

Lecture 18 CH102 A1 (MWF 9:05 am) Spring 2018 Copyright © 2018 Dan Dill dan@bu.edu

[TP] Which of the following is true about the a weak base?

13% 1. $K_b \ll 1$
 13% 2. $K_b \approx 1$
 13% 3. $K_b \gg 1$
 13% 4. $K_b \gg K_w$
 13% 5. $K_b \ll K_w$
 13% 6. 1 and 4
 13% 7. 1 and 5
 13% 8. 1, 4, and 5

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Response Counter

10 1

Lecture 18 CH102 A1 (MWF 9:05 am)
 Friday, March 2, 2018

- Complete: $[H_3O^+]$ when “too little” base added
- $[H_3O^+]$ when “just enough” base added
- $[H_3O^+]$ when “too much” base added

Next: Practice: Too little, just enough, too much?; $[H_3O^+]$ when different amounts of “not enough” base added

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Step 2: $[H_3O^+]$ when “too little” base added

After “too little” base is added, there are present both some acid, HA, and its conjugate base, A^- .

This means there are two possible ways the system can come to equilibrium,

$$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + A^-(aq), K = K_a$$

$$A^-(aq) + H_2O(l) \rightleftharpoons HA(aq) + OH^-(aq), K = K_b = K_w/K_a$$

One will result in an acidic solution, and the other will result in a basic solution.

Use the one that has the larger K !

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6

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Step 2: $[H_3O^+]$ when “too little” base added

Use the equilibrium that has the larger K !

Say $K_a = 1.0 \times 10^{-5} \gg K_b = K_w/K_a = \frac{10^{-14}}{1.0 \times 10^{-5}} = 1.0 \times 10^{-9}$

Then use ...

$$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + A^-(aq), K = K_a$$

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7

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Step 2: $[\text{H}_3\text{O}^+]$ when “too little” base added

Use the one that has the larger K !

Say $K_a = 1.0 \times 10^{-9} \ll K_b = K_w / K_a = \frac{10^{-14}}{1.0 \times 10^{-9}} = 1.0 \times 10^{-5}$

Then use ...

$$\text{A}^-(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HA}(aq) + \text{OH}^-(aq), K = K_b = K_w / K_a$$

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Step 2: $[\text{H}_3\text{O}^+]$ when “too little” base added

$V_b = 100.$ mL of $c_b = 0.20$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-5}$.

Step 1 results:

HA =
 $\text{A}^- =$
 $\text{OH}^- =$

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Step 2: $[\text{H}_3\text{O}^+]$ when “too little” base added

$V_b = 100.$ mL of $c_b = 0.20$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-5}$.

Step 1 results:

HA = $c_a V_a - c_b V_b = 0.020$ mol
 $\text{A}^- = c_b V_b = 0.020$ mol
 $\text{OH}^- = 0$

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Step 2: $[\text{H}_3\text{O}^+]$ when “too little” base added

$V_b = 100.$ mL of $c_b = 0.20$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-5}$.

In step 2, we need molarity, so here are step 1 results converted to concentrations:

$$[\text{HA}] = \frac{c_a V_a - c_b V_b}{V_a + V_b} = \frac{0.020 \text{ mol}}{0.200 \text{ L}} = 0.10 \text{ M}$$

$$[\text{A}^-] = \frac{c_b V_b}{V_a + V_b} = \frac{0.020 \text{ mol}}{0.200 \text{ L}} = 0.10 \text{ M}$$

$$[\text{OH}^-] = 0$$

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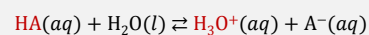
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Step 2: $[\text{H}_3\text{O}^+]$ when “too little” base added

$V_b = 100.$ mL of $c_b = 0.20$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-5}$.

$$K_b = K_w / K_a = \frac{10^{-14}}{1.0 \times 10^{-5}} = 1.0 \times 10^{-9} \ll K_a$$

So in this case, when “too little” base has been added, we find $[\text{H}_3\text{O}^+]$ using the ICE table for



14

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Step 2: $[\text{H}_3\text{O}^+]$ when “too little” base added

$V_b = 100.$ mL of $c_b = 0.20$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-5}$.

| | HA(aq) | H ₃ O ⁺ (aq) | A ⁻ (aq) | Q |
|-------------|--------|------------------------------------|---------------------|---|
| Initial | | | | |
| Change | | | | |
| Equilibrium | | | | |
| Approximate | | | | |

$[\text{H}_3\text{O}^+] = ?$



15

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Step 2: $[\text{H}_3\text{O}^+]$ when “too little” base added

$V_b = 100.$ mL of $c_b = 0.20$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-5}$.

| | HA(aq) | H ₃ O ⁺ (aq) | A ⁻ (aq) | Q |
|-------------|----------------|------------------------------------|---------------------|-----------------|
| Initial | 0.10 | 10^{-7} | 0.10 | $10^{-7} < K_a$ |
| Change | $-x$ | $+x$ | $+x$ | |
| Equilibrium | $0.10 - x$ | $10^{-7} + x$ | $0.10 + x$ | K_a |
| Approximate | ≈ 0.10 | $\approx x$ | ≈ 0.10 | K_a |

$$[\text{H}_3\text{O}^+] = x = \frac{K_a[\text{HA}]}{[\text{A}^-]} = \frac{1.0 \times 10^{-5} \times 0.10}{0.10} = 1.0 \times 10^{-5}$$



16

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$[\text{H}_3\text{O}^+]$ when “just enough” base added



17

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Step 2: $[\text{H}_3\text{O}^+]$ when “just enough” base added

$V_b = 100.$ mL of $c_b = 0.40$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-5}$.

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18

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Step 2: $[\text{H}_3\text{O}^+]$ when “just enough” base added

$V_b = 100.$ mL of $c_b = 0.40$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-5}$. Step 1 results:

Ignoring acid-base equilibrium, after the limiting reagent reaction is complete, the resulting concentrations of HA, A^- , and OH^- are ...

$[\text{HA}] =$
 $[\text{A}^-] =$
 $[\text{OH}^-] =$

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19

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Step 2: $[\text{H}_3\text{O}^+]$ when “just enough” base added

$V_b = 100.$ mL of $c_b = 0.40$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-5}$. Step 1 results:

Ignoring acid-base equilibrium, after the limiting reagent reaction is complete, the resulting concentrations of HA, A^- , and OH^- are ...

$$[\text{HA}] = \frac{c_a V_a - c_b V_b}{V_a + V_b} = 0$$

$$[\text{A}^-] = \frac{c_b V_b}{V_a + V_b} = \frac{0.040 \text{ mol}}{0.200 \text{ L}} = 0.20 \text{ M}$$

$$[\text{OH}^-] = 0$$

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20

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Step 2: $[\text{H}_3\text{O}^+]$ when “just enough” base added

We get $[\text{H}_3\text{O}^+]$ by **equilibrating** the limiting reagent reaction outcome.

When “just enough” base is added, **only the conjugate base** will be present after the limiting reagent reaction.

So **what equilibrium** do we work with?

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21

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Step 2: $[H_3O^+]$ when “just enough” base added


We get $[H_3O^+]$ by **equilibrating** the limiting reagent reaction outcome.

When “just enough” base is added, **only the conjugate base** will be present after the limiting reagent reaction.

So **what equilibrium** do we work with?

If **only conjugate base** is present, then work with



$$A^-(aq) + H_2O(l) \rightleftharpoons HA(aq) + OH^-(aq), K_b = K_w/K_a$$

 22

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[TP] Which of the following is true about the a weak base?


1. $K_b \ll 1$
2. $K_b \approx 1$
3. $K_b \gg 1$
4. $K_b \gg K_w$
5. $K_b \ll K_w$
6. 1 and 4
7. 1 and 5
8. 1, 4, and 5

 Response Counter  23

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[Quiz] Which of the following is true about the conjugate base A^- of the weak acid HA?

- 0% 1. A^- is a strong base
- 0% 2. A^- is a weak base
- 0% 3. Not a base, since $K_b \ll K_w$
- 0% 4. Further information needed

 24


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Step 2: $[H_3O^+]$ when “just enough” base added

$V_b = 100.$ mL of $c_b = 0.40$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-6}$ and $K_b = K_w / K_a = 1.0 \times 10^{-8}$

| | $A^-(aq)$ | $HA(aq)$ | $OH^-(aq)$ | Q |
|-------------|-----------|----------|------------|---|
| Initial | | | | |
| Change | | | | |
| Equilibrium | | | | |
| Approximate | | | | |

$[OH^-] = ?$
 $[H_3O^+] = ?$

 25

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Step 2: $[\text{H}_3\text{O}^+]$ when “just enough” base added

$V_b = 100.$ mL of $c_b = 0.40$ M of OH^- is combined with $V_a = 100.$ mL of $c_a = 0.40$ M of HA, $K_a = 1.0 \times 10^{-6}$ and $K_b = K_w / K_a = 1.0 \times 10^{-8}$

| | $\text{A}^-(aq)$ | $\text{HA}(aq)$ | $\text{OH}^-(aq)$ | Q |
|-------------|------------------|-----------------|-------------------|-------|
| Initial | 0.20 | 0 | 10^{-7} | 0 |
| Change | $-x$ | $+x$ | $+x$ | |
| Equilibrium | $0.20 - x$ | x | $10^{-7} + x$ | K_b |
| Approximate | ≈ 0.20 | x | $\approx x$ | K_b |

$$[\text{OH}^-] = x = \sqrt{K_b \times [\text{A}^-]} = \sqrt{1.0 \times 10^{-8} \times 0.20} = 4.5 \times 10^{-5}$$

$$[\text{H}_3\text{O}^+] = K_w / [\text{OH}^-] = \frac{1.0 \times 10^{-14}}{4.5 \times 10^{-5}} = 2.2 \times 10^{-10}$$

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$[\text{H}_3\text{O}^+]$ when “too much” base added

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Step 2: $[\text{H}_3\text{O}^+]$ when “too much” base added

$V_b = 200.$ mL of $c_b = 0.30$ M of OH^- is combined with $V_a = 200.$ mL of $c_a = 0.20$ M of HA, $K_a = 1.0 \times 10^{-6}$ and $K_b = K_w / K_a = 1.0 \times 10^{-8}$.

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Step 2: $[\text{H}_3\text{O}^+]$ when “too much” base added

$V_b = 200.$ mL of $c_b = 0.30$ M of OH^- is combined with $V_a = 200.$ mL of $c_a = 0.20$ M of HA, $K_a = 1.0 \times 10^{-6}$ and $K_b = K_w / K_a = 1.0 \times 10^{-8}$.

Step 1 results: Ignoring acid-base equilibrium, after the limiting reagent reaction is complete, the resulting concentrations of HA, A^- , and OH^- are ...

$[\text{HA}] =$

$[\text{A}^-] =$

$[\text{OH}^-] =$

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Step 2: $[\text{H}_3\text{O}^+]$ when “too much” base added

$V_b = 200.$ mL of $c_b = 0.30$ M of OH^- is combined with $V_a = 200.$ mL of $c_a = 0.20$ M of HA, $K_a = 1.0 \times 10^{-6}$ and $K_b = K_w / K_a = 1.0 \times 10^{-8}$.

Step 1 results: Ignoring acid-base equilibrium, after the limiting reagent reaction is complete, the resulting concentrations of HA, A^- , and OH^- are ...

$$[\text{HA}] = 0$$

$$[\text{A}^-] = \frac{c_a V_a}{V_a + V_b} = \frac{0.040 \text{ mol}}{0.400 \text{ L}} = 0.10 \text{ M}$$

$$[\text{OH}^-] = \frac{c_b V_b - c_a V_a}{V_a + V_b} = \frac{(0.060 - 0.040) \text{ mol}}{0.400 \text{ L}} = 0.050 \text{ M}$$



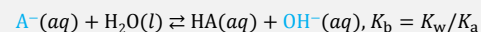
30

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Step 2: $[\text{H}_3\text{O}^+]$ when “too much” base added

If conjugate base is present and excess OH^- , then work with



31

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Step 2: $[\text{H}_3\text{O}^+]$ when “too much” base added

$V_b = 200.$ mL of $c_b = 0.30$ M of OH^- is combined with $V_a = 200.$ mL of $c_a = 0.20$ M of HA, $K_a = 1.0 \times 10^{-6}$ and $K_b = K_w / K_a = 1.0 \times 10^{-8}$.

| | $\text{A}^-(aq)$ | $\text{HA}(aq)$ | $\text{OH}^-(aq)$ | Q |
|-------------|------------------|-----------------|-------------------|-----|
| Initial | | | | |
| Change | | | | |
| Equilibrium | | | | |
| Approximate | | | | |

$$[\text{OH}^-] = ?$$

$$[\text{H}_3\text{O}^+] = ?$$

$$[\text{HA}] = ?$$



32

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Step 2: $[\text{H}_3\text{O}^+]$ when “too much” base added

$V_b = 200.$ mL of $c_b = 0.30$ M of OH^- is combined with $V_a = 200.$ mL of $c_a = 0.20$ M of HA, $K_a = 1.0 \times 10^{-6}$ and $K_b = K_w / K_a = 1.0 \times 10^{-8}$.

| | $\text{A}^-(aq)$ | $\text{HA}(aq)$ | $\text{OH}^-(aq)$ | Q |
|-------------|------------------|-----------------|-------------------|-------|
| Initial | 0.10 | 0 | 0.050 | 0 |
| Change | $-x$ | $+x$ | $+x$ | |
| Equilibrium | $0.10 - x$ | x | $0.050 + x$ | K_b |
| Approximate | ≈ 0.10 | x | ≈ 0.050 | K_b |

$$[\text{OH}^-] = 0.050 \text{ (easy!)}$$

$$[\text{H}_3\text{O}^+] = K_w / [\text{OH}^-] = \frac{1.0 \times 10^{-14}}{0.050} = 2.0 \times 10^{-13}$$

$$[\text{HA}] = x = \frac{K_b [\text{A}^-]}{[\text{OH}^-]} = \frac{1.0 \times 10^{-8} \times 0.10}{0.050} = 2.0 \times 10^{-8} \text{ (tiny!)}$$



33