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Unit-IV

Atmospheric Chemistry

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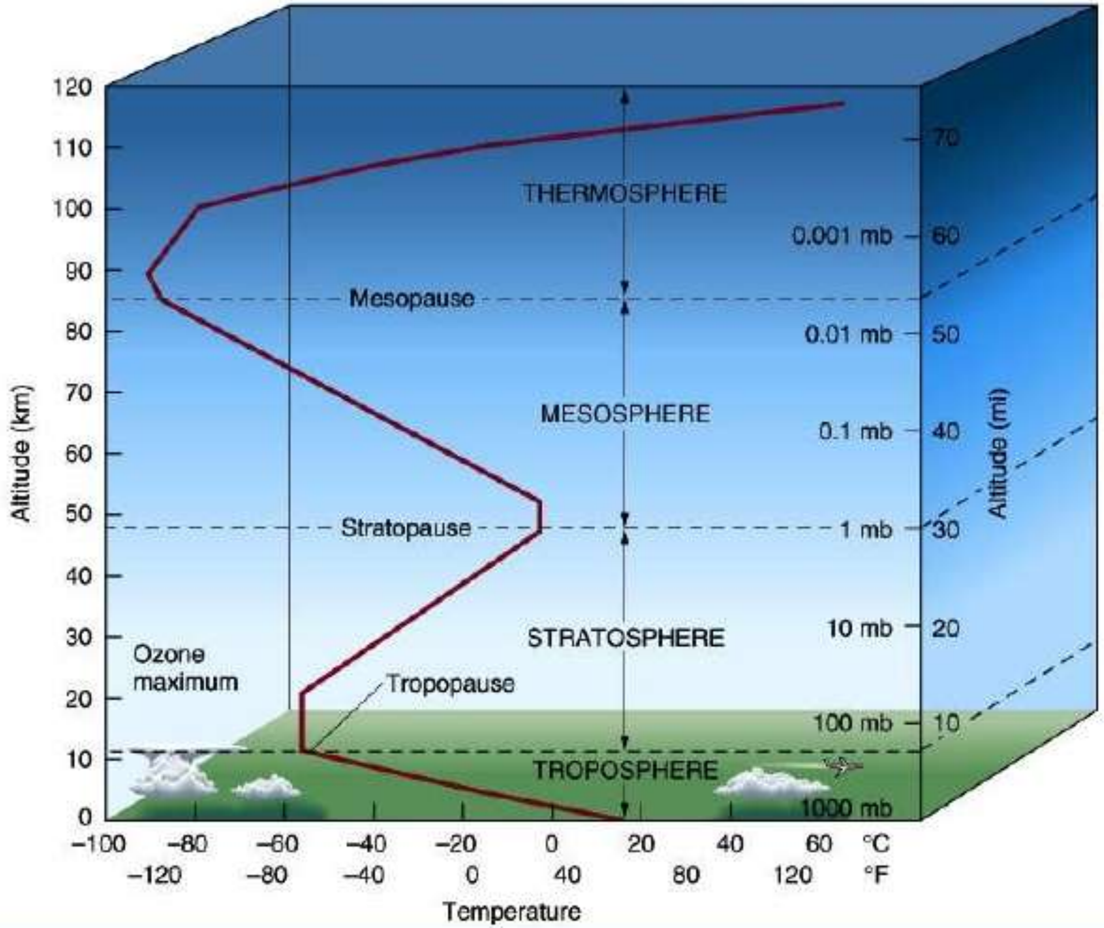
Atmosphere

- The **atmosphere of Earth** is the layer of gases ,commonly known as **air**, that surrounds the planet Earth and is retained by gravity.
- Atmospheric Composition: By volume, dry air contains 78.09% of nitrogen, 20.95% of Oxygen, 0.93% of Argon, 0.04% of Carbon di oxide, and small amounts of other gases. Air also contains a variable amount of water vapour , on an average around 1% at sea level, and 0.4% over the entire atmosphere. The remaining gases are often referred to as trace gases.
- The concentration of water vapor (a greenhouse gas) varies significantly from around 10 ppm by volume in the coldest portions of the atmosphere to as much as 5% by volume in hot, humid areas.

Structure of Atmosphere

- Earth’s Atmosphere has a series of layers. From ground level, these layers are named as the troposphere, stratosphere, mesosphere, thermosphere and exosphere.
- The troposphere is the lowest layer of our atmosphere. Starting at ground level, it extends upward to about 10 km (6.2 miles or about 33,000 feet) above sea level.
- All weather changes occurs in this lowest layer. Mostly clouds appear in this strata, as 99% of the water vapor in the atmosphere is found in the troposphere.

Stratification of the atmosphere



http://burro.cwru.edu/Academics/Astr201/Atmosphere/structure.jpg

- The temperature of the troposphere generally decreases with height above the surface of a planet. The temperature decreases because the troposphere is heated primarily by convection currents from the surface of the planet.
- Sometimes, the temperature of the troposphere increases with height. When the temperature increases with height it is called a **temperature inversion**.
- The highest point in the troposphere is called the *tropopause*. The height of the tropopause in Earth's atmosphere varies by latitude and by time of year, but it is at an altitude of approximately 11 kilometers.

conduction Heat transfer occurs through a heated solid object.	**convention** Heat transfer occurs through intermediate objects. For example, heat transfer between air and water.

Stratosphere

- In the Earth's atmosphere, the layer above the tropopause is called the *stratosphere*. Much of the ozone in our atmosphere is located in the stratosphere, and it absorbs ultraviolet radiation from the Sun. It is called the Life layer of Earth.
- The ozone is heated when it absorbs the radiation, and the temperature of the stratosphere increases with height. That is because more absorption takes place high in the stratosphere .
- The top of the stratosphere is called the *stratopause*. In Earth's atmosphere, the height of the stratopause is about 50 kilometers.

Mesosphere and Thermosphere

- The layer above the Earth's stratosphere is called the mesosphere. Here the temperature once again decreases with height. The mesosphere has the lowest temperatures in Earth's atmosphere.
- The top of the mesosphere is called the mesopause. The height of the mesopause is approximately 85 kilometers.
- The uppermost layer in our atmosphere is called the thermosphere. The temperature of this layer increases with altitude, due to the absorption of radiation from the Sun.
- The density and the pressure in the thermosphere are extremely low. The pressure can be one million times less than it is on the surface of the Earth.

Classification of Elements, Particulate Matter, Ions and Radicals in the Atmosphere

- The atmosphere contains a diverse array of elements, particulate matter, ions, and radicals. These components are essential in various atmospheric processes, including weather patterns, climate change, and air quality.
- **Elements in the Atmosphere**

1. **Major Elements**:
   1. **Nitrogen (N_2)**: Approximately 78% of the atmosphere by volume.
   2. **Oxygen (O_2)**: About 21% of the atmosphere.
   3. **Argon (Ar)**: Roughly 0.93%.
   4. **Carbon Dioxide (CO_2)**: Approximately 0.04%, but its concentration is increasing due to human activities.
2. **Trace Elements**:
   1. **Neon (Ne),Helium (He),Methane (CH_4),Krypton (Kr),Hydrogen (H_2)**
   2. These elements are present in very small amounts but can have significant impacts on atmospheric chemistry and processes.

- **Particulate Matter (PM)**
- Particulate matter consists of solid and liquid particles suspended in the air. PM is classified based on size and composition.

1. **Size Classification**:
   1. **PM10**: Particles with diameters less than 10 micrometers.
   2. **PM2.5**: Particles with diameters less than 2.5 micrometers. These are more harmful as they can penetrate deep into the lungs and even enter the bloodstream.
   3. **Ultrafine Particles**: Particles with diameters less than 0.1 micrometers.
2. **Composition Classification**:
   1. **Primary Particles**: Emitted directly into the atmosphere from sources like combustion engines, industrial processes, and natural sources (e.g., dust storms, volcanic eruptions).
   2. **Secondary Particles**: Formed in the atmosphere through chemical reactions involving gases like sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs).

- Particles of the size 0.1-1 micron (PM0.1-PM1), often referred to as ultrafine particles (UFPs), play a significant role in environmental and human health. Here are some key points highlighting their importance:
- **Environmental Importance**

1. **Air Quality and Climate**:
    1. **Climate Impact**: UFPs can influence the Earth's climate by affecting cloud formation and altering the albedo (reflectivity) of the atmosphere. These particles can act as cloud condensation nuclei (CCN), influencing cloud properties and precipitation patterns.
    2. **Atmospheric Chemistry**: They participate in complex chemical reactions in the atmosphere, affecting the concentration of other pollutants and greenhouse gases.
2. **Transport and Deposition**:
    1. **Long-Range Transport**: Due to their small size, UFPs can be transported over long distances from their source, contributing to pollution far from the original emission site.
    2. **Deposition**: These particles can deposit on surfaces, including water bodies, soil, and vegetation, potentially causing harm to ecosystems. They can affect water quality by settling in water bodies and influencing the chemical composition of the water.
3. **Source Identification**:
    1. **Emission Sources**: Understanding the sources of UFPs is crucial for developing strategies to reduce air pollution. Major sources include combustion processes (e.g., vehicle emissions, industrial processes), secondary formation from gaseous precursors, and natural sources like wildfires and volcanic activity.

Aerosol

- An aerosol is a suspension of fine solid particles or liquid droplets in a gas. These particles or droplets are usually very small, ranging from about 0.01 to 10 micrometers in diameter.
- **Examples of aerosols include**:
- **Spray Paint**: When you use spray paint, the paint is dispersed as tiny droplets in a propellant gas.
- **Deodorant Sprays**: These often contain fragrance and other ingredients in the form of tiny droplets suspended in a propellant gas.eg.,HFC,Propane,Butane
- **Fog**: Natural fog is an example of an aerosol where tiny water droplets are suspended in the air.
- **Cough Aerosols**: When you cough, you release tiny droplets that can carry viruses or bacteria into the air.
- Aerosols can be naturally occurring, like sea spray or volcanic ash, or man-made, like industrial emissions or consumer products.

Aitken particles

- Aitken particles, named after the Scottish meteorologist John Aitken, are a category of atmospheric aerosol particles with diameters typically less than 0.1 micrometers (100 nanometers). These ultrafine particles play a crucial role in atmospheric processes and have significant implications for both environmental and human health.
- **Characteristics and Sources**

1. **Size and Composition**:
    1. **Size Range**: Aitken particles are among the smallest atmospheric aerosols, with sizes ranging from a few nanometers to about 100 nanometers.
    2. **Composition**: These particles can consist of a variety of substances, including sulfate, nitrate, organic compounds, metals, and elemental carbon. Their composition depends on their sources and the atmospheric conditions.
2. **Formation and Sources**:
    1. **Primary Sources**: Aitken particles can be directly emitted from various natural and anthropogenic sources. Natural sources include sea spray, volcanic activity, and biological processes, while anthropogenic sources include combustion processes (e.g., vehicle emissions, industrial processes) and biomass burning.
    2. **Secondary Formation**: These particles can also form through the nucleation of gas-phase precursors, such as sulfur dioxide (SO2) and volatile organic compounds (VOCs), which undergo chemical reactions in the atmosphere to produce new particles.

- **Ions in the Atmosphere**
- Atmospheric ions are charged particles that play a significant role in various atmospheric processes, including electrical conductivity, cloud formation, and chemical reactions.

1. **Positive Ions (Cations)**:
   1. **Sodium (Na^{+})**
   2. **Ammonium (NH_4^{+})**
   3. **Calcium (Ca^{2+})**
   4. **Magnesium (Mg^{2+})**
   5. **Potassium (K^{+})**
2. **Negative Ions (Anions)**:
   1. **Chloride (Cl^{-})**
   2. **Nitrate (NO_3^{-})**
   3. **Sulfate (SO_4^{2-})**
   4. **Bicarbonate (HCO_3^{-})**

- **Radicals in the Atmosphere**
- Radicals are highly reactive species with unpaired electrons. They play crucial roles in atmospheric chemistry, particularly in the breakdown of pollutants and the formation of secondary pollutants.

1. **Hydroxyl Radical (OH)**:
   1. Known as the "atmospheric detergent," OH radicals are essential for the removal of many pollutants, including methane and VOCs.
2. **Hydroperoxyl Radical (HO_2)**:
   1. Forms in the atmosphere through reactions involving OH radicals and can participate in the formation of ozone (O_3).
3. **Nitrate Radical (NO_3)**:
   1. Important in nighttime chemistry, NO_3 radicals react with VOCs and other pollutants, leading to the formation of secondary pollutants.
4. **Alkylperoxy Radicals (RO_2)**:
   1. Formed during the oxidation of VOCs and play a role in the formation of ozone and secondary organic aerosols.

Examples for VOC

- Benzene,Toulene,Xylene,Ethylene Glycol,Methylene chloride,1,3 Butadiene
- VOCs are substances with low boiling points and high vapor pressure that evaporate from liquids or solids.
- They are seen in paints, pesticides, Personal care products, aerosol sprays, cleaners, room deodorizers, carpets, wood floors.
- They are used in the production of paints, pharmaceuticals and refridgerants.

- Chemical and photochemical reactions in the atmosphere are fundamental processes that shape air quality, weather patterns, and climate. These reactions involve the transformation of pollutants, the formation of secondary pollutants, and the overall chemistry of the atmosphere.
- **Chemical Reactions in the Atmosphere**

1. **Oxidation-Reduction Reactions**:

    Ozone Formation: Ground-level ozone (O_3) forms through reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. Nitrogen dioxide (NO_2) photolyzes to produce nitric oxide (NO) and an oxygen atom (O), which then reacts with molecular oxygen (O_2) to form ozone.

    $$NO2+hv \rightarrow NO+O$$

    $$O+O2 \rightarrow O3$$

    Sulfur Dioxide Oxidation: Sulfur dioxide (SO_2) is oxidized to sulfuric acid (H_2SO_4) through reactions with hydroxyl radicals (OH) and other oxidants.

    $$SO2+OH \rightarrow HSO3$$

    $$HSO3+O2 \rightarrow H2SO4$$

1. **Acid-Base Reactions**:
    1. **Acid Rain Formation**: Sulfuric acid (H_2SO_4) and nitric acid (HNO_3) formed from SO_2 and NO_x emissions dissolve in water droplets in the atmosphere, leading to acid rain.

$$H2SO4 \rightarrow H^{+} + HSO4^{-}$$

$$HNO3 \rightarrow H^{+} + NO3^{-}$$

2. **Nucleation and Condensation**:
    1. **Aerosol Formation**: Gaseous precursors like sulfuric acid, ammonia (NH_3), and organic compounds undergo nucleation to form new particles. These particles can grow through condensation of additional vapors.

$$H2SO4 + NH3 \rightarrow (NH4)2SO4$$

Photochemical Reactions in the Atmosphere

- Photochemical reactions are driven by sunlight, particularly ultraviolet (UV) radiation. These reactions are crucial for the formation and transformation of various atmospheric constituents.

1.Photodissociation:

1. **Ozone Depletion**: Chlorofluorocarbons (CFCs) and other ozone-depleting substances undergo photodissociation in the stratosphere, releasing chlorine atoms that catalytically destroy ozone molecules.

$$CFCl3+hv \rightarrow CFCl2+Cl$$

$$Cl+O3 \rightarrow ClO+O2$$

$$ClO + O \rightarrow Cl+O2$$

2.Photochemical Smog:

1. **Formation of Secondary Pollutants**: Photochemical smog is formed by the reaction of sunlight with primary pollutants like NO_x and VOCs. The result is a complex mixture of ozone, aldehydes, peroxyacetyl nitrates (PAN), and other reactive species.

$$VOCs+NO2+hv \rightarrow O3+PANs+Other\ \ Pollutants$$

1. **Hydroxyl Radical (OH) Formation**:
   1. **Atmospheric Cleaning**: The hydroxyl radical is often referred to as the "detergent" of the atmosphere because it reacts with many pollutants, initiating their breakdown. OH radicals are formed by the photodissociation of ozone and subsequent reactions with water vapor.

$$O_3 + h\nu \rightarrow O_2 + O$$

$$O + H_2O \rightarrow 2OH$$

- **Importance of These Reactions**

1. **Air Quality**:
   1. **Formation of Pollutants**: Chemical and photochemical reactions contribute to the formation of secondary pollutants like ozone, fine particulate matter ($PM_{2.5}$), and photochemical smog, which are major air quality concerns.
   2. **Removal of Pollutants**: These reactions also play a role in the removal of pollutants from the atmosphere through processes like oxidation and deposition.
2. **Climate Regulation**:
   1. **Greenhouse Gases**: Reactions involving carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases influence the Earth's radiative balance and contribute to climate change.
   2. **Aerosols**: The formation and transformation of aerosols affect cloud properties and the Earth's albedo, playing a crucial role in climate regulation.

3. **Stratospheric Ozone Layer**:

   1. **Protection from UV Radiation**: The ozone layer protects life on Earth from harmful ultraviolet (UV) radiation. Chemical reactions, particularly those involving ozone-depleting substances, impact the concentration and distribution of ozone in the stratosphere.

4. **Ecosystem Health**:

   1. **Deposition of Pollutants**: The deposition of acidic and other reactive pollutants can harm ecosystems, affecting soil and water quality, plant health, and biodiversity.

Photochemical smog

- Photochemical smog, also known as "summer smog," is a type of air pollution that is formed through complex chemical reactions involving sunlight, nitrogen oxides (NO_x), and volatile organic compounds (VOCs). This process results in a mixture of harmful pollutants, including ground-level ozone (O_3), peroxyacetyl nitrates (PANs), and various secondary organic aerosols. The formation of photochemical smog can be broken down into several key steps:
- **Key Steps in the Formation of Photochemical Smog**

1. **Emission of Primary Pollutants**:
    1. **Nitrogen Oxides (NO_x)**: Emitted primarily from combustion processes, such as vehicle exhaust, industrial activities, and power plants.
    2. **Volatile Organic Compounds (VOCs)**: Released from sources like vehicle exhaust, industrial processes, gasoline vapors, and the use of solvents and paints.

2.Photolysis of Nitrogen Dioxide (NO_2):

1. When NO_2 is exposed to sunlight, it absorbs energy and undergoes photolysis, breaking down into nitric oxide (NO) and an oxygen atom (O).
   $NO2+hv \rightarrow NO+O$
2. The free oxygen atom (O) then reacts with molecular oxygen (O_2) to form ozone (O_3).

$$O+O2 \rightarrow O3$$

3.Formation of Ozone (O_3):

1. Ground-level ozone forms through the reaction of the free oxygen atom with molecular oxygen.

$O+O2 \rightarrow O3$

1. This ozone can accumulate in the lower atmosphere, contributing to photochemical smog.

- Reactions Involving VOCs:VOCs undergo a series of complex reactions in the presence of sunlight and NO_x. These reactions produce various reactive intermediates, such as peroxy radicals (RO_2).The peroxy radicals react with NO to form nitrogen dioxide (NO_2) and other secondary pollutants.

$$RO2+NO \rightarrow NO2+RO$$

- Formation of Peroxyacetyl Nitrate (PAN):PAN is formed through reactions involving acetyl peroxy radicals (CH_3COO_2) and nitrogen dioxide (NO_2).
  - $CH3COO2+NO2 \rightarrow PAN$
- PAN is a major component of photochemical smog and can act as a reservoir for NO_x, transporting it over long distances.
- Formation of Secondary Organic Aerosols (SOAs):VOCs and their oxidation products can condense to form particulate matter, known as secondary organic aerosols (SOAs). These aerosols contribute to the haze and reduced visibility associated with photochemical smog.

- **Factors Influencing Photochemical Smog Formation**

1. **Sunlight**:
    1. Sunlight provides the energy necessary for the photolysis of NO_2 and other photochemical reactions. Hence, photochemical smog is more prevalent during sunny days with strong sunlight.
2. **Temperature**:
    1. Higher temperatures accelerate the chemical reactions involved in the formation of photochemical smog. Warm conditions also enhance the evaporation of VOCs, increasing their concentrations in the atmosphere.
3. **Stagnant Air Conditions**:
    1. Stagnant air conditions, such as those caused by temperature inversions, can trap pollutants near the ground, allowing their concentrations to build up and promoting the formation of photochemical smog.
4. **Emission Levels**:
    1. Areas with high emissions of NO_x and VOCs, such as urban and industrial regions, are more prone to photochemical smog formation.

- **Health and Environmental Impacts**

1. **Health Impacts**:
    1. **Respiratory Problems**: Ozone and other components of photochemical smog can irritate the respiratory system, causing symptoms like coughing, throat irritation, and shortness of breath. Long-term exposure can exacerbate conditions like asthma and bronchitis.
    2. **Eye Irritation**: Photochemical smog can cause eye irritation and discomfort.
    3. **Cardiovascular Issues**: Exposure to high levels of ozone and other pollutants in smog can increase the risk of cardiovascular diseases.
2. **Environmental Impacts**:
    1. **Vegetation Damage**: Ozone and other pollutants can damage plants, reducing crop yields and affecting natural ecosystems.
    2. **Reduced Visibility**: Particulate matter and other aerosols in photochemical smog can reduce visibility, impacting transportation and the aesthetic quality of the environment.

Aerosols

- Aerosols, tiny particles or droplets suspended in the atmosphere, have profound environmental significance. Their impact extends from influencing climate and weather patterns to affecting human health and ecosystems.
- **Types and Sources of Aerosols**

1. **Natural Aerosols**:
    1. **Dust**: Generated from soil, deserts, and volcanic eruptions.
    2. **Sea Spray**: Formed from ocean waves breaking, releasing salt particles into the air.
    3. **Biological Particles**: Including pollen, spores, and bacteria.
    4. **Volcanic Ash**: Ejected during volcanic eruptions.
    5. **Wildfire Smoke**: Produced by burning vegetation.
2. **Anthropogenic Aerosols**:
    1. **Industrial Emissions**: Released from factories, power plants, and industrial processes.
    2. **Vehicle Emissions**: From the combustion of fossil fuels in cars, trucks, and airplanes.
    3. **Biomass Burning**: From agricultural practices, deforestation, and residential heating.
    4. **Construction and Mining Activities**: Generating dust and particulate matter.

Environmental Significance

1. **Climate Impact**:
    1. **Radiative Forcing**: Aerosols can scatter and absorb sunlight. Depending on their composition, they can either cool the Earth by reflecting sunlight back into space (a negative radiative forcing) or warm it by absorbing heat (a positive radiative forcing).
    2. **Cloud Formation and Properties**: Aerosols act as cloud condensation nuclei (CCN) and ice nuclei, essential for cloud formation. They influence cloud properties, including reflectivity, lifetime, and precipitation patterns. Aerosols can lead to the formation of brighter clouds that reflect more sunlight, known as the "aerosol indirect effect."
    3. **Stratospheric Aerosols**: Volcanic eruptions can inject aerosols into the stratosphere, where they can remain for years, reflecting sunlight and leading to temporary global cooling.

- **Atmospheric Chemistry**:
- **Chemical Reactions**: Aerosols participate in atmospheric chemical reactions, influencing the concentration and distribution of other pollutants, such as ozone and nitrogen oxides. They provide surfaces for heterogeneous reactions, which can alter the chemical composition of the atmosphere.

Formation of Acid Rain

- **Emission of Precursors**:
  - **Sulfur Dioxide (SO_2)**: Emitted from burning fossil fuels (coal, oil, and natural gas) in power plants, industrial processes, and vehicles.
  - **Nitrogen Oxides (NO_x)**: Emitted from vehicle exhaust, industrial processes, power plants, and natural sources like lightning and microbial activity in soils.
- **Atmospheric Transformation**:
  - **Oxidation of Sulfur Dioxide (SO_2)**:
    - SO_2 can be oxidized in the gas phase by reaction with hydroxyl radicals (OH) to form sulfur trioxide (SO_3), which then reacts with water to produce sulfuric acid (H_2SO_4).
    - SO2+OH→HSO3
    - HSO3+O2→HO2+SO3
    - SO3+H2O→H2SO4
- SO_2 can also be oxidized in the aqueous phase within cloud droplets by ozone (O_3) or hydrogen peroxide (H_2O_2) to form sulfuric acid.
- SO2(aq)+O3(aq)→SO3(aq)+O2(g)
- SO3(aq)+H2O→H2SO4(aq)

- **Oxidation of Nitrogen Oxides (NO_x)**:
  - Nitrogen dioxide (NO_2) can react with hydroxyl radicals (OH) to form nitric acid (HNO_3).
  - $NO_2 + OH \rightarrow HNO_3$
  - NO_2 can also react with ozone (O_3) to produce nitrate radicals (NO_3), which can further react with other compounds to form nitric acid. $NO_2 + O_3 \rightarrow NO_3 + O_2$
  - $NO_3 + NO_2 \rightarrow N_2O_5$
  - $N_2O_5 + H_2O \rightarrow 2HNO_3$

- **Deposition**:
  - **Wet Deposition**: Acidic compounds dissolve in cloud droplets and fall to the ground as rain, snow, sleet, or fog.
  - **Dry Deposition**: Acidic gases and particles can settle on surfaces directly, including soil, water bodies, and vegetation.

Environmental and Health Impacts

- **Soil and Water Acidification**:
  - Acid rain lowers the pH of soil and water bodies, leading to the leaching of essential nutrients and minerals like calcium and magnesium, which can harm plant life and aquatic ecosystems.
  - The release of toxic metals, such as aluminum, from soil into water bodies can be toxic to fish and other aquatic organisms.
- **Vegetation Damage**:
  - Acid rain can damage the leaves and bark of trees, reducing their ability to photosynthesize and weakening their overall health. This makes them more susceptible to disease, extreme weather, and pests.
- **Aquatic Ecosystems**:
  - Lower pH levels in water bodies can lead to the death of aquatic organisms, including fish, insects, and plankton. Acidic waters can disrupt reproductive cycles and lead to a decline in biodiversity.
- **Human Health**:
  - While acid rain does not directly affect human health, the pollutants that cause acid rain (SO_2 and NO_x) can lead to respiratory problems, including asthma and bronchitis. Fine particulate matter (PM) formed from these pollutants can also cause cardiovascular diseases.
- **Infrastructure and Materials**:
  - Acid rain can accelerate the decay of buildings, monuments, and statues, especially those made of limestone and marble, through chemical reactions that dissolve the calcium carbonate in these materials. $CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$

Oxygen and Ozone Chemistry

- Ozone is formed throughout the atmosphere in multistep chemical processes that require sunlight. In the stratosphere, the process begins with an oxygen molecule (O_2) being broken apart by ultraviolet radiation from the Sun. In the lower atmosphere (troposphere), ozone is formed by a different set of chemical reactions that involve naturally occurring gases and those from pollution sources.
- Stratospheric ozone. Stratospheric ozone is formed naturally by chemical reactions involving solar ultraviolet radiation (sunlight) and oxygen molecules, which make up 21% of the atmosphere. In the first step, solar ultraviolet radiation breaks apart one oxygen molecule (O_2) to produce two oxygen atoms (2 O). In the second step, each of these highly reactive atoms combines with an oxygen molecule to produce an ozone molecule (O_3). These reactions occur continually whenever solar ultraviolet radiation is present in the stratosphere.

- As a result, the largest ozone production occurs in the tropical stratosphere. The production of stratospheric ozone is balanced by its destruction in chemical reactions. Ozone reacts continually with sunlight and a wide variety of natural and human produced chemicals in the stratosphere. In each reaction, an ozone molecule is lost and other chemical compounds are produced. Important reactive gases that destroy ozone are hydrogen and nitrogen oxides and those containing chlorine and bromine
- Overall reaction: $3\ O2 \longrightarrow 2\ O3$

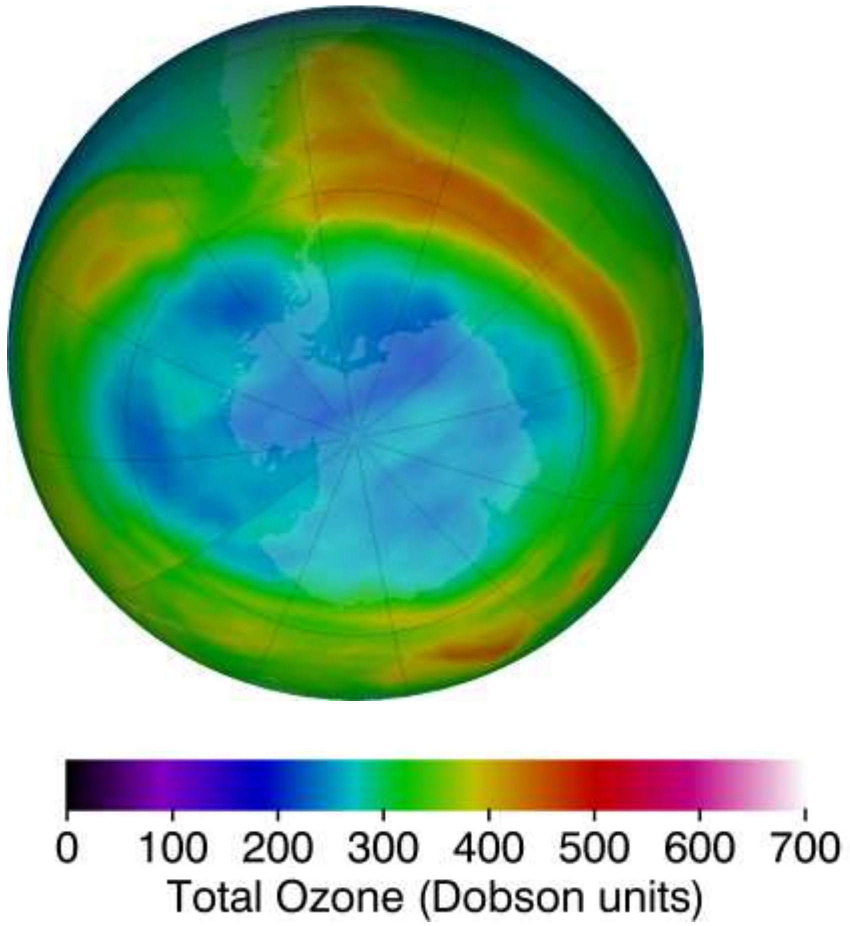
- Some stratospheric ozone is regularly transported down into the troposphere and can occasionally influence ozone amounts at Earth's surface, particularly in remote, unpolluted regions of the globe.
- Tropospheric ozone: Near Earth's surface, ozone is produced by chemical reactions involving naturally occurring gases and gases from pollution sources. Ozone production reactions primarily involve hydrocarbon and nitrogen oxide gases, as well as ozone itself, and all require sunlight for completion.
- Fossil fuel combustion is a primary source of pollutant gases that lead to tropospheric ozone production. The production of ozone near the surface does not significantly contribute to the abundance of stratospheric ozone. The amount of surface ozone is too small in comparison and the transport of surface air to the stratosphere is not effective enough.
- As in the stratosphere, ozone in the troposphere is destroyed by naturally occurring chemical reactions and by reactions involving human-produced chemicals. Tropospheric ozone can also be destroyed when ozone reacts with a variety of surfaces, such as those of soils and plants.

Balance of chemical processes

- Ozone abundances in the stratosphere and troposphere are determined by the balance between chemical processes that produce and destroy ozone. The balance is determined by the amounts of reactive gases and how the rate or effectiveness of the various reactions varies with sunlight intensity, location in the atmosphere, temperature, and other factors.
- As atmospheric conditions change to favor ozone-producing reactions in a certain location, ozone abundances increase. Similarly, if conditions change to favor other reactions that destroy ozone, abundances decrease.
- The balance of production and loss reactions combined with atmospheric air motions determines the global distribution of ozone on timescales of days to many months.
- Global ozone has decreased during the past several decades because the amounts of reactive gases containing chlorine and bromine have increased in the stratosphere.

https://ozonewatch.gsfc.nasa.gov/-
11.08.2024

The latest false-color view of total ozone over the Antarctic pole. The purple and blue colors are where there is the least ozone, and the yellows and reds are where there is more ozone.



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- **Thank You**

For Your Attention!