1 Chemical equilibrium

Chemical equilibrium is a dynamic equilibrium when the rate of the forward reaction equals the rate of the reverse reaction for a reversible reaction in a closed system.

- closed system: isolated from the surroundings, no reagents can escape
- reversible reaction: reverse reaction can take place

N_2 + $3H_2$ $\rightleftharpoons$ $2NH_3$

N_2 and H_2 is sealed in a container:

Initially:	Over time:	Eventually:
High [N_2] and [H_2] $\rightarrow$ Forward reaction fast [NH_3] = 0 $\rightarrow$ No reverse reaction	[N_2] & [H_2] decrease (used) $\rightarrow$ Forward reaction slower [NH_3] increases (produced) $\rightarrow$ Reverse reaction faster	Chemical equilibrium reached Forward and reverse reaction at the same rate. [N_2], [H_2] & [NH_3] constant.

Draw reaction rate vs time graphs for both reactions:

Equilibrium constant (K_c)

The equilibrium constant is the ratio of concentration of the products to the concentration of the reactants in the equilibrium mixture and the value holds only for a **specific temperature**.

aA + bB $\rightleftharpoons$ cC + dD $\quad$ $K_c = \frac{[C]^c[D]^d}{[A]^a[B]^b}$

Square brackets [ ] represent concentrations and K_c has no unit.
Pure solids and liquids/solvents are left out.

K_c > 1: More products than reactants in the equilibrium mixture.
K_c < 1: More reactants than products in the equilibrium mixture.

QUESTION 1

1.1 Write equations for the equilibrium constant for each of the following reactions:

$2H_2O_2(aq) \rightleftharpoons 2H_2O(l) + O_2(g)$	
$AgCl(s) \rightleftharpoons Ag^{+}(aq) + Cl^{-}(aq)$	
$6CO_2(g) + 6H_2O(l) \rightleftharpoons C_6H_{12}O_6(s) + 6O_2(g)$	

1.2 Ammonia is prepared according to the following reaction:

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

At a high temperature an equilibrium mixture for the above endothermic reaction has the following concentrations:

$$[NH_3] = 2\,\text{mol/dm}^3$$
$$[H_2] = 1{,}5\,\text{mol/dm}^3$$
$$[N_2] = 0{,}5\,\text{mol/dm}^3$$

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

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1.3 Hydrogen iodide can be produced by the following reversible reaction:

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad K_c = 56{,}00 \text{ at } 425°C$$

At a certain time during the reaction the concentrations in the container are:

$[H_2] = 1{,}5\,\text{mol/dm}^3$

$[I_2] = 1{,}0\,\text{mol/dm}^3$

$[HI] = 2{,}5\,\text{mol/dm}^3$

Do a calculation to determine if the reaction has reached chemical equilibrium.

1.4 Consider the following reaction: $2A(g) + B(g) \rightleftharpoons C(g)$.

12 mol A and 10 mol B are sealed in a 2 dm^3 container. At equilibrium there are 4 mole of A in the container. Calculate the K_c value.

Reaction			
Mole initially			
Mole react			
Mole at equilibrium			
Concentration at equilibrium $c = \frac{n}{V}$			

Le Chatelier's Principle:

When the equilibrium in a closed system is disturbed, the system will re-instate a new equilibrium by favouring the reaction that will oppose the disturbance.

The following dynamic equilibrium is reached in a closed container:

$$2A(g) + B(s) \leftrightarrows 2C(g) + D(g) \qquad \Delta H \text{ is negative}$$

$$K_c = \frac{[C]^2[D]}{[A]^2} \qquad c = \frac{n}{V}$$

If A is added to the mixture in the container:
Disturbance: [A] increases.
According to Le Chatelier's principle the system reacts to decrease the [A] .
The forward reaction is favoured. (Use A)
More C and D is produced.
K_c remains the same.

If C is added to the mixture in the container:
Disturbance: [C] increases.
According to Le Chatelier's principle the system reacts to decrease the [C] .
The reverse reaction is favoured. (Use C)
D decreases.
K_c remains the same.

If A is removed from the mixture in the container:
Disturbance: [A] decreases.
According to Le Chatelier's principle the system reacts to increase [A] .
The reverse reaction is favoured (make A).
C and D decreases.
K_c remains the same.

B(s) is added:
Solid has no effect on equilibrium.

If the volume of the container is decreased:
Disturbance: pressure increases (Boyle's Law).
According to Le Chatelier's principle the system reacts to lower the pressure.
Reacts to produce less moles of gas.
Reverse reaction is favoured.
C and D decreases.
K_c remains the same.

If the temperature is increased:
Disturbance: Temperature increases.
According to Le Chatelier's principle the system reacts to decrease the temperature.
Endothermic reaction is favoured (uses energy).
(ΔH is negative $\therefore$ forward reaction exothermic.)
The reverse reaction is favoured.
C and D decreases.
K_c decreases.

Catalyst is added:
No effect on equilibrium. The rate of both reactions increase **equally**.

Favoured does not indicate that the reaction happens faster than before, but that it happens faster than the reaction in the opposite direction.

Action	**Disturbance**	**Explanation**
Adding acid	$[H^+]$ increases	Acid donates H^+
Adding base	$[H^+]$ decreases	Base reacts with H^+
Adding $AgNO_3$	$[Cl^-]$ decreases	$Ag^+ + Cl^- \longrightarrow$ AgCl(s) precipitate
Adding $BaCl_2$ or $Ba(NO_3)_2$	$[SO_4{}^{-2}]$ decreases	$Ba^{+2} + SO_4{}^{-2} \longrightarrow$ $BaSO_4$(s) precipitate

The colours of compounds with transition elements are well-known. For example, consider the following equation of a reversible reaction:

$$\underbrace{2CrO_4{}^{2-}(aq)}_{\text{yellow}} + 2H^+(aq) \rightleftharpoons \underbrace{Cr_2O_7{}^{2-}(aq)}_{\text{orange}} + H_2O(\ell)$$

1. Write down an expression for te equilibrium constant.

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2. How will the equilibrium constant (K_c) be influenced in the following situations:

   a) sodium chromate (Na_2CrO_4) is added. ____________________

   b) Hydrochloric acid is added. ____________________

   c) Sodium hydoxide is added ____________________

3. Explain in detail how the colour of the solution will be influenced when sodium hydroxide is added.

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$$2A(g) + B(g) \rightleftharpoons 3C(g) + D(g)$$

	A and B into container	A added	B removed	D added
Disturbance				
Le Chatelier: System reacts to . . .				
The . . . reaction is favoured				
[C] . . .				
K_c				

Reaction rate

Concentrations

$\Delta H < 0$

Volume doubled	Temperatuur increased	Temperarature decreased	Catalyst added

Le Chatelier, Temperature and Equilibrium constants

QUESTION 2

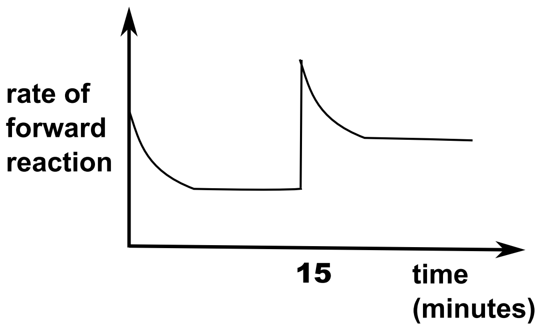
Choose the correct word in the brackets:

2.1 The following reaction is at equilibrium at 400K:
$A_2(g) + 3B_2(g) \rightleftharpoons 2AB_3(g)$ $\Delta H < 0$

If the temperature is increased to 600 K
the K_c-value will (increase/decrease/stay the same).

2.2 A mixture of NO and Br_2 is placed in a container. The following traction occurs: $2NO(g) + Br_2(g) \rightleftharpoons 2NOBr(g)$

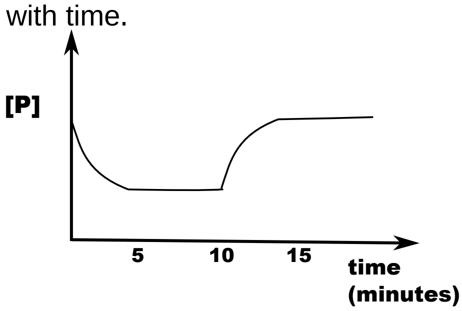
After 5 minutes chemical equilibrium is reached. The following graph shows how the rate of the forward reaction changes with time:



After 15 s the temperature was (increased/decreased) and
the K_c=value (increased/fecreased/remained constant).

2.3 P and Q are sealed in a container and the following chemical equilibrium is reached after 5 minutes at 500 K: $P(g) + 2Q(g) \rightleftharpoons R(g)$

After 10 minutes the temperature is increased to 600 K and after 5 minutes a new chemical equilibrium is established. The following graph shows the change in concentration with time.



The K_c-value (increased/decreased/remained constant).
ΔH for the reaction is (positive/negative).

2.4 The following reaction mixture turns more red when the temperature is increased:

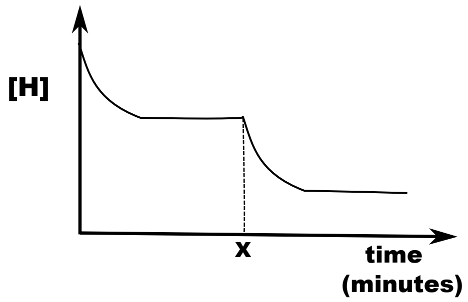
$$\underbrace{3H(g)}_{\text{pink}} \rightleftharpoons \underbrace{2F(g)}_{\text{red}} + 2D(g)$$

When the temperature is increased the equilibrium constant (increases/decreases).

ΔH is (positive/negative).

2.5 The following reaction reached chemical equilibrium in a closed container:

$2H(g) + I(g) \rightleftharpoons 2\,K(g) \qquad \Delta H < 0$



At time X the temperature was (increased/decreased) and
the K_c-value (increases/decreases/remains constant).

2.6 The following reaction is in chemical equilibrium:

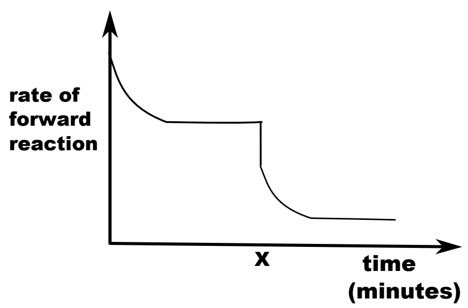
$$\underbrace{3M(g)}_{\text{green}} \rightleftharpoons \underbrace{2N(g)}_{\text{blue}} + 2P(g)$$

When the temperature increases the mixture turns more blue.

ΔH is (positive/negative).

2.7 The following reaction reached chemical equilibrium in a closed container:

$2X(g) + Y(g) \rightleftharpoons Z(g) + 2A(g)$



After time X the K_c value is (larger/smaller) than before.
The heat of the reaction is (positive/negative).

$$2A(g) + B(g) \rightleftarrows 3C(g) + D(g) \qquad \Delta H < 0$$

forwards exothermic

	A and B in a container	A added	B removed	D added	Volume doubled	Temperature increased	Temperature decreased	Catalyst added
Disturbance		[A]↑	[B]↓	[D]↑	P↓	T↑	T↓	Both reactions equally faster
Le Chatelier's principle: the system reacts to ...		[A]↓	[B]↑	[D]↓	P↑	T↓	T↑	
The ... reaction is favoured		forward	reverse	reverse	more mol gas forward	endothermic reverse	exothermic forward	
[C] will ...		↑	↓	↓	↑	↓	↑	
Kc ...		constant	constant	constant	constant	↓	↑	constant