

**HKDSE  
Past Paper Questions  
Industrial Chemistry**

**2012**

1. (a) Ammonia can be produced by the Haber process through the reaction of nitrogen and hydrogen at about 500 °C and 200 atm in the presence of a catalyst. The chemical equation for the reaction is shown below:

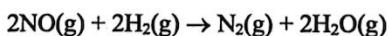


- (i) (1) What is the catalyst used in the Haber process?  
 (2) Explain the effect of a catalyst on a chemical reaction. (3 marks)
- (ii) Suggest how hydrogen can be obtained for the Haber process, and give a chemical equation involved. (2 marks)
- (iii) You are given that for the formation of  $\text{NH}_3(\text{g})$  from  $\text{N}_2(\text{g})$  and  $\text{H}_2(\text{g})$  at 300°C and 1000 atm, the yield of  $\text{NH}_3(\text{g})$  at equilibrium is about 98%. However, the operation conditions of the Haber process in industry are set at about 500°C and 200 atm with the yield of  $\text{NH}_3(\text{g})$  at equilibrium at about 20%. With reference to the given information, explain why such operation conditions are chosen in industry. (2 marks)
- (iv) In the Haber process, the product mixture is removed from the reaction chamber before reaching the yield of about 20%. Explain why this is so. (2 marks)

- (b) Methanol is an important compound in the chemical industry. Methanol can be produced from syngas made from methane.

- (i) Why is methanol an important compound in the chemical industry? (1 mark)
- (ii) Write the chemical equation for the reaction in the production of methanol from syngas, and state the conditions required. (3 marks)
- (iii) State an advancement of the methanol production technology. Explain why it is considered as an advancement. (2 marks)

- (c) Three trials of an experiment were performed at the same temperature for the study of the kinetics of the following reaction.



The table below shows the data obtained:

Trial	Initial concentration of NO(g)/ mol dm <sup>-3</sup>	Initial concentration of H <sub>2</sub> (g)/ mol dm <sup>-3</sup>	Initial rate with respect to N <sub>2</sub> (g)/ mol dm <sup>-3</sup> s <sup>-1</sup>
1	$2.50 \times 10^{-2}$	$5.00 \times 10^{-3}$	$1.20 \times 10^{-6}$
2	$2.50 \times 10^{-2}$	$1.00 \times 10^{-2}$	$2.40 \times 10^{-6}$
3	$1.25 \times 10^{-2}$	$1.00 \times 10^{-2}$	$6.00 \times 10^{-7}$

- (i) Explain why 'initial rate' is commonly used in the study of the kinetics of a reaction. (1 mark)
- (ii) Deduce the order of reaction with respect to NO(g) and that to H<sub>2</sub>(g). (2 marks)
- (iii) State the rate equation for the reaction, and calculate its rate constant at the temperature of the experiment. (2 marks)

	<u>Marks</u>
1. (a) (i) (1) finely divided iron / iron oxide <chem>FeO/Fe2O3/Fe3O4/FeOx</chem> OR <chem>Iron(II) oxide/Iron(III) oxide/Iron(II,III) oxide</chem>	1
(2) It can increase / decrease <del>rate</del> / <del>change</del> the rate of a reaction by providing an alternative pathway that requires lower / higher <del>different</del> activation energy. <del>(Observation and explanation should match)</del>	1+1
(ii) Steam reforming of natural gas / methane / <chem>CH4</chem>	1
<chem>CH4(g) + H2O(g) = 3H2(g) + CO(g)</chem> OR <del>(Accept irreversible sign)</del>	1
<chem>CO(g) + H2O(g) = H2(g) + CO2(g)</chem> <del>(Ignore state symbols, have to be balanced)</del> <del>Accept: Natural gas do not accept methane in steam reforming</del>	1
(iii) The <u>higher temperature</u> is used to <u>speed up</u> the reaction. The <u>lower pressure</u> is dictated by limits of <u>mechanical design</u> / <u>safety concerns</u> . (Lowering construction / maintenance costs of the plant / lower risk) <del>Answers should be in PAIRS. Do not accept (costs) without additional information.</del> <del>Correct reasons not pairing with temp/pressure (zero mark)</del>	1
(iv) • It takes a long time for the equilibrium (that the <chem>NH3(g)</chem> is of highest yield) to be attained. • It can increase the total amount of <chem>NH3(g)</chem> produced per unit time.	1 1
(b) (i) Methanol is important because it is a 1-carbon compound and acts as a starting material to make organic compounds with larger carbon numbers <del>(methanol)/formaldehyde/ethanoic acid/acetic acid/ether(dimethyl ether/MDBE)/as a solvent.</del> (Do not accept methanol as fuel to produce vinegar or it is used to produce hydrogen/ethene)	1
Mark first answer only!	
(ii) <chem>CO(g) + 2H2(g) = CH3OH(g)</chem> <del>(Accept irreversible sign)</del> Catalyst: Cu / <chem>ZnO</chem> / <chem>Al2O3</chem> <del>(Do not accept Pt/Pd/Ni)</del> Temperature: 200 – 300 °C <del>(Require correct unit)</del> Pressure: 50 – 100 atm <del>(Require correct unit)</del>	1 2
Mark "equation" (1) and "conditions" (2) separately! <del>Strict requirements on conditions, pressure and temperature, lenient on catalyst</del>	
(iii) Direct conversion of methane to methanol with the use of a metal oxide catalyst at high temperature and atmospheric pressure. The conversion uses a <u>catalytic reagent</u> <del>which atom economy</del> . OR Oxidation of methane to methanol by <u>microbial</u> reactions. The oxidation has <u>higher energy efficiency</u> . OR Conversion of <u>biomass</u> to syngas/biogas for methanol production. The conversion uses <u>renewable feed stocks</u> . OR Carbon dioxide in flue gas can be converted to form methanol. The conversion helps to reduce the <u>release of carbon dioxide</u> to the atmosphere. OR <del>Unconsumed hydrogen from chemical industries is allowed to react with carbon monoxide to form methanol. The conversion uses up the unconsumed raw materials (hydrogen)</del>	1+1 (1+1) (1+1) (1+1) (1+1)
(c) (i) Initial rate is used because the initial concentrations of reactants are known.	1
(ii) • Compare experiments 2 & 3, <chem>[H2]</chem> remains the same but <chem>[NO]</chem> is halved, <u>rate is decreased by a factor of 4</u> . Therefore reaction order with respect to <chem>[NO]</chem> is two. • Compare experiments 1 & 2, <chem>[NO]</chem> remains the same but <chem>[H2]</chem> is doubled, <u>rate is also doubled</u> . Therefore reaction order with respect to <chem>[H2]</chem> is one. <del>(Deduction must be shown. Accept other means to solve the problem, e.g., mathematical approach)</del>	1 1

(iii) rate =  $k[NO]^2[H_2]$  / ~~rate~~  $[NO][H_2] / k[NO]^2[H_2]$  Do not accept other symbols for rate.  
Must be an equation! Do not accept initial rate expressions like " $k[NO][H_2]$ " or " $k[NO]^2[H_2]$ ".

1\*

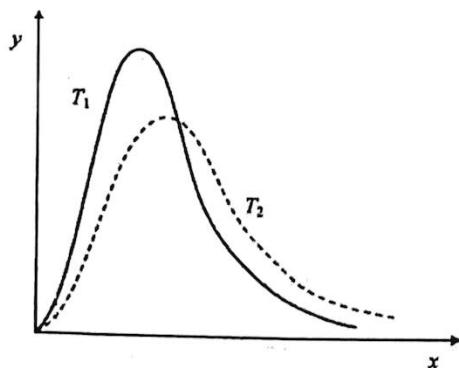
With data from experiment 1,

$$1.20 \times 10^{-6} = k \times [2.50 \times 10^{-2}]^2 \times [5.00 \times 10^{-3}]$$
$$\therefore k = 0.384 \text{ dm}^6 \text{ mol}^{-2} \text{ s}^{-1}$$

OR  $0.38 \text{ dm}^6 \text{ mol}^{-2} \text{ s}^{-1}$

1

1. (a) For gaseous reactions, an increase in temperature leads to an increase in reaction rate.  
 (i) The graph below shows the Maxwell-Boltzmann distribution curves of molecular kinetic energies of a gas at two temperatures  $T_1$  and  $T_2$ .

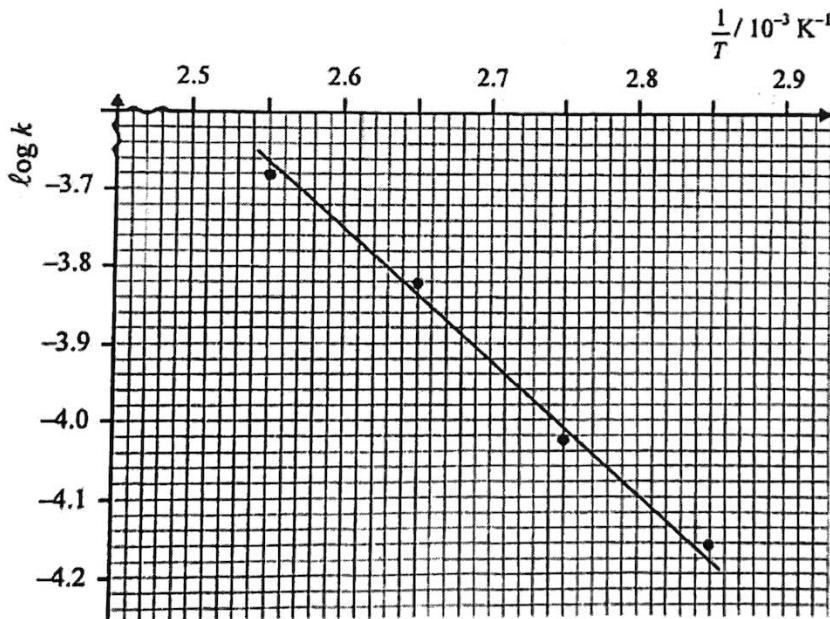


- (1) What do the axes, x and y, in the above graph respectively represent?  
 (2) With reference to the above graph, suggest why an increase in temperature can lead to an increase in the reaction rate of a gaseous reaction.

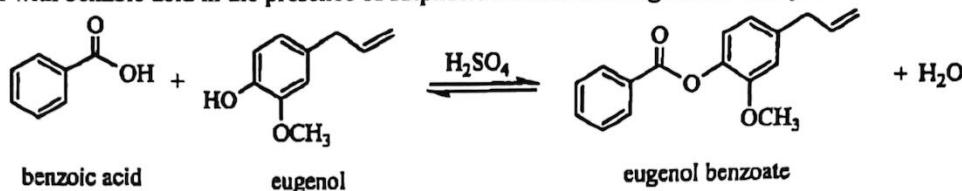
(5 marks)

- (ii) In a chemical kinetics experiment, the rate constants ( $k$ ) of a reaction at various temperatures ( $T$ ) were determined. The graph below shows the plot of  $\log k$  against  $\frac{1}{T} \times 10^{-3}$  K<sup>-1</sup>. Calculate the activation energy of this reaction.  
 (Gas constant,  $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$ )

(3 marks)



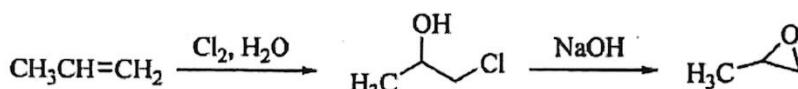
1. (b) Eugenol benzoate is a commonly used food flavoring agent. Eugenol benzoate can be synthesized from the reaction of eugenol with benzoic acid in the presence of sulphuric acid as a homogeneous catalyst.



- (i) Suggest why a catalyst can speed up a reaction. (1 mark)
- (ii) For the above reaction, would the use of concentrated sulphuric acid or that of dilute sulphuric acid give a better yield of eugenol benzoate? Explain your answer. (1 mark)
- (iii) Eugenol benzoate can also be synthesized from the reaction of eugenol with benzoic acid in the presence of a solid acid as a heterogeneous catalyst. With reference to the synthesis of eugenol benzoate, state ONE advantage of using a homogeneous catalyst and ONE advantage of using a heterogeneous catalyst. (2 marks)

- (c) Propylene oxide ( $\text{H}_3\text{C}-\text{C}(\text{O})-\text{CH}_2$ ) is a chemical commonly used in the plastics industry. Two methods for producing propylene oxide are shown below:

Method 1



Method 2



- (i) The  $\text{Cl}_2$  and  $\text{NaOH}$  used in Method 1 are products of the chloroalkali industry. Briefly describe how these two chemicals are produced. (3 marks)
- (ii) The atom economy of Method 1 is 29.7%. Calculate the atom economy of Method 2. (1 mark)
- (iii) Discuss, from TWO different perspectives, whether Method 1 or Method 2 is greener. (2 marks)
- (iv) Comment on the following statement, and explain your answer:  
'A reaction with a high atom economy should also have a high yield.'

(2 marks)

	<u>Marks</u>
1. (a)(i)(1) $x$ --- (molecular kinetic) energy / K.E.	1
y --- fraction/percentage / number / amount of molecules / particles	1
(2) (From the sketch), an increase in temperature (from $T_1$ to $T_2$ ) will increase the (average kinetic) energy of the molecules.	1
This will <u>increase the number of collisions / increase the collision frequency / result in greater effective collisions.</u>	1
(From the sketch,) there is a larger portion of molecules will have kinetic energy greater than $E_a$ .	1
(ii) $\log k = \text{constant} - \frac{E_a}{2.3RT}$	1
OR $k = Ae^{-\frac{E_a}{RT}}$	(1)
OR $\ln k = \ln A - \frac{E_a}{RT}$ BUT not accept ln as ln	(1)
Slope of curve = $-\frac{E_a}{2.3R}$	1*
$= -1.73 \times 10^3$ (Range: $-1.67$ — $-2.05$ )	(1*)
$E_a = 1.73 \times 10^3 \times (8.31 \text{ J K}^{-1} \text{ mol}^{-1}) \times 2.3$	
$= 33.1 \text{ kJ mol}^{-1}$ OR $33.100 \text{ J mol}^{-1}$ Accept mol <sup>-1</sup> as mol <sup>-1</sup>	1
(Acceptable range: $32$ to $39 \text{ kJ mol}^{-1}$ )	
Accept determination based on equation: $(\log k_1 - \log k_2)/(1/T_1 - 1/T_2) = -E_a/2.3R$	
(b) (i) A catalyst provides an <u>alternative pathway with lower activation energy.</u>	1
(ii) Concentrated $\text{H}_2\text{SO}_4$ Dilute $\text{H}_2\text{SO}_4$ contains a lot of $\text{H}_2\text{O}$ . <u>Water can shift the equilibrium position to the left / cause hydrolysis of ester (eugenol benzoate) / reactant side</u> , and thus lowers the yield of the product.	1
Also accept: <u>conc. <math>\text{H}_2\text{SO}_4</math> is a dehydrating agent / removes water from the product side of the reaction and will shift the equilibrium position to the right / product side</u>	(1)
(iii) Homogeneous catalyst --- $\text{H}_2\text{SO}_4$ is readily available / commonly found Heterogeneous catalyst --- can be reused / easily be regenerated / can be separated easily	1
	1

- (c) (i) Chlorine can be produced industrially by electrolysis of brine / concentrated sodium chloride solution using flowing mercury cell / diaphragm cell / membrane cell. 1  
 $\text{Cl}^-$  (aq) ions are discharged at the anode to give  $\text{Cl}_2(\text{g})$ . 1  
 Anode:  $2 \text{Cl}^- (\text{aq}) \rightarrow \text{Cl}_2 (\text{g}) + 2 \text{e}^-$  (1)

Diaphragm cell / membrane cell

$\text{H}^+$  (aq) ions are discharged at the cathode. With the removal of  $\text{Cl}^-$  (aq) ions and  $\text{H}^+$  (aq) ions, the resultant electrolytic solution contains  $\text{NaOH}$  (aq) in high concentration. 1  
 [If  $\text{Cl}^-$  (aq) ions mentioned above, accept only mention  $\text{H}^+$  (aq).]  
 Or, overall reaction:  $2 \text{NaCl} + 2 \text{H}_2\text{O} \rightarrow \text{Cl}_2 + \text{H}_2 + 2 \text{NaOH}$  (1)

OR

Flowing mercury cell

Sodium amalgam produced at cathode reacts with water forming  $\text{NaOH}$  (aq). (1)  
 Or,  $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$  (1)

- (ii) Method 2:

$$\text{Atom economy} = \frac{58}{76} = 76.32\%$$

[Accept also 76, 76.3, 76.316]

[If the fraction given, the numbers therein must be correct.]

- (iii) Method 2 is greener.

Any two of the following:

--- It has a higher atom economy.

--- It produces less waste (less side products) and less treatment is required / requires less steps.

--- Less hazardous chemicals are used such as method 1 uses (more) toxic  $\text{Cl}_2$  / Method 1 uses more corrosive  $\text{NaOH}$  / Method 1 uses more toxic  $\text{Cl}_2$ 

(Accept any reasonable answer based on the principles of green chemistry and note for comparative sense.)

- (iv) The calculation of atom economy is based on a 100% completed reaction. / complete conversion of reactants to products / Give definition of atom economy / high atom economy
- $\Rightarrow$
- less side product

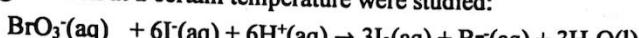
Most reactions do not go to completion / There is loss during handling. / The yield is related to the extent of reaction (percentage conversion).

Thus a reaction with high atom economy does not necessarily have a high yield.

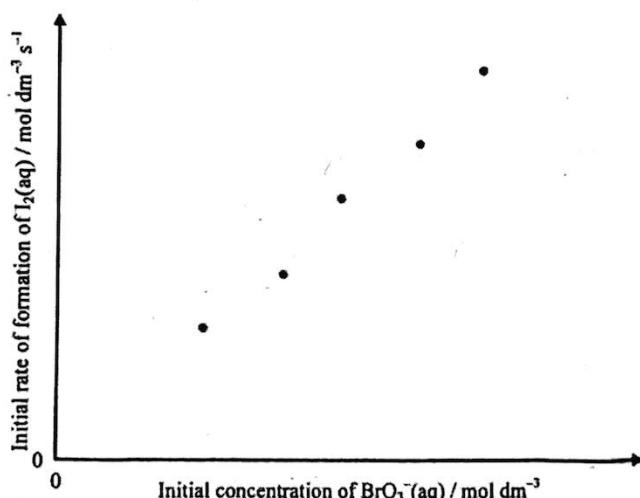
1. (a) Answer the following short questions:
- What is meant by the term 'activation energy'? (1 mark)
  - At room temperature, ethanol can be produced by fermentation of sugars in the presence of yeast. State the function of yeast, and explain why this function fails at high temperatures. (1 mark)
  - Vitamin C can be obtained from fruits. Explain why it is still necessary to synthesize vitamin C industrially. (2 marks)
  - Give TWO important chemicals manufactured in chloroalkali industry. (1 mark)

(1 mark)

- (b) The kinetics of the following reaction at a certain temperature were studied:



Several trials of an experiment were attempted under the same experimental conditions except varying the initial concentration of  $\text{BrO}_3^-(\text{aq})$  to measure the initial rate of formation of  $\text{I}_2(\text{aq})$ . The following graph shows the experimental results obtained from these trials:



- What is meant by the term 'initial rate'? (1 mark)
- Suggest a method, with justification, to follow the progress of the formation of  $\text{I}_2(\text{aq})$ . (2 marks)
- With reference to the graph above, deduce the order of reaction with respect to  $\text{BrO}_3^-(\text{aq})$ . (2 marks)
- The table below lists the information for two trials of an experiment on the same reaction performed at the same temperature:

	Initial concentration/ mol dm <sup>-3</sup>			Initial rate of formation of $\text{I}_2(\text{aq})$ / mol dm <sup>-3</sup> s <sup>-1</sup>
	$\text{BrO}_3^-(\text{aq})$	$\text{I}^-(\text{aq})$	$\text{H}^+(\text{aq})$	
Trial 1	0.17	0.15	0.10	$2.30 \times 10^{-3}$
Trial 2	0.17	0.30	0.20	$1.84 \times 10^{-2}$

- Given that the order of reaction with respect to  $\text{I}^-(\text{aq})$  is 1, deduce the order of reaction with respect to  $\text{H}^+(\text{aq})$ .
- Based on Trial 1, deduce the initial rate of reaction with respect to  $\text{BrO}_3^-(\text{aq})$  under the experimental conditions. (3 marks)

- (c) Read the following passage regarding the Haber process and answer the questions that follow.

Haber process is an important industrial process. It needs natural gas and air as raw materials. In order to speed up the reaction involved in Haber process, iron catalyst in highly porous form is used for increasing the efficiency of the catalyst. Haber process also needs suitable reaction temperature and pressure. Moreover, two factors related to chemistry have been considered before setting the optimal reaction conditions at about 500 °C and 200 atm. Under these conditions, the reaction yield at equilibrium is about 20%. Through some designs, without changing the optimal reaction conditions, the overall conversion percentage of nitrogen in the process can be increased significantly.

- (i) Explain why the Haber process is an important industrial process. (1 mark)
- (ii) Why does the Haber process need natural gas as a raw material? (1 mark)
- (iii) Explain why making the catalyst in highly porous form can increase the efficiency of the catalyst. (1 mark)
- (iv) State TWO factors related to chemistry that have been considered before setting the optimal reaction temperature and pressure. (2 marks)
- (v) Suggest one design so that the overall conversion percentage of nitrogen in the process can be increased significantly without changing the optimal reaction condition. (1 mark)
- (vi) The South American country Chile has a lot of natural nitrate mines. History tells us that the success of the Haber process had led to some impacts on the society of Chile. Suggest one of these impacts. (1 mark)

		<u>Marks</u>
1.	(a) (i) 'Activation energy' refers to the <u>minimum energy</u> possessed by the colliding reactant particles in order that <u>a reaction can occur</u> .	1
	(ii) • Yeast provides <u>enzyme / catalyst</u> . • At high temperature, the enzyme (yeast) is <u>denatured / destroyed</u> so that it cannot function as a catalyst.	1 1
	(iii) It is to solve the problems of <u>inadequate or shrinking supply</u> of vitamin C.	1
	(iv) Any TWO: chlorine, hydrogen, sodium hydroxide , <chem>NaOCl</chem> , <chem>HCl</chem> , <chem>NaClO3</chem> , <chem>ClO^-</chem> , <chem>ClO3^-</chem> , <u>bleaching solution</u>	1
	(b) (i) Initial rate is the <u>instantaneous rate at the start</u> of the reaction. OR rate at $t = 0$	1
	(ii) • Follow the <u>colour intensity</u> of the solution / by <u>colorimetry</u> • The solution changes from <u>colourless to brown/yellow</u> . <b>OR</b> • <u>Titrate with standard <chem>Na2S2O3</chem> solution.</u> • <u>Quenching. Add starch indicator. End point: blue to colourless.</u>	1 1 (1) (1)
	(iii) • The initial <u>rate</u> is <u>directly proportional</u> to $[BrO_3^-]$ (aq). / The graph is linear / a straight line. / rate $\propto [BrO_3^-]$ • Therefore, the order of reaction with respect to $BrO_3^-$ (aq) = 1	1 1
	(iv) (1) Rate = $k[BrO_3^-][I^-][H^+]^y$ where $y$ is the order of the reaction with respect to $H^+$ $\frac{\text{initial rate 1}}{\text{initial rate 2}} = \frac{(0.17)(0.15)}{(0.17)(0.30)} \left(\frac{0.10}{0.20}\right)^y = \frac{2.30 \times 10^{-3}}{1.84 \times 10^{-2}}$ $y = 2$ Reaction is second order with respect to $H^+$ (aq) (Accept other explanation.)	1 1 (1)
	When initial $[I^-]$ increases by a factor of 0.30 / 0.15 = <u>2/doubles</u> and initial $[H^+]$ increases by a factor of 0.20 / 0.10 = <u>2/doubles</u> while keeping initial $[BrO_3^-]$ constant, the initial rate increases by a factor of $1.84 \times 10^{-2} / 2.30 \times 10^{-3} = 8$ . Since the rate of reaction is first order with respect to $I^-$ , the initial rate increased by four times when the initial $[H^+]$ is doubled.	(1*)

(2) Rate of consumption of  $\text{BrO}_3^-$  =  $1/3 \times$  rate of formation of  $\text{I}_2$   
 The initial rate with respect to  $\text{BrO}_3^-$ (aq) in Trial 1  
 $= -2.30 \times 10^{-3} \times \frac{1}{3}$   
 $= -7.67 \times 10^{-4} \text{ mol dm}^{-3} \text{ s}^{-1}$  (Accept  $-7.7, -7.667, -7.6667$  but not  $-7.70$ ) 1

- (c) (i) Haber process produces ammonia which can be used to manufacture fertilizers / explosives, etc. ( $\text{HNO}_3, \text{NH}_4\text{NO}_3 / \text{NO}_3$ / refrigerant) 1
- (ii) Natural gas remains the more convenient / cheap way to provide hydrogen as feedstock for production of ammonia in the Haber process. 1
- (iii) Provide a larger surface area that makes the catalyst more effective. 1
- (iv)
- equilibrium position / yield 1
  - reaction rate / effective collisions 1
- (v) Any unreacted reactants are reused /recycled and are allowed to react again.  
Removing ammonia / Liquefying ammonia from the product mixture so as to shift the equilibrium position to the product side /Further H<sub>2</sub> addition. 1 (1)
- (vi) As the demand for mining the natural nitrate to produce fertilisers drops drastically, the mining work was no longer profitable /mining work might be closed/a high unemployment rate. (Accept other reasonable answers.) 1

1. (a) Answer the following questions:

(i) A certain reaction is zeroth order with respect to  $I_2(aq)$  and first order with respect to both  $CH_3COCH_3(aq)$  and  $H^+(aq)$ .

(1) State the effect, if any, a change in the concentration of  $I_2(aq)$  in the reaction mixture on the rate of the reaction.

(2) Write the rate equation for the reaction.

(2 marks)

(ii) Write a chemical equation for the reaction in forming ammonia in the Haber process.

(1 mark)

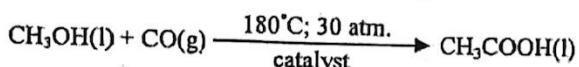
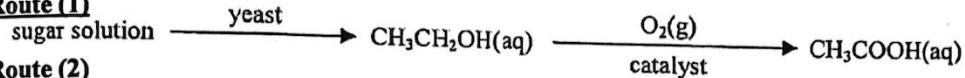
(iii) The rate constant of a certain reaction doubles when the temperature is increased from 298 K to 308 K. Calculate the activation energy of the reaction.

(Gas constant  $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$ ; Arrhenius equation:  $\log k = \text{constant} - \frac{E_a}{2.3 RT}$ )

(2 marks)

- (b) Ethanoic acid can be produced by two routes as listed below:

Route (1)



(i) The reactions in both Routes (1) and (2) require the use of catalysts.

(1) Draw, in the same sketch, TWO labelled energy profiles for a reaction, one with a catalyst and the other one without catalyst.

(2) Theoretically, catalysts are not consumed in reactions. Suggest why it is still necessary to replace the used catalyst from time to time in industrial processes.

(4 marks)

(ii) Suggest TWO reasons why Route (1) is considered as a green process.

(2 marks)

(iii) Suggest TWO reasons why ethanoic acid used in the plastic industry is manufactured by Route (2) instead of Route (1).

(2 marks)

- (c) Chlorine is one of the products manufactured in the chloroalkali industry. The electrolysis involved in the chloroalkali industry can be performed in a mercury electrolytic cell, a diaphragm electrolytic cell or a membrane electrolytic cell.

(i) State the raw material used in the chloroalkali industry.

(1 mark)

(ii) Suggest a criterion in choosing a site for building the chemical plant for a chloroalkali industry.

(1 mark)

(iii) Write an overall equation for the electrolysis involved in the chloroalkali industry.

(1 mark)

(iv) Explain why a mercury electrolytic cell is NOT considered to be environmentally friendly.

(1 mark)

(v) What is the advantage of a membrane electrolytic cell over a diaphragm electrolytic cell?

(1 mark)

(vi) The chloroalkali industry can also manufacture chlorine bleach and hydrochloric acid. Explain, with the aid of a chemical equation, why chlorine bleach should not be stored together with hydrochloric acid.

(2 marks)

Marks

1. (a) (i) (1) No effect / the reaction rate is independent of the change in  $[I_2(aq)]$ .

1

$$(2) \text{Rate} = k[\text{CH}_3\text{COCH}_3(\text{aq})][\text{H}^+(\text{aq})][\text{I}_2(\text{aq})]^0$$

[Accept R representing Rate] [NOT accept speed]

1



1

(iii)

$$\log \frac{k_2}{k_1} = \frac{E_a}{2.3R} \left( \frac{1}{T_1} - \frac{1}{T_2} \right) \text{ OR } \log 2 = \frac{E_a}{2.3R} \left( \frac{1}{298} - \frac{1}{308} \right)$$

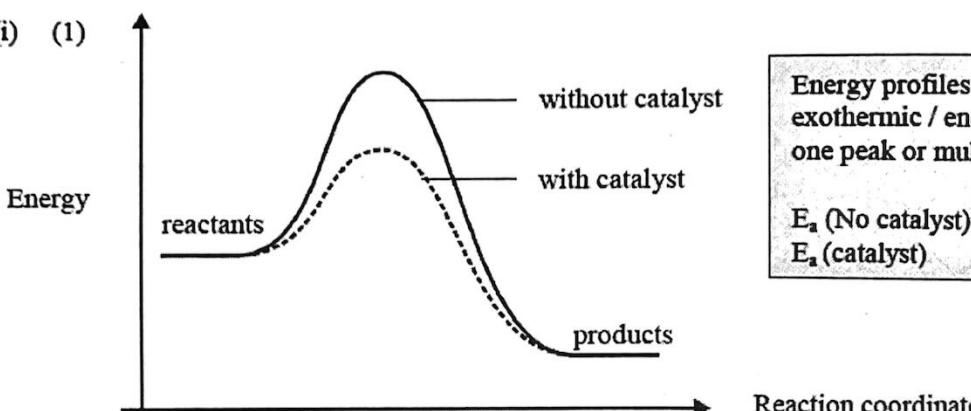
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$$\text{OR } \log k_2 - \log k_1 = \frac{E_a}{2.3RT_1} - \frac{E_a}{2.3RT_2}$$

$$E_a = 52.8 \text{ kJ mol}^{-1} \quad [\text{Range: } 52.3 - 53.3]$$

1

(b) (i) (1)



Energy profiles: Accept exothermic / endothermic; one peak or multiple peaks

$E_a$  (No catalyst) >  
 $E_a$  (catalyst)

(1 mark for each of the energy profiles – total 2 marks;

1 mark: one energy profile + labels (reactants & products)

1 mark:  $E_a$  (No catalyst) >  $E_a$  (catalyst)

1 mark for the labels: Accept potential energy / enthalpy but NOT kinetic energy /energy level)

(NOT accept reaction coordination.)

1

(2) Catalysts can be poisoned. / Their active sites can be occupied by other chemicals making them inactive.

1

(ii) Any TWO of the following:

2

- A (biological) catalyst /enzyme is used. [Accept: yeast's enzyme but NOT accept yeast is enzyme]
- The reagent ( $O_2$ ) used is non-toxic.
- The reactions take place in aqueous phase. (No organic solvents are used.)
- The feedstock (sugars) is renewable.
- The wastes formed are biodegradable.
- The reaction is carried out at room temperature / pressure / requires less energy.

(iii) Any TWO of the following:

2

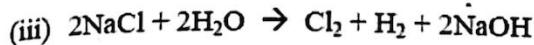
- The reactions in route (1) are carried out in dilute / aqueous solutions while route (2) is not. / The ethanoic acid produced in route (1) is in form of dilute/aqueous solutions while route (2) is not. / In route (2), the ethanoic acid produced is more pure /concentrated. / The recovery of the ethanoic acid from these solutions in route (1) requires much more energy than route (2). / The amount of ethanoic acid produced by the fermentation route / route (1) cannot meet the large demand of ethanoic acid but route (2) can.
- The rate of fermentation / aerial oxidation in route (1) is slower.
- Route (2) does not consume food but route (1) does.

(c) (i) Concentrated / Saturated sodium chloride (NaCl) solution / brine

1

(ii) Site should be near the sea (because easy to get the raw material.) / Easy transportation /  
Not too near residential places

1



1

(iv) Mercury is poisonous.

1

(v) In membrane cell, more pure sodium hydroxide can be obtained, but not for diaphragm cell. / No impurity (NaCl) in sodium hydroxide obtained in membrane cell but in diaphragm cell / Less energy is required for membrane cell.

1

(vi) Chlorine bleach can react with hydrochloric acid to give poisonous chlorine gas.

1



1

## 1. (a) Answer the following short questions:

- (i) Consider the following reaction for the production of ethanol by using a certain catalyst in industry:



Justify, under a pressure of 65 atm, why the operation temperature is set at 300°C with reference to equilibrium position and reaction rate.

(2 marks)

- (ii) What does the area under a Maxwell-Boltzmann distribution curve represent?

(1 mark)

- (iii) Syngas is an important starting material in many industrial processes.

(1) State the TWO major constituent gases in syngas.

(2) Suggest one important chemical that can be made directly from syngas through catalytic process.

(2 marks)

- (b) Consider the manufacture of ammonia by the Haber process in a chemical plant.

- (i) Suggest how nitrogen gas can be obtained in industry.

(1 mark)

- (ii) Explain why there is a need to install a heat exchanger in the chemical plant.

(2 marks)

- (iii) If 420 kg of nitrogen and 96 kg of hydrogen are introduced into the reaction chamber, and with the yield of ammonia of 15%, calculate the mass of ammonia produced.

(3 marks)

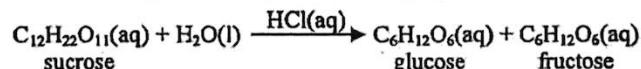
- (iv) Nitric acid can also be produced in the chemical plant. Firstly, ammonia is oxidised to give nitrogen monoxide, and nitrogen monoxide is further oxidised to nitrogen dioxide. Finally, oxidation of nitrogen dioxide gives nitric acid. Write the chemical equation for each of the following reactions:

(1) oxidising ammonia to give nitrogen monoxide

(2) oxidising nitrogen dioxide to give nitric acid

(2 marks)

## 1. (c) The hydrolysis of sucrose can be represented by the following equation:



- (i) Three trials of an experiment were performed under the same experimental conditions to study the kinetics of the hydrolysis. The table below shows the data obtained:

	Initial concentration of $\text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{aq})$ / mol dm <sup>-3</sup>	Initial concentration of $\text{HCl}(\text{aq})$ / mol dm <sup>-3</sup>	Initial rate of disappearance of $\text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{aq})$ / mol dm <sup>-3</sup> s <sup>-1</sup>
Trial 1	0.010	0.10	$6.0 \times 10^{-7}$
Trial 2	0.020	0.20	$2.4 \times 10^{-6}$
Trial 3	0.010	0.30	$1.8 \times 10^{-6}$

(1) Given that the order of reaction with respect to  $\text{H}_2\text{O}(\text{l})$  is zero, deduce the order of reaction with respect to  $\text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{aq})$  and that to  $\text{HCl}(\text{aq})$ .

(2) State the rate equation for the reaction.

(3) Based on the result in Trial 1, calculate the rate constant under the experimental conditions.

(4 marks)

- (ii) The hydrolysis of sucrose can also be performed by the action of a certain enzyme. Suggest the function of the enzyme in the hydrolysis.

(1 mark)

- (iii) Enzymatic hydrolysis of starch eventually gives glucose as the only product. According to the principles of green chemistry, suggest TWO reasons why starch is considered to be more suitable than sucrose as a source of glucose.

(2 marks)

		<u>Marks</u>
1. (a) (i)	<ul style="list-style-type: none"> <li>High(er) temperature will have a high(er) rate of reaction. But the (forward) reaction is exothermic, increasing the temperature will shift the equilibrium position to left / reactant side / reaction has a lower yield / favors the backward reaction Therefore, the operating temperature is set at 300°C. / As the (forward) reaction is exothermic, decreasing the temperature will shift the equilibrium position to right / product side / reaction has a higher yield. / lower temperature favours the reaction [must mention: exothermic/endothermic and then yield / eqm position / favors which side] and decreasing the temperature will decrease the rate of reaction. Therefore, the operating temperature is set at 300°C. / To set at the operating temperature at 300°C, the reaction rate is not too low and the yield is not too low. [Note: 1 mark for rate (+ high/low temperature) and 1 mark for equilibrium position / yield / favors ... side (+exothermic/endothermic)]</li> </ul>	1 1 1 1 1 1 1 1 1
(ii)	total number of particles / total number of molecules (sum of mole fractions is 1 / sum of probabilities is 1)	1
(iii) (1)	carbon monoxide / CO and hydrogen / H <sub>2</sub> (more than two gases: 0 mark)	1
	(2) methanol / CH <sub>3</sub> OH	1
(b) (i)	fractional distillation of liquefied air. / fractional distillation of liquid air	1
(ii)	<ul style="list-style-type: none"> <li>The hot gas from reaction chamber can help heat up the hydrogen and nitrogen / incoming gases / reactants / reactants mixture. / cool down the product mixture</li> <li>It is to save energy. / to save fuel / conserve (recycle / reuse) energy / heat / reduce the cost of fuel / energy</li> </ul>	1 1
(iii)	No. of moles of N <sub>2</sub> (g) = 420000/28 and no. of moles of H <sub>2</sub> = 96000/2 Mole ratio of N <sub>2</sub> (g) to H <sub>2</sub> (g) = 420000/28 : 96000/2 = 1: 3.2 (or 0.3125 : 1). [0 mark if just wrote 420/28 and 96/2 only 0 mark even mol ratio correct but number of moles as 420/28 (N <sub>2</sub> ) and 96/2 (H <sub>2</sub> ) are written 1 mark awarded if mol ratio correct and just mention N <sub>2</sub> as 420/28 (N <sub>2</sub> ) and 96/2 (H <sub>2</sub> ) but not mention mol] N <sub>2</sub> (g) is limiting reagent. Mass of NH <sub>3</sub> (g) produced = 420000/28 x 2 x 17 x 15% = 76.5 kg / 77 kg / 76500 g / 77000 g (76 kg / 77.0 kg / 76.5 g : 0 mark)	1* 1 1
(iv) (1)	4NH <sub>3</sub> + 5O <sub>2</sub> → 4NO + 6H <sub>2</sub> O [Accept reversible sign]	1
	(2) 4NO <sub>2</sub> + O <sub>2</sub> + 2H <sub>2</sub> O → 4HNO <sub>3</sub> [Accept reversible sign]	1

1. (c) (i) (1) • Compare experiments 1 & 3, ([sucrose] remains the same) but [HCl] is three times, rate is also three times. Therefore reaction order with respect to HCl is one. 1
- Compare experiments 1 & 2, [sucrose] and [HCl] are doubled, the rate is quadrupled. Therefore reaction order with respect to sucrose is one. (Accept an increase of / an increase to etc.) 1
- Mark independently. In other words, award 1 mark to second deduction without the first deduction.
- 1 mark if order of reaction w.r.t. HCl and order of reaction w.r.t. sucrose are both 1 but without any deduction.

$$\text{OR} \quad \text{rate} = k [C_{12}H_{22}O_{11}(\text{aq})]^m [HCl(\text{aq})]^n$$

$$\text{From Trial 1 } 6.0 \times 10^{-3} = k (0.010)^m (0.10)^n \quad \dots \dots \dots \quad (1)$$

$$\text{From Trial 2 } 2.4 \times 10^{-3} = k (0.020)^m (0.20)^n \quad \dots \dots \dots \quad (2)$$

$$\text{From Trial 3 } 1.8 \times 10^{-3} = k (0.010)^m (0.30)^n \quad \dots \dots \dots \quad (3)$$

$$(3)-(1) \quad n=1 \quad \text{and} \quad (2)-(1) \quad m=1$$

1  
1

$$(2) \quad (\text{initial}) \text{ rate} = k [C_{12}H_{22}O_{11}(\text{aq})] [HCl(\text{aq})]$$

1

$$(\text{initial}) \text{ rate} = k [\text{sucrose}] [H^+(\text{aq})][H_2O(l)]^0$$

(3) With data from Trial 1,

$$6.0 \times 10^{-3} = k (0.010) (0.10)$$

$$k = 6.0 \times 10^{-4} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1} / 6 \times 10^{-4} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1} / 0.0006 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$$

(accept unit as  $\text{mol}^{-1} \text{ dm}^3 \text{ s}^{-1} / \text{M}^{-1} \text{ s}^{-1}$ ) (wrong unit 0 mark)

1

- (ii) Acts as a catalyst. / Increase the rate of hydrolysis / provide another reaction path of lower  $E_a$ . 1

1

- (iii) - Need not to separate fructose from the mixture after hydrolysis of starch but the one with sucrose requires. 1

1

- Higher atom economy as glucose is the only product from the enzymatic hydrolysis of starch. / atom economy of hydrolysis of starch is 100% while that of sucrose is 50% / less than 100% 1

1

- Harmful / corrosive / irritating HCl(aq) is used in hydrolysis of sucrose while hydrolysis of starch involves enzyme which is biodegradable and less harmful

[NOT accept HCl is poisonous / toxic]

(Any 2 reasons of the above, with comparative sense 1 mark each)

1

2017

1. (a) Answer the following short questions:

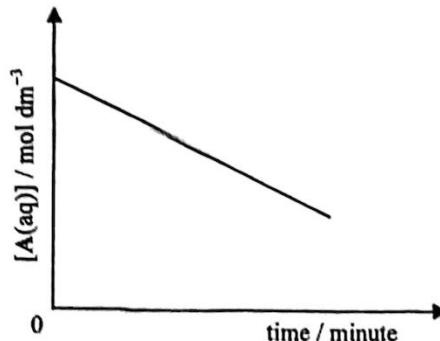
(i) Consider the Haber process:

(1) Write a chemical equation for the reaction.

(2) Suggest how ammonia can be separated from the reaction mixture obtained.

(2 marks)

(ii) The following graph shows the variation of the concentration of a reactant A(aq) in a certain reaction at a fixed temperature with time.



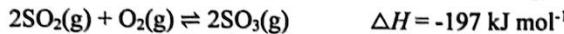
Suggest, with explanation, the order of reaction with respect to A(aq).

(2 marks)

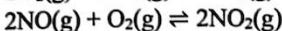
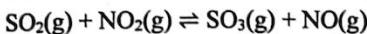
(iii) Suggest a potential hazard for storing methanol in a chemical plant.

(1 mark)

(b) The manufacture of sulphuric acid involves the following conversion of  $\text{SO}_2(\text{g})$  to  $\text{SO}_3(\text{g})$ :



(i) Nitrogen oxides (NO and  $\text{NO}_2$ ) were once used as catalysts for the conversion, and the catalytic process is considered to consist of the following two steps:



Draw, in the same sketch, TWO labelled energy profiles (x-axis: reaction coordinate; y-axis: potential energy) for the above conversion: one with nitrogen oxides as the catalysts (using dotted line '----'); the other one without catalysts (using solid line '—').

(3 marks)

(ii) Nowadays in industry, a solid catalyst vanadium(V) oxide is used for the conversion of  $\text{SO}_2(\text{g})$  to  $\text{SO}_3(\text{g})$ .

(1) The reactants needed to be purified before passing into the reaction chamber containing the catalyst. Why?

(2) The operation conditions are set at  $450^\circ\text{C}$  and 1 atm to achieve a 96% conversion. Suggest why it is NOT preferable to further increase the conversion percentage by each of the following methods:

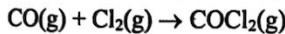
(I) lowering the temperature of the reaction system

(II) increasing the pressure of the reaction system

(3) In order to increase the conversion percentage, one of the reactants used is in slight excess. From the perspective of feedstock, which of  $\text{SO}_2(\text{g})$  or  $\text{O}_2(\text{g})$  would be in slight excess? Explain your answer.

(4 marks)

(c) Phosgene ( $\text{COCl}_2$ ) is an important chemical. It can be produced from the reaction of  $\text{CO}(\text{g})$  with  $\text{Cl}_2(\text{g})$ :



(i) Write a chemical equation to show how  $\text{CO}(\text{g})$  can be obtained from natural gas.

(1 mark)

(ii) Chlorine can be produced by the flowing mercury cell process.

(1) Write the half equation for the change occurring at the anode.

(2) Write the half equation for the change occurring at the cathode.

(3) Explain why the flowing mercury cell process has been gradually phased out.

(3 marks)

(iii) At a certain temperature, if the concentration of  $\text{CO}(\text{g})$  is doubled while the concentration of  $\text{Cl}_2(\text{g})$  is kept unchanged, the new rate of reaction will become 2.83 times the original rate. Deduce the order of reaction with respect to  $\text{CO}(\text{g})$ .

(Note: The order of a reaction may NOT be an integer.)

(2 marks)

(iv) Explain separately why the above process of producing  $\text{COCl}_2(\text{g})$  can be considered

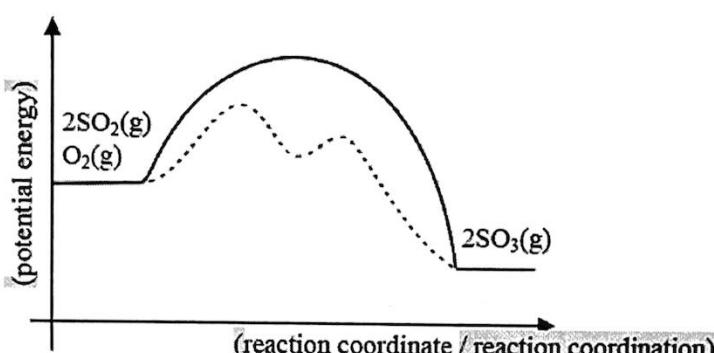
(1) green, or

(2) not green.

(2 marks)

1. (a) (i) (1)  $N_2 + 3H_2 \rightleftharpoons 2NH_3$  1  
           [NOT accept  $\rightarrow / =$ ]
- (2) The reaction mixture is cooled to condense ammonia to liquid. 1  
           [Accept: The reaction mixture is condensed / is cooled to liquid.]
- (ii) The order of reaction with respect to A is zero,  $0 / \text{rate} = k[A]^0$ . 1  
           From the graph, rate of change of [A] is independent to [A] / a constant. 1  
           [Accept: A straight line is obtained. / [A] and time has a linear relationship / The slope of the line is a constant.  
           NOT accept: [A] is directly proportional to time]
- (iii) flammable / inflammable / toxic / poisonous 1  
           [NOT accept harmful]

(b) (i)



- 1 mark for exothermic; i.e. energy of products is lower than that of reactants &  $E_{act}$  of the catalysed reaction is lower
- 1 mark for two steps for the one with catalyst (i.e. two peaks) & one/multiple steps for the energy profile without catalyst
- 1 mark for the labels of  $(2)SO_2$  &  $O_2$  and  $(2)SO_3$
- [NOT accept: reactants & products]

If the candidate did not use dotted line, marks can still be given if the diagram is clear. If you cannot determine, mark will not be given.

If the candidate drew two separate sketches of energy profiles, do not give the first mark (i.e. exothermic etc.). The subsequent marks can still be given.

If the candidate reversed the labels of axes, consider to give the 3<sup>rd</sup> mark.

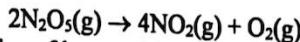
- (ii) (1) Impurities in the reaction mixture may poison the catalyst. 1  
           [Accept: Adsorb / The active sites of the catalyst are occupied by impurities.  
           NOT accept: the catalyst is poisoned by the reactants]
- (2) (I) Lowering the temperature makes the reaction proceed at a slower rate. 1  
           [NOT accept lower fuel cost]
- (II) The percentage conversion is already very high. / Increasing the pressure can only lead to a very small increase in the percentage conversion but very high cost is needed. 1  
           [Require to mention "percentage conversion" & "cost"]
- (3) Oxygen is used in a slight excess because it is more cost-effective/ cheaper to obtain / easier to obtain. 1  
           [Requires a comparative sense.]

- (c) (i)  $CH_4 + H_2O \rightarrow CO + 3H_2$  1  
           [Accept  $\rightleftharpoons$  NOT accept  $=$ ]
- (ii) (1)  $2Cl^- \rightarrow Cl_2 + 2e^-$  1  
           (2)  $Na^+ + e^- \rightarrow Na$  1  
           OR  $Na^+ + Hg + e^- \rightarrow Na/Hg$

	<u>Marks</u>
(3) Mercury is poisonous. [NOT accept harmful.]	1
(iii) Let rate = $k[CO]^m[Cl_2]^n$ From doubling [CO] while keeping [Cl <sub>2</sub> ] unchanged, $2.83 = 2^m$ $m = 1.5$ [Accept 1.50, 1.501]	1 1
(iv) (1) The atom economy is 100% in the reaction. / No solvent is required in the reaction. [Accept: The atom economy is high] (2) The reactants / (CO / Cl <sub>2</sub> ) are poisonous / toxic. NOT accept harmful.	1 1

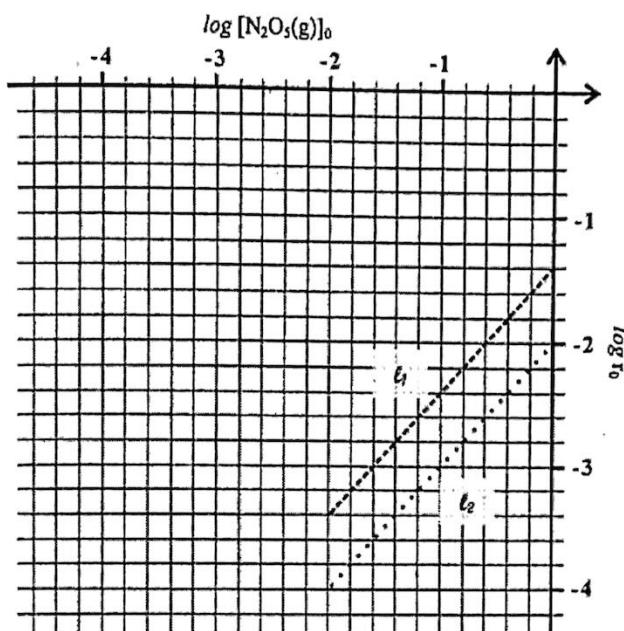
1. (a) Answer the following short questions:
- Write TWO half equations for the electrolysis of brine using membrane electrolytic cell in chloroalkali industry. (2 marks)
  - Sketch a labelled diagram for a Maxwell-Boltzmann distribution curve. (2 marks)
  - Which one of the following species can be a raw material for manufacturing vitamin C in industry?  
Acetic acid, acetone, formaldehyde, glucose (1 mark)
- (b) Reaction (I) below shows a process of producing methanol using catalyst at 100 atm and 250°C in industry:  
Reaction (I) :  $\text{CO(g)} + 2\text{H}_2\text{(g)} \rightleftharpoons \text{CH}_3\text{OH(g)}$
- (1) Suggest a suitable catalyst for the reaction.  
(2) Suggest why the reaction would proceed slowly in the absence of a catalyst.  
(3) Explain why the operation pressure in industry for the reaction is set at 100 atm but not at atmospheric pressure. (4 marks)
  - Methanol can also be produced from carbon dioxide, a side product of some industrial processes, using another catalyst as shown in Reaction (II) below:  
Reaction (II):  $\text{CO}_2\text{(g)} + 3\text{H}_2\text{(g)} \rightleftharpoons \text{CH}_3\text{OH(g)} + \text{H}_2\text{O(g)}$   
Based on the given information:  
(1) Suggest one reason why Reaction (II) can be considered as greener than Reaction (I).  
(2) Suggest a potential benefit of Reaction (II) to the environment.
  - One of the industrial applications of methanol is to produce ethanoic acid. Write a chemical equation for the reaction involved. (2 marks)  
(1 mark)

- (c) Two sets of experiments (one at 360K; another at 345 K) were performed to study the chemical kinetics of the decomposition of  $\text{N}_2\text{O}_5(\text{g})$ :



For each set of experiment, the variation of  $\log r_0$  with  $\log [\text{N}_2\text{O}_5(\text{g})]_0$  was plotted and both of them got a straight line as shown in the graph below:

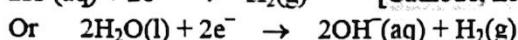
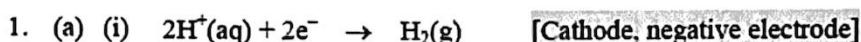
	Representing	Unit
$[\text{N}_2\text{O}_5(\text{g})]_0$	Initial concentration of $\text{N}_2\text{O}_5(\text{g})$	$\text{mol dm}^{-3}$
$r_0$	Initial rate of decomposition of $\text{N}_2\text{O}_5(\text{g})$	$\text{mol dm}^{-3} \text{ s}^{-1}$
$l_1$	Straight line obtained at 360 K	
$l_2$	Straight line obtained at 345 K	



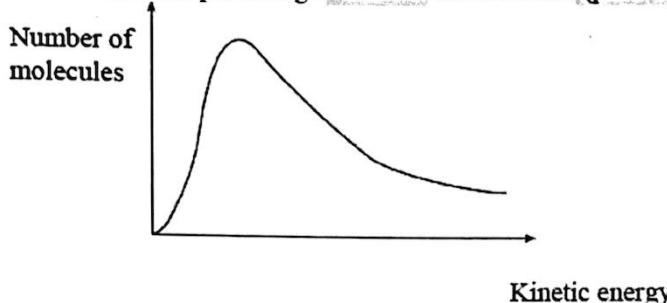
It is given that  $\log r_0 = \log k + n \log [\text{N}_2\text{O}_5(\text{g})]_0$ , where  $k$  is the rate constant and  $n$  is the order of reaction with respect to  $\text{N}_2\text{O}_5(\text{g})$ .

- (i) Given that  $l_1$  and  $l_2$  have the same slope, what can you deduce in terms of chemical kinetics? (1 mark)
- (ii) From  $l_1$ , deduce the order of reaction with respect to  $\text{N}_2\text{O}_5(\text{g})$ . (2 marks)
- (iii) From  $l_2$ , deduce the rate constant for the reaction at 345 K. (2 marks)
- (iv) According to the relevant information of the graph, calculate the activation energy of the reaction.  
(Gas constant,  $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$ ) (3 marks)

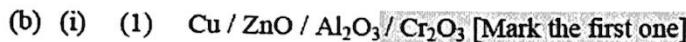
Marks



- (ii) x-axis: (molecular) kinetic energy / K.E. / velocity of molecules (particles); y-axis: fraction / percentage / number of molecules (particles) 1



- (iii) Glucose / the fourth one 1



(2) May be due to higher activation energy / energy barrier. 1

(3) Number of moles of gaseous products is less than that of gaseous reactants. 1

Increasing the pressure will shift the equilibrium position to the right 1

OR increase in collision frequency / effective collisions  
make the reaction faster to reach equilibrium. (1) (1)

- (ii) (1) This reaction does not involve poisonous reagent / CO but the original one involves poisonous CO. 1

- (2) It reduces the amount of atmospheric carbon dioxide and hence may alleviate global warming / greenhouse effect. 1



- (c) (i) Order of reaction is not affected by temperature change. / The order of reaction is the same. 1

- (ii) From line  $\ell_1$  on the graph,

$$\text{slope} = [(-1.4) - (-2)] \div [(0) - (-0.6)] = 1$$

It is first order with respect to N<sub>2</sub>O<sub>5</sub>(g). 1

$$\log k = -2 \\ k = 0.01 \text{ s}^{-1}$$

- (iv) The y-intercepts of  $\ell_1$  and  $\ell_2$  are -1.4 / log 0.0398 / log 10<sup>-1.4</sup> and -2 / log 0.01 / log 10<sup>-2</sup> respectively. [OR represented in equation] 1

Since the y-intercept = log k

$$\log k = \log A - Ea/2.3RT \quad [\text{OR } k = Ae^{-Ea/RT}]$$

$$\log k_2 - \log k_1 = Ea (1/T_1 - 1/T_2) / 2.3 R$$

$$(-2) - (-1.4) = Ea (1/360 - 1/345) / 2.3 \times 8.31$$

$$Ea = 94.95 \text{ kJ mol}^{-1} \quad [\text{Range: 92--98, Accept 0/1/2 decimal places}]$$

1

2019

Answer ALL parts of the question.

1. (a) Answer the following short questions:

1. (i) Explain why the Haber process significantly contributes to crop yield increase.

1. (ii) (1) Write the chemical equation for the formation of syngas from methane. (1 mark)

(2) Syngas can be obtained from the conversion of biomass. Suggest why it is considered as an advancement of the methanol production technology.

1. (iii) Three trials of an experiment were performed under the same experimental conditions to study the kinetics of the following reaction: (2 marks)



The table below shows the data obtained:

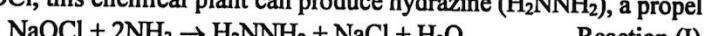
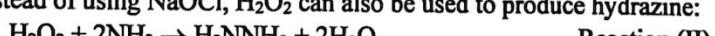
Trial	Initial concentration of A(aq) / mol dm <sup>-3</sup>	Initial concentration of B(aq) / mol dm <sup>-3</sup>	Initial rate of formation of D(aq) / mol dm <sup>-3</sup> s <sup>-1</sup>
1	0.0836	0.202	0.26 x 10 <sup>-4</sup>
2	0.0836	0.404	1.04 x 10 <sup>-4</sup>
3	0.0418	0.404	0.52 x 10 <sup>-4</sup>

Deduce the order of reaction with respect to A(aq) and that with respect to B(aq). (2 marks)

(b) A chloroalkaline chemical plant uses membrane electrolytic cells to produce hydrogen, chlorine and sodium hydroxide.

(i) With the help of chemical equations, briefly describe how hydrogen, chlorine and sodium hydroxide are produced in a membrane electrolytic cell.

(ii) Sodium hypochlorite (NaOCl) can be made from the products obtained in the membrane electrolytic cell. Write a chemical equation for its formation. (4 marks)

(iii) By using NaOCl, this chemical plant can produce hydrazine (H<sub>2</sub>NNH<sub>2</sub>), a propellant used in space vehicles: (1 mark)However, instead of using NaOCl, H<sub>2</sub>O<sub>2</sub> can also be used to produce hydrazine:

By calculating the respective atom economy of Reaction (I) and Reaction (II), compare which of them can be considered as greener.

(Formula masses: NaOCl = 74.5, NH<sub>3</sub> = 17.0, H<sub>2</sub>O<sub>2</sub> = 34.0, H<sub>2</sub>NNH<sub>2</sub> = 32.0, NaCl = 58.5, H<sub>2</sub>O = 18.0)

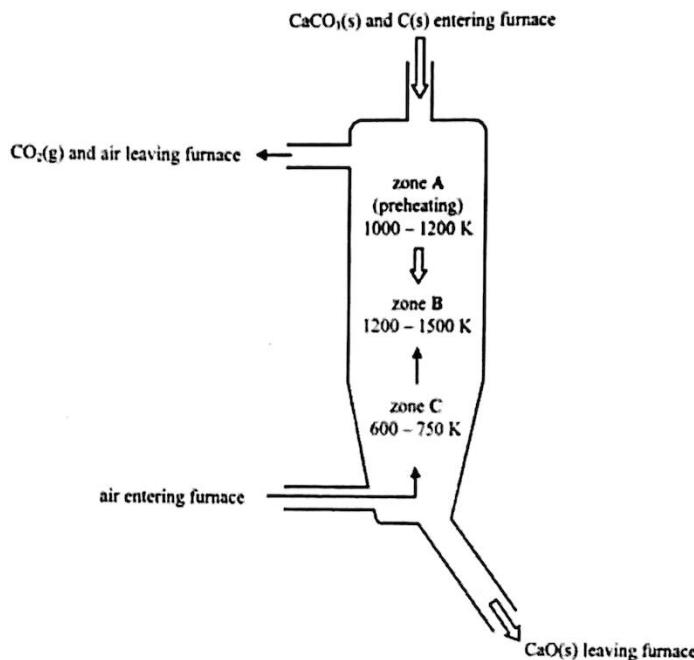
(2 marks)

- (c) In industry, CaO(s) is produced from the decomposition of  $\text{CaCO}_3(\text{s})$ :



$$\Delta H = +180 \text{ kJ mol}^{-1}$$

The diagram below shows an operating furnace for producing CaO(s) in an industrial plant.  $\text{CaCO}_3(\text{s})$  and C(s) enter the furnace from the top while air enters the furnace near the bottom.



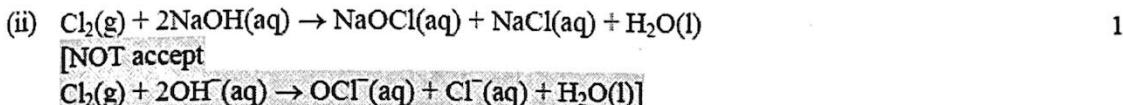
- (i) State one feedstock for  $\text{CaCO}_3(\text{s})$ . (1 mark)
- (ii) Explain why the injection of C(s) and air can result in a higher average temperature in zone B than in zone A. (1 mark)
- (iii) The operation pressure is set at about 1 atm. Given TWO reasons why a higher operation pressure is not preferred. (2 marks)
- (iv) The activation energy of the above decomposition of  $\text{CaCO}_3(\text{s})$  is 160 kJ mol<sup>-1</sup>. Calculate the ratio of the rate constant at 1500 K to the rate constant at 1200 K for the decomposition of  $\text{CaCO}_3(\text{s})$ . (Gas constant R = 8.31 J K<sup>-1</sup> mol<sup>-1</sup>) (3 marks)
- (v) According to chemical equilibrium, suggest why the decomposition of  $\text{CaCO}_3(\text{s})$  mainly occurs in zone B. (1 mark)

Marks

1. (a) (i) The Haber process produces ammonia /  $\text{NH}_3$ , which can make fertilisers / N-rich compounds /  $\text{NH}_4\text{NO}_3$  etc. to increase crop yield. 1
- (ii) (1)  $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$  1
- (2) Because biomass is a renewable (energy) resource. 1
- (iii) • Comparing Trial 3 with Trial 2 (both same in  $[\text{B}(\text{aq})]$ , double the  $[\text{A}(\text{aq})]$  leads to a double of the initial rate. Hence, the order of reaction with respect to  $\text{A}(\text{aq}) = 1$ . 1
- Comparing Trial 1 with Trial 2 (both same in  $[\text{A}(\text{aq})]$ , double the  $[\text{B}(\text{aq})]$  leads to four times of the initial rate. Hence, the order of reaction with respect to  $\text{B}(\text{aq}) = 2$ . 1

**[OR Express in calculations]**

- (b) (i) • Use concentrated / saturated sodium chloride solution / brine as electrolyte. 1
- (Anode:)  $2\text{Cl}^-(\text{aq}) \rightarrow \text{Cl}_2(\text{g}) + 2\text{e}^-$  1
- (Cathode:)  $2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$  OR  $2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$  1  
For those without equations:  
Chloride ions are oxidised to chlorine (at the anode) and water /  $\text{H}^+(\text{aq})$  is reduced to hydrogen (and hydroxide ions at the cathode). (Only 1 mark) 1
- The membrane is permeable to cations but not anions. 1
- OR**  
Sodium hydroxide solution is obtained in the cathode compartment. (1)



- (iii) Atom economy for Reaction (I) =  $32 / 108.5 = 29.5\%$  [30 / 29.49 / 29.493]  
Atom economy for Reaction (II) =  $32 / 68 = 47.1\%$  [47 / 47.06 / 47.059]  
Reaction (II) is greener (as it has a higher atom economy). 1

**For wrong answers,****Award 1 mark if Reaction (II) has a higher atom economy and mention Reaction (II) is greener.****Without calculations:****Award 1 mark if mention "Reaction (II) is greener as it has a higher atom economy."**

- (c) (i) limestone / marble / calcite / aragonite / chalk (mineral) 1
- (ii) Carbon burns in air to produce heat. / C(s) and air has an exothermic reaction. 1
- (iii) • High operation pressure needs high (construction) cost. 1  
 • High operation pressure shifts the equilibrium (position) to the left, decreasing the yield. 1  
 [Not accept easy to explode]
- (iv) •  $\log\left(\frac{k_2}{k_1}\right) = \frac{E_a}{2.3R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)$  OR  $k = Ae^{-E_a/RT}$  1\*
- $$\log\left(\frac{k_2}{k_1}\right) = \frac{160 \times 10^3}{2.3 \times 8.31} \left(\frac{1}{1200} - \frac{1}{1500}\right)$$
- [If just give this equation, can give 2 marks] 1\*
- $\frac{k_2}{k_1} = 24.8$  1
- [No answer mark for the answer if it has a unit.  
 No answer mark for  $k_1/k_2$   
 Range: 23.8 – 25.8, number of decimal places: maximum 3  
 Accept fraction and ratio  
 $k_1 : 1200 \text{ K}; k_2 : 1500 \text{ K}]$
- (v) Higher temperature shifts the equilibrium (position) to the right. (increasing the yield). 1

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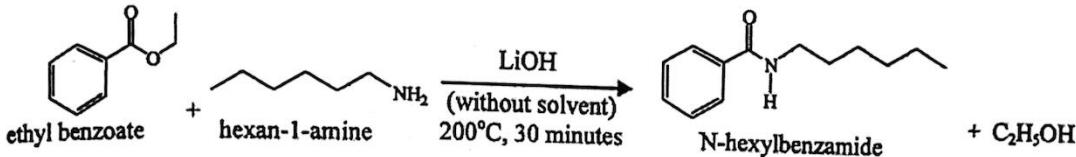
Answer ALL parts of the question.

Answer the following short questions:

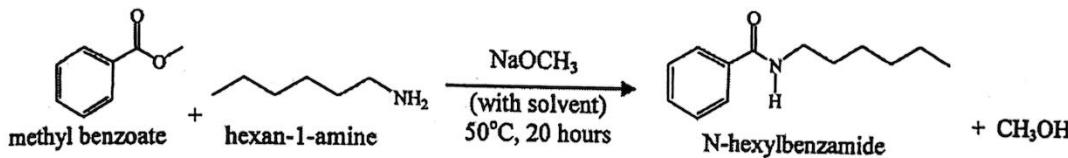
1. (a) Give TWO advantages of a membrane electrolytic cell over a flowing mercury cell in chloroalkali industry. (2 marks)
- (ii) Sketch the catalyst used in the Haber process. (2 marks)
- (iii) Sketch TWO Maxwell-Boltzmann distribution curves for a gaseous sample, one at temperature  $T_1$ , and the other at a lower temperature  $T_2$  (y-axis : number of molecules; x-axis : kinetic energy). (1 mark)

- (b) The two reactions below can produce N-hexylbenzamide: (2 marks)

Reaction (I) :



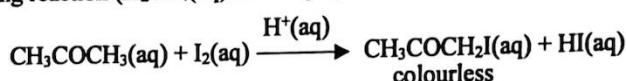
Reaction (II) :



- (i) Based on the above information, suggest one reason for each of the following:  
 (1) Reaction (I) can be considered as greener than Reaction (II).  
 (2) Reaction (II) can be considered as greener than Reaction (I). (2 marks)
- (ii) In Reaction (II), 3.00 g of methyl benzoate reacts with 2.23 g of hexan-1-amine to give 3.89 g of N-hexylbenzamide. Calculate the yield of this product.  
 (Relative molecular masses: methyl benzoate = 136, hexan-1-amine = 101, N-hexylbenzamide = 205) (2 marks)
- (iii) The methanol produced in Reaction (II) can be used to manufacture ethanoic acid in industry by the following reaction:  

$$\text{CH}_3\text{OH(l)} + \text{CO(g)} \xrightleftharpoons[\text{catalyst}]{180^\circ\text{C, 30 atm}} \text{CH}_3\text{COOH(l)} \quad \Delta H < 0$$
  
 (1) According to chemical equilibrium, explain why the operation pressure in industry for the reaction is set at 30 atm but not at atmospheric pressure.  
 (2) Explain why the optimal operation conditions are set at 180 °C and 30 atm. (3 marks)

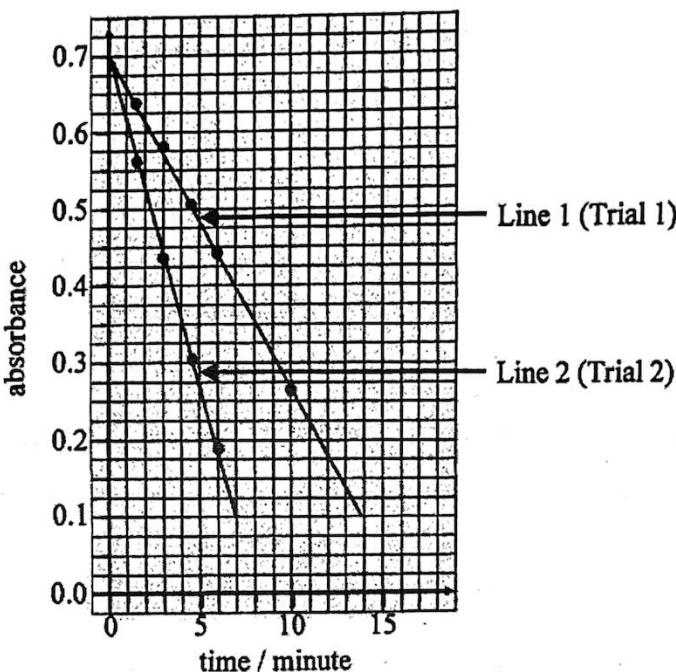
- (c) Consider the following reaction ( $\text{H}_2\text{SO}_4$ (aq) as catalyst) and its rate equation:



$$\text{Rate} = k_1[\text{I}_2(\text{aq})]^w[\text{CH}_3\text{COCH}_3(\text{aq})]^x[\text{H}^+(\text{aq})]^y \quad (\text{w, x and y are integers})$$

The trials of an experiment were performed under the same experimental conditions to study its chemical kinetics. The table below shows, in the reaction mixture, the initial concentrations of the reagents used; while the graph shows the variation of the absorbance of the reaction mixtures with time:

Trial	Initial concentration of $\text{CH}_3\text{COCH}_3(\text{aq}) / \text{mol dm}^{-3}$	Initial concentration of $\text{H}_2\text{SO}_4(\text{aq}) / \text{mol dm}^{-3}$	Initial concentration of $\text{I}_2(\text{aq}) / \text{mol dm}^{-3}$
1	1.0	0.10	0.0050
2	2.0	0.10	0.0050



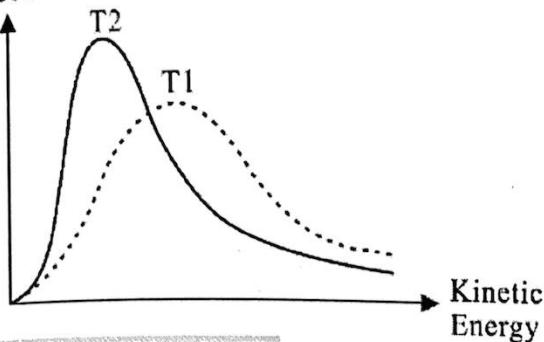
- (i) Explain why the rate of change of the absorbance can represent the rate of reaction. (1 mark)
- (ii) Under these experimental conditions, the rate equation can be simplified as  $\text{Rate} = k_2[\text{I}_2(\text{aq})]^w$ . With reference to Line 1, deduce w. (2 marks)
- (iii) With reference to Line 1 and Line 2, deduce x of the rate equation. (2 marks)
- (iv) Given that  $y = 1$  and the unit of the rate of reaction is  $\text{mol dm}^{-3} \text{s}^{-1}$ , what is the unit of the rate constant  $k_1$ ? (1 mark)
- (v) It is proposed that the reaction proceeds consecutively in two steps and is exothermic:
- $$\text{CH}_3\text{COCH}_3(\text{aq}) \rightleftharpoons \text{CH}_3\text{C(OH)=CH}_2(\text{aq}) \quad \text{slow}$$
- $$\text{CH}_3\text{C(OH)=CH}_2(\text{aq}) + \text{I}_2(\text{aq}) \rightarrow \text{CH}_3\text{COCH}_2\text{I}(\text{aq}) + \text{HI}(\text{aq}) \quad \text{fast}$$
- Draw an energy profile for the reaction. Label the axes. (2 marks)

Marks

- J. (a) (i) • No toxic mercury (will be produced by) membrane cell but toxic mercury (may leak out from) flowing mercury cell. 1  
 • Less energy is required. 1  
 • Less maintenance is required. 1 (1)

- (ii) Iron / iron(III) oxide / iron oxide / oxides of iron 1

- (iii) Number of Molecules 2



(1 mark for  $T_2$  higher than  $T_1$ )

1 mark for starting at zero and tail:  $T_1 > T_2$

Okay if not labelling the axes.)

- (b) (i) (1) No solvent will be emitted to the environment for Reaction (I) but Reaction (II) will. / The side product, ethanol, of Reaction (I) is less toxic. / No toxic methanol will be produced in Reaction (I) but Reaction (II) will. 1

(A comparative sense)

- (2) Lower temperature is needed. / Higher atom economy. (less energy is not accepted) 1  
 (A comparative sense)

$$(ii) 3.00 \div 136 = 0.022 \text{ mol}$$

$$2.23 \div 101 = 0.022 \text{ mol}$$

$$(3.89 \div 205) \div 0.022 \times 100\% = 86\%$$

(2 - 4 sign fig; range: 85.8 – 86.3)

(1 mark for steps and 1 mark for answer)

1\*

1

- (iii) (1) Because increasing the / higher pressure can shift the equilibrium position to the right / higher yield. 1

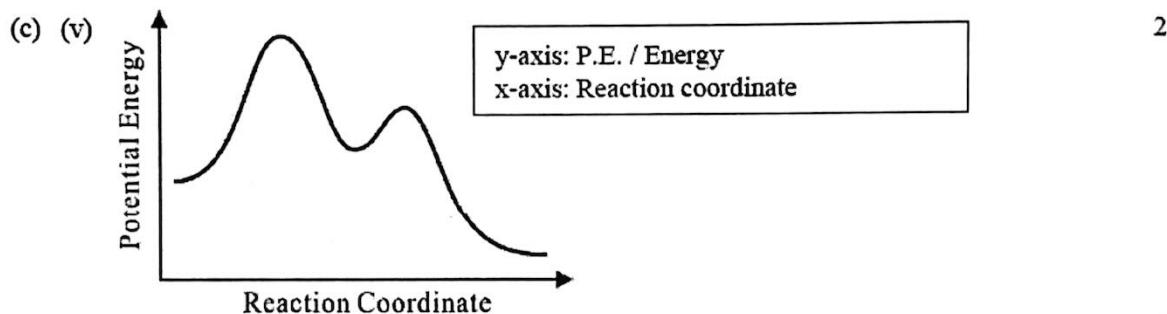
- (2) • Higher temperature will have a higher rate of reaction. But the forward reaction is exothermic, increasing the temperature will shift the equilibrium position to the left / lower yield. 1  
 • Higher pressure (will shift the equilibrium position to the right but) extra cost is needed. 1

(c) (i) (The absorbance is directly proportional to the concentration of  $I_2(aq)$  as  $I_2(aq)$  is purple / brown / coloured while the other species are colourless. 1

- (ii) • The absorbance decreases with time linearly / is directly proportional to the time, / so the rate is independent of  $[I_2(aq)]$ . 1  
• The order of reaction with respect to  $I_2(aq) = w = 0$ . 1

- (iii) Trial 2 : slope of the plot =  $-0.7 \div 8 = -0.0875$   
Trial 1 : slope of the plot =  $-0.7 \div 16 = -0.04375$   
 $(-0.0875) \div (-0.04375) = (2.0 / 1.0)^x$  1  
Order of reaction with respect to propanone =  $x = 1$  1

- (iv)  $\text{dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$  1

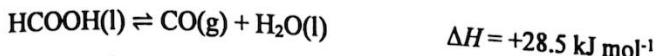


(1 mark for labels of axes and  
1 mark for 2 peaks + 1<sup>st</sup> one higher than the 2<sup>nd</sup> one + exothermic)

Answer ALL parts of the question.

1. (a) Answer the following short questions:

- (i) At certain conditions, the activation energy for the decomposition of HCOOH(l) to CO(g) and H<sub>2</sub>O(l) shown below is +77.7 kJ mol<sup>-1</sup>.



What is the activation energy for the formation of HCOOH(l) from CO(g) and H<sub>2</sub>O(l) at the same conditions, in kJ mol<sup>-1</sup>?

- (ii) The activation energy for a certain reaction is +65.0 kJ mol<sup>-1</sup>. The rate constant of the reaction at 27 °C is k<sub>1</sub>. Calculate the rate constant of the reaction at 37 °C in terms of k<sub>1</sub>. (1 mark)

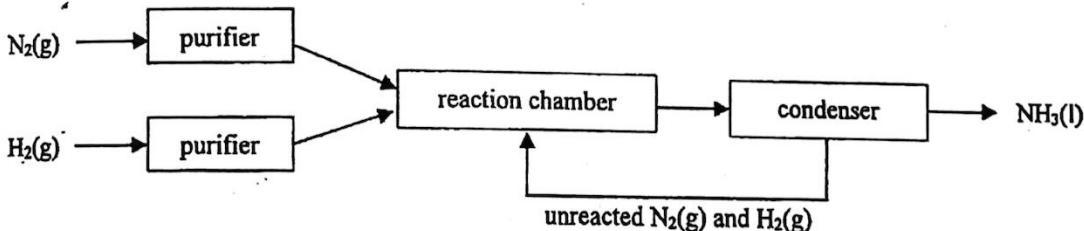
(Gas constant R = 8.31 J K<sup>-1</sup> mol<sup>-1</sup>, Arrhenius equation:  $\log k = \text{constant} - \frac{E_a}{2.3RT}$ )

- (iii) The rate equation for the reaction A(g) + B(g) → C(g) at certain conditions is given below, with k<sub>2</sub> being the rate constant: (2 marks)

$$\text{Rate} = k_2[\text{A(g)}][\text{B(g)}]^{\frac{3}{2}}$$

- (1) What is the order of reaction with respect to B(g)?  
(2) The unit of the rate is mol dm<sup>-3</sup> s<sup>-1</sup>. State the unit of k<sub>2</sub>.

- (b) The diagram below shows how liquid ammonia is produced by the Haber process. (2 marks)



- (i) Explain why N<sub>2</sub>(g) and H<sub>2</sub>(g) need to be purified before going into the reaction chamber. (1 mark)
- (ii) Explain why the unreacted N<sub>2</sub>(g) and H<sub>2</sub>(g) are passed again to the reaction chamber. (1 mark)
- (iii) Why does ammonia, but not the other gases, become a liquid in the condenser? (1 mark)
- (iv) Catalyst is used in the reaction of Haber process.  
(1) Suggest a catalyst that can be used.  
(2) With the aid of a Maxwell-Boltzmann distribution curve, explain why the reaction becomes faster when a catalyst is used. (5 marks)

- (c) Methanol is an important chemical in industry and can be produced from methane. The production can be considered as separated into two stages.

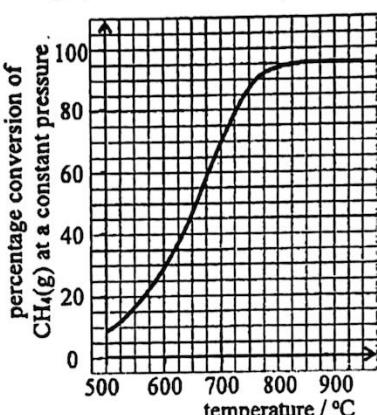
(i) State one potential hazard of methanol.

(1 mark)

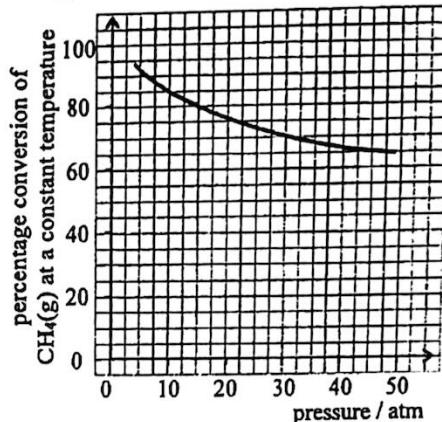
(ii) Other than natural gas, suggest one source of methane.

(1 mark)

(iii) In the first stage,  $\text{CH}_4(\text{g})$  reacts with  $\text{H}_2\text{O}(\text{g})$  to form  $\text{CO}(\text{g})$  and  $\text{H}_2(\text{g})$ , and equilibrium would be attained. The graphs below show the percentage conversion of  $\text{CH}_4(\text{g})$  at equilibrium under different conditions.



Graph 1



Graph 2

- (1) With reference to Graph 1, explain whether the forward reaction is endothermic or exothermic.  
(2) With reference to Graph 2, explain, with the aid of a chemical equation, the effect of pressure on the percentage conversion of  $\text{CH}_4(\text{g})$ .

(4 marks)

- (iv) In the second stage,  $\text{CO}(\text{g})$  reacts with  $\text{H}_2(\text{g})$  to form methanol. Write a chemical equation for the reaction.

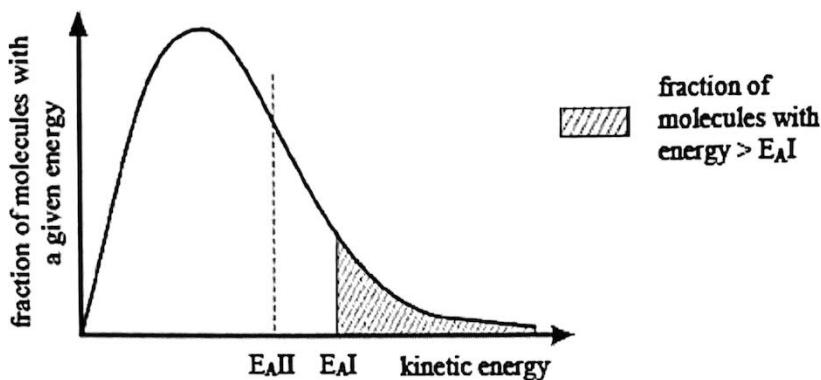
(1 mark)

Marks

1.	(a) (i)	$+49.2 \text{ kJ mol}^{-1}$ (Accept: $49.2 \text{ kJ mol}^{-1}$ ; Not accept: $-49.2$ or in $\text{J mol}^{-1}$ )	1
	(ii)	$\log \frac{k}{k_1} = \frac{-E_a}{2.3R} \left( \frac{1}{310} - \frac{1}{300} \right)$	1
		$\log \frac{k}{k_1} = \frac{-65 \times 10^3}{2.3 \times 8.31} \left( \frac{1}{310} - \frac{1}{300} \right)$	(1)
		$k = 2.32 k_1$	
		(Accept: $2.30 - 2.34$ ) (Not accept: $k_1 = 0.43k$ , $k = \frac{k_1}{0.43}$ )	1
		(1 mark for correct substitution and 1 mark for the answer)	
	(iii) (1)	3/2 OR 1.5	1
	(2)	$\text{mol}^{-1.5} \text{ dm}^{4.5} \text{ s}^{-1}$ OR $\text{mol}^{-3/2} \text{ dm}^{9/2} \text{ s}^{-1}$	1
		(Accept: 'min' or 'h' instead of 's', Not accept: 'M' instead of ' $\text{mol dm}^{-3}$ ')	
(b) (i)		$\text{N}_2(\text{g})$ and $\text{H}_2(\text{g})$ need to be purified for preventing the catalyst from being poisoned. / remove (catalytic) poisons/ $\text{CO}_2/\text{H}_2\text{O}$ .	1
		(Not accept: remove pollutants / pollute catalyst / reduce cost/wastage / heat up reactants)	
(ii)		Do not waste any $\text{N}_2(\text{g})$ / and $\text{H}_2(\text{g})$ left. / To conserve/save/recycle reactants.	1
		(Accept: 'reactants/chemicals/reagents' instead of ' $\text{N}_2(\text{g})$ / and $\text{H}_2(\text{g})$ ' )	
		(Not accept: increase the yield/amount of $\text{NH}_3$ )	
(iii)		$\text{NH}_3$ has a higher boiling point than $\text{N}_2$ / and $\text{H}_2$ (other gases / others). / $\text{N}_2$ / and $\text{H}_2$ (other gases / others) have a lower boiling point than $\text{NH}_3$ / $\text{NH}_3$ is easier to condense than $\text{N}_2$ / and $\text{H}_2$ (other gases / others)	1
		(A comparative sense)	
(iv) (1)		(finely divided) iron / Fe / oxides of iron / $\text{FeO}$ / $\text{Fe}_2\text{O}_3$ / $\text{Fe}_3\text{O}_4$	1

1. (b) (iv) (2)

4



2 marks for the diagram and 2 marks for explanation.

Diagram:

Shape of the curve (start at 0; Not accept: more than one curve for catalysed and uncatalysed reactions) (1)

Labeling axes (No need to consider  $E_{AII}$  and  $E_{AI}$ ) (x-axis: (kinetic) energy, Not accept: potential energy) (y-axis: number of molecules/particles / fraction of molecules/particles) (1)

- When a catalyst is added, the reaction would proceed in an alternative pathway with lower activation energy ( $E_{AII}$ ). (Not accept: the activation energy decreased) (1)
- For the pathway with lower activation energy ( $E_{AII}$ ), more particles would possess sufficient kinetic energy to react than that in the original pathway with higher activation energy ( $E_{AI}$ ). Number of effective collisions per unit time is thus greater.  
(The reaction pathway with smaller activation energy will proceed faster at the same temperature. The time to reach equilibrium will be shortened.) (1)

(c) (i) Methanol is toxic / flammable. 1

(ii) Landfill site / municipal waste / biomass / organic waste / crude oil / petroleum / biogas / combustible ice (Not accept: coal / LPG / cracking of naphtha) 1

(iii) (1) 

- Percentage conversion / yield increases as temperature increases (under constant pressure.) 1
- The forward reaction is endothermic because a higher temperature will shift the equilibrium position to the product side /  $CO / H_2$  to increase the percentage conversion / yield /  $CO / H_2$ . (i.e. 1 mark for endothermic + explanation) 1

(2) 

- Percentage conversion decreases as pressure increases (under constant temperature.) 1
- $CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$  (Accept " $\rightarrow$ "; Not accept " $\Rightarrow$ ") 1

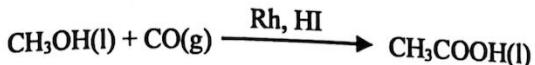
The no. of mole of gaseous products (4 moles) is more than the no. of moles of gaseous reactants (2 moles), an increase in pressure will shift the equilibrium position to the reactant / left side to decrease the percentage conversion / yield /  $CO / H_2$ . (i.e. 1 mark for chemical equation + explanation) (Accept: the balanced chemical equation presented in part (c)(iii)(1))

(iv)  $CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$  1  
(Accept " $\rightarrow$ " instead of " $\rightleftharpoons$ "; Not accept " $\Rightarrow$ ")  
(State symbols not required) (Ignore incorrect state symbols)

Answer ALL parts of the questions.

1. (a) Answer the following short questions:

(i) Under certain conditions, ethanoic acid can be manufactured by the following reaction:



(1) Suggest one reason why this reaction is considered to be green.

(2) Suggest one reason why this reaction is NOT considered to be green.

(2 marks)

(ii) A factory manufactures catalytic converters with a catalyst coating on a porous structure.

(1) Suggest one advantage of using a porous structure in the catalytic converters.

(2) Explain why the effectiveness of the catalyst may decrease after prolonged use.

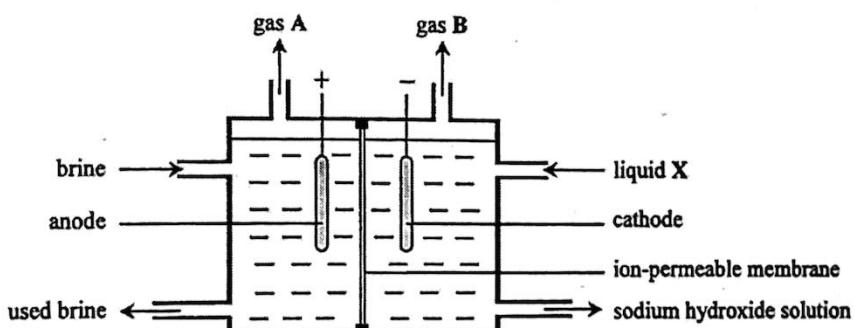
(2 marks)

(iii) Which one of the following items is NOT manufactured from petrochemicals?

nylon rope, glass bottle, soapless detergent

(1 mark)

(b) The diagram below shows a membrane electrolytic cell used in the chloroalkali industry. Brine and liquid X are continuously added into the membrane electrolytic cell to produce gas A, gas B and sodium hydroxide solution.



(i) What is X?

(1 mark)

(ii) Gas A is formed at the anode of the membrane electrolytic cell.

(1) What is A?

(2) Explain why A is formed.

(2 marks)

(iii) Gas B and sodium hydroxide solution are formed at the cathode of the membrane electrolytic cell.

(1) Write a half equation for the formation of B.

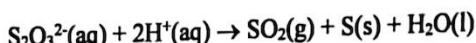
(2) Explain why sodium hydroxide solution is formed and why it does not contain sodium chloride.

(3 marks)

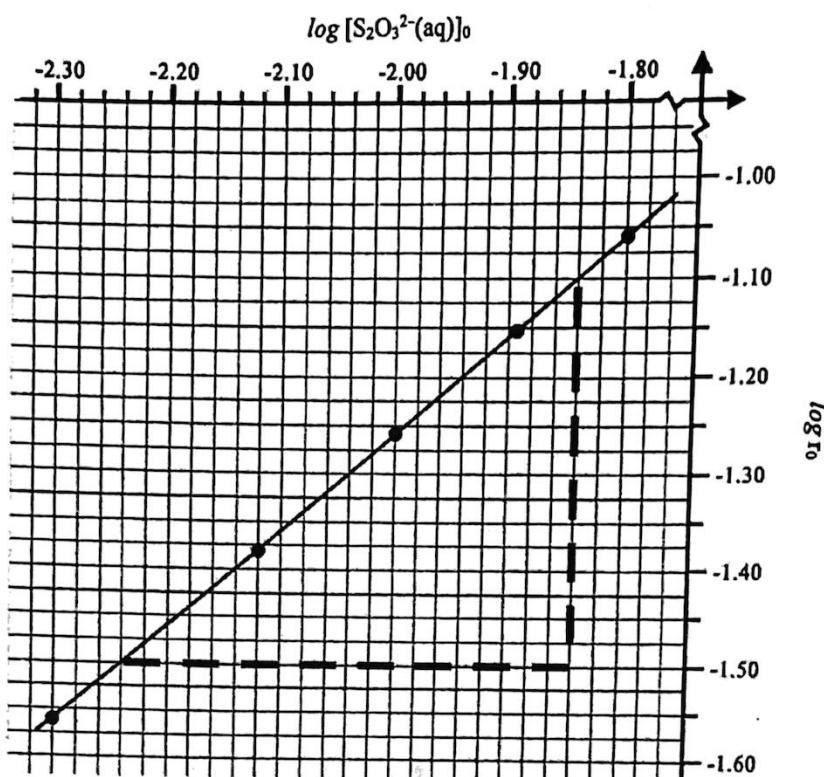
(iv) Suggest a chemical that can be manufactured from the reaction between A and sodium hydroxide solution.

(1 mark)

1. (c) The chemical kinetics of the following reaction at a certain temperature was studied:



Several trials of an experiment were performed under the same experimental conditions, except varying the initial concentration of  $\text{S}_2\text{O}_3^{2-}(\text{aq})$  (represented by  $[\text{S}_2\text{O}_3^{2-}(\text{aq})]_0$ ), to measure the initial rate of formation of  $\text{S}(\text{s})$  (represented by  $r_0$ ). The following graph shows the experimental results obtained from these trials:



- (i) What is meant by the term 'initial rate'?

(1 mark)

- (ii) The rate equation for the reaction is shown below:

$$\text{Rate} = k [\text{S}_2\text{O}_3^{2-}(\text{aq})]^a [\text{H}^+(\text{aq})]^b$$

where  $k$  is the rate constant,

$a$  is order of reaction with respect to  $\text{S}_2\text{O}_3^{2-}(\text{aq})$

and  $b$  is the order of reaction with respect to  $\text{H}^+(\text{aq})$ .

Given that the concentration of  $\text{H}^+(\text{aq})$  used was much higher than that of  $\text{S}_2\text{O}_3^{2-}(\text{aq})$  in each trial, explain why the above rate equation can be modified as shown below:

$$\text{Rate} = k' [\text{S}_2\text{O}_3^{2-}(\text{aq})]^a$$

where  $k'$  is regarded as a constant.

(2 marks)

- (iii) By using the dotted lines in the graph above, deduce the order of reaction with respect to  $\text{S}_2\text{O}_3^{2-}(\text{aq})$ .

(3 marks)

- (iv) The experiment was repeated at 25 °C and 35 °C separately, while other experimental conditions were the same. The rate constant of the reaction at 25 °C is  $k_1$  and the rate constant of the reaction at 35 °C is  $k_2$ . The ratio of  $k_2$  to  $k_1$  is 1.9 : 1.0. Calculate the activation energy of the reaction, in  $\text{kJ mol}^{-1}$ .

$$(\text{Gas constant } R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}, \text{Arrhenius equation: } \log k = \text{constant} - \frac{E_a}{2.3RT})$$

(2 marks)

1. (a) (i) (1) A catalyst is used. / HI/Rh is a catalyst. / Methanol can be made from renewable / biomass. / Atom economy is 100% / (very) high. / CH<sub>3</sub>COOH is the only product. / No waste is produced. 1
- (2) Methanol / CO(g) is toxic. / HI (or CH<sub>3</sub>COOH) is corrosive. 1
- (ii) (1) It can increase the surface area of the catalyst so as to increase the effectiveness of the catalyst. 1
- (2) Catalysts can be poisoned by impurities / lead compounds. / The active sites of catalysts are blocked. 1
- (iii) glass bottle 1
- (b) (i) water / H<sub>2</sub>O 1
- (ii) (1) chlorine / Cl<sub>2</sub> 1
- (2) The concentration of Cl<sup>-</sup>(aq) ions is much higher than that of OH<sup>-</sup>(aq) ions, Cl<sup>-</sup>(aq) ions are preferentially discharged.  
(A comparative sense) 1
- (iii) (1) 2H<sub>2</sub>O(l) + 2e<sup>-</sup> → H<sub>2</sub>(g) + 2OH<sup>-</sup>(aq) / 2H<sup>+</sup>(aq) + 2e<sup>-</sup> → H<sub>2</sub>(g)  
(State symbols not required)(Ignore incorrect state symbols) 1
- (2) • OH<sup>-</sup>(aq) ions are continuously formed in the cathode part. / H<sup>+</sup>(aq) ions are discharged while OH<sup>-</sup>(aq) ions are remained in the cathode part. 1
- The ion-permeable membrane only allows Na<sup>+</sup>(aq) ions but not Cl<sup>-</sup>(aq) ions to pass to the cathode part. 1
- (iv) sodium hypochlorite / NaOCl / NaClO /sodium chlorate / NaClO<sub>3</sub> 1

1. (c) (i) 'Initial rate' is the (instantaneous) rate at the start of a reaction / the rate at time zero. 1

- (ii) • Since  $[H^+(aq)]$  is much higher than  $[S_2O_3^{2-}(aq)]$ ,  $[H^+(aq)]$  changes only a little / the change in  $[H^+(aq)]$  is negligible at the start of the reaction. 1  
 •  $[H^+(aq)]$  is regarded as constant, / then  $k[H^+(aq)]^b$  can be regarded as a constant / only  $[S_2O_3^{2-}(aq)]$  is a variable. 1

(iii)  $\text{rate} = k'[S_2O_3^{2-}(aq)]^a$   
 $\log(\text{rate}) = \log k' + a \log([S_2O_3^{2-}(aq)])$  ( $a$  = the slope of the straight line) 1\*

Slope =  $[-1.10 - (-1.50)] \div [-1.84 - (-2.24)]$  (If not use the dotted lines, 0 mark)  
 $= 1$

It is first order with respect to  $S_2O_3^{2-}(aq)$ . 1

(1 mark for writing correct log equation,

1 mark for substituting correct data,

1 mark for giving correct answer)

(Accept : other methods of calculations)

(iv)  $\log\left(\frac{k_2}{k_1}\right) = \frac{E_a}{2.3R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$

$\log(1.9) = \frac{E_a}{2.3 \times 8.31}\left(\frac{1}{298} - \frac{1}{308}\right)$  1\*

$E_a = (+)48.90 \text{ kJ mol}^{-1}$  1

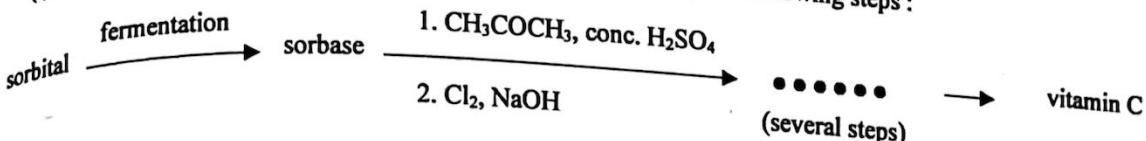
(Accept: 48.805 – 49.004;

Accept : no unit ;

Not accept: unit in kJ)

2023

1. (a) (i) In industry, sorbitol can be used to synthesize vitamin C by the following steps :



(1) Explain why it is necessary to synthesise vitamin C in industry.

(1 mark)

(2) Explain why this processes of synthesising vitamin C is NOT considered to be 'green' according to the principles of green chemistry.

(1 mark)

(ii) Methane can be used to form syngas.

(1) Suggest a source of methane.

(1 mark)

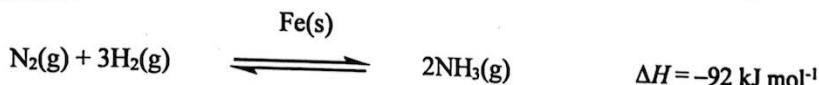
(2) Write the chemical equation for the formation of syngas from methane.

(1 mark)

(iii) State TWO chemicals manufactured by the chloroalkali industry.

(1 mark)

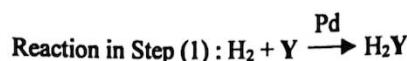
- (b) The Haber process is an important industrial process to produce ammonia. The chemical equation for the reaction involved is shown below :



Under the optimal operation conditions and in the presence of iron catalyst, the yield of  $\text{NH}_3(\text{g})$  at equilibrium is about 20 %. The activation energy of the forward reaction of the Haber process is  $20 \text{ kJ mol}^{-1}$ .

- (i) What is meant by the term 'activation energy'? (1 mark)
- (ii) Draw an energy profile for the reaction of the Haber process. Label the axes and the activation energy ( $E_a$ ) of the forward reaction. (2 marks)
- (iii) Find the activation energy, in  $\text{kJ mol}^{-1}$ , of the backward reaction of the Haber process under the same operation conditions. (1 mark)
- (iv) State the optimal operation temperature and pressure used in the Haber process. Explain why such conditions are used. (3 marks)
- (v) Comment on the following statement :  
 'Using more iron catalyst can increase the yield of ammonia in the Haber process.' (1 mark)

- (c) (i) Hydrogen gas and oxygen gas are the feedstocks for the industrial synthesis of hydrogen peroxide ( $H_2O_2$ ). The synthesis involves following two steps :

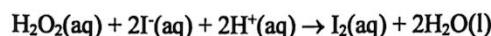


Y is an organic compound. Hydrogen gas is passed into Y (dissolved in an organic solvent). Palladium (Pd) metal is used as a catalyst. At the end of Step (1), the palladium catalyst is removed.



Air is blown into  $H_2Y$  (dissolved in an organic solvent). At the end of Step (2),  $H_2O_2$  is collected and Y is recovered.

- (1) Suggest a way to increase the effectiveness of the palladium catalyst. (1 mark)
  - (2) Explain why Y is recovered at the end of Step (2). (1 mark)
  - (3) Apart from the potential danger of explosion, explain why hydrogen peroxide is NOT synthesised from hydrogen gas and oxygen gas in a single step. (1 mark)
- (ii) Under the same experimental conditions, three trials of an experiment were performed to determine the rate equation of the following reaction :



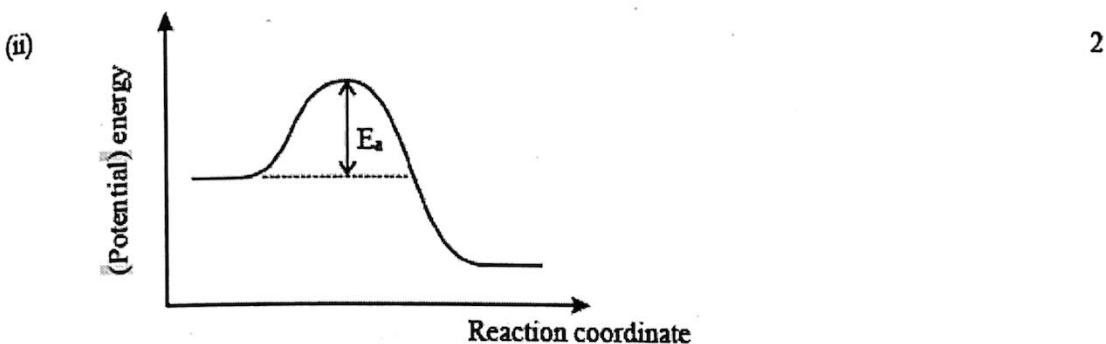
The table below shows the data obtained :

	Initial concentration of $H_2O_2(aq)$ / mol dm <sup>-3</sup>	Initial concentration of $I^-(aq)$ / mol dm <sup>-3</sup>	Initial concentration of $H^+(aq)$ / mol dm <sup>-3</sup>	Initial concentration of $I_2(aq)$ / mol dm <sup>-3</sup>
Trial 1	0.0010	0.10	0.10	$2.8 \times 10^{-6}$
Trial 2	0.0020	0.10	0.0010	$5.6 \times 10^{-6}$
Trial 3	0.0020	0.50	0.10	$2.8 \times 10^{-5}$

- (1) Given that the order of reaction with respect to  $H_2O_2(aq)$  is 1, deduce the order of reaction with respect to  $I^-(aq)$  and that with respect to  $H^+(aq)$ . (2 marks)
- (2) Based on the data in Trial 1, calculate the rate constant of the reaction under the same experimental conditions. (2 marks)

1. (2) (i) (1) It solves the problems of inadequate supply of vitamin C from natural sources. 1  
 (2)  $\text{Cl}_2$  is toxic. /  $\text{NaOH}$  is corrosive. / conc.  $\text{H}_2\text{SO}_4$  is corrosive. / Too many wastes will be produced or loss of materials will be resulted as many steps involved. 1
- (ii) (1) natural gas / crude oil / municipal waste / biomass / landfill site 1  
 (2)  $\text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2$  1
- (iii) Any TWO of the following :  
 chlorine ( $\text{Cl}_2$ ) / hydrogen ( $\text{H}_2$ ) / sodium hydroxide ( $\text{NaOH}$ ) / sodium hypochlorite ( $\text{NaOCl}$ ) / hydrogen chloride ( $\text{HCl}$ ) / hydrochloric acid ( $\text{HCl}$ ) / sodium chlorate ( $\text{NaClO}_3$ ) 1

- (b) (i) 'Activation energy' refers to the minimum energy possessed by the colliding reactant particles in order that a chemical reaction can occur. / The energy barrier to overcome for the reaction to occur. 1



(1 mark for correct drawing showing the potential energy of product is lower than that of reactants)

1 mark for correct labels of axes and  $E_a$ )

(iii)  $(20 + 92) = 112 \text{ (kJ mol}^{-1}\text{)}$  1

(iv) 400 – 500 °C and 200 atm 1

- Increasing temperature can increase the reaction rate. However, the forward reaction is exothermic, the higher temperature can shift the equilibrium position to the left and thus decrease the yield of ammonia.

- Increasing pressure can shift the equilibrium position to the right and thus increase the yield of ammonia. However, for a high pressure condition, it needs high cost to build up the plant and keep the maintenance and safety.

(v) The statement is incorrect. 1

Because a catalyst does not shift the equilibrium position and it does not affect the yield of ammonia. / Because a catalyst increases the rates of forward and backward reactions to the same extent.

1. (c) (i) (1) by making the palladium catalyst into finely divided / powdered form / porous structure 1

(2) To reduce production cost. / To reuse Y as the reactant in Step (1). 1

(3) Direct reaction between hydrogen gas and oxygen gas will give out water rather than hydrogen peroxide. 1

(ii) (1) By calculation.

$$2.8 \times 10^{-6} = k[0.0010][0.10]^x[0.10]^y \quad \dots \text{(equation 1)}$$

$$5.6 \times 10^{-6} = k[0.0020][0.10]^x[0.0010]^y \quad \dots \text{(equation 2)}$$

$$2.8 \times 10^{-5} = k[0.0020][0.50]^x[0.10]^y \quad \dots \text{(equation 3)}$$

(x = the order of reaction with respect to I<sup>-</sup>(aq);

y = the order of reaction with respect to H<sup>+</sup>(aq))

Solving equations 1 & 3,

$$\frac{2.8 \times 10^{-6}}{2.8 \times 10^{-5}} = \frac{k[0.0010][0.10]^x[0.10]^y}{k[0.0020][0.50]^x[0.10]^y}$$

$$x = 1$$

Therefore, the order of reaction with respect to I<sup>-</sup>(aq) is 1.

Solving equations 1 & 2,

$$\frac{2.8 \times 10^{-6}}{5.6 \times 10^{-6}} = \frac{k[0.0010][0.10]^x[0.10]^y}{k[0.0020][0.10]^x[0.0010]^y}$$

$$y = 0$$

Therefore, the order of reaction with respect to H<sup>+</sup>(aq) is 0.

(Must show steps)

(2)  $2.8 \times 10^{-6} = k \times (0.0010)^1 \times (0.10)^1 \times (0.10)^0$  Or  $2.8 \times 10^{-6} = k \times 0.0010 \times 0.10$

$$k = 0.028 \text{ mol}^{-1} \text{ dm}^3 \text{ s}^{-1}$$

(Correct unit is required.)

1

1

1

1

1

1\*

1