CHE152
Chapter 19 - Acid-Base Equilibria and Solubility Equilibria
Additional Problems
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19.1 Describe the preparation of 250.0 mL of a buffer with a pH of 9.95 assuming that 0.1250 M solutions of NH_3 and NH_4Cl are available.

19.2 Describe the preparation of 150.0 mL of a buffer with a pH of 4.00 assuming that 0.1005 M solutions of C_6H_5COOH and C_6H_5COONa are available.

19.3 Refer to Chapter 16 page 32 of your notes. What color will each of the solutions below exhibit int the indicators on page 32.

(a) 0.0001500 M $HClO_4$
(b) 0.09500 M $HC_2H_3O_2$
(c) 0.1000 M C_5H_5N
(d) 0.0005000 M KOH
(e) 0.01550 M HNO_2
(f) 1.500 M HCN

19.4 6 drops of 0.01250 M $Ba(NO_3)_2$ are added to 125.00 mL of 0.00150 M Na_2CO_3. Will $BaCO_3$ precipitate? 20 drops = 1 mL.

19.5 2 drops of 0.009950 M $CaCl_2$ are added to 150.00 mL of 0.0110 M NaOH. Will $Ca(OH)_2$ precipitate? 20 drops = 1 mL.

19.6 A solution that is 0.1025 M in Mg^{2+} also has a NaF concentration maintained at 0.009885 M. What will be the concentration of Mg^{2+} in the solution? Is the precipitation of MgF_2 complete?

19.7 A 15.00 mL sample of 0.07500 M $Pb(NO_3)_2$ is added to 75.00 mL of 0.05250 M Na_2CrO_4. Will $PbCrO_4$ precipitate and will the precipitation of Pb^{2+} be complete?

19.8 What concentration of $C_2H_5NH_3^+$ must be maintained in order to prevent the precipitation of $Mg(OH)_2$ in a solution that is 1.25×10^{-4} M in $Mg(NO_3)_2$ and 2.25×10^{-3} M in $C_2H_5NH_2$?

19.9 Calculate the solubility of $SrCO_3$ in a solution that is buffered to a pH of 5.25.

19.10 A 0.1250 mole sample of $Zn(NO_3)_2$ is dissolved in 2.50 L of 0.7595 M NaCN. If 0.1250 moles of Na_2S are added to this solution will ZnS precipitate?

19.11 What is the minimum concentration of NaCN required to prevent AgCl from precipitating in a solution that is 0.00002250 M in $AgNO_3$ and 0.00001125 M in NaCl?

19.12 What H_3O^+ concentration must be maintained in a saturated solution H_2S solution in order to separate 0.1250 M Sn^{2+} and 0.1005 M Ni^{2+}?

19.13 What is the solubility of CoS in 1.05 M HCl?

19.1 $\mathbf{pH = 9.95; [H_3O^+] = 1.1_2 \times 10^{-10}\ M; [OH^-] = 8.9_1 \times 10^{-5}\ M}$

$$\mathbf{K_b = \frac{[NH_4^+][OH^-]}{[NH_3]} = 1.74 \times 10^{-5} = \frac{[NH_4^+]\,8.9_1 \times 10^{-5}}{[NH_3]}; \frac{[NH_4^+]}{[NH_3]} = 0.19_5}$$

Let x = mL of $NaNH_4$ and y = mL of NH_3; x + y = 250.0; x = 250.0 − y

$$\mathbf{[NH_4^+] = \frac{x \cdot 0.1250}{250.0} = \frac{(250.0 - y)\ 0.1250}{250.0}; [NH_3] = \frac{y \cdot 0.1250}{250.0}}$$

$$\mathbf{\frac{\frac{(250.0 - y)\ 0.1250}{250.0}}{\frac{y \cdot 0.1250}{250.0}} = \frac{(250.0 - y)\ 0.1250}{y \cdot 0.1250} = 0.19_5}$$

$\mathbf{250.0 - y = 0.19_5\, y;\ y = 209;\ x = 250.0 - 209 = 41}$

Take 209 mL of 0.1250 M NH_3 and mix with 41 mL of 0.1250 M $NaNH_4$

19.2 $\mathbf{pH = 4.00; [H_3O^+] = 1.00 \times 10^{-4} M}$

$$\mathbf{K_a = \frac{[C_6H_5COO^-][H_3O^+]}{[C_6H_5COOH]} = 6.3 \times 10^{-5} = \frac{[C_6H_5COO^-]\,1.00 \times 10^{-4}}{[C_6H_5COOH]}}$$

$$\mathbf{\frac{[C_6H_5COO^-]}{[C_6H_5COOH]} = 0.63}$$

Let x = mL of C_6H_5COONa and y = mL of C_6H_5COOH; x + y = 150.0; x = 150.0 − y

$$\mathbf{[C_6H_5COO^-] = \frac{x \cdot 0.1005}{150.0} = \frac{(150.0 - y)0.1005}{150.0}; [C_6H_5COOH] = \frac{y \cdot 0.1005}{150.0}}$$

$$\mathbf{\frac{\frac{(150.0 - y)0.1005}{150.0}}{\frac{y \cdot 0.1005}{150.0}} = \frac{(150.0 - y)0.1005}{y \cdot 0.1005} = 0.63}$$

$\mathbf{150.0 - y = 0.63y;\ y = 92;\ x = 150.0 - 92 = 58}$

Take 58 **mL of 0.1005 M C_6H_5COONa and mix with** 92 **mL of 0.1005 M C_6H_5COOH.**

19.3 (a) pH = 3.82

methyl orange	orange-red
bromocresol green	yellow
methyl red	red
phenol red	yellow
phenolphthalein	colorless

(b)

	$HC_2H_3O_2$	+	H_2O	$\rightleftharpoons$	$C_2H_3O_2^-$	+	H_3O^+
I	0.09500				0		0
C	-x				+x		+x
E_x	0.09500 - x				x		x
E	0.09500						

$$\frac{\mathbf{x^2}}{\mathbf{0.09500}} = \mathbf{1.74 \times 10^{-5}};\ \mathbf{x} = \mathbf{0.00129};\ \mathbf{pH} = \mathbf{2.89}$$

methyl orange	red
bromocresol green	yellow
methyl red	red
phenol red	yellow
phenolphthalein	colorless

(c)

	C_5H_5N	+	H_2O	$\rightleftharpoons$	$C_5H_5NH^+$	+	OH^-
I	0.1000				0		0
C	-x				+x		+x
E_x	0.1000 - x				x		x
E	0.1000						

$$\frac{\mathbf{x^2}}{\mathbf{0.1000}} = \mathbf{2.0 \times 10^{-9}};\ \mathbf{x} = \mathbf{1.41 \times 10^{-5}};\ \mathbf{pOH} = \mathbf{4.85};\ \mathbf{pH} = \mathbf{9.15}$$

methyl orange	orange
bromocresol green	blue
methyl red	yellow
phenol red	red
phenolphthalein	colorless

(d) pOH = 3.30; pH = 10.7

methyl orange	orange
bromocresol green	blue
methyl red	yellow
phenol red	red
phenolphthalein	red

(e)

	HNO_2	+	H_2O	$\rightleftharpoons$	NO_2^-	+	H_3O^+
I	0.01550				0		0
C	-x				+x		+x
E_x	0.01550 - x				x		x
E	0.01550						

$$\frac{x^2}{0.01550} = 5.13 \times 10^{-4};\ x = 0.00282 - \text{assumption fails}$$

$$\frac{x^2}{0.01550 - 0.00282} = 5.13 \times 10^{-4};\ x = 0.00255;\ pH = 2.59$$

methyl orange	red
bromocresol green	yellow
methyl red	red
phenol red	yellow
phenolphthalein	colorless

(f)

	HCN	+	H_2O	$\rightleftharpoons$	CN^-	+	H_3O^+
I	1.500				0		0
C	-x				+x		+x
E_x	1.500 - x				x		x
E	1.500						

$$\frac{x^2}{1.500} = 4.0 \times 10^{-10};\ x = 2.4 \times 10^{-5};\ pH = 4.61$$

methyl orange	orange
bromocresol green	green
methyl red	red
phenol red	yellow
phenolphthalein	colorless

$$16.4\ \frac{6\ d}{1}\ x\ \frac{1\ mL}{20\ d} = 0.30\ mL$$

$$\frac{0.01250\ mol\ Ba(NO_3)_2}{L}\ x\ \frac{0.30\ mL}{125.30\ mL}\ x\ \frac{1\ mol\ Ba^{2+}}{1\ mol\ Ba(NO_3)_2} = 3.0\ x10^{-5}\ M\ Ba^{2+}$$

$$\frac{0.00150\ mol\ Na_2CO_3}{L}\ x\ \frac{125.00\ mL}{125.30\ mL}\ x\ \frac{1\ mol\ CO_3^{2-}}{1\ mol\ Na_2CO_3} = 1.50\ x\ 10^{-3}\ M\ CO_3^{2-}$$

$$Q = [Ba^{2+}][CO_3^{2-}] = 3.0\ x\ 10^{-5}\ x\ 1.50\ x\ 10^{-3} = 4.5\ x\ 10^{-8}$$

$$K_{sp} = 5.1\ x\ 10^{-9};\ Q > K_{sp}\ \therefore\ BaCO_3\ \text{will precipitate}$$

$$19.5\ \frac{2\ d}{1}\ x\ \frac{1\ mL}{20\ d} = 0.10\ mL$$

$$\frac{0.009950\ mol\ CaCl_2}{L}\ x\ \frac{0.10\ mL}{150.10\ mL}\ x\ \frac{1\ mol\ Ca^{2+}}{1\ mol\ CaCl_2} = 6.6\ x10^{-6}\ M\ Ca^{2+}$$

$$\frac{0.0110\ mol\ NaOH}{L}\ x\ \frac{150.00\ mL}{150.10\ mL}\ x\ \frac{1\ mol\ OH^-}{1\ mol\ NaOH} = 1.10\ x\ 10^{-2}\ M\ OH^-$$

$$Q = [Ca^{2+}][OH^-]^2 = 6.6\ x\ 10^{-6}\ x\ (1.10\ x\ 10^{-2})^2 = 8.0\ x\ 10^{-10}$$

$$K_{sp} = 5.5\ x\ 10^{-6};\ Q < K_{sp}\ \therefore\ Ca(OH)_2\ \text{will not precipitate}$$

$$19.6\ Q = [Mg^{2+}][F^-]^2 = 0.1025(0.009885)^2 = 1.002\ x\ 10^{-5}$$

$$K_{sp} = 3.7\ x\ 10^{-8};\ Q > K_{sp}\ \therefore\ MgF_2\ \text{will precipitate}$$

$$3.7\ x\ 10^{-8} = [Mg^{2+}](0.009885)^2;\ [Mg^{2+}] = 3.8\ x\ 10^{-4}\ M$$

$$\%Mg^{2+} = \frac{3.8\ x\ 10^{-4}\ M}{0.1025\ M}\ x\ 100 = 0.37\%\ \text{not quite complete (must be} < 0.1\%)$$

19.7 $\dfrac{\mathbf{0.07500\ mol\ Pb(NO_3)_3}}{\mathbf{L}} \mathbf{x} \dfrac{\mathbf{15.00\ mL}}{\mathbf{90.00\ mL}} \mathbf{x} \dfrac{\mathbf{1\ mol\ Pb^{2+}}}{\mathbf{1\ mol\ Pb(NO_3)_2}} = \mathbf{0.01250\ M\ Pb^{2+}}$

$\dfrac{\mathbf{0.05250\ mol\ Na_2CrO_4}}{\mathbf{L}} \mathbf{x} \dfrac{\mathbf{75.00\ mL}}{\mathbf{90.00\ mL}} \mathbf{x} \dfrac{\mathbf{1mol\ CrO_4^{2-}}}{\mathbf{1\ mol\ Na_2CrO_4}} = \mathbf{0.04375\ M\ CrO_4^{2-}}$

$\mathbf{Q = [Pb^{2+}][CrO_4^{2-}] = (0.01250)(0.04375) = 5.5 \times 10^{-4}}$

$\mathbf{K_{sp} = 2.8 \times 10^{-13}}$; $\mathbf{Q > K_{sp}}$ $\therefore$ **$PbCrO_4$ will precipitate**

	$PbCrO_4$ $\rightleftharpoons$	Pb^{2+}	+	CrO_4^{2-}
I		0.01250		0.04375
C		-0.01250		0.01250
I		0		0.03125
C		+x		+x
E_x		x		0.03125 + x
E				0.03125

$K_{sp} = [Pb^{+2}][CrO_4^{2-}] = x(0.03125) = 2.8 \times 10^{-13}$; $x = 9.0 \times 10^{-12}$

$[Pb^{+2}] = 9.0 \times 10^{-12}$ M; precipitation is complete

19.8 $K_{sp} = [Mg^{2+}][OH^-]^2 = 1.8 \times 10^{-11} = 1.25 \times 10^{-3}[OH^-]^2$; $[OH^-] = 1.2 \times 10^{-4}$ M

$$\mathbf{K_b = \frac{[C_2H_5NH_3^+][OH^-]}{[C_2H_5NH_2]} = 4.4\ x10^{-4} = \frac{[C_2H_5NH_3^+]1.2x10^{-4}}{2.25x10^{-3}}}$$

$\mathbf{[C_2H_5NH_3^+] = 0.0082_5\ M}$

19.9

$SrCO_3$ (s) $\rightleftharpoons$ Sr^{2+} (aq) + CO_3^{2-} $K_{sp} = 1.1 \times 10^{-10}$

CO_3^{2-} (aq) + $H_3O^+ \rightleftharpoons$ HCO_3^- (aq) + H_2O $K = 1/K_{a2} = 1.8 \times 10^{10}$

HCO_3^- (aq) + $H_3O^+ \rightleftharpoons$ H_2CO_3 (aq) + H_2O $K = 1/K_{a1} = 2.4 \times 10^6$

$SrCO_3$ (s) + 2 H_3O^+ (aq) $\rightleftharpoons$ Sr^{2+} (aq) + H_2CO_3 (aq) + 2 H_2O

$K = K_{sp} \times K_{a2} \times K_{a1} = 4.8 \times 10^6$

	$SrCO_3$ (s)	+	2 H_3O^+ (aq)	⇌	Sr^{2+} (aq)	+	H_2CO_3 (aq)	+	2 H_2O
I			5.6×10^{-6}		0		0		
C			----------		+x		+x		
E_x			----------		x		x		
E			5.6×10^{-6}						

$$\mathbf{K} = \frac{[\mathbf{Sr^{2+}}][\mathbf{H_2CO_3}]}{[\mathbf{H_3O^+}]^2} = \mathbf{4.8 \times 10^6} = \frac{\mathbf{x^2}}{(\mathbf{5.6 \times 10^{-6}})^2}; \mathbf{x} = \mathbf{0.012}$$

$$\textbf{solubility} = \mathbf{0.012\ M}$$

$$\mathbf{19.10}\ \frac{\mathbf{0.1250\ mol\ Zn(NO_3)_2}}{\mathbf{1}} \times \frac{\mathbf{1}}{\mathbf{2.50\ L}} \times \frac{\mathbf{1\ mol\ Zn^{2+}}}{\mathbf{1\ mol\ Zn(NO_3)_2}} = \mathbf{0.0500\ M\ Zn^{2+}}$$

$$\frac{\mathbf{0}.1250\ \mathbf{mol\ Na_2S}}{\mathbf{1}} \times \frac{\mathbf{1}}{\mathbf{2.50\ L}} \times \frac{\mathbf{1\ mol}\ S^{2-}}{\mathbf{1\ mol\ Na_2S}} = 0.0500\ \mathbf{M}\ S^{2-}$$

	Zn^{2+} (aq)	+	4 CN^- (aq)	⇌	$[Zn(CN)_4]^{2-}$
I	0.0500		0.7595		0
C	-0.0500		-4(0.0500)		+0.0500
I	0		0.5595		0.0500
C	+x		+4x		-x
E_x	x		0.5595 + 4x		0.0500 - x
E			0.5595		0.0500

$$\mathbf{K_f} = \frac{[[\mathbf{Zn(CN)_4}]^{2-}]}{[\mathbf{Zn^{2+}}][\mathbf{CN^-}]^4} = \mathbf{1 \times 10^{18}} = \frac{\mathbf{0.0500}}{[\mathbf{Zn^{2+}}](\mathbf{0.5595})^4}; [\mathbf{Zn^{2+}}] = \mathbf{5 \times 10^{-19}\ M}$$

$K_{sp} = [Zn^{2+}][S^{2-}] = 1 \times 10^{-21}$

$Q = [Zn^{2+}][S^{2-}] = 5 \times 10^{-19} \times 0.0500 = 2._5 \times 10^{-20}$

$Q > K_{sp}$ therefore ZnS will precipitate

19.11 $K_{sp} = [Ag^+][Cl^-] = 1.8 \times 10^{-10} = [Ag^+][0.00001125]$; $[Ag^+] = 1.6 \times 10^{-5}$ M

$$\mathbf{K_f = \frac{[[Ag(CN)_2]^-]}{[Ag^+][CN^-]^2} = 5.6 \times 10^{18} = \frac{0.00002250}{1.6 \times 10^{-5}[CN^-]^2}; [CN^-] = 5.0 \times 10^{-10}\ M}$$

$$\mathbf{\frac{0.00002250\ mol\ Ag^+}{L} \times \frac{2\ mol\ CN^-}{1\ mol\ Ag^+} = 0.00004500\ M}$$

$$\mathbf{[NaCN]_{total} = 0.00004500\ M + 5.0 \times 10^{-10}\ M = 0.00004500\ M}$$

19.12 $SnS\ (s) \rightleftharpoons Sn^{2+}\ (aq) + S^{2-}\ (aq)$; $K_{sp} = 1 \times 10^{-25}$
$NiS\ (s) \rightleftharpoons Ni^{2+}\ (aq) + S^{2-}\ (aq)$; $K_{sp} = 3 \times 10^{-19}$

$1 \times 10^{-25} = 0.125[S^{2-}]$; $[S^{2-}] = 8 \times 10^{-25}$ M
$3 \times 10^{-19} = 0.1005[S^{2-}]$; $[S^{2-}] = 3 \times 10^{-18}$ M

$$\mathbf{\frac{8 \times 10^{-25}[H_3O^+]^2}{0.10} = 1.1 \times 10^{-21}; [H_3O^+] = 11.7\ M}$$

$$\mathbf{\frac{3 \times 10^{-18}[H_3O^+]^2}{0.10} = 1.1 \times 10^{-21}; [H_3O^+] = 6 \times 10^{-3}\ M}$$

$$\mathbf{11.7\ M > [H_3O^+] > 6 \times 10^{-3} M}$$

19.13 $HCl\ (aq) + H_2O\ (aq) \longrightarrow H_3O^+ + Cl^-$
$CoS\ (s) \rightleftharpoons Co^{2+}\ (aq) + S^{2-}\ (aq)$ $K_{sp} = 4 \times 10^{-21}$
$S^{2-}\ (aq) + H_3O^+\ (aq) \rightleftharpoons HS^-\ (aq) + H_2O$ $1/K_{a2} = 1.0 \times 10^{14}$
$HS^-\ (aq) + H_3O^+\ (aq) \rightleftharpoons H_2S\ (aq) + H_2O$ $1/K_{a1} = 9.1 \times 10^{6}$

$CoS\ (s) + 2\ H_3O^+ \rightleftharpoons Co^{2+}\ (aq) + H_2S\ (aq) + 2\ H_2O$ $K = K_{sp} \times 1/K_{a2} \times 1/K_{a2} = 3.64$

	$CoS\ (s)$	+	$2\ H_3O^+$	$\rightleftharpoons$	$Co^{2+}\ (aq)$	+	H_2S	+	$2\ H_2O$
I			1.05		0		0		
R			-2x		+x		+x		
E_x			1.05 - x		x		x		
E									

$$\mathbf{K} = \frac{[\mathbf{Co^{2+}}][\mathbf{H_2S}]}{[\mathbf{H_3O^{+}}]^2} = \mathbf{3.64} = \frac{\mathbf{x}^2}{(\mathbf{1.05} - \mathbf{2x})^2}$$

$$\sqrt{\mathbf{3.64}} = \sqrt{\frac{\mathbf{x}^2}{(\mathbf{1.05} - \mathbf{2x})^2}}; \mathbf{1.91} = \frac{\mathbf{x}}{\mathbf{1.05} - \mathbf{2x}}$$

$$\mathbf{2.00} - \mathbf{3.85x} = \mathbf{x}; \mathbf{x} = \mathbf{0.416}$$

$$\mathbf{S} = \mathbf{0.416\ M}$$