International Journal of Engineering, Science and Mathematics
Vol. 7 Issue 11, November 2018,
ISSN: 2320-0294 Impact Factor: 6.765
Journal Homepage: **http://www.ijmra.us, Email: ijesmj@gmail.com**
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Chemical Reaction Analysis using Balancing Techniques

Dr. Mamata Tiwari, Associate Professor,
R.R. Government Autonomous College, Alwar

Abstract

A chemical reaction is a transformative procedure where the reactants, which can be chemical elements or compounds, undergo a conversion into new substances known as products. During this process, the arrangement of atoms within the reactants is modified, resulting in the formation of distinct chemical compounds. Chemical reactions play a vital role in various aspects of our lives, including technology, culture, and even the existence of life itself. Throughout the course of history, various activities have relied on chemical reactions as their fundamental processes. Instances of such activities encompass the process of fuel combustion, the iron smelting procedure, the craft of creating glass and pottery, the art of brewing beer, and the practice of producing wine and cheese. These chemical reactions have been engaged in and recognized over countless centuries. It is important to note that chemical reactions are not limited to human endeavors alone; they are widespread in Earth's geology, the atmosphere, the oceans, and the intricate processes within all living systems.It is crucial to distinguish chemical reactions from physical changes. Physical changes involve alterations in the state of matter, such as the transformation of ice into water or water into vapor. A physical change involves modifying the properties of a substance without altering its chemical composition. For instance, regardless of whether water exists as ice, liquid, or vapor, its molecular makeup always consists of two hydrogen atoms and one oxygen atom per molecule (H2O). However, when water, regardless of its physical state, reacts with sodium metal (Na), the atoms will rearrange themselves, leading to the formation of different substances: molecular hydrogen (H2) and sodium hydroxide (NaOH). This process represents a chemical change or reaction taking place.

Historical Perspective

The study of chemical reactions has a rich history spanning approximately 250 years, originating from early experiments that classified substances as elements and compounds and theories aimed at explaining these processes. Understanding chemical reactions has played a crucial role in shaping the modern field of chemistry.

The initial significant investigations in this field primarily focused on gases. The discovery of oxygen during the 18th century by Swedish scientist Carl Wilhelm Scheele and English clergyman Joseph Priestley held great importance. French chemist Antoine-Laurent Lavoisier made notable contributions by emphasizing the importance of quantitative measurements in chemical processes. Lavoisier's work, presented in his book "Traitéélémentaire de chimie" (1789; Elementary Treatise on Chemistry), identified 33 "elements" - substances that cannot be further broken down. One of Lavoisier's significant discoveries was accurately measuring the increase in weight when elements underwent oxidation and attributing it to the combination of the element with oxygen. His writings introduced the concept of chemical reactions involving the combination of elements, inspiring others to pursue experimental chemistry as a quantitative science.

Another crucial milestone in understanding chemical reactions was the development of atomic theory, primarily credited to English chemist John Dalton in the early 19th century. Dalton proposed that matter is composed of small, indivisible particles called atoms, with each element having its unique atoms, and that chemical reactions involve the rearrangement of atoms to form new substances. This perspective on chemical reactions aligns with the current understanding. Dalton's theory laid the groundwork for understanding the findings of earlier researchers, including the law of conservation of matter (which states that matter is neither created nor destroyed) and the law of constant composition (which states that all samples of a substance have identical elemental compositions).

Therefore, through a combination of experimentation and theoretical analysis, the fundamental concepts of chemistry were developed, with chemical reactions at their core. In today's world, practical chemistry provides numerous examples, while theoretical chemistry aids in interpreting and understanding their significance.

Basic Concepts of Chemical Reactions

Synthesis

Chemists use the terms "synthesis" or "synthesizing" to refer to the process of creating a new substance from existing ones. The transformation of starting materials into end products is represented by a chemical equation. For example, when iron (Fe) and sulfur (S) combine, they form iron sulfide (FeS). The chemical equation for this reaction can be expressed as $Fe(s) + S(s) \rightarrow FeS(s)$. In this equation, the plus sign denotes the reaction between iron and sulfur, while the arrow indicates the production or creation of iron sulfide, which is the final product. The physical state of the reactants and products is indicated by symbols such as (s) for solids, (l) for liquids, and (g) for gases.

The Conservation of Matter

In typical laboratory conditions, matter remains unchanged and does not undergo creation or elimination. Furthermore, elements do not transform into different elements. Therefore, it is essential to balance reaction equations to ensure an equal quantity of each type of atom on both sides of the equation. The balanced equation, which illustrates the reaction between iron and sulfur, shows that one iron atom can combine with one sulfur atom to form one unit of iron sulfide.

Chemists commonly manipulate measurable quantities of elements and compounds in their experiments. For example, in the iron-sulfur equation, the symbol Fe represents 55.845 grams of iron, S represents 32.066 grams of sulfur, and FeS corresponds to 87.911 grams of iron sulfide. Since matter is conserved in chemical reactions, the total mass of the reactants is equal to the total mass of the products. If a different amount of iron, such as 5.585 grams (one-tenth of the original amount), is used, the amount of sulfur consumed would also be 3.207 grams (one-tenth of the original amount), and the production of iron sulfide would be 8.791 grams (one-tenth of the original amount) as well. Assuming the initial amount of sulfur is 32.066 grams and it is combined with 5.585 grams of iron, at the end of the reaction, 28.859 grams of sulfur would remain unused.

The chemical equation below demonstrates the reaction between methane (CH4) and molecular oxygen (O2), resulting in the formation of carbon dioxide (CO2) and water (H2O): CH4(g) + 2O2(g) → CO2(g) + 2H2O(l)

Another important aspect of chemical equations becomes evident when considering the numerical coefficients assigned to the different molecules involved. The coefficient "2" before O2 and H2O serves as a stoichiometric factor. (The implied coefficient "1" before CH4 and CO2 signifies their balanced ratio.) This indicates that when one molecule of methane reacts with two molecules of oxygen, it produces one molecule of carbon dioxide and two molecules of water. The equation is considered balanced when an equal number of atoms for each element is present on both sides. In this case, there is one carbon, four hydrogen, and four oxygen atoms on each side.

Drawing a parallel with the iron-sulfur example, we can deduce that if we have 16 grams of methane and 64 grams of oxygen, we will obtain 44 grams of carbon dioxide and 36 grams of water. Consequently, if we start with 80 grams of reactants, we will obtain 80 grams of products.

The ratio between reactants and products in a chemical reaction is referred to as chemical stoichiometry. Stoichiometry is based on the principle of the conservation of matter in chemical processes, and calculations involving mass relationships rely on the concept of the mole. One mole of any element or compound contains the same number of atoms or molecules as one mole of any other element or compound. According to international agreement, one mole of the most common isotope of carbon (carbon-12) has a mass of exactly 12 grams (referred to as molar mass) and represents 6.022140857 × 10^23 atoms (known as Avogadro's number). The molar masses of iron, methane, molecular oxygen, and water are 55.847 grams, 16.043 grams, 31.999 grams, and 18.015 grams, respectively. Each of these masses corresponds to 6.022140857 × 10^23 molecules.

Energy Considerations

Energy plays a vital role in chemical processes. According to our current understanding of chemical reactions, the bonds between atoms in the initial substances need to be broken, and then the atoms or components of molecules are rearranged to form new products by establishing fresh bonds. Breaking bonds requires energy absorption, while forming new bonds releases energy. Some reactions demand more energy to break the bonds than the energy released from forming new bonds, resulting in a net absorption of energy. These reactions are referred to as endothermic, particularly when heat energy is involved. Conversely, exothermic reactions release heat energy. The broader terms "exoergic" (energy released) and "endoergic" (energy required) are used when forms of energy other than heat are involved. Numerous common reactions are exothermic. The formation of compounds from their constituent elements is almost always exothermic. For instance, the creation of water from molecular hydrogen and oxygen, or the formation of calcium oxide (CaO) from calcium metal and oxygen gas. One well-known exothermic reaction is the combustion of fuels, such as the reaction between methane and oxygen. Another instance of an exothermic reaction is the formation of slaked lime (calcium hydroxide, Ca(OH)2) when water is added to lime (CaO): CaO(s) + H2O(l) → Ca(OH)2(s). This phenomenon occurs during the creation of concrete when water is added to dry Portland cement. The mixture produces a noticeable release of heat energy, indicating an exothermic reaction as it becomes warm. However, not all reactions display exothermic characteristics. Certain compounds, like nitric oxide (NO) and hydrazine (N2H4), require an input of energy during their formation from elemental components. Similarly, the conversion of limestone (CaCO3) into lime (CaO) is an endothermic process. To initiate this reaction, limestone must be subjected to high temperatures: CaCO3(s) → CaO(s) + CO2(g). Additionally, the decomposition of water into its elemental constituents through electrolysis is another example of an endothermic process. In this case, electrical energy is used instead of thermal energy to facilitate the reaction: 2 H2O(g) → 2 H2(g) + O2(g). The release of heat during a reaction generally facilitates the conversion of reactants into products. However, the significance of entropy in determining the favorability of a reaction should not be overlooked. Entropy refers to the different ways in which energy can be distributed within a system and acknowledges that not all energy involved in a process can be effectively utilized to perform work. For a chemical reaction to favor the formation of products, the combined changes in entropy of the reaction system and its surroundings must be positive. Let's take the burning of wood as an example. Initially, wood has low entropy, but when it undergoes combustion, it produces ash along with high-entropy substances like carbon dioxide gas and water vapor. As a result, the entropy of the system undergoing the reaction increases during combustion. Furthermore, the heat energy released during combustion increases the entropy in the surroundings. When we consider the total entropy changes for the substances involved in the reaction as well as the surroundings, the overall sum is positive, indicating that the reaction is favorable for product formation. In the case of the reaction between hydrogen and oxygen to form water, the entropy of the resulting products is lower compared to that of the initial reactants. However, this decrease in entropy is compensated by the increase in entropy of the surroundings due to the heat transferred to it by the exothermic reaction. Once again, due to the overall increase in entropy, the combustion of hydrogen promotes the formation of products.

Kinetic Considerations

Chemical reactions usually need an initial energy input to start the process. For example, when wood, paper, or methane burn, they undergo an exothermic reaction. However, to initiate this reaction, a lit match or spark is necessary. The energy needed for the match comes from an exothermic chemical reaction that is triggered by the heat generated when the match is rubbed against a suitable surface.

Ozone Chemistry

Light has the ability to function as an energy source that triggers specific reactions. Many reactions occurring in the Earth's atmosphere are known as photochemical reactions, meaning they are activated by sunlight and driven by solar radiation. One example of such a reaction takes place in the troposphere, where ozone (O3) is converted into oxygen (O2). This process is initiated when ultraviolet light (hν) from the Sun is absorbed. By initiating this reaction, the harmful high-energy radiation is prevented from reaching the Earth's surface.

To facilitate a reaction, it is not sufficient for it to be energetically favorable in terms of the resulting products. The reaction must also occur at an observable rate. Several factors influence reaction rates, including the concentrations of the substances involved, temperature, and the presence of catalysts. The concentration of reactants affects the rate at which the molecules involved in the reaction collide, which is a crucial prerequisite for any reaction to occur. Temperature is another important factor since reactions only happen when the collisions between reactant molecules possess enough energy. The temperature is directly proportional to the proportion of molecules with sufficient energy to undergo the reaction. On the other hand, catalysts influence reaction rates by providing an alternative, lower energy pathway for the reaction to proceed. Common catalysts include precious metal compounds found in automotive exhaust systems, which expedite the conversion of pollutants like nitrogen dioxide into harmless nitrogen and oxygen. Moreover, there are various biochemical catalysts, such as chlorophyll in plants, which facilitate the conversion of atmospheric carbon dioxide into complex organic molecules like glucose. Enzymes, a type of biochemical catalyst, play a vital role in numerous reactions within living organisms. For example, the enzyme pepsin aids in the breakdown of large protein molecules during the digestionprocess.

Classification by Type of Product

Gas-Forming Reactions

Different gases, including carbon dioxide, hydrogen sulfide (H2S), ammonia (NH3), and sulfur dioxide (SO2), are formed through various chemical processes. One specific reaction that results in the production of a gas occurs when hydrochloric acid (HCl) reacts with a metal carbonate, such as calcium carbonate (CaCO3), which is commonly found in limestone, seashells, and marble. This particular reaction specifically generates carbon dioxide, along with other substances. The balanced equation representing this reaction is: CaCO3(s) + 2 HCl(aq) → CaCl2(aq) + CO2(g) + H2O(l). The notation (aq) in the equation signifies that the compound is dissolved in an aqueous or water-based solution.

Bread Dough Rising

The process of cake batter rising is a result of a chemical reaction that involves an acid and baking soda, also known as sodium hydrogen carbonate (NaHCO3). The acid commonly used in this process is tartaric acid (C4H6O6), which can be found in various food items. The reaction can be represented as follows: C4H6O6(aq) + NaHCO3(aq) → NaC4H5O6(aq) + H2O(l) +

CO2(g). In this equation, NaC4H5O6 represents sodium tartrate. Baking powders typically contain both tartaric acid and sodium hydrogen carbonate, with a starch filler separating them. When the moist batter combines with baking powder, the acid and sodium hydrogen carbonate dissolve to some extent, enabling them to undergo a reaction. This reaction produces carbon dioxide, which causes the batter to rise.

Precipitation Reactions

Sometimes, when you mix two solutions containing specific positively charged ions (cations) and specific negatively charged ions (anions), it is possible for a solid compound to be created, which is called a precipitate. Certain compounds that contain anions like sulfide (S2-), hydroxide (OH-), carbonate (CO32-), and phosphate (PO43-) have low solubility and remain insoluble in water. When a solution containing any of these anions is mixed with a solution containing a metal cation such as Fe2+, Cu2+, or Al3+, a precipitate is formed. For example, when Fe2+(aq) reacts with 2 OH-(aq), it produces Fe(OH)2(s). Similarly, the reaction between Al3+(aq) and PO43-(aq) results in the formation of AlPO4(s). Natural precipitation reactions play a significant role in the creation of minerals, which are compounds that do not dissolve in water. This phenomenon can be observed in various situations, including the formation of metal sulfides in undersea vents known as "black smokers."

Classification by Types of Reactants

There are two specific categories of reactions that involve the transfer of charged substances. Oxidation-reduction reactions occur when there is an exchange of electrons between the substances involved. Conversely, in aqueous acid-base reactions, a transfer of a proton (H+) happens from an acid to a base.

Oxidation-Reduction Reactions

Redox reactions, also known as oxidation-reduction reactions, involve the exchange of electrons between a reducing agent and an oxidizing agent. This electron transfer leads to a decrease in the electric charge of an atom in the substance being reduced and an increase in the electric charge of an atom in the substance being oxidized. When elements interact with oxygen, simple redox reactions can be observed. For example, the combination of magnesium and oxygen results in combustion, forming magnesium oxide (MgO). The resulting product is an ionic compound consisting of Mg2+ and O2- ions. In this reaction, each magnesium atom loses two electrons, undergoing oxidation, while each oxygen atom gains two electrons, undergoing reduction.

Liquid: Effects of Chemical Interactions

An often observed chemical reaction involving the transfer of electrons, known as redox reaction, occurs when iron comes into contact with moisture in the atmosphere. This reaction leads to the formation of rust. During this process, the iron metal (Fe) undergoes oxidation and is converted into iron dihydroxide (Fe(OH)2). The oxidizing agent responsible for this reaction is molecular oxygen (O2).

Redox reactions play a crucial role in the functioning of batteries. The production of electric current in a battery is achieved by the movement of electrons from a substance that undergoes reduction (reducing agent) to a substance that undergoes oxidation (oxidizing agent) through an external circuit. In dry cells and alkaline batteries, zinc atoms release two electrons to the oxidizing agent, resulting in the transformation of zinc metal into Zn2+ ions. Dry-cell batteries, commonly used in flashlights, transfer the released electrons from zinc to ammonium ions (NH4+) present in the battery, typically in the form of ammonium chloride (NH4Cl). On the other hand, alkaline batteries used in calculators and watches transfer electrons to a metal oxide, such as silver oxide (AgO), which is reduced to silver metal during the process.

Acid-Base Reactions

One commonly observed chemical reaction involves the interaction between iron and moisture in the atmosphere, leading to the formation of rust. This reaction involves the oxidation of iron metal (Fe) and its conversion into iron dihydroxide (Fe(OH)2). Molecular oxygen (O2) acts as the oxidizing agent responsible for this reaction.

Redox reactions are crucial for the operation of batteries. The production of electric current in a battery occurs when electrons are transferred from a reducing agent to an oxidizing agent through the external circuit. In dry cells and alkaline batteries, zinc atoms release two electrons to the oxidizing agent, causing the transformation of zinc metal into Zn^{2+} ions. Dry-cell batteries, commonly used in flashlights, transfer the released electrons from zinc to ammonium ions (NH_4^+) present in the battery, often in the form of ammonium chloride (NH_4Cl). On the other hand, alkaline batteries used in calculators and watches transfer electrons to a metal oxide, such as silver oxide (AgO), which undergoes reduction to form silver metal during the process.

The Arrhenius Theory

The Arrhenius theory, developed by Svante August Arrhenius, provides an explanation for acids and bases. According to this theory, acids cause an increase in the concentration of hydronium ions (H_3O^+) in a water-based solution, while bases increase the concentration of hydroxide ions (OH^-). Examples of common acids include hydrochloric acid (HCl), sulfuric acid (H_2SO_4), nitric acid (HNO_3), and acetic acid (CH_3COOH). Bases include sodium hydroxide (NaOH) and calcium hydroxide ($Ca(OH)_2$). Another well-known base is ammonia (NH_3), which reacts with water to produce a basic solution: $NH_3(aq) + H_2O(l) \rightarrow NH_4^+(aq) + OH^-(aq)$ (It's important to note that this reaction occurs to a limited extent, resulting in a small but detectable concentration of hydroxide ions). There are various natural bases such as morphine, cocaine, nicotine, and caffeine. Additionally, many synthetic drugs exhibit basic properties. These compounds contain a nitrogen atom bonded to three other groups and behave similarly to ammonia as they can react with water to form a solution containing the hydroxide ion. Amino acids, which are highly significant compounds, can act as both acids and bases. Amino acid molecules consist of acidic groups (—COOH) and basic sites (—NH_2). When amino acids are present in an aqueous solution, they exist in two forms: the molecular form and the zwitterionic form, represented as $H_3N^+CH_2CO_2^-$. In this structure, the nitrogen atom carries a positive charge, while the oxygen atom of the acid group carries a negative charge. According to the Arrhenius theory, acid-base reactions occur when hydrogen ions (H^+) and hydroxide ions combine, resulting in the formation of water. An example of this concept is the reaction between hydrochloric acid and sodium hydroxide solutions in an aqueous environment: $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$.

The Brønsted-Lowry theory

The Brønsted-Lowry theory, formulated by Johannes Nicolaus Brønsted and Thomas Martin Lowry, offers a comprehensive explanation of acid-base reactions. According to this theory, an acid is characterized as a substance that donates a proton, while a base is a substance that accepts a proton. The interaction between an acid and a base is represented by a reversible reaction:

acid (1) + base (2) ⇌ base (1) + acid (2)

The double arrows (⇌) indicate that the reactants can convert back into the products and vice versa, illustrating a dynamic process. Conjugate acid-base pairs are formed, such as acid (1) and base (1), as well as acid (2) and base (2). One of the advantages of the Brønsted-Lowry theory is its predictive nature. The direction of the equilibrium, whether favoring the reactants or products, depends on the relative strengths of the acids and bases involved.

This theory is commonly applied in the context of water as a solvent. When an acid dissolves in water, an acid-base reaction takes place, resulting in the creation of the hydronium ion and the corresponding acid anion. The classification of acids as strong or weak is determined by whether the equilibrium favors the reactants or the products. For instance, hydrochloric acid, classified as a strong acid, completely ionizes in water, leading to the production of hydronium and chloride ions in a reaction that favors the products:

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

By employing the Brønsted-Lowry theory, the reaction between ammonia and hydrochloric acid in water can be represented as: $NH_3(aq) + HCl(aq) \rightarrow NH_4^+(aq) + Cl^-(aq)$

In this equation, hydrochloric acid and the chloride ion form one conjugate acid-base pair, while the ammonium ion and ammonia constitute the other pair. The acid-base reaction involves the transfer of a hydrogen ion from the acid (HCl) to the base (NH_3). The equilibrium favors the weaker acid and base, resulting in the formation of the products. It is worth noting that the hydroxide ion is not included in this equation, emphasizing a distinction between the Arrhenius and Brønsted-Lowry theories.

The Lewis Theory

Gilbert Newton Lewis, a highly respected physical chemist from the United States, presented a thorough explanation of acids and bases. Lewis proposed that bases are substances that generously offer pairs of electrons, while acids are substances that readily accept pairs of electrons. In the context of acid-base reactions, the interaction between a Lewis acid and base entails the mutual sharing of the electron pair belonging to the base.

Ammonia Boron Trifluoride Formation

Ammonia is widely recognized as a Lewis base due to its nitrogen atom possessing a pair of electrons that can create a chemical bond with a Lewis acid like boron trifluoride (BF3). This interaction can be expressed using the equation: H3N: + BF3 → H3N— BF3.

Coordination compounds, a specific class of substances, are produced when various Lewis bases, such as ammonia and water, interact with metal ions. This reaction exemplifies another instance of a Lewis acid-base reaction. For instance, when copper ions (Cu2+) dissolve in water, the resulting solution takes on a light blue hue because of the presence of the [Cu(H2O)6]2+ ion. However, the introduction of ammonia to this solution replaces the water molecules bonded to the copper ions with ammonia molecules, resulting in the formation of the fascinating deep blue [Cu(NH3)4]2+ ion.

Classification by Reaction Outcome

Chemists often classify reactions according to their overall results. Different reactions that are frequently observed are grouped into classes. It is important to mention that many reactions cannot be exclusively assigned to a single category and may actually belong to multiple categories.

Decomposition Reactions

Decomposition reactions involve the breakdown of chemical substances into simpler components. Typically, these reactions require the addition of energy. For instance, a commonly used method in laboratories to produce oxygen gas is by heating potassium chlorate ($KClO3$), causing it to decompose. This reaction can be written as: $2KClO3(s) \rightarrow 2KCl(s) + 3O2(g)$.

Another example of a decomposition reaction occurs when molten sodium chloride (NaCl) is electrolyzed at high temperatures, resulting in the formation of sodium (Na) and chlorine ($Cl2$): $2NaCl(l) \rightarrow 2Na(l) + Cl2(g)$.

An important historical decomposition reaction involves the breakdown of mercury oxide (HgO) into mercury metal (Hg) and oxygen gas through the application of heat. This reaction played a significant role in the pioneering investigations on oxygen conducted by chemists like Carl Wilhelm Scheele, Joseph Priestley, and Antoine-Laurent Lavoisier in the 18th century. The reaction can be represented as: $2HgO(s) \rightarrow 2Hg(l) + O2(g)$.

Substitution, Elimination, and Addition Reactions

Chloromethane Production

The following principles are extremely valuable for elucidating organic reactions, specifically substitution reactions. Substitution reactions involve the exchange of a particular atom or a group of atoms within a compound with another atom or group of atoms. For example, when chlorine ($Cl2$) reacts with methane ($CH4$), it produces chloromethane ($CH3Cl$), which is widely employed as a local anesthetic. In this particular reaction, a chlorine atom replaces a hydrogen atom.

Tetrafluoroethylene Production

Substitution reactions play a crucial role in the field of industrial chemistry. A notable instance involves the transformation of chloroform ($CHCl3$) by replacing two chlorine atoms with fluorine atoms, resulting in the creation of chlorodifluoromethane ($CHClF2$). Under high temperatures, chlorodifluoromethane undergoes a subsequent reaction: $2CHClF2(g) \rightarrow F2C{=}CF2(g) + 2HCl(g)$. This reaction exemplifies an elimination process where a hydrogen atom and a chlorine atom are eliminated from the original compound, resulting in the formation of hydrochloric acid (HCl). Moreover, as a byproduct of this reaction, tetrafluoroethylene is generated, which serves as a precursor to the widely recognized commercial polymer known as Teflon.

Ethanol Production

Addition reactions and elimination reactions display distinct characteristics. In the context of addition reactions, one molecule joins another molecule. An example of this is the commonly used method of producing ethanol ($CH3CH2OH$) in industrial environments. In the past, ethanol was primarily generated through fermentation. However, a viable alternative has emerged since the 1970s, which involves adding water to ethylene. This process leads to the creation of ethanol, as shown in the equation: $C2H4 + H2O \rightarrow CH3CH2OH$.

Polymerization Reactions

Polymers are large chemical compounds composed of smaller units called monomers. They have a significant impact on society and are utilized in various fields such as plastics and a wide range of natural and synthetic fibers used in clothing. The formation of polymers occurs through two main methods: (a) addition reactions, which involve connecting small molecules together, and (b) condensation reactions, where two molecules, potentially of different types, combine and release a stable small molecule like water. Condensation reactions involve both addition and elimination processes.

For example, polyethylene is produced through the first type of reaction, in which multiple ethylene molecules combine: $nH2C{=}CH2 \rightarrow [—CH2CH2—]n$. Other instances of addition polymers include polypropylene (formed by polymerizing $H2C{=}CHCH3$), polystyrene (derived from $H2C{=}CHC6H5$), and polyvinyl chloride (obtained from $H2C{=}CHCl$).

Starch and cellulose serve as examples of the second type of polymers and belong to the carbohydrate group of compounds. Their formulas are multiples of the simple formula $CH2O$. Both starch and cellulose consist of glucose polymers, which is a sugar represented by the formula $C6H12O6$. In both starch and cellulose, glucose molecules link together, resulting in the release of a water molecule for each bond formed: $nC6H12O6 \rightarrow —[—C6H10O5—]—n + nH2O$.

Nylon Formation

Nylon, a remarkable synthetic substance, is produced through the combination of an organic acid with an amine, a derivative compound of ammonia. This chemical process leads to the development of nylon-6,6 while water is released as a byproduct.

Condensation Reaction

Natural fibers found in proteins, including hair, wool, and silk, consist of polymers made up of repeating units (-CHRCONH-), where R denotes a group of atoms bonded to the primary polymer. The process of fiber formation entails the bonding of amino acids and the elimination of a water molecule for every CONH or peptide bond created. To illustrate, a tripeptide chain is formed by linking three glycine amino acid units (NH2CH2CO2H) together.

Solvolysis and Hydrolysis

A solvolysis process involves a chemical reaction in which the solvent plays an active role. These reactions are commonly named based on the specific solvent employed. For instance, if water is utilized as the solvent, the reaction is referred to as hydrolysis. Let's examine a compound denoted as AB, where A and B represent atoms or groups of atoms, and water is represented as HOH. The hydrolysis reaction can be symbolized by a reversible equation: $AB + HOH \rightleftharpoons AH + BOH$.

Hydrolysis of an Ester

Hydrolysis refers to the breakdown of organic compounds through a reaction involving water and esters. Esters can be represented by the general formula RCOOR', where R and R' are combining groups like CH3. When esters undergo hydrolysis, they produce an acid and an alcohol. The specific reaction between methyl acetate and water can be expressed as follows: $CH3COOCH3(aq) + H2O(l) \rightarrow CH3COOH(aq) + CH3OH(aq)$.

Hydrolysis reactions play crucial roles in various chemical processes occurring in living organisms. For instance, proteins are broken down into amino acids, fats are converted into fatty acids and glycerol, and complex sugars and starches are transformed into simple sugars. These hydrolysis processes are often facilitated and accelerated by enzymes, which act as biological catalysts. Moreover, hydrolysis reactions are closely associated with acid-base behavior. Anions of weak acids dissolve in water, leading to the formation of basic solutions. This can be observed in the hydrolysis of the acetate ion, CH3COO−: CH3COO−(aq) + H2O (l) → CH3COOH(aq) + OH−(aq). Although this reaction generally favors the presence of reactants, it occurs to a sufficient extent to produce a solution containing the acetate ion with basic properties, such as the ability to turn red litmus paper blue. Hydrolysis reactions contribute to the alkaline nature of many common substances. For instance, salts containing borate, phosphate, and carbonate ions generate basic solutions that have long been utilized for cleaning purposes. Additionally, basic anions like tartrate and citrate ions are found in numerous food products.

Classification by Reaction Mechanism

Reaction mechanisms provide valuable information about how atoms rearrange and restructure when reactants are transformed into products. The specific terminology used to describe these processes depends on the governing mechanisms of chain reactions and photolysis reactions.

Chain Reactions

Chain reactions progress through a sequence of consecutive stages, where the outcome of each stage acts as a catalyst for the next stage. Typically, chain reactions consist of three main phases: an initial stage that triggers the reaction, a series of steps that propagate the chain, and finally, a termination stage.

An example of a chain reaction can be observed in polymerization reactions like the synthesis of Teflon from tetrafluoroethylene. In this specific reaction, a peroxide acts as an initiator. Peroxides have the ability to produce highly reactive free-radical species with unpaired electrons, which kickstart the reaction. There are various methods available to stop the chain, but we will focus on one particular approach. (In the following equations, dots indicate unpaired electrons, and R represents a generic organic group.)

Decomposition of a peroxide into radicals: ROOR → 2 RO·

Chain initiation: RO· + F2C=CF2 → ROCF2CF2·

Steps for chain propagation: ROCF2CF2· + F2C=CF2 → ROCF2CF2CF2CF2·ROCF2CF2CF2CF2· + (n−2)F2C=CF2 → RO—(CF2CF2·)n—

A possible chain termination step: RO—(CF2CF2·)n— + ·OR → RO(CF2CF2)nOR

Photolysis Reactions

Photolysis reactions take place when electromagnetic radiation is absorbed, initiating or sustaining the reactions. As previously mentioned in the section on Kinetic considerations, an example of such a reaction is the breakdown of ozone into oxygen in the Earth's atmosphere. Another instance involves the formation of chloromethane from methane and chlorine, which is triggered by the presence of light. The overall equation for this reaction can be represented as: CH4(g) + Cl2(g) + hʋ → CH3Cl(g) + HCl(g), where hʋ denotes light. It is important to note that this reaction is also categorized as a chain reaction. The process begins with the absorption of ultraviolet radiation by a chlorine molecule (Cl2), resulting in the creation of chlorine atoms. Some of these chlorine atoms recombine to form chlorine molecules, while others do not. When a chlorine atom collides with a methane molecule, a two-step chain propagation occurs. The initial propagation step yields the methyl radical (CH3), which then reacts with a chlorine molecule to produce the desired product along with a chlorine atom. This chlorine atom then continues the chain reaction, leading to multiple subsequent steps. Termination steps may involve the combination of two methyl radicals to form ethane (CH3CH3) or the combination of a methyl radical and a chlorine radical to produce chloromethane.

References

1. Risteski, I.B. (2012) New Very Hard Problems of Balancing Chemical Reactions. Bulgarian Journal of Science Education, 21, 574-580.
2. Risteski, I.B. (2014) A New Generalized Algebra for the Balancing of Chemical Reactions. Materials and Technology, 48, 215-219.
3. Vishwambharrao, K.R., et al. (2013) Balancing Chemical Equations by Using Mathematical Model. International Journal of Mathematical Research and Science, 1, 129-132.
4. Larson, R. (2017) Elementary Linear Algebra. 8th Edition, CENGAGE Learning, the Pennsylvania State University, State College, 4.
5. Charnock, N.L. (2016) Teaching Method for Balancing Chemical Equations: An Inspection versus an Algebraic Approach. American Journal of Educational Research, 4, 507-511.
6. Risteski, I.B. (2009) A New Singular Matrix Method for Balancing Chemical Equations and Their Stability. Journal of the Chinese Chemical Society, 56, 65-79.