Worksheet 8 Answers

Worksheet 8. Review: Structure for Working Simple Acid/Base Equilibrium Problems

Assuming high Ca and Cb and separated Ks, there are only three equations needed to solve simple acid base problems: strong, weak and buffer. There are only five possible variables to put into these equations: K_a, K_b, $[H^+]$, $[OH^-]$, C_a, C_b

Strong acid or base	$[H^+] = C_a$
	$[OH^-] = C_b$
Weak acid or base	$[H^+] = (K_a C_a)^{1/2}$
	$[OH^-] = (K_b C_b)^{1/2}$
Acid or basic buffer	$[H^+] = K_a C_a/C_b$
	$[OH^-] = K_b C_b/C_a$

So there isn't a lot of complexity at the bottom of this. The hard part is figuring out which equation to use and what each of the variables is. To accomplish this task, we use the following procedure: 1) strip away all the extraneous information (spectator ions), 2) identify strong acids and bases, 3) identify weak acids and bases, 4) determine if you should neutralize, 5) perform neutralization calculation, 6) decide whether to work the problem as an acid or a base. Once these steps are done, the problem is greatly simplified to the point that you can use the table above to work a calculation. The back of this page shows every possible type of starting conditions and how they reduce to one of the problems above.

1) Getting rid of **spectator ions**. Always eliminate the ions that do nothing: all alkali metals and alkali earths (Na^+, K^+, Ca^{++}) and all conjugate bases of strong acids (Cl^-, NO_3^-, ClO_4^-, I^-, Br^-). Thus
NH_4Cl is NH_4^+ NaOH is just OH^- KCOOH is just $COOH^-$

2) Identify strong acids and bases. **Strong acids** are HCl, HNO_3, H_2SO_4, $HClO_4$, HBr, HI. **Strong bases** are NaOH, KOH, $Mg(OH)_2$, $Ba(OH)_2$ and other alkali metal or earth hydroxides. Notice what happens when you get rid of spectator ions for strong acids and bases.

HCl become **H^+** HNO_3 becomes **H^+** NaOH becomes **OH^-** $Mg(OH)_2$ becomes **$2OH^-$**

In other words, all strong acids are **H^+**. All strong bases are **OH^-**.

3) Identify weak acids and weak bases. Hint: this is done by looking for the words: weak acid or weak base; it is also done by looking for a small K_a or small K_b values, (numbers like 1.4 x 10^{-5} or 6.3 x 10^{-9}, it is also done by looking for the word acid in a compound that is not strong acid; it is also done by looking for the suffix **ate.** Thus formic acid is a weak acid and sodium malonate is a weak base.

And how do you represent a weak acid? **HA** (instead of **HCH_3CH_2COO** which only serves to confuse you).
And how do you represent a weak base: **A^-** (instead of **$NaCH_3CH_2COO$** which only serves to confuse you).

By the time you are through with step 3, you will have identified the presence of all acids and bases. You should have only six possible symbols representing them:

H^+ or **OH^-** for strong acids and bases
HA or **BH^+** for weak acids
B or **A^-** for weak bases

Any other terminology is a waste of time on a test without much time.

4) If possible, **NEUTRALIZE.** You neutralize if:
   - you have both an acid and a base present
   - one or both of the acid or base are strong

for example:

• HCl and Sodium Acetate	are	H^+ and A^-	so	neutralize
• Acetic acid and NaOH	are	HA and OH^-	so	neutralize
• HCl and NaOH	are	H^+ and OH^-	so	neutralize
• Acetic acid and sodium acetate	are	HA and A^-	so	**do not neutralize**

5) To neutralize, you convert both acid and base into moles. Then create a neutralization reaction into which you place the initial mole amounts. Identify the limiting reagent and then calculate the final mole amounts. Convert back to molarity by dividing by total volume if necessary. Examples:

- 5 moles H^+ and 5 moles A^- → 5 moles of HA plus 0 moles of H^+ and A^-
- 2 moles of H^+ and 1 mole of A^- → 1 mole of HA with one mole of A^- left over.
- 0.03 moles of OH^- and 0.01 moles of HA → 0.01 moles A^- with 0.02 moles OH^- left over

Note that after neutralization, you can still have a weak base problem, a weak acid problem, a buffer, a strong acid problem or a strong base problem. In other words, you have to do a neutralization to find out what kind of problem you have.

6) Decide on your calculation terrain. Do you work with acids: calculate with pH, H^+ and K_a. Want to work with bases? Calculate with pOH, OH^- and K_b. It doesn't matter what you choose but remember to give the answer they ask for (H^+, OH^-, pH or pOH). How do you move between acid and base terrain? Use:

- to move from a K_a to a K_b: $K_w = K_aK_b = 10^{-14}$ or $pK_w = pK_a + pK_b = 14$
- to move from a pH to a pOH: $K_w = [H^+][OH^-] = 10^{-14}$ or $pK_w = pH + pOH = 14$

Examples of Acid/Base Problems Using Different Starting Materials

in calculations use K_a for acetic acid = 1.8×10^{-5} and K_b for ammonia = 1.8×10^{-5}

Starting Materials	Materials after neutralization	Equation to use	Sample problem	Calculate pH
Examples that use the strong acid equation				
Strong acid alone	H^+	[H+] = Ca	0.2 M HNO_3	0.7
Strong acid and weak acid	H^+ and HA (ignore HA)	[H+] = Ca	0.2 M HNO_3 and 0.4 M acetic acid	0.7
Strong acid and weak base	H^+ and HA (ignore HA)	[H+] = Ca	0.2 M HNO_3 and 0.1 M sodium acetate	1.0
Examples that use the strong base equation				
Strong base	OH^- alone	[OH-] = Cb	0.1 M $Ba(OH)_2$	13.3
Strong base and weak base	OH^- and A^- (ignore A-)	[OH-] = Cb	0.1 M Ba $(OH)_2$ and 0.1M sodium acetate	13.3
Strong base and weak acid	OH^- and A^- (ignore A^-)	[OH-] = Cb	0.4 M $Ba(OH)_2$ and 0.1M ammonium chloride	13.85
Examples that use the weak acid equation				
Weak acid	HA or BH^+	$[H^+] = (K_aC_a)^{1/2}$	0.3 M acetic acid	2.8
Equivalent strong acid and weak base	HA or BH^+	$[H^+] = (K_aC_a)^{1/2}$	0.1M HCl and 0.1 M ammonia	5.1
Examples that use the weak base equation				
Weak base	A^- or B	$[OH^-] = (K_bC_b)^{1/2}$	0.2 M NH_3	11.3
Equivalent strong base and weak acid	A^- or B	$[OH^-] = (K_bC_b)^{1/2}$	0.1M NaOH and 0.1M acetic acid	8.9
Examples that use the acid buffer equation				
Weak acid and conjugate weak base	HA and A	$[H^+] = K_aC_a/C_b$	0.2 M acetic acid and 0.1M sodium acetate	4.4
Strong acid and weak base	HA and A	$[H^+] = K_a C_a/C_b$	0.2 M HCl and 0.4 M sodium acetate	4.7
Examples that use the basic buffer equation				
Weak base and conjugate weak acid	B and BH^+	$[OH^-] = K_bC_b/C_a$	0.2 M ammonia and 0.3 M ammonium chloride	9.1
Strong base and weak acid	B and BH^+	$[OH^-] = K_bC_b/C_a$	0.3 M $Ba(OH)_2$ and 0.7 M ammonium chloride	10.0

Strong Acid Cases: Answers should all be pH 0 to 2

$\boxed{0.2\,M\ HNO_3} \rightarrow 0.2\,M\ H^+$

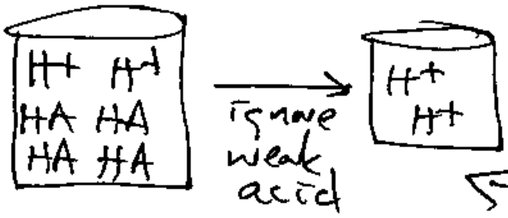
no neutralization

$[H^+] = C_a = 0.2$

pH = 0.7

$\boxed{0.2\,M\ HNO_3 + 0.4\,M\ \text{acetic acid}} \rightarrow 0.2\,M\ H^+ + 0.4\,M\ HA$

no neutralization



$[H^+] = C_a = 0.2$

pH = 0.7

$\boxed{0.2\,M\ HNO_3 + 0.1\,M\ \text{sodium acetate}} \rightarrow 0.2\,M\ H^+ + 0.1\,M\ A^-$

neutralize

a strong acid and weak acid. see above

assume 1 l volume for ease of calculation

$H^+ + A^- \rightleftharpoons HA$

H^+	A^-	HA
0.2	0.1	0
-.1	-.1	+.1
.1	0	.1 ↑ ignore

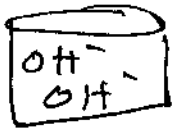
$[H^+] = 0.1\,M\ H^+$

pH = 1

Strong Base Cases: Answers should all be 12 to 14

$\boxed{0.1\,M\ Ba(OH)_2} \rightarrow 0.2\,M\ OH^-$ (two OH^- for every $Ba(OH)_2$)

no neutralization

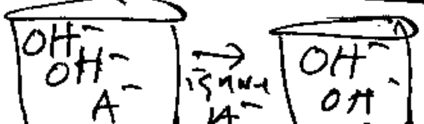


$[OH^-] = C_b = 0.2\,M$

pOH = 0.7 pH = 14 - .7 = 13.3

$\boxed{0.1\,M\ Ba(OH)_2 + 0.1\,M\ \text{sodium acetate}} \rightarrow 0.2\,M\ OH^- + 0.1\,M\ A^-$

no neutralization

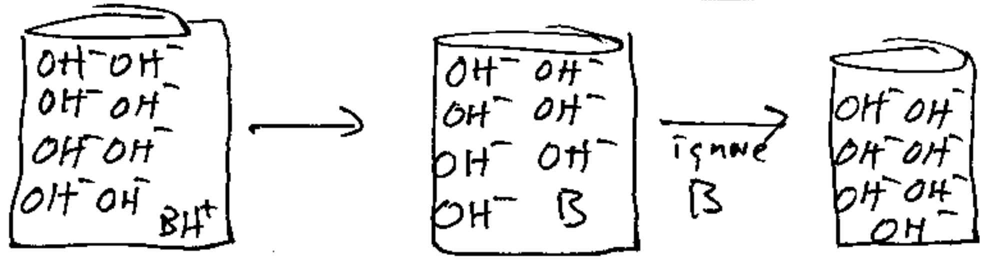


$[OH^-] = C_b = 0.2$

pOH = 0.7 pH = 14 - .7 = 13.3

$\boxed{0.4\,M\ Ba(OH)_2 \text{ and } 0.1\,M \text{ ammonium chloride}} \rightarrow 0.8\,M\,OH^- + 0.1\,M\,BH^+$

neutralize



a strong base and weak base. Ignore B, This is weak base case

assume 1 l for ease of calculation

$$OH^- + BH^+ \rightleftharpoons B$$

0.8	0.1	0
−0.1	−0.1	+0.1
0.7	0	0.1 ← ignore

$[OH^-] = C_b = 0.7\,M$

$pOH = 0.15 \quad pH = 13.85$

Weak Acid Cases : pH should be in 3 to 5 range

$\boxed{0.3\,M \text{ acetic acid}} \rightarrow 0.3\,M\ HA$

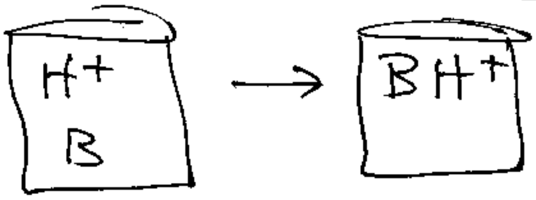
no neutralization

$$[H^+] = (K_a C_a)^{1/2}$$
$$= [(1.8 \times 10^{-5})(0.3)]^{1/2}$$

$pH = 2.8$

$\boxed{0.1\,M\,HCl \text{ and } 0.1\,M \text{ ammonia}} \rightarrow 0.1\,M\,H^+ + 0.1\,M\,B$

neutralize



⟸ This is 1:1 neutralization, all product, no reagents are left

assume 1 l for ~~[illegible]~~ ease of calculation

$$H^+ + B \rightleftharpoons BH^+$$

0.1	0.1	0
−0.1	−0.1	+0.1
0	0	0.1

↑ at equivalence point

$H^+ = (K_a C_a)^{1/2}$

$K_a = \frac{1 \times 10^{-14}}{1.8 \times 10^{-5}}$

$H^+ = [(5.5 \times 10^{-10})(0.1)]^{1/2}$

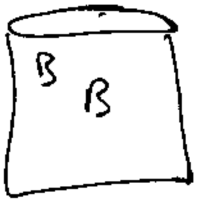
$K_a = 5.5 \times 10^{-10}$

$pH = 5.1$

Weak Base Cases: pH in 9 to 11 range

$\boxed{0.2 M\ NH_3}$ ⟶ 0.2 M B

no neutralization



$[OH^-] = (K_b C_b)^{1/2}$

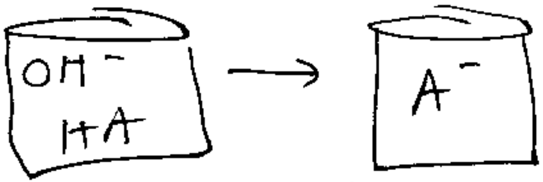
$[OH^-] = [(1.8\times10^{-5})(0.2)]^{1/2}$

$= 1.8\times10^{-3}$

$pOH = 2.7 \quad pH = 11.3$

$\boxed{0.1 M\ NaOH \text{ and } 0.1 M \text{ acetic acid}}$ ⟶ 0.1 M OH^- + 0.1 M HA

neutralize



← This is 1:1 neutralization. All products, no reagents left

assume 1 l for ease of calculation

$OH^- + HA \rightleftharpoons A^-$		
0.1	0.1	0
−0.1	−0.1	+0.1
0	0	0.1 ← at equivalence point, weak base case

$[OH^-] = (K_b C_b)^{1/2}$

$[OH^-] = [(5.5\times10^{-10})(0.1)]^{1/2}$

$pOH = 5.1 \quad pH = 8.9$

$K_b = \frac{10^{-14}}{K_a} = \frac{10^{-14}}{1.8\times10^{-5}} = 5.5\times10^{-10}$

Acid Buffer equation: pH in 5 to 7 range

$\boxed{0.2 M \text{ acetic acid and } 0.1 M \text{ sodium acetate}}$ ⟶ 0.2 M HA + 0.1 M A^-

no neutralization

a buffer ⟶

$[H^+] = K_a \frac{C_a}{C_b} = (1.8\times10^{-5})\left(\frac{0.2}{0.1}\right)$

$[H^+] = 3.6\times10^{-5} \quad pH = 4.4$

$\boxed{0.2 M\ HCl \text{ and } 0.4 M \text{ sodium acetate}}$ ⟶ 0.2 M H^+ 0.4 M A^-

neutralize

← a buffer!!

$H^+ + A^- \rightleftharpoons HA$		
0.4	0.2	0
−0.2	−0.2	+0.2

$[H^+] = K_a \frac{C_a}{C_b} = 1.8\times10^{-5}\left(\frac{.2}{.2}\right) = 1.8\times10^{-5}$

$pH = 4.7$

Basic Buffer Examples: pH in range 7 to 9

$\boxed{0.2\,M \text{ ammonia} + 0.3\,M \text{ ammonium chloride}} \rightarrow$ 0.2 M B, 0.3 M BH^+

no neutralization

a buffer →

$[OH^-] = K_b \frac{C_b}{C_a} = 1.8\times10^{-5}\left(\frac{.2}{.3}\right)$

$[OH^-] = 1.2\times10^{-5}$

pOH = 4.9 pH = 9.1

$\boxed{0.3\,M\ Ba(OH)_2 + 0.7\,M\ NH_4Cl} \rightarrow 0.6\,M\ OH^- + 0.7\,M\ BH^+$

neutralize

assume 1 l for ease of calculation

a buffer

$OH^- + BH^+ \rightleftharpoons B$

0.6	0.7	0
−0.6	−0.6	+0.6
0	0.1	0.6 ← a buffer!!

$[OH^-] = K_b \frac{C_b}{C_a} = 1.8\times10^{-5}\ \frac{.6}{.1}$

$[OH^-] = 1.1\times10^{-4}$

pOH = 4 pH = 10