Chem 102
D. Miller

Solutions to Review Problems for Acid/Base Chemistry

1. Glacial acetic acid, pure $HC_2H_3O_2$ (FW = 60.0), has a concentration of 17.54 M. If 85.5 mL of glacial acetic acid are diluted to 250 mL, what is the acetic acid concentration?

This is a dilution problem; use $M_1V_1 = M_2V_2$.

$$(17.54\ M)(85.5\ mL) = M_2\,(250\ mL)$$

$$M_2 = 6.0_0\ M$$

2. If 26 mL of this diluted acetic acid (see Prob. 1) are further diluted to exactly 800 mL, the solution pH is 2.74. Calculate K_a for acetic acid.

First, there is a dilution, followed by an equilibrium calculation involving a solution of a weak acid.

For the dilution, $(6.0_0\ M)(26\ mL) = M_2\ (800.\ mL)$ and $M_2 = 0.19_5\ M$

For the weak acid solution,

	$HC_2H_3O_2$ + H_2O	⇆ H_3O^+	+ $C_2H_3O_2^-$
init	0.19_5 M	~10^{-7} M	0
equil	0.19_5-x	~x	x

where x = increase in $[C_2H_3O_2^-]$. Since the pH is known, the $[H_3O^+]$, and hence x, is known.

$$pH = 2.74 \Rightarrow [H_3O^+] = 1.8_2 \times 10^{-3}\ M = x$$

$$K_a = \frac{[H_3O^+][C_2H_3O_2^-]}{[HC_2H_3O_2]} = \frac{(1.8_2 \times 10^{-3})(1.8_2 \times 10^{-3})}{(0.19_5 - 1.8_2 \times 10^{-3})} = 1.7_1 \times 10^{-5}$$

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3. If 13.2 g $NaC_2H_3O_2$ (FW = 82.0) are added to the 800 mL of solution in Problem 2, what is the resulting pH?

The addition of $C_2H_3O_2^-$ to a solution of $HC_2H_3O_2$ creates a $HC_2H_3O_2$ / $C_2H_3O_2^-$ buffer.

initially, $[HC_2H_3O_2] = 0.19_5$ M

and mol $C_2H_3O_2^-$ = 13.2 g/82.0 g/mol = 0.161 mol

$[C_2H_3O_2^-]$ = 0.161 mol/0.800 L = 0.201 M

	$HC_2H_3O_2$ + H_2O	⇆	H_3O^+	+	$C_2H_3O_2^-$
init	0.19_5 M		$\sim 10^{-7}$ M		0.201 M
equil	$\sim 0.19_5$		x		~0.201

$$K_a = 1.7_1 \times 10^{-5} = \frac{[H_3O^+][C_2H_3O_2^-]}{[HC_2H_3O_2]} = \frac{(x)(0.201)}{(0.19_5)}$$

$x = 1.6_6 \times 10^{-5}$ M = $[H_3O^+]$ ⇒ pH = 4.78

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4. The resulting 800 mL of solution in Problem 3 is divided into two 400-mL samples. If 5.0 mL of 6.0 M HCl are added to one sample, and 5.0 mL of 6.0 M NaOH are added to the other, what is the resulting pH in each case?

The added HCl is neutralized by the weak base and a new buffer is formed.

mol HCl added = (6.0 mol/L)(0.0050 L) = 0.030 mol

init mol $C_2H_3O_2^-$ = (0.201 mol/L)(0.400 L) = 0.0804 mol

init mol $HC_2H_3O_2$ = (0.19_5 mol/L)(0.400 L) = 0.078 mol

	H_3O^+	+ $C_2H_3O_2^-$	→ $HC_2H_3O_2$	+ H_2O
init mol	0.030	0.0804	0.078	
mol after rxn	0	0.0504	0.108	

$[HC_2H_3O_2]$ = 0.108 mol/0.405 L = 0.267 M

$[C_2H_3O_2^-]$ = 0.0504 mol/0.405 L = 0.124 M

	$HC_2H_3O_2$	+ H_2O	⇆ H_3O^+	+ $C_2H_3O_2^-$
init	0.267 M		$\sim 10^{-7}$ M	0.124 M
equil	~0.267		x	~0.124

$$K_a = 1.7_1 \times 10^{-5} = \frac{[H_3O^+][C_2H_3O_2^-]}{[HC_2H_3O_2]} = \frac{(x)(0.124)}{(0.267)}$$

$x = 3.6_8 \times 10^{-5}$ M = $[H_3O^+]$ ⇒ pH = 4.43

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4. (continued)

The added NaOH is neutralized by the weak acid and a new buffer is formed.

mol NaOH added = (6.0 mol/L)(0.0050 L) = 0.030 mol

init mol $HC_2H_3O_2$ = (0.19_5 mol/L)(0.400 L) = 0.078 mol

init mol $C_2H_3O_2^-$ = (0.201 mol/L)(0.400 L) = 0.0804 mol

	OH^- +	$HC_2H_3O_2$ →	$C_2H_3O_2^-$ +	H_2O
init mol	0.030	0.078	0.0804	
mol after rxn	0	0.048	0.110_4	

$[HC_2H_3O_2]$ = 0.048 mol/0.405 L = 0.12 M

$[C_2H_3O_2^-]$ = 0.110_4 mol/0.405 L = 0.273 M

	$HC_2H_3O_2$ +	H_2O ⇆	H_3O^+ +	$C_2H_3O_2^-$
init	0.12 M		$\sim 10^{-7}$ M	0.273 M
equil	~0.12		x	~0.273

$$K_a = 1.7_1 \, x \, 10^{-5} = \frac{[H_3O^+][C_2H_3O_2^-]}{[HC_2H_3O_2]} = \frac{(x)\,(0.273)}{(0.12)}$$

x = 7.5_2 x 10^{-6} M = $[H_3O^+]$ ⇒ pH = 5.12

5. Calculate the pH of 10^{-5} M HCl.

This is a solution of a strong acid and $[H_3O^+]$ ~ [acid].

$[H_3O^+] = 10^{-5}$ M ⇒ pH = 5.0

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6. If 0.050 mL of 6.0 M HCl is added to 400 mL of 10^{-5} M HCl, what is the resulting pH?

The added HCl is combines with the initial HCl to form a new strong acid solution.

mol H_3O^+ added = (6.0 mol/L)(0.000050 L) = 0.00030 mol

init mol H_3O^+ = (10^{-5} mol/L)(0.400 L) = 0.000004 mol

total mol H_3O^+ = 0.00030_4 mol

$[H_3O^+]$ = 0.00030_4 mol/0.400_{05} L = 7.6×10^{-4} M

pH = 3.12

(Notice that the pH of this unbuffered solution decreased by almost 2 pH units with this small addition of acid . Adding 100 times this volume of acid to a buffer (Prob. 4) changed the buffer pH by only 0.34 unit.)

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7. If 0.050 mL of 6.0 M NaOH is added to 400 mL of 10^{-5} M HCl, what is the resulting pH?

The added NaOH reacts with the HCl.

mol NaOH added = (6.0 mol/L)(0.000050 L) = 0.00030 mol

init mol H_3O^+ = (10^{-5} mol/L)(0.400 L) = 0.000004 mol

	OH^-	+ H_3O^+	→ $2H_2O$
init mol	0.00030	0.000004	
mol after rxn	0.00029_6	0	

The HCl is completely neutralized and you are left with a solution of a strong base.

[OH-] = 0.00029_6 mol/0.400_{05} L = 7.4×10^{-4} M

pOH = 3.13 ⇒ pH = 10.87

(Notice that the pH of this unbuffered solution increased by almost 6 pH units with this small addition of base . Adding 100 times this volume of base to a buffer (Prob. 4) changed the buffer pH by only 0.35 unit.)

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8. Characterize the solution formed (strong acid, strong, base, weak acid, weak base, buffer or neutral) when equal volumes of the following are mixed. Explain.

0.5 M NaOH + 0.5 M $HC_2H_3O_2$

The following reaction occurs: $HC_2H_3O_2 + OH^- \rightarrow H_2O + C_2H_3O_2^-$

Since the strong base exactly neutralizes the weak acid (same concentrations and same volumes), a solution containing a weak base ($C_2H_3O_2^-$) is formed.

0.5 M HCl + 0.2 M $NaNO_3$

$NaNO_3$ is a neutral electrolyte (NO_3^- is the conjugate base of a strong acid) so it will not react with the strong acid HCl. A strong acid solution is formed.

1.0 M HNO_3 + 2.0 M K_2CO_3

The following reaction occurs: $CO_3^{2-} + H_3O^+ \rightarrow H_2O + HCO_3^-$

Only one-half of the CO_3^{2-} is converted to HCO_3^- (the CO_3^{2-} concentration is twice that of the acid), so a CO_3^{2-}/HCO_3^- buffer solution is formed.