

### 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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# ENVIRONMENTAL CHEMISTRY



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# **ENVIRONMENTAL CHEMISTRY**

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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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## Chemical Processes for the Formation of Inorganic and Organic Particulate Matter in Atmosphere

Dr. Surabhi Singh & Insha Ara

### ABSTRACT

This abstract explores the intricate chemical processes responsible for the formation of inorganic and organic particulate matter in the Earth's atmosphere. Inorganic particulate matter originates from complex gas-phase reactions involving precursor compounds, leading to nucleation, condensation, and subsequent particle growth. Heterogeneous reactions on existing particles further contribute to the diversity and composition of inorganic aerosols. Conversely, the formation of organic particulate matter involves the oxidation of volatile organic compounds (VOCs) emitted from natural and anthropogenic sources. This oxidation process yields intermediate products that undergo additional reactions, resulting in the intricate composition of organic aerosols. The interplay between these chemical processes is dynamic and influenced by various environmental factors such as temperature, humidity, and atmospheric composition. Understanding these mechanisms is pivotal for accurate atmospheric modeling, air quality assessment, and comprehension of health and climate impacts associated with particulate matter. Continued research is essential for refining our understanding of these complex chemical processes, informing effective air quality management strategies, and mitigating the environmental and health implications of particulate matter in the atmosphere.

### Content-

1. Introduction
2. Inorganic Particulate Matter In The Atmosphere
3. Organic Particulate Matter In The Atmosphere
4. Conclusion

### 1. Introduction

The atmospheric presence of particulate matter, both inorganic and organic, is a critical aspect of environmental chemistry with far-reaching implications for air quality, human health, and climate. Understanding the chemical processes governing the formation of inorganic particulate matter is essential for accurately modeling atmospheric composition and predicting the impacts of air pollution (Zhang, 2010). Inorganic aerosols encompass a diverse array of particles, including sulfates, nitrates, ammonium, and mineral dust, which arise from complex chemical reactions in the atmosphere (Seinfeld & Pandis, 2016). This introduction provides an overview of the key chemical processes involved in the formation of inorganic particulate matter, emphasizing the importance of this research for environmental and public health (Finlayson-Pitts & Pitts, 2000).

## 2. Inorganic Particulate Matter In The Atmosphere

Inorganic particulate matter (PM) in the atmosphere plays a crucial role in air quality and environmental health. These particles, composed of various inorganic substances, can originate from both natural and anthropogenic sources, influencing air quality, climate, and human health. Understanding the sources, composition, and environmental impact of inorganic PM is essential for effective air quality management and public health protection.

### a) Sources of Inorganic Particulate Matter:

#### Natural Sources:

- Volcanic emissions: Volcanic activity releases significant amounts of inorganic particles such as sulfur dioxide (SO<sub>2</sub>) and ash into the atmosphere.
- Dust and soil: Natural erosion, wind, and geological processes contribute to the presence of mineral dust particles in the air.

#### Anthropogenic Sources:

- Combustion processes: Industrial activities, power plants, and vehicle emissions release inorganic particles, including sulfur oxides (SO<sub>x</sub>), nitrogen oxides (NO<sub>x</sub>), and metal particles.
- Construction activities: Dust generated from construction sites contributes to the presence of inorganic PM in urban areas.
- Agricultural activities: Fertilizer application and pesticide use can release inorganic particles into the atmosphere.

### b) Composition of Inorganic Particulate Matter:

**Sulfates (SO<sub>4</sub><sup>2-</sup>):** Resulting from the oxidation of sulfur dioxide, sulfates contribute to fine particulate matter and are linked to respiratory issues.

**Nitrates (NO<sub>3</sub><sup>-</sup>):** Formed through the oxidation of nitrogen dioxide, nitrates play a role in the formation of PM and have implications for both air quality and ecosystem health.

**Metals and Metal Compounds:** Transition metals such as lead, mercury, and cadmium can be present in particulate matter, posing significant health risks upon inhalation.

**Mineral Dust:** Particles from soil and mineral sources contribute to coarse particulate matter and can vary widely in composition based on geographical location.

### c) Environmental Impact:

**Air Quality:** Inorganic PM can degrade air quality, leading to respiratory and cardiovascular issues in exposed populations (Pope & Dockery, 2006).

**Climate Change:** Certain inorganic particles, like sulfate aerosols, can have a cooling effect on the climate by reflecting sunlight and influencing cloud formation.

**Ecosystem Effects:** Deposition of inorganic PM onto soil and water bodies can impact ecosystems, affecting nutrient cycles and biodiversity.

#### d) Chemical Processes for Formation of Inorganic Particulate Matter in Atmosphere

**Nucleation:** The initial step involves the formation of small clusters or nuclei from precursor gases. Nucleation is influenced by factors such as temperature, humidity, and the availability of condensable vapors.

**Condensation:** Once nuclei are formed, condensation of additional molecules onto these particles occurs, leading to the growth of particulates. This process is vital for the transition from ultrafine particles to larger aerosols.

**Heterogeneous Reactions:** Existing particles in the atmosphere serve as surfaces for heterogeneous reactions. These reactions play a crucial role in the transformation of gaseous species into solid or liquid particulate matter.

**Coagulation:** Particles collide and merge through coagulation, a process contributing to the growth of larger particles. Coagulation dynamics are influenced by factors like particle size, concentration, and collision frequency.

#### e) Applications of Chemical processes for formation of inorganic particulate matter

The study of chemical processes for the formation of inorganic particulate matter in the atmosphere has significant applications across several scientific domains. Some key applications include:

**Air Quality Monitoring and Regulation:** Understanding the chemical processes leading to the formation of inorganic aerosols is crucial for assessing and regulating air quality. This knowledge aids in the identification of sources and the development of effective pollution control measures (Seinfeld & Pandis, 2016).

**Climate Modeling:** Inorganic particulate matter influences climate through interactions with radiation and cloud formation. Incorporating accurate representations of inorganic aerosol formation processes enhances the reliability of climate models (Charlson, et al. 1992).

**Health Impact Assessment:** Certain inorganic aerosols, such as sulfate particles, have known health implications. Understanding the chemical processes leading to their formation is crucial for assessing their potential impacts on respiratory and cardiovascular health (Pope III, et al., 2002).

**Atmospheric Chemistry Research:** Investigating the chemical reactions involved in inorganic particulate matter formation contributes to advancements in atmospheric chemistry. This research aids in the development of comprehensive atmospheric models and the interpretation of observational data (Finlayson-Pitts & Pitts, 2000).

**Remote Sensing and Monitoring:** Knowledge of the chemical processes governing inorganic aerosol formation is essential for interpreting remote sensing data. Monitoring changes in the concentration and composition of inorganic particulate matter provides valuable information about atmospheric conditions (Andreae, & Gelencsér, 2006).

These applications underscore the importance of understanding the chemical processes involved in the formation of inorganic particulate matter for addressing air quality, climate, and public health concerns.

### 3. Organic Particulate Matter In The Atmosphere

Organic particulate matter (PM) is a significant component of air pollution, contributing to both urban and rural atmospheric compositions. Derived from natural and anthropogenic sources, organic PM poses various environmental and health challenges. Understanding its sources, composition, and impacts is crucial for effective air quality management and public health protection (Dockery & Pope, 1994).

#### a) Sources of Organic Particulate Matter:

**Biogenic Sources:** Forests and vegetation emit volatile organic compounds (VOCs), which can undergo chemical transformations in the atmosphere and contribute to the formation of organic PM. (Dockery & Pope, 1994)

#### **Anthropogenic Sources:**

- Combustion processes: Vehicle exhaust, industrial activities, and biomass burning release organic PM, including polycyclic aromatic hydrocarbons (PAHs) and other combustion by-products.
- Agricultural activities: Pesticide use, fertilizers, and biomass burning in agricultural fields contribute to the release of organic particles.

#### b) Composition of Organic Particulate Matter:

**Polycyclic Aromatic Hydrocarbons (PAHs):** Derived from incomplete combustion of fossil fuels and biomass, PAHs are carcinogenic and can be present in fine organic PM (Zhang, et al., 2015).

**Volatile Organic Compounds (VOCs):** Biogenic and anthropogenic VOCs, such as terpenes and benzene, can undergo atmospheric reactions to form organic aerosols.

**Secondary Organic Aerosols (SOAs):** Formed through the oxidation of VOCs, SOAs represent a significant fraction of organic PM and contribute to the complexity of atmospheric aerosol composition (Hallquist, et al., 2009).

#### c) Environmental Implications:

**Health Effects:** Exposure to organic PM has been linked to respiratory and cardiovascular diseases, with specific organic compounds posing additional risks, such as PAHs (Zhang, et al., 2015).

**Climate Change:** Organic aerosols can influence climate by directly scattering or absorbing solar radiation and by serving as cloud condensation nuclei, affecting cloud properties and precipitation.

**Ecosystem Impact:** Deposition of organic PM onto soil and water bodies can influence nutrient cycling and impact ecosystems, particularly in areas with intensive agricultural practices .

**d) Chemical processes for formation of organic particulate in Atmosphere**

The presence and composition of organic particulate matter in the Earth's atmosphere play a pivotal role in atmospheric chemistry, air quality, and climate dynamics. Organic aerosols, derived from the oxidation of volatile organic compounds (VOCs), contribute significantly to the complex particulate mixture suspended in the air. Understanding the chemical processes underlying the formation of organic particulate matter is essential for addressing the environmental and health implications associated with airborne particles. This introduction provides an overview of the key chemical processes involved in the formation of organic particulate matter, highlighting the importance of this research for a comprehensive understanding of atmospheric dynamics.

**e) Various Steps for Chemical Processes for Formation of Organic Particulate Matter:**

**VOC Emission:** The process initiates with the release of volatile organic compounds into the atmosphere from natural sources (e.g., vegetation) and anthropogenic activities (e.g., industrial processes, vehicular emissions).

**Oxidation:** VOCs undergo atmospheric oxidation through reactions with hydroxyl radicals (OH), ozone (O<sub>3</sub>), and other oxidants. This oxidation leads to the formation of intermediate compounds, such as peroxy radicals and organic peroxy radicals (Zhang, et al., 2007).

**Secondary Organic Aerosol (SOA) Formation:** The intermediate compounds further react and undergo condensation to form larger, complex organic molecules, resulting in the formation of secondary organic aerosols (SOA) (Jimenez, et al., 2009).

**Aging Processes:** Organic particulate matter undergoes aging processes, including further oxidation and reactions with other atmospheric constituents. These processes contribute to the chemical complexity and diversity of organic aerosols (Hallquist, et al., 2009).

**f) Applications of Chemical processes for formation of organic particulate matter**

The study of chemical processes for the formation of organic particulate matter in the atmosphere has numerous applications across various scientific disciplines. Some key applications include:

**Air Quality Management:** Understanding the chemical processes behind organic aerosol formation is crucial for developing effective air quality management strategies. Knowledge of the sources and transformation of organic particulate matter aids in the assessment and mitigation of air pollution (Donahue, et al., 2006)

**Climate Modeling:** Incorporating accurate representations of organic aerosol formation in climate models enhances predictions of aerosol-cloud interactions and radiative forcing. Understanding the impact of organic particulate matter on climate is essential for comprehensive climate modeling (Shrivastava, et al. (2011).

**Health Effects Assessment:** The characterization of organic aerosols formed through specific chemical processes aids in assessing their health effects. Different organic particulate matter may have varying impacts on respiratory and cardiovascular health (Lelieveld, J., et al. 2015).

**Environmental Chemistry:** Chemical processes leading to the formation of organic particulate matter contribute to the overall understanding of environmental chemistry. This knowledge is vital for comprehending the fate and transport of organic aerosols in the atmosphere (Kanakidou, et al., 2005).

**Atmospheric Research:** Investigating the chemical mechanisms behind the formation of organic particulate matter contributes to advancements in atmospheric research. This knowledge aids in the interpretation of field observations and the development of accurate atmospheric models (Hallquist, et al., 2009).

These applications highlight the interdisciplinary nature of research on organic aerosol formation, addressing crucial aspects of air quality, climate, and public health.

#### 4. Conclusion

The study of chemical processes governing the formation of organic particulate matter in the atmosphere is integral to comprehending the complex dynamics of air quality, climate, and environmental health. The intricate interplay of volatile organic compounds (VOCs) and their atmospheric oxidation processes results in the formation of secondary organic aerosols (SOA), contributing significantly to the atmospheric particulate burden. As we strive to mitigate the impacts of air pollution and understand the intricate relationships between organic aerosols and climate change, ongoing research into these chemical processes remains crucial. The knowledge gained not only advances our understanding of atmospheric chemistry but also informs effective strategies for air quality management and climate change mitigation. Emphasizing the interdisciplinary nature of this research, the conclusions drawn from studying organic particulate matter contribute to a more holistic approach in addressing the multifaceted challenges posed by airborne particles in the Earth's atmosphere.

Whereas the investigation of chemical processes governing the formation of inorganic particulate matter in the atmosphere is pivotal for our understanding of atmospheric chemistry, air quality, and climate dynamics. The diverse array of inorganic aerosols, including sulfates, nitrates, ammonium, and mineral dust, arises from intricate chemical reactions involving precursor gases. This knowledge is essential for developing accurate atmospheric models, assessing and regulating air quality, and predicting the environmental and health impacts associated with particulate matter. As we strive to address the challenges of air pollution and climate change, ongoing research into these chemical processes is imperative. The findings contribute to a comprehensive approach in managing the intricate relationships between inorganic aerosols and the Earth's atmospheric system, ultimately guiding effective strategies for environmental protection and public health.

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