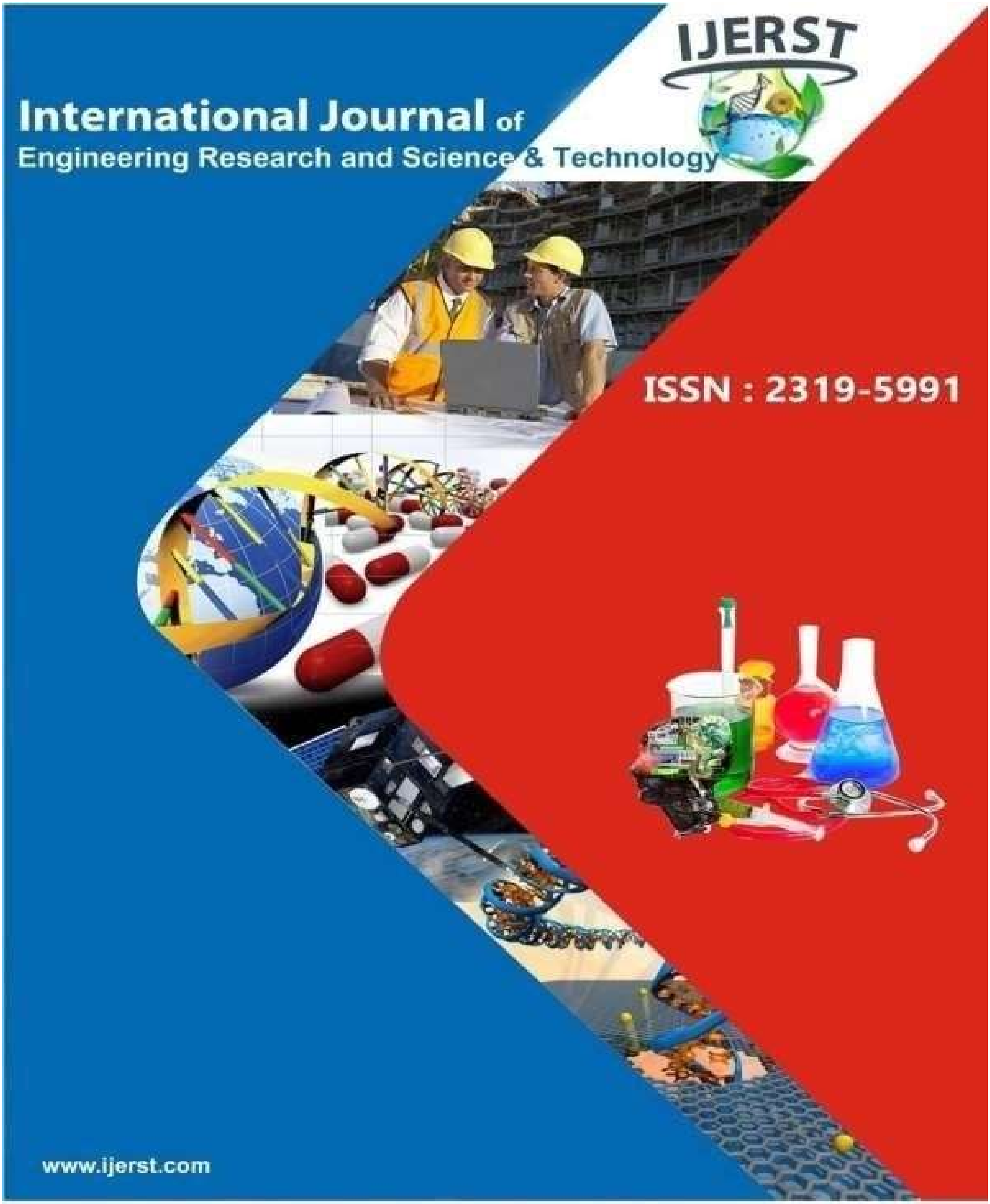

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Fundamental Concepts and Principles of Basic Chemistry: A Comprehensive Review

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ABSTRACT

Understanding the basics of chemistry introduces and provides students with a comprehensive view of the various fundamental concepts and principles of chemistry. This essay is well-researched and is divided into eight sections, all of which cover a wide array of basic chemical principles. Throughout, I tried to write in a student-friendly, conversational style, often using examples and analogies. It's my hope that in providing a solid foundation in general chemistry, this essay will come in handy (I hope it's like a one-stop solution) for students who need to go through important topics that I have covered herein or who want to get more help with learning the basic premise of the chemical science. Generally, ideal for high school level, junior college level. An attempt has been made herein to present the readers with the basics of chemistry from the ground up.

In this review article, we discussed about: - The atom – which is the smallest unit of an element. The smallest particle of an element, called an atom, still possesses the same chemical properties as the original element itself, in the absence of any pharmacological change, which occurs when an atom loses or gains an electron. - The molecules – which are the smallest units of compounds. They are formed by chemical bonding between groups of two or more atoms in a fixed ratio. - The reactivity of an element – which depends on its electrons in the outermost shell, also known as the 'valence shell'. An atom with a stable outermost shell will generally not react

with other atoms that have its valence singlet or duplet. Those elements can generally be found as inert gases in nature, in a non-ionized form.

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1. INTRODUCTION

Chemistry is of great importance for mankind. Wherever we look, we perceive basic chemical and physical phenomena and reactions. Moreover, a number of medical, biological, geo-science, and other phenomena may be also at least partially better understood if visualized in a chemical way. Chemistry is frequently considered as difficult (due to a different symbolic language). This has as a consequence that the legend "I hate chemistry, reactions do not work" remains widespread. Since many students and teachers of applied sciences in the disciplines geo-science, geo-engineering, materials science, petroleum engineering, etc., are in fact poorly equipped with "proper" chemistry background, this chapter offers a comprehensive review of the most fundamental concepts and principles of basic chemistry. At least, this should give support in the sense that a common language for interdisciplinary work can be achieved [1].

On a molecular basis, chemistry is basically the science of electrons. Electrons appear within negatively charged ions (anion), within metallic materials (metal), within covalent bonds in molecules, or as free (e.g., electrons in air causing chemical reactions; effect of non-ionizing or ionizing radiation on matter). The molecular structure (known as molecular topology) is a direct consequence of the electron arrangement. The electron movement (kinetic energy) is the origin of chemical reactions. The electron number in an atom and its arrangement are known as the valency of the specific atom. It is especially the electrons in the outer shell that are responsible for most chemical reactions. The arrangement of an atom and its outer electrons may vary depending on the local environment of the atom; in a molecule, an electron pair may be localized within the particular atom in order to facilitate the favorable formation of bonds [2-4].

2. ATOMIC STRUCTURE

The atom is the fundamental unit of an element that is composed of various subatomic particles. It is the smallest entity of an element that can enter into a chemical reaction. In turn, elements are pure substances that are made from atoms of a single type. Elements are the basic building blocks of matter, and over the course of human history, 118 different elements have been discovered; of these, 92 elements occur naturally on Earth. Atoms themselves are made up of different subatomic particles. The nucleus of an atom contains positively charged protons and neutral neutrons. Negatively charged electrons are found in "shells" surrounding the nucleus. The

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arrangement of these subatomic particles in an atom as well as their masses influences all of the behaviors seen in all elements. It is important to understand these components and their properties in creating the quantum mechanics that underpin the atomic theory, and, subsequently, the study of the many compounds that these elements combine to form [5-6].

Electrons are much less massive than protons or neutrons and carry a negative charge equal in magnitude to the positive charge of a proton. For the purposes of unit balancing in chemistry problems, the charge of an electron is usually approximated as -1. The number of protons in an atom's nucleus dictates the number of electrons that an atom has orbiting around it. This results in atoms being electrically neutral. The electrons, which are negatively charged, offset the positive charges of the protons and give net zero charge for an atom. Electrons are located in "shells" surrounding the atomic nucleus. An atom's first shell can hold up to two electrons while any subsequent shell can hold up to eight. The amounts of electrons that are present in the atom determine its stability and how readily it reacts with different elements to form new compounds [7].

2.1. SUBATOMIC PARTICLES

Subatomic particles are the tiny particles found in atoms, usually smaller in size and mass than atoms. Research over the past two centuries has revealed a whole host of subatomic particles. Three such particles, protons, neutrons, and electrons, form atoms and each bear unique characteristics through fundamental units that are present in everything [8].

Protons: Protons are positively charged, massive particles that are located in the atom's central nucleus. The magnitude of the charge of a proton is equal to +1 and is equivalent in strength to the negative charge of an electron because protons attract electrons. A proton's mass is equivalent to the mass of a neutron, but it is nearly 2000 times greater than that of an electron [9-11].

Neutrons: Neutrons are a kind of neutral charge and similarly massive subatomic particles located along with protons in the nucleus of an atom. Because they carry neutral charges and are present in the atom's core, neutrons play a significant role in maintaining the stability of the atomic nucleus. It is because of the addition of neutrons that facilitates isotopes to emerge due to their neutral charge. The mass of a neutron approximates to that of a proton; therefore, the addition of a neutron variable determines the mass number of the atom [12].

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Electrons: Electrons are extremely small and lightweight subatomic particles present outside the nucleus in shells. Their charge is opposite to that of protons; for the electron, -1 is the magnitude of charge and signifies a negative charge. The electron's charge is much more minuscule and weaker than the alternative positive charge, carrying a 1/1837 proportion to the mass of a proton, making the atom 2000 times bigger than its negative charge. Electrons attract and are attracted to protons primarily because its local orbit encases the protons of the nucleus to maintain the relative distances within the orbit [13].

2.2. ATOMIC NUMBER AND MASS NUMBER

The number of positively charged protons in an element is denoted as 'Atomic Number.' For a specific element, the atomic number is constant, and we can order different elements in the periodic table according to the atomic number. To sum up, what enables us to differentiate one element from another is its atomic number, and this determines the identities of the elements. The chemical behavior of an atom is dependent on its atomic number. The physical property that it carries in the greatest amount is called 'mass number.' It includes the total number of protons and neutrons, and actually, it provides the isotopic variation for a particular element. As a result, the mass number depends on the isotopic structure of the elements. Although the atomic number is a constant value for a particular element, the mass number can change according to its isotopic structure [14].

In both atoms and molecules, the total charge is zero. Protons, which are found in the nuclei of atoms, carry a positive charge, while electrons, which orbit the nucleus, carry a negative charge. Atoms are electrically neutral because the numbers of protons and electrons are equal. For any given atom, the number of protons is always constant. This constant positive number identifies the element and is called the atomic number. Loosely speaking, the atomic number of an atom is equivalent to the number of protons in its nucleus. None of these relations changes when we move through the periodic table from one element to the next. For all atoms of an element, the atomic number has the same value [15].

3. CHEMICAL BONDING

Chemicals are assembled of atoms that can be held together with a variety of interaction forms. Their properties and reactivities are greatly influenced by the types of forces in use. Interactions that hold atoms together forming individual, discrete chemicals such as HCl or CCl4

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from atoms are called bonding. There are 3 principal types of bonding: ionic, covalent, and metallic [16].

Ionic Compound: There is one kind of bonding that involves the transfer of electrons from one atom to another, forming an ion (charged particle). The force of attraction holding two ions of opposite charge together is called ionic bonding. The product of ionic bonding is called an ionic compound.

Covalent Compound: There is another type of bonding that occurs when the electrons are not transferred but are shared. This bond is formed by the sharing of electrons, wherein one pair (single bond), two pairs (double bond), or three pairs (triple bond) of electrons are involved in making the covalent bond. This is represented symbolically by a dash between atoms (H - H). The product of covalent bonding is called a covalent compound [17].

Metallic Compound: In metallic bonding, metal atoms lose some of their electrons such that a collection of metal cations is surrounded by a 'sea' of electrons that are delocalized throughout the metal. Conductivity and other properties are a result of this electron mobility.

Molecular Compound: This involves covalent bonding between nonmetals to form molecular compounds that are composed of molecules. The non-ionic nature of a molecule means these compounds have low melting and boiling points, and many are gases or liquids at room temperature. An exception to this is hydrocarbons, which can be solids at room temperature since they contain a greater proportion of electrons covalently bonded to the element with the highest electro negativity. Intermolecular forces are much weaker than covalent or ionic bonds, and generally, molecular compounds have much lower melting and boiling points compared to ionic and metallic compounds of the same element [18].

3.1. IONIC BONDING

Ionic bonding is the first major bond we will discuss. When two elements have a large difference in electro negativity, one will take an electron away from the other so that they both have the same number of electrons as the nearest noble gas. The atom that gains an electron becomes an anion, and the atom that loses an electron becomes a cation. These cations and anions are then attracted to each other, leading to a structure called an ionic crystalline lattice [19].

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Because cations and anions are attracted to each other, ionic compounds generally have high melting and boiling points. It takes a lot of energy to pull them apart. When they do break apart, ionic compounds can also conduct electricity when in solution or molten form. These ionic compounds also dissolve in water, where they are able to conduct electricity because the individual ions break completely free to move around. Sodium chloride is an example of an ionic compound; the equation for its formation from the elements is: $2Na(s) + Cl2\ (g) \rightarrow 2NaCl(s)$

3.2. COVALENT BONDING

Within a stable molecule, atoms are dedicated to satisfying the octet rule. They may do so through the sharing of two or more electrons, producing a covalent bond. The electrons between two atoms participating in a covalent bond, called bonding electrons, are also known as shared electrons. With regard to covalent bonding, the atoms which contribute electrons must also be nonmetals.

Electronegativity: Unequal sharing of electrons in a bond is crucial to consider and understand how innumerable compounds will behave or why they possess a specific property or properties. If the shared electron density in a bond is evenly distributed, said bond is classified as nonpolar covalent. On the other hand, when the shared electron density is uneven, a polar covalent bond exists. Electronegativity, defined as the relative ability of an element (when combined with another element) to attract electrons, determines which type of covalent bond will form between the participating atoms. Electronegativity values range from 0.7 to 4.0, with non-polar covalent bonds falling between 0.0 and 0.3, and polar covalent bonds ranging from 0.4 to 1.9 20.

In terms of the resulting molecules, it is easiest to consider extreme cases. Pure, diatomic elements (two atoms of the same element) like O2 and H2 consist of non-polar covalent bonds due to the identical electro negativities between the two atoms. Thus, since the electron pair stays in the middle of the atoms, each molecule is non-polar. Polarity directly affects the properties of a molecule (intermolecular forces, boiling and melting points, etc.) and readily, the interpretation of a variety of subjects. Triglycerides, a class of lipids, layer and store adipose tissue. A polar head faces the watery environment, and both polar and non-polar tails orient toward one another. The polar head features oxygen and nitrogen atoms that cling to water utilizing hydrogen bonds. Polar compounds interact with and dissolve in this way [21].

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4. CHEMICAL REACTIONS

When substances undergo transformation, the result is referred to as a chemical reaction. There are a variety of chemical reactions that can occur, and some of the principles that govern each of them can involve everything from changes in energy to the method of reaction. A few types of chemical reactions include acid-base reactions, precipitate reactions, and oxidation-reduction reactions. In order for one to analyze, predict, or take advantage of these types of chemical reactions, it is first necessary to understand the concept of chemical reactions and the principles that govern them [22].

Chemical reactions occur in an attempt to reach lower energy states. This means that the reactants that go into a particular reaction contain high amounts of energy, and when they transform themselves into the products, lower-energy states are achieved. Lower energy states are, of course, always favored by nature, and this characteristic is a result of entropy. Whenever substances reach a lower energy level, entropy will increase as nature attempts to reach the highest form of disorder it can. The principles of thermodynamics state that energy cannot be created or destroyed, only transformed. In the case of chemical reactions, this transformation of energy is reflected in the change between reactants and products. With the transformation of energy comes the notion that the total energy of reactants and products combined—referred to as H—is equal. However, increasing or decreasing the envelope also takes place as a result of entropy. In general, the chemical reaction can be measured in order to determine whether or not its overall energy is higher [23].

4.1. TYPES OF REACTIONS

Types of reactions. Reactions can be categorized into several different types. At a basic level, chemical reactions are combination or synthesis, combustion, decomposition, exchange, single displacement, and double displacement reactions. With synthesis reactions, two or more substances combine to form a new compound. The classic example of a synthesis reaction is the combination of sodium and chlorine to form sodium chloride as shown below:

$2Na + Cl2 \rightarrow 2NaCl$

Decomposition reactions occur when a compound is broken down into simpler substances through the input of energy. There are three sub-types of decomposition reactions: heat, light, and

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electricity. An example of a synthesis reaction is heating mercury (II) oxide to produce mercury and oxygen gas:

$2HgO \rightarrow 2Hg + O2$

A single displacement reaction occurs when the atoms of one element replace the atoms of another. During a single displacement reaction, the more reactive metal or non-metal element extracts the least reactive metal as a part of a compound. An example of a single displacement reaction is shown below:

$2Na + 2H2O \rightarrow 2NaOH + H2$

Furthermore, the reaction between concentrated hydrochloric acid and zinc can be classified as a single replacement reaction. In this context, zinc replaces the hydrogen ion to form zinc chloride and hydrogen gas:

$2HCl\ (aq) + Zn(s) \rightarrow ZnCl2\ (aq) + H2\ (g)$

Double displacement reactions involve an exchange of positive ions between two compounds. During a double displacement reaction, positive ions or cations in compounds, such as lead (II) nitrate and sodium iodide are exchanged and form lead (II) iodide and sodium nitrate as seen below:

$Pb\ (NO3)2 + 2NaI \rightarrow PbI2 + 2NaNO3$

4.2. BALANCING EQUATIONS

Balance equation is crucial as in simple words, it is necessary for the conservation of mass. In a chemical reaction, no matter how many atoms are in the reactants (left side of the chemical equation) or products (right side of the chemical equation), these numbers should always be equal. If these atomic ratios are different, the equation is unbalanced thus the mathematical expression cannot explain the chemical changes of the reaction. To balance a chemical equation, following can be done:

Initial balancing: Elements that appear in single substances on only one side of the arrow can be balanced first. Next, common polyatomic ions such as NH3 on one side and NH4+ on the other side are balanced. Multiplying the reactants and products by appropriate coefficients (whole

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number) can relate the mass or number of moles of one compound or element to another. Doing so, chemical equation extends to include stoichiometry. Stoichiometry is the calculation of the relative quantities of molecules and reactants [24].

Precision in chemical calculations, as well as the accuracy of chemical analyses and the correct formulation of balanced chemical equations, all depend on the ability to balance chemical equations. The goal in balancing chemical equations is to standardize the chemical reactions. Standardized reactions in turn provide the basis for a locale of chemists' communication. The act of undertaking chemical balances is not merely a rote exercise to improve eye-hand coordination. It is a muscling exercise in thinking the chemistry. As we make the equation more generally useful, stoichiometry now becomes a singular analytical device. One can measure, calculate, and predict what reactants are needed to produce a given amount of product or calculate what quantity of product forms when a given quantity of reactants reacts.

5. ACIDS AND BASES

In this section, you will learn about the different properties of acids and bases as two classifications of matter in the world around us. The pH scale to determine where a solution falls mathematically between acidic and basic properties will be explained. Finally, we will discuss some of the reasons why humans might need to interact with acids and bases in the world around us, in careers involving biology, environmental sciences, and the environment.

The characteristics of acids and bases have been studied by those with an interest in biological processes and chemistry since the earth was young. Acid and base properties indicate a solution or an ionic compound that releases cations and anions by dissociation. Acids are substances that furnish hydrogen ions (H+) as positive hydrogen ions, or cations, when they are dissolved in water. Bases are substances that furnish hydroxide ions (OH-) as negative hydroxide ions, or anions, when they are dissolved in water. The prefix "hypo" followed by the base name signifies one fewer H: HCl = hydrochloric acid; HC2H3O2 = acetic acid [25].

The first model that addressed the nature of acids and bases is the Arrhenius Theory. Arrhenius (ah-ren'-ee-uhs) determined that when a substance is dissolved in water to form an aqueous, or water-based, solution and it increases the concentration of H+ (protons) in the solution, then it is an acid. If the substance releases OH- or hydroxide ions into the solution, it is classified as a base. While these substances may possibly have a sufficient concentration of

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hydroxide ions to contribute hydroxide ions to the solution, many of these substances (especially food products or a lye product for cleaning) do not. The second acid/base model, called the Bronsted-Lowry Theory, proposed that any pair of substances could be classified as an acid or a base. In this process, when an acid (H+) is released, the reaction results in the formation of the base (H+). When a base (OH-) is released in the reaction, it forms an acid (OH-). The third acid/base model is called the Lewis Theory. In this acid/base model, an electron pair acceptor is classified as an acid, and an electron pair donor is classified as a base. These electron pairs can be on the H+ for hydrogen, oxygen, or hydroxide molecules so they can serve as an acid or a base [26].

5.1. PH SCALE

There are definitely some chemical systems in which [H+] or [OH-] as a product, substrate, or catalyst plays a significant role. In those cases, as mentioned above, scientists need to track the exact concentrations of those ions. More commonly, however, chemists and biologists merely need a relatively straightforward method for quickly overviewing the acid/base chemistry of a system. The pH (potenz Hydrogenii) is a measure of the acidity or basicity of a solution, so it can provide just that "quick view" of a system's chemical behavior. The concept of pH was introduced back in 1909 by the Danish biochemist Sørensen. The pH of a solution can be quickly determined by measuring its H+ ion concentration. Using logarithmic functions, pH allows for an increased range of H+ ion concentration to be reported easily and without writing down a large number. As a result, chemists and biologists frequently use the pH to determine if a system will be able to complete a chemical process or serves as a control on a biological response. In other words, the pH can reveal how a system will behave chemically or biologically [27].

Pure water is neutral (neither acidic nor basic) and has a pH of 7 at 25 degrees Celsius. Acidic solutions have a lower pH while basic, or alkaline, solutions have a higher pH. The pH scale ranges from 0 to 14. The pH of 0 to 6.9 is considered acidic, with 7 being neutral. A pH of 7 is exactly in the middle of the pH scale and means there are an equal amount of H+ and OH- ions. Anything above 7.0 is considered a base (or alkaline). Lower values are more acidic while higher values are more alkaline. The pH scale is logarithmic and consequently, each whole value difference between two readings represents a tenfold difference in acidity. In other words, pH 5 is ten times more acidic than pH 6. While the pH scale is an easy way to report the concentration of H+ ions in a solution, it is also very important in controlling biological and chemical systems. Numerous enzymes only function within a carefully defined narrow pH range. Concentration of

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proton (H+) between the pH 6.5 and 7.5 in the cytoplasm of animal cell increase (more H+) as go to the acidic region and decrease (less H+) as go to the basic region [28].

5.2. NEUTRALIZATION REACTIONS

Do you find it interesting to talk about reactions between acids and bases? In class, more examples of the kind of behavior for different acids and bases are described. Remember that when an acid and base react, they will form a salt.

Neutralization Reactions: A neutralization reaction occurs when an acid and base react to form a salt and water, the kind of reaction that we have described already in the foregoing sections. It is where we combine H+ ions with HO- ions from a base. Many neutralization reactions are the basis of modern technology; they have been known for centuries by the name hydroxide, or "lye" method. The following is a representation of the general form of a neutralization reaction: HX + MOH → MX + H2O [29].

Applications of Neutralization Reactions: Neutralization reactions are common in nature and are used in many technologies. In biological systems, reactions between acids and bases are important in maintaining homeostasis. In medicine, chemical reactions between acidic or basic drugs and H+ and HO- prevent absorption. Acid rain also results from natural substances released in the atmosphere. Ocean pH is determined by the balance between CO2, H2CO3, HCO3- and CO32-. When CO2 dissolves, it forms H2CO3, releasing H+. In industry, many reactions between acids and bases produce a gaseous product, often CO2. Some reactions produce solids in water and liberate heat, as with NH4OH and HCl. Concentrated bases react with animal fats to produce a gelatinous soap scum. Many other neutralization reactions produce useful products in everyday life [30-31].

6. CONCLUSION

The essay offers a detailed review of fundamental concepts and principles of basic chemistry which should be known and understood by pharmacy students of all specialties. Pharmacy students specializing in pharmaceutical analysis can understand and apply instrumental methods simply by studying physics and its applications in analytical chemistry, so the discussion of chemical analysis which involves basic chemistry in principle may not be too important for them. Nevertheless, these principles of basic chemistry are very important for some part of the

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subject of pharmacology, which discusses in vitro drug interactions and some other topics that require basic chemical principles to be known and understood.

Basic chemistry will also have to be carried on in studying other pharmacy subjects such as pharmaceutics inter dosage forms. Some properties of the material and chemicals used in drugs are determined by basic chemical principles. It is not uncommon that students of pharmaceutical analysis fail to make simple dilution solutions because they do not know the basic principles of isotonic solutions. Therefore, introductory core competencies in basic chemistry in pharmaceutical education based on the field of study is very important for students of all specialties in the pharmacy profession. Chemistry is an introduction to chemistry, including mathematics used for approximation, basic chemical quantities, and atomic theory. Chemical bonding, which involves ionic and covalent bonds, receives special attention as these bonds govern the behavior of large molecules such as drugs and ligand-biological receptor complexes. It also discusses basic acid-base theory which will be used to study one of the in vitro drug interactions. In addition, chemical equilibria are necessary to study the rate and order of drug imbibitions dissolution.

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