CHEMICAL POLLUTION TEMPLATE EDCH2205

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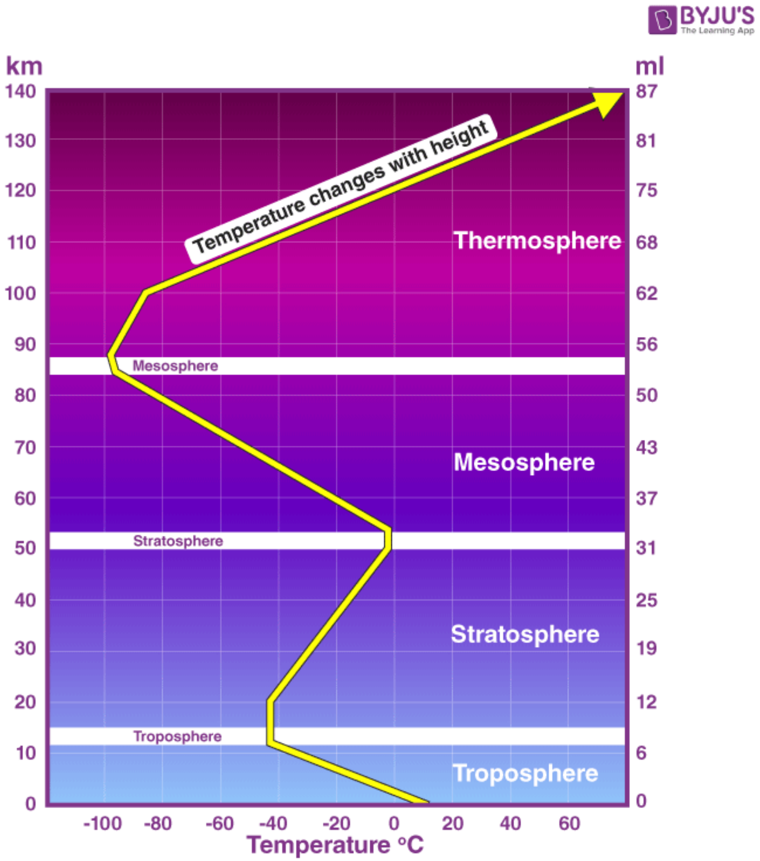
STRUCTURE & COMPOSITION OF ATMOSPHERE

- **LIFE ON EARTH WOULD NOT EXIST IF IT WERE NOT FOR THE ATMOSPHERE THAT WE HAVE. NITROGEN, WHICH ACCOUNTS FOR 78% OF THE ATMOSPHERE, AND OXYGEN, WHICH ACCOUNTS FOR 21%, ARE THE TWO GASES THAT MAKE UP THE MAJORITY OF THE ATMOSPHERE. IN ADDITION TO CARBON DIOXIDE AND A VARIETY OF TRACE GASES, THE REMAINING COMPONENTS ARE ARGON.**
- **SCIENTISTS CLASSIFIED THE ATMOSPHERE BY TEMPERATURE INTO TROPOSPHERE, STRATOSPHERE, MESOSPHERE, AND THERMOSPHERE.**
- **TEMPERATURE DECREASES IN THE TROPOSPHERE BUT RISES IN THE STRATOSPHERE. THE FARTHER AWAY FROM EARTH, THE THINNER THE ATMOSPHERE GROWS.**

STRUCTURE & COMPOSITION OF ATMOSPHERE

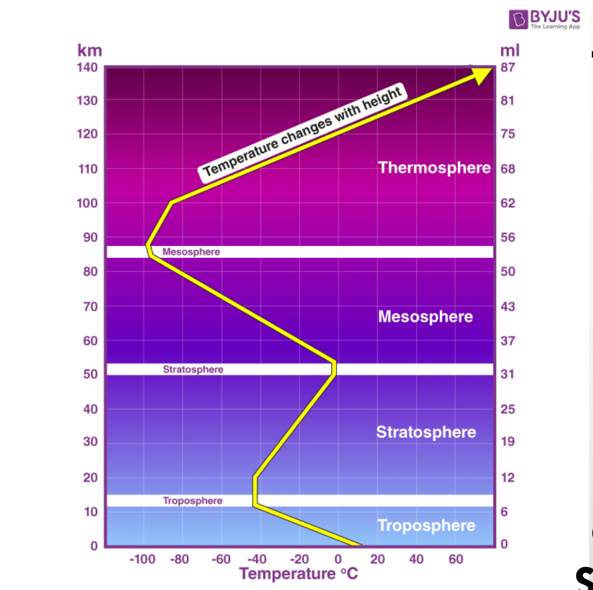


Temperature gradient diagram of different layers of atmosphere

Troposphere

Though the sunlight reaches the Earth's surface from top to bottom, the troposphere is primarily heated at the bottom. The Earth's surface is much better at absorbing a wide range of solar radiation than the air. When the parcel of warm air moves upwards, it expands, and when air expands, it cools. Due to this reason, the base of the troposphere is warmer than its base because the air on the surface of the Earth absorbs the sun's energy, gets heated up, and moves upward, which cools down.

STRUCTURE & COMPOSITION OF ATMOSPHERE



Temperature gradient diagram of different layers of atmosphere

Why is the Troposphere Warmer At The Base?

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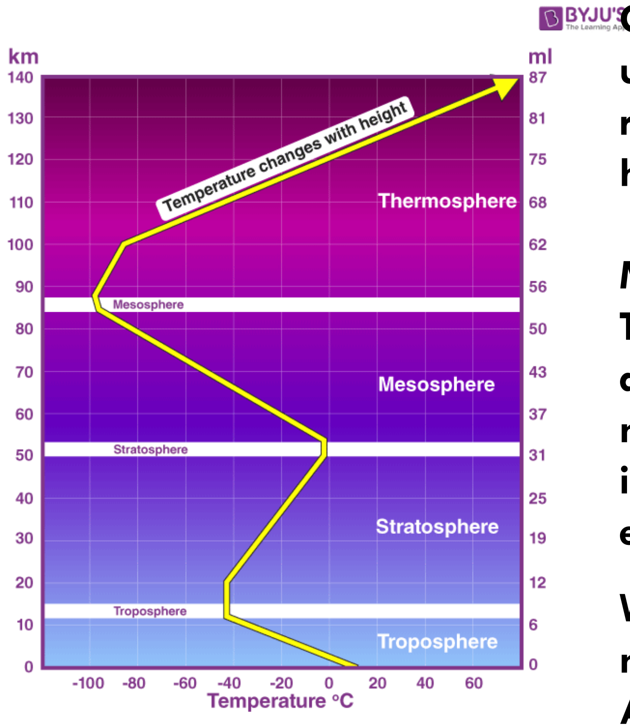
Stratosphere

The Stratosphere lies above the troposphere and extends up to a height of 50 km. This layer is free of clouds and devoid of any weather-related phenomenon. Due to this, aeroplanes fly in the Stratosphere for a smooth ride. The Stratosphere also houses the ozone layer that protects us from the harmful effect of the sun's rays.

STRUCTURE & COMPOSITION OF ATMOSPHERE



Temperature gradient diagram of different layers of atmosphere

Why is Stratosphere warmer than the troposphere?

Ozone molecules in the stratosphere absorb high-energy ultraviolet light from the sun and convert it into heat. Due to this reason, unlike the troposphere, the stratosphere gets warmer the higher you go!

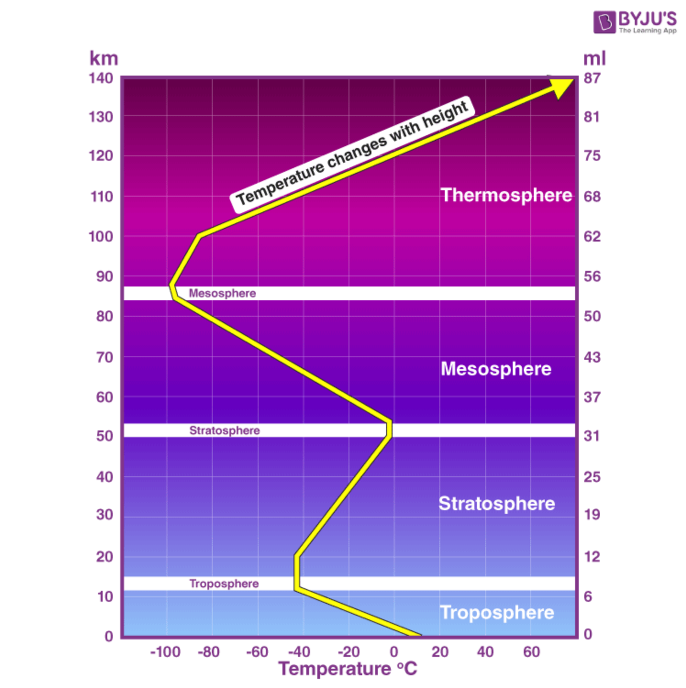
Mesosphere

The temperature in the mesosphere grows colder with the altitude. This is because there are few gas molecules in the mesosphere to absorb the Sun's radiation. The only heat source is the stratosphere below. The mesosphere is extremely cold, especially at the top, dropping to a temperature as low as -90°C.

Why would an unprotected astronaut's blood boil in the mesosphere?

An astronaut travelling through the mesosphere would experience severe burns from the sun's ultraviolet light because the ozone layer that provides UV protection is in the stratosphere below. Meteorites burn in this layer on entering the atmosphere from outer space.

STRUCTURE & COMPOSITION OF ATMOSPHERE



Temperature gradient diagram of different layers of atmosphere

Thermosphere and Beyond

The density of molecules in the thermosphere is very low. One gas molecule can go about a distance of 1 km without colliding with another molecule. Because so little energy is transferred, the air feels freezing. Satellites are found orbiting in the upper part of the thermosphere.

Ionosphere

The ionosphere lies within the thermosphere. The ionosphere gets its name from the solar radiation that ionizes gas molecules to create a positively charged ion and one or more negatively charged electrons. These freed electrons travel within the ionosphere as electric currents. Due to these free ions, the ionosphere has many interesting characteristics. The aurora, the Northern Lights and Southern Lights, occur in the Earth's ionosphere.

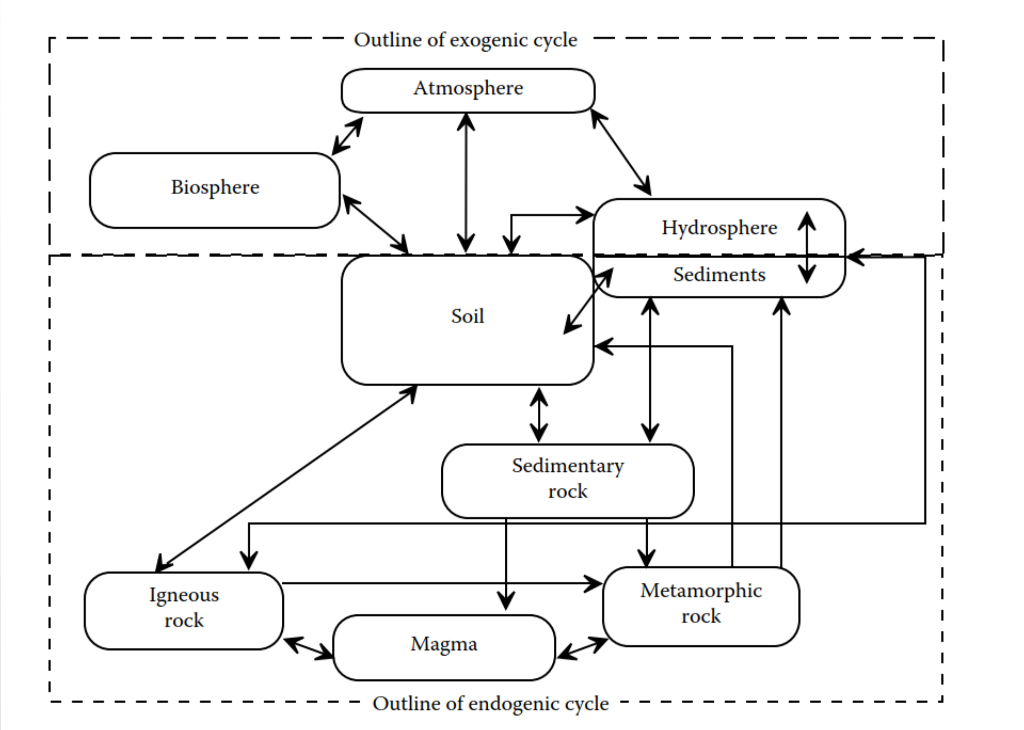
STRUCTURE & COMPOSITION OF ATMOSPHERE

- **Exosphere**
- **The exosphere is the final frontier of the earth's gaseous envelope. There is no clear-cut distinction between the earth's atmosphere layers and outer space. The air in the exosphere is constantly but gradually leaking out of the earth's atmosphere into outer space.**
- **The development of the spectrometer in the 1920s allowed scientists to find gases that existed in much smaller concentrations in the atmosphere, such as ozone and carbon dioxide. The concentrations of these gases, while small, varied widely from place to place. In fact, atmospheric gases are often divided up into the major, constant components and the highly variable components.**

Nitrogen (N_2)	78.08%
Oxygen (O_2)	20.95%
Argon (Ar)	0.93%
Neon, Helium, Krypton	0.0001%

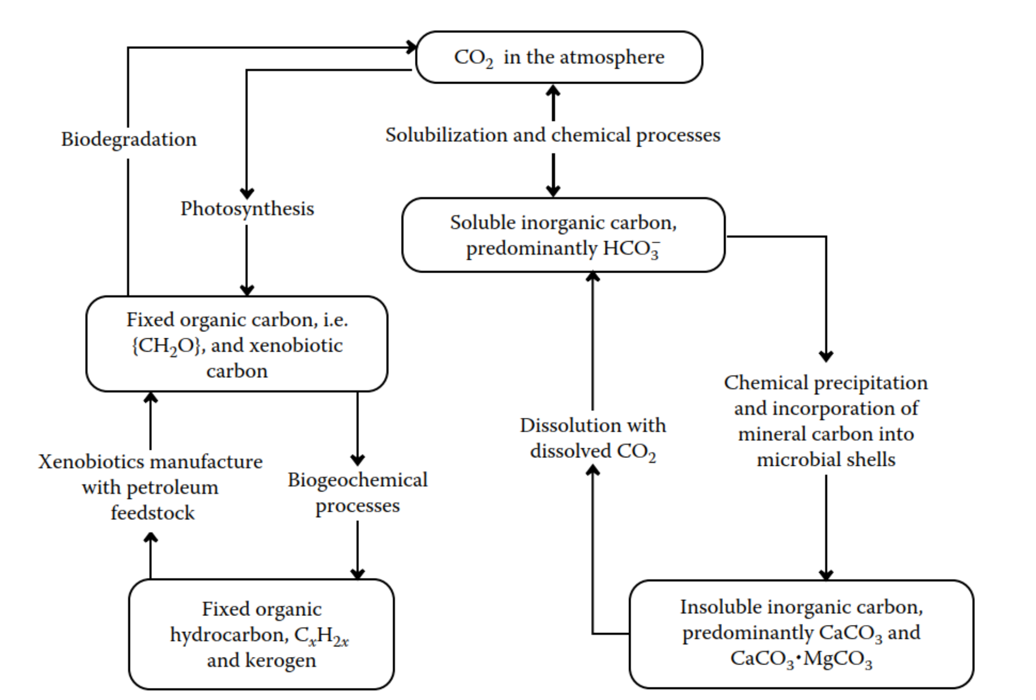
Carbon dioxide (CO_2)	0.038%
Water vapor (H_2O)	0-4%
Methane (CH_4)	*trace*
Sulfur dioxide (SO_2)	*trace*
Ozone (O_3)	*trace*
Nitrogen oxides (NO, NO_2, N_20)	*trace*

MATTER AND CYCLES OF MATTER

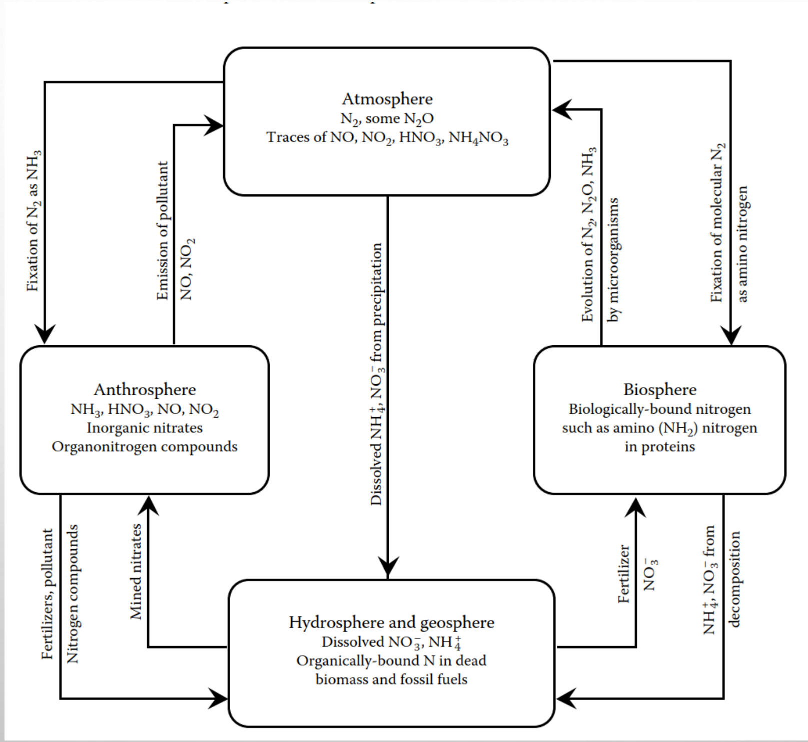


General outline of exogenic and endogenic cycles of matter.

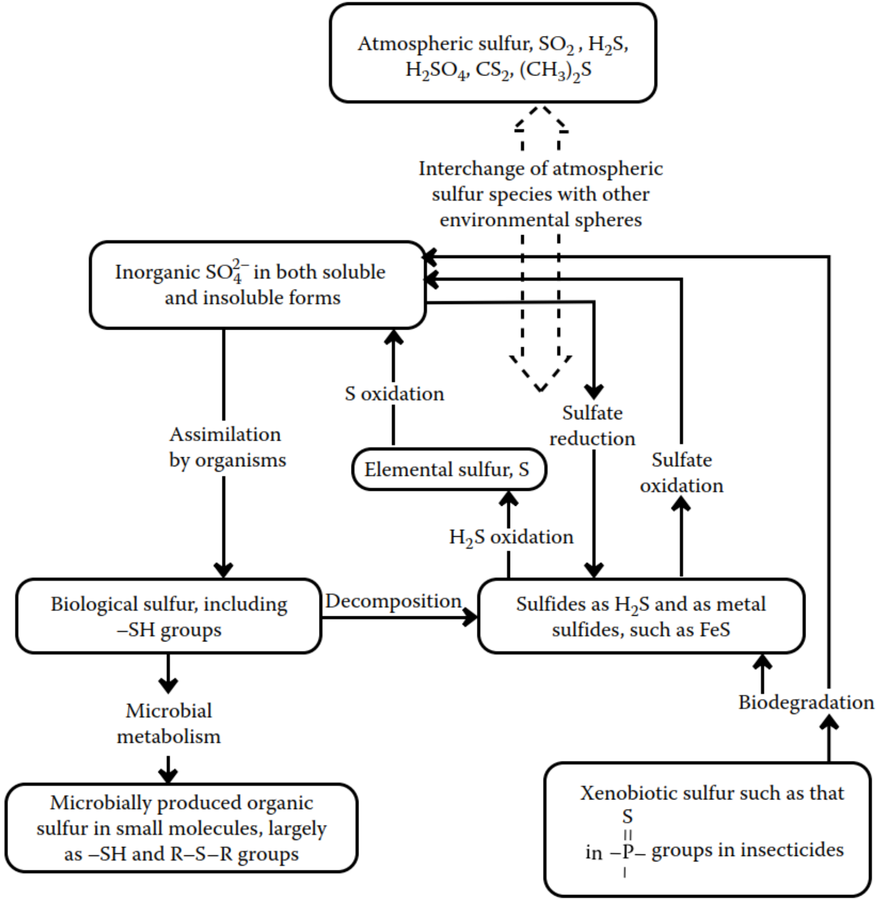
CARBON CYCLE



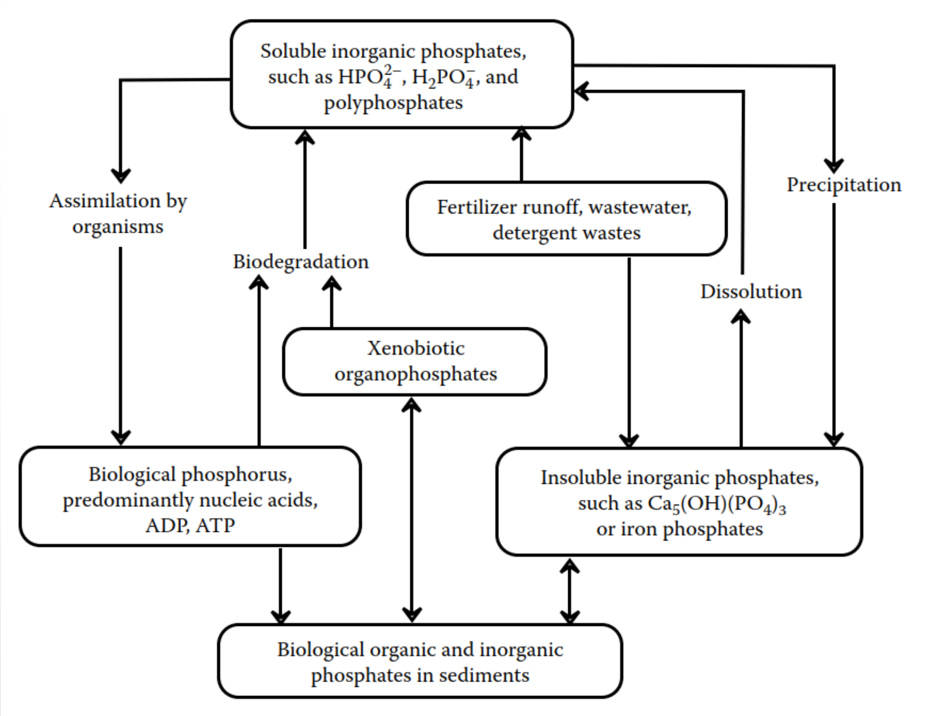
NITROGEN CYCLE



SULFUR CYCLE

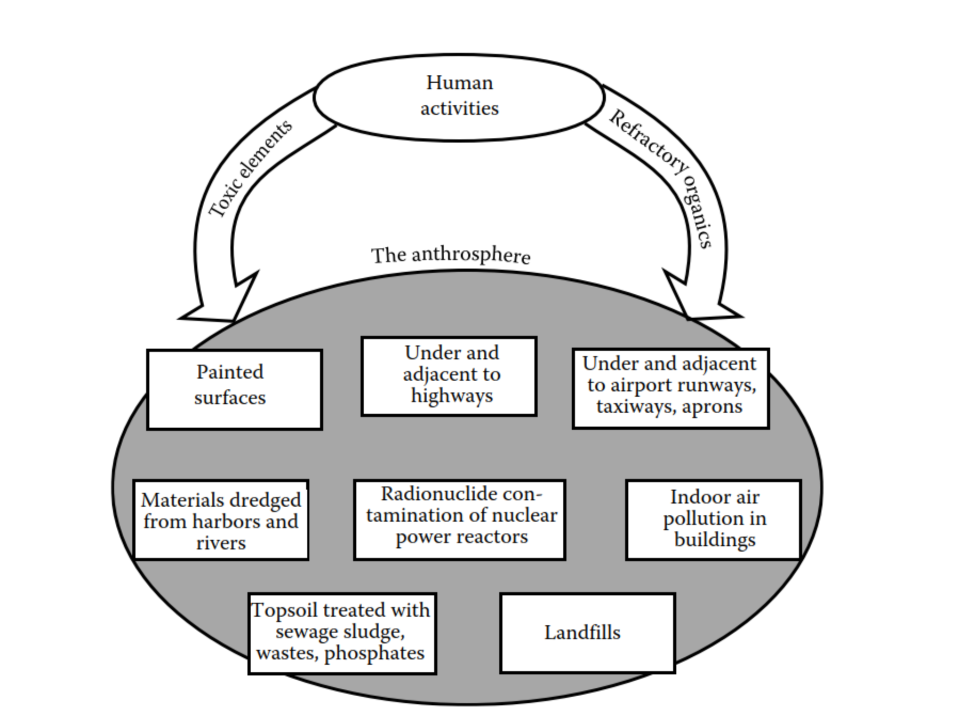


Phosphorus Cycle



ANTHROPOSPHERE

The anthroposphere encompasses the total human presence throughout the Earth system including our culture, technology, built environment, and associated activities.



Air pollution is the poisoning of air caused by the presence of compounds in the atmosphere that are hazardous to human and other living beings' health, as well as to the environment and materials.

Gases (like ammonia, carbon monoxide, sulphur dioxide, nitrous oxides, methane, carbon dioxide, and chlorofluorocarbons), particles (including organic and inorganic), and living molecules are all examples of air pollution.

Many pollution-related disorders, including respiratory infections, heart disease, COPD, stroke, and lung cancer, are all linked to air pollution.

Some of the natural sources of air pollution are organic compounds from plants, sea salt, suspended soils and dusts (e.g. from the Sahara). Other natural sources are released during catastrophes such as volcanic eruptions and forest fires.

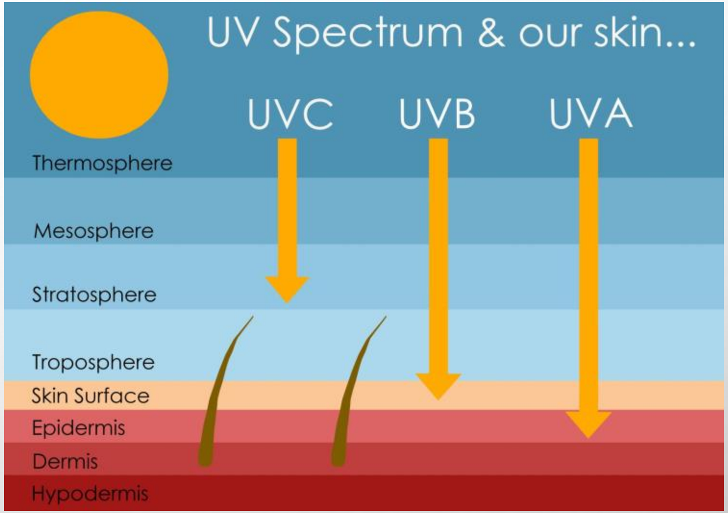
AIR POLLUTION

- Primary air pollutants: Pollutants that are formed and emitted directly from particular sources. Examples are particulates, carbon monoxide, nitrogen oxide, and sulfur oxide.
- Secondary air pollutants: Pollutants that are formed in the lower atmosphere by chemical reactions. The two examples are ozone and secondary organic aerosol (haze).
- Secondary pollutants are harder to control because they have different ways of synthesizing and the formation are not well understood. They form naturally in the environment and cause problems like photochemical smog.

haze, suspension in the atmosphere of dry particles of dust, salt, aerosols, or photochemical smog that are so small (with diameters of about 0.1 micron [0.00001 cm]) that they cannot be felt or seen individually with the naked eye, but the aggregate reduces horizontal visibility and gives the atmosphere an opalescent appearance. Haze appears as a bluish or yellowish veil depending on whether the background is dark or light, respectively. With respect to these colours, haze can be discriminated from mist, which gives a grayish cast to the sky.

OZONE LAYER

The ozone layer serves as a protective layer in the atmosphere. It has the highest concentration of ozone of any layer of the atmosphere. However, when compared to other gases, ozone makes up a small percentage of the air in the ozone layer. This layer blocks the sun's harmful UV rays from entering our atmosphere. UV rays cause skin cancer in people and animals and are also hazardous to plants. Any disruption to the ozone layer can have severe consequences for living things.



Ozone depletion indicates the progressive reduction of the Earth's ozone layer, chiefly attributed to the emission of specific chemical compounds into the atmosphere. The ozone layer, situated in the stratosphere, is essential for safeguarding life on Earth by absorbing most of the sun's detrimental ultraviolet (UV) radiation.

Factors Contributing to Ozone Depletion: Chlorofluorocarbons (CFCs):

Commonly employed in refrigeration, air conditioning, aerosol propellants, and foam-blowing agents.

Upon discharge into the atmosphere, CFCs ascend to the stratosphere, where ultraviolet radiation degrades them, liberating chlorine atoms.

Chlorine atoms catalyze the degradation of ozone molecules (O_3), resulting in ozone depletion.

Halons and Additional Halogenated Compounds:

Used in fire extinguishers and industrial procedures.

Similar to CFCs, they emit bromine and chlorine, which degrade ozone.

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Natural Origins:

Volcanic eruptions and specific natural processes can emit ozone-depleting compounds; nevertheless, their effect is negligible in comparison to anthropogenic activity.

Effects of Ozone Depletion: Increased UV Radiation:

The depletion of the ozone layer permits increased UV-B radiation to penetrate the Earth's surface.

This can lead to greater risks of skin cancer, cataracts, and impaired immune systems in people.
Environmental Impact:
UV radiation can disrupt marine ecosystems, notably phytoplankton, which form the foundation of the oceanic food chain.

Terrestrial plants may experience diminished growth and photosynthesis.

Climate Change:

Ozone depletion and climate change are related. Some ozone-depleting compounds are also potent greenhouse gases, contributing to global warming.

Global Response: Montreal Protocol (1987):

An international convention aimed to phase out the production and consumption of ozone-depleting chemicals.

Widely regarded as one of the most effective environmental agreements, contributing to a considerable reduction in CFCs and other dangerous chemicals. Effects of Ozone Depletion: Increased UV Radiation:

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Recovery of the Ozone Layer:
Due to global efforts, the ozone layer is progressively rebounding. Scientists anticipate it could return to pre-1980 levels by the middle of the 21st century.
Ongoing Challenges: Illegal Production and Use:
Despite prohibitions, clandestine manufacture and usage of CFCs have been recorded in some places.
Replacement Chemicals:
Some alternatives to CFCs, such as hydrofluorocarbons (HFCs), do not degrade ozone but are significant greenhouse gases, contributing to climate change.
Conclusion: Ozone depletion is a serious environmental concern that has been mostly addressed by international cooperation and regulation. Continued attention and commitment to the Montreal Protocol are required to ensure the full recovery of the ozone layer and to limit the related dangers to human health and the environment.

Breakdown of ODS by UV Radiation

In the stratosphere, strong ultraviolet (UV) radiation from the sun breaks down CFCs and other ODS, releasing chlorine (Cl) and bromine (Br) atoms.

For example:

$CFCl3 + UV\ light \rightarrow Cl + CFCl2$

catalytic Destruction of Ozone

Chlorine and bromine atoms act as catalysts in the destruction of ozone (O_3).

A single chlorine atom can destroy thousands of ozone molecules before being deactivated.

The process involves the following reactions:

$Cl+O3 \rightarrow ClO+O2$

$Cl+O3 \rightarrow ClO+O2$

$ClO+O \rightarrow Cl+O2$

$ClO+O \rightarrow Cl+O2$

The net reaction is:

$O3+O \rightarrow 2O2$

$O3 +O \rightarrow 2O2$

Formation of Ozone

•**The free oxygen atoms (O) produced in the first step are highly reactive. They collide with other oxygen molecules (O_2) to form ozone (O_3):**

$O+O2 \rightarrow O3O+O2 \rightarrow O3$

Dynamic Equilibrium

•**Ozone is not stable and can be broken down by UV radiation (UV-B and UV-C) into an oxygen molecule (O_2) and a free oxygen atom (O):**

•**O3+UV-B/UV-C→O2+OO3+UV-B/UV-C→O2+O**

•**The free oxygen atom can then recombine with O_2 to form ozone again, creating a continuous cycle of ozone formation and destruction.**

Ozone-Oxygen Cycle

•**The balance between ozone formation and destruction is known as the ozone-oxygen cycle:**

•**O2+UV-C→2OO2+UV-C→2OO+O2→O3O+O2→O3O3+UV-B/UV-C→O2+OO3+UV-B/UV-C→O2+O**

•**This cycle maintains a relatively stable concentration of ozone in the stratosphere.**

AIR POLLUTANTS

1. Primary Pollutants

These are emitted directly into the atmosphere from identifiable sources.

Common Primary Pollutants:

- **Carbon Monoxide (CO):**
  - **Source: Incomplete combustion of fossil fuels (e.g., vehicles, power plants, wildfires).**
  - **Impact: Reduces oxygen delivery in the bloodstream, causing headaches, dizziness, and even death at high concentrations.**
- **Sulfur Dioxide (SO_2):**
  - **Source: Burning of sulfur-containing fuels (e.g., coal, oil) in power plants and industrial processes.**
  - **Impact: Causes respiratory issues, acid rain, and damage to ecosystems.**
- **Nitrogen Oxides (NO_x):**
  - **Source: Combustion processes in vehicles, power plants, and industrial facilities.**
  - **Impact: Contributes to smog, acid rain, and respiratory problems.**

AIR POLLUTANTS

- Particulate Matter (PM):
  - Source: Combustion of fossil fuels, industrial processes, construction activities, and natural sources like dust and wildfires.
  - Impact: $PM_{2.5}$ (fine particles) and PM_{10} (coarse particles) can penetrate the lungs and bloodstream, causing respiratory and cardiovascular diseases.
- Volatile Organic Compounds (VOCs):
  - Source: Vehicle emissions, industrial processes, solvents, paints, and household products.
  - Impact: Contributes to smog formation and can cause eye, nose, and throat irritation.
- Ammonia (NH_3):
  - Source: Agricultural activities (e.g., livestock waste, fertilizer use).
  - Impact: Contributes to particulate matter formation and acid rain.

AIR POLLUTANTS

2. Secondary Pollutants

These are formed in the atmosphere through chemical reactions involving primary pollutants.

Common Secondary Pollutants:

- **Ozone (O_3):**
  - **Formation: Reaction of NO_x and VOCs in the presence of sunlight.**
  - **Impact: A key component of smog; causes respiratory issues, damages crops, and harms ecosystems.**
- **Peroxyacetyl Nitrate (PAN):**
  - **Formation: Reaction of NO_x and VOCs.**
  - **Impact: Irritates eyes and respiratory system, damages plants.**
- **Sulfuric Acid (H_2SO_4) and Nitric Acid (HNO_3):**
  - **Formation: Reaction of SO_2 and NO_x with water vapor.**
  - **Impact: Major components of acid rain, which harms ecosystems, buildings, and soil.**

AIR POLLUTANTS

3. Other Air Pollutants

- **Heavy Metals:**
  - **Examples: Lead (Pb), mercury (Hg), cadmium (Cd).**
  - **Source: Industrial processes, vehicle emissions (lead), and coal combustion.**
  - **Impact: Toxic to humans and wildlife; can accumulate in the food chain.**
- **Greenhouse Gases:**
  - **Examples: Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O).**
  - **Source: Burning of fossil fuels, agriculture, and industrial processes.**
  - **Impact: Contributes to global warming and climate change.**
- **Biological Pollutants:**
  - **Examples: Pollen, mold spores, bacteria, and viruses.**
  - **Source: Natural processes and human activities (e.g., agriculture, waste disposal).**
  - **Impact: Can cause allergies, asthma, and infectious diseases.**

AIR POLLUTANTS

Sources of Air Pollutants

- **Anthropogenic (Human-Made) Sources:**
    - **Transportation (cars, trucks, airplanes).**
    - **Industrial processes (factories, power plants).**
    - **Agricultural activities (fertilizer use, livestock).**
    - **Residential activities (heating, cooking, waste burning).**
- **Natural Sources:**
    - **Wildfires.**
    - **Volcanic eruptions.**
    - **Dust storms.**
    - **Biological decay.**

AIR POLLUTANTS

Carbon Monoxide (CO) Formation in Air Pollution

Sources of Carbon Monoxide:

A. Incomplete Combustion:

Vehicles: Automobiles, trucks, and other vehicles burning fossil fuels like gasoline and diesel emit CO due to incomplete combustion.

Industrial Processes: Factories and power plants that burn fuel for energy can release CO if combustion is not complete.

Natural Sources: Wildfires, volcanic eruptions, and biomass burning also contribute to CO emissions.

B. Chemical Reactions:

In complete combustion, hydrocarbons react with oxygen to form CO_2 and water. However, with insufficient oxygen, CO is produced:

Complete combustion: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

Incomplete combustion: $C_3H_8 + 3.5O_2 \rightarrow 3CO + 4H_2O$

AIR POLLUTANTS

Measurement and Monitoring:
•**CO is measured using instruments like nondispersive infrared (NDIR) analyzers and monitored globally through satellite remote sensing.**

Introduction to Sulfur Dioxide
Sulfur dioxide is a gas formed primarily through the burning of fossil fuels containing sulfur, such as coal and oil. It is a significant air pollutant with various environmental and health impacts.

Formation and Sources of Sulfur Dioxide
•**Anthropogenic Sources:**

- **Fossil Fuel Combustion: Power plants and industries burning coal and oil release SO_2.**
- **Vehicle Emissions: Although less significant than power plants, vehicles contribute to SO_2 emissions.**
- **Industrial Processes: Metal smelting and other industrial activities emit SO_2.**

AIR POLLUTION

- **Natural Sources:**
  - **Volcanic Eruptions: Release large amounts of SO_2.**
  - **Geothermal Activities: Contribute to natural SO_2 emissions.**

3. Environmental and Health Impacts

•Acid Rain: SO_2 reacts with water vapor to form sulfuric acid, leading to acid rain, which damages ecosystems and infrastructure.

•Human Health: Irritates the respiratory system, exacerbates asthma, and can lead to respiratory diseases.

•Climate Impact: Reflects sunlight, potentially cooling the Earth, though its impact is complex and interacts with other pollutants.

•During combustion, sulfur in the fuel reacts with oxygen:

$S+O2 \rightarrow SO2S+O2 \rightarrow SO2$

AIR POLLUTION

Nitrogen Oxides as Air Pollutants: A Comprehensive Overview

1. Introduction to Nitrogen Oxides (NO_x):

Nitrogen oxides refer to a set of gases, notably nitrogen monoxide (NO) and nitrogen dioxide (NO_2), generated during high-temperature combustion processes.

2. Formation and Sources:

Combustion Processes: Formed when fossil fuels containing nitrogen are burned in automobiles, power plants, and businesses.

Natural Sources: Includes lightning and microbiological activity in soil from agricultural activities.

3. Environmental and Health Impacts:

Smog Formation: NO_2 combines with other pollutants in sunlight to generate ground-level ozone, contributing to smog.

AIR POLLUTION

Acid Rain: Reacts with water and oxygen to form sulfuric and nitric acids, harming ecosystems and infrastructure.
Health Effects: Irritates lungs, reduces lung function, and increases respiratory problems, particularly in asthmatics.
4. Mitigation Strategies:
Technological Solutions: Catalytic converters in vehicles and scrubbers in industries to reduce emissions.
Cleaner Energy: Transition to wind and solar power to minimize fossil fuel use.
Individual Actions: Carpooling, public transportation, biking, and energy conservation.
5. Regulatory and Policy Measures:
Emission Standards: Euro standards in Europe and similar regulations globally to limit NO_x emissions.
Challenges: Enforcement and compliance, especially in rapidly developing economies.

AIR POLLUTION (SMOG AND SMOKE)

Smog and smoke are both significant air pollutants, but they differ in their composition, formation, and environmental impact. Understanding these differences is crucial for developing effective strategies to address air pollution.

- **Smoke: A mixture of particles and gases released during combustion, including soot, ash, carbon monoxide, and nitrogen dioxide. It originates from sources like wildfires, industrial activities, and vehicle exhausts.**
- **Smog: A complex mixture of pollutants, primarily involving nitrogen oxides and volatile organic compounds, which react in the presence of sunlight to form ozone and other harmful substances. There are two main types: traditional (London) smog and photochemical (Los Angeles) smog.**

Composition and Formation:

- **Smoke is a primary pollutant, directly emitted from combustion sources.**
- **Smog involves secondary pollutants, such as ozone, formed through atmospheric reactions.**

Health and Environmental Impacts:

- **Both smoke and smog can cause respiratory issues, eye irritation, and other health problems.**
- **Smog, particularly photochemical smog, contributes to ground-level ozone, which is harmful to humans and the environment.**
- **Meteorological factors, such as temperature inversions, can exacerbate smog conditions.**

TYPES OF SMOG

There are two types of smog:

A. Sulphureous or London Smog

It is a mixture of smoke, fog and sulphur dioxide that affected London so badly after the introduction of coal as a fuel, is chemically reducing mixture, so it is called reducing smog.

Components of Reducing Smog

These are:

1.SOx

2.Particulates such as soot, ammonium sulphate etc.

3.Humidity from fog and aerosol

B. Photochemical Smog

During the 1940s, a novel form of air pollution known as photochemical smog was initially identified in Los Angeles. This unique type of smog i s caused by a combination of several major air pollutants, including car bon oxides (CO, CO2), nitrogen oxides and nitric acid (NO, NO2, HNO3), sulphur dioxide and sulphuric acid (SO2, H2SO4), suspended particulat e matter (SPM), ozone (O3), and volatile organic compounds (VOCs).

1.Components of Photochemical Smog

Vehicular exhaust, unsaturated hydrocarbons, oxides of nitrogen, carbo n monoxide, hydrogen peroxide, ozone, some compounds containing s ulphur, organic peroxides, hydroperoxides, peroxy acetyl nitrate, perox ybenzyl nitrate, peroxy propionyl nitrate, aldehydes, tertiary butyl hydro peroxide, and particulates constitute components of smog.

2. Mechanism of Smog Formation

$$NO_2 + H_2O \rightarrow NO + 2\,\dot{O}H$$

$$NO + NO_2 + H_2O \rightarrow 2HONO \xrightarrow[400nm]{SUNLIGHT} 2NO + 2\,\dot{O}H$$

c) Oxidation of Hydrocarbons

The vehicular exhaust also emits volatile hydrocarbons which are oxidized by $\dot{O}H$ radical.

$$\dot{O}H + RCH_3 \rightarrow R\dot{C}H_2 + H_2O$$
$$R\dot{C}H_2 + O_2 + M \rightarrow RCH_2OO^{\cdot} + M$$
$$RCH_2OO^{\cdot} + NO \rightarrow RCH_2O^{\cdot} + NO_2$$
$$RCH_2O^{\cdot} + O_2 \rightarrow RCHO + HOO^{\cdot}$$
$$HOO^{\cdot} + NO \rightarrow NO_2 + \dot{O}H$$

The sum of the above reaction is

$$RCH_3 + 2O_2 + 2NO \rightarrow RCHO + 2NO_2 + H_2O$$

Oxidation of hydrocarbon can also be written as

$$RCH_3 + 2O_2 + H_2O \rightarrow RCHO + 4\dot{O}H$$

Other important reactions include the aldehyde product of oxidation by hydrocarbons.

$$CH_3CHO + \dot{O}H \rightarrow CH_3\dot{C}O + H_2O$$
$$CH_3\dot{C}O + O_2 + M \rightarrow CH_3COOO^{\cdot} \xrightarrow{NO_2} CH_3COOONO_2$$

Peroxy acetyl nitrate (PAN) is relatively stable at low temperatures. In warmer regions PAN breaks down releasing NO_2 and the latter has the potential of producing more O_3 and hydroxyl radicals.

$$CH_3COOONO_2 \rightarrow CH_3COOO^{\cdot} + NO_2$$

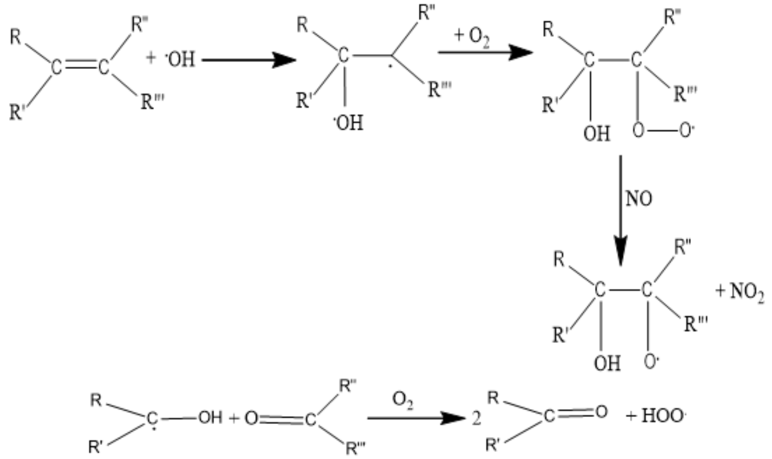
d) Volatile organic compounds and their oxidation.

There are two ways by which hydroxyl radicals initiate the oxidation of hydrocarbon reactants.

Hydroxyl radical abstracts H atom.

$$\dot{O}H + CO \rightarrow H^{\cdot} + CO_2$$
$$\dot{O}H + CH_4 \rightarrow \dot{C}H_3 + H_2O$$

The second type of hydroxyl radical initiation reaction is expressed with olefins. In this way electrophilic $\dot{O}H$ adds to the double bond.



Temperature inversion is a phenomenon in which the temperature of the atmosphere increases with height, rather than the usual decrease with height. In normal conditions, air temperature decreases as altitude increases, which is why it's colder at the top of a mountain than at the base. However, during a temperature inversion, the situation is reversed, and warmer air is found above cooler air.

Causes of Temperature Inversion:

1.Radiation Inversion: This occurs on clear, calm nights when the ground cools rapidly by radiating heat away. The air in contact with the ground also cools, forming a layer of cool air near the surface. If the cooling is strong enough, a temperature inversion can form.

2.Advection Inversion: This happens when warm air is blown over a cooler surface by wind. For example, warm air moving over a cold ocean current can lead to an inversion.

3.Subsidence Inversion: This occurs when air descends and warms due to compression. As air sinks, it warms up, creating a layer of warm air above cooler air. This is common in areas of high pressure.

4.Orographic Inversion: This happens when air is forced to rise over mountains. As it rises, it cools and may reach a point where it stops rising and flows parallel to the mountain range, creating an inversion layer.