# ACID-BASE REACTIONS & THE pH SCALE

## ***Introduction***

- In acid-base reactions in *aqueous solution*, the active agents are commonly the hydronium ion $H_30^+$ or the hydroxide ion $OH^-$.
- The range of concentrations of these species is very large, so a ***logarithmic scale*** is used to specify these concentrations by a number between 0 and 14. This is ***known as the pH scale***.
- The rates, and therefore equilibrium, of many chemical reactions (especially those occurring in nature) are highly sensitive to the pH of their environment, therefore it is essential to gain a full understanding of the pH scale.
- Acid-base chemistry can also take place in organic solvents.
- As such, acid-base chemistry does not always involve protons and hydroxide ions.
- The diversity of acid-base chemistry has resulted in three historically distinct definitions.

  1. ***Arrhenius acid-base***
  2. ***Bronsted-Lowry acid-base***
  3. ***Lewis acid-base***

## ***Objectives and Success Criteria***

- Indentification of acids and bases and their conjugates.
- Understand and use the pH scale

## ***Prerequisites***

- Introduction to acid-base reaction

***MODEL 1:*** **Identifying classes of acids and bases**

***<u>Arrhenius acids and bases</u> are defined in terms of aqueous*** **proton and hydroxide concentrations respectively.**

- Arrhenius acids increases proton concentration when dissolved in water, $[H^+_{(aq)}]$ .
- Arrhenius bases increases hydroxide concentration when dissolved in water, $[OH^-_{(aq)}]$ .

e.g., Hydrochloric acid can be described as an Arrhenius acid in aqueous solution and sodium hydroxide can be described as an Arrhenius base.

$$HCl\,(aq) + H_2O\,(l) \longrightarrow H_3O^+\,(aq) + Cl^-\,(aq)$$

$$NaOH\,(aq) \longrightarrow OH^-\,(l) + Na^+\,(aq)$$

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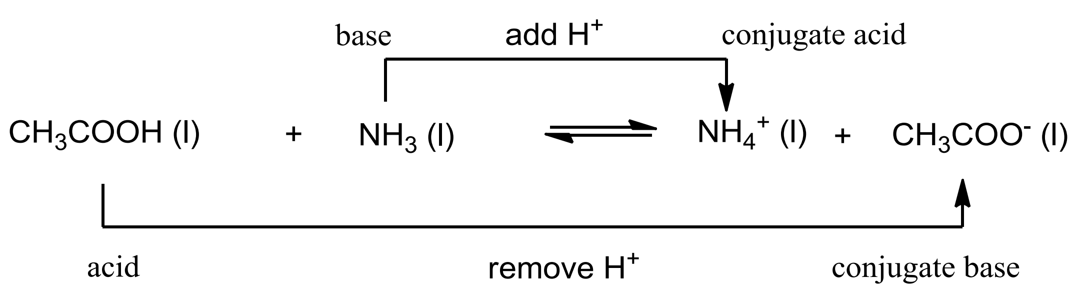
$$HCl\,(aq) + NaOH\,(aq) \longrightarrow H_2O\,(l) + Na^+\,(aq) + Cl^-\,(aq)$$

***<u>Bronsted-Lowry acids and bases</u> are defined in terms of only proton donating and accepting abilities.***

- *They are not restricted to aqueous solutions and can involve a base other than the hydroxide ion.*
- *A Bronsted-Lowry acid is capable of donating protons to a Bronsted-Lowry base.*
- *Bronsted-Lowry base is capable of accepting protons from a Bronsted-Lowry base.*

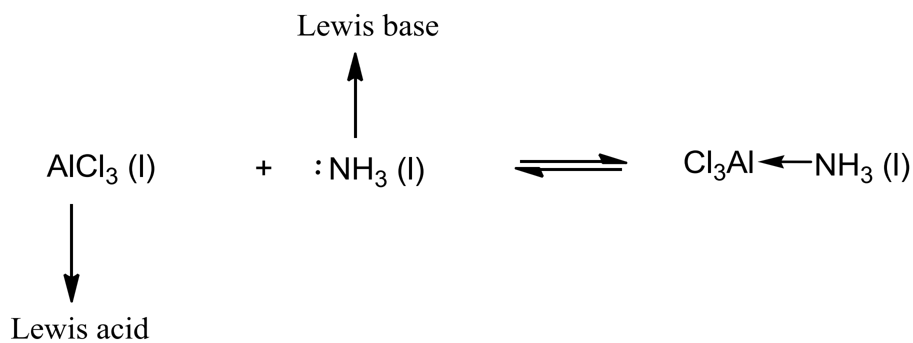
e.g., Acetic acid (*aka* vinegar) can be described as a Bronsted-Lowry acid and ammonia can be described as a Bronsted-Lowry base.



***<u>Lewis acids and bases</u> are defined in terms of electron-pair donating and accepting abilities.***

- *They may or may not involve proton and/or hydroxide ions.*
- *A Lewis acid is capable of accepting an electron-pair from a Lewis base.*
- *A Lewis base is capable of donating an electron-pair to a Lewis acid.*

e.g., Aluminium chloride can be described as a Lewis acid and ammonia can be described as a Lewis base.




***EXERCISES***

1. For the following reactions identify the Arrhenius acid *and/or* base.

a) $HClO_4$ (aq) + $H_2O$ (l) ⇆ $H_3O^+$ (aq) + $ClO_4^-$ (aq)

b) $HC_2O_4^-$ (aq) + $H_2O$ (l) ⇆ $H_2C_2O_4$ (aq) + $OH^-$ (aq)

c) KOH (aq) + $H_2O$ (l) ⇆ $OH^-$ (aq) + $H_2O$ (aq) + $K^+$ (aq)

d) $H_2O$ (l) + $H_2O$ (l) ⇆ $H_3O^+$ (aq) + $OH^-$ (aq)

2. For the following reactions identify the Bronsted-Lowry acid and base and their conjugate Bronsted-Lowry acid and base.

a) $CF_3COOH\ (l) + NH_3\ (aq) \leftrightarrows CF_3COO^-\ (l) + NH_4^+\ (l)$

b) $CH_3COOH\ (aq) + H_2O\ (l) \leftrightarrows CH_3COO^-\ (aq) + H_3O^+\ (aq)$

c) $CF_3COOH\ (aq) + F^-\ (aq) \leftrightarrows CF_3COO^-\ (aq) + HF\ (aq)$

d) $H_2O\ (l) + H_2O\ (l) \leftrightarrows H_3O^+\ (aq) + OH^-\ (aq)$

3. For the following reactions identify the Lewis acid and base.

a) $H^+\ (aq) + NH_3\ (aq) \leftrightarrows NH_4^+\ (l)$

b) $BF_3\ (l) + NH_3\ (l) \leftrightarrows F_3B\text{–}NH_3\ (l)$

c) $AlCl_3\ (l) + H_2O\ (l) \leftrightarrows Cl_3Al\text{–}OH_2\ (l)$

e) $I_2\ (aq) + I^-\ (aq) \leftrightarrows I_3^-\ (aq)$

***Problems***

For the following acid base reactions

- identify the reaction products
- identify the Bronsted-Lowry acids and bases and their conjugates.

1. $CH_3COOH$ (aq) + $H_2O$ (l) ⇆

2. $CF_3COOH$ (aq) + KOH (aq) ⇆

3. HCl (aq) + $F^-$ (aq) ⇆

4. $H_2PO_4^-$ (aq) + $PO_4^{3-}$ (aq) ⇆

## *MODEL 2:* **Logarithms and pH**

- The common, or base-10, logarithm (abbreviated log) of any number is the power to which 10 must be raised to equal the number, e.g., the common logarithm of 1000 (written log 1000) is equal to 3 because raising 10 to the third power gives 1000.

- The range of concentrations of $[H_30^+]$ and $[OH^-]$ species is very large, so *the pH scale* is used to specify these concentrations by a number between 0 and 14.

**Properties of Logarithms**

$\log(10^2) = 2$

$\log(0.01) = -2.0$ since $0.01 = 10^{-2.0}$

$\log(1) = 0$ since $1 = 10°$

$\log(0.00851) = -2.070$ since $0.00851 = 10^{-2.070}$

$\log(1.1 \times 10^{-14}) = -13.95$ since $1.122 \times 10^{-14} = 10^{-13.95}$

**Definition of pH**

$pH = -\log[H^+] = -\log[H_30^+]$

$[H_30^+] = 0.01\ M = 10^{-2.0}$ so $pH = 2.0$

$[H_30^+] = 0.00851\ M = 10^{-2.070}$ so $pH = 2.070$

$[H_30^+] = 1.1 \times 10^{-14}\ M = 10^{-13.96}$ so $pH = 13.96$

***Exercises***

1. According to the Model, if you are given the hydronium ion concentration, what do you need to do to obtain the pH of the solution?

2. The pH scale ranges from 0 to 14. What is the range of the hydronium ion concentration covered by this scale?

3. Why is the pH scale used to measure hydronium ion concentrations?

4. Using your calculator, check the mathematical calculations shown in the Model to make sure that they are correct, confirming that you know how to interconvert between numbers and their logarithms. Write the results that you got for the following calculations.

a) $10^2$ =

b) log(0.01) =

c) $10^{-2.07}$ =

d) log(1.22 x $10^{-14}$) =

***Problems***

1. What is the pH of a neutral aqueous solution at 25°C given that the hydronium ion concentration is 1.0 x $10^{-7}$ M?

2. Does a pH of 2.7 describe a solution with a higher or lower hydronium ion concentration as compared to a neutral solution? Is such a solution called acidic or basic?

3. Compared to a neutral solution, would you expect a basic solution to have a higher or lower pH and a higher or lower hydronium ion concentration?

4. Answer the questions below regarding the following substances:

   milk: $[H_3O^+]$ = 3.2 x $10^{-7}$ M

   pickle juice: $[H_3O^+]$= 2.0 x $10^{-4}$M oven cleaner: $[H_3O^+] = 3.16 \times 10^{-14}$ M

a. Identify which substance has the highest hydronium ion concentration.

b. Identify which substance is the most acidic.

c. Identify which substance is the most basic.

d. Identify which substance has the highest pH.