About the Book

Welcome to "Environmental Chemistry," a thorough examination of the intricate relationship between chemical processes and the environment. This book explores the fundamental principles, applications, and implications of environmental chemistry, offering insights into the dynamic interplay between human activities and the natural world.

In the opening chapter, "Fundamentals of Environmental Chemistry," readers establish a foundation for understanding environmental systems, including pollutant sources, reactions, and fates.

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Arun Sharma is currently serving as Associate Professor in the department of chemistry at Career Point University, Kota (Rajasthan). His fields of research are electrochemistry, material science, immunosensors, quantum dots and warfare agents. He obtained his Ph.D. in Chemistry from Jiwaji University Gwalior (NAAC A++), in 2016.

Dr. Erum Gull Naz is a famous researcher in theoretical and computational chemistry, specializing in chemical reaction dynamics, rate constants, thermodynamics, and kinetics. She earned her Ph.D. at the prominent Indian Institute of Technology (IIT) in Jodhpur, Rajasthan. Her study also includes organo-physical chemistry and interstellar chemistry, which investigate basic processes that occur on Earth and beyond.

Surabhi Singh, a visionary leader having exemplary research, academic, & administrative experience in the field of Higher Education, obtained her Ph.D. in Environmental Chemistry from Career Point University, Kota (Rajasthan). Currently, she is serving as Associate Professor cum Head of Department of School of Basic and Applied Sciences at Career Point University, Kota (Rajasthan).

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Ms. Insha Ara, a researcher in theoretical and analytical chemistry, specializing in organic chemistry. She earned her Master of Science at the prominent Career point University in Kota , Raj where she studied many aspects of chemical processes, such as their Analytical and practical and get a Gold medalist in academics and got many certificates in academic

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Preface

Welcome to "Environmental Chemistry," a thorough examination of the intricate relationship between chemical processes and the environment. This book explores the fundamental principles, applications, and implications of environmental chemistry, offering insights into the dynamic interplay between human activities and the natural world.

In the opening chapter, "Fundamentals of Environmental Chemistry," readers establish a foundation for understanding environmental systems, including pollutant sources, reactions, and fates.

Chapter 2, "The Impact of Various Environmental Pollutants on the Earth's Atmosphere," illuminates diverse pollutants affecting air quality and climate dynamics.

"Thermodynamic Principles and Applications in Engineering," Chapter 3, explores thermodynamics' role in environmental processes and engineering solutions, emphasizing energy considerations in sustainability efforts.

Chapter 4, "Biochemical Kinetics: Exploring Gibbs Free Energy and Enzyme Catalysis," focuses on biological transformations' mechanisms and relevance to environmental systems.

Chapters 5 through 8 delve into atmospheric chemistry, examining processes leading to inorganic and organic particulate matter formation, thermochemical and photochemical reactions, and their implications for atmospheric composition and climate change.

Chapter 9, "Green Chemistry for Water: Sustainable Solutions to Pollution," addresses the nexus between chemistry and water quality, proposing innovative approaches for mitigating pollution and promoting sustainable water management.

Lastly, Chapter 10, "Soil Chemistry," explores chemical dynamics within terrestrial ecosystems, including soil pollution, nutrient cycling, and human activities' impact on soil health.This multidisciplinary journey deepens our understanding of environmental chemistry's role in addressing contemporary challenges and fostering sustainable solutions for our planet's well-being.

We extend our heartfelt thanks to Pramod Maheshwari, Sir, Managing Director and Chairman of Career Point University, Kota, as well as the HOD and Dean for their inspiration and support during the book's development. Gratitude is also expressed to our families for their constant encouragement, and to students and the teaching community for their support. Suggestions to improve the book's quality are welcomed.

Dr. Arun Sharma

Dr. Erum Gull Naz

Dr. Surabhi Singh

Ms. Kriti Tripathi

Ms. Insha Ara

Environmental Chemistry

Syllabus

Unit-I (Dr. Arun)

Stoichiometry, Gibb's energy, Chemical potential, Chemical equilibria, acid-base. reactions Solubility product, solubility of gases in water, the carbonate system, unsaturated and saturated hydrocarbons, Radio nuclides.

Unit -II (Dr. Surabhi)

Classification of elements, chemical speciation, Particles, ions and radicals in the atmosphere. Chemical processes for formation of inorganic and organic particulate matter. Thermochemical and photochemical reactions in the atmosphere

Unit - III (Dr. Erum)

First law of thermodynamics, enthalpy, adiabatic transformations, second law of thermodynamics, Carnot's cycle, entropy.

Unit - IV (Dr. Erum)

Gibbs free energy, chemical potential, phase equilibria, Gibbs Donnan equilibrium, third law of thermodynamics, enzymes catalysis, Michaelis/Menten equation.

Unit - V (Ms. Kriti Tripathi)

Oxygen and ozone chemistry, Chemistry of air pollutants, Photochemical Smog, Chemistry of water, concept of D.O., B.O.D., and C.O.D, water treatment : Sedimentation, Coagulation, Filtration, tertiary and advanced treatment, redox potential. Inorganic and organic components of soil, nitrogen pathways and NPK in soils.

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Dr. Arun Sharma, Dr. Erum Gull Naz

Dr. Surabhi Singh and Ms. Kriti Tripathi

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CHAPTER 1

Fundamentals of Environmental Chemistry

Dr. Arun Sharma

ABSTRACT

Environmental chemistry is a multidisciplinary field that explores the chemical processes and interactions occurring in the environment. This includes the study of natural processes, such as the biogeochemical cycles of elements, as well as the impact of human activities on the environment, such as pollution and climate change. The field of environmental chemistry is crucial for understanding and addressing environmental issues, such as air and water pollution, soil contamination, and the depletion of natural resources. The fundamentals of environmental chemistry encompass a range of topics, including the composition and structure of the Earth's atmosphere, hydrosphere, and lithosphere, as well as the chemical reactions and transformations that occur within these systems. This includes the study of the sources, fate, and transport of pollutants in the environment, as well as the development of strategies for mitigating and remediating environmental pollution. Key concepts in environmental chemistry include the principles of chemical equilibrium, thermodynamics, and kinetics, as well as the application of analytical techniques for the detection and quantification of pollutants. Additionally, the field of environmental chemistry is closely linked to other disciplines, such as biology, geology, and engineering, and requires a multidisciplinary approach to address complex environmental issues.

Overall, the fundamentals of environmental chemistry are essential for understanding the chemical processes that govern the environment and for developing sustainable solutions to environmental problems.

Content-

1. Introduction

Environmental chemistry is a multidisciplinary field that explores the chemical processes and interactions occurring in the environment. It encompasses the study of natural processes, such as the biogeochemical cycles of elements, as well as the impact of human activities on the environment, such as pollution and climate change. The field of environmental chemistry is crucial for understanding and addressing environmental issues, such as air and water pollution, soil contamination, and the depletion of natural resources [1].

The Earth's environment is a complex system composed of the atmosphere, hydrosphere, lithosphere, and biosphere. Each of these components interacts with one another through various chemical processes, which are influenced by both natural and anthropogenic factors. For example,

the atmosphere is composed of a mixture of gases, including nitrogen, oxygen, and carbon dioxide, which play a crucial role in regulating the Earth's climate and supporting life. However, human activities, such as the burning of fossil fuels and deforestation, have led to an increase in greenhouse gas concentrations, resulting in global warming and climate change [2].

Similarly, the hydrosphere, which includes oceans, rivers, lakes, and groundwater, is essential for supporting life on Earth. However, pollution from industrial and agricultural activities, as well as urbanization, has led to the contamination of water bodies with toxic chemicals, heavy metals, and pathogens, posing a threat to human health and ecosystems [3].

The lithosphere, which includes the Earth's crust and upper mantle, is also affected by human activities, such as mining, deforestation, and urbanization. These activities can lead to soil erosion, loss of biodiversity, and the release of pollutants into the environment, further exacerbating environmental problems. The biosphere, which includes all living organisms on Earth, is also impacted by environmental chemistry. For example, pollutants can accumulate in the tissues of plants and animals, leading to bioaccumulation and biomagnification in food chains. Additionally, changes in the environment, such as deforestation and habitat destruction, can lead to the loss of biodiversity and the extinction of species [4].

Key concepts in environmental chemistry include the principles of chemical equilibrium, thermodynamics, and kinetics, as well as the application of analytical techniques for the detection and quantification of pollutants. Additionally, the field of environmental chemistry is closely linked to other disciplines, such as biology, geology, and engineering, and requires a multidisciplinary approach to address complex environmental issues. Overall, the fundamentals of environmental chemistry are essential for understanding the chemical processes that govern the environment and for developing sustainable solutions to environmental problems .

2. Terminology of Environmental Chemistry

Terminology in environmental chemistry refers to the specialized language and vocabulary used to describe the chemical processes, interactions, and phenomena that occur in the environment. This includes terms related to the composition and structure of the Earth's atmosphere, hydrosphere, and lithosphere, as well as the sources, fate, and transport of pollutants in the environment [5]. Key terms in environmental chemistry include greenhouse gases, acid rain, ozone depletion, and eutrophication. Understanding and using this terminology is essential for effectively communicating and addressing environmental issues and for developing sustainable solutions to environmental problems.

a) Stoichiometry

Stoichiometry is a fundamental concept in chemistry that deals with the quantitative relationships between reactants and products in chemical reactions. It is based on the law of conservation of mass, which states that matter cannot be created or destroyed in a chemical reaction, only rearranged. Stoichiometry allows chemists to predict the amount of product that will be formed in a reaction, given the amount of reactants present, and vice versa.

The stoichiometric coefficients in a balanced chemical equation represent the relative amounts of reactants and products in a reaction. For example, in the reaction $2H2 + O2 \rightarrow 2H2O$, the

stoichiometric coefficients are 2, 1, and 2, respectively. This means that two molecules of hydrogen react with one molecule of oxygen to produce two molecules of water.

Stoichiometry can be used to calculate the amount of product that will be formed in a reaction, given the amount of reactants present, or to determine the amount of reactant that is needed to produce a certain amount of product. This is done using stoichiometric calculations, which involve converting between moles of reactants and products using the stoichiometric coefficients in the balanced chemical equation [6]. Stoichiometry is an essential tool for chemists in the laboratory, as it allows them to accurately predict and control the outcome of chemical reactions. It is also used in industry to optimize chemical processes and minimize waste.

b) Gibb's Energy

Gibbs energy, also known as Gibbs free energy or Gibbs function, is a thermodynamic quantity that represents the maximum amount of reversible work that can be performed by a system at constant temperature and pressure. It is named after the American physicist Josiah Willard Gibbs, who introduced the concept in the late 19th century.

Gibbs energy is defined as the difference between the enthalpy (H) and the product of the temperature (T) and the entropy (S) of a system:

$$G = H - TS$$

where G is the Gibbs energy, H is the enthalpy, T is the temperature, and S is the entropy.

The Gibbs energy is a measure of the spontaneity of a chemical reaction or physical process. If the Gibbs energy of a reaction is negative, the reaction is spontaneous and can occur without the input of external energy. If the Gibbs energy is positive, the reaction is nonspontaneous and requires the input of external energy to occur [7].

The Gibbs energy is also used to calculate the equilibrium constant (K) for a reaction:

$K = e^{(-\Delta G/RT)}$

where ΔG is the change in Gibbs energy, R is the gas constant, and T is the temperature in Kelvin. Overall, Gibbs energy is a fundamental concept in thermodynamics that is used to predict and understand the behavior of chemical reactions and physical processes.

c) Chemical Potential:

Chemical potential is a thermodynamic quantity that represents the tendency of a substance to undergo a chemical reaction or phase change. It is defined as the partial molar free energy of a substance in a mixture, and it is related to the Gibbs energy by the equation:

$\mu = \partial G/\partial n$

where μ is the chemical potential, G is the Gibbs energy, and n is the number of moles of the substance. Chemical potential is a measure of the driving force for a chemical reaction or phase change. If the chemical potential of a substance is higher in one phase than in another, the substance will tend to move from the phase with higher chemical potential to the phase with lower chemical potential, until equilibrium is reached [8].

d) Chemical Equilibria

Chemical equilibrium is a state in which the rates of the forward and reverse reactions in a chemical reaction are equal, and the concentrations of reactants and products remain constant over time. It is a dynamic process in which reactants are continuously being converted into products and vice versa, but the overall concentrations of reactants and products do not change.

Chemical equilibrium is governed by the equilibrium constant (K), which is the ratio of the concentrations of products to reactants at equilibrium. The value of K depends on the temperature and pressure of the system, and it can be used to predict the direction in which a reaction will proceed to reach equilibrium.

e) Acid-Base Reactions

Acid-base reactions are chemical reactions that involve the transfer of a proton (H+) from an acid to a base. Acids are substances that can donate a proton, while bases are substances that can accept a proton. When an acid and a base react, they form salt and water. The strength of an acid or base is determined by its ability to donate or accept a proton, respectively. Strong acids and bases completely dissociate in water, while weak acids and bases only partially dissociate. Acid-base reactions play a crucial role in many biological processes, as well as in industrial and environmental chemistry [9] .

3. Some Basic Aspects of Environmental Chemistry

Basic aspects of environmental chemistry include the study of natural processes, such as the biogeochemical cycles of elements, and the impact of human activities on the environment, such as pollution and climate change. It also involves the development of strategies for mitigating and remediating environmental pollution.

a) Solubility

Solubility is a measure of the ability of a substance to dissolve in a solvent. It is typically expressed as the maximum amount of solute that can dissolve in a given amount of solvent at a specified temperature and pressure [10]. The solubility of a substance depends on several factors, including the nature of the solute and solvent, the temperature and pressure of the system, and the presence of other solutes.

The solubility of a substance can be determined experimentally by measuring the concentration of the solute in the solvent at equilibrium. The solubility of a substance can also be predicted using solubility rules, which are based on the chemical properties of the solute and solvent. Solubility is an important concept in chemistry, as it determines the extent to which a substance can be dissolved in a solvent and the conditions under which it will dissolve. Solubility is also important in many industrial processes, such as the production of pharmaceuticals, food and beverage processing, and the extraction of minerals from ores.

Overall, solubility is a fundamental concept in chemistry that plays a crucial role in many chemical processes and applications.

b) Solubility Product

Solubility product (Ksp) is a thermodynamic quantity that represents the equilibrium constant for the dissolution of a sparingly soluble salt in water [11]. It is defined as the product of the concentrations of the ions in solution, each raised to the power of its stoichiometric coefficient in the balanced chemical equation for the dissolution reaction. For example, for the dissolution of the salt MX in water, the solubility product is given by:

$Ksp = [M+]^m [X-]^n$

where [M+] and [X-] are the concentrations of the cation and anion, respectively, and m and n are the stoichiometric coefficients for the cation and anion in the balanced chemical equation.

The solubility product is a measure of the extent to which a salt will dissolve in water. If the solubility product is greater than the concentration of the ions in solution, the salt will dissolve completely. If the solubility product is less than the concentration of the ions in solution, the salt will precipitate out of solution. The solubility product is an important concept in chemistry, as it allows chemists to predict the solubility of a salt in water and to determine the conditions under which a salt will dissolve or precipitate. It is also used in many industrial processes, such as the production of pharmaceuticals, food and beverage processing, and the extraction of minerals from ores.

c) Solubility of Environmental Gases In Water

The solubility of environmental gases in water is a critical aspect of environmental chemistry, as it influences the transport, fate, and impact of gases in aquatic ecosystems. Gases can dissolve in water through physical and chemical processes, and the solubility of a gas in water depends on several factors, including the nature of the gas and the water, the temperature and pressure of the system, and the presence of other solutes [12].

The solubility of a gas in water is typically expressed as the concentration of the gas in the water, usually in units of moles per liter (M). The solubility of a gas in water can be determined experimentally using a variety of methods, such as gas chromatography or Henry's law. The solubility of environmental gases in water is an important consideration in many environmental processes, such as the exchange of gases between the atmosphere and the ocean, the transport of gases in rivers and lakes, and the fate of gases in groundwater. It also plays a crucial role in the impact of gases on aquatic ecosystems, as the solubility of a gas in water determines its availability to aquatic organisms and its potential to cause harm. Overall, the solubility of environmental gases in water is a complex and important aspect of environmental chemistry that influences the behavior and impact of gases in aquatic ecosystems. [13]

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