DATE: NAME: CLASS:

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) $H_3PO_{4(aq)} + N_2H_{4(aq)} \leftrightarrow H_2PO_4{}^-{}_{(aq)} + N_2H_5{}^+{}_{(aq)}$
(b) $SO_4{}^{2-}{}_{(aq)} + CH_3CHOHCO_2H_{(aq)} \leftrightarrow CH_3CHOHCOO^-{}_{(aq)} + HSO_4{}^{2-}{}_{(aq)}$
(c) $H_2CO_{3(aq)} + SO_4{}^{2-}{}_{(aq)} \leftrightarrow HCO_3{}^-{}_{(aq)} + HSO_4{}^-{}_{(aq)}$

Problem 2

What is the pH of each of the following solutions?
(a) 50.0 mL of a solution of pOH = 9
(b) 50.0 mL of an acid with $[H_3O^+{}_{(aq)}] = 1.0 \times 10^{-4}$ mol/L
(c) 10.0 mL water + 10.0 mL 0.0050 mol/L HCl
(d) 20.0 mL of 0.0250 mol/L H_2SO_4
(e) 4.92 g NaOH in 2.00 L water

Problem 3

An excess of 6.00 L of 4.00 mol/L H_2SO_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?
$2NaHCO_{3(s)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)} + 2CO_{2(g)}$

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 H_3Cit 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 H_2Cit^{2-} ions in the acid solution?

Problem 5

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

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.

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Problem 7

Calculate the pH of a 0.0482 mol/L solution of NH_4Cl. The value of K_b for NH_3 is 1.8×10^{-5}.

Problem 8

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

$[Zn(OH_2)_6]^{2+}_{(aq)} + H_2O_{(l)} \rightarrow [Zn(OH)(OH_2)_5]^{+}_{(aq)} + H_3O^{+}_{(aq)}$

The acid dissociation constant for this reaction is 1.06×10^{-9}. Calculate the pH of a 0.0040 mol/L solution of $ZnCl_2$.

(b) A solution of $FeCl_3$ has a pH of 2.500. Calculate the acid dissociation constant for a 0.0200 mol/L solution of $Fe^{3+}_{(aq)}$. The reaction is represented by the following equation.

$[Fe(OH_2)_6]^{3+}_{(aq)} + H_2O_{(l)} \rightarrow [Fe(OH)(OH_2)_5]^{2+}_{(aq)} + H_3O^{+}_{(aq)}$

Problem 9

The pH of a 0.455 mol/L hypoiodous acid solution, $HIO_{(aq)}$, 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 NH_2OH, given that its pH at this concentration is 9.191? The value of K_b for NH_2OH is 8.80×10^{-9}.

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Answers

1.

(a) The acid / conjugate base pair is $H_3PO_{4(aq)}$ / $H_2PO_4^-{}_{(aq)}$.
The base / conjugate acid pair is $N_2H_{4(aq)}$ / $N_2H_5^+{}_{(aq)}$.
Products favoured

(b) The acid / conjugate base pair is $CH_3CHOHCO_2H_{(aq)}$ / $CH_3CHOHCOO^-{}_{(aq)}$.
The base / conjugate acid pair is $SO_4^{2-}{}_{(aq)}$ / $HSO_4^{2-}{}_{(aq)}$.
Products favoured

(c) The acid / conjugate base pair is $H_2CO_{3(aq)}$ / $HCO_3^-{}_{(aq)}$.
The base / conjugate acid pair is $SO_4^{2-}{}_{(aq)}$ / $HSO_4^-{}_{(aq)}$.
Reactants favoured

2.

(a) pH = 14 – pOH = 14 – 9 = 5

(b) $[H_3O^+{}_{(aq)}] = 1.0 \times 10^{-4}$ mol/L
pH = –log (1.0×10^{-4}) = 4

(c) $[H^+]$ = 0.0025 mol/L
pH = –log (0.0025) = 2.60

(d) $[H^+] = 2\,[H_2SO_4] = 2 \times 0.0250$ mol/L = 0.0500 mol/L
pH = –log (0.0500) = 1.301

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

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

pOH = –log (0.0615) = 1.211
pH = 14.000 – pOH = 14.000 – 1.211 = 12.789

3.

(a) $2KOH_{(s)} + H_2SO_{4(aq)} \rightarrow K_2SO_{4(aq)} + 2H_2O_{(l)}$

Amount of $H_2SO_4 = 6.00 \text{ L} \times \dfrac{4.00\text{ mol}}{1\text{ L}} = 24.0 \text{ mol}$

Amount of KOH = 2 × 24.0 mol = 48.0 mol

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

(b) Amount of $NaHCO_3$ = 2 × 24.0 mol = 48.0 mol

Mass of $NaHCO_3 = 48.0 \text{ mol} \times \dfrac{84.01\text{ g}}{1\text{ mol}} = 4.03 \times 10^3 \text{ g}$

4.

(a) $H_3Cit_{(aq)} + H_2O_{(l)} \rightarrow H_2Cit^-{}_{(aq)} + H_3O^+{}_{(aq)}$ $K_{a1} = 7.42 \times 10^{-4}$
$H_2Cit^-{}_{(aq)} + H_2O_{(l)} \rightarrow HCit^{2-}{}_{(aq)} + H_3O^+{}_{(aq)}$ $K_{a2} = 1.68 \times 10^{-5}$
$HCit^{2-}{}_{(aq)} + H_2O_{(l)} \rightarrow Cit^{3-}{}_{(aq)} + H_3O^+{}_{(aq)}$ $K_{a3} = 4.00 \times 10^{-7}$

(b)

Concentration (mol/L)	$H_3Cit_{(aq)}$	+	$H_2O_{(l)}$	$\leftrightarrow$	$H_2Cit^-{}_{(aq)}$	+	$H_3O^+{}_{(aq)}$
Initial	0.002 00				0		0
Change	$-x$				$+x$		$+x$
Equilibrium	$0.002\,00 - x$				x		x

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$$K_{a1} = \frac{[H_2Cit^-][H_3O^+]}{[H_3Cit]} = \frac{x^2}{(0.002\,00 - x)} = 7.42 \times 10^{-4}$$

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

$$x = \frac{-7.42\times10^{-4} \pm \sqrt{(7.42\times10^{-4})^2 - 4(1)(-1.48\times10^{-6})}}{2(1)}$$

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

$[H_3O^+_{(aq)}] = 9.00 \times 10^{-4}$ mol/L

pH = –log (9.00×10^{-4}) = 3.048

(c)

Concentration (mol/L)	$H_2Cit^-_{(aq)}$	+	$H_2O_{(l)}$	↔	$HCit^{2-}_{(aq)}$	+	$H_3O^+_{(aq)}$
Initial	9.00×10^{-4}				0		9.00×10^{-4}
Change	$-x$				$+x$		$+x$
Equilibrium	$9.00 \times 10^{-4} - x$				x		$9.00 \times 10^{-4} + x$

$$K_{a2} = \frac{[HCit^{2-}][H_3O^+]}{[H_2Cit^-]} = \frac{x(9.00\times10^{-4} + x)}{9.00\times10^{-4} - x} = 1.68 \times 10^{-5}$$

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

$$x = \frac{-9.17\times10^{-4} \pm \sqrt{(9.17\times10^{-4})^2 - 4(1)(-1.51\times10^{-8})}}{2(1)}$$

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

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

5.

$Al(OH)_{3(s)} \rightarrow Al^{3+}_{(aq)} + 3OH^-_{(aq)}$

2.41×10^{-5} mol/L $\qquad$ 7.23×10^{-5} mol/L

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

pOH = –log (7.23×10^{-5}) = 4.141

pH = 14.000 – pOH = 14.000 – 4.141 = 9.859

6.

Use the abbreviation HBu for butanoic acid.

pH = 3.22

$[H_3O^+_{(aq)}] = 10^{-pH} = 6.0 \times 10^{-4}$ mol/L

$HBu_{(aq)} + H_2O_{(l)} \rightarrow Bu^-_{(aq)} + H_3O^+_{(aq)}$

$0.0240 - 6.0 \times 10^{-4}$ $\qquad$ 6.0×10^{-4} $\qquad$ 6.0×10^{-4}

$$K_a = \frac{[Bu^-][H_3O^+]}{[HBu]} = \frac{(6.0\times10^{-4})^2}{0.0240 - 6.0\times10^{-4}} = 1.6 \times 10^{-5}$$

7.

$NH_4Cl_{(aq)} \rightarrow NH_4^+_{(aq)} + Cl^-_{(aq)}$

$$K_a \text{ for } NH_4^+_{(aq)} = \frac{K_w}{K_b \text{ for } NH_3} = \frac{10^{-14}}{1.8\times10^{-5}} = 5.6 \times 10^{-10}$$

Concentration (mol/L)	$NH_4^+_{(aq)}$	+	$H_2O_{(l)}$	↔	$NH_{3(aq)}$	+	$H_3O^+_{(aq)}$
Initial	0.0482				0		0
Change	$-x$				$+x$		$+x$
Equilibrium	$0.0482 - x$				x		x

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

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

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

$[H_3O^+_{(aq)}] = 5.2 \times 10^{-6}$ mol/L

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

8.

(a)

Concentration (mol/L)	$[Zn(OH_2)_6]^{2+}_{(aq)}$	+	$H_2O_{(l)}$	$\leftrightarrow$	$[Zn(OH)(OH_2)_5]^+_{(aq)}$	+	$H_3O^+_{(aq)}$
Initial	0.0040				0		0
Change	$-x$				$+x$		$+x$
Equilibrium	$0.0040 - x$				x		x

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

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

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

$[H_3O^+_{(aq)}] = 2.1 \times 10^{-6}$ mol/L

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

(b)

pH = 2.500

$[H_3O^+_{(aq)}] = 10^{-\text{pH}} = 0.003\ 16$

Concentration (mol/L)	$[Fe(OH_2)_6]^{3+}_{(aq)}$	+	$H_2O_{(l)}$	$\leftrightarrow$	$[Fe(OH)(OH_2)_5]^{2+}_{(aq)}$	+	$H_3O^+_{(aq)}$
Initial	0.0200				0		0
Change	–0.003 16				+0.003 16		+0.003 16
Equilibrium	0.0200 – 0.003 16				0.003 16		0.003 16

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

9.

pH = 1.502

$[H_3O^+_{(aq)}] = 10^{-\text{pH}} = 0.0315$

Concentration (mol/L)	$HIO_{(aq)}$	+	$H_2O_{(l)}$	$\leftrightarrow$	$IO^-_{(aq)}$	+	$H_3O^+_{(aq)}$
Initial	0.455				0		0
Change	–0.0315				+0.0315		+0.0315
Equilibrium	0.455 – 0.0315				0.0315		0.0315

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

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10.

pH = 9.191
pOH = 14.000 – pH = 14.000 – 9.191 = 4.809
$[OH^-] = 10^{-pOH} = 1.55 \times 10^{-5}$ mol/L

$NH_2OH_{(aq)} + H_2O_{(l)} \rightarrow NH_2OH_2{}^+{}_{(aq)} + OH^-{}_{(aq)}$

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

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