HWA CHONG INSTITUTION
C2 Preliminary Examination
Higher 2

CANDIDATE NAME		**CT GROUP**	2	4	S	
CENTRE NUMBER	S					**INDEX NUMBER**

CHEMISTRY

9729/01

Paper 1 Multiple Choice

22 September 2025

1 hour

Additional Materials: Multiple Choice Answer Sheet
Data Booklet

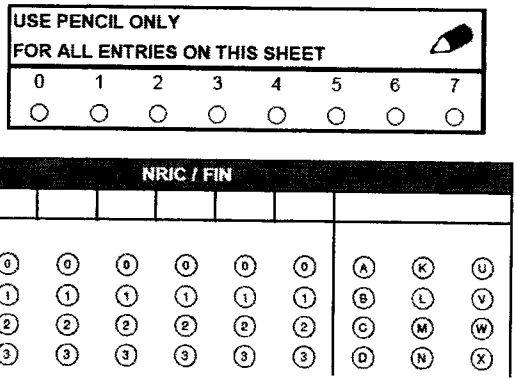
READ THESE INSTRUCTIONS FIRST

Write in soft pencil.

Do not use staples, paper clips, glue or correction fluid.

Complete the information on the Answer Sheet as shown below.

1. Enter your **NAME** (as in NRIC).
2. Enter the **PAPER NUMBER**.
3. Enter your **CT GROUP**.
4. Enter your **NRIC NUMBER** or **FIN Number**
5. Now **SHADE** the corresponding circles in the grid for **EACH DIGIT** or **LETTER**



There are **thirty** questions on this paper. Answer **all** questions. For each question, there are four possible answers **A**, **B**, **C** and **D**.

Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer Sheet.

Read the instructions on the Answer Sheet very carefully.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.

Any rough working should be done in this booklet.

The use of an approved scientific calculator is expected, where appropriate.

1 The successive ionisation energies of an element **X** are given below.

	1st	2nd	3rd	4th	5th	6th
ionisation energy / kJ mol^{-1}	950	1800	2700	4800	6000	12300

What could be the formula of the chloride **X**?

A **X**C*l* **B** **X**C*l*$_2$ **C** **X**C*l*$_4$ **D** **X**C*l*$_5$

2 In which row are G and H atoms or ions of different isotopes of the same element?

	G			H		
	number of electrons	charge	nucleon number	number of electrons	charge	nucleon number
A	8	0	18	10	−2	18
B	17	+1	37	16	0	34
C	16	0	36	18	0	38
D	20	0	42	18	+2	40

3 Which pair of species has a similar shape?

A A*l*C*l*$_3$ and PC*l*$_3$

B BF_3 and NH_3

C SF_4 and XeF_4

D PH_4^+ and BF_4^-

4 A small bulb with a capacity of 10 m^3 is connected to another with a capacity of 30 m^3. Before connection, the pressure in the smaller bulb is 50 kPa and that in the larger bulb is 120 kPa.

If all measurements are made at the same temperature, what is the pressure in the combined arrangement after connection?

A 67.5 kPa **B** 85 kPa **C** 103 kPa **D** 170 kPa

5 Which statement is correct?

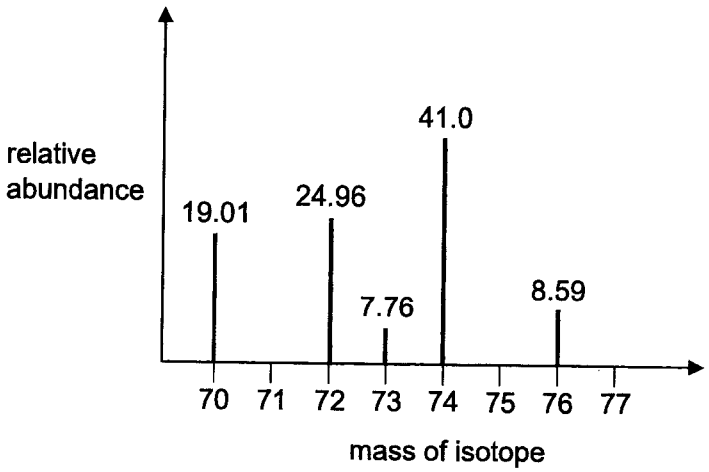
A The relative isotopic mass of an element is the mass of one atom of an isotope of the element relative to $\frac{1}{12}$ the mass of one atom of ^{12}C.

B The relative atomic mass of an element is the mass of one atom of the element relative to $\frac{1}{12}$ the mass of one atom of ^{12}C.

C The relative molecular mass of a compound is the average mass of one molecule of the compound relative to the mass of one atom of ^{1}H.

D The relative formula mass of an ionic compound is the average mass of one formula unit of the ionic compound relative to the mass of one atom of ^{12}C.

6 The relative abundance of all the isotopes present in a sample of germanium are shown.



What is the relative atomic mass of germanium calculated from these data?

A 72.6 **B** 72.8 **C** 73.8 **D** 74.0

7 The combustion of magnesium in oxygen is shown in the equation below.

$$Mg(s) + \frac{1}{2}O_2(g) \rightarrow MgO(s)$$

Some enthalpy changes are given below.

$MgO(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l)$ $\quad \Delta H = -89$ kJ mol^{-1}

$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$ $\quad \Delta H = -435$ kJ mol^{-1}

$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$ $\quad \Delta H = -572$ kJ mol^{-1}

What is the enthalpy change of combustion for magnesium?

A −632 kJ mol^{-1} **B** −918 kJ mol^{-1}

C −1262 kJ mol^{-1} **D** −1352 kJ mol^{-1}

8 Assuming the pressure of each system remains at 1 atm, which processes show an increase in entropy?

1 1 mol of $Cl_2(g)$ at 298 K is heated to 373 K.

2 1 mol of $Cl_2(g)$ at 298 K is added to 1 mol of $N_2(g)$ at 298 K.

3 1 mol of $Cl_2(g)$ at 1000 K is photolysed according to the following equation.

$$Cl_2(g) \rightarrow 2Cl^{\bullet}(g)$$

4 1 mol of $Cl_2(g)$ at 298 K is reacted with iodine according to the following equation.

$$Cl_2(g) + \frac{1}{3}I_2(s) \rightarrow \frac{2}{3}ICl_3(l)$$

A 1, 2 and 3 only

B 1, 2 and 4 only

C 1, 3 and 4 only

D 2, 3 and 4 only

9 The equation for the reduction of nitrogen monoxide is shown below.

$$2NO + 2H_2 \rightarrow N_2 + 2H_2O$$

The mechanism involves the following steps.

$2NO \rightleftharpoons N_2O_2$ (fast)

$N_2O_2 + H_2 \rightarrow N_2O + H_2O$ (slow)

$N_2O + H_2 \rightarrow N_2 + H_2O$ (fast)

Which statement about the reaction is correct?

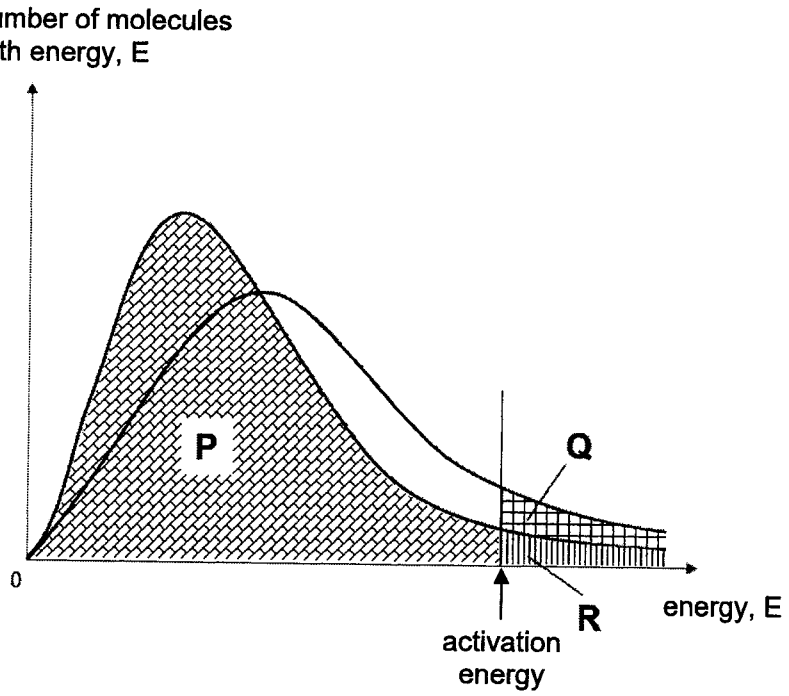
A The overall order of the reaction is 4.

B The units of the rate constant are $mol^{-2}\ dm^6\ s^{-1}$.

C The reaction is second order with respect to $[H_2]$.

D The reaction is zeroth order with respect to [NO].

10 The distribution of the number of molecules with energy, E, for a reaction at two different temperatures is shown below. The letters P, Q and R refer to separate and differently shaded areas.



Which expression gives the fraction of molecules that have energy greater than or equal to the activation energy at the lower temperature?

A $\frac{R}{P+R}$ **B** $\frac{Q+R}{P+R}$ **C** $\frac{R}{P}$ **D** $\frac{Q+R}{P}$

11 The Haber Process is an important industrial process in which nitrogen and hydrogen are reacted to give ammonia.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H < 0$$

Which statement is correct?

A A temperature of 250 °C is used to ensure that the rate of reaction is fast enough.

B A moderately high pressure is used to ensure high yield without being too costly.

C Iron is added to increase the yield because the temperature cannot be too high.

D Ammonia is constantly removed from the system to increase the rate of reaction.

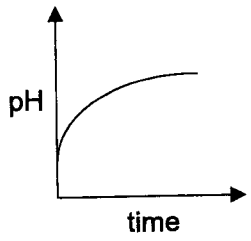
12 Sulfur dioxide gas is converted into sulfate ions when it is bubbled into aqueous manganate(VII) ions.

$$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$$

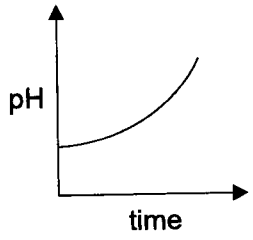
$$SO_2(g) + 2H_2O(l) \rightarrow SO_4^{2-}(aq) + 4H^+(aq) + 2e^-$$

Which graph shows how the pH changes as sulfur dioxide is bubbled at a constant rate into a well-stirred solution of manganate(VII) ions until its colour just fades?

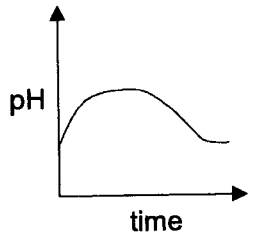
A



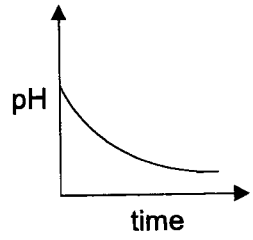
B



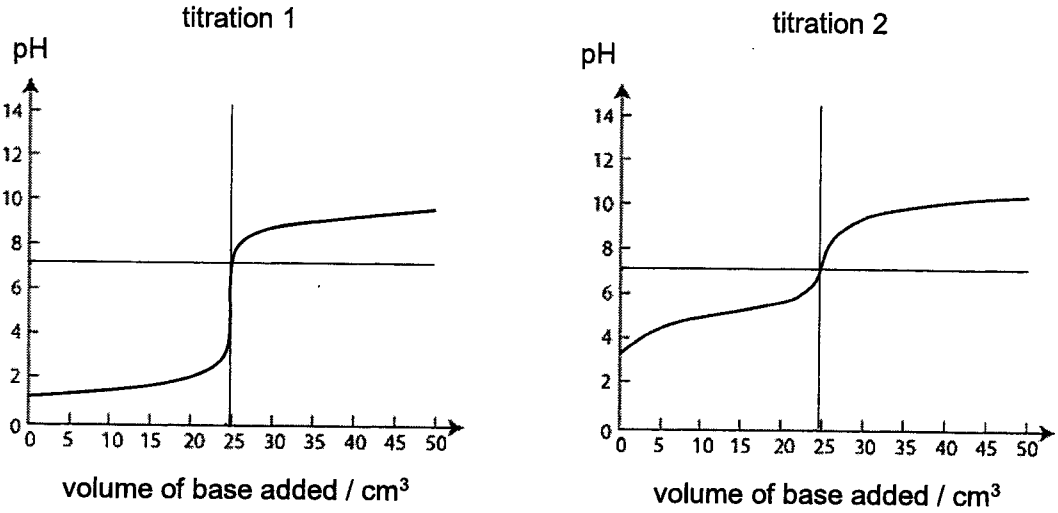
C



D



13 The titration curves for two acid-base reactions are shown below.



The working ranges of some indicators are given in the table below.

indicator	working range pH
methyl orange	3.1 – 4.4
bromothymol blue	6.0 – 7.0

Which statement about the two titrations is correct?

A Bromothymol blue may be used for titration 2.

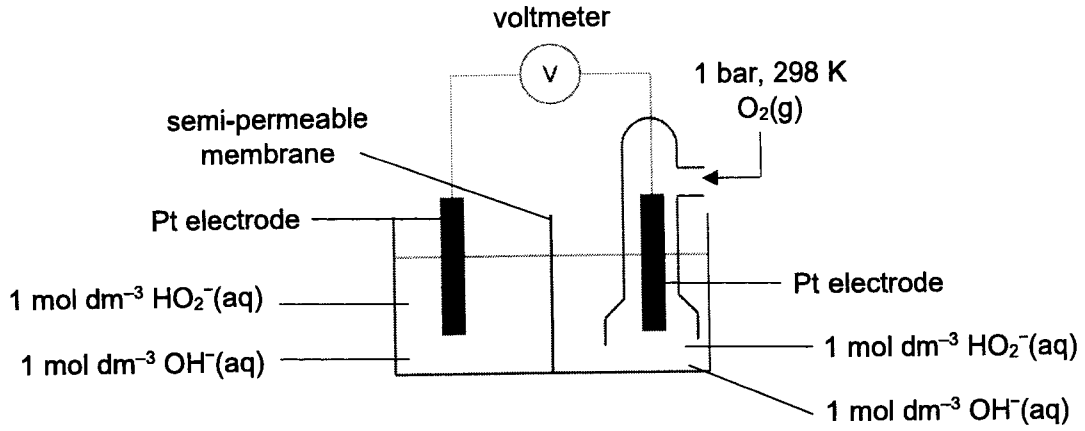
B Methyl orange may be used for titrations 1 and 2.

C Both titrations involve weak acids.

D Both titrations involve weak bases.

14 *Use of the Data Booklet is relevant to this question*

Hydrogen peroxide deprotonates in alkaline medium to form HO_2^-. The diagram below shows an electrochemical cell set up to measure the cell potential for the decomposition of HO_2^- to form OH^- and O_2 gas.



Which statements are correct?

1 The voltmeter gives a reading of −0.96 V.

2 The reaction at the cathode may be given as $HO_2^- + H_2O + 2e^- \rightarrow 3OH^-$.

3 The semi-permeable membrane behaves like a salt bridge in the cell.

A 1 only

B 1 and 3 only

C 2 and 3 only

D 1, 2 and 3 only

15 *Use of the Data Booklet is relevant to this question.*

An electrolysis cell is set up with an anode made of an alloy of 75% Cu and 25% Ni by mass and a cathode made of pure Cu. The electrolyte is a solution which contains 1.0 mol dm^{-3} of $NiSO_4$(aq) and 1.0 mol dm^{-3} of $CuSO_4$(aq).

A current of 0.50 A is passed through the cell for 1.5 hours. The cathode increased in mass by 0.88 g.

What value of Avogadro's constant does **these figures** give?

A 6.02×10^{23} **B** 6.09×10^{23} **C** 8.12×10^{23} **D** 1.22×10^{24}

16 Covalent bonds are formed by orbital overlap.

Which bond is **not** present in $HC{\equiv}CCH_2CH{=}CH_2$?

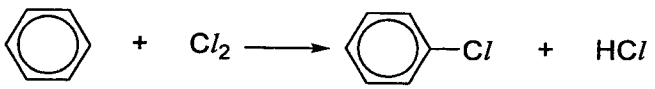
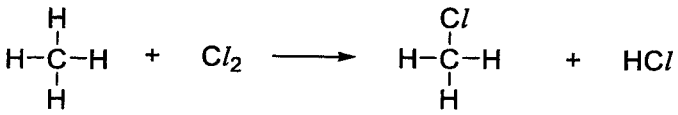
A a π bond formed by 2p–2p overlap

B a σ bond formed by 1s–2sp overlap

C a σ bond formed by $2sp–2sp^2$ overlap

D a σ bond formed by $2sp^2–2sp^3$ overlap

17 Which row correctly shows the nature of the reactive chlorine species?

	reaction	nature of reactive chlorine species
1		electrophile
2		nucleophile
3		free radical

A 1 and 2 only

B 1 and 3 only

C 2 and 3 only

D 1, 2 and 3

18 A non-cyclic molecule, J, has the formula $C_4H_7O_2N$.

What are the possible combinations of functional groups present in molecule J?

1 one amide group and one ketone group

2 one carboxylic acid group and one nitrile group

3 one alkene group, one ester group and one amine group

4 one nitrile group, one alcohol group and one aldehyde group

A 1 and 3 only

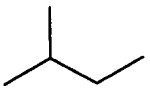
B 1 and 4 only

C 2 and 3 only

D 2 and 4 only

19 In the free radical substitution of 2-methylbutane with limited bromine in the presence of ultraviolet light, a mixture of mono-brominated products is obtained.

Which is the correct combination of the products obtained? Ignore stereoisomers.



2-methylbutane

A 5 possible products in the ratio of 3:3:3:2:1

B 4 possible products in the ratio of 3:3:3:2

C 4 possible products in the ratio of 6:3:2:1

D 3 possible products in the ratio of 9:2:1

20 Modern cars are fitted with catalytic converters to reduce atmospheric pollution caused by unwanted reactions during the combustion of the fuel.

Which reaction does **not** occur in a catalytic converter?

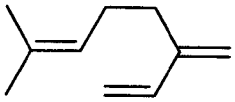
A $CO_2 + NO \rightarrow CO + NO_2$

B $2CO + 2NO \rightarrow 2CO_2 + N_2$

C $4C_xH_y + (4x + y)O_2 \rightarrow 4xCO_2 + 2yH_2O$

D $4C_xH_y + (8x + 2y)NO \rightarrow 4xCO_2 + 2yH_2O + (4x + y)N_2$

21 A species of termite produces a chemical defence secretion which contains the following molecule.



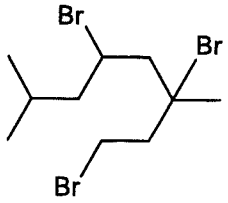
Which statement about this compound is correct?

A It reacts with excess cold alkaline manganate(VII) ions to give an organic product with three chiral centres.

B It reacts with excess hot acidified manganate(VII) ions to give three organic products.

C It reacts with aqueous Br_2 to give a major product containing two secondary alcohol functional groups.

D It can be formed from reacting the following compound with hot ethanolic sodium hydroxide.



22 *Use of the Data Booklet is relevant to this question.*

Which synthesis sequence, using benzene as the starting material, is expected to give the best yield of 2-bromo-4-nitromethylbenzene?

A alkylation, nitration, bromination

B alkylation, bromination, nitration

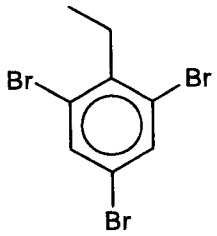
C bromination, nitration, alkylation

D nitration, bromination, alkylation

23 0.10 mol of liquid K, L and M are shaken separately for some time with hot ethanolic silver nitrate.

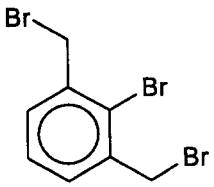
What are the relative amounts of pale cream precipitate formed by K, L and M?

1



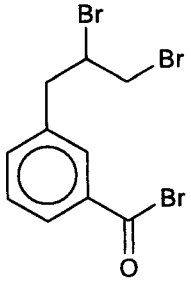
K

2



L

3



M

A K = L < M

B K < L < M

C K < L = M

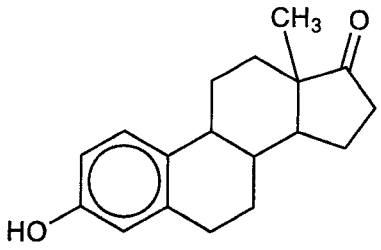
D M < L < K

24 Compounds V, W and X all react with sodium to give hydrogen gas, but only one of them reacts with Fehling's reagent.

Which combination could be V, W and X?

	V	W	X
A	CH_2OH | CH_2OH	CHO | CHO	CO_2H | CO_2H
B	CH_2OH | CH_2OH	CH_2OH | CHO	CHO | CO_2H
C	CH_2OH | CHO	CH_2OH | CO_2H	CHO | CO_2H
D	CH_2OH | CO_2H	CHO | CO_2H	CO_2H | CO_2H

25 The diagram shows the structure of a molecule of the hormone oestrone.



oestrone

Which statement about oestrone is **incorrect**?

A It gives an orange precipitate with 2,4-dinitrophenylhydrazine.

B It gives a salt with aqueous sodium hydroxide.

C It gives a dicarboxylic acid with hot acidified potassium manganate(VII).

D It gives white fumes with phosphorus(V) chloride.

26 The small hive beetle, which invades colonies of the honeybee, identifies these colonies by detecting the bees' own alarm signal, the pheromone 3-methylbutyl ethanoate.

How may this ester be made in the laboratory?

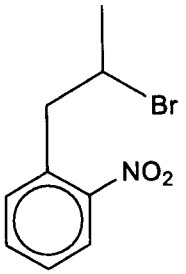
A $(CH_3)_2CHCH_2CO_2H + CH_3CH_2OH \xrightarrow[\text{heat}]{\text{conc. } H_2SO_4} \text{ester} + H_2O$

B $(CH_3)_2CHCH_2CH_2CO_2H + CH_3OH \xrightarrow[\text{heat}]{\text{conc. } H_2SO_4} \text{ester} + H_2O$

C $CH_3COCl + (CH_3)_2CHCH_2CH_2OH \longrightarrow \text{ester} + HCl$

D $CH_3COCl + CH_3CH_2CH(CH_3)CH_2OH \longrightarrow \text{ester} + HCl$

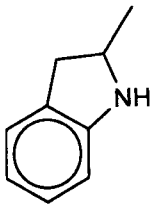
27 Compound Y is heated with tin and concentrated hydrochloric acid. Aqueous sodium hydroxide is then added to the hot mixture, producing compound Z.



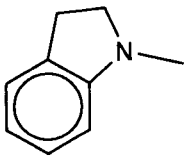
compound Y

What is the structure of compound Z?

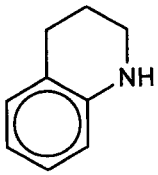
A



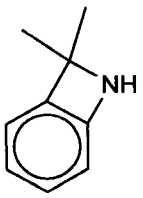
B



C



D



28 Which statement about Group 2 and Group 17 elements is correct?

A The melting point of Group 2 elements increases down the group.

B The reducing power of Group 2 elements increases down the group.

C The volatility of Group 17 elements increases down the group.

D The oxidising power of Group 17 elements increases down the group.

29 Which statements explain the difference in density of vanadium compared to calcium?

1 Relative atomic mass is higher for vanadium.

2 Outer shell electrons are more shielded in vanadium.

3 The outer shell electrons of vanadium experience greater attraction to the nucleus.

A 1 only **B** 2 only **C** 1 and 3 only **D** 2 and 3 only

30 Platinum(IV) chloride is combined with ammonia to form a new platinum(IV) complex with only chloride and ammonia as ligands. This complex ion has a 2+ charge and a co-ordination number of 6.

What is the number of ammonia ligands in this complex ion?

A 2 **B** 4 **C** 5 **D** 6

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HWA CHONG INSTITUTION
C2 Preliminary Examination
Higher 2

CANDIDATE NAME		**CT GROUP**	2	4	S		
CENTRE NUMBER	S					**INDEX NUMBER**	

CHEMISTRY

9729/02

Paper 2 Structured Questions

3 September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your **name, CT group, centre number** and **index number** on all the work you hand in.

Write in dark blue or black pen.

You may use a HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

DO **NOT** WRITE ON ANY BARCODES.

Answer all questions in the spaces provided in the Question Paper.

The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

For Examiner's Use	
1	/ 10
2	/ 18
3	/ 14
4	/ 14
5	/ 19
Deductions (s.f.)	
Deductions (units)	
Deductions (structures)	
Total	/ 75

Answer **all** questions in the space provided.

1 (a) In Fig.1.1, sketch a graph to show the variation of ionic radius across Period 3. Explain the shape of your graph.

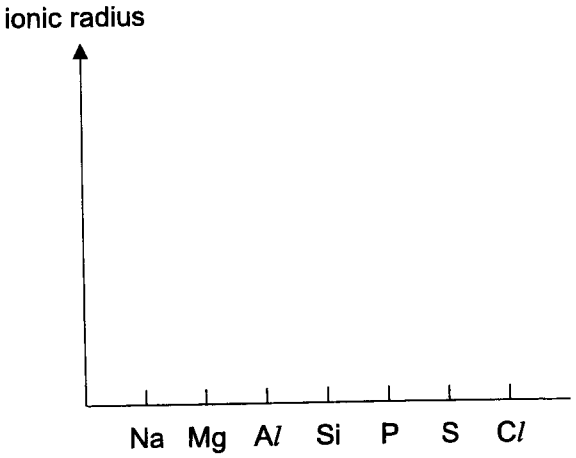

Fig.1.1

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.....

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.....

.....

..... [3]

(b) Write an equation for the reaction of P_4O_{10} with water. State the pH of the resulting mixture.

equation .....

pH ..... [1]

(c) Describe the acid-base behaviour of Al_2O_3 by reference to its reaction separately with sulfuric acid, H_2SO_4, and with sodium hydroxide, NaOH.

Write equations for any reactions described.

.....

.....

.....

..... [2]

(d) Aluminium chloride, $AlCl_3$, and beryllium chloride, $BeCl_2$, can act as Lewis acids.

(i) Explain what is meant by a Lewis acid.

.....

..... [1]

(ii) When heated with $AlCl_3$, bromine monochloride, $BrCl$, reacts with benzene in an electrophilic substitution reaction to produce bromobenzene.

Describe the mechanism for this reaction. In your answer, show how the electrophile is generated and include relevant lone pairs of electrons, dipoles and curly arrows.

[2]

(iii) In the solid form, $BeCl_2$ molecules polymerise to make long chains by forming co-ordinate (dative covalent) bonds.

Draw a diagram to represent part of a beryllium chloride polymer which contains at least three repeat units of $BeCl_2$. Label the co-ordinate bonds on your diagram.

The bonding in the beryllium chloride polymer is similar to that in Al_2Cl_6(g).

[1]

[Total: 10]

2 (a) In an experiment, 25.0 cm^3 of 0.500 mol dm^{-3} LiOH(aq) was mixed rapidly in a polystyrene cup with 40.0 cm^3 of 0.500 mol dm^{-3} HC*l*(aq), as shown in reaction 2.1.

reaction 2.1 $\quad LiOH(aq) + HCl(aq) \rightarrow LiCl(aq) + H_2O(l) \quad \Delta H^{\ominus}_{neut}$

The initial temperature of each solution is 27.8 °C and the final temperature of the mixture is 30.5 °C.

(i) Define the term *standard enthalpy change of neutralisation*.

.....

.....

..... [1]

(ii) Calculate the standard enthalpy change of neutralisation of lithium hydroxide, $\Delta H^{\ominus}_{neut}$, assuming that the solutions have a density of 1.00 g cm^{-3} and a specific heat capacity of 4.18 J g^{-1} $°C^{-1}$.

[2]

(b) Lithium hydroxide is used in air purification systems, particularly in enclosed environments like spacecrafts and submarines, to absorb carbon dioxide from the air. It achieves this by reacting with carbon dioxide to form lithium carbonate and water, as shown in reaction 2.2.

reaction 2.2 $2LiOH(s) + CO_2(g) \rightarrow Li_2CO_3(s) + H_2O(l)$ $\Delta H_2^{\ominus}$

(i) Construct an energy cycle to determine the standard enthalpy change of reaction 2.2, $\Delta H_2^{\ominus}$, using your answer in **(a)(ii)** and the data below.

$LiOH(s) \rightarrow Li^+(aq) + OH^-(aq)$ $\Delta H_3^{\ominus} = -21.0$ kJ mol^{-1}

$Li_2CO_3(s) + 2HCl(aq) \rightarrow 2LiCl(aq) + CO_2(g) + H_2O(l)$ $\Delta H_4^{\ominus} = -29.0$ kJ mol^{-1}

If you were unable to calculate a value for the standard enthalpy change of neutralisation of lithium hydroxide in **(a)(ii)**, you should use −48.2 kJ mol^{-1}. This is **not** the correct answer.

[3]

(ii) Deduce the sign of the entropy change for reaction 2.2, $\Delta S_2^{\ominus}$, and hence predict the effect of increasing temperature on the spontaneity of reaction 2.2, using your answer in **(b)(i)**.

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..... [2]

(iii) A spacecraft mission to the moon is planned with 8 crewmembers and supplied with 250 canisters of LiOH to purify the air via reaction 2.2. Each canister carries 5.2 kg of LiOH.

reaction 2.2 $2LiOH(s) + CO_2(g) \rightarrow Li_2CO_3(s) + H_2O(l) \quad \Delta H_2^{\ominus}$

Calculate the mass of CO_2 that would be exhaled, in terms of kg/CM-d (kilograms per crewmember per day), using the information below.

average volume of CO_2 exhaled per breath = 25 cm^3

number of breaths per minute = 15

density of CO_2 at room temperature = 1.98 g dm^{-3}

[2]

(iv) Determine the maximum number of days that this mission can last before all the LiOH in the canisters are used up. Give your answer as a whole number.

[2]

(v) Suggest one advantage of using lithium hydroxide for the space mission compared to other Group 1 hydroxides.

.....

..... [1]

(c) Unlike other Group 1 carbonates, lithium carbonate, Li_2CO_3, decomposes in a similar manner to magnesium carbonate.

(i) Write an equation, with state symbols, for the thermal decomposition of Li_2CO_3. Suggest a reason for the ease of decomposition of Li_2CO_3.

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..... [3]

(ii) The thermal decomposition temperatures of three carbonates are given in Table 2.1.

Table 2.1

carbonate	decomposition temperature / °C
$MgCO_3$	350
$CaCO_3$	635
Na_2CO_3	851

Using data from the *Data Booklet* and Table 2.1, suggest a minimum temperature at which Li_2CO_3 will decompose, giving your reasoning.

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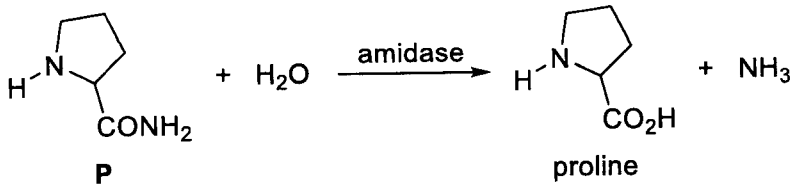
..... [2]

[Total: 18]

3 (a) An amide, **P**, can be hydrolysed by an enzyme, amidase, to form proline and ammonia.

reaction 3.1



P proline

(i) An optically inactive sample of **P** is used in the above reaction. State the maximum percentage of this sample that would be converted to proline by the enzyme amidase. Explain your reasoning.

.....

..... [1]

A series of experiments were carried out to study the kinetics of reaction 3.1. The initial rate of the reaction was measured for different initial concentrations of **P** at a constant temperature, while keeping the enzyme concentration fixed. The rate equation observed is in the form

$$\text{rate} = k[\mathbf{P}]^n$$

where n is the order of reaction with respect to [**P**] and k is the observed rate constant.

The results of the experiments are shown in Table 3.1.

Table 3.1

experiment	1	2	3	4	5	6
initial [**P**] / 10^{-3} mol dm^{-3}	0.50	1.00	2.00	4.00	8.00	16.00
initial rate / 10^{-4} mol dm^{-3} s^{-1}	1.25	2.50	5.00	7.00	8.00	8.00

(ii) Explain why the concentrations of the enzyme amidase and the reactant H_2O do not appear in the rate equation.

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..... [2]

(iii) The order of reaction with respect to [**P**] may vary at lower and higher concentrations of **P**.

Using the data in Table 3.1, deduce the order of reaction with respect to [**P**], giving your reasoning.

- lower concentrations of **P**

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- higher concentrations of **P**

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..... [3]

(iv) Explain the relationship between the initial rate of the reaction and the concentration of **P** in this enzyme-catalysed reaction.

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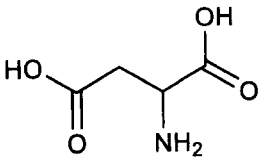
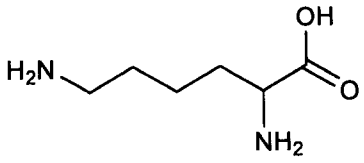
..... [2]

(b) The polypeptide chain of the enzyme amidase contains residues of two α-amino acids, aspartic acid and lysine.



aspartic acid (asp)



lysine (lys)

(i) There are three pK_a values associated with aspartic acid: 2.1, 3.7 and 9.8.

Draw the structures of the major species present in solutions of aspartic acid at

- pH 3 and
- pH 14.

pH 3

pH 14

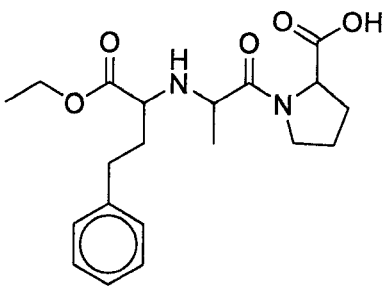
[2]

(ii) Aspartic acid and lysine can form a dipeptide named asp-lys, in which asp bears the free NH_2 end while lys bears the free CO_2H end.

Draw the structure of the asp-lys dipeptide. The peptide bond formed should be shown displayed.

[1]

(c) Enalapril is a synthetic analog of proline used to treat hypertension.



enalapril

Draw the structures of the three organic products formed when enalapril is heated in excess dilute NaOH.

[3]

[Total: 14]

4 The mercury cell electrolysis process shown in Fig. 4.1 is an industrial method used primarily to produce $Cl_2(g)$ and NaOH(aq) from brine, a concentrated solution of NaCl(aq). A pump circulates mercury liquid, Hg(l), between the primary and secondary chambers where different reactions take place.

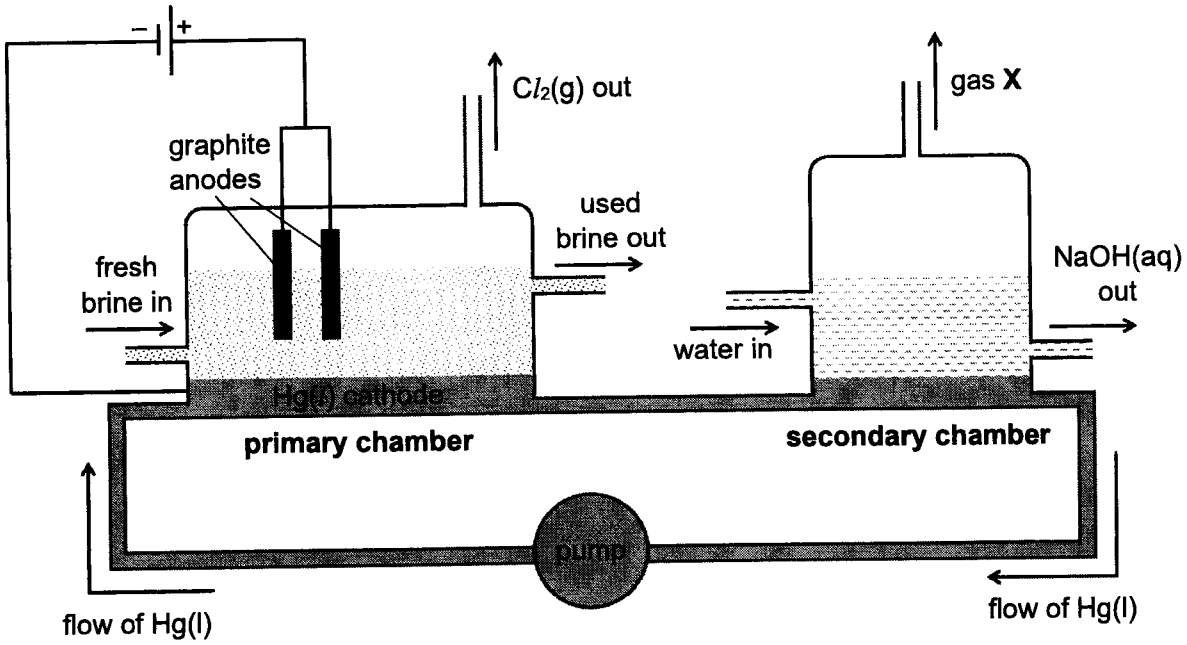


Fig. 4.1

The typical conditions under which the mercury cell is operated are summarised in Table 4.1.

Table 4.1

temperature of mercury cell and its gaseous products	70 °C
concentration of brine, NaCl(aq)	5.0 mol dm^{-3}
pressure of all gases	1.0 bar
average operating current	5000 A
coulombic efficiency	88%

Primary chamber

At the graphite anodes, Cl^- ions are preferentially discharged to form $Cl_2(g)$.

reaction at anodes: $2Cl^- \rightarrow Cl_2(g) + 2e^-$

At the Hg(l) cathode, Na^+ ions are discharged as Na atoms, which immediately dissolve in Hg to form a liquid mixture of Na and Hg known as a sodium amalgam, NaHg(l). The oxidation state of Na in NaHg is 0.

reaction at cathode: $Na^+(aq) + Hg(l) + e^- \rightarrow NaHg(l)$

Although a competing reaction is $2H_2O + 2e^- \rightarrow H_2 + 2OH^-$, it is more feasible to reduce Na^+ due to the high stability of NaHg.

Secondary chamber

The NaHg(l) flows to a secondary chamber where it reacts with water to produce NaOH(aq) and gas **X**. This reaction regenerates Hg(l), which is cycled back by the pump into the primary chamber. Gas **X** is the third industrially useful product of the mercury cell electrolysis process.

(a) A key benefit of producing Cl_2 and NaOH in separate chambers is to prevent them from reacting with each other to produce NaCl, $NaClO_3$ and water, as shown in reaction 4.1.

reaction 4.1 $\quad Cl_2 + NaOH \rightarrow NaCl + NaClO_3 + H_2O$ (unbalanced)

(i) By considering electron transfer, state the type of reaction that chlorine undergoes in reaction 4.1.

..... [1]

(ii) Hence, balance the equation for reaction 4.1.

..... Cl_2 + ... NaOH $\rightarrow$ ..... NaCl + ... $NaClO_3$ + ... H_2O [1]

(b) At the graphite anodes, a competing reaction is: $2H_2O \rightarrow O_2 + 4H^+ + 4e^-$.

(i) By quoting relevant $E^\ominus$ values from the *Data Booklet*, explain why O_2 will be produced at the anode instead of Cl_2 if dilute NaCl(aq) was electrolysed under standard conditions.

..... [2]

(ii) Explain how using conditions stated in Table 4.1 allows for Cl_2 to be produced at the anodes of this mercury cell electrolysis process.

..... [2]

(c) Coulombic efficiency measures the percentage of the total charge that is used to produce a desired product. A high coulombic efficiency indicates that minimal charge is wasted on producing unwanted side products.

$$\text{coulombic efficiency} = \frac{\text{actual charge used to produce } Cl_2(g)}{\text{total charge passed through mercury cell}} \times 100\%$$

Use relevant data from Table 4.1 to calculate the actual yield of Cl_2 gas in m^3 per hour. You may assume that Cl_2 gas behaves ideally.

[3]

(d) **(i)** Write an equation for the reaction that takes place in the secondary chamber and identify gas **X**.

.....

..... [1]

(ii) State an industrial use for gas **X**.

..... [1]

(e) Studies into the high stability of sodium amalgam, NaHg(l), revealed the following characteristics about its chemical structure:

- Na atoms lose their valence electrons to form Na^+ ions.
- Some electron density is delocalised to form a sea of electrons.
- Some Hg atoms accept electron density to form Hg-rich polyanions like Hg_4^{4-} and Hg_2^{2-}.

Table 4.2 shows the electronegativity values of the atoms in NaHg(l). The electronegativity of fluorine is listed as a reference.

Table 4.2

atom	electronegativity / Pauling units
Na	0.93
Hg	2.00
F	3.98

(i) Explain what is meant by the term *electronegativity*.

.....

..... [1]

(ii) Use the information given above to suggest two types of chemical bonds that are present in NaHg(l). Using the electronegativity values in Table 4.2, explain why each chemical bond is formed.

chemical bond	explanation
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[2]

[Total: 14]

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5 (a) Describe and explain the trend in the thermal stability of the hydrogen halides HC*l*, HBr and HI. Include an equation for the thermal decomposition reaction in your answer.

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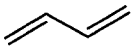
..... [3]

(b) Alkanes react with chlorine to form chloroalkanes and HC*l* as a by-product.

Draw the mechanism of the reaction between cyclopentane and chlorine in UV light to form chlorocyclopentane.

[3]

(c) Conjugated dienes contain C=C double bonds separated by exactly one C–C single bond. 1,3-butadiene is an example of a conjugated diene.



1,3-butadiene

Conjugated dienes exhibit chemical properties similar to alkenes but also undergo unique reactions.

When an equimolar ratio of 1,3-butadiene and HBr are reacted together, two different products can form via an electrophilic addition mechanism, as shown in Fig. 5.1.

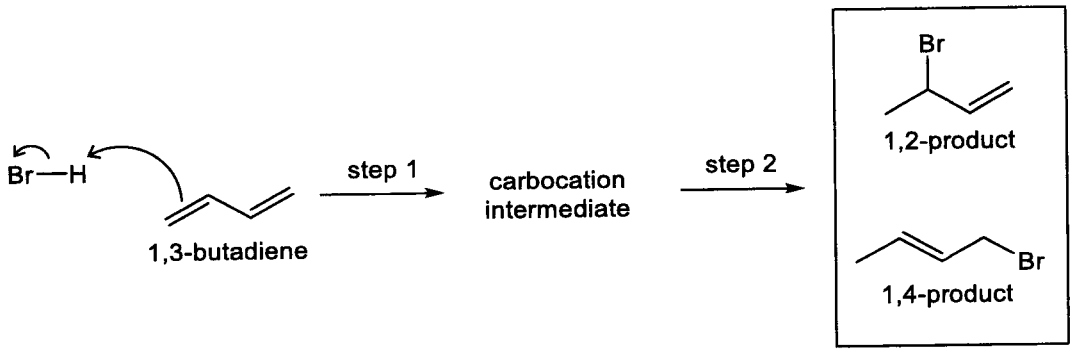


Fig. 5.1

(i) Draw the structure of the carbocation intermediate that forms **each** of the products shown in Fig. 5.1, and hence explain why the 1,4-product can be obtained from this reaction.

carbocation structure that forms 1,2-product	carbocation structure that forms 1,4-product

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..... [3]

(ii) The major product in the above reaction with HBr is the 1,2-product.

When IBr is used instead of HBr in the reaction, the same mechanism occurs. However, the 1,4-product becomes the major product.

Suggest a reason for this difference in product ratios.

.....

..... [1]

(iii) Table 5.1 shows the energies involved in the mechanism leading to the two products.

Table 5.1

activation energy for step 2 to form 1,2-product, $E_{a2}(1,2)$	50 kJ mol^{-1}
activation energy for step 2 to form 1,4-product, $E_{a2}(1,4)$	70 kJ mol^{-1}
enthalpy change of reaction to form 1,2-product, $\Delta H_r^{\ominus}(1,2)$	–100 kJ mol^{-1}
enthalpy change of reaction to form 1,4-product, $\Delta H_r^{\ominus}(1,4)$	–120 kJ mol^{-1}

Using the data in Table 5.1, complete the energy profile diagram for the two-step mechanism in Fig. 5.1, on the axes provided in Fig. 5.2. Show clearly the pathway to form **both** products. Include labels to show the activation energies, enthalpy changes and products clearly.

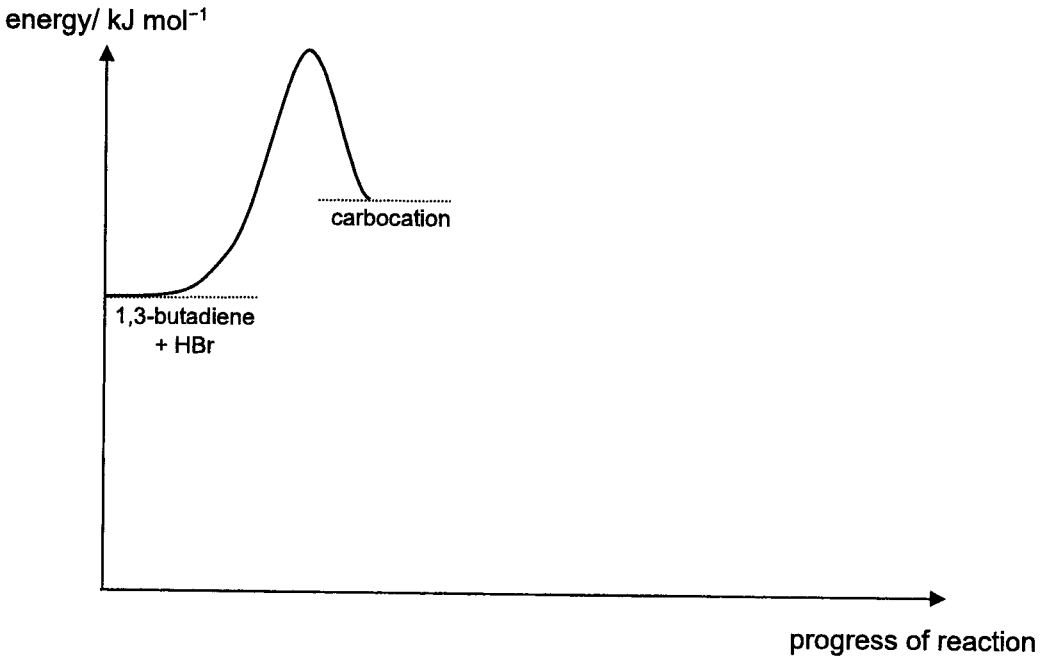

Fig. 5.2

[2]

(iv) The product ratios of a reversible reaction with the above energy profile can vary according to the temperature.

By considering the rates of reaction and enthalpy changes, use your answer in **(c)(iii)** to explain the following observations.

- At low temperature, the 1,2-product is the major product.

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- At high temperatures, the 1,4-product is the major product.

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..... [2]

(d) Sunscreens protect against harmful UV radiation using organic and inorganic filters. Organic filters are typically aromatic compounds with extended conjugated systems which enable them to absorb UV light. Inorganic filters are usually metal oxides.

Table 5.2 shows a list of sunscreen ingredients and their properties.

Table 5.2

ingredient	type of filter	UV range (nm)	appearance at room temperature	opacity on skin	particle size (nm)
avobenzone	organic	310 – 400	colourless liquid	transparent	–
octocrylene	organic	280 – 320	colourless liquid	transparent	–
ZnO	inorganic	280 – 370	white solid	nearly transparent	20 – 50
TiO_2	inorganic	290 – 340	white solid	nearly transparent	15 – 30

1 nm = 1×10^{-9} m

(i) By considering their electronic configurations, explain why ZnO and TiO_2 appear white at room temperature.

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..... [1]

Table 5.3 shows the active ingredients in three sunscreen formulations.

Table 5.3

formulation	active ingredients
X	5% avobenzone + 3% octocrylene
Y	10% ZnO
Z	7% TiO_2

(ii) A broad-spectrum sunscreen protection refers to protection against two forms of solar radiation – UVA and UVB, with ranges of 315 – 400 nm and 280 – 315 nm respectively.

Using data from Tables 5.2 and 5.3, suggest and explain which formulation is the most effective as a broad-spectrum sunscreen.

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..... [1]

(e) Octocrylene degrades via a first-order reaction with a half-life of 12.8 hours when applied to skin exposed to sunlight.

(i) Explain what is meant by the *half-life* of a reaction.

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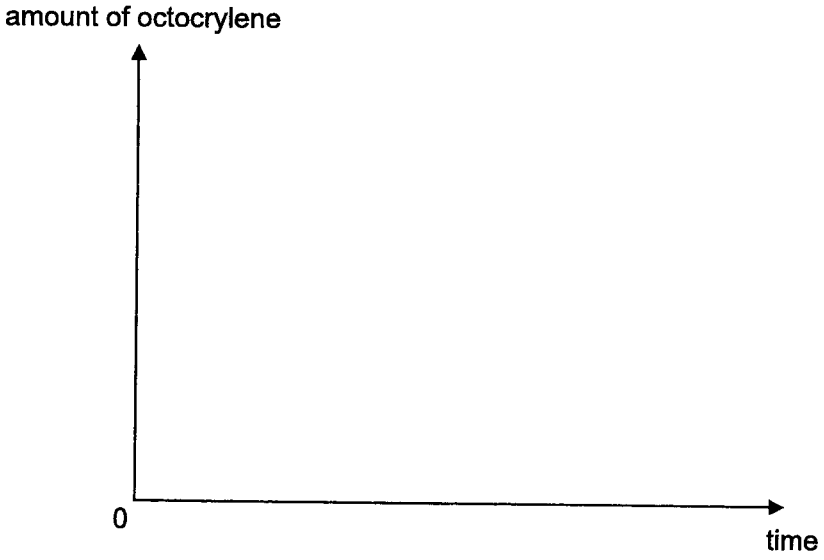
..... [1]

(ii) Calculate how long it would take for octocrylene to fall to $\frac{1}{8}$ of its initial value.

[1]

(iii) Sketch a graph to show how the amount of octocrylene decreases with time after application on the skin. Indicate two half-lives on your sketch, labelling your sketch clearly.



[1]

[Total: 19]

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HWA CHONG INSTITUTION
C2 Preliminary Examination
Higher 2

CANDIDATE NAME							**CT GROUP**	2	4	S		
CENTRE NUMBER	S						**INDEX NUMBER**					

CHEMISTRY

9729/03

Paper 3 Free Response

18 September 2025

2 hours

Candidates answer on the Question Paper.

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your **name**, **CT group, centre number** and **index number** on all the work you hand in.

Write in dark blue or black pen.

You may use a HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

DO **NOT** WRITE ON ANY BARCODES.

Answer all questions in the spaces provided in the Question Paper. If additional space is required, you should use the pages at the end of this booklet. The question number must be clearly shown.

Section A

Answer **all** questions.

Section B

Answer **one** question.

A Data Booklet is provided.

The use of an approved scientific calculator is expected, where appropriate.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

FOR EXAMINER'S USE	
1	/ 22
2	/ 17
3	/ 21
* Circle your option below	
* 4 / 5	/ 20
Deductions (s.f.)	
Deductions (units)	
Deductions (structures)	
Total	/ 80

Section A

Answer **all** questions in this section.

1 (a) Magnesium oxide, MgO, can be obtained from sea water which contains significant amounts of Mg^{2+} and Ca^{2+} ions.

The steps involved are shown in Fig. 1.1.

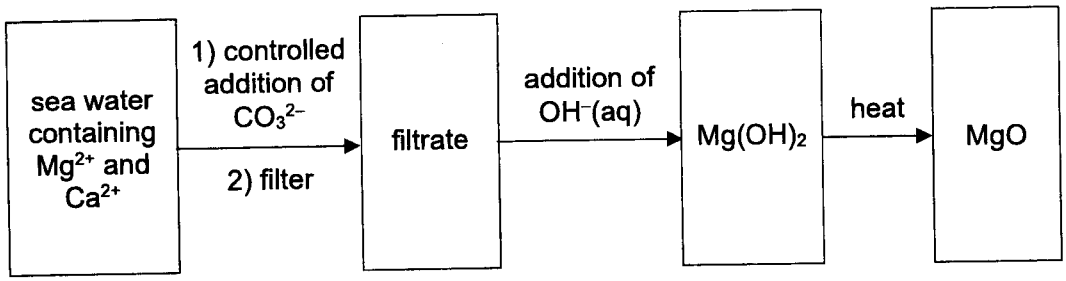

Fig. 1.1

The numerical values of the relevant solubility products, K_{sp}, are given in Table 1.1.

Table 1.1

compound	K_{sp}
$MgCO_3$	1.0×10^{-5}
$CaCO_3$	8.7×10^{-9}
$Mg(OH)_2$	1.1×10^{-11}
$Ca(OH)_2$	5.5×10^{-6}

(i) Calculate the solubilities of $MgCO_3$ and $Mg(OH)_2$ respectively, in mol dm^{-3}. [2]

(ii) If the concentration of Mg^{2+} ions in the filtrate is 3.0×10^{-5} mol dm^{-3}, calculate the concentration of OH^- ions present in the filtrate when the first trace of solid $Mg(OH)_2$ appears. [1]

(iii) Explain why CO_3^{2-} ions are added to the sea water before the addition of OH^- ions, and why this must be controlled. [2]

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(b) **(i)** Define the term *lattice energy*. [1]

(ii) Using the data in Table 1.2 and data from the *Data Booklet*, construct a Born-Haber cycle to calculate a value for the lattice energy of magnesium hydroxide, $Mg(OH)_2(s)$.

Table 1.2

	value / kJ mol^{-1}
standard enthalpy change of atomisation of Mg(s)	+148
standard enthalpy change of formation of $Mg(OH)_2(s)$	–925
standard enthalpy change of formation of OH(g), $\frac{1}{2}O_2(g) + \frac{1}{2}H_2(g) \rightarrow OH(g)$	+6
electron affinity of OH(g), $OH(g) + e^- \rightarrow OH^-(g)$	–173

[4]

(iii) Deduce the order of lattice energy, in decreasing magnitude, of MgO, $Mg(OH)_2$, and $Ca(OH)_2$. Explain your answer. [3]

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(c) Magnesium and aluminium are Period 3 elements with different physical and chemical properties.

(i) State the electronic configurations of Mg and Al, and explain why the first ionisation energy of aluminium is lower than that of magnesium. [2]

(ii) Both magnesium and aluminium react with chlorine to form their respective chlorides.

Describe and explain the reactions, if any, of each of these chlorides with an excess of water. Write equations for any reactions that occur and suggest the pH of the resulting mixtures. [4]

(d) Draw a labelled diagram of the electrolysis cell used to anodise aluminium. Include details of the cathode, anode and electrolyte. Write an equation for the reaction at **each** electrode. [3]

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[Total: 22]

2 (a) Explain why phenols are more acidic than alcohols such as ethanol. [2]

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(b) Salbutamol is a bronchodilator drug used for the treatment of an asthma attack.

Fig. 2.1 shows a synthesis of salbutamol from methyl salicylate.

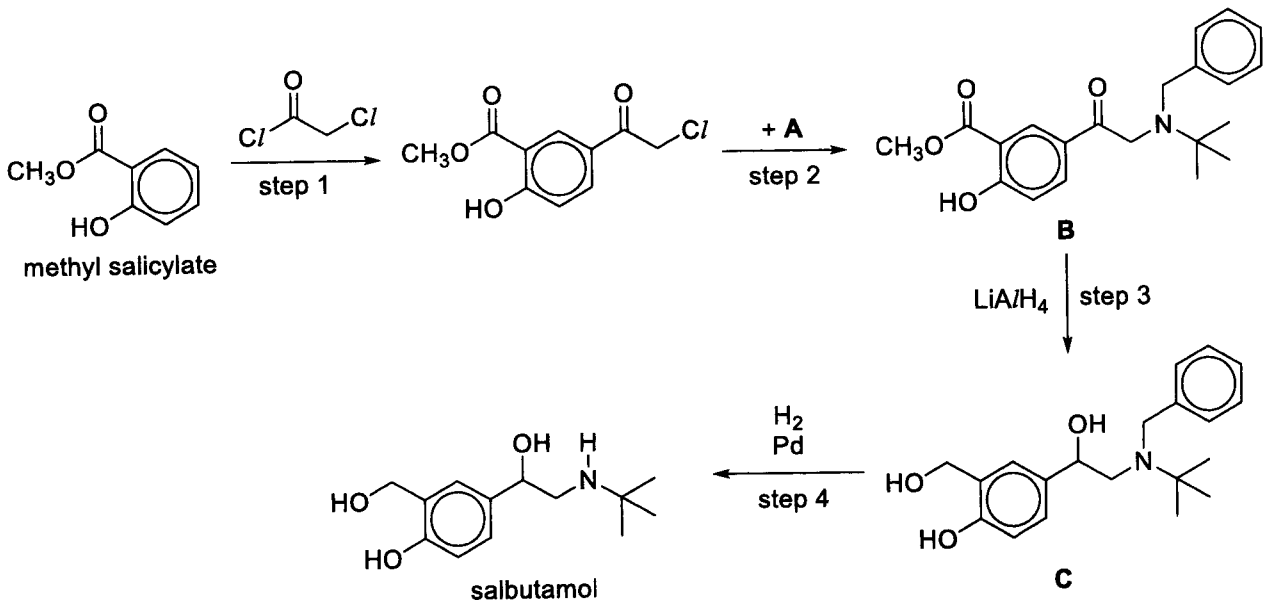

Fig. 2.1

(i) Name the mechanisms of the reactions in steps 1 and 2 respectively. [2]

(ii) Draw the structure of reagent **A** in step 2. [1]

(iii) Explain why the amine group in compound **C** would be a stronger base than the amine group in salbutamol in the gaseous phase. [2]

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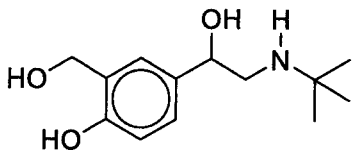
(c) The reaction of salbutamol (M_r = 239) with aqueous H_2SO_4 produces the ionic salt, salbutamol sulfate (M_r = 576.1), that is present in asthma inhalers.



salbutamol

(i) Draw the structure of salbutamol sulfate. [2]

(ii) Identify two types of forces of attraction that are responsible for the high solubility of salbutamol sulfate in water. [2]

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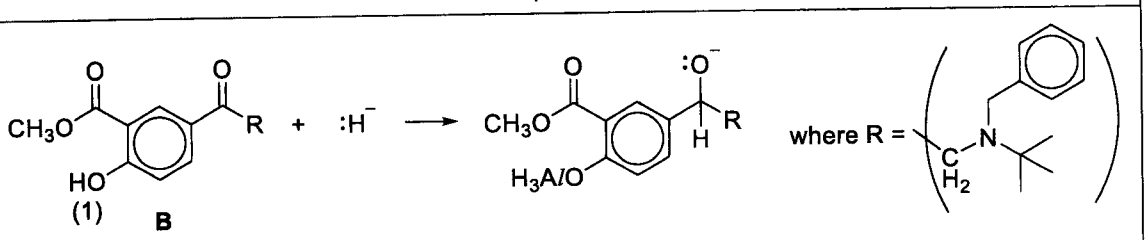
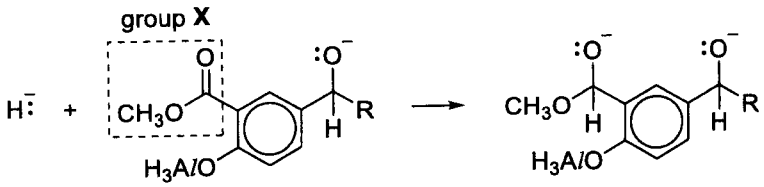
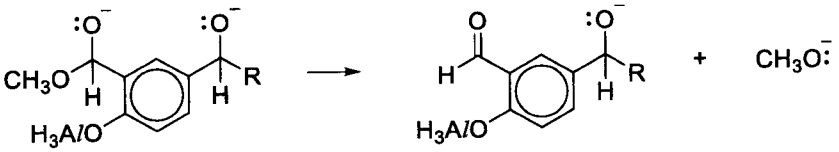
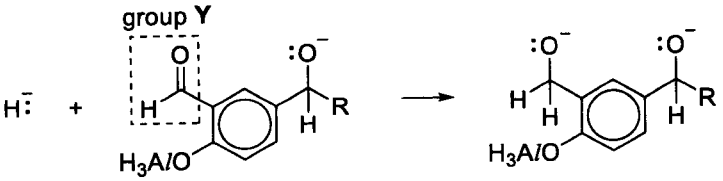
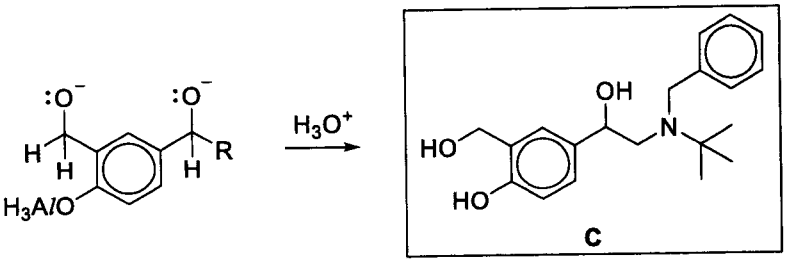
(d) Part of the mechanism for step 3 in Fig. 2.1 is illustrated by stages as shown in Table 2.1.

Table 2.1

stage	equation
1	 As the –OH group (1) of compound **B** is acidic, it also reacts with $LiAlH_4$ to form $-OAlH_3$.
2	
3	
4	
5	

(i) The hydride ion, $:H^-$, is assumed to be the reacting species produced by $LiAlH_4$ and acts as a nucleophile in stages 1, 2 and 4.

Draw the curly arrows and all relevant dipoles in stages 2 and 3 of Table 2.1. [2]

(ii) In stage 4, group **Y** reacts with $:H^-$ in a similar manner to group **X** in stage 2.

Group **X** is expected to be less reactive towards $:H^-$ than group **Y**. Suggest two reasons to explain this. [2]

(iii) Label the chiral centre in compound **C** of stage 5 of Table 2.1 with an asterisk (*). [1]

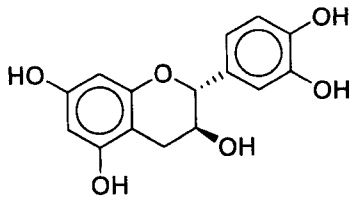
(iv) With reference to the mechanism in stage 1, explain why compound **C** produced in stage 5 is a racemic mixture. [1]

[Total: 17]

3 Cast iron kettles, or *tetsubin*, are traditionally used in Japan for boiling water. However, if the kettles are not dried thoroughly after use, rust (Fe_2O_3) forms readily on the inner surfaces.

To remove this rust, one method suggested on the Internet is to boil a mixture of water and green tea leaves in the *tetsubin* and leaving it overnight. When heated in water, rust forms $Fe(OH)_3$, which is sparingly soluble in water.

Green tea leaves contain catechins, which belong to a class of polyphenols.



(+)catechin

When the mixture of water and green tea leaves is boiled in a rusty *tetsubin*, $Fe^{3+}(aq)$ ions from $Fe(OH)_3$ can interact with catechins, giving a dark-coloured solution which is then discarded. Repeating these steps a few times apparently removes the rust.

(a) Explain why iron is classified as a *transition element*. [1]

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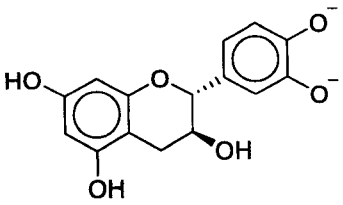
(b) Fe^{3+} ions can interact with the deprotonated form of catechin, Cat^{2-}.



Cat^{2-}

(i) Three Cat^{2-} ions bind to one Fe^{3+} ion to form an octahedral complex. Explain how each Cat^{2-} interacts with the Fe^{3+} ion to form the complex. [1]

(ii) Draw the 3-dimensional structure of the complex formed.

In your answer, you may simplify the structure of each Cat^{2-} ion to:  [2]

(iii) Name the type of reaction that occurs between $Fe^{3+}(aq)$ and Cat^{2-} ions to form the complex and write an equation to illustrate it. [2]

(c) Using the principles of solubility equilibria, suggest how the above method may be able to remove rust from the *tetsubin*. [2]

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(d) The five *d* orbitals in a transition metal ion are split into two levels when the ion is in an octahedral complex.

(i) Draw diagrams to illustrate the **two** different shapes of *d* orbitals in a transition metal ion. Explain why the *d* orbitals split into two levels in an octahedral complex, stating which of the *d* orbitals are in each level. [4]

(ii) Hence explain why transition element complexes are usually coloured. [2]

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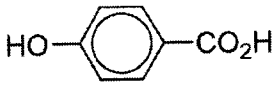
(e) The biosynthesis of catechin in green tea leaves involves the formation of compound **P**, $C_{15}H_{12}O_5$.

P is a *trans*-isomer which contains one six-membered aliphatic ring and one benzene ring.

P is also a tetraketone where each carbonyl carbon is separated from another by one carbon atom.

Heating **P** with acidified potassium manganate(VII) solution gives compound **Q** and 4-hydroxybenzoic acid as the only products.



4-hydroxybenzoic acid

P reacts with aqueous bromine to give compound **R**, $C_{15}H_{11}O_6Br_3$. Treatment of **P** with H_2 over Pd catalyst gives compound **S**.

Suggest the structures of **P**, **Q**, **R** and **S**.
For each reaction, state the type of reaction(s) described. [7]

[Total: 21]

Section B

Answer **one** question in this section.

4 In the chemical industry, ethanoic acid, CH_3CO_2H, is produced via the Monsanto process, which uses a homogeneous rhodium catalyst to convert methanol and carbon monoxide into ethanoic acid under high pressure and temperature. The process involves the following stages:

stage 1: $CH_3OH + HI \rightarrow CH_3I + H_2O$

stage 2: $CH_3I + CO \rightleftharpoons CH_3COI$

stage 3: $CH_3COI + H_2O \rightarrow CH_3CO_2H + HI$

(a) Write the overall equation for the formation of ethanoic acid from methanol and carbon monoxide in this process. [1]

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(b) Stage 1 of the Monsanto process involves the reaction between methanol and hydrogen iodide to form methyl iodide and water.

(i) Suggest the type of reaction occurring in this stage. [1]

(ii) The mechanism involves the following steps:

- step 1: protonation of the −OH group by hydrogen iodide to form an intermediate
- step 2: attack of the intermediate by iodide ion to form the final products

Draw the mechanism described above. Include all relevant lone pairs, dipoles, curly arrows, charges and the structure of the intermediate. [2]

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(c) Stage 2 of the Monsanto process is a reversible, exothermic reaction.

stage 2: $CH_3I + CO \rightleftharpoons CH_3COI$

(i) State and explain the effect of:
- increasing the temperature
- presence of a catalyst

on the position of equilibrium of stage 2. [2]

(ii) An experiment was carried out at 400 K, where 0.400 mol of CH_3I and 0.300 mol of CO were mixed in 700 cm^3 of solvent. At equilibrium, the concentration of CH_3COI was found to be 0.150 mol dm^{-3}.

Write the expression for the equilibrium constant, K_c, for stage 2.
Calculate the value of K_c, stating its units. [4]

(d) In stage 2 of the Monsanto process, the active catalyst is a rhodium(I) complex, $[Rh(CO)_2I_2]^-$.

The mechanism involves several steps, with the first step shown in Fig. 4.1.

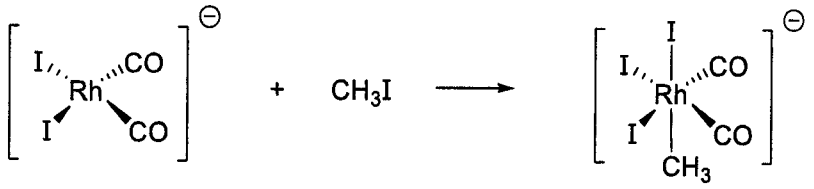

Fig. 4.1

In this first step, the catalyst undergoes an oxidative addition with CH_3I to produce a rhodium(III) complex, $[Rh(CH_3)(CO)_2I_3]^-$. The C–I bond breaks and new Rh–CH_3 and Rh–I bonds are formed.

(i) Explain the difference in the mode of action of a homogeneous catalyst as compared to a heterogeneous catalyst. [2]

(ii) With reference to its ligands and possible oxidation states, suggest two reasons how the $[Rh(CO)_2I_2]^-$ complex is able to function as a catalyst in stage 2 of the Monsanto process. [2]

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(e) To maintain the acidity within an optimal range for catalyst performance, a buffer is formed by adding a limited amount of sodium hydroxide to ethanoic acid.

A student adds 300 cm^3 of 0.500 mol dm^{-3} sodium hydroxide to 500 cm^3 of 0.800 mol dm^{-3} ethanoic acid to produce a buffer solution.

The K_a of ethanoic acid is 1.8×10^{-5} mol dm^{-3} at 298 K.

(i) Write the ionic equation for the reaction that occurs between ethanoic acid and sodium hydroxide. [1]

(ii) Calculate the concentrations of the acid and conjugate base present after the reaction. Hence, calculate the pH of the buffer. [3]

(iii) Explain, by reference to the equilibrium in the buffer, how this mixture resists pH changes on the addition of a small amount of acid. [2]

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[Total: 20]

5 The Maillard reaction is a series of chemical reactions that produces the characteristic browning of bread crusts in baking.

In one of the pathways of the Maillard reaction in the baking of bread, the reaction between ammonia and methanal produces a reactive imine intermediate, as shown in Reaction 1. This eventually leads to the production of compounds that gives bread crusts its brown colouration and flavour.

reaction 1 $\quad NH_3(g) + HCHO(g) \rightleftharpoons \underset{\text{imine}}{CH_2{=}NH(g)} + H_2O(g) \quad \Delta H = -56 \text{ kJ mol}^{-1}$

(a) **(i)** State *Le Chatelier's Principle.* [1]

(ii) Explain the effect of increasing
- temperature
- pressure

on the position of equilibrium of reaction 1. [2]

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(b) (i) An equilibrium mixture contains the four gases in reaction 1.

reaction 1 $NH_3(g) + HCHO(g) \rightleftharpoons CH_2{=}NH(g) + H_2O(g)$

At time t_1, a small amount of NH_3 is added while the temperature is kept constant. The mixture is then allowed to establish equilibrium again. At time t_2, a new equilibrium is established.

Complete the graph in Fig. 5.1 to show how the amount of each of the three gases would change from time t_1 until *after* time t_2. Show clearly the relative change in amount of each gas and the new amount of each gas at the new equilibrium.

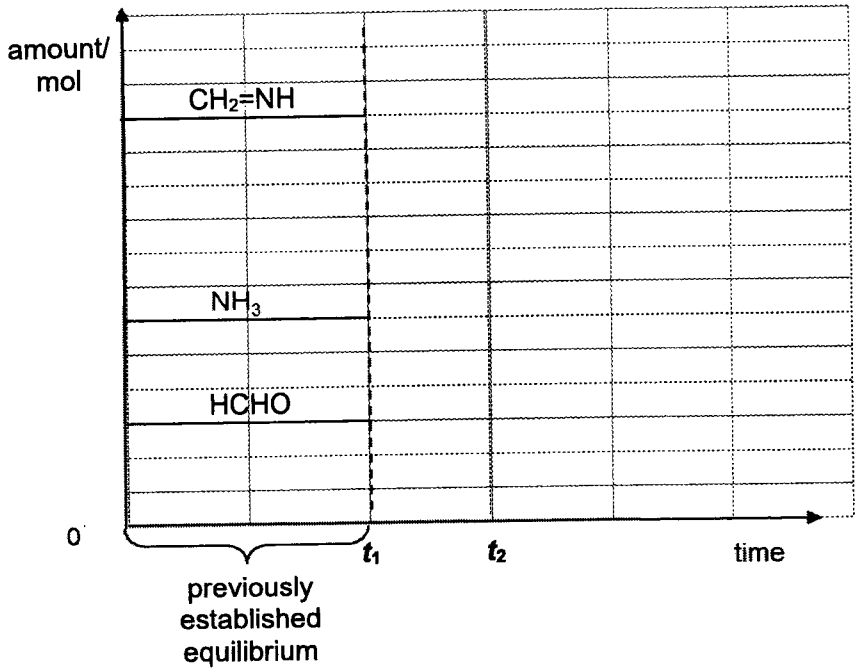

Fig. 5.1

[3]

(ii) Write the expression for the equilibrium constant, K_p, for reaction 1 and state its units. [1]

(iii) 5 moles of NH_3 and 5 moles of HCHO are introduced into a 1.2 dm^3 chamber at 180 °C. Reaction 1 occurs and when equilibrium is established, 9% of NH_3 remains unconverted.

Determine the value of K_p at 180 °C. [3]

(iv) Suggest the sign for the Gibbs free energy change of reaction 1 at 180 °C and comment on the position of equilibrium of the reaction. [1]

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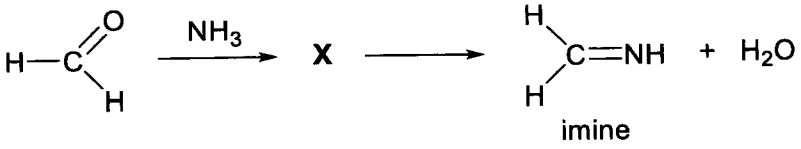
(c) **(i)** Suggest the type of reaction that has occurred in reaction 1. [1]

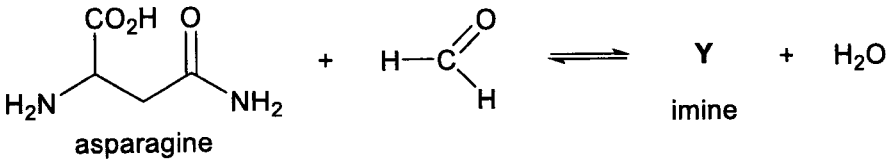
(ii) The imine in reaction 1 is formed in two steps via compound **X**, as shown below.



imine

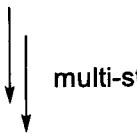
Suggest the structure of compound **X**. [1]

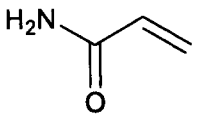
Reaction 1 is similar to the process that occurs when asparagine, an amino acid found in wheat flour, reacts with methanal in the bread crust at high temperatures during baking. This reaction leads to the formation of acrylamide, a potentially carcinogenic compound.



asparagine

imine





acrylamide

Fig 5.2

(iii) On Fig. 5.2, circle the functional group in asparagine that reacts with methanal to form the imine **Y**. [1]

(iv) Draw the structure of the imine **Y**. [1]

(v) Acrylamide formation is found to decrease in acidic medium. With reference to the role of asparagine to form **Y**, explain why this is so. [1]

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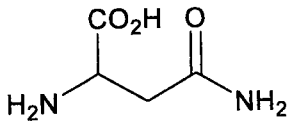
(d) A solution of asparagine is electrically neutral at pH 5.41. The pK_a values associated with asparagine are 2.02 and 8.80.



asparagine

(i) Draw the predominant form of asparagine present in the solution at pH 5.41. [1]

(ii) Write two equations to show how the asparagine in **(c)(i)** reacts with small amounts of acid and alkali when added separately. [2]

(iii) Calculate the ratio of the concentration of the two predominant forms of asparagine present in the solution at pH 8. [1]

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[Total: 20]

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Additional answer space

If you use the following pages to complete the answer to any question, the question number must be clearly shown.