CHAPTER 0

Chemical Equilibrium

0.1 True or false:(a) At equilibrium, the rate of the reverser reaction is twice the rate of the forward reaction (b) At equilibrium, the concentration of products do not change (c) At equilibrium, the concentration of reactants do not change (d) At equilibrium, the concentration of reactants and products do not change

0.2 True or false:(a) At equilibrium, the rate of the reverse reaction do not change (b) At equilibrium, the rate of the forward reaction do not change (c) At equilibrium, the rate of the reverse reaction equals the rate of the forward reaction (d) At equilibrium, the concentration of reactants and products are not constant

Equilibrium constants

0.3 Write down the forward and reverse reactions for the following reactions in equilibrium:

(a) $CH_{4(g)} + O_{2(g)} \rightleftharpoons CO_{2(g)} + H_2O_{(g)}$

(b) $2\,Mg_{(s)} + O_{2(g)} \rightleftharpoons 2\,MgO_{(s)}$

0.4 For the reactions below and given the value of the equilibrium constant indicate whether the equilibrium mixture will have: (a) More reactants than products (b) More products than reactants (c) Same amount of products and reactants

(a) $CO_{2(g)} + H_2O_{(g)} \rightleftharpoons CH_{4(g)} + O_{2(g)}$ $\quad K_c = 0.001$

(b) $N_{2(g)} + O_{2(g)} \rightleftharpoons 2\,NO_{(g)}$ $\quad K_c = 2 \cdot 10^{25}$

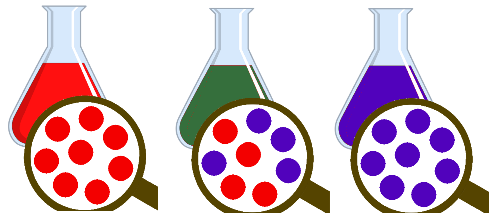
(c) $2\,NO_{(g)} + O_{2(g)} \rightleftharpoons 2\,NO_{2(g)}$ $\quad K_c = 6.4 \cdot 10^{9}$

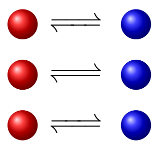
0.5 For the reactions below and given the value of the equilibrium constant indicate whether the equilibrium mixture will have: (a) More reactants than products (b) More products than reactants (c) Same amount of products and reactants

(a) $N_{2(g)} + 3\,H_{2(g)} \rightleftharpoons 2\,NH_{3(g)}$ $\quad K_c = 1$

(b) $2\,NO_{(g)} + Cl_{2(g)} \rightleftharpoons 2\,NOCl_{(g)}$ $\quad K_c = 6.5 \cdot 10^{4}$

0.6 Indicate which of the following diagrams represent better the system at equilibrium:





(a) $K_c = 10$

(b) $K_c = 0.1$

(c) $K_c = 1$

0.7 Write down the expression of K_c for the following reaction:

(a) $2\,SO_{2(g)} + O_{2(g)} \rightleftharpoons 2\,SO_{3(g)}$

(b) $CO_{(g)} + 2\,H_{2(g)} \rightleftharpoons CH_3OH_{(g)}$

(c) $C_2H_{6(g)} + Cl_{2(g)} \rightleftharpoons C_2H_2Cl_{(s)} + HCl_{(g)}$

0.8 Write down the expression of K_c for the following reaction:

(a) $BaCO_{3(s)} \rightleftharpoons Ba^{2+}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$

(b) $2\,H_{2(g)} + O_{2(g)} \rightleftharpoons 2\,H_2O_{(l)}$

Using equilibrium constants

0.9 The reaction of carbon monoxode with hydrogen to produce methanol has a equilibrium constant in terms of concentration that at a certain temperature is larger than one

$$CO(g) + 2\,H_2(g) \rightleftharpoons CH_3OH(g) \qquad K_c = 14.5$$

Calculate: (a) the equilibrium concentration of hydrogen (H_2) given that the equilibrium concentration of methanol (CH_3OH) and carbon monoxice (CO) for the reaction is 2M, respectively. (b) the equilibrium concentration of hydrogen (H_2) given that the equilibrium concentration of methanol (CH_3OH) and carbon monoxide (CO) for the reaction are 3M and 1M, respectively.

0.10 Consider the following reaction:

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

(a) Write down the expression of K. (b) Calculate the numerical value of K for the reaction if the concentrations at equilibrium at 1000K are 2M for SO_3, 0.3M for O_2 and 1M for SO_2. (c) indicate whether an equilibrium mixture will contain mostly products, mostly reactants or maybe both.

0.11 Complete the table and calculate K_c and K_p at 300K:

	Reaction	K_c	K_p
(a)	$2\,NH_{3(g)} \rightleftharpoons N_{2(g)} + 3\,H_{2(g)}$	17	
(b)	$2\,SO_{3(g)} \rightleftharpoons 2\,SO_{2(g)} + O_{2(g)}$	0.243	
(c)	$SO_2Cl_{2(g)} \rightleftharpoons SO_{2(g)} + Cl_{2(g)}$		0.05
(d)	$Cl_{2(g)} + Br_{2(g)} \rightleftharpoons 2\,BrCl_{2(g)}$		0.196

Concentration ratio

0.12 For the reactions below indicate whether they will evolve towards the right or towards the left in order to reach equilibrium.

	Reaction	K_c	Q
(a)	$2\,NH_{3(g)} \rightleftharpoons N_2 + 3\,H_2$	17	20
(b)	$2\,SO_{3(g)} \rightleftharpoons 2\,SO_{2(g)} + O_{2(g)}$	0.243	10
(c)	$H_{2(g)} + I_2 \rightleftharpoons 2\,HI_{(g)}$	50	0.1
(d)	$H_2O_{(l)} \rightleftharpoons H_2O_{(g)}$	0.196	0.196

0.13 For the decomposition of calcium chloride hexahydrate

$$CaCl_2 \cdot 6\,H_2O(s) \rightleftharpoons CaCl_2(s) + 6\,H_2O(g)$$

we have that K_c=3.5 × 10^{-54} and Q=10 at 300K. Indicate towards which direction the reaction will evolve to reach equilibrium.

Le Châtelier principle

0.14 Using the Le Châtelier principle indicate whether the reaction below

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

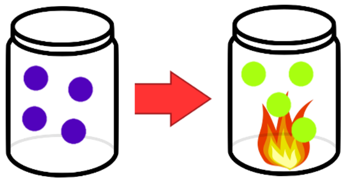
will shift in the direction of products ($\longrightarrow$) or reactants ($\longleftarrow$) after the following actions: (a) add SO_2 (b) add SO_3(c) remove O_2

0.15 According to Le Châtelier principle indicate whether the reaction will shift in the direction of products ($\longrightarrow$) or reactants ($\longleftarrow$):

(a) $CO(g) + 2\,H_2(g) \rightleftharpoons CH_3OH(g) + \text{Heat}$ increase temperature

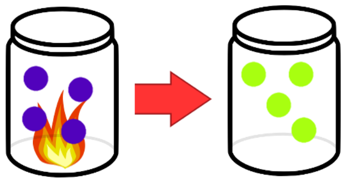
(b) $2\,B(s) + 3\,H_2(g) + \text{Heat} \rightleftharpoons B_2H_6(g)$ increase temperature

0.16 According to Le Châtelier principle indicate whether the following reaction will shift in the direction of products ($\longrightarrow$) or reactants ($\longleftarrow$) after the following changes:



(a) adding reactants (b) increasing temperature (c) decreasing temperature

0.17 According to Le Châtelier principle indicate whether the following reaction will shift in the direction of products ($\longrightarrow$) or reactants ($\longleftarrow$) after the following changes:



(a) adding products (b) removing products(c) increasing temperature

Answers **0.1** (a) At equilibrium, the rate of the reverser reaction is twice the rate of the forward reaction (False) (b) At equilibrium, the concentration of products do not change (False) (c) At equilibrium, the concentration of reactants do not change (False) (d) At equilibrium, the concentration of reactants and products do not change (True) **0.2** (a) At equilibrium, the rate of the reverse reaction do not change (True) (b) At equilibrium, the rate of the forward reaction do not change (True) (c) At equilibrium, the rate of the reverse reaction equals the rate of the forward reaction (True) (d) At equilibrium, the concentration of reactants and products are not constant (False) **0.3** (a) $CH_{4(g)} + O_{2(g)} \longrightarrow CO_{2(g)} + H_2O_{(g)}$; $CH_{4(g)} + O_{2(g)} \longleftarrow CO_{2(g)} + H_2O_{(g)}$ (b) $2\,Mg_{(s)} + O_{2(g)} \longrightarrow 2\,MgO_{(s)}$;$2\,Mg_{(s)} + O_{2(g)} \longleftarrow 2\,MgO_{(s)}$ **0.4** (a) More reactants (b) More products (c) More products **0.5** (a) same amount (b) More products **0.6** (a) Left (b) Right (c) Center **0.7** (a) $K_c = \frac{\left[SO_3\right]^2}{\left[SO_2\right]^2 \cdot \left[O_2\right]}$; $K_p = \frac{p^2_{SO_3}}{p^2_{SO_2} \cdot p_{O_2}}$ (b) $K_c = \frac{\left[CH_3OH\right]}{\left[H_2\right]^2 \cdot \left[CO\right]}$;$K_p = \frac{p_{CH_3OH}}{p^2_{H_2} \cdot p_{CO}}$ (c) $K_c = \frac{\left[HCl\right]}{\left[C_2H_6\right] \cdot \left[Cl_2\right]}$; $K_p = \frac{p_{HCl}}{p_{C_2H_6} \cdot p_{Cl_2}}$ **0.8** (a) $\left[Ba^{2+}\right] \cdot \left[{CO_3}^{2-}\right]$ (b) $\frac{1}{\left[H_2\right]^2 \cdot \left[O_2\right]}$ **0.9** (a) 0.034 M (b) 0.46M **0.10** (a) $\frac{\left[SO_3\right]^2}{\left[SO_2\right]^2 \cdot \left[O_2\right]}$ (b) 3.4 (c) mostly products **0.11** (a) K_c =17 ;K_p =10288 (b) K_c =0.243 ;K_p =5.977 (c) K_c =2×10^{-3} ;K_p =0.05 (d) K_c =0.196 ;K_p =0.196 **0.12** (a) $< -$ (b) $< -$ (c) $- >$ (d) $<=>$ (e) $< -$ **0.13** $< -$ **0.14** (a) $\longrightarrow$ (b) $\longleftarrow$ (c) $\longleftarrow$ **0.15** (a) $\longleftarrow$ (b) $\longrightarrow$ **0.16** (a) $\longrightarrow$ (b) $\longleftarrow$ (c) $\longrightarrow$ **0.17** (a) $\longleftarrow$ (b) $\longrightarrow$ (c) $\longrightarrow$