethers or esters	50–90
		90–150
		110–125
		110–160
	esters or acids	160–185
	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 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

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 (November 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.