CHE109: Engineering Chemistry-I
[Spring 2023]
[Section 5]

Assignment: Arrhenius Concept of Acids and Bases

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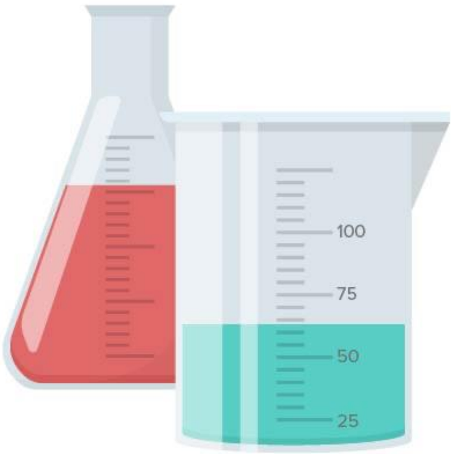
Arrhenius's Concept of Acids and Bases

Introduction:

Acids and bases are two fundamental and complementary concepts in chemistry that play important roles in many chemical reactions and processes.

The concept of acids and bases have been defined many times differently. Several scientists put various definitions to characterise the acid and bases in which some of the concepts are quite narrow and some are comprehensive. The Arrhenius acid-base theory was proposed by Swedish Svante Arrhenius in 1884 based on the theory of ionization. It was the first modern approach to the acid-base concept. This theory is quite simple and useful. This concept is only applicable to those compound which dissolves in aqueous solutions. In this concept, we understood how acids and bases react in solutions.



Discussion:

Arrhenius Acid:

According to Arrhenius's theory, Acids are defined as a compound or element that releases hydrogen (H^+) ions into the solutions. That increases the concentration of H+ or proton in an aqueous solution. The released H+ ion or proton is not a free-floating proton, it exists in a combined state with the water molecule and forms hydronium ion (H3O+). The common examples of Arrhenius acid include HCl (hydrochloric acid), H2SO4 (Sulphuric acid), and HNO3 (nitric acid).

$$HNO_{3\,(aq)} + H_2O\,(l) \text{-------->} H_3O^+ + NO^{3-}(aq)$$

In this reaction, nitric acid (HNO3) disassociate into hydrogen (H+) and nitrate (NO3-) ions when dissolved in water. It is now known that the hydrogen ion cannot exist alone in a water solution; rather, it exists in a combined state with a water molecule, such as the hydronium ion (H_3O^+).

The other acids and their dissolved form in water:

$$HCl + H_2O \text{ --------> } H_3O^+ + Cl^-$$

$$H_2SO_4 + H_2O \text{ --------> } H_3O^+ + HSO_4^-$$

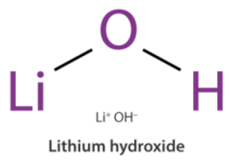
Arrhenius acid formula	**Name**
HClO	Chloric Acid
HNO_3	Nitric Acid
$HClO_4$	Percholric Acid
H_3PO_4	Phosphoric Acid
H_2SO_4	Sulphuric Acid
H_2SO_3	Sulphurus Acid
HCl	Hydrochloric Acid
CH_3COOH	Acetic Acid
HBr	Hydrobomic Acid

Table: Some Arrhenius Acid

Arrhenius Bases:

Similarly, Arrhenius bases are compounds that increase the concentration of OH or hydroxide ion in aqueous solution or having at least one OH ion in formula. The common examples of Arrhenius base include NaOH (sodium hydroxide), KOH (potassium hydroxide), Ca(OH)2 (calcium hydroxide), Mg(OH)2 (magnesium hydroxide), NH4OH (ammonium hydroxide), etc.

$$LiOH(s) \text{ ----> } Li+ (aq) + OH^- (aq)$$



The other bases and their dissolved form in water:

$$NaOH(aq) + H_2O \dashrightarrow Na^+ + OH^-$$

$$KOH + H_2O \dashrightarrow K^+ + OH^-$$

$$Ca(OH)_2 \dashrightarrow Ca^{2+} + 2OH^-$$

$$Mg\ (OH)_2 \dashrightarrow Mg^+ + OH^-$$

$$NH_4OH \dashrightarrow NH_4^+ + OH^-$$

Arrhenius Base	**Name**
NaOH	Sodium Hydroxide
NH_4OH	Ammonium Hydroxide
KOH	Potassium Hydroxide
Mg $(OH)_2$	Magnesium Hydroxide
Al $(OH)_2$	Aluminium Hydroxide
LiOH	Lithium Hydroxide

Table: Some Arrhenius Base

Advantages of Arrhenius theory:

This theory is used to explains:

- Strength of acid and bases.
- The properties of acids and bases in aqueous medium.
- Neutralization of acid by reaction with a base.

Utility of Arrhenius Acid:

This theory explains many phenomena like-

The strength of Acid or base:

According to the Arrhenius theory, the strength of an acid or a base is determined by the extent to which it dissociates in water. An acid is a substance that produces hydrogen ions (H^+) when it dissociates in water, while a base is a substance that produces hydroxide ions (OH^-) when it dissociates in water.

The strength of an acid can be determined by measuring its dissociation constant (Ka). The dissociation constant is a measure of the extent to which the acid dissociates in water. Strong acids have a large dissociation constant and dissociate almost completely in water. The lower the pKa value of an acid, the stronger it is. Strong acids have pKa values less than 0, while weak acids have pKa values greater than 0. For example, hydrochloric acid (HCl) is a strong acid because it completely dissociates in water to produce H^+ ions and chloride ions (Cl^-).

$$HCl + H_2O \text{ ----> } H_3O^+ + Cl^- \text{ (HCl has Fully Dissociated)}$$

Weak acids have a small dissociation constant and only partially dissociate in water. For example, acetic acid (CH_3COOH) is a weak acid because it only partially dissociates in water to produce H^+ ions and acetate ions (CH_3COO^-).

$$CH_3COOH + H_2O \text{ ----> } H_3O^+ + CH3COO^- \text{ (}CH_3COOH\text{ is not Dissociated Entirely)}$$

pKa	Chemical Formula	Name
–10	$HClO_4$	Perchloric acid
–7	HCl	Hydrochloric acid
–3.0	H_2SO_4	Sulfuric acid
–1.74	H_3O^+	Hydronium
–1.37	HNO_3	Nitric acid
+1.96	HSO_4^-	Bisulfate ion
+1.90	H_2SO_3	Sulfurous acid
+2.16	H_3PO_4	Phosphoric acid
+2.46	$[Fe(H_2O)_6]^{3+}$	–
+3.18	HF	Hydrofluoric acid
+4.75	CH_3COOH	Acetic acid
+4.97	$[Al(H_2O)_6]^{3+}$	–
+6.35	H_2CO_3	Carbonic acid
+6.74	$[Fe(H_2O)_6]^{2+}$	–
+6.99	H_2S	Dihydrogen sulfide
+7.20	HSO_3^-	Sulfurous acid
+7.21	$H_2PO_4^-$	Dihydrogen phosphate
+8.96	$[Zn(H_2O)_6]^{2+}$	–
+9.21	HCN	Hydrogen cyanide
+9.25	NH_4^+	Ammonium
+10.33	HCO_3^-	Bicarbonate

Similarly, the strength of a base can be determined by measuring its dissociation constant (Kb). Strong bases have a large dissociation constant and dissociate almost completely in water to produce OH- ions. For example, sodium hydroxide (NaOH) is a strong base because it completely dissociates in water to produce Na^+ ions and OH^- ions.

$$NaOH + H_2O \text{ ----> } Na^+ + OH^- \text{ (NaOH is Fully Dissociated)}$$

Weak bases have a small dissociation constant and only partially dissociate in water to produce OH- ions. For example, ammonia (NH3) is a weak base because it only partially dissociates in water to produce NH_4^+ ions and OH^- ions.

$$NH_4OH \text{ ----> } NH_4^+ + OH^- \text{ (} NH_4OH \text{ is not Dissociated Entirely)}$$

In summary, the strength of an acid or a base in the Arrhenius theory is determined by the extent to which it dissociates in water. Strong acids and bases dissociate almost completely in water and have a large dissociation constant, while weak acids and bases only partially dissociate in water and have a small dissociation constant.

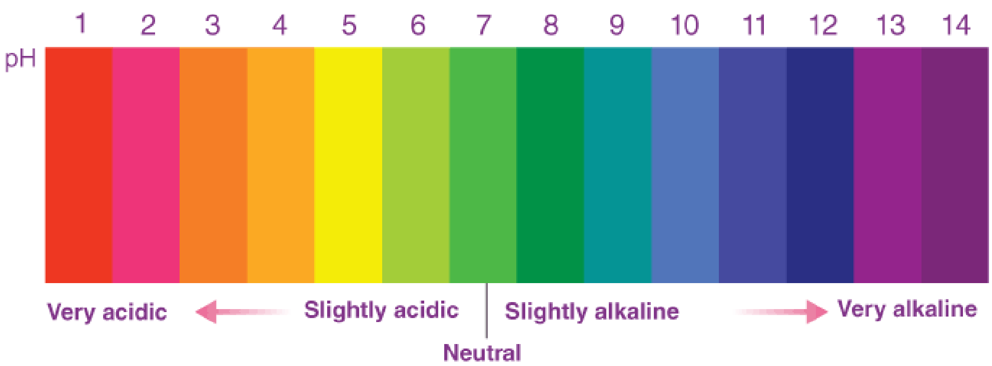
It is not necessary that strong acids or bases are concentrated and weak acids/ bases are dilute. Because the dissociation of a substance does not depend on its concentration.

The power of Hydrogen (pH):

In Arrhenius acid. We can have H_3O^+ in a solution. The pH of the solution can be determined by the concentration of hydronium ions.

$$pH = \log (H_3O^+)$$

From this equation, we can find the pH of pure water. The pH of pure water comes to 7 which is considered to be neutral. The solution is either acidic or basic depending on the change in the concentration of hydronium ion.



Source: Byju's: pH colour change

If the concentration of the hydronium ion in the solution increases means more than 10^{7} mol/L, pH increases which makes the solution more acidic.

If the concentration of the hydronium ion in the solution decreases means less than 10^{7} mol/L, pH decreases which makes the solution more basic.

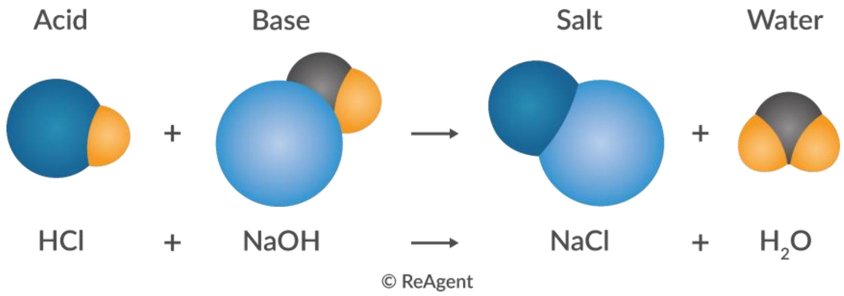
Likewise, we can also determine the pOH by considering the concentration of OH^-.

$$pOH = \log (OH^-)$$

Neutralization Reaction:

When Arrhenius acid and Arrhenius base react, salt and water are formed as products, the reaction is known as a neutralization reaction. For example

$$HCl + NaOH \dashrightarrow NaCl + H_2O$$



Limitation of Arrhenius acid-base theory:

1. This theory is very limited, out of three theories. According to this theory, the solution medium should be aqueous and the acid should produce hydrogen ion (H^+) or the base should produce hydroxide ion (OH) on dissociation with water. Hence, the substance is regarded as Arrhenius acid or Arrhenius base when it is dissolved in water. For example, HNO_3 is regarded as Arrhenius acid when it is dissolved in aqueous solution. But when it is dissolved in any other solvent like benzene, no dissociation occurs. This is against the Arrhenius theory.
2. Arrhenius theory is not applicable to the non-aqueous or gaseous reactions because it explains the acid-base behavior in terms of aqueous solutions.
3. In Arrhenius theory, salts are produced in the product which is neither acidic nor basic. So, this theory cannot explain the neutralization reaction without the presence of ions. For example, when acetic acid (weak acid) and sodium hydroxide (strong base) react, then the resulting solution is basic. But this concept is not explained by Arrhenius.
4. Arrhenius theory is only applicable to those compounds which having the formula HA or BOH for acids and bases. There are some acids like $AlCl_3$, $CuSO_4$, CO_2, SO_2 which cannot

be represented by HA formula, this theory is unable to explain their acidic behavior. Similarly, there are some bases like Na_2CO_3, NH_3, etc. which do not represent by BOH formula, this theory is unable to explain their basic behavior.

Conclusion:

It can be concluded that The Arrhenius Theory of Acids and Bases played an important role in physical chemistry. Though this theory is not sufficient enough to discuss all the acids and bases, this theory introduced so many properties of acids and bases. It opened the way to discovering more about chemical compounds.

By this theory, the overall properties of acids:

1. Arrhenius acids dissociate in water to produce hydrogen ions (H^+).
2. Arrhenius acids react with bases to form salts and water.
3. Arrhenius acids have a sour taste and can cause a burning sensation when in contact with the skin.
4. Arrhenius acids can conduct electricity when dissolved in water, as they produce ions that can carry an electric charge.
5. Arrhenius acids have a pH value of less than 7. The pH of a solution is a measure of its acidity or basicity, with values below 7 indicating acidity.
6. The strength of an Arrhenius acid is determined by its degree of dissociation in water. Strong acids completely dissociate in water, while weak acids only partially dissociate.
7. Arrhenius acids can react with metals to produce hydrogen gas.

By this theory, the overall properties of base:

1. Arrhenius bases dissociate in water to produce hydroxide ions (OH-).
2. Arrhenius bases react with acids to form salts and water.
3. Arrhenius bases have a bitter taste and can feel slippery to the touch.
4. Arrhenius bases can conduct electricity when dissolved in water, as they produce ions that can carry an electric charge.
5. Arrhenius bases have a pH value greater than 7. The pH of a solution is a measure of its acidity or basicity, with values above 7 indicating basicity.

6. The strength of an Arrhenius base is determined by its degree of dissociation in water. Strong bases completely dissociate in water, while weak bases only partially dissociate.
7. Arrhenius bases can react with acidic oxides to form salts and water.

By considering these properties, we can determine if a compound is an acid or a base.

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