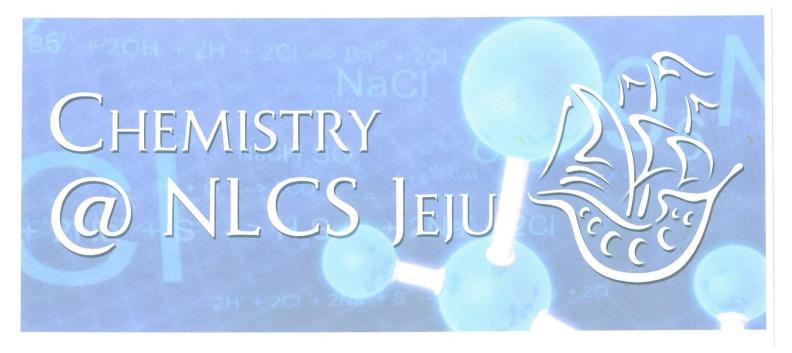
# Topic 7 STANDARD Level



## Summer & Winter Papers Summer 1999 to Summer 2013

Name:

Topic Exam Statistics (Paper 2):

Section	Marks	% of All Marks	Last four exams marks	Last four exams %
Α	72/810	9%	/120	%
В	155/1620	10%	/240	%
TOTAL	227/2430	9%	/360	%

Total number of papers represented here is 27, each with 30 marks of Section A and 60 marks of section B (3 questions from which you chose to answer only 1)

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## IB SL 7 EQ Paper 2 s99 to s13 incl W $\,$

SL SECTION A 12w

3.

Che	mical e	quilibrium and kinetics are i	mportant concepts in chemi	stry.	
(a)		ss container is half-filled with es a dynamic equilibrium. S	_		[1]
(b)		oxidation of sulfur dioxide in facture sulfuric acid.	-	-	
		$2SO_2(g) + O_2(g)$	$(g) \rightleftharpoons 2SO_3(g)$ $\Delta H = -$	198.2 kJ	
	(i)	Deduce the equilibrium con	stant expression, $K_{\rm e}$ .		[1]
	(ii)	Predict how each of the followed the value of $K_c$ .	lowing changes affects the	position of equilibrium and	[3]
			Position of equilibrium	Value of K <sub>c</sub>	
		Decrease in temperature			
		Increase in pressure			
		Addition of a catalyst			

SL SECTION A 11s

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	$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$ $\Delta H^{\oplus} = -103 \text{ kJ}$	
(a)	State the equilibrium constant expression, $K_c$ , for the production of methanol.	[1]
(b)	State and explain the effect of changing the following conditions on the amount of methanol present at equilibrium:	
	(i) increasing the temperature of the reaction at constant pressure.	[2]
	(ii) increasing the pressure of the reaction at constant temperature.	[2]

Methanol may be produced by the exothermic reaction of carbon monoxide gas and

3.

hydrogen gas.

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(c)	The conditions used in industry during the production of methanol are a temperature of
	450 °C and pressure of up to 220 atm. Explain why these conditions are used rather than
	those that could give an even greater amount of methanol.

[1]

•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	 	•	•	•	•		•	•	•	•		•	•	•	•	•	 			
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(d)	A catalyst of copper mixed with zinc oxide and alumina is used in industry for this
	production of methanol. Explain the function of the catalyst.


### SL SECTION A 09sQ1

Biodiesel makes use of plants' ability to fix atmospheric carbon by photosynthesis.
 Many companies and individuals are now using biodiesel as a fuel in order to reduce
 their carbon footprint. Biodiesel can be synthesized from vegetable oil according to the
 following reaction.

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(c)		reversible arrows in the equation indicate that the production of biodiesel is an librium process.	
	(i)	State what is meant by the term dynamic equilibrium.	[1]
	(ii)	Using the abbreviations [vegetable oil], [methanol], [glycerol] and [biodiesel] deduce the equilibrium constant expression $(K_{\rm c})$ for this reaction.	[1]
	(iii)	Suggest a reason why excess methanol is used in this process.	[1]
	(iv)	State and explain the effect that the addition of the sodium hydroxide catalyst will have on the position of equilibrium.	[2]
SL SE	CTION	A 07s	

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		$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ $\Delta H$ is negative	
	(a)	State the equilibrium constant expression for the above reaction.	[1]
	(b)	Predict, giving a reason, the effect on the position of equilibrium when the pressure in the reaction vessel is increased.	[2]
	(c)	State and explain the effect on the value of $K_{c}$ when the temperature is increased.	[2]
	(d)	Explain why a catalyst has no effect on the position of equilibrium.	[1]
SL SEC	TION	A 04s	

Ammonia is produced by the Haber process according to the following reaction.

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4.	Cons	sider the following equilibrium reaction.	
		$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ $\Delta H = -198 \text{ kJ}$	
	Usin	g Le Chatelier's Principle, state and explain what will happen to the position of equilibrium if	
	(a)	the temperature increases.	[2]
	(b)	the pressure increases.	[2]
SI SE	CTION	Δ 03s	

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 The table below gives information about the percentage yield of ammonia obtained in the Haber process under different conditions.

Pressure/		Tempera	ature/°C	
atmosphere	200	300	400	500
10	50.7	14.7	3.9	1.2
100	81.7	52.5	25.2	10.6
200	89.1	66.7	38.8	18.3
300	89.9	71.1	47.1	24.4
400	94.6	79.7	55.4	31.9
600	95.4	84.2	65.2	42.3

(a)		n the table, identify which combination of temperature and pressure gives the highest of ammonia.	[1]
(b)	The	equation for the main reaction in the Haber process is	
		$N_2(g) + 3H_2(g) \implies 2NH_3(g)$ $\Delta H$ is negative	
	Use	this information to state and explain the effect on the yield of ammonia of increasing the	
	(i)	pressure:	[2]
	(ii)	temperature:	[2]

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(c)	ар	ressure of 200 atmospheres. Explain why these conditions are used rather than those that e the highest yield.	[2]
(d)	Wr	ite the equilibrium constant expression, $K_c$ , for the production of ammonia.	[1]
SL SE	CTION	A 03s	
3.	(a)	The relative molecular mass of aluminium chloride is 267 and its composition by mass is 20.3 % Al and 79.7 % chlorine. Determine the empirical and molecular formulas of aluminium chloride.	[4]
	(b)	Sodium reacts with water as follows.	
		$2\text{Na(s)} + 2\text{H}_2\text{O(l)} \rightarrow 2\text{NaOH(aq)} + \text{H}_2(g)$	
		$1.15~g$ of sodium is allowed to react completely with water. The resulting solution is diluted to $250~cm^3$ . Calculate the concentration, in mol dm $^{-3}$ , of the resulting sodium hydroxide solution.	[3]

SL SECTION A 02w

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3. The table below gives information about the percentage yield of ammonia obtained in the Haber Process under different conditions.

		Tempera	ture / °C	
Pressure / atm	200	300	400	500
10	50.7	14.7	3.9	1.2
100	81.7	52.5	25.2	10.6
200	89.1	66.7	38.8	18.3
300	89.9	71.1	47.1	24.4
400	94.6	79.7	55.4	31.9
600	95.4	84.2	65.2	42.3

(a)	Ded	ace which combination of temperature and pressure gives the highest yield of ammonia.	[1]
(b)	The	equation for the main reaction in the Haber Process is shown below.	
		$N_2(g) + 3H_2(g) \Longrightarrow 2NH_3(g)$ $\Delta H = -92 \text{ kJ}$	
		this information to state and explain, using Le Chatelier's Principle, the effect on the librium yield of ammonia of	
	(i)	an increase in pressure.	[2]
	(ii)	an increase in temperature.	[2]
(c)	-	actice, the conditions used are typically 500 °C and 200 atm. Explain why the conditions give the highest yield are not used.	[2]

SL SECTION A 01w

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	$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$ $\Delta H = -10 \text{ kJ mol}^{-1}$	
(a)	State the qualitative effect of an increase in pressure on the rate of the forward reaction on the equilibrium position. Explain your answer in each case.	n and <i>[4]</i>
(b)	After equilibrium has been established, some $H_2$ is added to the system. Describe changes in the concentrations of $I_2$ and HI until a new equilibrium is established.	e the [2]
SL SECTION	N A 00w	

Hydrogen and iodine are placed in a closed container and allowed to react at  $750~^{\circ}\text{C}$  and one atmosphere pressure. The following equilibrium is reached:

1.

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3.	For	the	reversi	hle	reaction
J.	LOI	uic	Teversi	OIC	reaction

the e	quilibrium constant $K_{\rm c}=60$ at a particular temperature.	
(a)	Give the equilibrium expression and explain why the equilibrium constant has no units.	[2]
(b)	For this reaction, what information does the value of $K_{\rm e}$ provide about the <b>relative</b> concentrations of the product and reactants at equilibrium?	[1]
(c)	What effect, if any, will an increase in pressure have on the equilibrium position?	[1]
(d)	Explain why an increase in temperature increases the value of the <b>equilibrium constant</b> for the above reaction.	[1]

 $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$   $\Delta H > 0$ 

SL SECTION A .99s

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1. Ammonia, NH<sub>3</sub>, is manufactured by the Haber process according to the following equilibrium reaction:

$$N_2(g) + 3H_2(g) = 2NH_3(g)$$

The following data gives approximate values for the yield of ammonia at various temperatures and pressures.

Temperature (° C)	Pressure (atm)	Molar % of NH <sub>3</sub> at equilibrium
400	200	40
400	300	50
400	400	57
450	200	25
500	200	18

Use the data to deduce:

	(a)	(i)	the effect of pressure on the yield of ammonia. Explain your answer.	[2]
		(ii)	whether the synthesis of ammonia is endothermic or exothermic. Explain your answer.	[2]
	(b)		e what combination of pressure (i.e. high or low) and temperature (i.e. high or low) ld give the highest % of ammonia.	[1]
	(c)	Writ	te the equilibrium constant expression, $K_{\rm e}$ , for the formation of ammonia.	[2]
(d)	Stat	e and	explain what happens to the value of $K_{\rm e}$ if the temperature is increased.	[2]
		<b></b>		
	• • •			
(e)	Hov	v doe:	s the catalyst affect:	
	(i)	the	rate of formation of ammonia;	[1]
	(ii)	the	position of equilibrium?	[1]

(c)	The	manufacture of gaseous methanol from CO and H <sub>2</sub> invol	lves an equilibrium reaction.
		$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$	$\Delta H^{\odot} < 0$
	(i)	Outline the characteristics of a chemical equilibrium.	

(i)	Outline the characteristics of a chemical equilibrium.	[2]
(ii)	Deduce the equilibrium constant expression, $K_c$ , for this reaction.	[1]
(iii)	Identify one other important industrial synthesis that is an equilibrium reaction.	[1]

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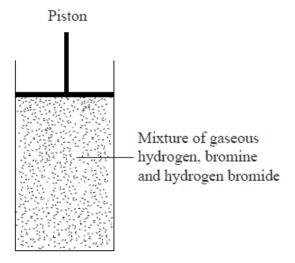
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(i)	Increase in temperature.
(ii)	Increase in pressure.
(iii)	Addition of a catalyst.
(111)	

SL B 12s

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6. Consider the equilibrium system involving bromine and its hydride.



State	e an equation to represent the equilibrium with $H_2(g)$ and $Br_2(g)$ as reactants.	[1]
(i)	Predict what happens to the position of equilibrium if a small amount of hydrogen is introduced.	[1]
(ii)	State and explain the effect of increasing the pressure on the position of equilibrium.	[2]
	(i)	(i) Predict what happens to the position of equilibrium if a small amount of hydrogen is introduced.  (ii) State and explain the effect of increasing the pressure on the position of equilibrium.

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(c)	(i) Deduce the equilibrium constant expression, $K_c$ , for the equilibrium in (a).					
	(ii)	State the effect of increasing $[H_2]$ on the value of $K_c$ .	[1]			
(e)		en bromine dissolves in water, 1% of the original bromine molecules react according ne following equation.				
(;;;)	Est	$\operatorname{Br}_2(\operatorname{aq}) + \operatorname{H}_2\operatorname{O}(\operatorname{I}) \rightleftharpoons \operatorname{HOBr}(\operatorname{aq}) + \operatorname{HBr}(\operatorname{aq})$				
(iii)		imate the magnitude of $K_{\epsilon}$ for this reaction. Choose your value from the following ions:	[1]			
		$K_{c} = 0$ $K_{c} < 1$ $K_{c} = 1$ $K_{c} > 1$				
	• •					
	(iv)	State and explain what happens to the equilibrium, in (e), when aqueous sodium hydroxide is added to the reaction solution at equilibrium.	[2]			

SL B 11w

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<b>o.</b> (a) Consider the following equilibrium	6.	(a)	Consider the following equilibrium
--	----	-----	------------------------------------

$$4\mathrm{NH_3}(\mathrm{g}) + 5\mathrm{O_2}(\mathrm{g}) \rightleftharpoons 4\mathrm{NO}(\mathrm{g}) + 6\mathrm{H_2O}(\mathrm{g}) \qquad \Delta H^{\ominus} = -909\;\mathrm{kJ}$$

(i)	Deduce the equilibrium constant expression, $K_{\rm e}$ , for the reaction.	[1]
(ii)	Predict the direction in which the equilibrium will shift when the following changes occur.	[4]
	The volume increases.	
	The temperature decreases.	
	$H_2O(g)$ is removed from the system.	
	A catalyst is added to the reaction mixture.	

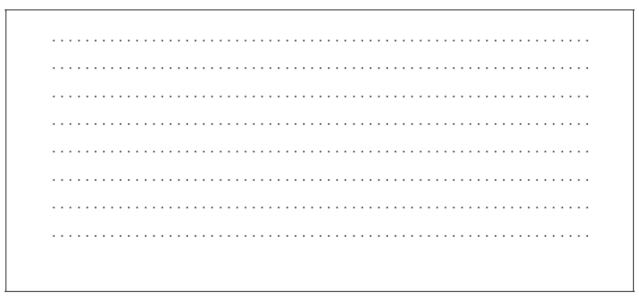
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(e) Nitrogen reacts with hydrogen to form ammonia in the Haber process, according to the following equilibrium.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$
  $\Delta H^{\oplus} = -92.6 \text{ kJ}$ 

(ii) A high pressure such as 1000 atm and a low temperature such as 300 K can produce a high yield of ammonia. Discuss how these conditions compare with the actual conditions of pressure and temperature used in the Haber process.

[4]

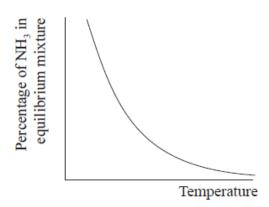


**SL B 10w** 

- 6. The Haber process enables the large-scale production of ammonia needed to make fertilizers.
  - (a) The equation for the Haber process is given below.

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

The percentage of ammonia in the equilibrium mixture varies with temperature.



- Use the graph to deduce whether the forward reaction is exothermic or endothermic and explain your choice.
- (ii) State and explain the effect of increasing the pressure on the yield of ammonia. [2]
- (iii) Explain the effect of increasing the temperature on the rate of reaction. [2]

[2]

### **SL B 10s**

A state of equilibrium can exist when a piece of copper metal is placed in a solution (d) (i) of copper(II) sulfate. Outline the characteristics of a chemical system in dynamic equilibrium.

For an exothermic reaction state how an increase in temperature would affect both  $K_{\epsilon}$  and the position of equilibrium.

[2]

[2]

### **SL B 09w**

Consider the following reaction taking place at 375 °C in a 1.00 dm<sup>3</sup> closed container. 5. (a)

$$Cl_2(g) + SO_2(g) \rightleftharpoons SO_2Cl_2(g)$$
  $\Delta H^{\Theta} = -84.5 \text{ kJ}$ 

(i) Deduce the equilibrium constant expression,  $K_s$ , for the reaction. [1]

If the temperature of the reaction is changed to 300 °C, predict, stating a reason in each case, whether the equilibrium concentration of  $SO_2Cl_2$  and the value of  $K_e$  will increase or decrease.

[3]

(iii) If the volume of the container is changed to 1.50 dm<sup>3</sup>, predict, stating a reason in each case, how this will affect the equilibrium concentration of SO2Cl2 and the value of  $K_c$ .

[3]

Suggest, stating a reason, how the addition of a catalyst at constant pressure and temperature will affect the equilibrium concentration of SO<sub>2</sub>Cl<sub>2</sub>.

*[2]* 

### **SLB 08s**

7. The following equilibrium is involved in the industrial production of nitric acid (a) from ammonia.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$$
  $\Delta H^{\oplus} = -910 \text{ kJ mol}^{-1}$ 

Describe the effect, if any, of each of the following changes on the equilibrium concentration of nitrogen monoxide in a particular equilibrium mixture, giving a reason in each case.

(i) Increasing the pressure, at constant temperature

[2]

Increasing the temperature, at constant pressure

[2]

(iii) Addition of a heterogeneous catalyst, at constant pressure and temperature

[2]

(b) Deduce the equilibrium constant expression,  $K_c$ , including units for the forward reaction in part (a).

[2]

Identify which of the changes in part (a) will affect the value of  $K_c$  and predict whether the value of  $K_{\varepsilon}$  will increase or decrease.

[2]

### **SL B 07w**

Page 20 of 36 PB 7. (a) The equation for the exothermic reaction in the Contact process is given below:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

- Write the equilibrium constant expression for the reaction.
- (ii) State and explain qualitatively the pressure and temperature conditions that will give the highest yield of sulfur trioxide.

[1]

- (iii) In practice, conditions used commercially in the Contact process are 450 °C and 2 atmospheres of pressure. Explain why these conditions are used rather than those that give the highest yield. [3]
- (iv) Name a catalyst used in the Contact process. State and explain its effect on the value of the equilibrium constant. [3]

SL B 06w

6. Information about some reactions used in industry is shown in the following table:

Reaction	Equation	$\Delta H^{\Theta}/\mathrm{kJ}$
A	$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$	-184
В	$CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$	+210
С	$CO(g) + H_2O(g) \rightleftharpoons H_2(g) + CO_2(g)$	-42
D	$CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$	+180
E	$nC_2H_4(g) \rightarrow (-CH_2-CH_2-)_n(s)$	-92

- (a) Identify, with a reason, which of the reactions A to E is/are
  - the two in which an increase in temperature shifts the position of equilibrium to the right.
  - (ii) the two in which an increase in pressure shifts the position of equilibrium to the left. [2]
- (b) Many reversible reactions in industry use a catalyst. State and explain the effect of a catalyst on the position of equilibrium and on the value of  $K_c$ . [4]

**SL B 06s** 

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Consider the following reaction in the Contact process for the production of sulfuric acid for parts (a) to (f) in this question.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

- (a) Write the equilibrium constant expression for the reaction. [1]
- (b) (i) State the catalyst used in this reaction of the Contact process. [1]
  - (ii) State and explain the effect of the catalyst on the value of the equilibrium constant and on the rate of the reaction. [4]
- (c) Use the collision theory to explain why increasing the temperature increases the rate of the reaction between sulfur dioxide and oxygen. [2]
- (d) Using Le Chatelier's principle state and explain the effect on the position of equilibrium of
  - (i) increasing the pressure at constant temperature. [2]
  - (ii) removing of sulfur trioxide. [2]
  - (iii) using a catalyst. [2]
- (e) Using the following data, explain whether the above reaction is exothermic or endothermic. [2]

Temperature / K	Equilibrium constant K <sub>c</sub> /dm³ mol <sup>-1</sup>
298	9.77×10 <sup>25</sup>
500	8.61×10 <sup>11</sup>
700	1.75×10 <sup>6</sup>

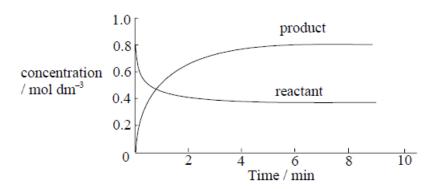
**SL B 05w** 

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6. The equation for one reversible reaction involving oxides of nitrogen is shown below: (a)

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$
  $\Delta H^{\oplus} = +58 \text{ kJ}$ 

Experimental data for this reaction can be represented on the following graph:



Write an expression for the equilibrium constant,  $K_s$ , for the reaction. Explain the (i) significance of the horizontal parts of the lines on the graph. State what can be deduced about the magnitude of  $K_c$  for the reaction, giving a reason.

[2]

Use Le Chatelier's principle to predict and explain the effect of increasing the temperature on the position of equilibrium.

[2]

[4]

(iii) Use Le Chatelier's principle to predict and explain the effect of increasing the pressure on the position of equilibrium.

(iv) State and explain the effects of a catalyst on the forward and reverse reactions, on the [6] position of equilibrium and on the value of  $K_c$ .

**SL B 04w** 

(d) Carbon dioxide gas in the atmosphere reacts slightly with rainwater as shown below.

$$CO_2(g) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$$

(i) State the meaning of the  $\rightleftharpoons$  sign. [1]

Predict the effect, if any, of the presence of a catalyst on the acidity of rainwater. Give (ii) a reason for your answer.

[2]

Use Le Chatelier's principle to predict the effect of the addition of a small quantity of an alkali on the acidity of rainwater. Explain what effect, if any, this would have on the equilibrium constant,  $K_c$ .

[3]

**SL B 03w** 

Page 23 of 36 PB (b) The following equilibrium is established at 1700 °C.

$$CO_{2}(g) + H_{2}(g) \rightleftharpoons H_{2}O(g) + CO(g)$$

If only carbon dioxide gas and hydrogen gas are present initially, sketch on a graph a line representing rate against time for (i) the forward reaction **and** (ii) the reverse reaction until shortly after equilibrium is established. Explain the shape of each line.

[7]

(c)  $K_c$  for the equilibrium reaction is determined at two different temperatures. At 850 °C,  $K_c = 1.1$  whereas at 1700 °C,  $K_c = 4.9$ .

On the basis of these  $K_c$  values explain whether the reaction is exothermic or endothermic.

[3]

### **SL B 02s**

5. Ammonia is made on a large scale by the Haber process. The main reaction occurring is

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$
  $\Delta H = -92 \text{ kJ mol}^{-1}$ .

- (a) State two characteristics of a reversible reaction at equilibrium. [2]
- (b) This reaction is described as homogeneous. State what is meant by the term homogeneous. [1]
- (c) Write the equilibrium constant expression for the reaction. [2]
- (d) When nitrogen and hydrogen are mixed together at room temperature and atmospheric pressure the reaction is very slow. In industry, typical values of pressure and temperature used are 250 atmospheres and 450 °C.
  - State the effects on both the rate of reaction and the value of the equilibrium constant of increasing the temperature.
  - (ii) State the effects on both the rate of reaction and the value of the equilibrium constant of increasing the pressure. [2]
  - (iii) Suggest why a pressure of 1000 atmospheres is not used. [1]
- (e) Name the catalyst used in the Haber process. State and explain its effect on the value of the equilibrium constant. [3]
- (g) A mixture of nitrogen and hydrogen is left at 450 °C and 250 atmospheres until equilibrium is reached. Use Le Chatelier's principle to state and explain what will happen to the position of equilibrium when
  - (i) some of the ammonia is removed; [2]
  - (ii) the pressure is increased. [2]

SL B 01s

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- **4.** (a) Define the term *rate of reaction*. For a reaction of your choice, state the reactants and outline an experimental procedure by which you could obtain a value for the rate of reaction.
  - (b) (i) State Le Chatelier's Principle. [1]
    - (ii) State the factors which affect the **position** of equilibrium in a reaction. Explain the influence of **one** of these factors using Le Chatelier's Principle. [3]

[5]

[3]

- (iv) State the factors which affect the **time** taken to reach equilibrium and explain briefly the influence of **one** of these factors.

  [3]
- (c) Write an equation, including state symbols, for the synthesis of ammonia by the Haber process. Explain the use of high pressure and moderately-high temperatures in the production of ammonia.
  [4]

### IB SL 7 EQ Paper 2 s99 to s13 incl W Mark Scheme

### SL SECTION A 12w

3. (a) rate of forward process/reaction = rate of backwards/reverse process/reaction / rate of vaporization/evaporation = rate of condensation; concentrations of reactants and products remain constant; no change in macroscopic properties / closed system / constant matter/energy / OWTTE; [1 max] Do not accept concentration of reactants and products are equal. Accept constant colour of Br2 vapour/liquid.

(b) (i) 
$$(K_c =) \frac{[SO_3]^2}{[SO_2]^2[O_2]}$$
; [1]

(ii)		Position of equilibrium	Value of Kc
	Decrease in temperature	shifts to right/products	increases
	Increase in pressure	shifts to right/products	no effect
	Addition of a catalyst	no effect	no effect

Award [1] for any two or three correct, [2] for any four or five correct, [3] for six correct.

SL SECTION A 11s

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3.	(a)	$(K_c =) \frac{[CH_3OH]}{[CO][H_3]^2};$	[1]
		Do not award mark if incorrect brackets are used or brackets are missing.	
	(b)	<ul> <li>(i) amount (of methanol)/product decreases / less methanol;</li> <li>(forward reaction) exothermic / reverse reaction endothermic / OWTTE;</li> </ul>	[2]
		<ul> <li>(ii) amount (of methanol)/product increases / more methanol;</li> <li>3 gas molecules/mol → 1 / decrease in volume / fewer gas molecules on right hand side/products / more gas molecules on left hand side/reactants;</li> </ul>	[2]
	(c)	high pressure expensive / greater cost of operating at high pressure; lower temperature – lower (reaction) rate;	[2]
	(d)	increases rate of forward and reverse reactions (equally) / lowers activation energy/ $E_a$ (of both the forward and reverse reaction equally) / provides alternative path with lower activation energy/ $E_a$ ;  Accept reactants adsorb onto the catalyst surface and bonds weaken resulting in a decrease in the activation energy.	[1]
SL SE	CTION	I A 09s	
(c)	(i)	rate of the forward reaction is equal to the rate of the reverse reaction / forward and reverse reactions occur <b>and</b> the concentrations of the reactants and products do not change / <i>OWTTE</i> ;	[1]
	(ii)	$K_c = \frac{[\text{glycerol}] \times [\text{biodiesel}]^3}{[\text{vegetable oil}] \times [\text{methanol}]^3};$	[1]
	(iii)	to move the position of equilibrium to the right/product side / increase the yield of biodiesel;	[1]
	(iv)	no effect (on position of equilibrium); increases the rate of the forward and the reverse reactions equally (so equilibrium reached quicker) / it lowers $E_a$ for both the forward and reverse reactions by the same amount / OWTTE; No ECF for explanation.	[2]
SL SE	CTION	I A 07s	
4.	(a)	$(K_{c}) = \frac{[NH_{3}]^{2}}{[H_{2}]^{3}[N_{2}]};$ Do not allow round brackets unless $K_{p}$ is used.	[1]
	(b)	equilibrium shifts to the right / products; $4 \text{ mol} \rightarrow 2 \text{ mol} \underline{\text{ of gas}}$ / fewer moles of gas on the right/products;	[2]
	(c)	$K_{\rm c}$ decreases; equilibrium position shifts to the left/reactants / forward reaction is exothermic / reverse reaction is endothermic;	[2]
	(d)	catalyst increases the rate of the forward and backward reactions $\underline{\text{equally}}$ / lowers the activation energy of both forward and backward reaction $\underline{\text{equally}}$ / $\underline{\text{lowers } E_a}$ so $\underline{\text{rate}}$ of forward and backward reactions increase;	[1]
SL SE	CTION	I A 04s	

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- (a) (position of) equilibrium shifts to the left / towards reactants;
   (forward) reaction is exothermic / ΔH is negative / the reverse reaction is endothermic / OWTTE;
   Do not accept "Le Chatelier's Principle" without some additional explanation.
  - (b) (position of) equilibrium shifts to the right / towards products; fewer gas molecules on the right hand side / volume decreases in forward reaction / OWTTE;
     Do not accept "Le Chatelier's Principle" without some additional explanation.

### SL SECTION A 03s

- 1. (a) 200 °C 600 atm. (both for [1], units not needed); [1] allow the "highest pressure and the lowest temperature"
  - (b) (i) yield increases / equilibrium moves to the right / more ammonia;
     4 (gas) molecules → 2 / decrease in volume / fewer molecules on right hand side; [2]
    - (ii) yield decreases / equilibrium moves to the left / less ammonia; exothermic reaction / OWTTE; [2]
  - (c) high pressure expensive / greater cost of operating at high pressure / reinforced pipes etc. needed;
    lower temperature greater yield, but lowers rate;
    Do not award a mark just for the word "compromise".

    [2]

(d) 
$$K_{c} = \frac{[NH_{3}]^{2}}{[N_{2}][H_{2}]^{3}}$$
 (ignore units); [1]

### SL SECTION A 03s

3. (a) Al  $\frac{20.3}{26.98}$  Cl  $\frac{79.70}{35.45}$  or similar working (no penalty for use of 27 or 35.5); empirical formula AlCl<sub>3</sub>;

Full credit can be obtained if the calculations are carried out by another valid method. Two correct formulas but no valid method scores [2 max].

(b) moles of Na = 
$$\frac{1.15}{23}$$
 = 0.05;  
moles of NaOH = 0.05;  
Accept "same as moles of Na"  
concentration =  $\left(\frac{0.05}{0.25}\right)$  = 0.20 (mol dm<sup>-3</sup>); [3]

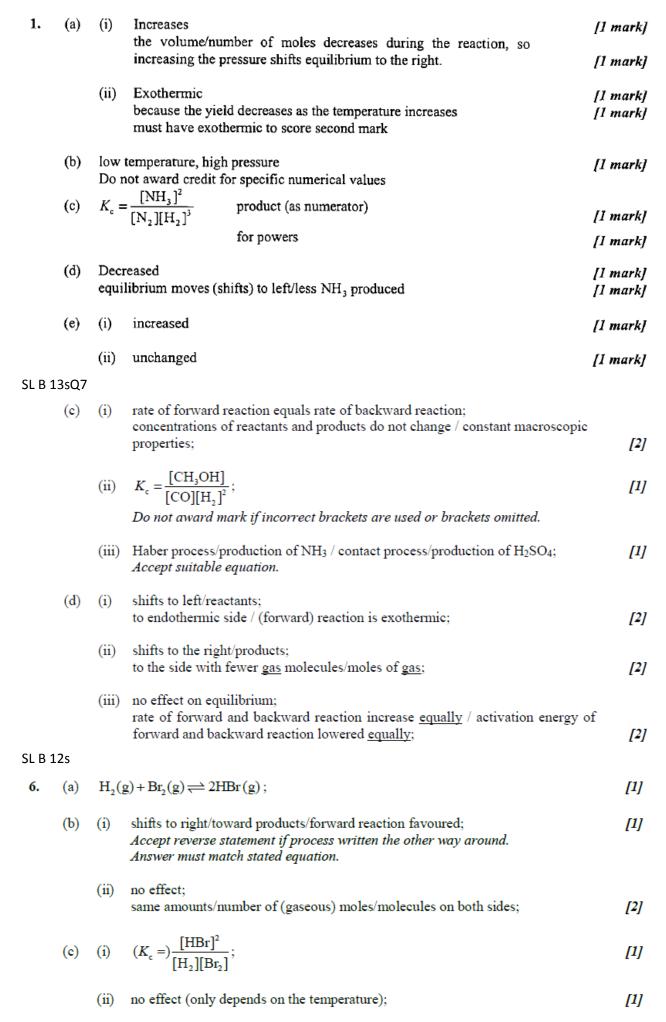
### SL SECTION A 02w

Allow ECF from moles of NaOH

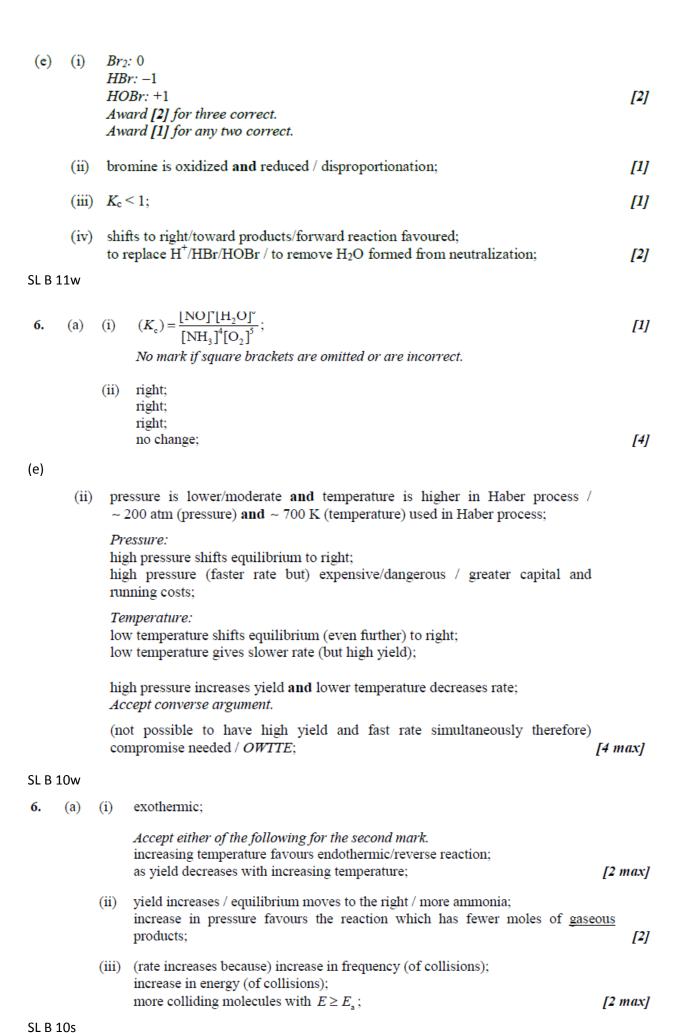
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3.	(a)	600 atm and 200 °C (units needed, do not accept just low temperature and high pressure);	[1]
	(b)	(i) yield increases / more ammonia formed; (not just forward reaction favoured) equilibrium shifts to side with fewer gas moles / molecules / volumes / OWTTE;	[2]
		<ul> <li>(ii) yield decreases / less ammonia formed; (not just reverse reaction favoured) equilibrium shifts in endothermic direction / to side which absorbs energy / OWTTE;</li> </ul>	[2]
		(c) at 200 °C / low temperature reaction is (too) slow; at 600 atm / high pressure the cost / danger is (too) great; (Do not allow just high cost if no mention of pressure).	[2]
SL SE	CTIO	N A 01w	
1.	(a)	Reaction rate is faster.  Increase in pressure increases concentration of reactants / same amount in less volume,	[1]
		and the rate increases as the number of collisions per unit volume increases.	[1]
		Equilibrium position does not change. $K$ is independent of concentration / depends on T only.	[1] [1]
	(b)	<ul><li>[I<sub>2</sub>]: Decreases slightly, then becomes constant.</li><li>[HI]: Increases slightly, then becomes constant.</li></ul>	[1] [1]
SL SE	CTIO	N A 00w	
3.	(a)	$K_{\mathrm{e}} = \frac{[\mathrm{HI}]^2}{[\mathrm{H}_2][\mathrm{I}_2]}$	[1]
		Units cancel for reactants and products / for numerator and denominator.	[1]
	(b)	Concentration of product / HI greater (than $[H_2]$ and $[I_2]$ )	[1]
	(c)	It will have no effect.	[1]
	(d)	As the reaction is endothermic, increasing $T$ will shift equilibrium position to the right.	[1]
SL SE	CTIO	N A .99s	

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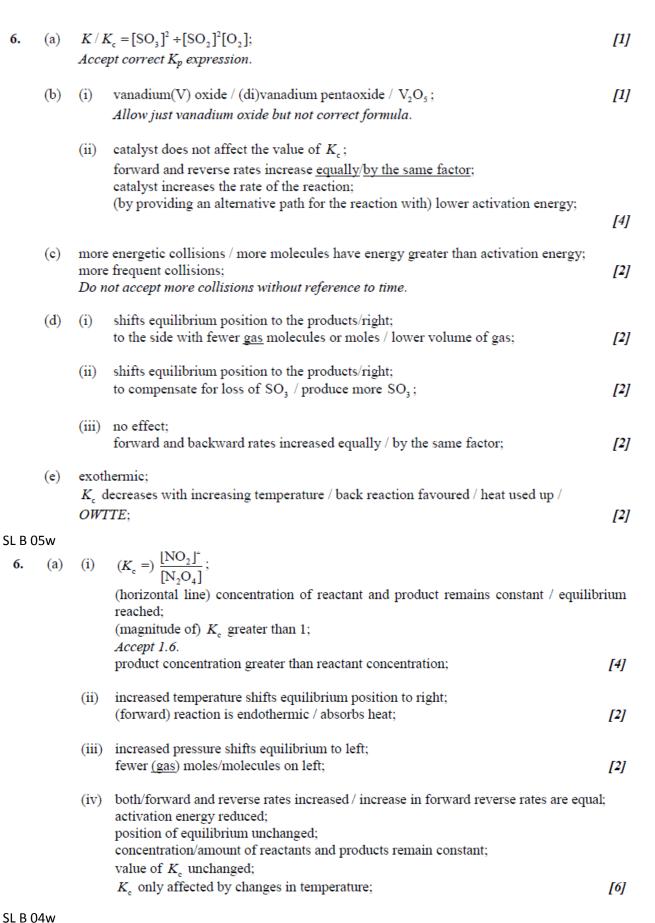
(a)	(1)	change to copper solution seen; rate of reverse/backwards reaction = rate of forward reaction;	[2]
	(ii)	$K_{\rm c}$ decreases; position of equilibrium shifts to left;	[2]
SL B (	09w		
5.	(a)	$(K_c) = \frac{[SO_2Cl_2]}{[Cl_2][SO_2]};$ $Ignore state symbols.$	[1]
		Square brackets [] required for the equilibrium expression.	
		(ii) value of K <sub>c</sub> increases;	
		[SO <sub>2</sub> Cl <sub>2</sub> ] increases; decrease in temperature favours (forward) reaction which is exothermic; Do not allow ECF.	[3]
		(iii) no effect on the value of $K_c$ / depends only on temperature;	
		[SO <sub>2</sub> Cl <sub>2</sub> ] decreases;	
		increase in volume favours the reverse reaction which has more gaseous moles; Do not allow ECF.	[3]
		<ul> <li>(iv) no effect;</li> <li>catalyst increases the rate of forward and reverse reactions (equally) / catalyst decreases activation energies (equally);</li> </ul>	[2]
SL B (	08s		
7.	(a)	<ul> <li>(i) (equilibrium shifted to the left) equilibrium concentration of NO is reduced; more gas molecules on the right hand side than on the left;</li> </ul>	[2]
		<ul><li>(ii) (equilibrium shifted to the left) equilibrium concentration of NO is reduced; (forward) reaction is exothermic;</li></ul>	[2]
		<ul> <li>(iii) no effect on the equilibrium concentration of NO;</li> <li>catalyst increases the rate of forward and reverse reaction equally;</li> </ul>	[2]
	(b)	$K_{c} = \frac{[\text{NO}]^{4}[\text{H}_{2}\text{O}]^{6}}{[\text{NH}_{1}]^{4}[\text{O}_{1}]^{5}};$	
		mol dm <sup>-3</sup> ;	[2]
	(c)	increase in temperature;	
		$K_{c}$ decreases;	[2]

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SL B 07w

7.	(a)	(i)	$K_{c} = \frac{[SO_{3}]^{2}}{[SO_{2}]^{2}[O_{2}]};$	[1]
		(ii)	$\label{eq:pressure} \begin{split} &\textit{pressure} \\ &\textit{high pressure (will allow system to occupy smaller volume);} \\ &V_{\textit{product}} < V_{\textit{reactant}}  / \ \ \text{equilibrium moves to the right to reduce pressure} \ / \ \ \text{reaction} \\ &\textit{proceeds to lower/lowest number of } \ \underline{\textit{gaseous}} \ \ \text{molecules} \ / \ \textit{OWTTE}; \end{split}$	
			temperature low temperature; (exothermic reaction) forward reaction favoured to replace some of the heat removed / equilibrium moves to the right to produce heat / OWTTE; No mark for just saying "due to Le Chatelier's principle"	[4]
		(iii)	rate is faster at $450^{\circ}$ C (than at low temperatures); > $95\%/90-99\%$ yield / (very) high conversion takes place; unnecessary to use expensive high pressure equipment / (to achieve) high pressure is very expensive;	[3]
		(iv)	$\label{eq:constraint} \mbox{vanadium(V) oxide / $V_2O_5$/ finely divided platinum / Pt;} \\ \mbox{no effect on $K_e$;} \\ \mbox{forward and reverse rates speeded up (equally);}$	[3]
SL B 0	6w			
6.	(a)	(i)	B and D; (reactions are) endothermic / have positive $\Delta H^{\oplus}$ values;	[2]
		(ii)	B and D; fewer gas volumes/moles on left / more gas volumes on right;	[2]
(b)	forv exte	varda ntoft	on position of equilibrium; and reverse reactions speeded up equally / effects the rate of reaction but not the reaction; on value $K_c$ of;	the
	no c	hange	in concentrations of reactants or products / $K_{\rm c}$ only changes if temperature alters;	[4]
SL B 0	6s			

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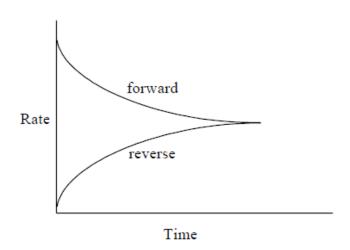
3L B 04W

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(d) (i) reversible reaction / reaction may proceed in either direction (depending on reaction conditions) equilibrium / dynamic equilibrium;
(ii) no effect;
 catalyst will speed up both forward and reverse reactions (equally) /
 increase the rate at which equilibrium is achieved;
(iii) acidity: no effect;
 equilibrium shifts to the right;
 K<sub>c</sub>: no change;

**SL B 03w** 

(b)



two curves - one labled "forward" starting up high up y-axis and one labeled "reverse" starting from zero; curves merge and become horizontal;

No penalty for failing to label axes.

### forward reaction:

highest concentration, thus rate high to begin with; as reaction proceeds, concentrations decrease, so does rate;

### reverse reaction:

zero rate initially / at t = 0 (since no products present); rate increases as concentration of products increases;

equilibrium established when rate of forward reaction = rate of reverse reaction; [7]

[3]

(c) reaction is) endothermic;

K<sub>e</sub> increases with (increasing) temperature; forward reaction favoured / heat used up / OWTTE;

SL B 02s

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5.	(a)	forward and reverse reactions still occurring / forward and reverse rates equal [1]; concentrations of reactants and products unchanged [1].	[2]
	(b)	Reactants and products in the same phase/state.	[1]
	(c)	$K_{c} = \frac{[\mathrm{NH_{3}}]^{2}}{[\mathrm{N_{2}}][\mathrm{H_{2}}]^{3}}$ Accept correct expression for $K_{p}$ Use of [] and formulas in correct position [1]; powers correct [1].	[2]
	(d)	(i) rate increased [1]; equilibrium constant decreased [1].	[2]
		(ii) rate increased [1]; equilibrium constant unchanged [1].	[2]
		(iii) too expensive / greater cost of energy or pipes / more safety precautions / thicker pipes	[1]
	(e)	iron / Fe [1]; equilibrium constant unchanged [1]; only temperature affects $K_{\rm c}$ / catalyst speeds up forward and reverse reactions equally / activation energy reduced by same amount for both forward and reverse reactions [1].	[3]
	(f)	(Award [1] for any three of the following:)	
		successful collisions need minimum/activation energy / correct geometry [1]; increasing temperature causes increase in energy of particles [1]; so increased proportion of successful collisions [1]; so increased frequency of collisions / more collisions per unit time [1]. Do not accept just "more collisions".	[3]
	(g)	(i) shifted to right [1];	[°]
	(6)	to replace the ammonia removed [1];	[2]
		(ii) shifted to right [1]; fewer gas moles on the right / OWTTE [1].	[2]

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SL B 01s

Identify feasible reaction [1] State what is to be measured [1] Record time for specific event [1] Plot graph of reciprocal time  $\left(\frac{1}{t}\right)$  [1] [5 max] (N.B. we are timing [1] a specific process e.g. gas/precipitate appearing, etc. [1]) If a system at equilibrium is disturbed, the equilibrium moves in the direction (b) which tends to reduce the disturbance (OWTTE). [1] Temperature and pressure / concentration [1] (ignore others) For the factor chosen, [1] for effect/influence and [1] for explanation [3 max] Temperature: effect depends on whether endothermic or exothermic [1], explanation [1] Pressure: effect depends on number of moles of gaseous reactants and products [1], explanation [1] Concentration: effect depends on whether change is to reactants or products [1], explanation [1] (iii) Molecules must collide in order to react [1] Not all collisions lead to a reaction [1] Minimum energy needed/activation energy [1] Appropriate collision geometry required [1] [4 max] (iv) Temperature, concentration/pressure, catalyst, surface area [2] (Award [2] for 3 or 4 factors and [1] for 2 factors) (Award [1] for explanation, for example) increases frequency / number of collisions / more Temperature increase: molecules have sufficient energy to react [1] Conc./pressure increase: increase in the number / frequency of collisions [1] Catalyst: reduces minimum energy needed to react / reduces  $E_a$  / provides alternative reaction pathway with lower energy [1] Surface area: increases number of collisions [1] [3 max] (c)  $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$  (state symbols and  $\rightleftharpoons$  required) [1]

Change of concentration of reactant/product with time [1]

Low temperature, high yield [1]
Low temperature, low rate [1]
High pressure, high yield [1]
High pressure, high rate [1]

[3 max]

[4 max]

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