

## Chapter 8

### Acids, Bases, and pH

## Practice Problems

### Problem 1

Identify the conjugate acid-base pairs in the following reactions. Indicate if reactants or products are favoured.

- (a)  $\text{H}_3\text{PO}_4(\text{aq}) + \text{N}_2\text{H}_4(\text{aq}) \leftrightarrow \text{H}_2\text{PO}_4^-(\text{aq}) + \text{N}_2\text{H}_5^+(\text{aq})$   
(b)  $\text{SO}_4^{2-}(\text{aq}) + \text{CH}_3\text{CHOHCO}_2\text{H}(\text{aq}) \leftrightarrow \text{CH}_3\text{CHOHCOO}^-(\text{aq}) + \text{HSO}_4^{2-}(\text{aq})$   
(c)  $\text{H}_2\text{CO}_3(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \leftrightarrow \text{HCO}_3^-(\text{aq}) + \text{HSO}_4^-(\text{aq})$

### Problem 2

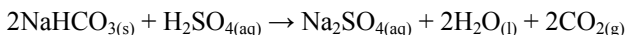
What is the pH of each of the following solutions?

- (a) 50.0 mL of a solution of  $\text{pOH} = 9$   
(b) 50.0 mL of an acid with  $[\text{H}_3\text{O}^+(\text{aq})] = 1.0 \times 10^{-4} \text{ mol/L}$   
(c) 10.0 mL water + 10.0 mL 0.0050 mol/L HCl  
(d) 20.0 mL of 0.0250 mol/L  $\text{H}_2\text{SO}_4$   
(e) 4.92 g NaOH in 2.00 L water

### Problem 3

An excess of 6.00 L of 4.00 mol/L  $\text{H}_2\text{SO}_4$  is left after a student laboratory exercise. For safe disposal of the acid, it has to be neutralized before discarding.

- (a) What mass of KOH will neutralize this acid solution?  
(b) The reaction between baking soda and the acid is shown below. What mass of baking soda will neutralize this acid solution?



### Problem 4

Citric acid is a weak polyprotic acid that has three replaceable hydrogen atoms. The ionization constants for citric acid are as follows:

$$K_{a1} = 7.42 \times 10^{-4}$$
$$K_{a2} = 1.68 \times 10^{-5}$$
$$K_{a3} = 4.00 \times 10^{-7}$$

- (a) Using the abbreviation  $\text{H}_3\text{Cit}$  for citric acid, write the equations to represent the three steps in the dissociation of this acid.  
(b) What is the pH of a 0.002 00 mol/L solution of this acid?  
(c) Calculate the concentration of the  $\text{H}_2\text{Cit}^{2-}$  ions in the acid solution?

### Problem 5

Calculate the pH of a  $2.41 \times 10^{-5} \text{ mol/L}$  solution of  $\text{Al}(\text{OH})_3$ .

### Problem 6

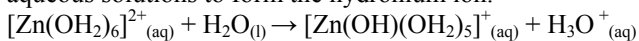
Determine the dissociation constant for butanoic acid, given that the pH of a 0.0240 mol/L solution of this acid is 3.22.

**Problem 7**

Calculate the pH of a 0.0482 mol/L solution of  $\text{NH}_4\text{Cl}$ . The value of  $K_b$  for  $\text{NH}_3$  is  $1.8 \times 10^{-5}$ .

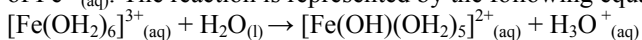
**Problem 8**

(a) Some metallic ions undergo acid dissociation in aqueous solutions. For example,  $\text{Zn}^{2+}$  is hydrated in aqueous solutions to form the hydronium ion.



The acid dissociation constant for this reaction is  $1.06 \times 10^{-9}$ . Calculate the pH of a 0.0040 mol/L solution of  $\text{ZnCl}_2$ .

(b) A solution of  $\text{FeCl}_3$  has a pH of 2.500. Calculate the acid dissociation constant for a 0.0200 mol/L solution of  $\text{Fe}^{3+}_{(\text{aq})}$ . The reaction is represented by the following equation.

**Problem 9**

The pH of a 0.455 mol/L hypoiodous acid solution,  $\text{HIO}_{(\text{aq})}$ , is 1.502. What is the dissociation constant for this acid?

**Problem 10**

What is the percent dissociation of a 0.0274 mol/L solution of  $\text{NH}_2\text{OH}$ , given that its pH at this concentration is 9.191? The value of  $K_b$  for  $\text{NH}_2\text{OH}$  is  $8.80 \times 10^{-9}$ .

## Answers

### 1.

- (a) The acid / conjugate base pair is  $\text{H}_3\text{PO}_{4(\text{aq})} / \text{H}_2\text{PO}_{4(\text{aq})}^-$ .  
The base / conjugate acid pair is  $\text{N}_2\text{H}_{4(\text{aq})} / \text{N}_2\text{H}_5^+(\text{aq})$ .  
Products favoured
- (b) The acid / conjugate base pair is  $\text{CH}_3\text{CHOHCO}_2\text{H}_{(\text{aq})} / \text{CH}_3\text{CHOHCOO}^-(\text{aq})$ .  
The base / conjugate acid pair is  $\text{SO}_4^{2-}(\text{aq}) / \text{HSO}_4^-(\text{aq})$ .  
Products favoured
- (c) The acid / conjugate base pair is  $\text{H}_2\text{CO}_{3(\text{aq})} / \text{HCO}_3^-(\text{aq})$ .  
The base / conjugate acid pair is  $\text{SO}_4^{2-}(\text{aq}) / \text{HSO}_4^-(\text{aq})$ .  
Reactants favoured

### 2.

- (a)  $\text{pH} = 14 - \text{pOH} = 14 - 9 = 5$
- (b)  $[\text{H}_3\text{O}^+(\text{aq})] = 1.0 \times 10^{-4} \text{ mol/L}$   
 $\text{pH} = -\log(1.0 \times 10^{-4}) = 4$
- (c)  $[\text{H}^+] = 0.0025 \text{ mol/L}$   
 $\text{pH} = -\log(0.0025) = 2.60$
- (d)  $[\text{H}^+] = 2 [\text{H}_2\text{SO}_4] = 2 \times 0.0250 \text{ mol/L} = 0.0500 \text{ mol/L}$   
 $\text{pH} = -\log(0.0500) = 1.301$

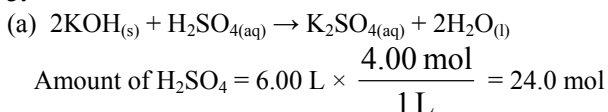
(e)  $n \text{ mol NaOH} = 4.92 \text{ g} \times \frac{1 \text{ mol}}{40.0 \text{ g}} = 0.123 \text{ mol}$

$$[\text{OH}^-] = [\text{NaOH}] = \frac{0.123 \text{ mol}}{2.00 \text{ L}} = 0.0615 \text{ mol/L}$$

$$\text{pOH} = -\log(0.0615) = 1.211$$

$$\text{pH} = 14.000 - \text{pOH} = 14.000 - 1.211 = 12.789$$

### 3.



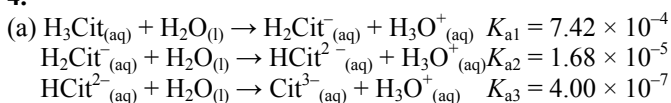
Amount of  $\text{KOH} = 2 \times 24.0 \text{ mol} = 48.0 \text{ mol}$

Mass of  $\text{KOH} = 48.0 \text{ mol} \times \frac{56.11 \text{ g}}{1 \text{ mol}} = 2.69 \times 10^3 \text{ g}$

(b) Amount of  $\text{NaHCO}_3 = 2 \times 24.0 \text{ mol} = 48.0 \text{ mol}$

Mass of  $\text{NaHCO}_3 = 48.0 \text{ mol} \times \frac{84.01 \text{ g}}{1 \text{ mol}} = 4.03 \times 10^3 \text{ g}$

### 4.



### (b)

Concentration (mol/L)	$\text{H}_3\text{Cit}_{(\text{aq})}$	+	$\text{H}_2\text{O}_{(\text{l})}$	$\leftrightarrow$	$\text{H}_2\text{Cit}^-(\text{aq})$	+	$\text{H}_3\text{O}^+(\text{aq})$
Initial	0.002 00				0		0
Change	-x				+x		+x
Equilibrium	0.002 00 - x				x		x

$$K_{a1} = \frac{[\text{H}_2\text{Cit}^-][\text{H}_3\text{O}^+]}{[\text{H}_3\text{Cit}]} = \frac{x^2}{(0.00200 - x)} = 7.42 \times 10^{-4}$$

$$x^2 + (7.42 \times 10^{-4})x - 1.48 \times 10^{-6} = 0$$

$$x = \frac{-7.42 \times 10^{-4} \pm \sqrt{(7.42 \times 10^{-4})^2 - 4(1)(-1.48 \times 10^{-6})}}{2(1)}$$

$$x = 9.00 \times 10^{-4}$$

$$[\text{H}_3\text{O}^+_{(\text{aq})}] = 9.00 \times 10^{-4} \text{ mol/L}$$

$$\text{pH} = -\log(9.00 \times 10^{-4}) = 3.048$$

(c)

Concentration (mol/L)	$\text{H}_2\text{Cit}^-_{(\text{aq})}$	+	$\text{H}_2\text{O}_{(\text{l})}$	$\leftrightarrow$	$\text{HCit}^{2-}_{(\text{aq})}$	+	$\text{H}_3\text{O}^+_{(\text{aq})}$
Initial	$9.00 \times 10^{-4}$				0		$9.00 \times 10^{-4}$
Change	-x				+x		+x
Equilibrium	$9.00 \times 10^{-4} - x$				x		$9.00 \times 10^{-4} + x$

$$K_{a2} = \frac{[\text{HCit}^{2-}][\text{H}_3\text{O}^+]}{[\text{H}_2\text{Cit}^-]} = \frac{x(9.00 \times 10^{-4} + x)}{9.00 \times 10^{-4} - x} = 1.68 \times 10^{-5}$$

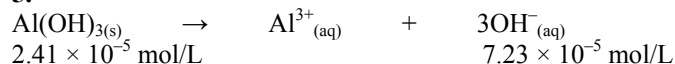
$$x^2 + (9.17 \times 10^{-4})x - 1.51 \times 10^{-8} = 0$$

$$x = \frac{-9.17 \times 10^{-4} \pm \sqrt{(9.17 \times 10^{-4})^2 - 4(1)(-1.51 \times 10^{-8})}}{2(1)}$$

$$x = 1.60 \times 10^{-5}$$

$$[\text{HCit}^{2-}_{(\text{aq})}] = 1.60 \times 10^{-5} \text{ mol/L}$$

5.



$$[\text{OH}^-] = 7.23 \times 10^{-5} \text{ mol/L}$$

$$\text{pOH} = -\log(7.23 \times 10^{-5}) = 4.141$$

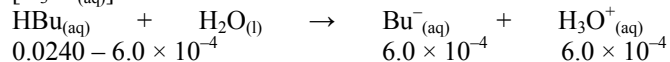
$$\text{pH} = 14.000 - \text{pOH} = 14.000 - 4.141 = 9.859$$

6.

Use the abbreviation HBu for butanoic acid.

$$\text{pH} = 3.22$$

$$[\text{H}_3\text{O}^+_{(\text{aq})}] = 10^{-\text{pH}} = 6.0 \times 10^{-4} \text{ mol/L}$$



$$K_a = \frac{[\text{Bu}^-][\text{H}_3\text{O}^+]}{[\text{HBu}]} = \frac{(6.0 \times 10^{-4})^2}{0.0240 - 6.0 \times 10^{-4}} = 1.6 \times 10^{-5}$$

7.



$$K_a \text{ for } \text{NH}_4^+_{(\text{aq})} = \frac{K_w}{K_b \text{ for } \text{NH}_3} = \frac{10^{-14}}{1.8 \times 10^{-5}} = 5.6 \times 10^{-10}$$

Concentration (mol/L)	$\text{NH}_4^+_{(\text{aq})}$	+	$\text{H}_2\text{O}_{(\text{l})}$	$\leftrightarrow$	$\text{NH}_3_{(\text{aq})}$	+	$\text{H}_3\text{O}^+_{(\text{aq})}$
Initial	0.0482				0		0
Change	-x				+x		+x
Equilibrium	$0.0482 - x$				x		x

$$\frac{\text{Initial concentration}}{K_a} = \frac{0.0482}{5.6 \times 10^{-10}} \gg 500, 0.0482 - x \approx 0.0482$$

$$K_a = \frac{x^2}{0.0482} = 5.6 \times 10^{-10}$$

$$x = 5.2 \times 10^{-6}$$

$$[\text{H}_3\text{O}^+_{(\text{aq})}] = 5.2 \times 10^{-6} \text{ mol/L}$$

$$\text{pH} = -\log(5.2 \times 10^{-6}) = 5.28$$

8.

(a)

Concentration (mol/L)	$[\text{Zn}(\text{OH}_2)_6]^{2+}_{(\text{aq})}$	+	$\text{H}_2\text{O}_{(\text{l})}$	$\leftrightarrow$	$[\text{Zn}(\text{OH})(\text{OH}_2)_5]^{+}_{(\text{aq})}$	+	$\text{H}_3\text{O}^+_{(\text{aq})}$
Initial	0.0040				0		0
Change	-x				+x		+x
Equilibrium	0.0040 - x				x		x

$$\frac{\text{Initial concentration}}{K_a} = \frac{0.0040}{1.06 \times 10^{-9}} \gg 500, 0.0040 - x \approx 0.0040$$

$$K_a = \frac{x^2}{0.0040} = 1.06 \times 10^{-9}$$

$$x = 2.1 \times 10^{-6}$$

$$[\text{H}_3\text{O}^+_{(\text{aq})}] = 2.1 \times 10^{-6} \text{ mol/L}$$

$$\text{pH} = -\log(2.1 \times 10^{-6}) = 5.68$$

(b)

$$\text{pH} = 2.500$$

$$[\text{H}_3\text{O}^+_{(\text{aq})}] = 10^{-\text{pH}} = 0.00316$$

Concentration (mol/L)	$[\text{Fe}(\text{OH}_2)_6]^{3+}_{(\text{aq})}$	+	$\text{H}_2\text{O}_{(\text{l})}$	$\leftrightarrow$	$[\text{Fe}(\text{OH})(\text{OH}_2)_5]^{2+}_{(\text{aq})}$	+	$\text{H}_3\text{O}^+_{(\text{aq})}$
Initial	0.0200				0		0
Change	-0.00316				+0.00316		+0.00316
Equilibrium	0.0200 - 0.00316				0.00316		0.00316

$$K_a = \frac{(0.00316)^2}{0.0200 - 0.00316} = 5.94 \times 10^{-4}$$

9.

$$\text{pH} = 1.502$$

$$[\text{H}_3\text{O}^+_{(\text{aq})}] = 10^{-\text{pH}} = 0.0315$$

Concentration (mol/L)	$\text{HIO}_{(\text{aq})}$	+	$\text{H}_2\text{O}_{(\text{l})}$	$\leftrightarrow$	$\text{IO}^-_{(\text{aq})}$	+	$\text{H}_3\text{O}^+_{(\text{aq})}$
Initial	0.455				0		0
Change	-0.0315				+0.0315		+0.0315
Equilibrium	0.455 - 0.0315				0.0315		0.0315

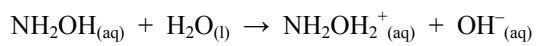
$$K_a = \frac{(0.0315)^2}{0.455 - 0.0315} = 2.34 \times 10^{-3}$$

**10.**

$$\text{pH} = 9.191$$

$$\text{pOH} = 14.000 - \text{pH} = 14.000 - 9.191 = 4.809$$

$$[\text{OH}^-] = 10^{-\text{pOH}} = 1.55 \times 10^{-5} \text{ mol/L}$$



$$\text{Percent dissociation} = \frac{1.55 \times 10^{-5}}{0.0274} \times 100\% = 0.0566 \%$$