



ENVIRONMENTAL CHEMISTRY



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MAJOR THEMES

Atmosphere, Hydrosphere & Geosphere Overlap

- **Atmosphere:** the 10,000-km layer of gas enveloping Earth
 - Regulates climate, protects life from solar radiation
- **Hydrosphere:** all of Earth's water
 - Vital for chemical cycling and supporting life; impacts climate patterns
- **Geosphere:** Earth's solid layer, including rocks and soil

Biogeochemical cycling

- Movement and transformation of elements and compounds between living organisms and the atmosphere, hydrosphere, and geosphere
- Natural processes, such as precipitation and erosion, drive this phenomenon
- Anthropogenic processes, such as fossil fuel combustion, also contribute
- Conservation of mass: mass is neither created nor destroyed in an isolated system
 - Underpins biogeochemical cycles and the flow of pollutants

- Most molecules and minerals can exist in air, water, or soil
 - Their natural biogeochemical cycles reflect such transformations

- Flow between environments has important consequences
 - Generally impossible to fully prevent industrial byproducts, emissions, and pollutants from affecting the surrounding environment

- Thermodynamics assess direction and extent of chemical processes
 - $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

- Kinetics assess their speed

- Changes in temperature and pressure alter the energy and solubility of substances, thereby altering reaction of both direction and speed

Abiotic & Biotic Overlap

- Abiotic components: nonliving elements, such as minerals, water, and air, which affect ecosystems
- Biotic components: living and once-living elements, such as soil microbes, plankton, and animal decay
- Underlying principle of biogeochemistry—elements cycle freely between living organisms and the “nonliving” environment
- Components of one organism's DNA can transform over time into carbon dioxide for plants, gaseous N_2 for nitrogen-fixing microbes, sugar in a banana, phosphorus in a mineral deposit, benzene in crude oil, or smog in the atmosphere
- Reverse is also true—mercury in crude oil can accumulate in fish; volcanic sulfur can wind up in eggs

Anthropogenic Effects

- Originate from human activity (e.g., industrial pollution, urban runoff)
- See Pollution, p. 4 and Anthropogenic Effects, p. 6, for further discussion

Industrial compounds & processes

- Can impact:
 - Surrounding ecosystems (e.g., car emissions create smog in a city)
 - Distant ecosystems (e.g., microplastic pollution in the deepest parts of the ocean)
 - Future ecosystems (e.g., climate change and climate feedback)

Extractive processes

- The power of anthropogenic effects often arises from extractive processes (e.g., mining, deforestation, and production of fossil fuels)
- This accentuates individual facets of a biogeochemical cycle
 - EX: Burning fossil fuels transfers nearly 40 billion tons of CO_2 from Earth into the atmosphere. This unnatural shift disrupts the carbon cycle and Earth's other abiotic, biotic, atmospheric, aquatic, and soil systems.

Climate feedback

- Self-reinforcing processes
- Change in one facet of global climate triggers additional changes
 - Amplifies or dampens the initial change
- EX: As rising global temperatures melt polar ice caps, Earth's reflectivity (albedo) decreases, leading to more absorption of solar radiation and more warming.



For other chemical cycles, see p. 6

ATMOSPHERIC CHEMISTRY

Key Definitions & Concepts

- **Aerosols:** influence climate by scattering and absorbing solar radiation and serving as cloud condensation nuclei
 - Can also have adverse health effects when inhaled, leading to respiratory issues
- **Carbon dioxide:** primarily from burning fossil fuels and deforestation
 - Natural sinks, such as oceans, marine photosynthesizers, and forests, absorb and sequester carbon
 - Help regulate atmospheric CO_2 levels
 - Sometimes lead to other problems, such as ocean acidification
- **Free radicals**
 - Hydroxyl radicals (HO^\bullet): drive atmospheric reactions that lead to smog
 - Nitric oxide (NO): a GHG pollutant; precursor to nitrogen oxides (NO_x)
 - Chlorine (Cl): depletes ozone (O_3) in the stratosphere
- **Greenhouse gases (GHG):** trap heat by absorbing incoming sunlight and distributing that heat across the atmosphere
 - EX: carbon dioxide, methane, nitrous oxide (N_2O)
- **Methane:** more potent, less abundant GHG than CO_2
 - Sources include livestock, clothes manufacturing, natural gas production, and wetland microbes
- **Nitrous oxide**
 - Soil and oceans form natural sinks
 - Sources include agricultural activities and combustion
- **Radioactive decay:** spontaneous process where unstable atomic nuclei (e.g., alpha particles, beta particles, or gamma rays) emit radiation
- **Radon:** radioactive gas released from decay of uranium in soil and rocks
 - Known carcinogen
- **Stratospheric ozone:** absorbs UVB radiation, reducing radiation that reaches Earth's surface
- **Tropospheric ozone (ground-level ozone):** forms from light-accelerated reactions of oxides and VOCs
 - Harmful to health and the ecosystem
- **Volatile organic compounds (VOCs):** small, airborne molecules at room temperature
 - Impact human health and contribute to ozone and particulate formation (e.g., benzene, toluene, acetone, formaldehyde)
- **Water droplets** can act as PM in the atmosphere
 - Trigger cloud formation and precipitation, reduce visibility
 - Humid air traps pollutants near the ground, worsening smog
- **Water vapor:** more abundant GHG than CO_2
 - Shorter lifetime in the atmosphere makes it less problematic

Photosynthesis

- **Origins:** 3+ billion years ago, cyanobacteria evolved the ability to split water molecules and produce oxygen as a byproduct
- This early photosynthesis led to the Great Oxidation Event
 - Increased Earth's atmospheric oxygen levels
 - Allowed for the evolution of all aerobic life forms

Radiative forcing

- Disrupted balance of incoming solar radiation versus outgoing infrared radiation
 - Due to atmospheric composition
- **Positive forcing:** traps infrared radiation and increases warming potential

EX: GHG

- **Negative forcing:** reflects solar radiation and decreases warming potential

EX: some types of brighter clouds and aerosols

Particulate matter (PM)

- Tiny, solid or liquid particles suspended in air, categorized by size and composition
- Originate from natural sources and human activities, such as combustion
- **PM_{2.5}:** 2.5 microns or less in diameter
- **PM₁₀:** 10 microns or less in diameter; therefore, includes PM_{2.5}
- **Impactors** for PM separate solids from an air sample into different size ranges for analysis
- **Electrostatic precipitators** remove PM from industrial exhaust gases by:
 - Charging particles
 - Collecting them on oppositely charged plates

Chemical Processes

Chemical composition of air



Key atmospheric layer processes

- Roughly 1,340 W/m^2 of solar radiation reaches Earth's upper atmosphere
 - 47% is absorbed by Earth's surface
 - 17% is absorbed by the atmosphere
- For every 2,090 W of infrared radiation emitted by the atmosphere, 1,293 W is absorbed at the surface
- For every 1,504 W of infrared radiation from Earth's surface, 1,460 W is absorbed in the atmosphere
- Radiation energy not absorbed by Earth's atmosphere or surface is reflected back to space

Radiation

Earth's radiation budget

- Altitude ranges above sea level and temperature ranges:
 - **Troposphere:** sea level (–15°C) to 10–16 km (–56°C)
 - **Stratosphere:** 10–16 km to –50 km (–2°C)
 - **Mesosphere:** –50 km to –85 km (–92°C)
 - **Thermosphere:** –85 km to –500 km (–1,200°C)

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