Acid, Base and Buffers

What are Acid and Bases?

- **Definition of Svante Arrhenius (Sweden) in 1884**

"An Acid is a substance that can release a proton or hydrogen ion (H^+) when dissolved in water"

$$HCl \longrightarrow H^+ + Cl^-$$

" A Base is a substance that can release a Hydroxyl ion when dissolved in water"

$$NaOH \longrightarrow Na^+ + OH^-$$

- According to Thomas Lowry (England) or J.N. Brønsted (Denmark) working independently in 1923:

"An Acid is a material that donates a proton:

$$HCl \longrightarrow H^{+} + Cl^{-}$$

$$CH3COOH \longrightarrow CH3COO^{-} + H^{+}$$

$$NH4^{+} \longrightarrow NH3 + H^{+}$$

"A Base is a material that can accept a proton

$$OH- + H+ \longrightarrow H2O$$

$$CH3COO^{-} + H^{+} \longrightarrow CH3COOH$$

$$NH3 + H^{+} \longrightarrow NH4^{+}$$

Every ion dissociation that involves a hydrogen or hydroxide ion could be considered an acid- base reaction

- The G.N. Lewis (1923) idea of acids and bases is broader than the Lowry- Bron̈sted model.

  The Lewis definitions are:

  "Acids are electron pair acceptors.

  $$H^{+} + e^{-} \longrightarrow H$$

  "Bases are electron pair donors.

  $$OH^{-} \longrightarrow OH + e^{-}$$

- Each ionizable pair has a proton donor and a proton acceptor. Acids are paired with bases.
- One can accept a proton and the other can donate a proton.
- Each acid has a proton available (an ionizable hydrogen) and another part, called the ***conjugate base***.
- When the acid ionizes, the hydrogen ion is the acid and the rest of the original acid is the conjugate base e.g:

Nitric acid, **HNO3**, ***dissociates*** (splits) into a hydrogen ion and a nitrate ion. The hydrogen almost immediately joins to a water molecule to make a hydronium ion.

The nitrate ion is the conjugate base of the hydrogen ion. In the second part of the reaction, water is a base (because it can accept a proton) and the hydronium ion is its conjugate base.

$$HNO_3 + H_2O \rightleftharpoons NO^{3-} + H_3O^+$$

HNO_3	H_2O	NO^{3-}	H_3O^+
acid	base	conjugate base	conjugate acid

Properties of acids

- Acids release a hydrogen ion into water (aqueous) solution
- Acids neutralize bases in a neutralization reaction

An acid and a base combine to make a ***salt*** and water. A salt is any ionic compound that could be made with the anion of an acid and the cation of a base.

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

- Acids corrode active metals.
- Acids turn blue litmus to red.

Litmus is the oldest known pH indicator. It is red in acid and blue in base.

Acids taste sour.

Examples of Some Acids

- Stomach acid is hydrochloric acid.
- Acetic acid is the acid ingredient in vinegar.
- Citrus fruits such as lemons, grapefruit, oranges, and limes have citric acid in the juice.
- Sour milk, sour cream, yogurt, and cottage cheese have lactic acid from the fermentation of the sugar lactose.
- Carbon dioxide formed in the body, dissolves in water to form an acid carbonic acid:

  $$CO_2 + H_2O \longrightarrow H_2CO_3 \text{ [carbonic acid]}$$

- Proteins are acidic at pH below their isoelectric point, and can give out hydrogen ions.

Properties of bases

- Bases release a hydroxide ion into water solution
- Bases neutralize acids in a neutralization reaction.

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

- Bases denature protein.
- Bases turn red litmus to blue.
- Bases taste bitter.

Water [H_2O]

- Essential for life.
- 70-90% of the weight of all living things is water.
- It is a polar molecule [has dipole] I.e. has partial positive charge on hydrogen and partial negative charge on oxygen.
- Each water molecule forms H-bonds with other water molecules.
  - H-bonds: week non-covalent bonds,
  - formed when H is shared between two electronegative molecules.
  - Break easily by increasing temperature.
  - Vapors have no H-bond; on cooling water molecules come closer and form H-bonds and change to a liquid i.e water; On further cooling the water molecules come closer and make more H-bond and change to ice.

H- Bonds in water

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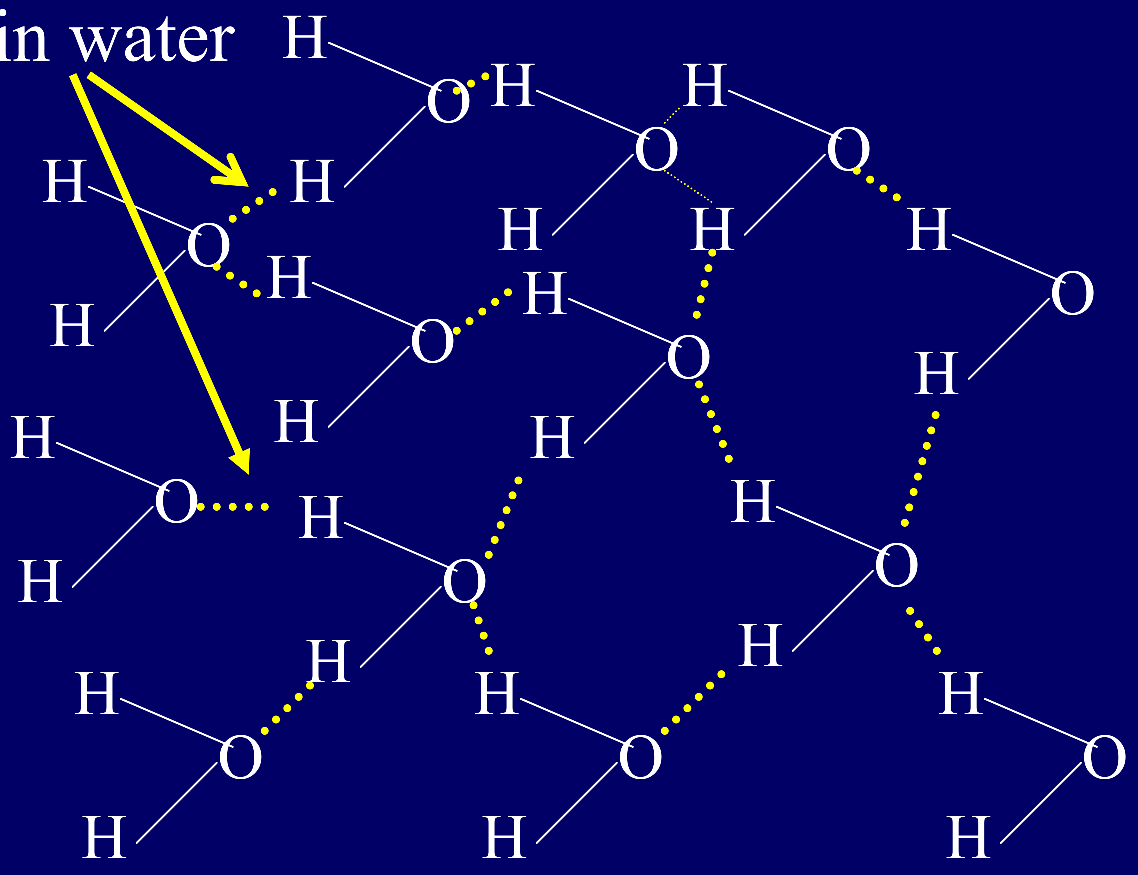


Dissociation of Water

- Dissociation of water

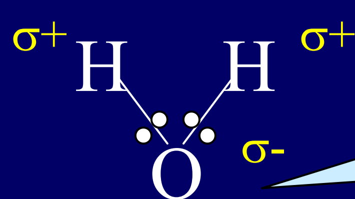
$H_2O \rightleftharpoons H^+ + OH^-$

Water ⟶ Proton + Hydroxyl ion

$H^+ + H_2O \longrightarrow H_3O^+$

Proton + Water ⟶ Hydronium ion

In water there is a strong partial negative charge on the side of the oxygen atom and a strong partial negative charge on the hydrogen side



O_2 is electronegative i.e pulls electrons towards its self

Each hydrogen ion unites with a water molecule to produce a ***hydronium ion***, H_3O^+

Special Properties of Water

- Boiling Point---------------100^0
- Freezing Point--------------0^0
- Viscosity-------------------1.01
- Specific Gravity-----------1 gm [1ml water weighs 1 gm]
- Shows capillary action
- Helps to solubilize other substances.
- An excellent solvent. Water surrounds charged and uncharged molecules and helps to dissolve them.
- Water acts as a week acid and a week base.

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

$$H_2O + H_2O \longleftrightarrow H_3O^+ + OH^-$$

pH

- pH is a way to express acidity or alkalinity of an aqueous solution.
- It is the negative log of the hydrogen ion concentration.
- It is a measure of the concentration of protons in solution $[H_3O^+]$

$$pH = -\log_{10} [H^+] \quad \text{or}$$

$$pH = -\log_{10} [H_3O^+]$$

- pH Scale:

10^{-1} M H_3O^+ — 10^{-7} M H_3O^+ — 10^{-14} M H_3O^+

Acidic — **7 Neutral** — **Basic**

- e.g At Neutral pH, H_3O is 10^{-7} M

  $$pH = -\log [H_3O^+]$$

  $$pH = -\log [10^{-7}] \quad = -[-7] \;= +7$$

- pH is a log scale and one number represents a H_3O^+ concentration that is either 10 times greater or ten times smaller in magnitude then the next. e.g. 10^{-2} M is ten times greater than 10^{-3} .

	pH	H^+ conc [M]
Gastric Juice	1 - 2	10^{-1} to 10^{-2}
Coca cola	3	10^{-3}
Urine	5-8	10^{-5} to 10^{-8}
Saliva	6.4	4×10^{-7}
Blood	7.4	4×10^{-8}
Pure water	7.0	10^{-7}

Strong acids and strong bases

- Strong acids that are almost one hundred percent ionized in aqueous solution . $HCl \longrightarrow H^+ + Cl^-$
- eg:

  HNO_3 - nitric acid
  HCl - hydrochloric acid
  H_2SO_4 - sulfuric acid
  $HClO_4$ - perchloric acid
- Strong bases are almost one hundred percent ionized in aqueous solution. $NaOH \longrightarrow Na^+ + OH^-$
- eg:

  LiOH - lithium hydroxide
  NaOH - sodium hydroxide
  KOH - potassium hydroxide

  Mg(OH)**2** - magnesium hydroxide
  Ca(OH)**2** - calcium hydroxide

Weak Acids and Weak Bases

- Weak acids and weak bases dissociate partially in aqueous solution

$$HA \rightleftharpoons H^+ + A^-$$

$$CH_3COOH \rightleftharpoons CH_3COO- + H+$$

$$BOH \rightleftharpoons B^+ + OH^-$$

$$NH_3 + H^+ \rightleftharpoons NH_4^+$$

- The equilibrium expression for the dissociation of a weak acid is:

$$HA \underset{[\text{Association}]}{\overset{[\text{Dissociation}]}{\rightleftharpoons}} H^+ + A^-$$

- Ka = Dissociation Constant = $\frac{[\text{Product}]}{[\text{Reactants}]} = \frac{[H^+][A^-]}{[HA]}$

- Rearrange $Ka = \frac{[H^+][A^-]}{[HA]}$

$$H+ = \frac{[Ka][HA]}{[A^-]}$$

- Take log of each side

$\log H^+ = \log Ka + \log [HA] – \log [A^-]$ Multiply by –1, we get

$-\log H^+ = - \log Ka - \log [HA] + \log [A^-]$

Sorenson defined $pH = -\log H^+$ and $pKa = -\log Ka$

So the equation becomes:

$$pH = pKa + \log + \frac{\log[A-]}{[HA]}$$

This is Handerson-Hasselbalch Equation. It may be written as

$$pH = pKa + \log + \frac{\log[Salt]}{[Acid]}$$

- Dissociation Constants are usually numbers much less than 1 (10-2 to 10-8), and indicate the relative strength of the week acid.
- Dissociation Constants can be replace by pKa= $-\log_{10}$ Ka
- e.g. If a week acid has a Ka =10-2, then the pKa=$-\log(10^{-2})$ =2
- For bases there is Kb

$$BOH \rightleftharpoons B^{+} + OH^{-}$$

$$Kb = \frac{[B^{+}][OH^{-}]}{[BOH]}$$