Equilibrium Work Book

Writing Equilibrium Constants Expressions

1. Write the equilibrium law (mass action expression) for each of the following reactions:
   a. $SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g)$
   b. $2\ C(s) + 3\ H_2(g) \rightleftharpoons C_2H_6(g)$
   c. $3\ O_2(g) \rightleftharpoons 2\ O_3(g)$
   d. $MgCO_3(s) \rightleftharpoons CO_2(g) + 2\ MgO(s)$
   e. $2\ Bi^{3+}(aq) + 3\ H_2S(g) \rightleftharpoons 2\ Bi_2S_3(s) + 6\ H^+(aq)$
   f. $I_2(aq) \rightleftharpoons I_2(s)$
   g. $Cl_2(g) + PCl_3(g) \rightleftharpoons PCl_5(g)$
   h. $I_2(g) + Cl_2(g) \rightleftharpoons 2\ ICl(g)$
   i. $2\ NO_2(g) \rightleftharpoons 2\ NO(g) + O_2(g)$
   j. $2\ SO_2(g) + O_2 \rightleftharpoons 2\ SO_3(g)$
   k. $Cl_2(g) + PCl_3(g) \rightleftharpoons PCl_5(g)$

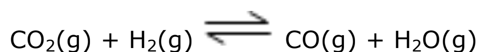
2. Comment on the favorability of product formation in each of the reactions.
   a. $H_2(g) + F_2(g) \rightleftharpoons 2\ HF(g)$ $K_C = 1.0 \times 10^{13}$
   b. $SO_2(g) + NO_2(g) \rightleftharpoons NO(g) + SO_3(g)$ $K_C = 1.0 \times 10^{2}$
   c. $2\ H_2O(g) \rightleftharpoons 2\ H_2(g) + O_2(g)$ $K_C = 6.0 \times 10^{-28}$

3. Chemists have determined the equilibrium constants for several reactions. In which of these reactions are the products favoured over the reactants?
   a. $K_C = 1.0\times10^{2}$
   b. $K_C = 3.5$
   c. $K_C = 0.003$
   d. $K_C = 6.0 \times 10^{-4}$

Calculating equilibrium constants

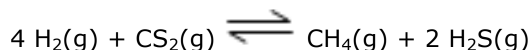
Answer the following questions. Be sure to show all your work.

1. A mixture at equilibrium at 827°C contains 0.552 moles of CO_2, 0.552 moles H_2, 0.448 moles CO, and 0.448 moles of H_2O in a 1.00 L container. What is the value of the equilibrium constant, Kc?



$$CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(g)$$

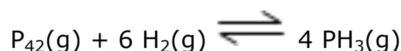
2. The equilibrium constant for the reaction



$$4\ H_2(g) + CS_2(g) \rightleftharpoons CH_4(g) + 2\ H_2S(g)$$

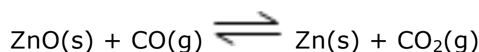
at 755°C is 0.256. What is the equilibrium concentration of H_2S if at equilibrium $[CH_4]$ = 0.00108 mol/L, $[H_2]$ = 0.316 mol/L, $[CS_2]$ = 0.0898 mol/L?

3. Find the value of K if at equilibrium there is 25.0 moles of P_4, 10.0 moles of H_2 and 5.00 moles of PH_3, in a 5.00 L container. The equation is



$$P_{42}(g) + 6\ H_2(g) \rightleftharpoons 4\ PH_3(g)$$

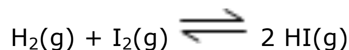
4. Find the value of K for the equilibrium system



$$ZnO(s) + CO(g) \rightleftharpoons Zn(s) + CO_2(g)$$

if at equilibrium there are 3.0 moles of CO, 4.0 moles of Zn and 4.0 moles of CO_2 in a 500.0 mL container.

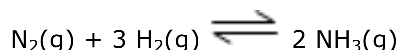
5. If K = 46.0 for



$$H_2(g) + I_2(g) \rightleftharpoons 2\ HI(g)$$

what $[I_2]$ would be in equilibrium with 0.50 mol/L HI and 0.10 mol/L H_2?

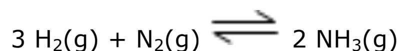
6. If K = 10.0 for



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

how many moles of NH_3, at equilibrium, will be in a 2.00 L container if $[H_2]$ is 0.600 mol/L and $[N_2]$ is 0.100 mol/L?

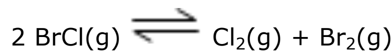
7. The formation of ammonia from hydrogen and nitrogen occurs by the reaction below:



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

Analysis of an equilibrium mixture of nitrogen, hydrogen, and ammonia contained in a 1.0 L flask at 300°C gives the following results: hydrogen 0.15 moles; nitrogen 0.25 moles: ammonia 0.10 moles. Calculate K_C for the reaction.

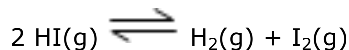
8. Bromine chloride, BrCl, decomposes to form bromine and chlorine.



$$2\ BrCl(g) \rightleftharpoons Cl_2(g) + Br_2(g)$$

At a certain temperature the equilibrium constant for the reaction is 11.1, and the equilibrium mixture contains 4.00 mol of Cl_2. How many moles of Br_2 and BrCl are present in the equilibrium mixture?

9. The decomposition of hydrogen iodide to hydrogen and iodine occurs by the reaction



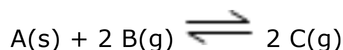
$$2\ HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

Hydrogen iodide is placed in a container at 450°C an equilibrium mixture contains 0.50 moles of hydrogen iodide. The equilibrium constant is 0.020 for the reaction. How many moles of iodine and hydrogen iodide are present in the equilibrium mixture?

10. $H_2(g) + Cl_2(g) \rightleftharpoons 2\ HCl(g)$

A student places 2.00 mol H_2 and 2.00 mol Cl_2 into a 0.500 L container and the reaction is allowed to go to equilibrium at 516°C. If K_C is 76.0, what are the equilibrium concentrations of H_2, Cl_2 and HCl?

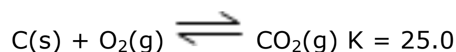
11. If K = 78.0 for the reaction



$$A(s) + 2\ B(g) \rightleftharpoons 2\ C(g)$$

and initially there are 5.00 moles of A and 4.84 moles of B in a 2.00 L container, how many moles of B are left at equilibrium?

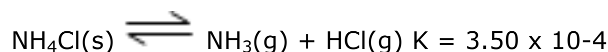
12. For the reaction:



$C(s) + O_2(g) \rightleftharpoons CO_2(g)$ K = 25.0

Find the moles of CO_2 at equilibrium, if initially there are 100.0 moles of C, 50.0 moles of O_2 and 2.0 moles of CO_2 in a 2.00 L container.

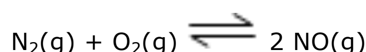
13. For the reaction:



$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$ K = 3.50 x 10-4

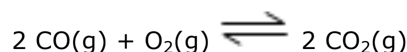
Find the concentration of NH_3 in a 1.00 L container at equilibrium if initially there were 0.200 moles of NH_3 added to 0.200 moles of HCl.

14. Initially the concentrations of N_2 and O_2 are 1.8 mol/L each and there is no NO. If at equilibrium the [NO] is 2.0 mol/L, find K.



$$N_2(g) + O_2(g) \rightleftharpoons 2\ NO(g)$$

15. Find K for the reaction



$$2\ CO(g) + O_2(g) \rightleftharpoons 2\ CO_2(g)$$

if initially, there is 5.0 moles of CO, 10.0 moles of O_2 and 1.0 mole of CO_2 in a 2.0 L container and at equilibrium CO_2 has a concentration of 2.5 mol/L.

Reaction Quotient Calculations

Answer the following questions. You may use the solubility chart from Module 1 to identify precipitates. Be sure to show all your work.

1. To 1.0 L of 1.0 M H_2SO_4 is added 0.0020 mole of solid $Pb(NO_3)_2$. As the lead nitrate dissolves, will lead sulfate precipitate? ($K_{sp} = 1.3\times10^{-8}$)

2. The K_{sp} of CaF_2 at 25°C is 1.7×10^{-10}. If 0.75 g of CaF_2 are dissolved in 25.0 L of hot water then cooled to 25°C, will a precipitate form? Assume no volume change.

3. If 2.5×10^{-5} moles of aluminum hydroxide are added to 10.0 L of water, will all the solid dissolve if the K_{sp} is 5.0×10^{-33}?

4. The K_{sp} of $PbSO_4$ is 1.3×10^{-8}. If 0.20 g of solid lead (II) sulfate is added to 7.5 L of water, will all the solid dissolve?

5. If equal volumes of 0.020 mol/L $TlNO_3$ and 0.0040 mol/L NaCl are mixed, will a precipitate form? K_{sp} = 1.9×10^{-4}

6. 50.0 mL of 0.040 mol/L calcium nitrate solution is added to 150.0 mL of 0.0080 mol/L ammonium sulphate solution . Does a precipitate form? Justify your answer. $K_{sp} = 2.6\times10^{-4}$
7. Does a precipitate form when 2.0×10^{-3} moles of strontium nitrate are added to 50.0 mL of 4.2×10^{-6} mol/L ammonium sulphate? Justify your answer. $K_{sp} = 7.6\times10^{-7}$

8. If 2.5 mL of 0.30 mol/L $AgNO_3$ is mixed with 7.5 mL of 0.015 mol/L Na_2CrO_4will a precipitate form? ($K_{sp} = 9.2\times10^{-12}$)

<u>Le Chatelier's Principle</u>

1. For the reaction

$PCl_3(g) + Cl_2(g) \quad PCl_5(g)\ \Delta H = -92.5$ kJ

predict the effect on the position of the equilibrium that results from

a) increasing the total pressure by decreasing volume.
b) injecting more Cl_2 gas without changing the volume.
c) increasing the temperature.
d) increasing the volume of the container.
e) adding a catalyst.

2. For the reaction

$CH_4(g) + H_2O(g) + 49.3$ kJ $\quad CO(g) + 3\ H_2(g)$

predict the effect on the position of the equilibrium that results from

a) increasing temperature.
b) decreasing temperature.
c) decreasing the pressure.
d) decreasing the volume of the container.
e) adding a solid drying agent such as $CaCl_2$ which reacts with $H_2O(g)$.

3. For the reaction

9.4 kJ + 2 $HI(g) \quad H_2(g) + I_2(g)$

a) What is the effect on [HI] if a small amount of H_2 is added?
b) What is the effect on [HI] if the pressure of the system is increased?
c) What is the effect on [HI] if the temperature is increased?
d) What is the effect on [HI] if a catalyst is added?

4. For the reaction

$CO(g) + 2\ H_2(g) \quad CH_3OH(g)$ + energy

predict the effect of the following changes on the equilibrium concentration of $CH_3OH(g)$

a) a decrease in temperature.
b) an increase in pressure.
c) addition of $H_2(g)$.
d) addition of a catalyst.

5. In the equilibrium reaction

$2\ NO(g) + O_2(g) \quad 2\ NO_2(g) + 114.6\ kJ$

What will be the change in the equilibrium $[NO_2]$ under each of the following conditions?

a) O_2 is added.
b) NO is removed.
c) energy is added.

6. For the following reaction $\Delta H = +58.9$ kJ

$N_2O_4(g) \quad 2\ NO_2(g)$

how will the equilibrium $[NO_2]$ be affected by the following?

a) an increase in pressure.
b) an increase in temperature.
c) the addition of a catalyst.

<u>Writing Ksp expressions</u>

Answer the following questions. Be sure to show all your work.

1. Write the dissociation equation and the solubility product expression for each of the following (assume that all the solid that dissolves exists as ions).
   a. $PbSO_4$
   b. $Al_2(SO_4)_3$
   c. $Ba(OH)_2$
   d. CuCl
   e. Ag_2CO_3
   f. $Fe_2(SO_4)_3$
2. Given the following compounds' K_{sp}, calculate their solubilities in mol/L and g/L.
   a. CuS, $K_{sp} = 6.31\times10^{-36}$
   b. PbI_2, $K_{sp} = 1.39\times10^{-8}$
   c. SrC_2O_4, $K_{sp} = 1.58\times10^{-7}$
   d. $Al(OH)_3$, $K_{sp} = 1.26\times10^{-33}$
3. From the following solubilities, calculate the Ksp.
   a. $Pb(OH)_2$, 4.20×10^{-6} mol/L
   b. AgI, 2.88×10^{-6} g/L
   c. $Ca_3(PO_4)_2$, 7.15×10^{-7} mol/L
   d. CaF_2, 1.70×10^{-2} g/L

4. If 6.7×10^{-5} g of AgBr is all that can be dissolved at 25°C in 500.0 mL, calculate the solubility product of AgBr.

5. A saturated solution of calcium hydroxide has an hydroxide ion concentration of 3.0×10^{-3} mol/L. Calculate the Ksp of calcium hydroxide.

6. What are the equilibrium concentrations of all the ions in a saturated solution of AgCN at 25°C, if the Ksp is 1.6×10^{-14}?

7. At 25°C, a saturated solution of iron (III) hydroxide has an iron (III) ion concentration of 1.3×10^{-13} mol/L. Calculate the Ksp of iron (III) hydroxide.

8. What are the equilibrium concentrations of all the ions in a saturated solution of $Cu(OH)_2$ at 25°C, if the Ksp is 1.6×10^{-19}.

Common Ion Effect

Answer the following questions. Be sure to show all your work.

1. Silver iodide, AgI, has a solubility product of 8.5×10^{-17}. What is the solubility, in moles per Litre, of AgI in
   a. pure water
   b. 0.010 mol/L HI
   c. 0.010 mol/L MgI_2
   d. 0.010 mol/L $AgNO_3$
   e.
2. Magnesium fluoride, MgF_2, has a solubility product of 8.0×10^{-8}. Calculate the solubility, in mol/L, of magnesium fluoride in

   a. pure water
   b. 0.50 mol/L NaF
   c. 0.50 mol/L $MgCl_2$

3. Gold (III) chloride, $AuCl_3$, has a Ksp of 3.2×10^{-25}. Calculate its solubility, in mol/L, in
   a. pure water
   b. 0.20 mol/L HCl
   c. 0.20 mol/L $MgCl_2$
   d. 0.20 mol/L $Au(NO_3)_3$