

Worksheet #1: Equilibrium Constants

Write the expression for the equilibrium constant K_{eq} for the reaction below:

Using the equilibrium constant expressions you determined in column 1, calculate the value of K_{eq} when the following concentrations are present:

1) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$	$[NH_3] = 0.0100 \text{ M}; [N_2] = 0.0200 \text{ M}; [H_2] = 0.0200$
2) $2KClO_3(s) \rightleftharpoons 2KCl(s) + 3O_2(g)$	$[O_2] = 0.0500 \text{ M}; [KCl] = 0.00250 \text{ M}; [KClO_3] = 2.00 \text{ M}$
3) $H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq)$	$[H^+] = 1 \times 10^{-8} \text{ M}; [OH^-] = 1 \times 10^{-6} \text{ M}; [H_2O] = 1 \times 10^{-14} \text{ M},$
4) $2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g)$	$[CO] = 2.0 \text{ M}; [O_2] = 1.5 \text{ M}; [CO_2] = 3.0 \text{ M}$
5) $Li_2CO_3(s) \rightleftharpoons 2Li^+(aq) + CO_3^{2-}(aq)$	$[Li^+] = 0.20 \text{ M}; [CO_3^{2-}] = 0.10 \text{ M}; [Li_2CO_3] = 6.0 \text{ M}$

Worksheet 2 - Equilibrium Expressions and Calculations (K_{eq} and Q)

1. Write the equilibrium expression for the oxidation of hydrogen to form water vapor.
 $2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{H}_2\text{O}(\text{g})$

2. Write the equilibrium expression for the formation of nitrosyl bromide.
 $2\text{NO}(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2\text{NOBr}(\text{g})$

3. Write the equilibrium expression for the following reaction:
 $\text{NO}(\text{g}) + \text{O}_3(\text{g}) \rightleftharpoons \text{O}_2(\text{g}) + \text{NO}_2(\text{g})$

4. Write the equilibrium expression for the following reaction:
 $\text{CH}_4(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{Cl}(\text{g}) + \text{HCl}(\text{g})$

5. Write the equilibrium expression for the following reaction:
 $\text{CH}_4(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}(\text{g}) + 3\text{H}_2(\text{g})$

6. Write the equilibrium expression for the following reaction:
 $\text{CO}(\text{g}) + 2\text{H}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{OH}(\text{g})$

7. Write the equilibrium expression for the combustion of ethane at high temperature.
 $2\text{C}_2\text{H}_6(\text{g}) + 7\text{O}_2(\text{g}) \rightleftharpoons 4\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{g})$

8. Write the equilibrium expression for the decomposition of ethane.
 $\text{C}_2\text{H}_6(\text{g}) \rightleftharpoons \text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g})$

Worksheet 2 - Equilibrium Expressions and Calculations (K_{eq} and Q) continued...

9. Ammonia is synthesized from nitrogen and hydrogen in the following reaction:
 $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$
At 500 °C, the equilibrium constant for this reaction is 0.080.
Given that $[NH_3] = 0.0596$ M, $[N_2] = 0.600$ M, and $[H_2] = 0.420$ M, find Q and predict how the reaction will proceed.
10. The decomposition of antimony pentachloride ($SbCl_5$) is described by the following equation:
 $SbCl_5(g) \rightleftharpoons SbCl_3(g) + Cl_2(g)$
At 448 °C, the equilibrium constant for this reaction is 0.0251. What is the value of Q if $[SbCl_5] = 0.095$ M, $[SbCl_3] = 0.020$ M, and $[Cl_2] = 0.050$ M? How will this reaction proceed?
11. At 1000 °C, $K_{eq} = 1.0 \times 10^{-13}$ for the decomposition of hydrofluoric acid (HF), as described in the reaction **$2HF(g) \rightleftharpoons H_2(g) + F_2(g)$** .
If $[HF] = 23.0$ M, $[H_2] = 0.540$ M, and $[F_2] = 0.380$ M, determine the value of Q and predict how the reaction will proceed.
12. At 1227 °C, K_{eq} for the following reaction is 0.15: **$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$**
If $[SO_2] = 0.344$ M, $[O_2] = 0.172$ M, and $[SO_3] = 0.056$ M, find Q and determine how the reaction will proceed.

Worksheet #3: LE CHATELIER'S PRINCIPLE

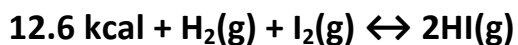
Le Chatelier's Principle states that when a system at equilibrium is subjected to a stress, the system will shift its equilibrium point in order to relieve the stress.

Complete the following chart by writing left, right or none for equilibrium shift, and decreases, increases or remains the same for the concentrations of reactants and products, and for the value of K.

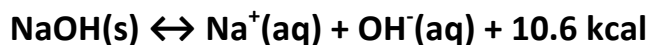


Stress	Equilibrium Shift	[N ₂]	[H ₂]	[NH ₃]	K
1. Add N ₂	Right	_____	decreases	increases	Remains the same
2. Add H ₂			_____		
3. Add NH ₃				_____	
4. Remove N ₂		_____			
5. Remove H ₂			_____		
6. Remove NH ₃				_____	
7. Increase Temperature					
8. Decrease Temperature					
9. Increase Pressure					
10. Decrease Pressure					

WS #3: LE CHATELIER'S PRINCIPLE continued...



Stress	Equilibrium Shift	[H ₂]	[I ₂]	[HI]	K _{eq}
1. Add H ₂	right	_____	decreases	increases	Remains the same
2. Add I ₂			_____		
3. Add HI				_____	
4. Remove H ₂		_____			
5. Remove I ₂			_____		
6. Remove HI				_____	
7. Increase Temperature					
8. Decrease Temperature					
9. Increase Pressure					
10. Decrease Pressure					



(Remember that pure solids and liquids do not affect equilibrium values.)

Stress	Equilibrium Shift	Amount of NaOH(s)	[Na ⁺]	[OH ⁻]	K _{eq}
1. Add NaOH(s)		_____			
2. Add NaCl (adds Na ⁺)			_____		
3. Add KOH (adds OH ⁻)				_____	
4. Add H ⁺ (removes OH ⁻)				_____	
5. Increase temperature					
6. Decrease temperature					
7. Increase Pressure					
8. Decrease Pressure					

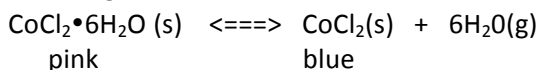
Worksheet #4: Equilibrium Problem Set

1. For each of the following reactions, describe what effect and **increase in pressure** would have on the equilibrium position of the reaction (i.e. shift right, shift left, no change)

- a) $2\text{H}_2\text{S}(\text{g}) \rightleftharpoons 2\text{H}_2(\text{g}) + \text{S}_2(\text{g})$
- b) $2\text{N}_2\text{O}_5(\text{g}) \rightleftharpoons 4\text{NO}_2(\text{g}) + \text{O}_2(\text{g})$
- c) $4\text{NO}(\text{g}) + 2\text{O}_2(\text{g}) \rightleftharpoons 2\text{N}_2\text{O}_4(\text{g})$
- d) $2\text{NO}(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2\text{NOBr}(\text{g})$
- e) $\text{CO}(\text{g}) + 2\text{H}_2(\text{g}) \rightleftharpoons \text{CH}_3\text{OH}(\text{g})$
- f) $\text{SO}_2(\text{g}) + \text{NO}_2(\text{g}) \rightleftharpoons \text{SO}_3(\text{g}) + \text{NO}(\text{g})$

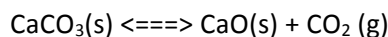
- 2. In which direction would the equilibrium shift for the equation in 1a if S_2 were removed from the reaction vessel?
- 3. In which direction would the equilibrium shift for the equation in 1b if N_2O_5 were added?
- 4. In which direction would the equilibrium shift for the equation in 1c if O_2 were removed?
- 5. In which direction would the equilibrium shift for the equation in 1d if pressure were decreased?
- 6. In which direction would the equilibrium shift for the equation in 1e if CH_3OH were removed?
- 7. In which direction would the equilibrium shift for the equation in 1f if heat were added? (the rxn is endothermic).
- 8. What would be the effect on the equilibrium position of an equilibrium mixture of Br_2 , F_2 , and BrF_5 if the total pressure of the system were decreased? $2\text{BrF}_5(\text{g}) \rightleftharpoons \text{Br}_2(\text{g}) + 5\text{F}_2(\text{g})$
- 9. What would be the effect on the equilibrium position of an equilibrium mixture of carbon, oxygen, and carbon monoxide if the total pressure of the system were decreased?
 $2\text{C}_2(\text{s}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{CO}(\text{g})$

10. A weather indicator can be made with a hydrate of cobalt (II) chloride, which changes color as a result of the following reaction:



Does a pink color indicate "moist" or "dry" air? Explain.

11. Consider the reaction:

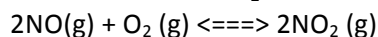


Will the mass of CaCO_3 at equilibrium increase, decrease or remain the same if

- (a) CO_2 is added to the equilibrium system?
- (b) the pressure is increased?
- (c) solid CaO is removed?

WS #4: Equilibrium Problem Set Continued...

12. The reaction between NO and O₂ is exothermic.



Will the concentration of NO₂ at equilibrium increase, decrease, or remain the same if

- (a) additional O₂ is introduced?
(b) additional NO is introduced?
(c) the total pressure is decreased?
(d) the temperature is increased?
13. Predict whether the equilibrium for the photosynthesis reaction described by the equation:
- $$6\text{CO}_2(g) + 6\text{H}_2\text{O}(\ell) \rightleftharpoons \text{C}_6\text{H}_{12}\text{O}_6(s) + 6\text{O}_2(g) \quad \Delta H^\circ = 2801.69 \text{ kJ/mol}$$
- would shift to the right, shift to the left, or remain unchanged if
- (a) [CO₂] were increased;
(b) P_{O₂} were increased;
(c) one half of the C₆H₁₂O₆ were removed;
(d) the total pressure were decreased;
(e) the temperature were decreased;
(f) a catalyst were added.
14. What would be the effect of increasing the temperature on each of the following systems at equilibrium?
- a) $\text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) + 9.45 \text{ kJ}$
b) $\text{PCl}_5(g) + 92.5 \text{ kJ} \rightleftharpoons \text{PCl}_3(g) + \text{Cl}_2(g)$
c) $2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g); \Delta H^\circ = -198 \text{ kJ/mol}$
d) $2\text{NOCl}(g) \rightleftharpoons 2\text{NO}(g) + \text{Cl}_2(g); \Delta H^\circ = 75 \text{ kJ/mol}$
e) $\text{C}(s) + \text{H}_2\text{O}(g) + 131 \text{ kJ} \rightleftharpoons \text{CO}(g) + \text{H}_2(g)$
15. What would be the effect of increasing the pressure by decreasing the volume on each of the following systems at equilibrium?
- a) $2\text{CO}(g) + \text{O}_2(g) \rightleftharpoons 2\text{CO}_2(g)$
b) $2\text{NO}(g) \rightleftharpoons \text{N}_2(g) + \text{O}_2(g)$
c) $\text{N}_2\text{O}_4(g) \rightleftharpoons 2\text{NO}_2(g)$
d) $\text{Ni}(s) + 4\text{CO}(g) \rightleftharpoons \text{Ni}(\text{CO})_4(g)$
e) $\text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g)$
16. The value of K_c is 0.020 at 2870° for the reaction shown below. There are 0.800 mole of N₂, 0.500 mole of O₂, and 0.400 mole of NO in a 1.00-liter container at 2870°C. Is the system at equilibrium or must the forward or reverse action occur to a greater extent to bring the system to equilibrium?
- $$\text{N}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{NO}(g)$$
17. Given: $\text{A}(g) + \text{B}(g) \rightleftharpoons \text{C}(g) + \text{D}(g)$
At equilibrium a 1.00-liter container was found to contain 1.60 mole of C, 1.60 mol of D, 0.40 mol of A, and 0.40 mole of B. Calculate the equilibrium constant for this reaction.