*Unit 14: Acids, Bases and their Equilibria*



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| Homework | Quiz |
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Important vocabulary for unit 14

Arrhenius Acid and Base

Bronsted Lowry Acid and Base

Lewis Acid and Base

Conjugate acid

Conjugate base

amphoteric

Neutralization Reaction

Titration

pH

pOH

Kw

Ka

Kb

Indicator

Equivalence Point

End Point

Buffer

Monoprotic

Diprotic

Triprotic

***Notes: Review of Acid Nomenclature***

HBr carbonic acid

H2S acetic acid

H2SO4 sulfurous acid

HNO2 hydrofluoric acid

H3PO4 oxalic acid

*Strength of Acids* – state whether the above acids are strong or weak (note – remember that ANY acid that has carbon in it is weak)

**Memorize the 7 strong acids:** HCl, HBr, HI, H­2SO4, HNO3, HClO4, HClO3

# Acid Base Theories

Arrhenius Theory

Bronsted-Lowry Theory

Lewis Theory.**Notes - pH scale and pH calculations**

The pH scale is based on the auto-ionization of water. At 25oC, water ionizes to a small extent according to the below equation:

H2O(l) ⇄ H+(aq) + OH-(aq)

An equilibrium expression can be written for the above equation, which is:

Kw = [H+][OH-] = 1.00 x 10-14

Notice that water doesn’t appear in the equilibrium expression, and also that a subscript w signifies that the constant is for the equation shown above. The constant doesn’t change as long as you are at 25oC, so if you know concentration of either the protons or hydroxides in water, you can calculate the other.

**EX1** The concentration of OH- ions in a certain household ammonia cleaning solution it 0.0025 M. Calculate the concentration of the H+ ions.

Since the concentrations of the species we have been talking about are usually quite small, it is more convenient to use a logarithmic scale, called the pH scale . There is also a scale which will be using called the pOH scale. Both of these are defined as follows:

pH = -log [H+]

pOH = -log[OH-]

Another useful relationship which we will use is:

pH + pOH = 14

**EX2** What is the pH of neutral water? What is the pOH of neutral water?

**EX3** The concentration of H+ ions in a newly opened bottle of wine was 3.2 x 10-4 M. Only half the wine was consumed and the rest was left open to the air for a month. The remainder was found to have an H+ ion concentration of 1.0 x 10-3M. Calculate the pH of the wine on these two occasions.

**EX4** The pH of rainwater collected in a certain region of the U.S. Northeast on a particular day was 4.82. Calculate the H+ ion concentration of the rainwater.

**EX5** Calculate the pH of a1.0 x 10-3 M HCl solution and 0.020 M Ba(OH)2 solution.

**EX6** The pH of a solution is 5.79. Calculate, in order, the concentration of H+, OH-, pOH, pH. If you do everything correctly, you will return to the starting value, with minor variations because of round-offs.

**Notes - Titration Calculations**

 A titration is the process of adding a certain amount of “titrant” to a solution containing an “analyte” in order to determine the concentration of a substance.

 In this unit we will do neutralization titrations: adding a base to an acid until you completely react both. The end of the reaction is usually determined by an indicator. This is a substance that changes colors in different pH ranges.

Some reactions are:

 HCl + NaOH → NaCl + H2O

 acid + base → “ a salt” + water (This is the general form of an acid/base reaction)

 H2SO4 + LiOH → Li2SO4 + H2O

Titration Calculations:

 To work any titration calc, follow the same general format:

 • write a balanced reaction

 • find the moles of the acid or base. This is determined by the information you are given in the problem.

 • convert the moles of that substance into moles of the other substance

 • solve for your unknown

EX1 32.14 mL of a NaOH solution react with 2.9362 g of HKC8H4O4. Calculate the molarity of the NaOH solution.

EX2 25.8 mL of 0.396 M KOH are required to titrate a 25.0 mL sample of phosphoric acid. Find the molarity of the acid solution.

**Notes: Salt Hydrolysis**

Some aqueous solutions of salts do not have a pH of 7. These salts have one or more ions that undergo hydrolysis, that is they react with water to form a weak acid and hydroxide ions (the solution will have a pH > 7) or a weak base and hydrogen ions (the solution will have a pH < 7). To determine if a salt will produce an acidic or basic aqueous solution, you must first look at the “parent acid” and “parent base” of that salt. Remember that salts are formed in the reaction between an acid and a base:

Acid + Base → Salt + Water

There are four possible scenarios – only three of which we will be concerned about

Strong Acid + Strong Base → Neutral Salt (pH of aqueous solution = 7)

Strong Acid + Weak Base → Acidic Salt (pH of aqueous solution < 7)

Weak Acid + Strong Base → Basic Salt (pH of aqueous solution >7)

Weak Acid + Weak Base → it depends – this is beyond the scope of this course

## Salt Hydrolysis Demo

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Salt Solution | Parent Acid | Strength of Acid | Parent Base | Strength of Base | Predicted pH(7, <7, >7) | Color | Tested pH(7, <7, >7) |
|  1. NaCl |  |  |  |  |  |  |  |
|  2. Na2CO3 |  |  |  |  |  |  |  |
|  3. NaHCO3 |  |  |  |  |  |  |  |
|  4. NaC2H3O2 |  |  |  |  |  |  |  |
|  5. AlCl3 |  |  |  |  |  |  |  |
|  6. ZnSO4 |  |  |  |  |  |  |  |
|  7. Na3PO4 |  |  |  |  |  |  |  |
|  8. NH4Cl |  |  |  |  |  |  |  |
|  9. Cd(NO3)2 |  |  |  |  |  |  |  |
| 10. Pb(NO3)2 |  |  |  |  |  |  |  |
| 11. KClO3 |  |  |  |  |  |  |  |
| 12. CuSO4 |  |  |  |  |  |  |  |
| 13. KSCN |  |  |  |  |  |  |  |
| 14. NaF |  |  |  |  |  |  |  |

**Notes - Weak Acid Calculations**

Weak acids cause the pH to lower and weak bases cause an increase. The difference is that while strong acids and bases ionize completely, weak acids and bases only do so partially - that is, they set up and equilibrium situation. To work out weak acid and base problems, you need to use an ice box.

**EX1** A 0.21 M solution of a weak acid, HA, has a pH of 3.14. Find [H+] for the solution, Ka for the acid, and the percentage dissociation.

**EX2** Calculate the pH and percentage dissociation of 0.44 M HC2H3O2. Ka for acetic acid is 1.8 × 10-5

Organic bases are the most common type of weak bases you will run across. They are made up of nitrogen attaced to carbon groups. The only other weak base you need to worry about is NH3, ammonia. Remember, instead of donating a proton to water, they will accept a proton from water.

**EX3** Calculate the pH of 0.29 M (CH3)3N. Kb = 6.3 × 10-5

**Notes – Weak Acid/Weak Base Calculations**

To calculate the pH of a strong acid or strong base, you just use the concentration of the acid or base, because it completely breaks up. Weak acids don’t break up completely, so you have to determine how much it breaks up by using an ICE box and equilibrium expressions. You can find values of Ka in your book

There are two types of weak acid/base – either the pH is given, which allows you to calculate the equilibrium concentration of H+ or OH- and the equilibrium constant, Ka or Kb. If the pH is not given, then you must use the Ka to calculate equilibrium concentrations.

\*\*\*\*\*In these problems, x will always be so small that you can ignore it compared to the number it is subtracted from or added to, ie, 0.100 - x ≈ 0.100

\*\*\*\*\*Remember that H30+ and H+ are equivalent.

**EX1**. The pH of 0.100 M HIO solution is 4.50. Calculate the Ka for this weak acid.

The [H+]eq = 10-4.50 = 3.16 x 10-5 M. Now we can set up our ICE table. The equation will always show the weak acid or base reacting with water.

HClO + H2O ⇄ ClO- + H3O+

I **0.100** **0** **0**

C *-3.16 x 10-5* *+3.16 x 10-5 +3.16 x 10-5*

E 0.100 *- 3.16 x 10-5* ≈ 0.100 *3.16 x 10-5* **3.16 x 10-5**



**EX2** What is the pH of a 0.500 M HC2H3O2 solution? The Ka for acetic acid is 1.8 x 10-5.

HC2H3O2 + H2O ⇄ C2H3O2- + H3O+

I 0.500 0 0

C -x +x +x

E 0.500-x ≈0.500 x x



x = 0.0038 = [H3O+] pH = -log(0.0038) **pH = 2.42**

Weak in chemistry are typically nitrogenous bases. These will either be ammonia or nitrogen/carbon compounds. The hydrogen that is accepted always attaches to the nitrogen of the base. For example

CH3NH2 + H20 ⇄ CH3NH3+ + OH-

(C6H5)3N + H20 ⇄ (C6H5)NH+ + OH-

**EX3** What is the pH of 0.250 M NH3? The Kb of ammonia is 1.8 x 10-5.

NH3 + H2O ⇄ OH- + NH4+

I 0.250 0 0

# C -x +x +x

E 0.250-x ≈0.250 x x



x = 0.0021 = [OH-] pOH = -log(0.0021) pOH = 2.67 **pH = 11.33**

**EX4** What is the percent ionization for the weak base in example 3?

Percent ionization is always calculated as the amount that broke up divided by the amount that was there times 100. The amount that broke up is always equal to x.

% ionization = 0.0021/0.250 x 100 = 0.84%

This is a very small amount – it is 100% for a strong acid or base.

*Problem Set #1*

1. An aqueous solution tastes bitter and turns litmus blue. Is the solution acidic or basic?

2. Ammonia contains three hydrogen atoms per molecule. However, an aqueous ammonia solution is basic. Explain using the Brønsted-Lowry theory of acids and bases.

3. Identify the conjugate acid-base pairs in the equilibrium equation:

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| HC2H3O2 | + | H2O | ↔ | H3O+1 | + | C2H3O2-1 |
|  |  |  |  |  |  |  |

4. Gaseous HCl molecules interact with gaseous NH3 molecules to form a white smoke made up of solid NH4Cl particles. Explain whether or not this is an acid-base reaction according to both the Arrhenius theory and the Brønsted-Lowry theory.

5. Explain the difference between a weak acid and a strong acid.

6. Why are strong acids and bases also strong electrolytes?

7. State whether each of the following acids is strong or weak.

|  |  |
| --- | --- |
| a. acetic acid |  |
| b. hydroiodic acid |  |
| c. hydrofluoric acid |  |
| d. phosphoric acid |  |

8. State whether each of the following bases is strong or weak.

|  |  |
| --- | --- |
| a. rubidium hydroxide |  |
| b. methylamine (CH3NH2) |  |
| c. ammonia |  |
| d. calcium hydroxide |  |

9. An acidic solution reacts with magnesium carbonate to produce a gas. What is the formula of the gas?

*Problem Set #2*

1. In terms of ion concentrations, distinguish between acidic, neutral, and basic solutions.

2. Write a balanced equation that represents the self-ionization of water.

3. What is the relationship between the pOH and the hydroxide ion concentration of a solution?

4. If the concentration of hydrogen ions in an aqueous solution decreases, what mush happen to the concentration of hydroxide ions? Why?

5. Explain why pure water has a very slight electrical conductivity.

6. Write the balanced chemical equation for the ionization of perchloric acid in water.

7. Write the balanced chemical equation for the dissociation of solid magnesium hydroxide in water.

8. Given the concentration of either hydrogen or hydroxide ion, use the ion product constant of water to calculate the concentration of the other ion at 298 K.

|  |  |
| --- | --- |
| a. [H+1] = 1.0 x 10-4 M |  |
| b. [OH-1] = 1.3 x 10-2 M |  |

9. Calculate the pH at 298 K of solutions having the following ion concentrations.

|  |  |
| --- | --- |
| a. [H+1] = 1.0 x 10-4 M |  |
| b. [H+1] = 5.8 x 10-11 M |  |
| c. [OH-1] = 1.0 x 10-12 M |  |
| d. [OH-1] = 1.3 x 10-2 M |  |

10. Calculate the [H+1] and [OH-1] in of the following solutions at 298 K.

|  |  |
| --- | --- |
| a. pH = 3.00 | [H+1] = |
|  | [OH-1] = |
| b. pOH = 5.24 | [H+1] = |
|  | [OH-1] = |

*Problem Set #3*

1. The pH of a 0.655 M HBrO solution is 3.67. What is the Ka of the acid?
2. The pH of a 0.100 M (C6H5)3N solution is 11.56. What is the Kb of the base?
3. What is the pH of a 0.564 M HF solution? The Ka is 6.61 x 10-4.
4. What is the pH of a 0.250 M HCOOH solution? The Ka is 1.77 x 10-4.
5. What is the pH of a 0.355 M (CH3)3N solution? The Kb is 6.5 x 10-5.

6. What is the pH of a 0.840 M (CH3)2NH solution? The Kb is 5.9 x 10-4.

7. The pH of a 8.6 x 10-3 M H3PO4 solution is 2.30. What is Ka of the first dissociation of the acid?

8. The pH of a 0.112 M C2H3ClO2 (chloroacetic acid) solution is 1.92. What is the Ka of the acid?

9. What is the pH of a 3.000 M HBrO solution? The Ka is 2.8 x 10-3.

10. What is the percent ionization for each of the weak acids or bases in #1-9?

|  |  |  |
| --- | --- | --- |
| 1. | 4. | 7. |
| 2. | 5. | 8. |
| 3. | 6. | 9. |

*Problem set #4*

1. Draw a picture of the apparatus used for a titration. Clearly indicate the location of the titrant and analyte.
2. How do you recognize the end-point in an acid-base titration?
3. An aqueous solution causes bromothymol blue to turn blue and phenolphthalein to turn colorless. What is the approximate pH of the solution?
4. Write formula equations for the following acid-base neutralization reactions.

 a. sulfuric acid + sodium hydroxide

 b. acetic acid + potassium hydroxide

5. A 35.00 mL sample of NaOH solution is titrated to an endpoint by 14.76 mL of 0.4122 M HBr solution. What is the molarity of the NaOH solution?

6. How many mL of 0.225 M HCl would be required to titrate 6.00 g KOH?

7. In a titration, 33.21 mL of 0.3020 M rubidium hydroxide solution is required to exactly neutralize 20.00 mL hydrofluoric acid solution. What is the molarity of the hydrofluoric acid solution?

8. How many mL of 0.3500 M HCl would be needed to titrate 10.00 g Ca(OH)2?

9. It takes 45.11 mL of 0.5000 M NaOH to titrate 35.0 mL of H3PO4. What is the molarity of the acid?

10. What mass of NaOH could be titrated by 15.00 mL of 0.4507 M hydrobromic acid?

*Problem Set #5*

Part I: For each of the following salts identify the parent acid and parent base and each parents relative strength. Then predict if the aqueous solution of the salt will be acidic, basic, or neutral.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Salt | Parent Acid | Strength | Parent Base | Strength | ­Acidic, Basic or Neutral |
| 1. | Rb2S |  |  |  |  |  |
| 2. | Zn(NO3)2 |  |  |  |  |  |
| 3. | KBr |  |  |  |  |  |
| 4. | AgNO3 |  |  |  |  |  |
| 5. | Li2CO3 |  |  |  |  |  |

Part II: Solve each of the following - show all work.

1. Calculate the pH of a solution that is 0.450 M HClO2 and 0.650 M. ClO2-1. Ka for HClO2 = 5.6 x 10-11.
2. Calculate the pH of a solution that is 0.350 M C6H5NH2 and 0.450 M C6H5NH3+1. Kb for C6H5NH2 = 4.3 x 10-10.