PH, ACID AND BASES IN CHEMISTRY

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Introduction

pH is a fundamental concept in chemistry that measures the acidity or alkalinity of a solution. The term refers to the power of hydrogen? It quantifies the concentration of Hydrogen ions in solution. The pH and pH scale was introduced was introduced by Danish chemist Soren Peder Lauritz Sorensen in 1909. He developed the pH scale as a way to express the acidity or alkalinity of a solution, ranging from 0 to 14.They play a crucial role in understanding chemical reactions, biological processes, and various industrial applications. Compounds (organic and inorganic) including drugs are classified as acids or bases based on the pH scale.

Sample Solution	**pH**	**pOH**	**[H]+ (M)**	**pH**
	-1	15	10^{1}	
1M HCl (Battery acid)	0	14	10^{0} or 1	
Gastric Juice	1	13	10^{-1}	
Lemon juice	2	12	10^{-2}	
1M CH_3COOH Vinegar	3	11	10^{-3}	
Tomatoes	4	10	10^{-4}	
Black Coffee	5	9	10^{-5}	
Milk	6	8	10^{-6}	
Portable Water	7	7	10^{-7}	
Ocean Water	8	6	10^{-8}	
Baking Soda	9	5	10^{-9}	
Milk of Magnesia	10	4	10^{-10}	
Milk of Magnesia	11	3	10^{-11}	
Ammonia	12	2	10^{-12}	

Bleach	13	1	10^{-13}	
1M NaOH Caustic Soda	14	0	10^{-14}	
	15	-1	10^{-15}	

An illustration of the pH scale with common substance is as follows

pH 0-1 strong acids like HCl acid (Battery acid)

pH 2-3 lemon juice and Vinegar

pH 4-5 tomatoes and black coffee

pH 6 milk

pH 7 portable water

pH 8-9 Baking soda

pH 10-11 Ammonia solution

pH 12-14 Caustic soda and bleach

The pH of portable water is 7 which is neutral that is neither acidic nor basic. The presence of contaminants can thus lower the pH of water (acidic) or increase it (basic).

Measurement

The pH of a solution can be determined by the pH paper (indicator strips), the Universal Indicator and the pH meter.

pH paper/Indicator strips are simple and cost effective tools used to determine the pH of a solution. They consist of a paper or plastic strip impregnated with a mixture of different chemical indicators. These indicators change their color in response to different pH values. The strips were developed in the 19th century when scientists began exploring natural dyes as pH papers. An example is the litmus paper which turns red in the acidic medium and blue in the basic medium. The pH indicator strips is available in various forms as the pH paper, the pH tape or the pH strips. They provide a rapid, qualitative and cost effective assessment of the pH of a solution. It is widely used in titrimetric methods. They have distinct colours for each pH and are provided with matching charts with the specific test strips provided. The strip is placed on the surface of the wet substance. Or a few drops

The Universal Indicator

The measurement tool provides a more comprehensive analysis of pH values across the entire

These strips change colour depending on the pH of the solution. It is exhibits smooth color changes over a wide range of pH from 1 to 14. Examples examples include

Indicator	Low pH colour	Transition pH range	Description	High pH colour
m-Cresol Purple	Strong Acid	0.5-2.5	Red	Yellow
Thymol Blue	Strong Acid	1.2-2.8	Red	Yellow or Orange
2,4-Dinitrophenol	Strong Acid	2.6-4.0	Colourless	Yellow
Bromophenol blue	Strong Acid	3.0-4.6	Yellow	Blue
Methyl Orange	Weak Acid	3.1-4.4	Red	Yellow or Orange
Sodium Alizarin sulphonate	Weak Acid	3.7-5.2	Yellow	Violet
Bromocresol green	Weak Acid	3.8-5.4	Yellow	Blue
Methyl Red	Weak Acid	4.2-6.2	Red	Yellow
Bromocresol Purple	Weak Acid	6.0-7.6	Yellow	Blue
Alizarin	Weak Acid	5.5-6.8	Yellow	Red
p-Nitrophenol	Weak Acid	5.5-7.6	Colourless	Yellow
Bromothymol blue	Weak Acid	6.0-7.6	Yellow	Blue
Phenol red	Weak Acid	6.8-8.4	Yellow	Red
Cresol red	Weak Base	7.2-8.8	Yellow	Red
m-Cresol Purple	Base	7.4-9.0	Yellow	Purple
Thymol Blue	Base	8.0-9.6	Yellow	Blue
Phenopthalein	Strong Base	8.3-10.0	Colourless	Fuchsia
Thymophenopthalein	Strong Base	9.3-10.5	Colourless	Blue
Alizarin Yellow	Strong Base	10.2-12.0	Yellow	Red

pH meters

These are electronic devices that provide a precise measurement of pH by measuring the voltage difference between a reference electrode and a glass electrode immersed in the solution. It is a highly precise and quantitative instrument used to measure the pH of a solution. It is developed from early 20th century with significant advancements occurring during the mid 20th.

Application

Water Quality Analysis

pH meters are extensively used in water quality analysis to determine the acidity or alkalinity of water samples. This is crucial in accessing the suitability of water for various purposes, such as drinking, irrigation and industrial processes. pH measurements help identify potential issue such as acid rain, pollution, or changes in natural water bodies. They also assist in monitoring the effectiveness of water treatment processes.

Food and Beverage Industry

The pH of food and beverages plays a critical role in product quality, safety and preservation. pH meters are used to monitor and control acidity levels during food processing and manufacturing. They ensure that the desired pH is maintained in products such as fruit juices, dairy products, canned goods and fermented foods. pH meter measurements are included in quality control protocols and food safety regulations.

Soil Analysis

pH meters ar e employed in soil analysis to determine the pH of soil samples. Soil pH affects nutrient availability, microbial activity and plant growth.pH measurements assist in soil fertility assessments, determination of lime or fertilizer requirements and identification of acidic or alkaline conditions. It is valuable for agricultural practices, horticulture and land management strategies.

Pharmaceutical Research and Development

In pharmaceutical research and developments, pH meters are used to access the pH of drug formulations including solutions, suspensions and emulsions. pH pays a crucial role in drug stability, solubility, bioavailability and efficacy. The pH measurements helps to optimize drug formulations and ensure their quality and effectiveness.

Medicine and Medical Diagnosis

pH is measured in the human body to diagnose certain medical conditions and monitor effectiveness of treatments for example, blood pH is titghtly regulated to maintain proper physiological functioning.

Test strips are used as diagnostic tools to test the urine

Chemical and Industrial Processes

They are employed to monitor and control pH levels in chemical reactions, wastewater treatment plants, electroplating, paper and pulp manufacturing and many other industrial operations. Process efficiency, product quality and complying with environmental regulations

pH meters are used in various chemical and industrial processes.

Environmental monitoring

Field studies and environmental monitoring programs to quickly access the pH of natural water bodies such as rivers, lakes and oceans.

Chemistry and Biochemistry

pH is essential for understanding chemical reactions, enzyme activity and the behavior of acids and bases in solution.

Food and Beverage Industry

pH is a critical parameter in food production, preservation and quality control. It affects taste, texture and microbial growth in various food products.

Limitation

pH values do not give directly the concentration of the solution.

pH value of zero is obtained in a solution of strong acid.

pH value of an acid with low concentration is not above 8 but below the neutral pH 7.

1.Acid-Base Balance and Blood pH

A range of disorders can result from acid-base imbalance and these disorders are classified based on the cause and the direction of the pH change into respiratory or metabolic acidosis. Hydrogen ions with some other anions like serum sodium ion, potassium ions, sulphate, chloride ions and protein. The pH of the arterial blood is tightly regulated within a narrow range of 7.35 to 7.45. This balance is essential for proper oxygen delivery, enzyme function, and overall cellular metabolism. Acidosis ($pH<7.35$) or alkalosis ($pH>7.45$) can disrupt normal physiological processes and lead to serious complications as revealed below by the following examples.

2.Respiratory pH regulation

The respiratory system acts as a primary regulator of pH by controlling the elimination of carbon dioxide (CO_2). Increased CO_2 levels lead to acidosis, while decreased CO_2 levels cause alkalosis. Conditions such as Chronic Obstructive Pulmonary Disease (COPD) can impair respiratory function, resulting in respiratory acidosis.

3.Gastric pH and Digestion

The stomach maintains an acidic environment (pH 1.5-3.5) to aid in the digestion and breakdown of food. Alterations in gastric pH can impact the activity of digestive enzymes and the absorption of nutrients. Conditions like gastritis or the use of acid-suppressing medications can disrupt the normal gastric pH, leading to impaired digestion.

4.Urinary pH and Kidney Function

The Kidney help regulate the body's pH by selectively reabsorbing excreting hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). Changes in urinary pH can affect the formation of kidney stones and the elimination.

5.Vaginal pH

6.Tumorigenesis

7.Skin

Application of the principle of pH

Acids and Bases

Acids and Bases are important in various chemical processes which occur within our bodies and outside in our environment for instance the biochemical reactions that occur at the molecular level in our bodies, the synthesis and reactions carried out in the laboratory, industrial processes and others. The human body comprises of 70-75% water and drugs may be ingested which is first diluted , it's acid-base behavior can thus be described by the theory described by Bronsted and Lowry. Acid-base imbalance in the body can also result in various diseases A quatic life also depends on specific pH as pollutants from oil spillage or acid rain can alter the pH and destroy plants, microbes and fishes in the aquatic terrain. The quality of water obtained from boreholes and wells can be affected by dissolved mineral acids/bases and result in various neurological diseases, cognitive impairment in children, skin reactions/lesions, kidney damage, endocranial damage, reproductive disorders, cardiovascular problems and immunological issues upon ingestion provided the impurities are not dealt with to restore the pH. Soil contamination by acid rain can result in serious consequences on the vegetables and food produced. Corrosion in pipes made of lead has also result in grave consequences when the pip-borne water is consumed.The process in the Pharmaceutical industries must be carried out with utmost caution to the pH, acids and bases. Essentially, it can affect the totality of our lives.

Scientists from centuries past have discovered that the sour taste in certain fruits or substances have been attributed to acids for instance the sour taste of grape, lemon and some oranges is due to the presence of citric acid. The acid is capable of dissolving metals like lead, iron and zinc, can also dissolve organic dyes to generate definitive colors, turns blue litmus paper red and react with bases to form salts.

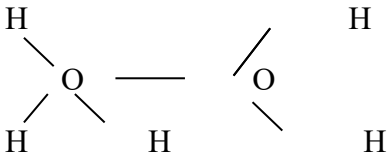
The relationship between the structure, composition and properties was studied extensively by chemists and Arrhenius (1859-1927) defined acids and bases. Bronsted-Lowry The Bronsted-Lowry theory defines an "acid" as any substance capable of yielding a proton (H+) and a "base " as a substance capable of accepting a proton. Arrhenius, a Swedish chemist however defined acids as substances that produce hydrogen (H+) ions in solution while bases produce hydroxide (OH-) ions in solution. An acidic solution therefore contains a higher proportion of Hydrogen (H+) ions than hydroxide (OH-) ions. Acids are corrosive and can cause damage to living tissues and materials, they react with metals to yield hydrogen gas and metal salts. They also react with bases to form salt and water. They are electrolytes and conduct electricity in aqueous solution. Bases on the other hand, are caustic

Bases react with acids to form

Proton in water

Water is a universal solvent. Commercially available HCl is 12M and contains 37-38% HCl. An acid like HCl dissociates in water to give a proton. It is highly soluble in water due to the dissociation into the constituent proton and Chloride ion. The resulting proton associates with water and is strongly bond between two molecules of water as discovered using the latest ultrafast spectroscopy. Ultrafast snapshots of protons using 2-D vibrational spectroscopy revealed many structural variations have been found and the structures persist not as the hydronium ion (H_3O^+)as generally believed but as "Zundel-like" ($H_5O_2^+$) and ($H_9O_4^+$). These structures are important in computational models of transient water structure, oxidation-reduction reactions and generation of fuel from water. HCl has a low solubility in organic solvent like benzene.

Illustration



The Bronsted-Lowry

Johannes Bronsted (1879-1947) - a Danish chemist and Thomas M.Lowry (1874-1936) described the reaction between acid- base reaction and proposed via independent study that it is related to their ability to transfer protons. They proposed independently in 1923 the definition of acids as substances capable of donating a proton and a base as a substance capable of accepting a proton. Hydrochloride in water thus acts as an acid by donating a proton to water which accepts the proton as a base. It can therefore be extrapolated to reactions occurring in non aqueous solvents (though with modification) as long as proton is donated by one and accepted by the other as exemplified by hydrochloric acid and ammonia, acetic acid in acetic acid, Ammonia in acetic acid

HCl + NH3 Cl- + NH4 +

CH3COOH + NH3 CH3COO- +NH4+

Ammonia acts as a base in the presence of acetic acid where the resulting species CH3COO- is the conjugate base of acetic acid and ammonium ion is the conjugate acid of the ammonia.

In non-aqueous solvents, the solvent molecules themselves can act as both a solvent and a base, A compound like Boron Trifluoride BF3 in ammonia

$BF_3 + NH_3$ $(BF_3.NH_3) + NH4^+$

Here ammonia donates a proton to NH_3 and becomes NH_4^+ is the conjugate acid of ammonia.

It is important to know that the strength of an acid or base in non-aqueous solvent is often different from its strength in aqueous solutions. This is due to the effect of the

solvent and its ability to protonate or deprotonate species. Identification of the acid-base pair in non-aqueous solvents …….

G.N. Lewis in 1923 described an acid as an electron pair acceptor while a base is an electron pair donor. Therefore non hydrogen compounds can be included in the definition of acids and bases for example

$AlCl_3 + OR_2 \quad Cl_3Al{:}OR_2$

$AlCl_3$ is an acid by Lewis definition as it accepts electron pair from OR_2 which functions as the base by donating the pair of electrons.

Acid, Base, Conjugate Acid and Conjugate Base

When an acid dissociates in an aqueous or non aqueous solvent by losing its proton, it is left with an extra pair of electrons that cannot be neutralized by the proton again. It is referred to as the "ionized" form of the acid and it is water soluble. Strong acids are completely ionized in solution while weak bases are partially ionized example is acetic acid. The acid dissociation constant can thus be calculated.

A large proportion of organic functional groups behave like acids. They contain functional groups like hydroxide (in phenol), Thiophenol, N-Aryl Sulphonamide, Aryl carboxylic acid, Sulphonic acid, Imide, Alkylcarboxylic acid, sulphonamide. Alkyl thiol, Sulphonic acid.

Examples are tabulated below

Compound	**Acidic Functional Group**	**Conjugate base**		
Ibuprofen	-COOH	Carboxylate		
Naproxen	-COOH	Carboxylate		
Acetylsalicylic acid	Acetyl (-COOCH3)	Carboxylate		
Phenol	OH	Phenolate		
Indomethacin	-COOH	Carboxylate		
Warfarin	-COOH	Carboxylate		

Compounds with basic functional groups

Amphetamine	-NH2			
Cimetidine	-NH2			
Lignocaine	-CONH2			

Morphine	-NH2			
Diphenhydramine				
Guanidine				
Amidine				

Some organic functional groups that are considered neutral under physiologic conditions include alkyl alcohol R-CH_2-OH, Amide R-$CONH_2$, Amine oxide NRR'R"-O, Diarylamine Ar-NH-Ar, Ether R-O-R, Ester R-COOR', Ketone R-O-R', Aldehyde R-CHO, NitrileR-CN, Thioether R-S_R', Sulphonic acid Ester R-SOOO-R', Quaternary ammonium RR'R"N, Sulphoxide RSOR', Sulphone RSO_2R, Examples include Propanolol where the secondary alcohol group is located on the middle on the 3rd Carbon atom and the group plays a role in its interaction and Pharmacological properties.

Environmental Application

Rainwater contains dissolved carbondioxide as carbonic acid hence pH is between 5 and 6

H20 (l)+ CO2 (g)→ H2CO3 (aq)

H2CO3 (aq) →H+(aq) +HCO3-(aq)

Acid rain is rainwater with a pH of less than 5 due to the presence of dissolved oxides sulphur dioxide SO2, Sulphur trioxide SO3 and Carbondioxide. CO2 is present in the atmosphere when released during respiration by living organism. It is also liberated during combustion of fuel and forest fires. However Sulphurdioxide and Sulphur trioxide are generated as industrial by products during the heating of ores (metal sulphides). The resultant effect varied as in the destruction of forests when the acid rain makes the plants susceptible to insect infestation and degradation. The soil is also damaged and lake water is acidified such that it cannot support life.

pH calculations involve

Kw = ionic product of water

Ka= Acid dissociation constant

Kb =Base dissociation constant

This is based on the exchange of proton.

Acid-Base Application in Pharmaceuticals

1 Analytical Procedures in Chemistry and Pharmacy

Analytical methods in Chemistry and Pharmacy depends on acid-base reaction such as acid-base titration which may involve dtrect titration for example standardization of 1M NaOH using sulphamic acid as a primary standard, or a back titration for example determination of Aspirin. The accurate determination of the strength of a standard solution is important for a successful analytical work . Sodium hydropxide

is one of the most used standard solutions in acid-base titrations, and it must be standardized against a standard acid (for instance HCl) in the presence of a suitable indicator like methy orange or phenopthalein indicator. The acid HCl itself must have been standardized with exsiccated sodium bicarbonate which is the Analar.

A back titration consists of the addition of a definite excess of a standard volumetric solution to a weighed amount of the sample and the determination of the excess not consumed by the sample. Applied in the determination of the amount of Aspirin, Lactic acid and Ammonia solution.

2. Buffer systems

3. Acids and bases are used to dissolve insoluble medications for example Lidocaine hydrochloride injection U.S.P. is prepared by reacting Lignocaine with HCl. Niacin Injection U.S.P. is prepared by reacting Niacin with sodium hydroxide or sodium bicarbonate. Other solid acids that can be used are tartaric acid, citric acid and sodium dihydrogen phosphate. The sodium bicarbonate must be in the right particle size.

4. Preparation of effervescent mixtures where sodium bicarbonate is used as the source of carbondioxide.

pH and aquatic life

It is one of the most important environmental factors limiting species distributions in aquatic habitats[5]. Different species flourish within different ranges of pH, with the optima for most aquatic organisms falling between pH 6.5-8. The pH of water determines the solubility and biological availability of chemical constituents such as nutrients and heavy metals. For example, in addition to affecting how much and what form of phosphorus is most abundant in the water, pH also determines whether aquatic life can use it. In the case of heavy metals, the degree to which they are soluble determines their toxicity.

Not only does the pH of a stream affect organisms living in the water, but a changing pH in a stream can also be an indicator of increasing pollution or some other environmental factor. Even small changes in pH can shift community composition in streams because pH alters the chemical state of many pollutants (e.g., copper, ammonia), changing their solubility, transport, and bioavailability. This can increase exposure to and toxicity of metals and nutrients to aquatic plants and animals.

Summary

pH, Acids and Bases are fundamental concepts in chemistry. pH is used to measure the extent of acidity or alkalinity of a system , product, environment or the part of a human body. They play a crucial role in understanding chemical reactions, biological processes, reactions that occur in the body, living cell and microorganisms as well as various industrial processes. It determines the outcome of some reactions as certain reactions take place at specific pH while they do not at other pH while other conditions are constant for example neutralization reactions and hydrolysis.Lack of balance in pH in our body can result in diseases. Microorganisms also thrive at certain pH and enzymes within them may catalyze a reaction give rise to certain products at specific pH as in fermentation reaction. pH is important and its application spans across

various industries like the chemical industry, industrial sector where it plays a role in water treatment, metal plating, paper and pulp industry, pharmaceutical industry (drug formulation, drug synthesis and drug delivery systems). Microorganisms thrive, grow and carry out basic processes like metabolism at specific pH while their growth are inhibited at other pH depending on the species. In conclusion, pH in general and acids and bases influences microbial growth, enzyme activity, metabolic pathways , pH stability during industrial processes and manufacturing of pharmaceutical drugs/drug products. It is essential to optimize the pH of any process or reaction via monitor and control to get the desired result.

Scientific Ethics Declaration

The author say that she is responsible for the scientific, moral, and legal aspects of this chapter, which is published in In Junejo Y (Eds.), *Chemistry for the Life.* ISRES Publishing

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Conflict of Interest

The authors declare no conflict of interest.

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