Laboratory #8 pH of Acids, Bases & Buffers

B. pH of distilled water:

1. $2\ H_2O \rightleftharpoons H_3O^+ + OH^-$

2. Expected pH 7.00

3. The acidic pH of distilled water is due to the absorption of CO_2 from the atmosphere:

$$CO_2\ (g) + H_2O \longrightarrow H_2CO_3$$
$$H_2CO_3 + H_2O \rightleftharpoons HCO_3^- + H_3O^+$$
$$HCO_3^- + H_2O \rightleftharpoons CO_3^{-2} + H_3O^+$$

C. pH of strong acids & bases:

1. $HCl \longrightarrow H^+ + Cl^-$
   $H^+ + H_2O \longrightarrow H_3O^+$

2. 0.05 M HCl; $[H_3O^+] = 0.05$ M; pH = -log(0.05) = 1.30

4. $NaOH \longrightarrow Na^+ + OH^-$

5. 0.0050 M NaOH; $[OH^-] = 0.0050$ M; pOH = -log(0.0050) = 2.30
   pH = 14.00 - 2.03 = 11.70

D. pH of weak acids & bases:

1.

	HOAc	+	H_2O	$\rightleftharpoons$	OAc^-	+	H_3O^+
I	0.50				0		0
C	-x				+x		+x
E_x	0.50 - x				x		x
E	≈ 0.50						

$$K_a = \frac{[OAc^-][H_3O^+]}{[HOAc]} = 1.74 \times 10^{-5} = \frac{x^2}{0.50};\ x = 0.0029$$

$$[H_3O^+] = 0.0029\ M;\ pH = -\log(0.0029) = 2.53$$

2. Expected pH: 2.53

4.

	NH_3	+	H_2O	$\rightleftharpoons$	NH_4^+	+	OH^-
I	0.10				0		0
C	-x				+x		+x
E_x	0.10 - x				x		x
E	≈ 0.10						

$$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]} = 1.74 \text{ x } 10^{-5} = \frac{x^2}{0.10}; x = 0.013$$

$$[OH^-] = 0.0013 \text{ M}; pOH = -\log(0.0013) = 2.88$$

$$pH = 14.00 - 2.88 = 11.12$$

5. Expected pH: 11.12

E. Hydrolysis of Salts of weak acids and bases

2. a)

	OAc^-	+	H_2O	$\rightleftharpoons$	HOAc	+	OH^-
I	0.50				0		0
C	-x				+x		+x
E_x	0.50 - x				x		x
E	≈ 0.50						

$$K_b = \frac{[HOAc][OH^-]}{[OAc^-]} = \frac{K_w}{K_a} = \frac{1.00 \text{ x } 10^{-14}}{1.74 \text{ x } 10^{-5}} = 5.75 \text{ x } 10^{-10}$$

$$5.75 \text{ x } 10^{-10} = \frac{x^2}{0.50}; x = 1.7 \text{ x } 10^{-5}$$

$$[OH^-] = 1.7 \text{ x } 10^{-5} \text{ M}; pOH = 4.77; pH = 14.00 - 4.77 = 9.23$$

Expected pH = 9.23

2. b)

	NH_4^+	+	H_2O	$\rightleftharpoons$	NH_3	+	H_3O^+
I	0.10				0		0
C	-x				+x		+x
E_x	0.10 - x				x		x
E	≈ 0.10						

$$K_a = \frac{[NH_3][H_3O^+]}{[NH_4^+]} = \frac{K_w}{K_b} = \frac{1.00 \times 10^{-14}}{1.74 \times 10^{-5}} = 5.75 \times 10^{-10} = \frac{x^2}{0.10}$$

$$x = 7.6 \times 10^{-6}; [H_3O^+] = 7.6 \times 10^{-6}\ M; pH = -\log(7.6 \times 10^{-6}) = 5.12$$

Expected pH = 5.12

2. c)

	SO_4^{-2}	+	H_2O	$\rightleftharpoons$	HSO_4^-	+	OH^-
I	0.10				0		0
C	-x				+x		+x
E_x	0.10 - x				x		x
E	≈ 0.10						

$$K_b = \frac{[HSO_4^1][OH^-]}{[SO_4^{-2}]} = \frac{K_w}{K_{a_2}} = \frac{1.00 \times 10^{-14}}{1.29 \times 10^{-2}} = 7.75 \times 10^{-13} = \frac{x^2}{0.10}$$

$$x = 2.78 \times 19^{-7}; [OH^-] = 2.78 \times 10^{-7}\ M; pOH = -\log(2.78 \times 10^{-7}) = 6.56$$

$$pH = 14.00 - 6.56 = 7.44$$

Expected pH = 7.44

F. pH of amphoteric (half-acid) compounds:

1. a) $HCO_3^- + H_2O \rightleftharpoons CO_3^{-2} + H_3O^+$; $K_{a_2} = 5.6 \times 10^{-11}$

$HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$; $K_b = \frac{K_w}{K_{a_1}} = \frac{1.00 \times 10^{-14}}{4.2 \times 10^{-7}} = 2.38 \times 10^{-8}$

1. b) $HPO_4^{-2} + H_2O \rightleftharpoons PO_4^{-3} + H_3O^+$; $K_{a_3} = 4.22 \text{ x } 10^{-13}$

$$HPO_4^{-2} + H_2O \rightleftharpoons H_2PO_4^- + OH^-;\ K_b = \frac{K_w}{K_{a_2}} = \frac{1.00 \text{ x } 10^{-14}}{6.34 \text{ x } 10^{-8}} = 1.58 \text{ x } 10^{-7}$$

1. c) $H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{-2} + H_3O^+$; $K_{a_2} = 6.34 \text{ x } 10^{-8}$

$$H_2PO_4^- + H_2O \rightleftharpoons H_3PO_4 + OH^-;\ K_b = \frac{K_w}{K_{a_1}} = \frac{1.00 \text{ x } 10^{-14}}{7.11 \text{ x } 10^{-3}} = 1.41 \text{ x } 10^{-12}$$

2. a) since $K_b > K_a$ solution will be basic and pH > 7

b) since $K_b > K_a$ solution will be basic and pH > 7

c) since $K_a > K_b$ solution will be acidic and pH < 7

H. A balanced buffer solution:

1.

$$\frac{10.0 \text{ mL}}{1} \text{ x } \frac{0.50 \text{ mmol HOAc}}{\text{mL}} \text{ x } \frac{1}{20.0 \text{ mL}} = \frac{0.25 \text{ mmol HOAc}}{\text{mL}}$$

$$\frac{10.0 \text{ mL}}{1} \text{ x } \frac{0.50 \text{ mmol NaOAc}}{\text{mL}} \text{ x } \frac{1}{20.0 \text{ mL}} = \frac{0.25 \text{ mmol NaOAc}}{\text{mL}}$$

	HOAc	+	H_2O	$\rightleftharpoons$	OAc^-	+	H_3O^+
I	0.25				0.25		0
C	-x				+ x		+x
E_x	0.25 - x				0.25 + x		x
E	≈ 0.25				≈ 0.25		

$$K_a = \frac{[OAc^-][H_3O^+]}{[HOAc]} = 1.74 \text{ x } 10^{-5} = \frac{0.25x}{0.25}$$

$$x = 1.74 \text{ x } 10^{-5}; [H_3O^+] = 1.74 \text{ x } 10^{-5} \text{ M; pH} = -\log(1.74 \text{ x } 10^{-5}) = 4.76$$

2. reaction of buffer with strong base: $HOAc + OH^- \rightleftharpoons OAc^- + H_2O$

   reaction of buffer with strong acid: $OAc^- + H_3O^+ \rightleftharpoons HOAc + H_2O$

3. Strong base addition: $HOAc + OH^- \longrightarrow OAc^- + H_2O$

$$\frac{2.0\ \text{mL}}{1} \times \frac{0.25\ \text{mmol HOAc}}{\text{mL}} \times \frac{1\ \text{mmol NaOH}}{1\ \text{mmol HOAc}} \times \frac{1\ \text{mL}}{1.0\ \text{mmol NaOH}} \times \frac{1\ \text{drop}}{0.05\ \text{mL}}$$

$$= 10\ \text{drops}$$

Strong acid addition: $OAc^- + H_3O^+ \longrightarrow HOAc + H_2O$

$$\frac{2.0\ \text{mL}}{1} \times \frac{0.25\ \text{mmol OAc}^-}{\text{mL}} \times \frac{1\ \text{mmol HCl}}{1\ \text{mmol OAc}^-} \times \frac{1\ \text{mL}}{1.0\ \text{mmol HCl}} \times \frac{1\ \text{drop}}{0.05\ \text{mL}}$$
$$= 10\ \text{drops}$$

5. 10 drops NaOH calculated

   10 drops HCl calculated

I. An unbalanced buffer solution:

1.
$$\text{pH} = 5.30; [H_3O^+] = \text{anti}\log(-5.30) = 5.0 \times 10^{-6}\ \text{M}$$

$$K_a = \frac{[OAc^-][H_3O^+]}{[HOAc]} = 1.74 \times 10^{-5}; \frac{[OAc^-]5.0 \times 10^{-6}}{[HOAc]} = 1.74 \times 10^{-5}$$
$$\frac{[OAc^-]}{[HOAc]} = 3.5$$

$$[OAc^-] = \frac{0.50\ \text{mmol OAc}^-}{\text{mL}}\ \text{x}\ \frac{X\ \text{mL}}{20.0\ \text{mL}} = \frac{0.50}{20.0}X$$

$$[HOAc] = \frac{0.50\ \text{mmol HOAc}}{\text{mL}}\ \text{x}\ \frac{Y\ \text{mL}}{20.0\ \text{mL}} = \frac{0.50}{20.0}Y$$

$$X + Y = 20.0;\ X = 20.0 - Y;\ [OAc^-] = \frac{0.50}{20.0}(20.0 - Y)$$

$$\frac{\frac{0.50}{20.0}(20.0 - Y)}{\frac{0.50}{20.0}Y} = 3.5;\ \frac{20.0 - Y}{Y}\ 3.5;\ 20.0 - Y = 3.5Y$$

$$4.5Y = 20.0;\ Y = 4.4;\ X = 20.0 - 4.4 = 15.6$$

Take 4.4 mL HOAc and 15.6 mL NaOAc

3. Strong base addition: $HOAc + OH^- \longrightarrow OAc^- + H_2O$

Strong acid addition: $OAc^- + H_3O^+ \longrightarrow HOAc + H_2O$

$$\frac{4.4\ \text{mL}}{1}\ \text{x}\ \frac{0.50\ \text{mmol HOAc}}{\text{mL}}\ \text{x}\ \frac{1}{20.0\ \text{mL}} = \frac{0.11\ \text{mmol HOAc}}{\text{mL}}$$

$$\frac{2.0\ \text{mL}}{1}\ \text{x}\ \frac{0.11\ \text{mmol HOAc}}{\text{mL}}\ \text{x}\ \frac{1\ \text{mmol NaOH}}{1\ \text{mmol HOAc}}\ \text{x}\ \frac{1\ \text{mL}}{1.0\ \text{mmol NaOH}}\ \text{x}\ \frac{1\ \text{drop}}{0.05\ \text{mL}} = 4.4\ \text{drops}$$

$$\frac{15.6\ \text{mL}}{1}\ \text{x}\ \frac{0.50\ \text{mmol OAc}^-}{\text{mL}}\ \text{x}\ \frac{1}{20.0\ \text{mL}} = \frac{0.39\ \text{mmol OAc}^-}{\text{mL}}$$

$$\frac{2.0\ \text{mL}}{1}\ \text{x}\ \frac{0.39\ \text{mmol OAc}^-}{\text{mL}}\ \text{x}\ \frac{1\ \text{mmol HCl}}{1\ \text{mmol OAc}^-}\ \text{x}\ \frac{1\ \text{mL}}{1.0\ \text{mmol HCl}}\ \text{x}\ \frac{1\ \text{drop}}{0.05\ \text{mL}} = 15.6\ \text{drops}$$

5. 4.4 drops of NaOH

15.6 drops of HCl