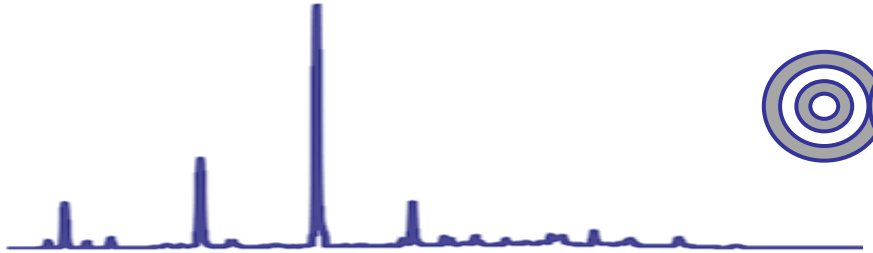
بسم الله الرحمن الرحيم

Introduction to Environmental Chemistry



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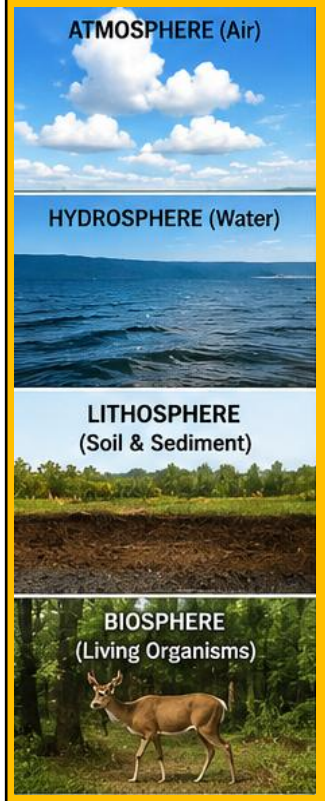
Environmental Science

Scientific study of the environment and interactions among its physical, chemical, biological, microbiological, and geological components

How does the environmental system work & how is it changing?

Environmental Chemistry

The scientific study of the chemical and biochemical phenomena that occur in natural places such as air, soil, and water environments



Acid–Base Reactions

$HA \rightleftarrows H^+ + A^-$

Oxidation–Reduction

$Fe^{2+} \rightarrow Fe^{2+}$ (e^- transfer)

Complexation

$Cu^{2+} + 4NH_3 \rightleftarrows [Cu(NH_3)_4]^{2+}$

Adsorption–Desorption

Precipitation–Dissolution

$Ag^+ + Cl^- \rightleftarrows AgCl(s)$

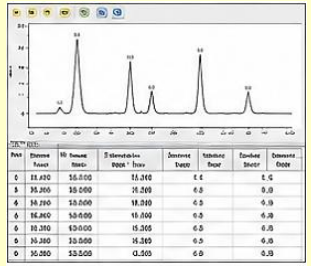
Photochemical Reactions

$NO_2 + h\nu \rightarrow NO + O(^3P)$

How chemicals behave in the environmental system?

Environmental Analysis

The use of analytical and statistical methods to study the chemical and biological factors that determine the quality of an environment



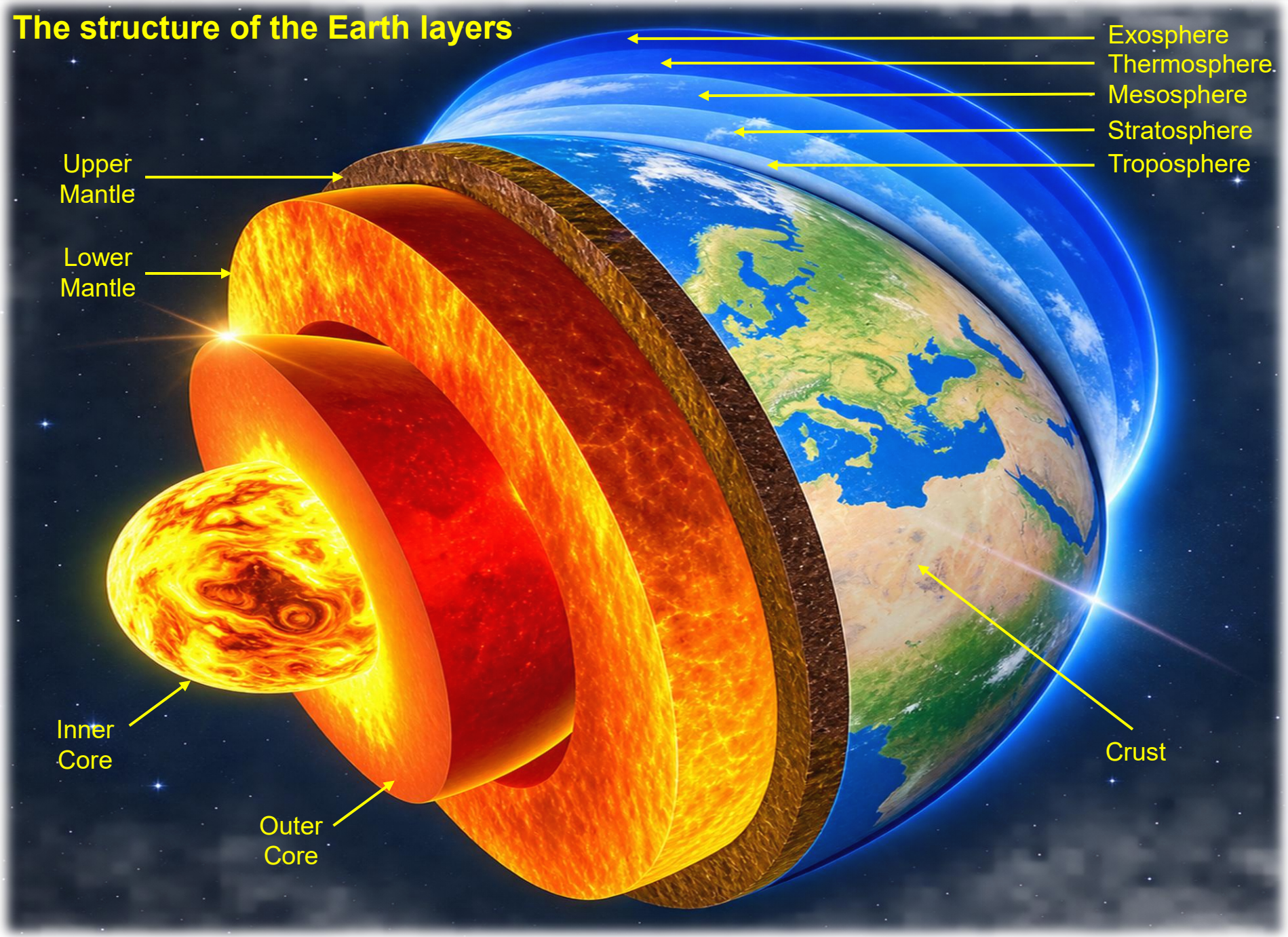
What substances are present & how much is there?

Environmental Chemistry

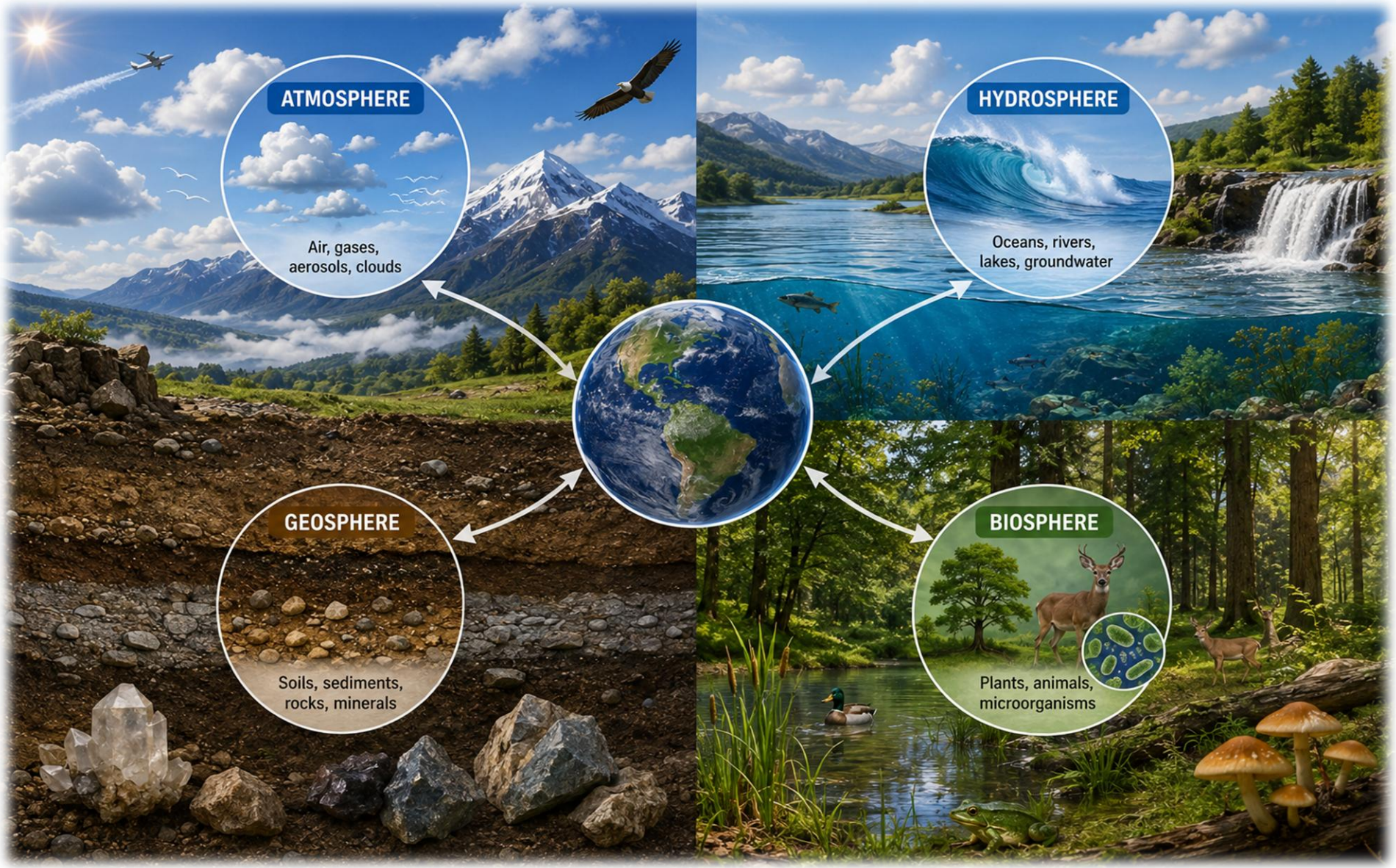
Environmental chemistry is the scientific study of the chemical and biochemical phenomena that occur in natural places.

Environmental chemistry is the study of the chemical composition, sources, reactions, transport, effect, and fate of substances in the environment.

Environmental chemistry examines both naturally occurring chemicals and substances introduced by human activities. The ultimate goal is to understand environmental change, pollutant behavior, exposure, and potential impacts.


The structure of the Earth layers
Exosphere
Thermosphere
Mesosphere
Stratosphere
Troposphere
Upper Mantle
Lower Mantle
Inner Core
Outer Core
Crust

Major Environmental Compartments



Sources of Chemicals

Natural sources	Anthropogenic sources
Volcanic emissions	Industrial emissions
Weathering of rocks and minerals	Transportation (vehicle exhaust)
Wildfires and dust	Agriculture (pesticides and fertilizers)
Biological decomposition	Mining and petroleum activities
Ocean-atmosphere exchange	Municipal and hazardous wastes
Sea spray	Wastewater discharge
Soil minerals	Solid waste

Pollutants and Contaminants

Contaminants	Pollutants
A chemical or substance present in an environmental medium at a concentration or location where it is not normally expected.	A contaminant that causes, or has the potential to cause, adverse environmental, ecological, or human-health effects.
Examples	**Examples**
Trace pharmaceutical detected in water	Persistent pharmaceutical affecting aquatic organisms
Low-level pesticide residue in soil	Toxic pesticide at ecologically relevant concentration
CO_2 at levels that alter the natural balance of the air	Excess atmospheric CO_2 contributing to climate change
Ozone in a controlled environment	Elevated ozone at ground level
Trace mercury detected in natural water or sediment	Methylmercury accumulating in fish
Trace PFAS detected in groundwater	Persistent PFAS causing human-health risk

Not every chemical detected in the environment is a pollutant

The distinction depends on concentration, chemical form, exposure, persistence, mobility, toxicity, and environmental context.

Chemical Composition of the Environment

	Atmosphere (Air)	Hydrosphere (Water)	Geosphere (Soil)
Major components	N_2, O_2, Ar, CO_2, H_2O vapor	H_2O	Minerals, rocks, soil
Important ions/species	NO_x, SO_2, NH_3, O_3	Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, Cl^-, SO_4^{2-}	Si, Al, Fe, Ca, Mg, K, Na
Carbon chemistry	CO_2, CH_4, VOCs	$CO_2/HCO_3^-/CO_3^{2-}$, organic C	Carbonates, organic matter
Nutrients	N_2, NH_3, NO_x	NH_4^+, NO_3^-, PO_4^{3-}	Organic N, NH_4^+, NO_3^-, phosphate
Important solids	Aerosols	Suspended particles	Clay, quartz, oxides
Natural organic matter	VOCs, aerosols	Dissolved organic compounds, humic substances	Humic matter, biomass
Major pollutants	Particulate matter, SO_2, NO_x, O_3, VOCs	Metals, pesticides, nutrients, PFAS	Metals, pesticides, PAHs, PFAS

Chemical composition varies with location, season, temperature, pH, redox conditions, and biological activity.
Concentrations range from major components (g/L or %) to trace and ultra-trace contaminants (mg/L, µg/L, ng/L).

Classification of Environmental Pollutants

Based on their chemical nature and composition

Inorganic pollutants	Organic pollutants	Biological pollutants	Particulate pollutants
Heavy metals: Hg, Pb, Cd, Cr, As, Ni Nutrients: NO_3^-, NH_4^+, PO_4^{3-} SO_2, NO_x Cyanide (CN^-) Fluoride (F^-)	Pesticides PAHs PCBs VOCs Petroleum hydrocarbons Phenols Organic solvents	Pathogenic bacteria Viruses Protozoa Parasites Harmful algal blooms Biological toxins	Particulate matter Dust Soot/black carbon Smoke Aerosols Suspended sediments Microplastics
Mining, industry, fertilizers, combustion, wastewater	Agriculture, petroleum industry, industrial processes, combustion	Sewage, agricultural runoff, animal waste, contaminated water	Combustion, construction, industry, transportation, erosion

Based on their physical state/form

Gases pollutants	Liquids pollutants	Solids pollutants	Particulates pollutants
Gases or vapors	Liquids or dissolved substances	Solid materials	Suspended solid or liquid particles
SO_2, NO_2, CO, O_3, VOCs	e.g., petroleum/oil, solvents, liquid industrial wastes	e.g., heavy metals, solid waste, plastic debris	e.g., particulate matter, dust, soot, smoke, aerosols

Classification of Environmental Pollutants

Based on their formation and emission

Primary pollutants	Secondary pollutants
Emitted directly from a specific source into the environment	Formed when primary pollutants react in the environment
e.g., CO, SO_2, NO	e.g., H_2SO_4, HNO_3, ground-level O_3, acid rain

Based on their persistence and degradability

Non-persistent (biodegradable) pollutants	Persistent pollutants
Pollutants that can be broken down relatively quickly by microorganisms or natural processes	Pollutants that resist degradation and remain in the environment for long periods
e.g., sewage organic matter, food waste, biodegradable pesticides	e.g., PFAS, PCBs, DDT, Hg

Based on their toxicity/effect

Toxic	Carcinogenic	Mutagenic	Teratogenic	Endocrine-disrupting	Ecotoxic
Cause harmful effects	Cause or promote cancer	Cause genetic/DNA damage	Cause developmental abnormalities	Interfere with hormones	Harm organisms or ecosystems
e.g., Hg, Pb, pesticides	e.g., benzene, PAHs	e.g., benzene, some PAHs	e.g., methylmercury	e.g., BPA, PCBs	e.g., pesticides, NH_3, heavy metals

Major Chemical Processes in the Environment

Acid-Base reactions

Transfer of protons (H^+) that controls environmental pH and chemical speciation

Example

$CO_2 + H_2O \rightleftharpoons H_2CO_3$

$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$

$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$

Oxidation-Reduction

Transfer of electrons between chemical species, changing their oxidation states

Example

$Fe^{2+} \rightarrow Fe^{3+} + e^-$ (oxidation)

$NO_3^- \rightarrow N_2$ (reduction)

Dissolution-Precipitation

Dissolution: transfers substances into solution/water; **Precipitation:** forms solid phases from dissolved species

Example

$CaCO_3(s) + H^+ \rightarrow Ca^{2+} + HCO_3^-$

$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3(s)$

Adsorption-Desorption

Chemicals attach to or are released from surfaces such as soil and clay minerals

Example

$Pb^{2+}(aq) + Clay \rightleftharpoons Clay\text{-}Pb^{2+}$

$Clay\text{-}Pb^{2+} \rightleftharpoons Pb^{2+}(aq) + Clay$

Major Chemical Processes in the Environment

Complexation/Chelation

Metal ions bind with ligands to form dissolved or particulate complexes

Example

$Cu^{2+} + Ligand \rightleftharpoons CuL^{2+}$

Ligand: Humic and fulvic substances

Hydrolysis

Reaction of a chemical with water

Example

$R–X + H_2O \rightarrow R–OH + HX$

It is particularly important for some pesticides, pharmaceuticals, industrial chemicals, or organophosphorus compounds

Photochemical reactions

Chemical reactions initiated or accelerated by sunlight

Example

NO_2 + sunlight $\rightarrow$ NO + O

Biodegradation/ Biotransformation

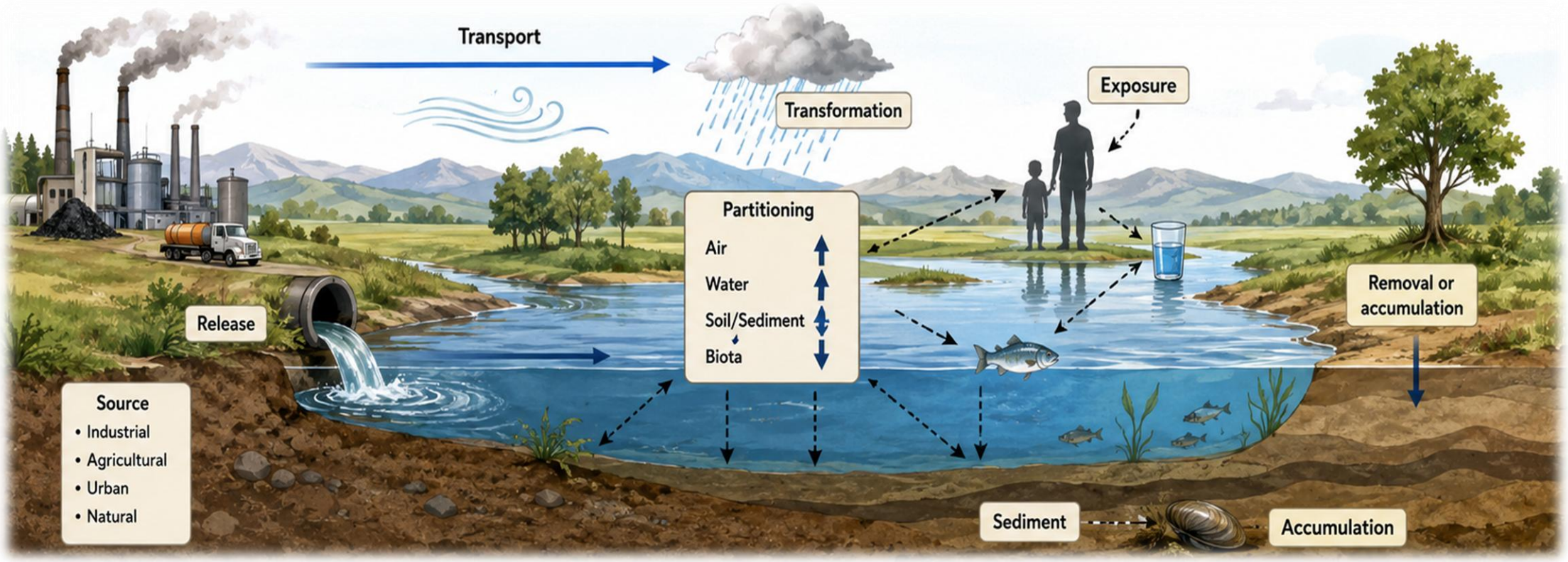
Microorganisms chemically transform or break down substances

Example

Organic matter + $O_2 \rightarrow CO_2 + H_2O$

Organic matter $\rightarrow CH_4 + CO_2$

Fate and Transport of Chemicals



Source

Release

Transformation

Exposure

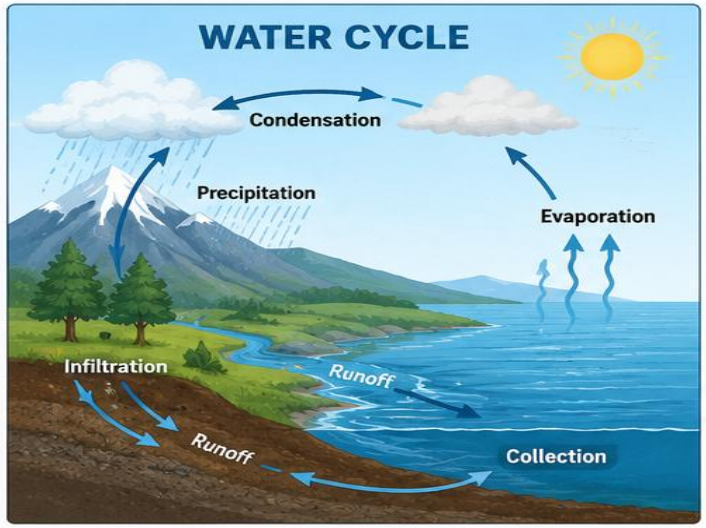
Transport

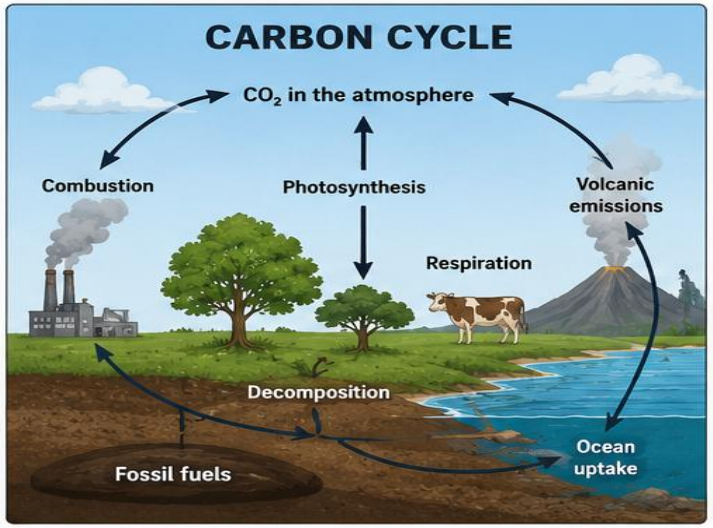
Partitioning

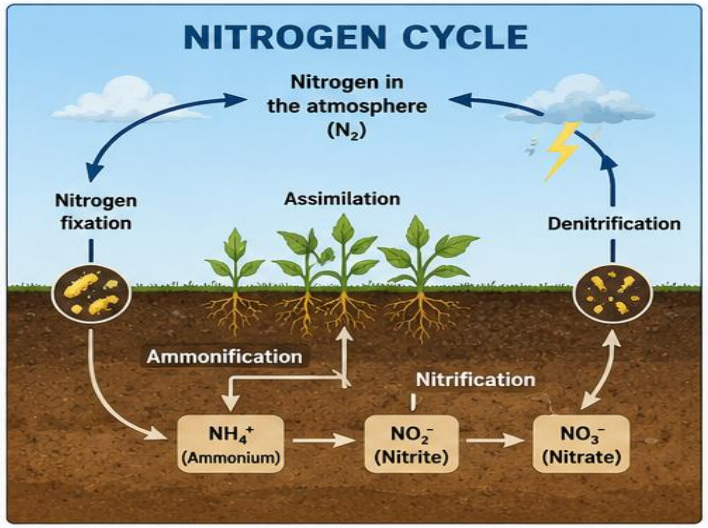
Removal or accumulation

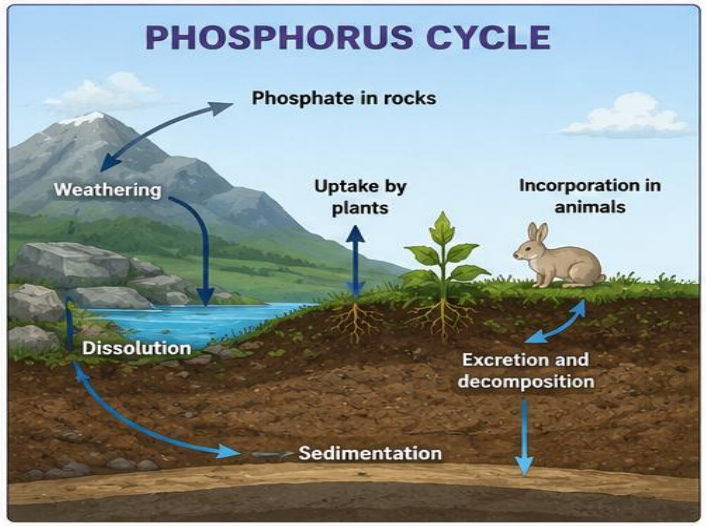
Major Biogeochemical Cycles

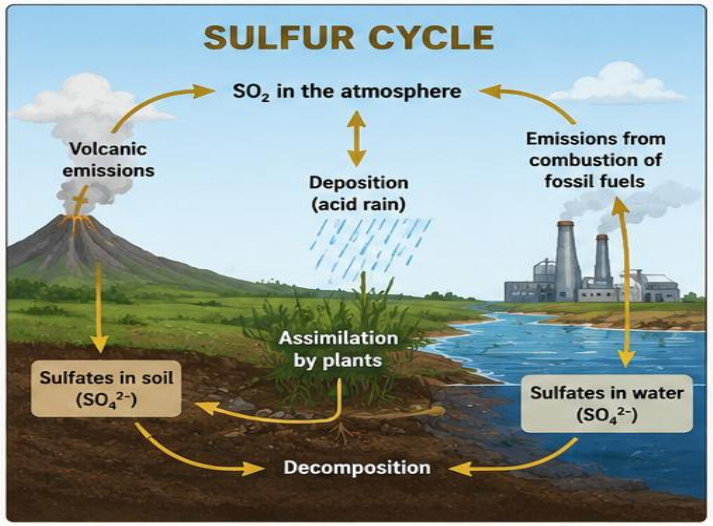
Biogeochemical cycles describe the continuous movement and transformation of chemical elements between the atmosphere, hydrosphere, geosphere, and biosphere.

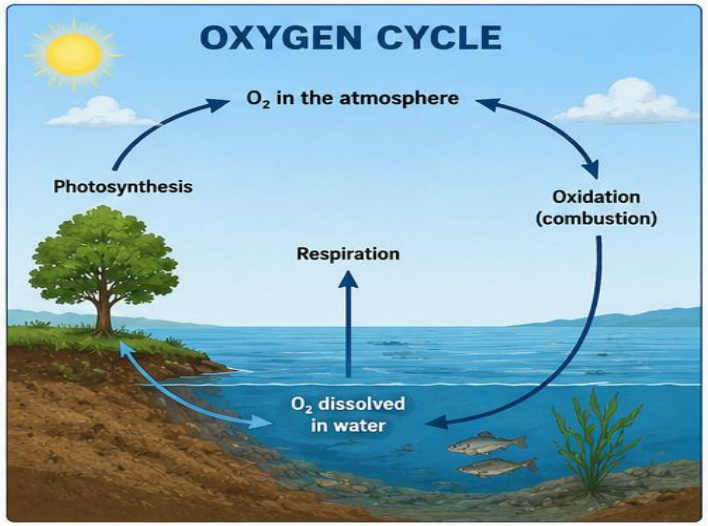












Persistence, Degradation, and Accumulation

Persistence
Resistance of a chemical to environmental transformation or removal

Biomagnification
Increasing concentration of a substance at higher trophic levels

Degradation
Conversion of a substance into other chemical products

Bioaccumulation
Net accumulation of a chemical in an organism from environmental and dietary exposure

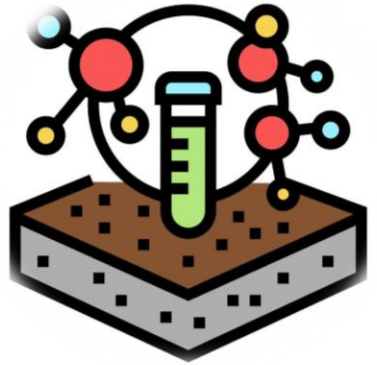
Importance of Environmental Chemistry

- Pollution tracking and control
- Water quality management
- Air quality and climate insights
- Remediation strategies
- Informing regulations
- Advancing green chemistry

Scope of Environmental Chemistry

Atmospheric chemistry

Soil chemistry



Pollutant

Chemistry

Aquatic chemistry

Biogeochemistry


Thank You!