



NSW Education Standards Authority

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Centre Number

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Student Number

**2023** HIGHER SCHOOL CERTIFICATE EXAMINATION

# Chemistry

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## General Instructions

- Reading time – 5 minutes
- Working time – 3 hours
- Write using black pen
- Draw diagrams using pencil
- Calculators approved by NESA may be used
- A formulae sheet, data sheet and Periodic Table are provided at the back of this paper
- Write your Centre Number and Student Number at the top of this page

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## Total marks: 100

### Section I – 20 marks (pages 2–11)

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

### Section II – 80 marks (pages 13–40)

- Attempt Questions 21–37
- Allow about 2 hours and 25 minutes for this section

## Section I

20 marks

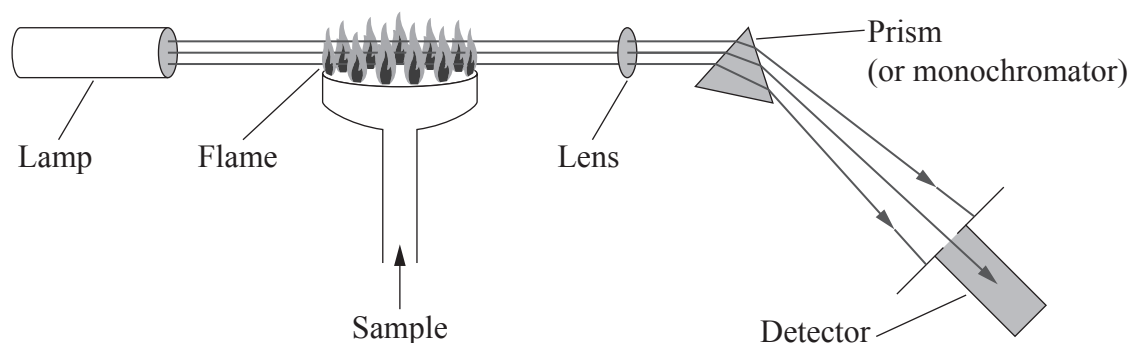
Attempt Questions 1–20

Allow about 35 minutes for this section

Use the multiple-choice answer sheet for Questions 1–20.

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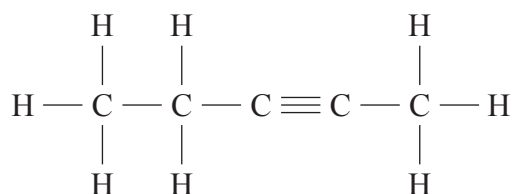
- 1 What is the safest method for disposing of a liquid hydrocarbon after an experiment?
- A. Pour it down the sink
  - B. Place it in a garbage bin
  - C. Burn it by igniting with a match
  - D. Place it in a separate waste container
- 2 The technique illustrated is used to analyse chemical substances in a sample.



What is the technique shown?

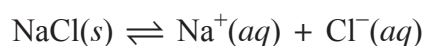
- A. Flame test
- B. Mass spectrometry
- C. Atomic absorption spectroscopy
- D. Ultraviolet-visible spectrophotometry

- 3 The structural formula of a compound is given.



What is the preferred IUPAC name of this compound?

- A. Pent-2-ene
  - B. Pent-2-yne
  - C. Pent-3-ene
  - D. Pent-3-yne
- 4 Sodium chloride dissolves in water according to the following equation.



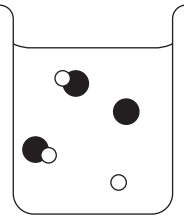
A saturated solution of NaCl in water contains sodium and chloride ions at the following concentrations.

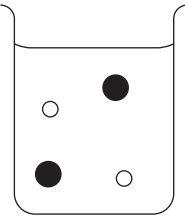
<i>Ion</i>	<i>Concentration</i> (mol L <sup>-1</sup> )
Na <sup>+</sup>	6.13
Cl <sup>-</sup>	6.13

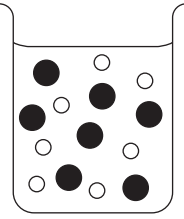
What is the  $K_{sp}$  of sodium chloride?

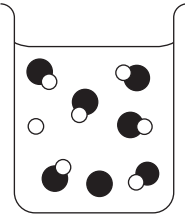
- A.  $2.65 \times 10^{-2}$
- B.  $8.16 \times 10^{-2}$
- C. 12.26
- D. 37.6




5 Which diagram represents the most concentrated weak acid?

A. 

B. 

C. 

D. 

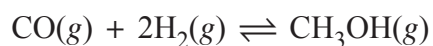
KEY    acid     H<sup>+</sup> ion     anion 

6 The pH of a solution changes from 8 to 5.

What happens to the concentration of hydrogen ions during this change of pH?

- A. It increases by a factor of 3.
- B. It decreases by a factor of 3.
- C. It increases by a factor of 1000.
- D. It decreases by a factor of 1000.

7 A mixture of 0.8 mol of CO(g) and 0.8 mol of H<sub>2</sub>(g) was placed in a sealed 1.0 L container. The following reaction occurred.



When equilibrium was established, the mixture contained 0.5 mol of CO(g).

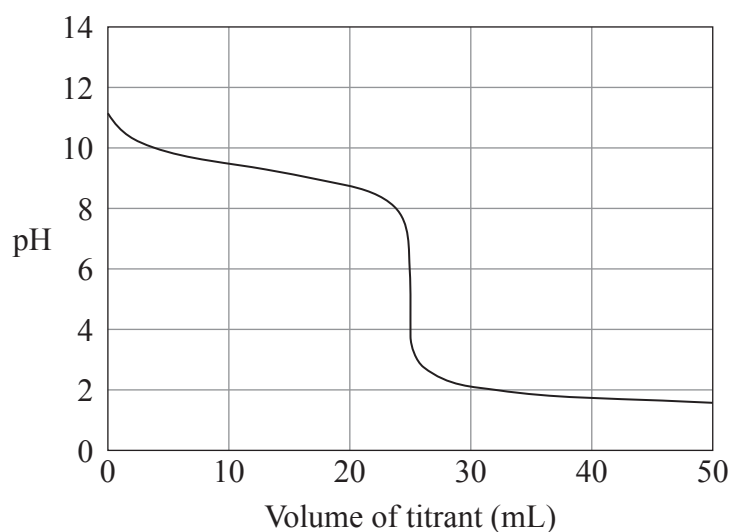
What amount of H<sub>2</sub>(g) was present at equilibrium?

- A. 0.2 mol
- B. 0.4 mol
- C. 0.6 mol
- D. 1.0 mol

8 How many structural isomers have the molecular formula  $C_3H_6F_2$ ?

- A. 2
- B. 3
- C. 4
- D. 5

9 A titration was performed using two solutions of equal concentration, producing the following titration curve.



Which combination of solutions does the titration curve represent?

- A. Addition of a weak base to a weak acid
- B. Addition of a weak base to a strong acid
- C. Addition of a strong acid to a weak base
- D. Addition of a strong acid to a strong base

- 10 Which of the following correctly lists the compounds in order of increasing boiling point?
- A. Heptane < heptan-2-one < heptan-1-ol < heptanoic acid  
 B. Heptane < heptan-1-ol < heptan-2-one < heptanoic acid  
 C. Heptanoic acid < heptan-2-one < heptan-1-ol < heptane  
 D. Heptanoic acid < heptan-1-ol < heptan-2-one < heptane
- 11 An indicator solution was obtained by boiling a flower in water.

**Flower water indicator chart**

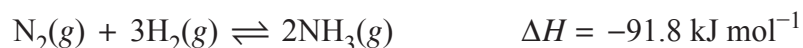
<i>Colour</i>	Red			Purple			Blue		Blue-green		Green-yellow	
<i>pH</i>	1	2	3	4	5	6	7	8	9	10	11	12

Two solutions were tested with this indicator.

Which row of the table correctly identifies the colour of each solution?

	$\text{H}_2\text{SO}_4 (1 \times 10^{-5} \text{ mol L}^{-1})$	$\text{NaOH} (5 \times 10^{-5} \text{ mol L}^{-1})$
A.	Red	Green-yellow
B.	Red	Blue-green
C.	Purple	Blue-green
D.	Purple	Green-yellow

- 12 The industrial production of ammonia is represented by the Haber process reaction shown.



Factors such as temperature and pressure need to be considered in order to maximise yield.

Which of the following is correct?

- A. A lower pressure would result in a higher yield.
  - B. A higher pressure would result in a higher yield.
  - C. A lower temperature would result in a lower yield.
  - D. A higher temperature would result in a higher yield.
- 13 The table shows four separate tests used to identify a dilute, aqueous sample of a compound.

<i>Test number</i>	<i>Test</i>	<i>Observations</i>
1	Test with red litmus	Stays red
2	Add Ba <sup>2+</sup> ions to a sample	White precipitate formed
3	Add OH <sup>-</sup> ions to a sample	Brown precipitate formed
4	Add Cl <sup>-</sup> ions to a sample	White precipitate formed

Which compound would produce the observations shown?

- A. Silver sulfate
- B. Lead(II) acetate
- C. Iron(II) bromide
- D. Magnesium carbonate

- 14 What volume of  $0.540 \text{ mol L}^{-1}$  hydrochloric acid will react completely with 1.34 g of sodium carbonate?
- A. 11.7 mL  
B. 23.4 mL  
C. 29.9 mL  
D. 46.8 mL
- 15 The table gives the heat of combustion of three different alcohols at  $25^\circ\text{C}$ .

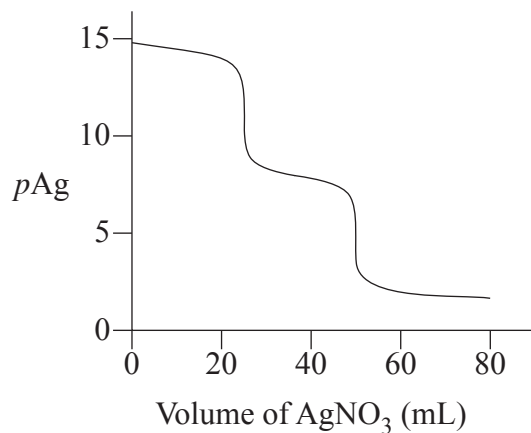
<i>Alcohol</i>	<i>Heat of combustion</i> ( $\text{kJ g}^{-1}$ )
Methanol	22.68
Ethanol	29.67
Butan-1-ol	36.11

Which of the following gives the best approximation for the molar heat of combustion of propan-1-ol, expressed in  $\text{kJ g}^{-1}$ ?

- A.  $\left(\frac{22.68 + 29.67 + 36.11}{3}\right)$   
B.  $\left(\frac{29.67 + 36.11}{2}\right)$   
C.  $\left(\frac{22.68 + 29.67}{2}\right)$   
D.  $\left(\frac{3 \times 36.11}{4}\right)$



- 16 A solution contains potassium iodide and potassium chloride. It was analysed by performing a precipitation titration using silver nitrate. The titration curve for this reaction is shown, where  $pAg = -\log_{10}[Ag^+]$ .



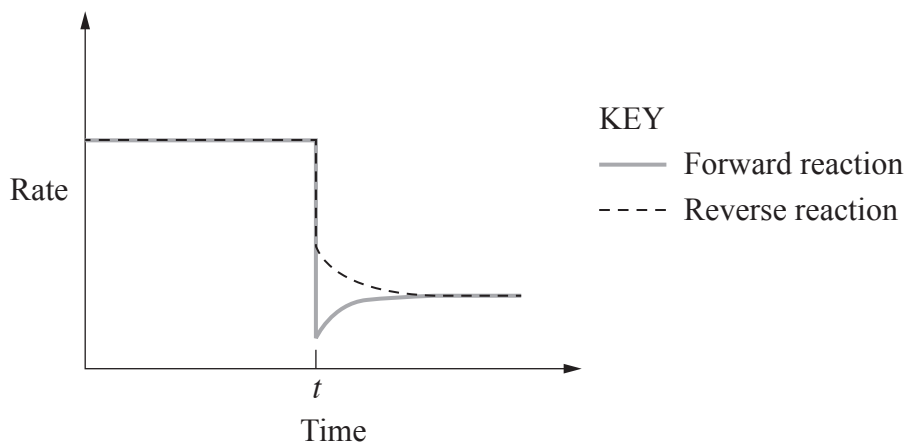
Why is this a valid and correct procedure for quantifying the amount of each anion present in the mixture?

- A. AgCl would precipitate out first, followed by AgI.
  - B. AgI would precipitate out first, followed by AgCl.
  - C. Both AgI and AgCl precipitate out of the solution together.
  - D. Neither AgCl nor AgI would precipitate out of the solution.
- 17 What mass of lead(II) iodide ( $MM = 461 \text{ g mol}^{-1}$ ) will dissolve in 375 mL of water?
- A. 0.233 g
  - B. 0.293 g
  - C. 0.369 g
  - D. 0.621 g

- 18 Carbon dioxide reacts with hydrogen gas to form carbon monoxide and water vapour in a sealed flask, according to the following equation.



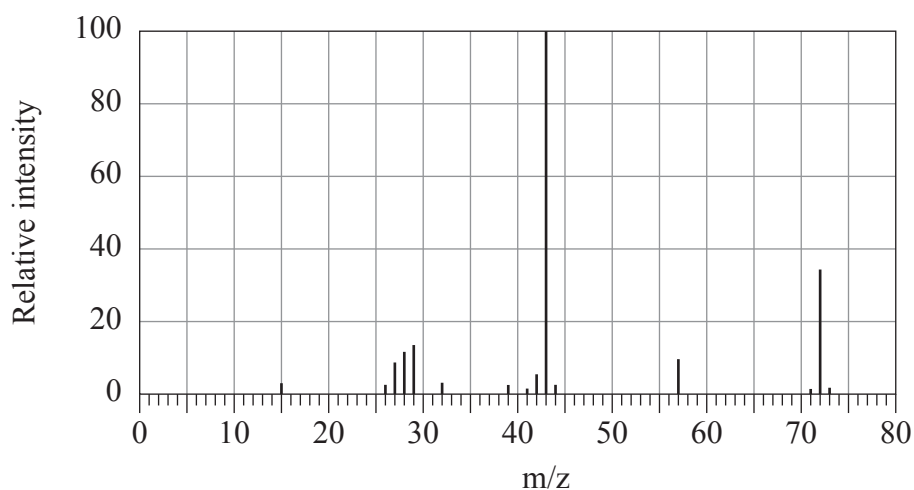
A temperature change was imposed on the equilibrium system at time  $t$  and the rates of both the forward and reverse reactions were monitored.



Which row of the table correctly identifies the nature of both temperature change at time  $t$  and the  $\Delta H$  of the forward reaction?

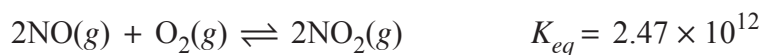
	<i>Temperature change at time <math>t</math></i>	<i><math>\Delta H</math> of the forward reaction</i>
A.	Decrease	+
B.	Decrease	-
C.	Increase	+
D.	Increase	-

- 19 The diagram shows a simplified mass spectrum for butan-2-one.



Which equation best represents the process that produces the particle responsible for the peak at  $m/z$  43?

- A.  $\text{CH}_3\text{COCH}_2\text{CH}_3^+ \rightarrow \text{CH}_3\text{CO} + ^+\text{CH}_2\text{CH}_3$   
 B.  $\text{CH}_3\text{COCH}_2\text{CH}_3^+ \rightarrow \text{CH}_3\text{CO}^+ + \text{CH}_2\text{CH}_3$   
 C.  $\text{CH}_3\text{COCH}_2\text{CH}_3^+ \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2 + ^+\text{CHO}$   
 D.  $\text{CH}_3\text{COCH}_2\text{CH}_3^+ \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2^+ + \text{CHO}$
- 20 Nitrogen monoxide and oxygen combine to form nitrogen dioxide, according to the following equation.



A 2.00 L vessel is filled with 1.80 mol of  $\text{NO}_2(g)$  and the system is allowed to reach equilibrium.

What is the equilibrium concentration of  $\text{NO}(g)$ ?

- A.  $0.00 \text{ mol L}^{-1}$   
 B.  $4.34 \times 10^{-5} \text{ mol L}^{-1}$   
 C.  $6.90 \times 10^{-5} \text{ mol L}^{-1}$   
 D.  $8.69 \times 10^{-5} \text{ mol L}^{-1}$

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Centre Number

# Chemistry

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## Section II Answer Booklet

**80 marks**

**Attempt Questions 21–37**

**Allow about 2 hours and 25 minutes for this section**

### Instructions

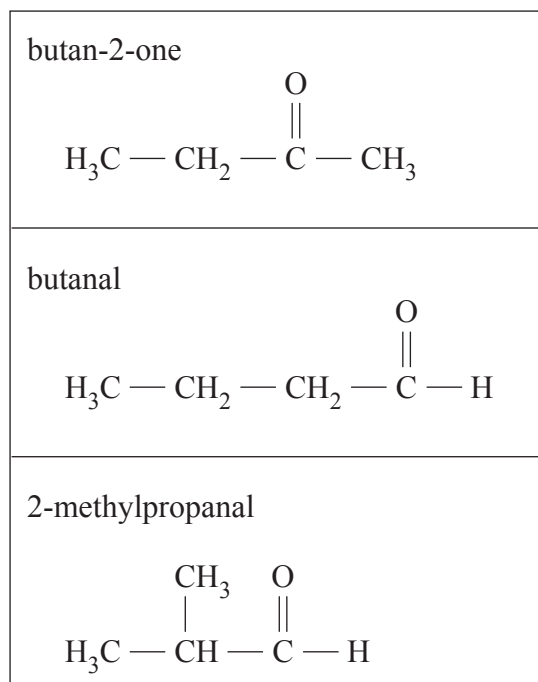
- Write your Centre Number and Student Number at the top of this page.
- Answer the questions in the spaces provided. These spaces provide guidance for the expected length of response.
- Show all relevant working in questions involving calculations.
- Extra writing space is provided at the back of this booklet. If you use this space, clearly indicate which question you are answering.

**Please turn over**

**Question 21** (2 marks)

Some isomers with the formula  $C_4H_8O$  are shown.

2



Name ONE pair of functional group isomers and ONE pair of chain isomers from the structures above.

<i>Type of isomer</i>	<i>Pair of isomers</i>
Functional group	..... and .....
Chain	..... and .....

Do NOT write in this area.

**Question 22** (4 marks)

Explain how the following substances would be classified under the Arrhenius and Brønsted–Lowry definitions of acids. Support your answer with relevant equations.

**4**

- $\text{HCl}(aq)$
- $\text{NH}_4\text{Cl}(aq)$

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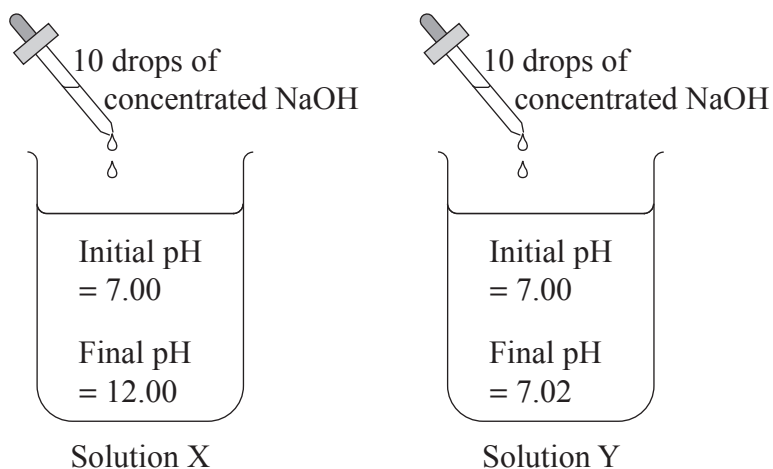
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**Question 23** (3 marks)

The pH of two solutions, X and Y, were measured before and after 10 drops of concentrated NaOH was added to each.

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Explain the pH changes that occurred in solutions X and Y.

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**Question 24** (2 marks)

The hydrogen oxalate ion ( $\text{HC}_2\text{O}_4^-$ ) is classified as amphiprotic.

**2**

Describe, using chemical equations, how this ion is amphiprotic.

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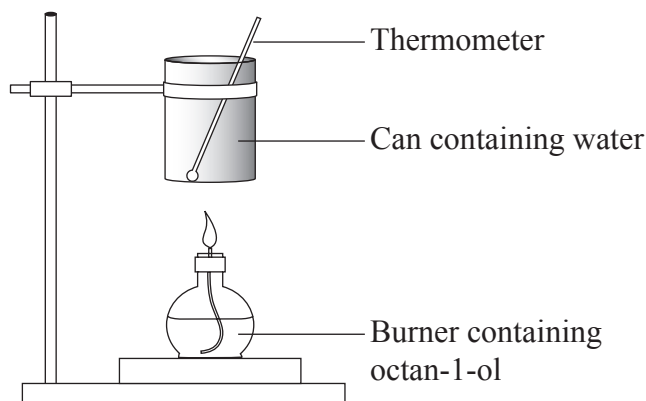
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**Question 25** (5 marks)

A student used the apparatus shown to investigate the combustion of octan-1-ol.



The following results were obtained by the student.

Mass of water heated	= 205 g
Initial temperature of water	= 23.7°C
Final temperature of water	= 60.4°C

The following data are given.

Molar enthalpy of combustion of octan-1-ol	= -5294 kJ mol <sup>-1</sup>
Molar mass of octan-1-ol	= 130.23 g mol <sup>-1</sup>

- (a) Assuming that no energy released by this combustion is lost to the surroundings, calculate the mass of octan-1-ol burnt. **3**

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**Question 25 continues on page 19**

Question 25 (continued)

(b) Explain ONE advantage of using a biofuel compared to fossil fuels.

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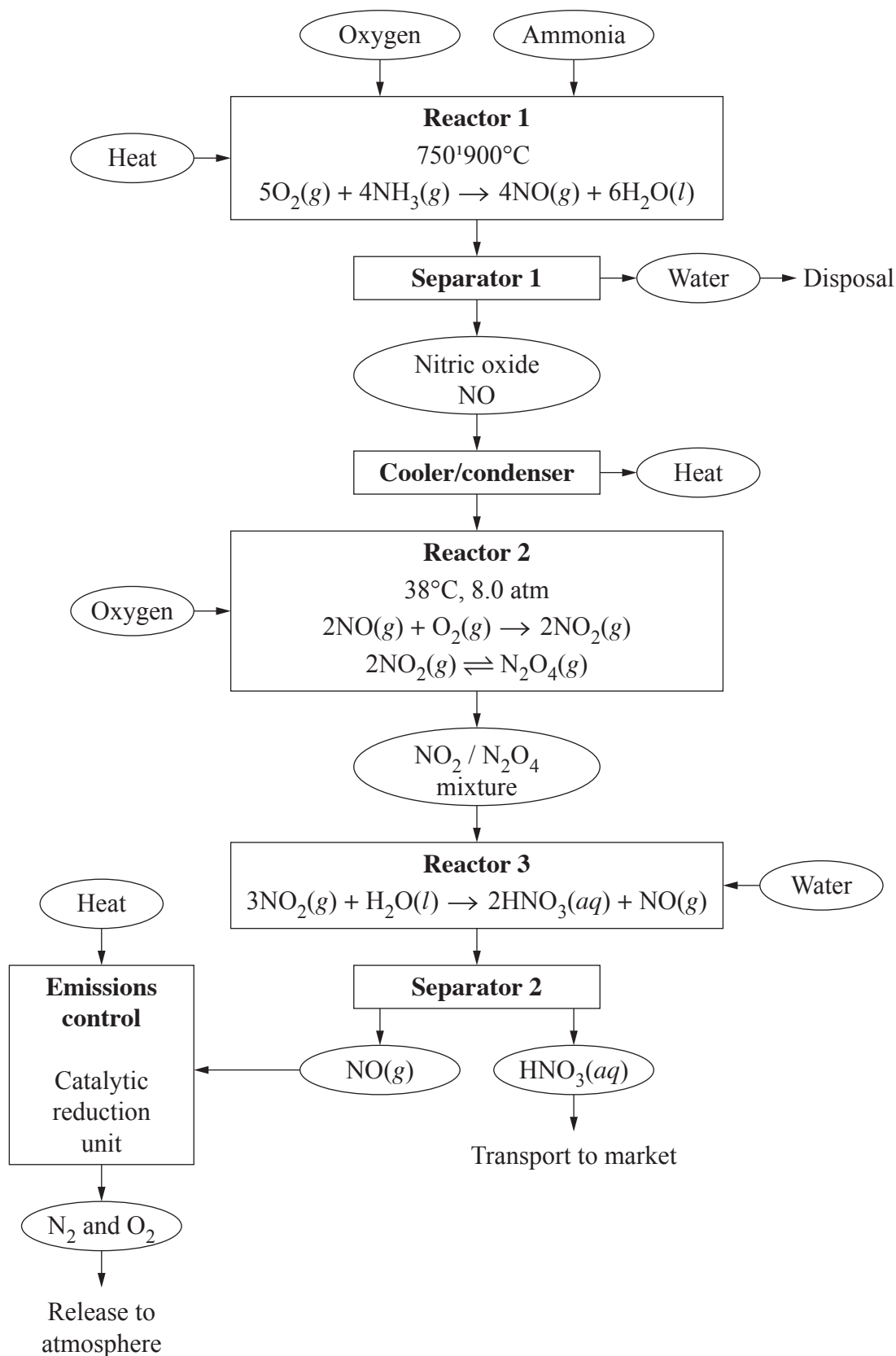
**End of Question 25**

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**Question 26** (5 marks)

Nitric acid can be produced industrially using the process shown.



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**Question 26** continues on page 21

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Question 26 (continued)

- (a) A mixture of  $\text{NO}_2$  and  $\text{N}_2\text{O}_4$  enters Reactor 3, where only  $\text{NO}_2$  is consumed by the reaction with water. 2

Explain, with respect to Le Chatelier's principle, what happens to the  $\text{N}_2\text{O}_4$ .

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- (b) Explain TWO improvements that can be made to the design of the process shown. 3

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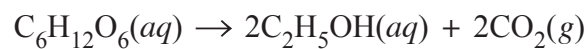
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**End of Question 26**

**Question 27** (4 marks)

A student has been asked to produce 185 mL of ethanol ( $MM = 46.068 \text{ g mol}^{-1}$ ) by fermenting glucose using yeast, as shown in the equation.

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Given that the density of ethanol is  $0.789 \text{ g mL}^{-1}$ , calculate the volume of carbon dioxide gas produced at 310 K and 100 kPa.

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**Question 28** (5 marks)

Alkene Q undergoes an addition reaction with chlorine gas to form compound R.

- (a) Describe a chemical test that could be done in a school laboratory to confirm that Q is an alkene. Include expected observations in your answer. 2

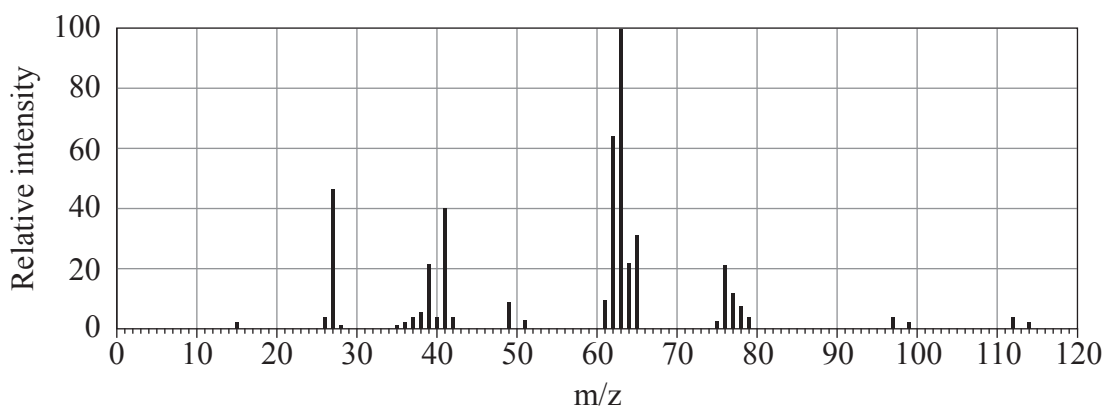
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- (b) Compound R was analysed and found to contain approximately 32% carbon by mass. The mass spectrum of compound R is shown. 3



Provide a structural formula for compound R. Support your answer with calculations.

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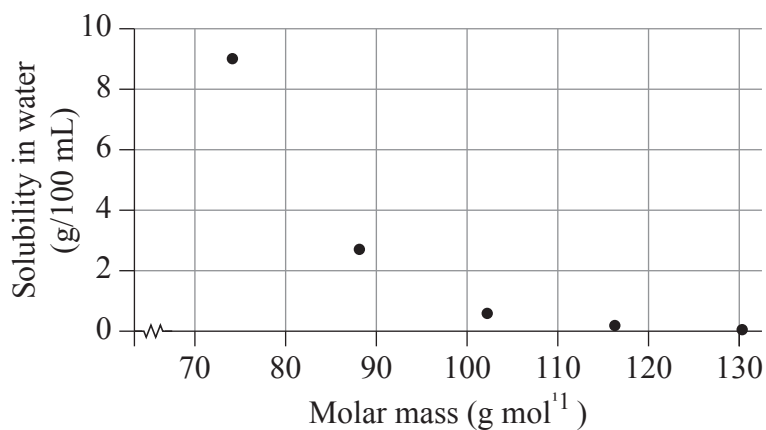
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Structural formula of compound R:

**Question 29** (3 marks)

The following graph shows the solubility of some alkan-1-ols in water at 20°C.

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Explain the relationship between the trend shown in the graph and the relevant intermolecular forces.

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**Question 30** (4 marks)

A water sample contains at least one of the following anions at concentrations of  $1.0 \text{ mol L}^{-1}$ .

**4**

- bromide ( $\text{Br}^-$ )
- carbonate ( $\text{CO}_3^{2-}$ )

Outline a sequence of tests that could be performed in a school laboratory to confirm the identity of the anion or anions present. Include expected observations and TWO balanced chemical equations in your answer.

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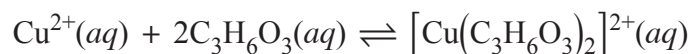
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**Question 31** (7 marks)

Copper(II) ions ( $\text{Cu}^{2+}$ ) form a complex with lactic acid ( $\text{C}_3\text{H}_6\text{O}_3$ ), as shown in the equation.

7



This complex can be detected by measuring its absorbance at 730 nm. A series of solutions containing known concentrations of  $[\text{Cu}(\text{C}_3\text{H}_6\text{O}_3)_2]^{2+}$  were prepared, and their absorbances measured.

Concentration of $[\text{Cu}(\text{C}_3\text{H}_6\text{O}_3)_2]^{2+}$ (mol L <sup>-1</sup> )	Absorbance
0.000	0.00
0.010	0.13
0.020	0.28
0.030	0.43
0.040	0.57
0.050	0.72

Two solutions containing  $\text{Cu}^{2+}$  and  $\text{C}_3\text{H}_6\text{O}_3$  were mixed. The initial concentrations of each in the resulting solution are shown in the table.

Species	Initial concentration (mol L <sup>-1</sup> )
$\text{Cu}^{2+}$	0.056
$\text{C}_3\text{H}_6\text{O}_3$	0.111

When the solution reached equilibrium, its absorbance at 730 nm was 0.66.

You may assume that under the conditions of this experiment, the only species present in the solution are those present in the equation above, and that  $[\text{Cu}(\text{C}_3\text{H}_6\text{O}_3)_2]^{2+}$  is the only species that absorbs at 730 nm.

With the support of a line graph, calculate the equilibrium constant for the reaction.

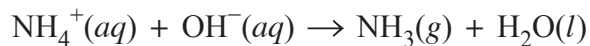
**Question 31 continues on page 27**



**Question 32** (5 marks)

The ammonium ion content of mixtures can be determined by boiling the mixture with a known excess of sodium hydroxide. This converts the ammonium ions into gaseous ammonia, which is removed from the system.

5



The excess sodium hydroxide can then be titrated with an acid solution of known concentration.

A fertiliser containing ammonium ions was analysed as follows.

- A sample of fertiliser was treated with 50.00 mL of 1.124 mol L<sup>-1</sup> sodium hydroxide solution and the solution boiled.
- After all of the ammonia was removed, the resulting solution was transferred to a 250.0 mL volumetric flask and made up to the mark with deionised water.
- 20.00 mL aliquots of this solution were titrated with 0.1102 mol L<sup>-1</sup> hydrochloric acid, giving the following results.

<i>Titration</i>	<i>Volume HCl (mL)</i>
1	22.65
2	22.05
3	22.00
4	21.95

**Question 32 continues on page 29**

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Question 32 (continued)

Calculate the mass of ammonium ions in the sample of fertiliser.

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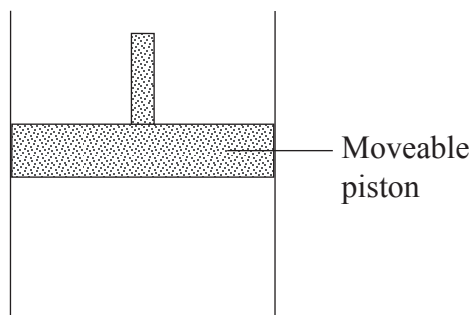
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**End of Question 32**

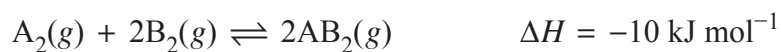
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**Question 33** (6 marks)

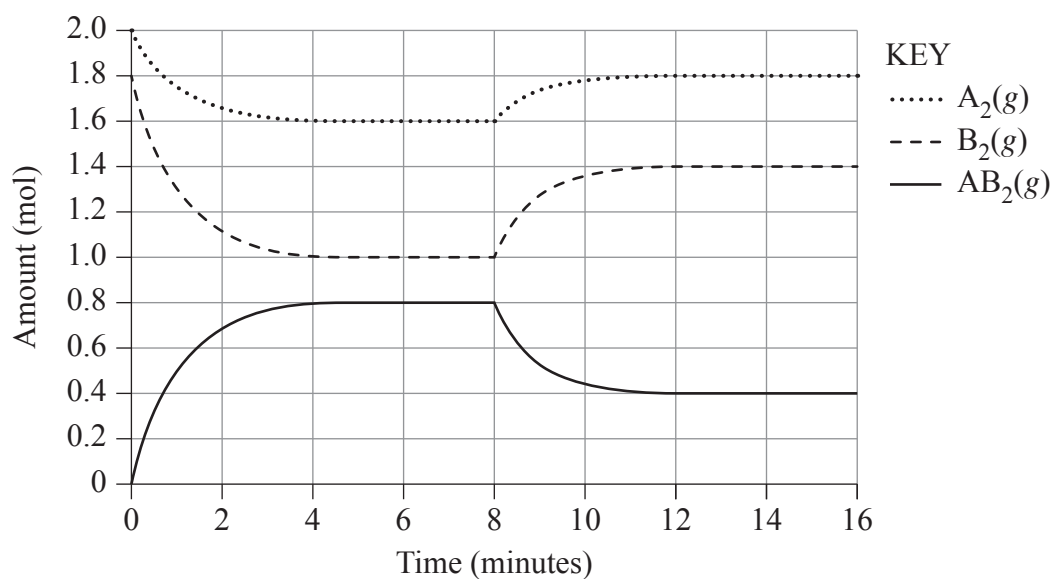
Gases  $A_2$  and  $B_2$  are placed in a closed container of variable volume, as shown.



The reaction between these substances is as follows.



The following graph shows changes in the amounts (in mol) of these three substances over time in this container.



**Question 33 continues on page 31**

Do NOT write in this area.

Question 33 (continued)

- (a) Explain what is happening in this system between 6 minutes and 8 minutes. **2**

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- (b) Explain TWO different factors that could result in the disturbance at 8 minutes. **4**

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**End of Question 33**

**Question 34** (5 marks)

When 125 mL of a magnesium nitrate solution is mixed with 175 mL of a  $1.50 \text{ mol L}^{-1}$  sodium fluoride solution, 0.6231 g of magnesium fluoride ( $MM = 62.31 \text{ g mol}^{-1}$ ) precipitates. The  $K_{sp}$  of magnesium fluoride is  $5.16 \times 10^{-11}$ .

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Calculate the equilibrium concentration of magnesium ions in this solution.

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**Question 35** (6 marks)

- (a) A  $0.2000 \text{ mol L}^{-1}$  solution of dichloroacetic acid ( $\text{CHCl}_2\text{COOH}$ ) has a pH of 1.107. Dichloroacetic acid is monoprotic. **3**

Calculate the  $K_a$  for dichloroacetic acid.

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- (b) The following data apply to the ionisation of acetic acid ( $\text{CH}_3\text{COOH}$ ) and trichloroacetic acid ( $\text{CCl}_3\text{COOH}$ ). **3**

	$\text{CH}_3\text{COOH}$	$\text{CCl}_3\text{COOH}$
$pK_a$	4.76	0.51
$\Delta H^\circ$ ( $\text{kJ mol}^{-1}$ )	-0.1	+1.2
$\Delta S^\circ$ ( $\text{J K}^{-1} \text{mol}^{-1}$ )	-91.6	-5.8
$-T\Delta S^\circ$ ( $\text{kJ mol}^{-1}$ )	+27.3	+1.7
$\Delta G^\circ$ ( $\text{kJ mol}^{-1}$ )	+27.2	+2.9

Explain the relative strength of these acids with reference to the data.

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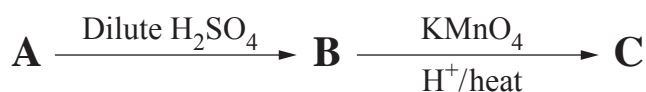
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**Question 36** (9 marks)

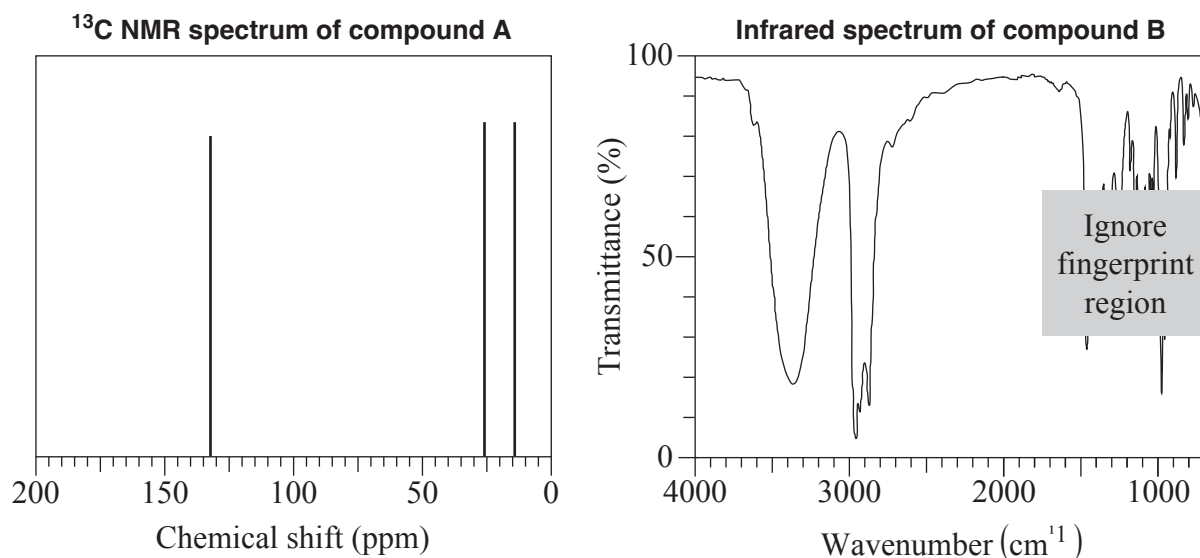
An organic reaction pathway involving compounds A, B and C is shown in the flow chart.

9



The molar mass of A is  $84.156 \text{ g mol}^{-1}$ .

A chemist obtained some spectral data for the compounds as shown.

**Data from  $^1\text{H}$  NMR spectrum of compound C**

Chemical shift (ppm)	Relative peak area	Splitting pattern
1.01	3	Triplet
1.05	3	Triplet
1.65	2	Multiplet
2.42	2	Triplet
2.46	2	Quartet

 **$^1\text{H}$  NMR chemical shift data**

Type of proton	$\delta/\text{ppm}$
$\text{R}-\text{CH}_3$ , $\text{R}-\text{CH}_2-\text{R}$	0.7–1.7
$\text{H}_3\text{C}-\text{CO}-$ $-\text{CH}_2-\text{CO}-$ } (aldehydes, ketones, carboxylic acids or esters)	2.0–2.6
$\text{R}-\text{CHO}$	9.4–10.0
$\text{R}-\text{COOH}$	9.0–13.0

**Question 36 continues on page 35**

Question 36 (continued)

Identify the functional group present in each of compounds A to C and draw the structure of each compound. Justify your answer with reference to the information provided.

Compound A

Functional group: .....

Compound B

Functional group: .....

Compound C

Functional group: .....

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**Question 36 continues on page 36**

Do NOT write in this area.



**Question 37** (5 marks)

When performing industrial reductions with  $\text{CO}(g)$ , the following equilibrium is of great importance.



A 1.00 L sealed vessel at a temperature of 1095 K contains  $\text{CO}(g)$  at a concentration of  $1.10 \times 10^{-2} \text{ mol L}^{-1}$ ,  $\text{CO}_2(g)$  at a concentration of  $1.21 \times 10^{-3} \text{ mol L}^{-1}$ , and excess solid carbon.

- (a) Is the system at equilibrium? Support your answer with calculations. **2**

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- (b) Carbon dioxide gas is added to the system above and the mixture comes to equilibrium. The equilibrium concentrations of  $\text{CO}(g)$  and  $\text{CO}_2(g)$  are equal. Excess solid carbon is present and the temperature remains at 1095 K. **3**

Calculate the amount (in mol) of carbon dioxide added to the system.

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**End of paper**

Do NOT write in this area.



**Section II extra writing space**

**If you use this space, clearly indicate which question you are answering.**

Do NOT write in this area.





## Chemistry

## FORMULAE SHEET

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

$$q = mc\Delta T$$

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

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

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

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

$$PV = nRT$$

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

Avogadro constant, $N_A$ .....	$6.022 \times 10^{23} \text{ mol}^{-1}$
Volume of 1 mole ideal gas: at 100 kPa and	
at 0°C (273.15 K) .....	22.71 L
at 25°C (298.15 K) .....	24.79 L
Gas constant .....	$8.314 \text{ J mol}^{-1} \text{ K}^{-1}$
Ionisation constant for water at 25°C (298.15 K), $K_w$ .....	$1.0 \times 10^{-14}$
Specific heat capacity of water .....	$4.18 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

## DATA SHEET

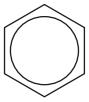
## Solubility constants at 25°C

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

### Infrared absorption data

Bond	Wavenumber/cm <sup>-1</sup>
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

### <sup>13</sup>C NMR chemical shift data

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

### UV absorption

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

Chromophore	λ <sub>max</sub> (nm)
C—H	122
C—C	135
C=C	162

Chromophore	λ <sub>max</sub> (nm)
C≡C	173 178 196 222
C—Cl	173
C—Br	208

### Some standard potentials

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

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

# PERIODIC TABLE OF THE ELEMENTS

1 H 1.008 Hydrogen		KEY										2 He 4.003 Helium																																																											
3 Li 6.941 Lithium		Atomic Number Symbol		Standard Atomic Weight Name		79 Au 197.0 Gold		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																																																							
11 Na 22.99 Sodium		4 Be 9.012 Beryllium		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		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 99.91 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 209.0 Polonium	85 At 210.0 Astatine	86 Rn 222.0 Radon	87 Fr 223.0 Francium	88 Ra 226.0 Radium	89-103 Actinoids	104 Rf 261.0 Rutherfordium	105 Db 262.0 Dubnium	106 Sg 263.0 Seaborgium	107 Bh 264.0 Bohrium	108 Hs 265.0 Hassium	109 Mt 266.0 Meitnerium	110 Ds 268.0 Darmstadtium	111 Rg 269.0 Roentgenium	112 Cn 270.0 Copernicium	113 Nh 271.0 Nihonium	114 Fl 272.0 Flerovium	115 Mc 273.0 Moscovium	116 Lv 274.0 Livermorium	117 Ts 275.0 Tennessine	118 Og 276.0 Oganesson

## Lanthanoids

57 La 138.9 Lanthanum	58 Ce 140.1 Cerium	59 Pr 140.9 Praseodymium	60 Nd 144.2 Neodymium	61 Pm 144.9 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
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## Actinoids

89 Ac 227.0 Actinium	90 Th 232.0 Thorium	91 Pa 231.0 Protactinium	92 U 238.0 Uranium	93 Np 237.0 Neptunium	94 Pu 244.0 Plutonium	95 Am 243.0 Americium	96 Cm 247.0 Curium	97 Bk 247.0 Berkelium	98 Cf 251.0 Californium	99 Es 252.0 Einsteinium	100 Fm 257.0 Fermium	101 Md 258.0 Mendelevium	102 No 259.0 Nobelium	103 Lr 260.0 Lawrencium
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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.