

13.7: End-of-Chapter Material

Exercises (Chemical Equilibrium)

1. Define the law of mass action.
2. What is an equilibrium constant for a chemical reaction? How is it constructed?

3. Write the K_{eq} expression for each reaction.

- a. $H_2 + Cl_2 \rightleftharpoons 2HCl$
- b. $NO + NO_2 \rightleftharpoons N_2O_3$

4. Write the K_{eq} expression for each reaction.

- a. $C_2H_5OH + NaI \rightleftharpoons C_2H_5I + NaOH$
- b. $PCl_3 + Cl_2 \rightleftharpoons PCl_5$

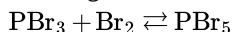
5. Write the K_P expression for each reaction.

- a. $2H_2(g) + O_2(g) \rightleftharpoons 2H_2O(g)$
- b. $2H_2O_2(g) \rightleftharpoons 2H_2O(g) + O_2(g)$

6. Write the K_P expression for each reaction.

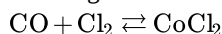
- a. $CH_4(g) + 2O_2(g) \rightleftharpoons CO_2(g) + 2H_2O(g)$
- b. $CH_4(g) + 4Cl_2(g) \rightleftharpoons CCl_4(g) + 4HCl(g)$

7. The following reaction is at equilibrium:



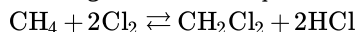
The equilibrium $[Br_2]$ and $[PBr_5]$ are 2.05M and 0.55M, respectively. If the K_{eq} is 1.65, what is the equilibrium $[PBr_3]$?

8. The following reaction is at equilibrium:



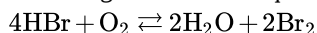
The equilibrium $[CO]$ and $[Cl_2]$ are 0.088M and 0.103M, respectively. If the K_{eq} is 0.225, what is the equilibrium $[CoCl_2]$?

9. The following reaction is at equilibrium:



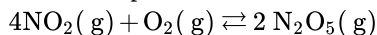
If $[CH_4]$ is 0.250M, $[Cl_2]$ is 0.150M, and $[CH_2Cl_2]$ is 0.175M at equilibrium, what is $[HCl]$ at equilibrium if the K_{eq} is 2.30?

10. The following reaction is at equilibrium:

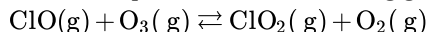


If $[HBr]$ is 0.100M, $[O_2]$ is 0.250M, and $[H_2O]$ is 0.0500M at equilibrium, what is $[Br_2]$ at equilibrium if the K_{eq} is 0.770?

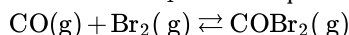
11. Write the K_P expression for the following gas-phase reaction:



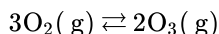
12. Write the K_P expression for the following gas-phase reaction:



13. What is the equilibrium partial pressure of $COBr_2$ if the equilibrium partial pressures of CO and Br_2 are 0.666 atm and 0.235 atm and the K_P for this equilibrium is 4.08?



14. What is the equilibrium partial pressure of O_3 if the equilibrium partial pressure of O_2 is 0.0044 atm and K_P for this equilibrium is 0.00755?



15. Calculate the K_P for this reaction at 298 K if the $K_{eq} = 1.76 \times 10^{-3}$.
 $3O_2(g) \rightleftharpoons 2O_3(g)$
16. Calculate the K_P for this reaction at 310 K if the $K_{eq} = 6.22 \times 10^3$.
 $4NO_2(g) + O_2(g) \rightleftharpoons 2N_2O_5(g)$
17. Calculate the K_{eq} for this reaction if the $K_P = 5.205 \times 10^{-3}$ at 660°C.
 $CO(g) + F_2(g) \rightleftharpoons COF_2(g)$
18. Calculate the K_{eq} for this reaction if the $K_P = 78.3$ at 100°C.
 $4HCl(g) + O_2(g) \rightleftharpoons 2H_2O(g) + 2Cl_2(g)$
19. Write the correct K_{eq} expression for this reaction.
 $NaOH(aq) + HCl(aq) \rightleftharpoons NaCl(aq) + H_2O(l)$
20. Write the correct K_{eq} expression for this reaction.
 $AgNO_3(aq) + NaCl(aq) \rightleftharpoons AgCl(s) + NaNO_3(aq)$
21. Write the correct K_P expression for this reaction.
 $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$
22. Write the correct K_P expression for this reaction.

Answers

1. the relationship between the concentrations of reactants and products of a chemical reaction at equilibrium

$$3. a. K_{eq} = \frac{[HCl]^2}{[H_2][Cl_2]}$$

$$b. K_{eq} = \frac{[N_2O_3]}{[NO][NO_2]}$$

$$5. a. K_P = \frac{P_{H_2O}^2}{P_{H_2}^2 P_{O_2}}$$

$$b. K_P = \frac{P_{H_2O}^2 P_{O_2}}{P_{H_2O_2}^2}$$

$$7. 0.163M$$

$$9. 0.272M$$

$$11. K_P = \frac{P_{N_2O_5}^2}{P_{NO_2}^4 P_{O_2}}$$

$$13. 0.639 \text{ atm}$$

$$15. 7.20 \times 10^{-5}$$

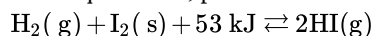
$$17. K_{eq} = 3.98 \times 10^{-1}$$

$$19. K_{eq} = \frac{[NaCl]}{[NaOH][HCl]}$$

$$21. K_P = P_{CO}$$

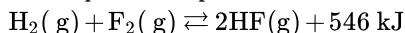
Exercises (Le Chatelier's principle)

1. Define Le Chatelier's principle.
2. What is meant by a stress? What are some of the ways an equilibrium can be stressed?
3. Given this equilibrium, predict the direction of shift for each stress.



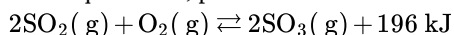
- a. decreased temperature
- b. increased pressure
- c. removal of HI

4. Given this equilibrium, predict the direction of shift for each stress.



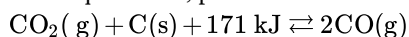
- a. increased temperature
- b. addition of H_2
- c. decreased pressure

5. Given this equilibrium, predict the direction of shift for each stress.



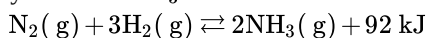
- a. removal of SO_3
- b. addition of O_2
- c. decreased temperature

6. Given this equilibrium, predict the direction of shift for each stress listed.



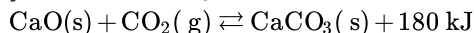
- a. addition of CO
- b. increased pressure
- c. addition of a catalyst

7. The synthesis of NH_3 uses this chemical reaction.



Identify three stresses that can be imposed on the equilibrium to maximize the amount of NH_3 .

8. The synthesis of CaCO_3 uses this chemical reaction.



Identify three stresses that can be imposed on the equilibrium to maximize the amount of CaCO_3 .

Answers

1. When an equilibrium is stressed, the equilibrium shifts to minimize that stress.

3.

- a. toward reactants
- b. toward reactants
- c. toward products

5.

- a. toward products
- b. toward products
- c. toward products

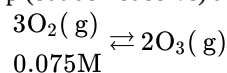
7. increased pressure, decreased temperature, removal of NH_3

Exercises (Calculating Equilibrium Constant Values)

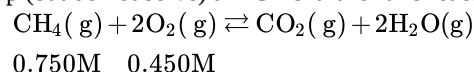
1. Describe the three parts of an ICE chart.

2. What is the relationship between the equilibrium row in an ICE chart and the other two rows?

3. Set up (but do not solve) an ICE chart for this reaction, given the initial conditions.

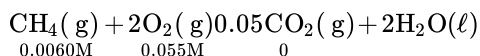


4. Set up (but do not solve) an ICE chart for this reaction, given the initial conditions.

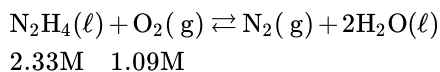


5. Given that pure solids and liquids do not appear in K_{eq} expressions, set up the ICE chart for this reaction, given the initial

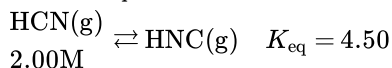
conditions.



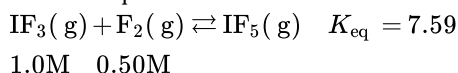
6. Given that pure solids and liquids do not appear in K_{eq} expressions, set up the ICE chart for this reaction, given the initial conditions.



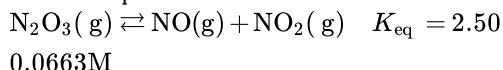
7. Determine the equilibrium concentrations for this chemical reaction with the given K_{eq} .



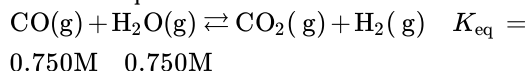
8. Determine the equilibrium concentrations for this chemical reaction with the given K_{eq} .



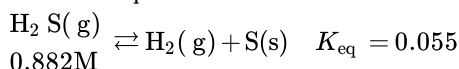
9. Determine the equilibrium concentrations for this chemical reaction with the given K_{eq} .



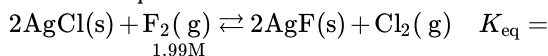
10. Determine the equilibrium concentrations for this chemical reaction with the given K_{eq} .



11. Determine the equilibrium concentrations for this chemical reaction with the given K_{eq} .



12. Determine the equilibrium concentrations for this chemical reaction with the given K_{eq} .



Answers

1. I = initial concentrations; C = change in concentrations; E = equilibrium concentrations

3.

	3O_2	\rightleftharpoons	2O_3
I	0.075		0
C	-3 x		+2 x
E	0.075-3 x		+2 x

5.

	CH_4	+	2O_2	\rightleftharpoons	CO_2	+	$2\text{H}_2\text{O}$
I	0.0060		0.055		0		0
C	-x		-2 x		+x		-
E	0.0060-x		.055-2 x		+x		-

7. $[\text{HCN}] = 0.364\text{M}$; $[\text{HNC}] = 1.64\text{M}$

9. $[\text{N}_2\text{O}_3] = 0.0017\text{M}$; $[\text{NO}] = [\text{NO}_2] = 0.0646\text{M}$

11. $[\text{H}_2\text{S}] = 0.836\text{M}$; $[\text{H}_2] = 0.046\text{M}$

Exercises (Some Special Types of Equilibria)

1. Explain the difference between the K_{eq} and the K_{sp} .

- Explain the difference between the K_a and the K_b .
- Write the balanced chemical equation that represents the equilibrium between $\text{HF}(\text{aq})$ as reactants and $\text{H}^+(\text{aq})$ and $\text{F}^-(\text{aq})$ as products.
- Write the balanced chemical equation that represents the equilibrium between $\text{CaF}_2(\text{s})$ as reactants and $\text{Ca}^{2+}(\text{aq})$ and $\text{F}^-(\text{aq})$ as products.
- Assuming that all species are dissolved in solution, write the K_{eq} expression for the chemical equation in Exercise 3.
- Noting the phase labels, write the K_{sp} expression for the chemical equation in Exercise 4.
- Determine the concentrations of all species in the ionization of 0.100M HClO_2 in H_2O . The K_a for HClO_2 is 1.1×10^{-2} .
- Determine the concentrations of all species in the ionization of 0.0800M HCN in H_2O . The K_a for HCN is 6.2×10^{-10} .
- Determine the pH of a 1.00M solution of HNO_2 . The K_a for HNO_2 is 5.6×10^{-4} .
- Determine the pH of a 3.35M solution of $\text{HC}_2\text{H}_3\text{O}_2$. The K_a for $\text{HC}_2\text{H}_3\text{O}_2$ is 1.8×10^{-5} .
- Write the chemical equations and K_a expressions for the stepwise dissociation of H_3PO_4 .
- Write the chemical equations and K_a expressions for the stepwise dissociation of $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$.
- If the K_a for HNO_2 is 5.6×10^{-4} , what is the K_b for $\text{NO}_2^-(\text{aq})$?
- If the K_a for HCN is 6.2×10^{-10} , what is the K_b for $\text{CN}^-(\text{aq})$?
- What is $[\text{OH}^-]$ in a solution whose $[\text{H}^+]$ is $3.23 \times 10^{-6}\text{M}$?
- What is $[\text{OH}^-]$ in a solution whose $[\text{H}^+]$ is $9.44 \times 10^{-11}\text{M}$?
- What is $[\text{H}^+]$ in a solution whose $[\text{OH}^-]$ is $2.09 \times 10^{-2}\text{M}$?
- What is $[\text{H}^+]$ in a solution whose $[\text{OH}^-]$ is $4.07 \times 10^{-7}\text{M}$?
- Write the balanced chemical equation and the K_{sp} expression for the slight solubility of $\text{Mg}(\text{OH})_2(\text{s})$.
- Write the balanced chemical equation and the K_{sp} expression for the slight solubility of $\text{Fe}_2(\text{SO}_4)_3(\text{s})$.
- What are $[\text{Sr}^{2+}]$ and $[\text{SO}_4^{2-}]$ in a saturated solution of $\text{SrSO}_4(\text{s})$? The K_{sp} of $\text{SrSO}_4(\text{s})$ is 3.8×10^{-4} .
- What are $[\text{Ba}^{2+}]$ and $[\text{F}^-]$ in a saturated solution of $\text{BaF}_2(\text{s})$? The K_{sp} of $\text{BaF}_2(\text{s})$ is 1.8×10^{-7} .
- What are $[\text{Ca}^{2+}]$ and $[\text{OH}^-]$ in a saturated solution of $\text{Ca}(\text{OH})_2(\text{s})$? The K_{sp} of $\text{Ca}(\text{OH})_2(\text{s})$ is 5.0×10^{-6} .
- What are $[\text{Pb}^{2+}]$ and $[\text{I}^-]$ in a saturated solution of PbI_2 ? The K_{sp} for PbI_2 is 9.8×10^{-9} .

Answers

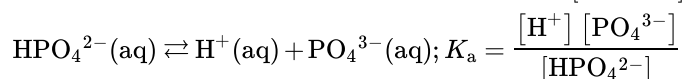
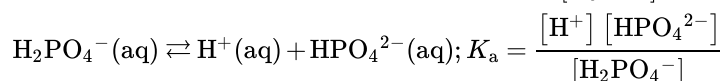
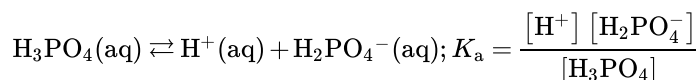
- The K_{sp} is a special type of the K_{eq} and applies to compounds that are only slightly soluble.
- $\text{HF}(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{F}^-(\text{aq})$

$$5. K_{eq} = \frac{[H^+][F^-]}{[HF]}$$

$$7. [HClO_2] = 0.0719M; [H^+] = [ClO_2^-] = 0.0281M$$

$$9. 1.63$$

11.



$$13. 1.8 \times 10^{-11}$$

$$15. 3.10 \times 10^{-9}M$$

$$17. 4.78 \times 10^{-13}M$$



$$21. [Sr^{2+}] = [SO_4^{2-}] = 1.9 \times 10^{-2}M$$

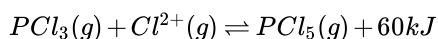
$$23. [Ca^{2+}] = 0.011M; [OH^-] = 0.022M$$

Additional Exercises

1. What is the relationship between the K_{sp} expressions for a chemical reaction and its reverse chemical reaction?

2. What is the relationship between the K_w value for H_2O and its reverse chemical reaction?

3. For the equilibrium



list four stresses that serve to increase the amount of PCl_5 .

4. For the equilibrium

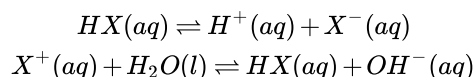


list four stresses that serve to increase the amount of NO_2 .

5. Does a very large K_{eq} favor the reactants or the products? Explain your answer.

6. Is the K_{eq} for reactions that favor reactants large or small? Explain your answer.

7. Show that $K_a \times K_b = K_w$ by determining the expressions for these two reactions and multiplying them together.



8. Is the conjugate base of a strong acid weak or strong? Explain your answer.

9. What is the solubility in moles per liter of AgCl? Use data from Table 13.7.2- Solubility Product Constants for Slightly Soluble Ionic Compounds.
10. What is the solubility in moles per liter of Ca(OH)₂? Use data from Table 13.7.2- Solubility Product Constants for Slightly Soluble Ionic Compounds.
11. Under what conditions is $K_{eq} = K_p$?
12. Under what conditions is $K_{eq} > K_p$ when the temperature is 298 K?
13. What is the pH of a saturated solution of Mg(OH)₂? Use data from Table 13.7.2- Solubility Product Constants for Slightly Soluble Ionic Compounds.
14. What are the pH and the pOH of a saturated solution of Fe(OH)₃? The K_{sp} of Fe(OH)₃ is 2.8×10^{-39} .
15. For a salt that has the general formula MX, an ICE chart shows that the K_{sp} is equal to x^2 , where x is the concentration of the cation. What is the appropriate formula for the K_{sp} of a salt that has a general formula of MX₂?
16. Referring to Exercise 15, what is the appropriate formula for the K_{sp} of a salt that has a general formula of M₂X₃ if the concentration of the cation is defined as $2x$, rather than x ?
17. Consider a saturated solution of PbBr₂(s). If $[Pb^{2+}]$ is 1.33×10^{-5} M, find each of the following.
 - a. $[Br^-]$
 - b. the K_{sp} of PbBr₂(s)
18. Consider a saturated solution of Pb₃(PO₄)₂(s). If $[Pb^{2+}]$ is 7.34×10^{-14} M, find each of the following.
 - a. $[PO_4^{3-}]$
 - b. the K_{sp} of Pb₃(PO₄)₂(s)

Answers

1. They are reciprocals of each other.
3. increase the pressure; decrease the temperature; add PCl₃; add Cl₂; remove PCl₅
5. favor products because the numerator of the ratio for the K_{eq} is larger than the denominator
9. 1.3×10^{-5} mol/L
11. $K_{eq} = K_p$ when the number of moles of gas on both sides of the reaction is the same.
13. 10.35
15. $4x^3$
17. a. 2.66×10^{-5} M
b. 9.41×10^{-15}

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