

## Stepwise process for Working Acid/Base Equilibrium Problems (red stuff is not on exam 1)

There are only six equations needed to solve acid base problems. There are only five possible variables to put into these equations:  $K_a$ ,  $K_b$ ,  $[H^+]$ ,  $[OH^-]$ ,  $C_{acid}$ ,  $C_{base}$

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

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 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  $1.4 \times 10^{-5}$  or  $6.3 \times 10^{-9}$ , 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<sup>-</sup>** (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<sup>+</sup>** or **OH<sup>-</sup>** for strong acids and bases

**HA** or **BH<sup>+</sup>** for weak acids

**B** or **A<sup>-</sup>** 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 <b>not</b> 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  $\text{H}^+$  and 5 moles  $\text{A}^- \rightarrow$  5 moles of HA plus 0 moles of  $\text{H}^+$  and  $\text{A}^-$
- 1 moles of  $\text{H}^+$  and 2 mole of  $\text{A}^- \rightarrow$  1 mole of HA with one mole of  $\text{A}^-$  left over.
- 0.03 moles of  $\text{OH}^-$  and 0.01 moles of HA  $\rightarrow$  0.01 moles  $\text{A}^-$  with 0.02 moles  $\text{OH}^-$  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,  $\text{H}^+$  and  $K_a$ . Want to work with bases? Calculate with pOH,  $\text{OH}^-$  and  $K_b$ . It doesn't matter what you choose but remember to give the answer they ask for ( $\text{H}^+$ ,  $\text{OH}^-$ , pH or pOH). How do you move between acid and base terrain? Use:

- to move from a  $K_a$  to a  $K_b$ :  $K_w = K_a K_b = 10^{-14}$  or  $\text{p}K_w = \text{p}K_a + \text{p}K_b = 14$
- to move from a pH to a pOH:  $K_w = [\text{H}^+][\text{OH}^-] = 10^{-14}$  or  $\text{p}K_w = \text{pH} + \text{pOH} = 14$

### Examples of Acid/Base Problems Using Different Starting Materials

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

Starting Materials	Materials after neutralization	Equation to use	Sample problem	Calculate pH
<b>Examples that use the strong acid equation</b>				
Strong acid alone	$\text{H}^+$	$\text{pH} = -\log [\text{H}^+]$	0.2 M $\text{HNO}_3$	
Strong acid and weak acid	$\text{H}^+$ and HA (ignore HA)	$\text{pH} = -\log [\text{H}^+]$	0.2 M $\text{HNO}_3$ and 0.4 M acetic acid	
Strong acid and weak base	$\text{H}^+$ and HA (ignore HA)	$\text{pH} = -\log [\text{H}^+]$	0.2 M $\text{HNO}_3$ and 0.1 M sodium acetate	
<b>Examples that use the strong base equation</b>				
Strong base alone	$\text{OH}^-$ alone	$\text{pOH} = -\log [\text{OH}^-]$	0.1 M $\text{Ba}(\text{OH})_2$	
Strong base and weak base	$\text{OH}^-$ and $\text{A}^-$ (ignore $\text{A}^-$ )	$\text{pOH} = -\log [\text{OH}^-]$	0.1 M $\text{Ba}(\text{OH})_2$ and 0.1M sodium acetate	
Strong base and weak acid	$\text{OH}^-$ and $\text{A}^-$ (ignore $\text{A}^-$ )	$\text{pOH} = -\log [\text{OH}^-]$	0.4 M $\text{Ba}(\text{OH})_2$ and 0.1M ammonium chloride	
<b>Examples that use the weak acid equation</b>				
Weak acid	HA or $\text{BH}^+$	$[\text{H}^+] = (K_a C_a)^{1/2}$	0.3 M acetic acid	
Equivalent strong acid and weak base	HA or $\text{BH}^+$	$[\text{H}^+] = (K_a C_a)^{1/2}$	0.1M HCl and 0.1 M ammonia	
<b>Examples that use the weak base equation</b>				
Weak base	$\text{A}^-$ or B	$[\text{OH}^-] = (K_b C_b)^{1/2}$	0.2 M $\text{NH}_3$	
Equivalent strong base and weak acid	$\text{A}^-$ or B	$[\text{OH}^-] = (K_b C_b)^{1/2}$	0.1M NaOH and 0.1M acetic acid	
<b>Examples that use the acid buffer equation</b>				
Weak acid and conjugate weak base	HA and $\text{A}^-$	$[\text{H}^+] = K_a C_a / C_b$	0.2 M acetic acid and 0.1M sodium acetate	
Strong acid and weak base	HA and $\text{A}^-$	$[\text{H}^+] = K_a C_a / C_b$	0.2 M HCl and 0.4 M sodium acetate	
<b>Examples that use the basic buffer equation</b>				
Weak base and conjugate weak acid	B and $\text{BH}^+$	$[\text{OH}^-] = K_b C_b / C_a$	0.2 M ammonia and 0.3 M ammonium chloride	
Strong base and weak acid	B and $\text{BH}^+$	$[\text{OH}^-] = K_b C_b / C_a$	0.3 M $\text{Ba}(\text{OH})_2$ and 0.4 M ammonium chloride	

