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.

About the Editors:

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).

Kriti Tripathi, a highly accomplished professional in the field of Higher Education, brings a wealth of research and academic experience to her endeavors.
Currently, she is serving as Assistant Professor of School of Basic and Applied Sciences at Career Point University, Kota (Rajasthan).

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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Editor:
Arun Sharma
Erum Gul Naz
Surabhi Singh
Kriti Tripathi
Insha Ara

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CP Tower, Road No.-1, IPIA, Kota (Raj.)
Email : publication@cpil.in

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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.

Table of Contents

Editors

Dr. Arun Sharma, Dr. Erum Gull Naz

Dr. Surabhi Singh and Ms. Kriti Tripathi

Ms. Insha Ara

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CHAPTER 8

Atmospheric Chemistry and Climate Change

Ms.Kriti Tripathi

Content-

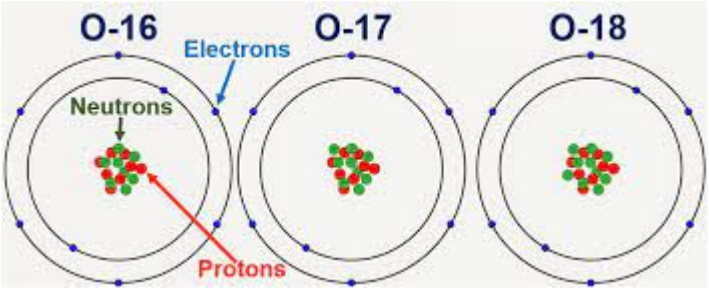
1. Oxygen (O_2)

- Oxygen is an element in chemistry with the atomic number 8 and symbol O. It is a non-metallic chemical element belonging to Group VIa in the periodic table. Its Molecular Mass is 15.999. Its electron configuration is $1s^2\,2s^{\,2}2p^4$ M.P. is −218.4 °C, B.P. is −183.0 °C, and density (1 atm, 0 °C) is 1.429 g/litre.
- Colourless, odourless, and tasteless gas, which makes up around 21% of the Earth's atmosphere and essential to cellular respiration. Animals absorb it and transform it into carbon dioxide, which plants then use as a source of carbon and release back into the atmosphere as oxygen.
- Water is the most significant component of it. Oxygen can combine with almost any element to form compounds, and it can also react with other elements to remove them from combinations
- Oxygen has several uses in medicine. Supplemental oxygen treatment is frequently used to treat respiratory disorders and help patients with compromised lung function.
- The metabolic processes on Earth depend critically on the cycling of oxygen via the atmosphere, oceans, and terrestrial ecosystems.

a) Occurrence and properties of Oxygen

- On the surface of the earth, oxygen is the most prevalent element with 46% of mass. 20% of the air's bulk is made up of it. The total oxygen content of water is approximately 89% by mass.
- Oxygen can be found in air as O_2 molecules and, to a lesser degree, as O_3 (ozone) molecules. When it is mixed with other elements, primarily silicon, oxygen makes up around 50% of the bulk of the earth's crust, but these are not useful as a source of oxygen.

b) Isotopes of Oxygen



- Three stable isotopes of oxygen—^{18}O, ^{17}O, and ^{16}O—occur naturally.
- Out of all these stable isotopes, ^{16}O is the most prevalent on Earth, making up 99.75% of all atoms.
- There are around 17 radioactively decaying unstable isotopes of oxygen known to exist, 14 of which are radiogenic (formed by the decay of other atoms), none of these isotopes lasts longer than two minutes.

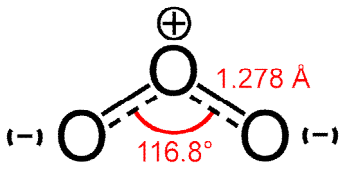
c) Allotropes of Oxygen

Four known forms of oxygen are known as allotropes:

- dioxygen, O_2, which is colourless
- ozone O_3, which is blue
- Tetraoxygen O_4,which is red
- metallic oxygen, which is produced at extremely high pressures and

$$\mathbf{3O_2 \rightarrow 2O_3}$$

d) Ozone (O_3)



Three oxygen atoms (O_3) make up the triatomic molecule known as ozone. Usually, to create ozone, an electric discharge is run through a dry air or oxygen current. Ozone is a very potent oxidizing agent because it is significantly more reactive than oxygen in many ways.

It is used in food bleaching, air sterilizing and purifying the water. Most of the sun's harmful ultraviolet (UV) radiation is absorbed and blocked by the ozone layer, which serves as a shield.

e) Physical Properties of Ozone:

Pale blue gas with a distinctive, pungent and poisonous odour known as ozone is also explosive. Denser than both oxygen and air, displaying a bluish colour in its gaseous state; despite reactivity, it is a poor conductor of electricity.

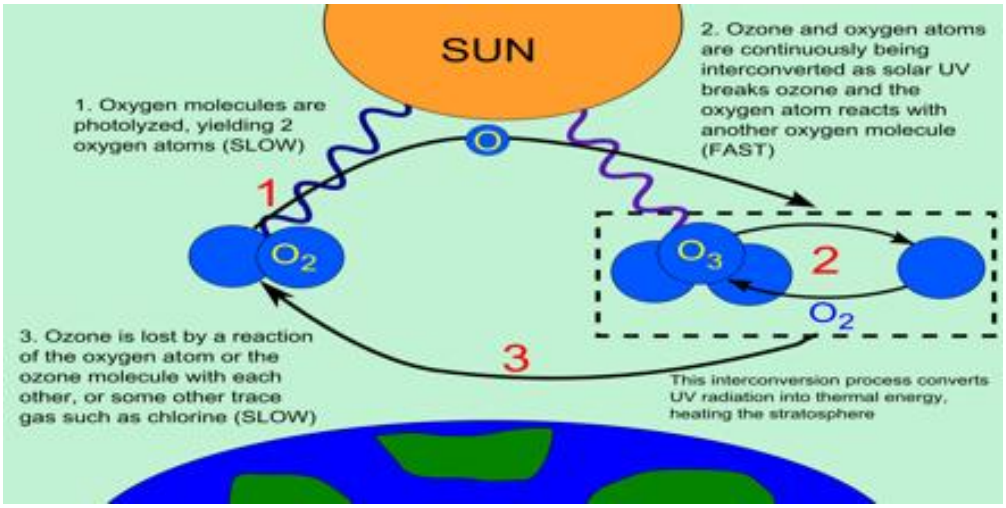
2. Chemical Properties of Ozone

High reactivity due to an unstable molecular structure. Acts as a powerful oxidizer, participating in various chemical reactions; crucial in environmental chemistry, breaking down pollutants and contributing to atmospheric processes like the ozone-oxygen cycle.

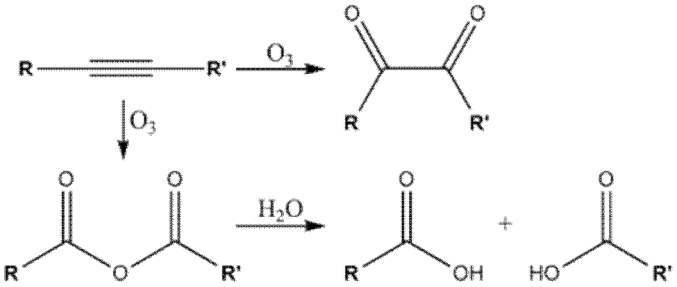
Ozone reactions

Ozone (O_3) is a triatomic molecule that is reactive and participates in a number of chemical reactions that are important to industrial uses as well as atmospheric processes. The following five points indicate important reactions to ozone:

a) Ozone-Oxygen Cycle: Ozone participates in the ozone-oxygen cycle in the stratosphere. Solar ultraviolet (UV) radiation induces the dissociation of oxygen molecules, leading to the formation of ozone. This protective layer absorbs harmful UV radiation, preventing it from reaching Earth's surface.

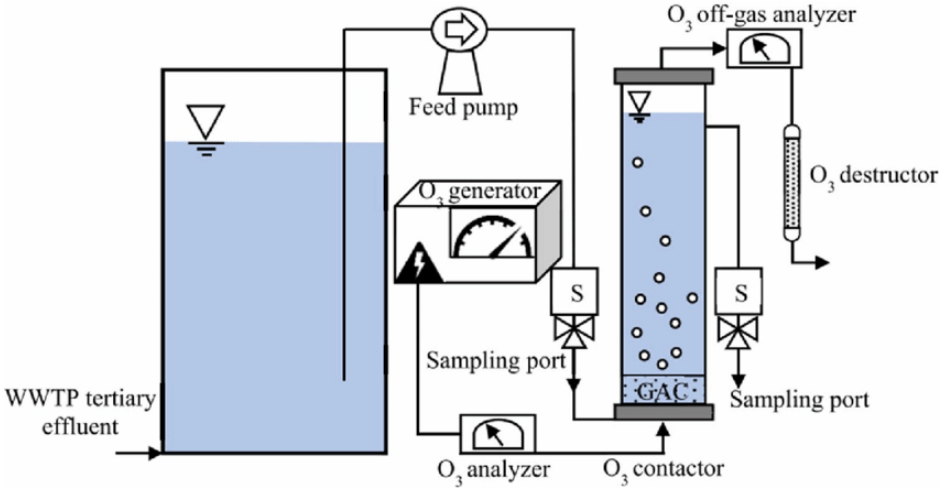


b) Ozone Decomposition (Ozonolysis): Ozone undergoes decomposition, known as ozonolysis, in response to factors like UV radiation or electrical discharges. This process breaks down ozone molecules into simpler components, releasing oxygen atoms or leading to the formation of other compounds.



c) Ozone and Pollutant Oxidation: Ozone acts as a potent oxidising agent in the atmosphere. It reacts with pollutants such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs), initiating oxidation processes that break down these pollutants into less harmful substances. This contributes to air purification.

d) Ozone in Water Treatment: Ozone is applied in water treatment processes, where it reacts with organic and inorganic impurities. Ozone's oxidative properties facilitate the breakdown of contaminants, ensuring the purification of water by eliminating bacteria, viruses, and undesirable substances.

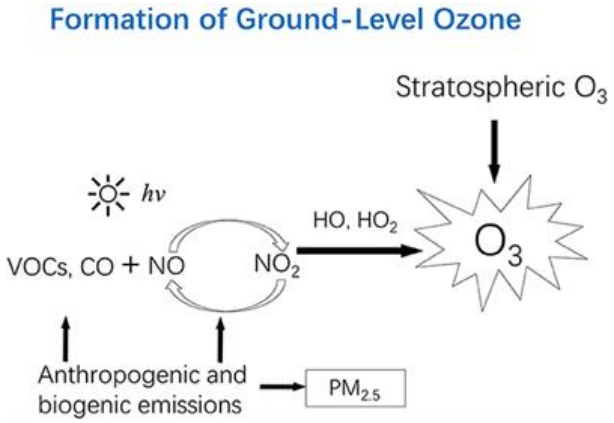


e) Ozone in Industrial Processes: Ozone finds diverse applications in industries. It is used for oxidation reactions, sterilization, and the removal of impurities in manufacturing processes. Ozone's reactivity is harnessed to enhance the efficiency of industrial processes and ensure the quality of end products.

Ozone is an unstable molecule, it reacts mostly with sunlight in the atmosphere. Low-level ozone and high-level ozone refer to ozone concentrations at different altitudes in the Earth's atmosphere, each with distinct characteristics and implications.

3. Low-Level Ozone:

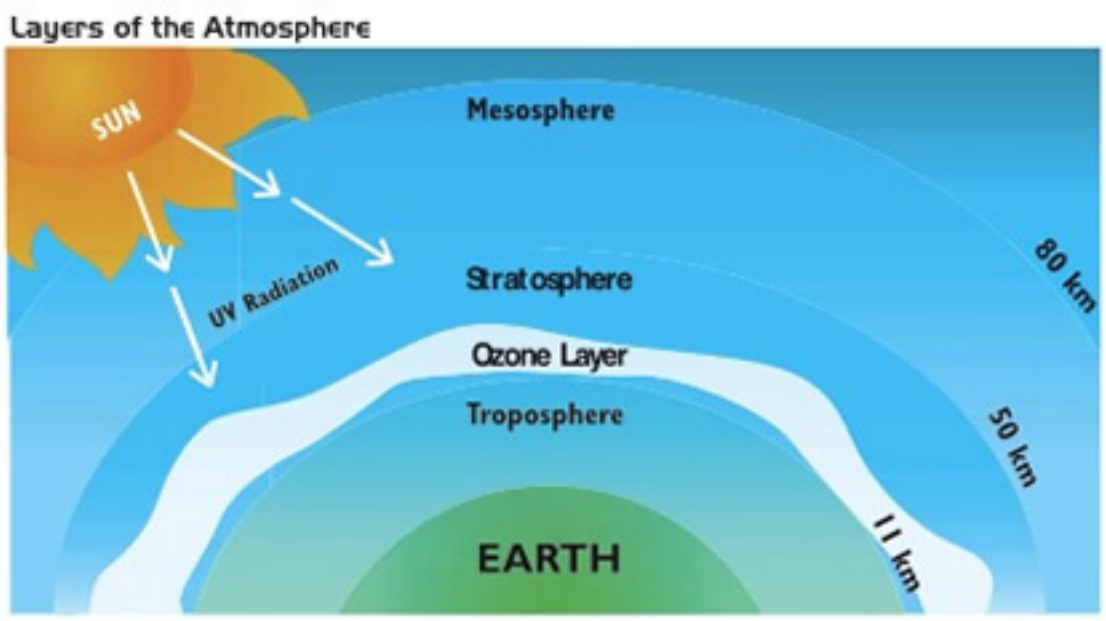
a) Tropospheric Ozone: The lowest layer of the atmosphere, the troposphere, is where this type of ozone, also referred to as ground-level ozone, develops. It is a secondary pollutant that is produced when nitrogen oxides (NO_x) and volatile organic compounds (VOCs) interact chemically in the presence of sunlight.



b) Concerns about Air Quality: One of the main causes of smog is low-level ozone, which is bad for human health. Extended exposure can worsen asthma, trigger other respiratory disorders, and create respiratory difficulties. It is bad for the vegetation as well.

c) High-Level Ozone:

(i) Stratospheric Ozone: This ozone layer is made up of stratospheric ozone, which is located in the stratosphere, an altitude of between 10 and 50 km above Earth. The main process by which it is produced is the ozone-oxygen cycle, which is initiated by solar UV radiation breaking apart and recombining oxygen molecules.



(ii) UV energy Absorption: A large portion of the sun's damaging ultraviolet (UV) energy is absorbed by stratospheric ozone. By preventing excessive UV rays from penetrating the Earth's surface, this absorption protects ecosystems and living things.

- A delicate balance required for life on Earth is maintained by high-level ozone in the stratosphere, but low-level ozone is harmful to human health and air quality. The distinction between the two highlights how crucial it is to comprehend the dynamics of ozone at various atmospheric levels as well as the effects each has on the ecosystem.
- Understanding these ozone reactions is vital for addressing environmental challenges, such as ozone layer depletion, as well as for leveraging ozone's versatile properties in beneficial applications, ranging from atmospheric protection to industrial processes.

4. Chemistry of Air Pollutants

A major environmental problem that affects both human health and the fragile balance of Earth's atmosphere is air pollution. The intricacy of atmospheric processes is increased by the dynamic interaction of numerous substances, both man-made and natural, in the chemistry of air pollution. The complex world of air pollutants is examined in this essay, with particular attention paid to their sources, chemical changes, and the wide-ranging effects of their existence in our atmosphere.

a) **Anthropogenic and Natural Sources:** Air pollutants come from a variety of sources, which can be broadly divided into two categories: anthropogenic and natural. Emissions from energy generation, transportation, and industry are examples of anthropogenic sources. The chemical makeup of the atmosphere is influenced by natural processes including wildfires, volcanic eruptions, and biogenic activity. This interaction highlights how diverse air pollution is.

b) **Nitrogen Oxides (NO_x):** A major pollutant that affects the chemistry of the atmosphere, nitrogen oxides are created during combustion activities. When sunlight is present in the sky, NO_x reacts with volatile organic compounds (VOCs) to generate ground-level ozone, which is a primary cause of photochemical smog. Human health and air quality are directly affected by this intricate chemistry.

c) **Sulfur Dioxide (SO_2):** Mainly released via the burning of fossil fuels, sulfur dioxide can oxidise and create sulphate aerosols in the atmosphere. These aerosols are linked to respiratory and cardiovascular health problems and add to particulate matter. Moreover, sulfur dioxide degrades aquatic habitats and soil quality since it is a precursor to acid rain.

d) **Particulate Matter (PM):** Particulate matter is made up of minute particles that are suspended in the atmosphere and vary in size and content. PM is produced by industrial operations, natural sources, and combustion processes. When inhaled, PM's chemical makeup of metals, inorganic salts, and organic chemicals can be harmful to one's health. Heart and lung conditions are associated with prolonged exposure to PM.

e) **Ground-Level Ozone:** A significant contributor to smog is ground-level ozone, which is created by photochemical interactions between NO_x and VOCs. This secondary pollutant aggravates respiratory disorders like asthma and has negative impacts on respiratory health.Ozone has an adverse effect on plants as well, impeding plant development and lowering agricultural output.

f) **Acid Rain:** Acid rain is a type of precipitation, which includes rain, snow, and fog, that has high concentrations of acidic substances, mainly nitric acid (HNO_3) and sulfuric acid (H_2SO_4). The atmospheric deposition of pollutants, primarily sulfur dioxide (SO_2) and nitrogen oxides (NO_x), emitted by industrial operations and the burning of fossil fuels, is the cause of this occurrence. Acids are created when these pollutants combine with oxygen, water vapor, and other elements in the atmosphere. These acids are then transported to the Earth's surface via precipitation. Infrastructure, marine life, soil quality, and ecosystems can all suffer from acid rain. Mitigating actions include cutting back on sulfur and nitrogen compound emissions as well as putting plans in place to lessen the environmental effects of acidic precipitation.

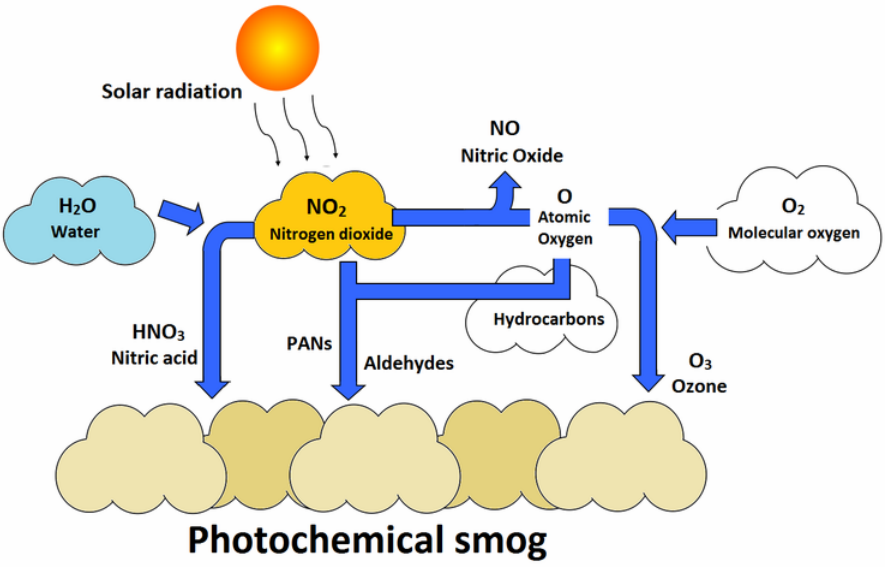
g) **Health Effects:** Air pollution's chemical make-up and reactivity have a direct impact on people's health. Prolonged exposure to pollutants including NO_x, SO_2, and PM is linked to respiratory and cardiovascular disorders, including lung cancer. Particularly vulnerable groups include the elderly and children.

h) **Global Implications:** The atmospheric chemistry of contaminants affects global climate patterns, and air pollution has an impact beyond national borders. Certain pollutants, including black carbon, have a global impact on weather patterns and temperature by warming the atmosphere and accelerating climate change.

i) **Mitigation Plans and Future Outlook:** Creating successful mitigation plans requires a thorough understanding of the chemistry of air pollutants. Important measures include encouraging

sustainable practices, implementing stricter emission regulations, and switching to greener energy sources. Policy choices intended to protect human health and the integrity of Earth's atmosphere will be influenced by ongoing study into the intricate relationships between air contaminants.

j) Photochemical Smog:



One ubiquitous kind of air pollution, known as photochemical haze, is caused by the complex interaction of many contaminants with sunlight, especially in cities. Ten main ideas that clarify the causes and characteristics of photochemical fog are as follows:

(i) Formation Mechanism: When nitrogen oxides (NO_x) and volatile organic compounds (VOCs) react chemically in the presence of sunlight, ground-level ozone and other secondary pollutants are produced. This is how photochemical smog is formed.

(ii) Components: Its unique hazy appearance is caused by a variety of contaminants, such as ozone, particulate matter, aldehydes, and other oxidants.

(iii)Urban Hotspots: Densely inhabited urban areas with heavy traffic and industrial activity, where NO_x and VOC emissions are higher, are the most common locations for photochemical smog.

(iv) Health Impacts: Residents in cities may be at risk for respiratory problems, asthma flare-ups, and eye and throat discomfort as a result of photochemical smog exposure.

(v) Environmental Consequences: Ozone, a crucial ingredient, has a detrimental effect on flora, which damages crops and has an influence on forest ecosystems. When pollutants interact with water bodies, aquatic ecosystems may also suffer.

(vi)Temperature Inversions: Meteorological phenomena such as temperature inversions have the ability to trap pollutants near the surface, so enhancing the production of smog and aggravating problems with air quality.

(vii) Ozone at the surface against that in the stratosphere: While ozone in the stratosphere protects Earth from harmful UV radiation, ozone at the surface causes respiratory irritation and environmental degradation in smog.

(viii) Mitigation Strategies: Tighter emission regulations, the promotion of greener technology, and more public knowledge of air quality issues are some of the measures used to lessen photochemical haze.

(ix) Urban Planning: Reducing the sources of NO_x and VOCs is a key component of sustainable urban planning and transportation methods, which helps to minimize smog.

(x) Impact Worldwide: Photochemical smog is a global problem that cannot be contained inside geographical limits. As such, international cooperation is essential to addressing air quality issues and reducing their impact.

5. Conclusion:

Photochemical smog poses a serious threat to the environment and human health, thus comprehensive approaches to cut emissions, improve air quality monitoring, and promote sustainable urban development are required. Understanding the effects of smog on the world at large highlights how urgent it is for everyone to work together to address this enduring problem in metropolitan areas.

The intricate chemistry of air pollutants contributes to the formation of photochemical smog, characterized by elevated levels of ozone and other secondary pollutants. Photochemical smog poses significant challenges for urban areas, where high levels of vehicle emissions and industrial activities intensify atmospheric reactions.

- In conclusion, the chemistry of air pollutants is a multifaceted and dynamic field with profound implications for the environment and public health. As we grapple with the challenges of air pollution, interdisciplinary efforts in atmospheric chemistry, environmental science, and public policy are essential to devise comprehensive solutions that address the complexity of this pervasive issue.