*2023 April 3*
*Kian Ali Agheli*

# *Chemistry 2, Lesson 2*

## *Acids and Bases*
### *Introduction*

*1.* Classify each compound as Arrhenius, Brønsted-Lowry, and/or Lewis acids and bases by putting the name of the compound into the appropriate column in the table. Note: Some compounds fall into multiple categories. ammonia, ammonium, boron trifluoride, carbonate ion, magnesium

| | *Arrhenius* | *Brønsted-Lowry* | *Lewis* |
|---|---|---|---|
| *Acid* | | water | boron trifluoride, magnesium |
| *Base* | ammonia, ammonium | ammonia, ammonium, water | ammonia, ammonium, water, carbonate ion |

*2.* Which of these is a product of the first step in the ionization of phosphoric acid, $H_3PO_4$?

a. $H_3PO_4$
**b. $H_2PO_4$**
c. $PO_4$
d. $HPO_4$

In the provided text, there is a table of “Some Common Acids and Their Conjugate Bases”. It is written in the text: “A conjugate base is the species that results when an acid donates a hydrogen ion.“ It may be assumed that this is the first step in the ionization of the given acid. The following is an excerpt of the mentioned table.

| *Acid* | | *Conjugate Base* | |
|---|---|---|---|
| *Name* | *Formula* | *Name* | *Formula* |
| Phosphoric acid | $H_3PO_4$ | Dihydrogen phosphate ion | $H_2PO_4^-$ |

*3.* Compare and contrast the Arrhenius model, Brønsted-Lowry model, and Lewis model.

The Arrhenius model “states that an acid is a substance that contains hydrogen and ionizes to produce hydrogen ions in an aqueous solution. A base is a substance that contains a hydroxide group and dissasociates to produce a hydroxide ion in an aqueous solution.” This model does not include every real base within an aqueous solution. “For example, ammonia ($NH_3$) and sodium carbonate ($NA_2CO_3$) do not contain a hydroxide group, yet both substances produce hydroxide ions in solution and are well-known bases.” “In the Brønsted-Lowry model of acids and bases, an acid is a hydrogen-ion donor. A base is a hydrogen-ion acceptor.” This model is broader than the Arrhenius model, pertaining to compounds both within and without aqueous solutions. “According to the Lewis model, a Lewis acid is an electron-pair acceptor and a Lewis base is an electron-pair donor.” This model is most encompassing, pertaining to all electron-pair acceptors and electron-pair donors.

4. The formula for citric acid is $H_3C_6H_5O_7$.

   a. How many ionizable hydrogen atoms does it contain? Explain.

      Citric acid contains three ionizable hydrogen atoms. Hydrogen atoms bonded with carbon are ionizable. Hydrogen atoms bonded with oxygen atoms are not ionizable.

   b. What is the name applied to acids with this number of ionizable hydrogen atoms?

      "The term *polyprotic acid* can be used for any acid that has more than one ionizable hydrogen atom."

   c. Use equations to show the steps involved in the complete ionization of this acid.

      $H_3C_6H_5O_7(aq) + H_2O(l) \leftrightarrows H_3O^+(aq) + H_2C_6H_5O_7^-(aq)$
      $H_2C_6H_5O_7^-(aq) + H_2O(l) \leftrightarrows H_3O^+(aq) + HC_6H_5O_7^{2-}(aq)$
      $HC_6H_5O_7^{2-}(aq) + H_2O(l) \leftrightarrows H_3O^+(aq) + C_6H_5O_7^{3-}(aq)$

5. Compare the physical and chemical properties of acids and bases.

   Whereas acids generally gain a piece in a reaction, bases generally lose a piece in a reaction. Acids are generally more violent in their reactions than bases.

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

   $H_2O \leftrightarrows H^+ + OH^-$

7. Why can H+ and H3O+ be used interchangeably in chemical equations?

   Due to expressing the same meaningful information in this context, that being ionized hydrogen, H+ and H3O+ can be used interchangeably in chemical equations.

8. Use the symbols <, >, and = to express the relationship between the concentrations of H+ ions and OH- ions in acidic, neutral, and basic solutions.

   acidic: >
   neutral: =
   basic: <

9. Write balanced chemical equations for the two successive ionizations of carbonic acid in water. Identify the conjugate-base pair in each of the equations.

   $H_2CO_3(aq) + H_2O(l) \leftrightarrows HCO_3^-(aq) + H_3O^+(aq)$
   In the above equation, $H_2CO_3(aq)$ and $HCO_3^-(aq)$ are the conjugate bases.

   $HCO_3^-(aq) + H_2O(l) \leftrightarrows CO_3^{2-}(aq) + H_3O^+(aq)$
   In the above equation, $HCO_3^-(aq)$ and $CO_3^{2-}(aq)$ are the conjugate bases.

## *Strengths*

1. Compared to strong acids, weak acids produce __________ ions and conduct electricity __________ efficiently.

   a. fewer, less
   b. more, less
   c. fewer, more
   **d. more, more**

2. In a weak acid, the conjugate base has a greater attraction for the H+ ion than does the base ________.

$$HY + H_2O \rightarrow H_3O+ +Y^-$$

   **a. HY**
   b. $NH_4^+$
   c. $H_2O$
   d. $H_3O^+$

3. Which of the following is a weak acid?

   a. $HNO_3$
   b. $HClO_4$
   c. HCl
   **d. HF**

4. Which of the following is the strongest base according to the Brønsted-Lowry theory?

   a. I-
   b. Cl-
   c. F-
   **d. $NO_3^-$**

5. *a.* Below are three steps showing the ionization of arsenic acid (H3AsO4). Number the equations for the three steps in the order they occur.

   A. H2AsO4−(aq) + H2O(l) → H3O+(aq) + HAsO42−(aq)
   B. H3AsO4(aq) + H2O(l) → H3O+(aq) + H2AsO4−(aq)
   C. HAsO42−(aq) + H2O(l) → H3O+(aq) + AsO43−(aq)

   1: B
   2: A
   3: C

*b.* The three values for Ka are listed below, one for each step of the ionization. Match each equation with the value of Ka for that step.

Ka Values Options:

D. $4.5\times10–3$

E. $4.5\times10–7$

F. $4.5\times10–12$

Step A ←→ {Value D

Step B ← →{Value E

Step C ← →{Value F

*6.* Assume that H2Z is a strong acid. The ionization steps of H2Z are as follows.

H2Z(aq) + H2O(l) → H3O+(aq) + HZ−(aq)

HZ−(aq) + H2O(l) ⟷ H3O+(aq) + Z−(aq)

Explain why a single arrow was used in the first equation and a double arrow was used in the second.

The first equation represents a dissociation, the second equation

*7.* Describe the contents of dilute aqueous solutions of the strong acid HI and the weak acid HCOOH.

Dilute aqueous solutions of HI contain many ions produced by the acid. Dilute aqueous solutions of HCOOH contain fewer ions produced by the acid.

*8.* Relate the strength of a weak acid to the strength of its conjugate base.

A weak acid's conjugate base is strong. "The acid on the reactant side of the equation produces a conjugate base on the product side. Similarly, the base on the reactant side produces a conjugate acid."

*9.* Write the chemical equation and Kb expression for the ionization of ammonia in water.

$NH_3 + H_2O \leftrightarrows NH_4^+ + OH^-$

$2.5 \times 10^{-5}$

*10.* Why is it safe for a window cleaner to use a solution of ammonia, which is basic?

Ammonia is a weak base, that which becomes "partially ionized in a dilute aqueous solution."

*11.* Strontium hydroxide is used in the refining of beet sugar. Only 4.1 g of strontium hydroxide can be dissolved in 1 L of water at 273 K. Given that its solubility is so low, explain how it is possible that strontium hydroxide is considered a strong base.

Strontium hydroxide is considered a strong base due to being a compound "that dissociates entirely into metal ions and hydroxide ions".

## *Hydrogen Ions and pH*

1. Calculate the pH of a solution that has a [OH-] = 2.50 x 10-4M.

a. -3.6
b. 3.6
c. 0.4
**d. 10.4**

Show Your Math Work Here:

Given the value of a solution's $OH^-$ value, that solution's pOH may be calculated.

$pOH = -\log(2.5 \times 10^{-4}) = \approx 3.6$

A given solution's pOH has an inverse value to that solution's pH. Negating the pOH from 14 results in the pH.

$pH = 14 - pOH = 14 - \approx 3.6 = \approx 10.4$

2. Calculate the pH of 0.075M KOH.

a. 11.12
b. 10.4
**c. 12.88**
d. 11.46

Show Your Math Work Here:

$pOH = -\log(0.075) = \approx 1.12$

$pH = 14 - pOH = 14 - \approx 1.12 = \approx 12.88$

3. Find the [H+], the pOH, and the [OH−] of a solution with a pH of 4.20. Show your work.

$[H+] = 6.3 \times 10^{-5} M$
$pOH = 9.8$
$[OH–] = 1.58489 \times 10^{-10} M$

Show Your Math Work Here:

$H^+ = \text{antilog}(-pH) = \text{antilog}(-4.2) = 6.309573 \times 10^{-5}$
$pOH = 14 - pH = 14 - 4.2 = 9.8$
$OH^- = \text{antilog}(-pOH) = \text{antilog}(-9.8) = 1.58489 \times 10^{-10}$

4. Determine the pH of a solution that contains 1.0×10-9 mol of OH- ions per liter.

$pH = 9$

Show Your Math Work Here:

$pOH = -\log(OH-) = -\log(1 \times 10^{-9}) = -(-9) = 9$

5. Calculate the pH of the following solutions.

1.0M HI pH = $4.34 \times 10^{-11}$
0.050M HNO3 pH = 1.302
1.0M KOH pH = 14
$2.4 \times 10$-5M Mg(OH)2 pH = 9.38

6. *a.* Answer the following questions below using the pH data provided.

| *Substance* | *pH* |
|---|---|
| Household ammonia | 11.3 |
| Lemon juice | 2.3 |
| Antacid | 9.4 |
| Blood | 7.4 |
| Soft drinks | 3.0 |

a. Which substance is the most basic?

Household ammonia.

b. Which substance is closest to neutral?

Blood.

c. Which has [H+] = $4.0 \times 10$-10M?

Antacid.
$H^{+} = \text{antilog}(-\text{pH}) = \text{antilog}(-9.4) = 3.98107 \times 10^{-10}$

d. Which has a pOH of 11.0?

Soft drinks. 14 - 3 = 11.

*b.* Fill in the blank question.

a. How many times more basic is antacid than blood? ______ times

Assuming that basicity is measured in ion concentration, antacid is 100 times more basic than blood.

7. If 5.00 mL of 6.00M HCl is added to 95.00 mL of pure water, the final volume of the solution is 100.00 mL. What is the pH of the solution?

pH = $\approx 0.222$

Show Your Math Work Here:

It is written in the text given: “Every HCl molecule produces one $H^+$ ion. The bottle labeled 0.1M contains 0.1 mol of $H^+$ ions per liter and 0.1 mol of $Cl^-$ ions per liter.” Understanding this, there are 6 mol of $H^+$ ions per liter, and that the solution has a volume of 0.1L, the solution has 6 × 0.1 mol of $H^+$ ions. From this, pH may be calculated.

$pH = -\log(H^+) = -\log(6.0 \times 10^{-1}) = \approx 0.222$

8. Given two solutions, 0.10M HCl and 0.10M HF, which solution has the greater concentration of H+ ions? Calculate pH values for the two solutions, given that [H+] = 7.9 × 10-3M in the 0.10M HF.

For 0.10M HCl, pH = 1
For 0.10M HF, pH = 2.102373
Therefore, HCl has the greater concentration of hydrogen ions because it has the greater pH.

Show Your Math Work Here:

Each hydrogen chloride molecules provides one $H^+$ ion.

$pH = -\log(H^+) = -\log(7.9 \times 10^{-3}) = 2.102373$

$pH = -\log(H^+) = -\log(0.1) = 1$

9. What is the pH of a 0.200M solution of hypobromous acid (HBrO)?

$$K_a = 2.8 \times 10^{-9}$$

$pH = \approx 4.625852$

Show Your Math Work Here:

$K_a = \frac{H^+ \times A^-}{HA} = \frac{[H^{+]^2}}{HA}$

$2.8 \times 10^{-9} = \frac{x^2}{0.2}$

$0.56 \times 10^{-9} = x^2$

$\sqrt{0.56 \times 10^{-9}} = \sqrt{x^2}$

$x = \approx 2.366 \times 10^{-5}$

$pK_a = -\log(K_a) = -\log(2.8 \times 10^{-9}) = 8.552842$

$pH = pK_a + \log\left(\frac{x}{HA}\right) = 8.552852 + \log\left(\frac{\approx 2.366 \times 10^{-5}}{0.2}\right) = 8.552852 + \log(\approx 1.183 \times 10^{-4}) = 8.552852 - \approx 3.927 = \approx 4.625852$

10. What is the pH of a 0.40M solution of cyanoacetic acid, which has a Ka of 3.55 x 10-3?

a. 1.22
b. 2.06
c. 2.45
**d. 1.44**

11. What is the Ka of a 1.000M solution of propanoic acid with a pH of 2.43?

a. 0.24
b. 3.7 × 10-3
c. 7.2 × 10-3
d. 1.4 x 10-5

$H^+ = \text{antilog}(-\text{pH}) = \text{antilog}(-2.43) = 3.715352 \times 10^{-3}$

$$K_a = \frac{[H^+]^2}{HA} = \frac{(3.715352 \times 10^{-3})^2}{1} = \approx 1.4 \times 10^{-5}$$

## *Neutralization*

1. In a neutralization reaction, an acid and a base react to produce a(n) _______ and water.

**a. Salt**
b. Oxide

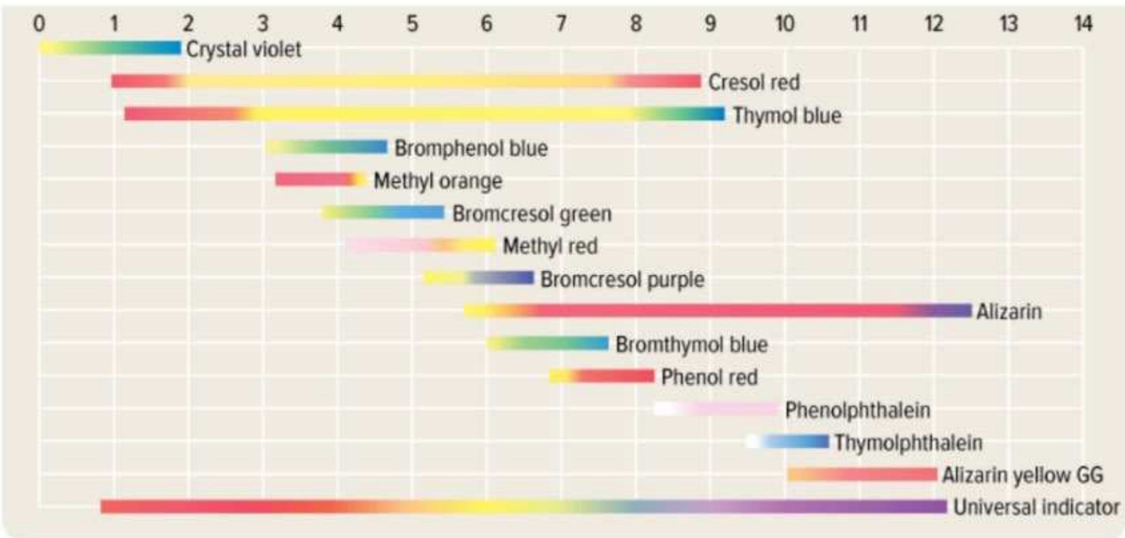
2. Explain the difference between the equivalence point and the end point of a titration.

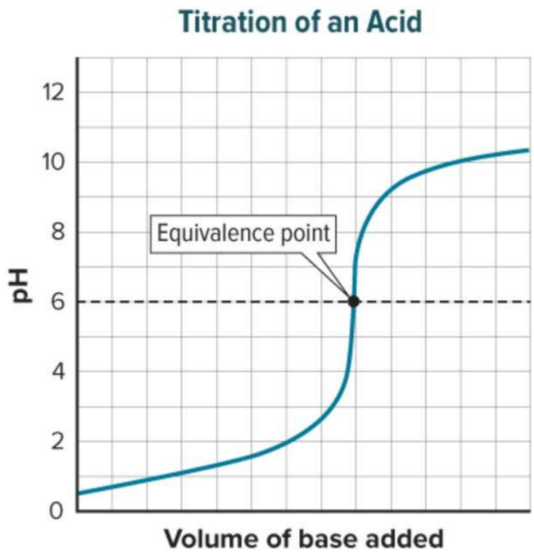
The equivalence point is “the point at which moles of $H^+$ ion from the acid equal moles of $OH^-$ ion from the base.” The end point is “The point at which the indicator used in a titration changes color”.

3. Use Le Châtelier’s principle to explain what happens to the equilibrium H2O(l) ⇆ H+(aq) + OH-(aq) when a few drops of HCl are added to pure water.

Water’s equivalence point of 7 is surpassed, resulting in a small increase in pH.

4. What acid-base indicators would be suitable for the neutralization reaction whose titration curve is shown below? Why?






Given the acid's equivalence point of 6, Methyl red, Bromcresol purple, Alizarin, and Bromethyl blue may be suitable. Each of those acid-base indicators have clear points of intersection with 6 pH.

5. What happens when an acid is added to a solution containing the HF/F- buffer system?

When an acid is added to a solution containing the HF/F- bu er system, "the equilibrium shifts to the left. According to Le Chântelier's principle, the added $H^+$ ions from the acid are a stress on the equilibrium, which is relieved by their reaction with $F^-$ ions to form additional undissasociated HF molecules."

6. Write formula equations and net ionic equations for the hydrolysis of each salt in water.

*a.* sodium carbonate

$Na^2 + 2H_2O \rightarrow H_2CO_3 + 2Na^+ + 2OH^-$

*b.* ammonium bromide

$H_4^+ + H_2O \rightarrow NH_3 + H_3O^+$

*c.* How many milliliters of 0.225M HCl would be required to titrate 6.00 g of KOH? [This problem seems inappropriately marked as part c of problem 6, rather than problem 7. There is no clean way for a student to correct this.]

475 mL

Show Your Math Work Here:

$$n = \frac{m}{M} = \frac{6g}{56.106g/mol} = \approx 0.1069mol$$

$$0.225M = \frac{\approx 0.1069mol}{v}$$

$$v = \frac{\approx 0.1069mol}{0.225mol/L} = \approx 0.475L$$

7. Write the complete ionic equation and the net ionic equation for the neutralization of H2S by Ca(OH)2.

$H_2S + Ca(OH)_2 \rightarrow SCa + 2H_2O$

8. This question has two parts. First, answer Part A. Then, answer Part B.

*Part A*

Two students performed a titration to determine the concentration of a solution of acetic acid (HC2H3O2). They used a known solution of 0.100M potassium hydroxide (KOH) as the standard solution.

*a.* Write a balanced formula equation for this acid-base reaction.

$HC_2H_3O_2 + KOH \leftrightarrows C + 2H_2O$

*b.* From the balanced equation for this reaction, what is the mole ratio of the acid and the base?

1:2

*c.* Consider the strengths of the acid and base used in the titration. Would you expect the results of the reaction to be neutral, slightly acidic, or slightly basic? Explain.

I would expect the results to be slightly basic, given that acetic acid is weak, and potassium hydroxide is a strong base.

*d.* Phenolphthalein was chosen as an indicator for the reaction. Why was phenolphthalein a good choice?

Phenolphthalein was a good choice because it "changes color at the equivalence point of a titration of a weak acid with a strong base."

*Part B*

Fill in the blank question.

Use the burette readings and mole ratio from the balanced equation, to fill out the remainder of the table and determine the concentration of acetic acid used.

| *Initial Buret Volume (mL)* | *Final Buret Volume (mL)* | *Volume KOH (mL)* | *Volume $HC_2H_3O_2$ (mL)* | *Amount KOH (mol)* | *Amount $HC_2H_3O_2$ (mol)* | *Concentration $HC_2H_3O_2$ (M)* |
|---|---|---|---|---|---|---|
| 4.28 | 34.30 | 9.3 | 25.00 | $9.3 \times 10^{-4}$ | $2.5 \times 10^{-2}$ | 0.372 |