



# 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 dissipating 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
- **Radium:** 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<sub>2.5</sub>:** 2.5 microns or less in diameter
- **PM<sub>10</sub>:** 10 microns or less in diameter; therefore, includes PM<sub>2.5</sub>
- **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)

# Environmental Chemistry Study Guide

**Lingjun Ying**



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