

Chem 103 lecture 3a

Pop quiz
pH and pOH calculations
Polyprotic acids
Lewis acids/bases

Summary

$$[\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}; \text{pH} + \text{pOH} = 14.00$$

$$\text{pH} = -\log[\text{H}_3\text{O}^+] \quad \text{and} \quad \text{pOH} = -\log[\text{OH}^-]$$

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} \quad K_b = \frac{[\text{HA}][\text{OH}^-]}{[\text{A}^-]}$$

$$K_a K_b = 1.0 \times 10^{-14} \Rightarrow \text{p}K_a + \text{p}K_b = 14.00$$

$$[\text{H}^+] = 10^{-\text{pH}} \quad [\text{OH}^-] = 10^{-\text{pOH}}$$

$$\text{p}K_a = -\log K_a \quad \text{and} \quad \text{p}K_b = -\log K_b$$

Recall the 5 scenarios:

There are at least 5 scenarios we'll encounter involving pH calculations. You are expected to **MASTER** these calculations.

- 1) Strong acid solutions
- 2) Strong base solutions
- 3) Pure Weak acid solutions
- 4) Pure weak base solutions
- 5) Buffer solutions

pH of a strong acid solution

As mentioned earlier, there are at least 5 "scenarios" involving pH calculations. Most simple: pH of a strong acid solution.

For example: What is the pH of a 0.020 M HCl solution?

Answer:

Since HCl is a strong acid, it dissociates completely:

$$[\text{HCl}]_F = 0.020 \text{ M} = [\text{H}_3\text{O}^+]$$

$$\text{So, pH} = -\log [\text{H}_3\text{O}^+] = -\log [\text{HCl}]_F = -\log(0.020) = 1.70$$

pH of a strong base solution

2nd scenario:

What is the pH of a 5.2×10^{-4} M NaOH solution?

Answer: Since NaOH is a strong base, we can write:

$$[\text{NaOH}] = [\text{OH}^-] = 5.2 \times 10^{-4} \text{ M}$$

It is easier to determine pOH first:

$$\text{pOH} = -\log[\text{OH}^-] = -\log(5.2 \times 10^{-4}) = 3.28$$

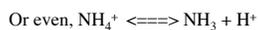
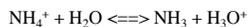
$$\text{pH} = 14.00 - 3.28 = 10.72 \quad (\text{makes sense?})$$

Yes because it is a basic pH

Net ionic equations and ICE

You are also expected to know how to write and recognize *net ionic equations*.

e.g. What is the K_a equilibrium for a NH_4Cl solution?



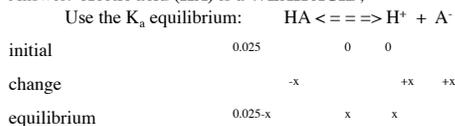
You are supposed to master ICE type calculations involving K_a and K_b equilibria.

I=initial, C=change, E= equilibrium

pH of a weak acid solution

What is the pH of a $2.5 \times 10^{-3} \text{M}$ acetic acid (HA, $K_a = 1.8 \times 10^{-5}$)

Answer: **Acetic acid (HA)** is a **WEAK ACID**,

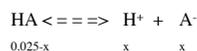


$$x^2 / (0.025 - x) = 1.8 \times 10^{-5} \Rightarrow x^2 + 1.8 \times 10^{-5}x - 4.5 \times 10^{-7} = 0$$

Solve for x by the quadratic equation. $x = 6.6 \times 10^{-4}$

$$\text{pH} = -\log(6.6 \times 10^{-4}) = 3.18$$

pH of a weak acid solution..,



$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]} = \frac{x^2}{0.025 - x} = 1.8 \times 10^{-5}$$

$$x^2 / (0.025 - x) = 1.8 \times 10^{-5} \Rightarrow x^2 + 1.8 \times 10^{-5}x - 4.5 \times 10^{-7} = 0$$

Solve for x by quadratic formula. $x = (-b \pm \sqrt{b^2 - 4ac}) / 2a$

$$x = \frac{-(-1.8 \times 10^{-5}) \pm \sqrt{(1.8 \times 10^{-5})^2 - 4(1)(-4.5 \times 10^{-7})}}{2(1)}$$

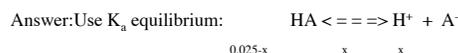
$$\Rightarrow x = 6.6 \times 10^{-4} \text{ M or } x = -6.8 \times 10^{-4} \text{ (choose positive value)}$$

$$\text{pH} = -\log(6.6 \times 10^{-4}) = 3.18$$

pH of a weak acid (5% rule)

Redo same problem using approximation (5% rule):

What's pH of $2.5 \times 10^{-2} \text{M}$ acetic acid (HA, $K_a = 1.8 \times 10^{-5}$)



$$x^2 / (0.025 - x) = 1.8 \times 10^{-5} \Rightarrow x^2 / (0.025) \approx 1.8 \times 10^{-5}$$

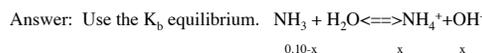
$$\text{Solve for } x: x = \{(0.025)(1.8 \times 10^{-5})\}^{1/2} = 6.7 \times 10^{-4}$$

$$\text{pH} = -\log(6.7 \times 10^{-4}) = 3.17 \text{ (compare with 3.18)}$$

Note: $6.7 \times 10^{-4} / (100\%) / 0.025 = 3\% < 5\%$

pH of a weak base solution

What is the pH of 0.10 M ammonia? ($K_b = 1.8 \times 10^{-5} \text{M}$)



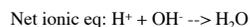
$$x^2 / (0.10 - x) = 1.8 \times 10^{-5} \text{ . Using 5% rule:}$$

$$x^2 \approx (1.8 \times 10^{-5})(0.10) \Rightarrow x = 1.3 \times 10^{-3} = [\text{OH}^-]$$

$$\text{pOH} = 2.87 \Rightarrow \text{pH} = 14.00 - 2.87 = 11.13 \text{ (makes sense?)}$$

Neutralization reactions

When an acid encounters a base, neutralization occurs:



Strong acid + strong base \rightarrow 100% completion

Strong + weak \rightarrow 100% completion

Weak + weak \rightarrow not 100% completion

Strong Acid + strong base. pH = ?

Problem: 20.0 mLs of 1M HCl + 21.0 mLs of 1M NaOH. pH = ?



$$\text{mmol HCl} = M_{\text{HCl}} V_{\text{HCl}} = (1\text{M})(20.0\text{mL}) = 20.0 \text{ mmol HCl}$$

$$\text{mmol NaOH} = M_{\text{NaOH}} V_{\text{NaOH}} = (1\text{M})(21.0\text{mL}) = 21.0 \text{ mmol NaOH}$$

Limiting reagent is HCl: mmol NaOH excess = $21.0 - 20.0 = 1.0 \text{ mmol}$

So $[\text{OH}^-] = \text{mole OH}^- / \text{total Vol}(\text{L}) = \text{mmol OH}^- / \text{total mLs}$

$$[\text{OH}^-] = 1.0 \text{ mmol} / (20.0 + 21.0) \text{ mL} = 1.0 / 41.0 \text{ M} = 0.0244 \text{ M}$$

$$\text{pOH} = -\log(0.0244) = 1.613; \text{pH} = 14.00 - 1.613 = 12.387$$

pH of pure intermediate form

pH =? for 0.100M NaHCO_3 . ($K_{a1}=4.2 \times 10^{-7}$, $K_{a2}=4.7 \times 10^{-11}$)

We have the same 2 equilibria as in the previous example:



Express K_a 's as $\text{p}K_a$'s: $\text{p}K_{a1} = -\log(4.2 \times 10^{-7}) = 6.38$; $\text{p}K_{a2} = 10.33$

What is the major species in this problem?

It's the intermediate species: HCO_3^- . (without proof)

$$\text{pH} = (1/2)(\text{p}K_{a1} + \text{p}K_{a2}) = (1/2)(6.38 + 10.33) = 8.36$$

Lewis Acids

Lewis acids = electron pair acceptors

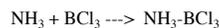
Lewis bases = electron pair donors

Consider ammonia, NH_3 and a boron trichloride, BCl_3

Do the Lewis structures of both of them.

NH_3 has a lone pair; BCl_3 has an empty orbital

NH_3 can "donate" its lone pair to BCl_3 to form a coordinate covalent bond or "dative" bond:



Which is the base? Which is the acid?

Answers to the pop quiz 1

1) Because water can act as a Bronsted-Lowry acid or base, it is said to be _____.

- a. amphiphilic
- b. amphihydrous
- c. amphiphobic
- d. amphiprotic
- e. amphoteric

D: amphiprotic

Answers to the pop quiz 2

2) Organic compounds classified as bases often have the formula

- a. R-CHO.
- b. $\text{CH}_3\text{-(CH}_2\text{)}_n\text{-CH}_3$.
- c. R-COOH.
- d. R-NH₂.
- e. R-OH.

D: R-NH₂

Answers to the pop quiz 3

3) The product of the reaction between methylamine, CH_3NH_2 , and hydrochloric acid is

- a. $\text{CH}_3\text{NH}_2^+ \text{Cl}^-$
- b. $\text{CH}_3\text{NH} \cdot \text{H}_2\text{Cl}^+$
- c. $\text{CH}_3\text{NH}_3^+ \text{Cl}^-$
- d. $\text{CH}_3\text{NH}_3^- \text{Cl}^+$
- e. $\text{CH}_3\text{NH}_4^{2+} (\text{Cl}^-)_2$

C: $\text{CH}_3\text{NH}_3^+ \text{Cl}^-$

Answers to the pop quiz 4

4) A solution is not neutral. Which one of these statements is true?

- a. $[\text{H}_3\text{O}^+] = 1.0 \times 10^{-7} \text{ M}$
- b. $[\text{H}_3\text{O}^+] = [\text{OH}^-]$
- c. $[\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-7}$
- d. $[\text{OH}^-] = 1.0 \times 10^{-7} \text{ M}$
- e. $[\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$

E: $[\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$

Answers to the pop quiz 5

- 5) In a neutral polyprotic acid, the value of K_{a2} will be _____ the value of K_{a1} because _____.
- a. smaller than; it is more difficult to remove a hydrogen ion from a cation than from a neutral molecule
 - b. larger than; it is more difficult to remove a hydrogen ion from an anion than from a neutral molecule
 - c. larger than; it is more difficult to remove a hydrogen ion from a cation than from a neutral molecule
 - d. smaller than; it is more difficult to remove a hydrogen ion from an anion than from a neutral molecule
 - e. the same as; both hydrogen ions are bonded to the same anion

D