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CHEMICAL EQUILIBRIUM

Important terms

- *** Open system – a system that continuously interacts with its environment
i.e. matter can enter and leave the system
- *** Closed system – a system that is isolated from its surroundings
i.e. matter cannot enter or leave the system
- *** Chemical equilibrium – a stage in a chemical reaction in which the rate of the forward reaction equals the rate of the reverse reaction
- *** Reversible reaction – a reaction in which the products can be converted back to reactants
 $\rightleftharpoons$ means reversible reaction

Conditions for chemical equilibrium

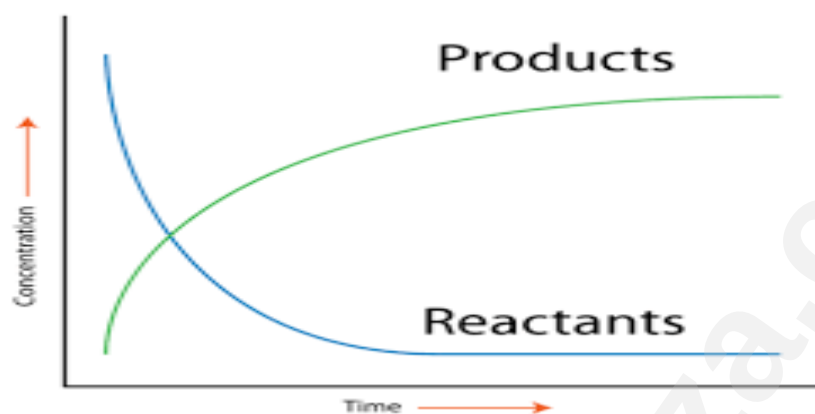
- (1) Reaction must be reversible
- (2) The system must be closed

Characteristics of chemical equilibrium

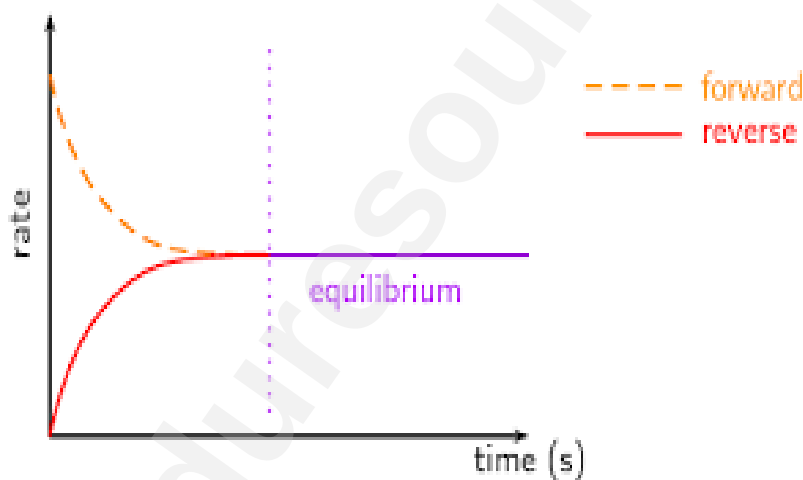
- (1) The rate of forward reaction is equal the rate of reverse reaction
- (2) Concentration of reactants and products remains constant

For the reaction: $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$

Graph of concentration versus time



Graph of reaction rate versus time



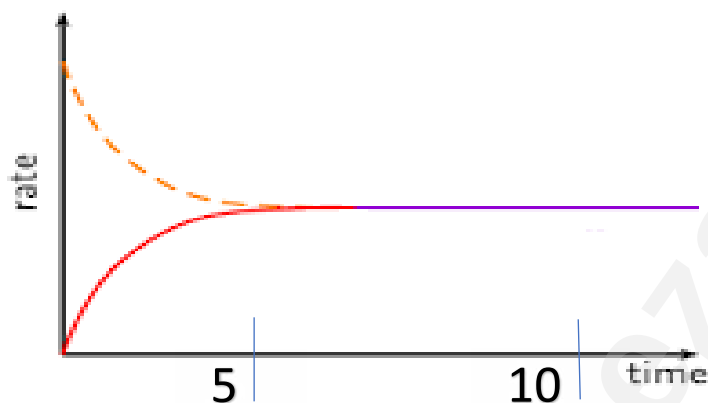
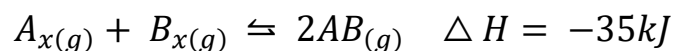
Factors that affect the position of equilibrium

- (1) Temperature
- (2) Concentration
- (3) Pressure (gases only)
- (4) A catalyst does not affect the position of equilibrium but only enables equilibrium to be reached faster

CLASSWORK

MARKS:11

1. The graph below shows the change in rate per unit time of a reaction.



- 1.1. Write the equation for the reaction which takes place in first 10mins as represented by solid graph line (2)
- 1.2. State with a reason if the reaction as shown (2)
- 1.2.1. A homogeneous or heterogeneous equilibrium (2)
- 1.2.2. Exothermic or endothermic for formation of AB (2)
- 1.3. Use the graph to answer the question below:
- 1.3.1. How much of AB were present at the start (1)
- 1.3.2. Explain the horizontal shape between 5 and 10 mins (2)

APPLICATION OF EQUILIBRIUM PRINCIPLES

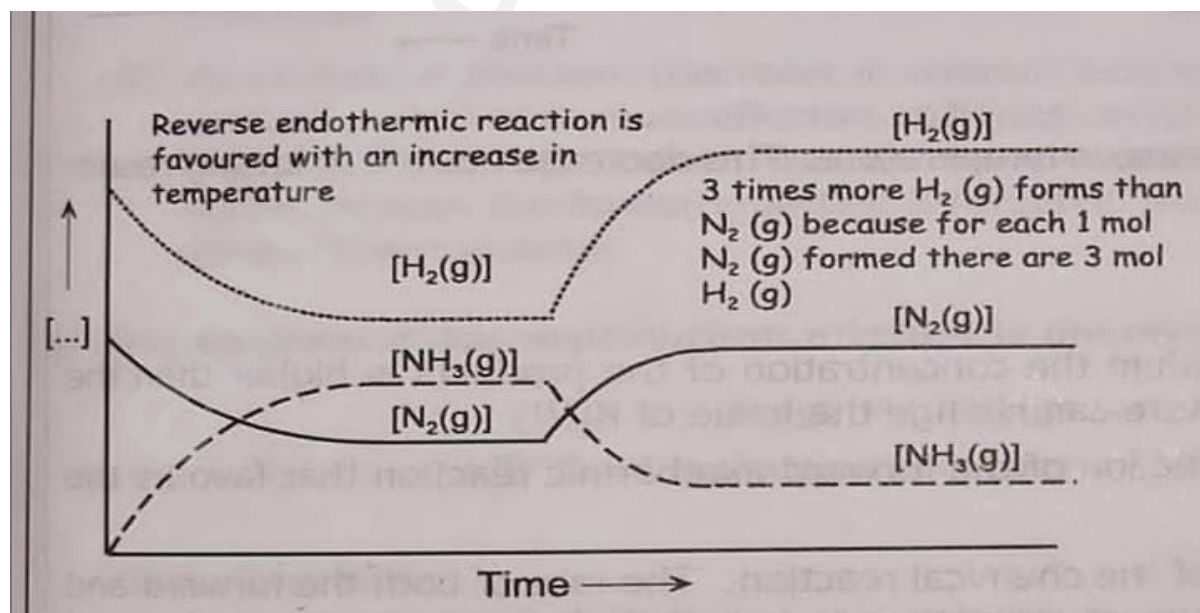
*** Le chatelier's principle: when the equilibrium of a closed system is disturbed, the system will re-instate a new equilibrium by favoring the reaction that will oppose the disturbance.

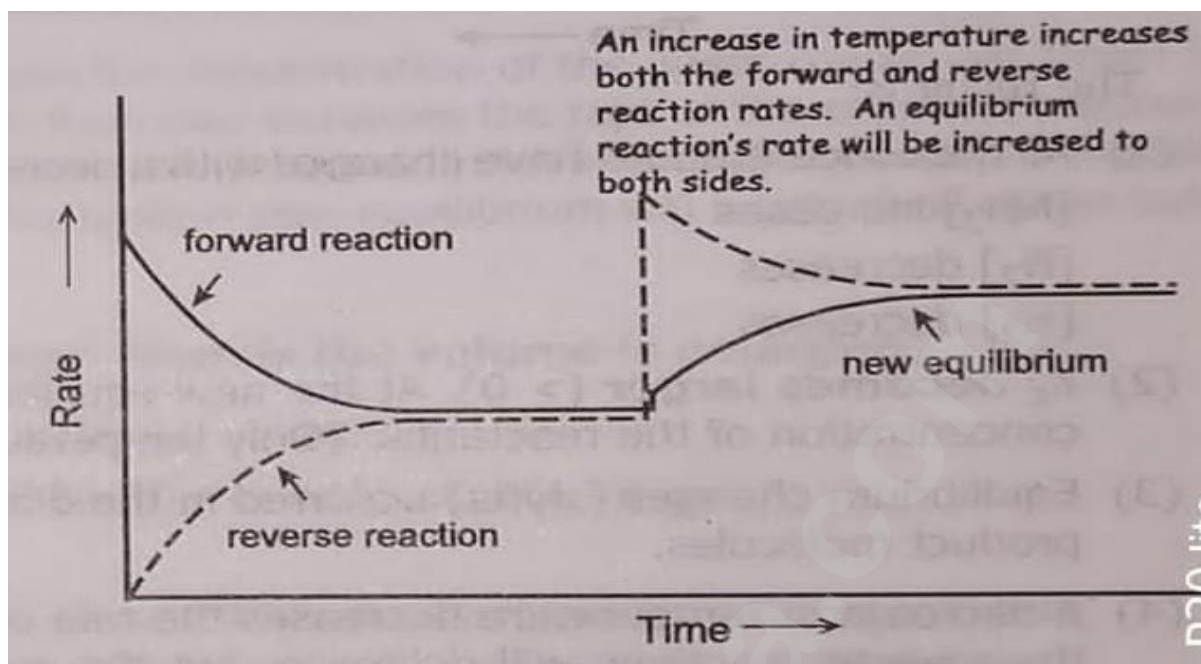
NB: The reaction used is: $N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)} \quad \Delta H < 0$

(a) The effect of change in temperature

- (i) Increase in temperature
 - An increase in temperature favours the endothermic reaction
 - The forward reaction is exothermic
 - Reverse reaction is favoured
 - $[N_2]$ and $[H_2]$ increase; $[NH_3]$ decrease

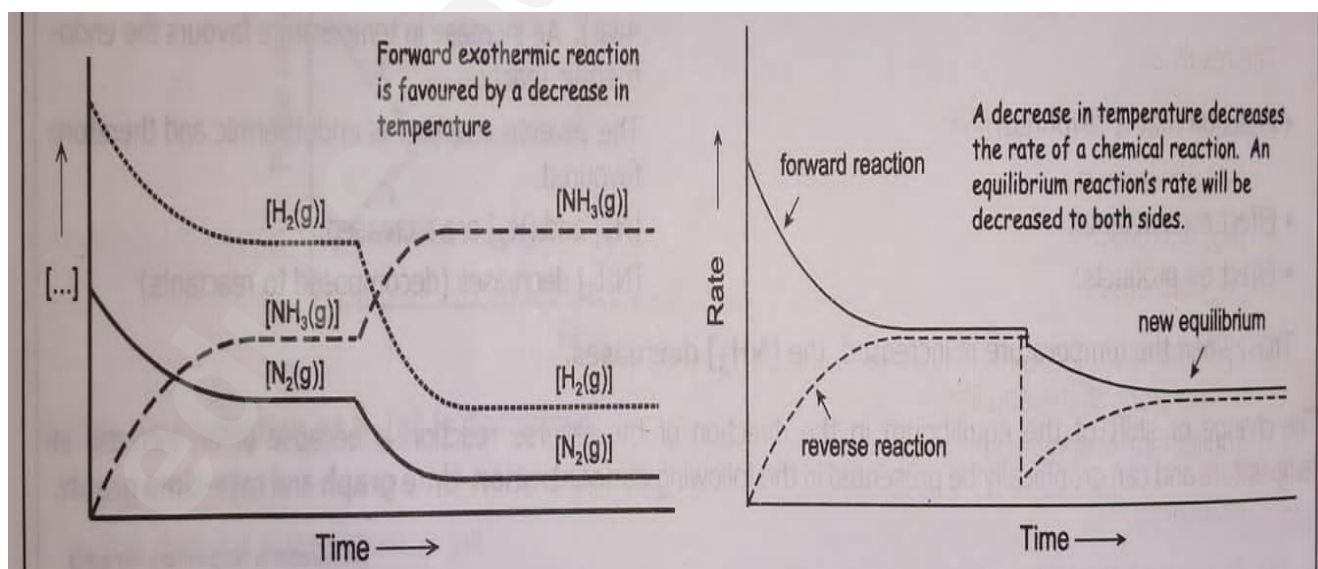
Graph of concentration against time





(ii) Decrease in temperature

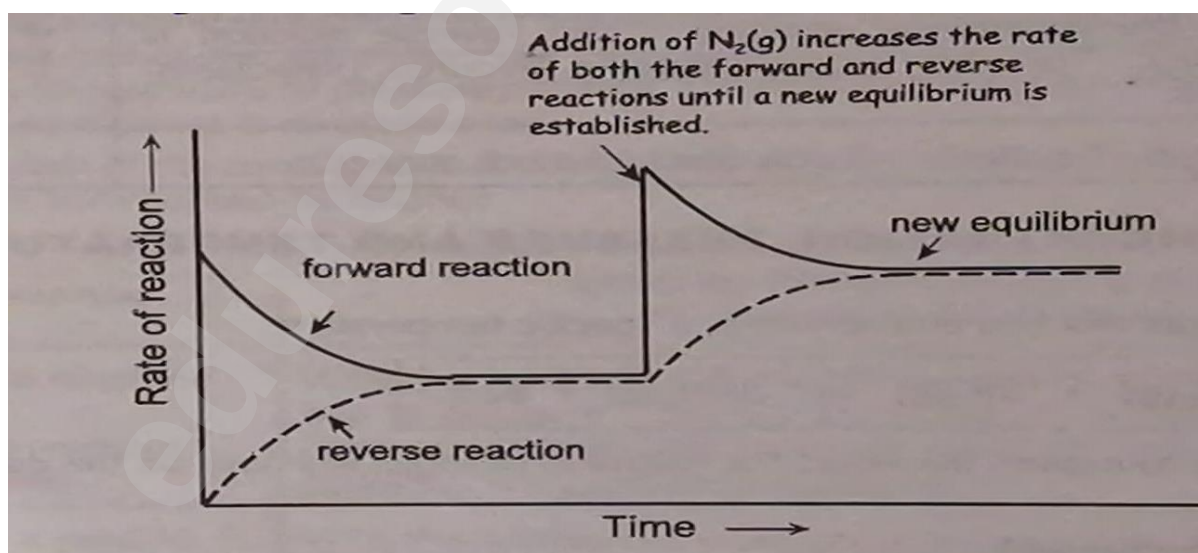
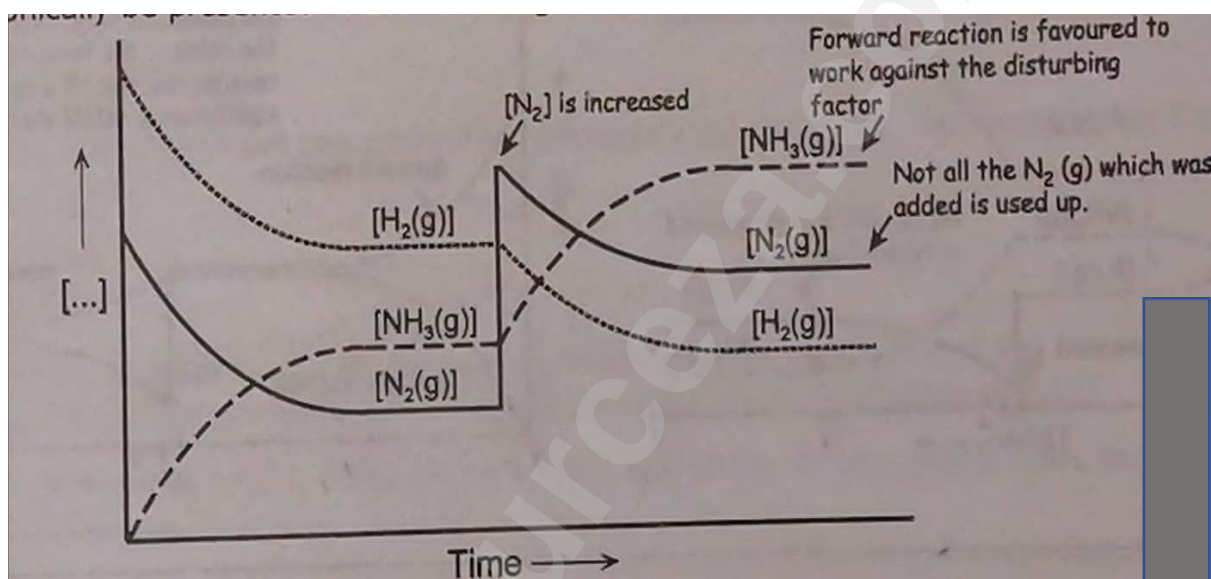
- An increase in temperature favors the exothermic reaction
- The forward reaction
- Forward reaction is favoured
- $[N_2]$ and $[H_2]$ decreases; $[NH_3]$ increases



(b) Effect of change in concentration

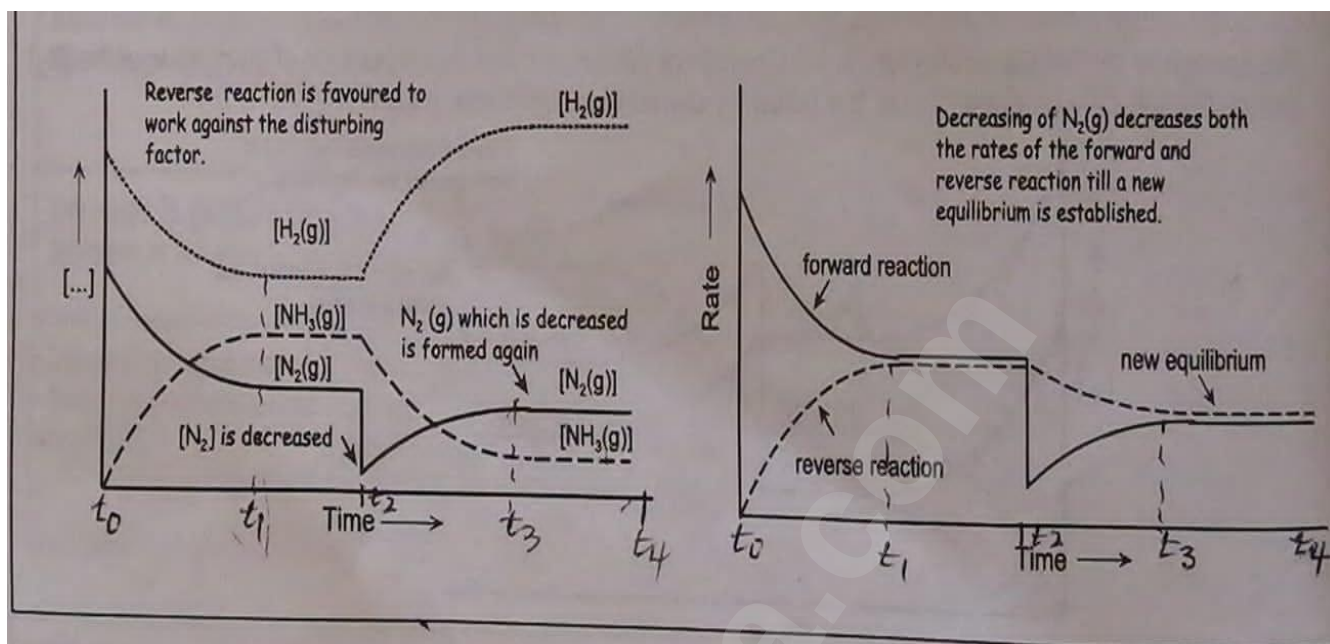
(i) Increase in concentration of N_2

- An increase in $[N_2]$ (reactant) favours the reaction that reduces it
- Forward reaction is forward
- $[N_2]$ and $[H_2]$ decreases;
- $[NH_3]$ increases



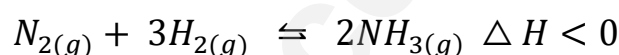
(ii) Decrease in concentration of N_2

- A decrease in N_2 (reactant) favours the reaction that increases it
- Reverse reaction is favoured
- $[N_2]$ and $[H_2]$ increases;
- $[NH_3]$ decreases



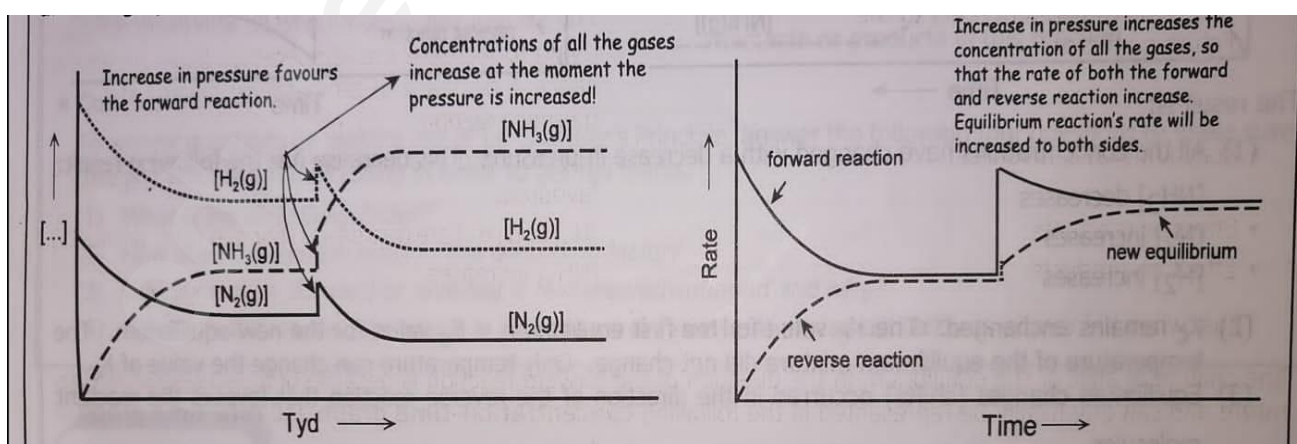
(c) Effect of change in pressure (by reducing volume)

NB: Remember to count the no. of moles of gaseous reactants and products.



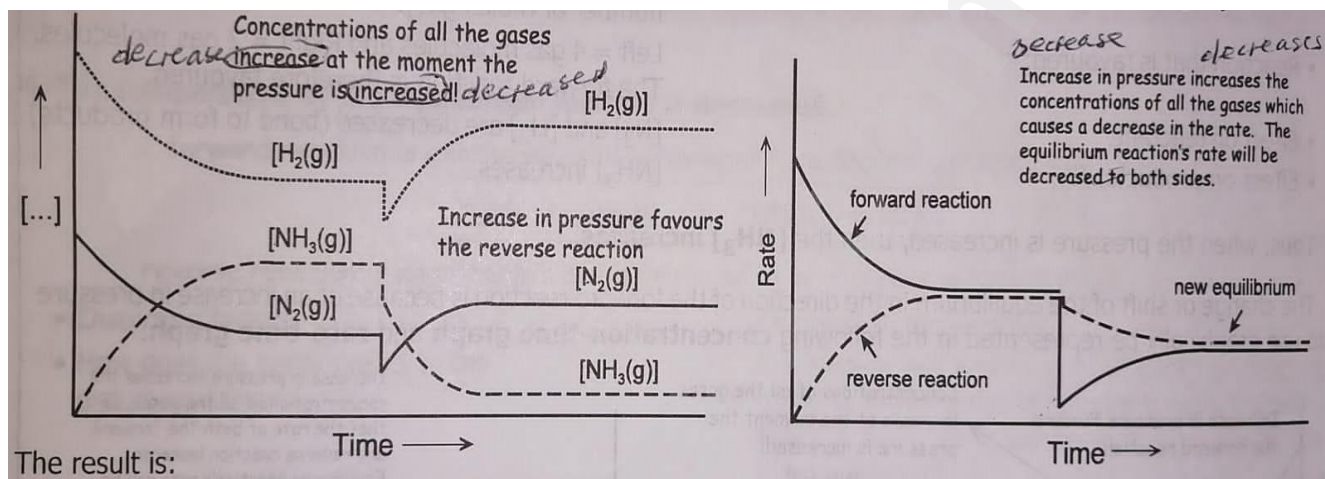
(i) Increase in pressure

- An increase in pressure favours the reaction that leads to a decrease in the no. of moles/ reduce the no. of moles
- Forward reaction is favoured (from 4 moles $\rightarrow$ 2 moles)
- $[N_2]$ and $[H_2]$ decreases;
- $[NH_3]$ increases



(ii) Decrease in pressure

- A decrease in pressure favours the reaction that leads to an increase in the no. of moles/reduce the no. of moles
- Reverse reaction is favoured (from 2 moles $\rightarrow$ 4 moles)
- $[N_2]$ and $[H_2]$ increases;
- $[NH_3]$ decreases

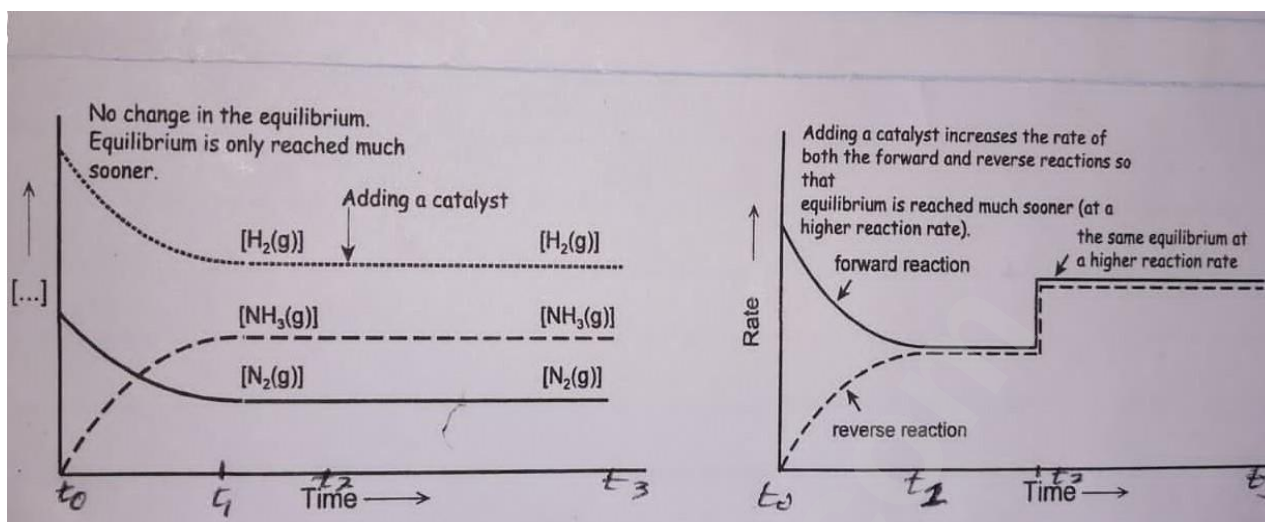


NB: when the total moles of gas reactants = total moles of gas products, change in pressure has NO EFFECT

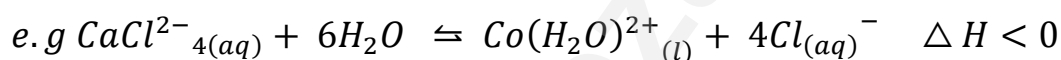
NB: Addition of an inert gas to the reaction mixture has NO EFFECT

(d) Effect of presence of catalyst

Addition of catalyst does not affect position of equilibrium it only enables equilibrium to be reached faster



Common ion effect



Add heat: colour changes to blue

Add dilute HCl : colour change to blue

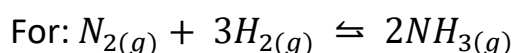
Add H_2O : colour turns pink

EQUILIBRIUM CONSTANT (K_c)

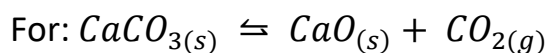
***Equilibrium constant – the ratio of the product of concentrations of products to the product of concentration of products

➤ K_c is a ratio and has no unit

NB: pure liquids and solids are not included in the K_c expression



$$K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3}$$



$$K_c = [\text{CO}_{2(g)}]$$

Significance of the value of K_c

NB: a value of $K_c = 1$ indicates that there are equal concentration of products and reactants in the reaction mixture at equilibrium

NB: A value of $K_c > 1$ indicates more products than reactants in the reaction mixture at equilibrium

NB: A value of $K_c < 1$ indicates more reactants more than products in the reaction mixture at equilibrium

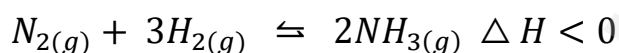
K_c and Le Chatelier's Principle

Temperature increase	-forward reaction forward -[products] increases -[reactants] decreases - K_c increases	-Reverse reaction forward -[reactants] increases -[products] decreases - K_c decreases	
Temperature decreases	-Reverse reaction forward -[reactants] increases -[products] decreases - K_c decreases	-forward reaction forward -[products] increases -[reactants] decreases - K_c increases	

CALCULATIONS ON K_c

Examples

1. Consider the following equilibrium:



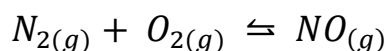
9 moles of N_2 and 15 moles of H_2 are pumped into a 500cm^3 container at room temperature. The temperature of the gas mixture is now raised to 405°C resulting in 8 mol NH_3 being present at equilibrium.

Calculate the value of K_c at 405°C

	N_2	H_2	NH_3	Note
R	1	3	2	From balanced equation
I	9	15	0	There are no products yet i.e 0
C	-4	-12	+8	Correct ration
E	5	3	8	Reactants decreases while products increase
$c = \frac{n}{v}$	$\frac{5}{0,5} = 10$	$\frac{3}{0,5} = 6$	$\frac{8}{0,5} = 16$	

$$K_c = \frac{[NH_3]^2}{[N_2][H_2]^3} = \frac{(16)^2}{(10)(6)^3} = 0,12$$

2. During a research experiment carried out by initially adding 1mol of $O_{2(g)}$ and 1 mol of $N_{2(g)}$ in a 2dm^3 closed container at 300k, it was found that the concentration of the $NO_{(g)}$ present in the container at equilibrium was $0,1\text{mol} \cdot \text{dm}^{-3}$. The reaction is:

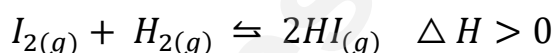


Calculate the equilibrium constant, K_c , for the reaction at this temperature [8]

	$N_{2(g)}$	$O_{2(g)}$	$NO_{(g)}$	
R	1	1	2	
I	1	1	0	
C	-0,1	-0,1	+0,2	
E	0,9	0,9	0,2	
$c = \frac{n}{v}$	$\frac{0,9}{2} = 0,45$	$\frac{0,9}{2} = 0,45$	0,1	$c = \frac{n}{v}$ $n = cV = (0,1)(2)$

$$K_c = \frac{[NO]^2}{[N_2][O_2]} = \frac{(0,1)^2}{(0,45)(0,45)} = 4,94 \times 10^{-2}$$

3. 8 mol HI is placed in an empty reaction vessel containing 2 mol $I_{2(g)}$ and $H_{2(g)}$. The reaction chamber is at a temperature of $130^\circ C$ with a volume of 500 cm^3 . When the equilibrium is reached, there are 4 mol of HI left.

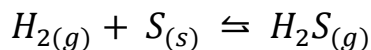


Calculate the equilibrium constant for this reaction at $130^\circ C$

	I_2	H_2	HI
R	1	1	2
I	2	0	8
C	+2	+2	-4
E	4	2	4
$c = \frac{n}{v}$	$\frac{4}{0,5} = 8$	$\frac{2}{0,5} = 4$	$\frac{4}{0,5} = 8$

$$K_c = \frac{[HI]^2}{[I_2][H_2]} = \frac{(8)^2}{(8)(4)} = 0,5$$

4. 0,40mol $H_{2(g)}$ and an excess of Sulphur(s) powder are sealed in a $2dm^3$ container at a temperature of 360K. the reaction reaches equilibrium as follows:



The value of K_c for the reaction is 6.8×10^{-2} at this temperature.

Calculate the concentration of $H_2S_{(g)}$ at equilibrium

	$H_{2(g)}$	S	$H_2S_{(g)}$
R	1	1	1
I	0,4	-	0
C	-x		+x
E	0,4-x		x
$C = \frac{n}{v}$	$\frac{0,4 - x}{2}$		$\frac{x}{2}$

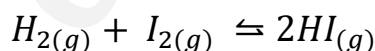
$$K_c = \frac{[H_2S]}{[H_2]} = \frac{\frac{x}{2}}{\frac{0,4 - x}{2}} = 6,8 \times 10^{-2}$$

$$\Rightarrow x = 0,0272 - 0,068x$$

$$x = 0,025 \text{ mol}$$

$$[H_2S] = \frac{x}{2} = \frac{0,025}{2} = 0,0125 \text{ mol} \cdot \text{dm}^{-3}$$

5. Hydrogen and iodine react in a closed $1,5dm^3$ container at a constant temperature of $490^\circ C$. The reaction reaches equilibrium as follows:



The K_c at this temperature is 45,9. Calculate the concentration of HI at equilibrium, if 0,4mol H_2 and 0,4mol I_2 were initially injected into the container

	H_2	I_2	HI
R	1	1	2
I	0,4	0,4	0
C	-x	-x	+2x
E	0,4-x	0,4-x	2x
$c = \frac{n}{v}$	$\frac{0,4-x}{1,5}$	$\frac{0,4-x}{1,5}$	$\frac{2x}{1,5}$

$$K_c = \frac{[HI]^2}{[I_2][H_2]}$$

$$2,708 - 6,77x = 2x$$

$$= \frac{\left(\frac{2x}{1,5}\right)^2}{\left(\frac{0,4-x}{1,5}\right)\left(\frac{0,4-x}{1,5}\right)}$$

$$8,77x = 2,708$$

$$45,9 = \frac{\left(\frac{2x}{1,5}\right)^2}{\left(\frac{0,4-x}{1,5}\right)^2}$$

$$x = 0,31 \text{ mol} \cdot \text{dm}^{-3}$$

$$6,77 = \frac{\frac{2x}{1,5}}{\frac{0,4-x}{1,5}}$$

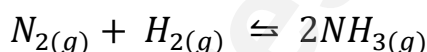
$$[HI] = \frac{2x}{1,5} = \frac{0,62}{1,5}$$

$$6,77 = \frac{3x}{0,4-x}$$

$$= 0,41 \text{ mol} \cdot \text{dm}^{-3}$$

6. An engineer injects 5mol N_2 and 5 mol H_2 into a 5dm^3 sealed empty container. Equilibrium is reached at 450°C . upon analysis of the equilibrium mixture, he finds that the mass of NH_3 is 20,4g

The reaction reaches equilibrium as follows:



Calculate the value of K_c at 450°C

[9]

	$N_{2(g)}$	$H_{2(g)}$	$NH_{3(g)}$
R	1	3	2
I	5	5	0
C	-0,6	-1,8	+1,2
E	4,4	3,2	1,2
$c = \frac{n}{v}$	$\frac{4,4}{5} = 0,88$	$\frac{3,2}{5} = 0,64$	$\frac{1,2}{5} = 0,24$

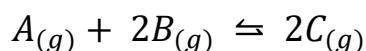
$$K_c = \frac{[NH_3]^2}{[N_2][H_2]} = \frac{(0,24)^2}{(0,88)(0,64)} = 0,25$$

CLASSWORK

MARKS

QUESTION 7

A hypothetical reaction is represented by the balanced equation below.



Initially 3 moles of $A_{(g)}$ and 6 moles of $B_{(g)}$ are mixed in a 5dm^3 sealed container. When the reaction reaches equilibrium at 25°C , it is found that 4 moles of $B_{(g)}$ is present

7.1. Define the term chemical equilibrium (2)

7.2. Show by calculation that the equilibrium concentration of $C_{(g)}$ is $0,4\text{mol}.\text{dm}^{-3}$ (3)

7.3. How will an increase in pressure, by decreasing the volume of the container, influence the amount of $C_{(g)}$ in the container at 25°C ? write down INCREASES, DECREASES, or REMAIN THE SAME. Explain the answer (3)

7.4. The initial number of moles of $B_{(g)}$ is now increased while the initial number of moles of $A_{(g)}$ remains constant at 25°C .

Calculate the number of moles of $B_{(g)}$ that must be ADDED to the original amount (6 mol) so that the concentration of $C_{(g)}$ is $0,8\text{mol}.\text{dm}^{-3}$ at equilibrium. The equilibrium constant (K_c) for this reaction at 25°C is 0,625. (9)

[17]

H/WORK

MARKS: 19

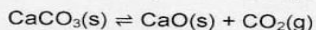
QUESTION 5

Initially, 2,2 g of pure $\text{CO}_2(\text{g})$ is sealed in an empty 5 dm^3 container at 900°C .

5.1 Calculate the initial concentration of $\text{CO}_2(\text{g})$. (4)

5.2 Give a reason why equilibrium will not be established. (1)

$\text{CaCO}_3(\text{s})$ is now added to the $2,2 \text{ g CO}_2(\text{g})$ in the container and after a while equilibrium is established at 900°C according to the following balanced equation:



The equilibrium constant for this reaction at 900°C is 0,0108.

5.3 Give a reason why this reaction will only reach equilibrium in a SEALED container. (1)

5.4 Calculate the minimum mass of $\text{CaCO}_3(\text{s})$ that must be added to the container to achieve equilibrium. (7)

5.5 How will EACH of the following changes affect the amount of $\text{CO}_2(\text{g})$? Write down only INCREASES, DECREASES or REMAINS THE SAME.

5.5.1 More $\text{CaCO}_3(\text{s})$ is added at 900°C (1)

5.5.2 The pressure is increased (1)

5.6 It is found that the equilibrium constant (K_c) for this reaction is $2,6 \times 10^{-8}$ at 727°C . Is the reaction EXOTHERMIC or ENDOTHERMIC? Fully explain how you arrived at the answer. (4)

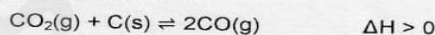
[19]

CLASSWORK

MARKS: 17

QUESTION 6

Carbon dioxide reacts with carbon in a closed system to produce carbon monoxide, $\text{CO}(\text{g})$, according to the following balanced equation:



6.1 What does the double arrow indicate in the equation above? (1)

6.2 Is the above reaction an EXOTHERMIC reaction or an ENDOTHERMIC reaction? Give a reason for the answer. (2)

Initially an unknown amount of carbon dioxide is exposed to hot carbon at 800°C in a sealed 2 dm^3 container. The equilibrium constant, K_c , for the reaction at this temperature is 14. At equilibrium it is found that $168,00 \text{ g}$ carbon monoxide is present.

6.3 How will the equilibrium concentration of the product compare to that of the reactants? Choose from LARGER THAN, SMALLER THAN or EQUAL TO.

Give a reason for the answer. (No calculation is required.) (2)

6.4 Calculate the initial amount (in moles) of $\text{CO}_2(\text{g})$ present. (9)

6.5 State how EACH of the following will affect the yield of $\text{CO}(\text{g})$ at equilibrium. Choose from INCREASES, DECREASES or REMAINS THE SAME.

6.5.1 More carbon is added at constant temperature. (1)

6.5.2 The pressure is increased. (1)

6.5.3 The temperature is increased. (1)

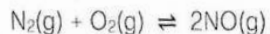
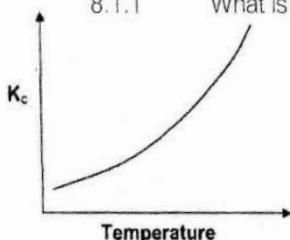
[17]

H/WORK

MARKS: 16

QUESTION 8

8.1 Consider the balanced equation for a reversible reaction below.

8.1.1 What is meant by the term *reversible reaction*? (1)

The sketch graph alongside shows the relationship between the value of the equilibrium constant (K_c) for this reaction and temperature.

8.1.2 Is the reaction ENDOTHERMIC or EXOTHERMIC? (1)

8.1.3 Fully explain the answer to QUESTION 8.1.2. (3)

How will EACH of the following changes affect the amount of $\text{NO}(\text{g})$ at equilibrium? Choose from INCREASES, DECREASES or REMAINS THE SAME.

8.1.4 More $\text{N}_2(\text{g})$ is added. (1)

8.1.5 The pressure is increased by decreasing the volume. (1)

8.2 Initially 336 g titanium (Ti) and 426 g chlorine gas (Cl_2) are mixed in a sealed 2 dm³ container at a certain temperature. The reaction reaches equilibrium according to the following balanced equation: $\text{Ti}(\text{s}) + 2\text{Cl}_2(\text{g}) \rightleftharpoons \text{TiCl}_4(\text{s})$

At equilibrium it is found that 288 g titanium is left in the container.

8.2.1 Calculate the equilibrium constant (K_c) for the reaction at this temperature. (8)

8.2.2 More titanium is now added to the equilibrium mixture. How will this change affect the yield of $\text{TiCl}_4(\text{s})$? Choose from INCREASES, DECREASES or REMAINS THE SAME. (1)

[16]