

Problems - Chapter 15 (without solutions)

1) What is the significance of the equilibrium constant? What does a large equilibrium constant tell us about a reaction? A small one?

2) (15.18) Write equilibrium constants for  $K_C$ , and, if applicable, for  $K_p$ , for the following processes:

- a)  $2 \text{CO}_2(\text{g}) \rightleftharpoons 2 \text{CO}(\text{g}) + \text{O}_2(\text{g})$
- b)  $3 \text{O}_2(\text{g}) \rightleftharpoons 2 \text{O}_3(\text{g})$
- c)  $\text{CO}(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{COCl}_2(\text{g})$
- d)  $\text{H}_2\text{O}(\text{g}) + \text{C}(\text{s}) \rightleftharpoons \text{CO}(\text{g}) + \text{H}_2(\text{g})$
- e)  $\text{HCOOH}(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{HCOO}^-(\text{aq})$
- f)  $2 \text{HgO}(\text{s}) \rightleftharpoons 2 \text{Hg}(\ell) + \text{O}_2(\text{g})$

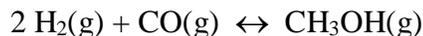
3) The reaction below has an equilibrium constant  $K_p = 2.2 \times 10^6$  at 298. K



Calculate  $K_p$  for each of the reactions below (at the same temperature) and predict whether reactants or products will be favored at equilibrium

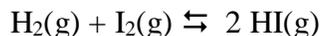
- a)  $\text{COF}_2(\text{g}) \rightleftharpoons \frac{1}{2} \text{CO}_2(\text{g}) + \frac{1}{2} \text{CF}_4(\text{g})$
- b)  $6 \text{COF}_2(\text{g}) \rightleftharpoons 3 \text{CO}_2(\text{g}) + 3 \text{CF}_4(\text{g})$
- c)  $2 \text{CO}_2(\text{g}) + 2 \text{CF}_4(\text{g}) \rightleftharpoons 4 \text{COF}_2(\text{g})$

4) (15.12) The equilibrium constant for the reaction



is  $K_C = 1.6 \times 10^{-2}$  at a certain temperature. It is found that there are  $1.17 \times 10^{-2}$  moles of  $\text{H}_2$  and  $3.46 \times 10^{-7}$  moles of  $\text{CH}_3\text{OH}$  in a 5.60 L system at equilibrium at this temperature. What is the concentration of  $\text{CO}$  in the system?

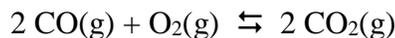
5) Consider the following reaction



Complete the table below. You may assume that all concentrations are equilibrium concentrations in units of mol/L.

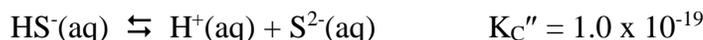
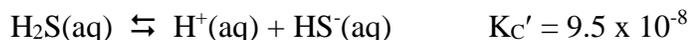
T(°C)	[H <sub>2</sub> ]	[I <sub>2</sub> ]	[HI]	K <sub>C</sub>
25.0	0.0355	0.0388	0.922	----
340.0	----	0.0455	0.387	96.
445.0	0.0485	0.0468	----	50.2

6) (15.24) What is the numerical value for  $K_p$  at  $T = 1273. \text{ }^\circ\text{C}$  for the reaction

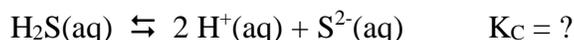


At this temperature  $K_C = 2.24 \times 10^{22}$ .

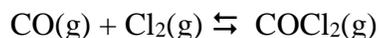
7) (15.34) The following equilibrium constants have been determined for hydrosulfuric acid at  $T = 25.0 \text{ }^\circ\text{C}$



Find the equilibrium constant for the following reaction at the same temperature



8) For the reaction below,  $K_C = 255$ . at  $T = 1000. \text{ K}$



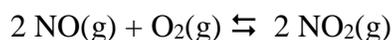
A reaction mixture (kept at  $T = 1000. \text{ K}$ ) initially contains no  $\text{COCl}_2$ . The initial concentrations of  $\text{CO}$  and  $\text{Cl}_2$  are  $[\text{CO}] = 0.1500 \text{ M}$ , and  $[\text{Cl}_2] = 0.1750 \text{ mol/L}$ . What are the equilibrium concentrations of  $\text{CO}$ ,  $\text{Cl}_2$ , and  $\text{COCl}_2$ ?

9) Consider the reaction



If the reaction (kept at  $T = 227. \text{ }^\circ\text{C}$ ) initially contains  $0.175 \text{ mol/L SO}_2\text{Cl}_2$  (and no  $\text{SO}_2$  or  $\text{Cl}_2$ ), what is the equilibrium concentration of  $\text{Cl}_2$ ?

10) The equilibrium constant for the reaction



is  $K_C = 6.9 \times 10^5$  at  $T = 500. \text{ K}$ . Consider a system at this temperature where the initial concentration of  $\text{NO}_2$  is  $[\text{NO}_2] = 0.1000 \text{ mol/L}$ , and where no  $\text{NO}$  or  $\text{O}_2$  are initially present. What are the concentrations of  $\text{NO}$ ,  $\text{O}_2$ , and  $\text{NO}_2$  when equilibrium is reached?

11) In which direction will a reaction proceed for each of the following conditions:

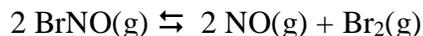
- a)  $Q < K$       b)  $Q > K$       c)  $Q = K$

12) Consider the reaction



A reaction mixture contains 0.112 atm of  $\text{H}_2$ , 0.055 atm of  $\text{S}_2$ , and 0.445 atm of  $\text{H}_2\text{S}$ . Is the reaction mixture at equilibrium? If not, in what direction will the reaction proceed?

13) Consider this reaction at equilibrium



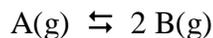
Predict whether the reaction will shift left, shift right, or remain unchanged after each disturbance.

- NO is added to the reaction mixture.
- BrNO is added to the reaction mixture.
- Br<sub>2</sub> is removed from the reaction mixture.

14) Each of the following reactions is allowed to come to equilibrium, and the volume is then changed as indicated. Predict the effect (shift right, shift left, or no effect) of the indicated volume change.

- $\text{CO}(\text{g}) + \text{H}_2\text{O}(\text{g}) \rightleftharpoons \text{CO}_2(\text{g}) + \text{H}_2(\text{g})$       volume is decreased
- $\text{PCl}_3(\text{g}) + \text{Cl}_2(\text{g}) \rightleftharpoons \text{PCl}_5(\text{g})$       volume is increased
- $\text{CaCO}_3(\text{s}) \rightleftharpoons \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$       volume is increased

15) (15.86) Consider the following reaction



Data for this reaction for systems at equilibrium are given below.

T(°C)	[A] (M)	[B] (M)
200.0	0.0125	0.843
300.0	0.171	0.764
400.0	0.250	0.724

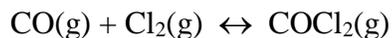
- Find the value for  $K_C$  and  $K_p$  at each of the above temperatures.
- Is the above reaction exothermic or endothermic? Justify your answer.

16) (15.47) Find  $\Delta G^\circ$  and  $K$  for the following equilibrium reaction at  $T = 25.^\circ\text{C}$



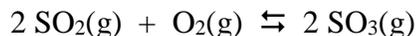
Also find  $\Delta G$  for the reaction if  $p(\text{PCl}_5) = 0.0029 \text{ atm}$ ,  $p(\text{PCl}_3) = 0.27 \text{ atm}$ , and  $p(\text{Cl}_2) = 0.40 \text{ atm}$ .

17) (15.50) The equilibrium constant for the reaction



is  $5.62 \times 10^{35}$  at  $T = 25.^\circ\text{C}$ . Using only this information find the value for  $\Delta G^\circ_{\text{rxn}}$  for this process at this temperature.

18) The gas phase reaction of sulfur dioxide ( $\text{SO}_2$ ) with molecular oxygen ( $\text{O}_2$ ) can produce sulfur trioxide ( $\text{SO}_3$ ). The balanced equation for the reaction is

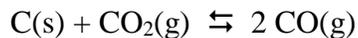


Thermodynamic data for the reactants and products are given below, at  $T = 25.^\circ\text{C}$ .

Substance	$\Delta H^\circ_f$ (kJ/mol)	$\Delta G^\circ_f$ (kJ/mol)	$S^\circ$ (J/mol·K)
$\text{O}_2\text{(g)}$	0.0	0.0	205.2
$\text{SO}_2\text{(g)}$	- 296.8	- 300.1	248.2
$\text{SO}_3\text{(g)}$	- 395.7	- 371.1	256.8

Based on this information find  $\Delta G^\circ_{\text{rxn}}$  and  $K$  for the above reaction at  $T = 25.^\circ\text{C}$

19) The equilibrium constant for the reaction



measured at  $T = 850.^\circ\text{C}$ , is  $K_p = 1.2 \times 10^{14}$ .

A system initially has  $p_{\text{CO}} = 0.400$  atm and  $p_{\text{CO}_2} = 0.300$  atm. What are the pressures of CO and  $\text{CO}_2$  when the system reaches equilibrium?