2 The Composition of the Atmosphere

Learning Goals

After studying this chapter, students should be able to:

- describe the composition of Earth's atmosphere, and the processes by which the most common gases enter and leave the atmosphere (pp. 20–32);
- evaluate the roles of carbon dioxide, water vapour, ozone, and aerosols in the climate system (pp. 26–36); and
- outline the evolution of Earth's atmosphere (pp. 36–40).

Summary

1. Atmospheric gases are either constant or variable. Those that are **constant** are found in the same concentrations throughout the atmosphere up to a height of about 80 km; this lower compositional layer is known as the **homosphere**. Above 80 km, in the layer known as the **heterosphere**, the gases settle out based on their molecular weights. The **variable gases** are those that occur in different amounts in different times and places.
2. Elements and compounds are transferred through the four spheres of the Earth system in **biogeochemical cycles**. The average amount of time that a gas spends in the atmosphere, or other **reservoir**, is known as its **residence time**. Constant gases have long residence times, while variable gases have shorter residence times.
3. Nitrogen entered the early atmosphere through **outgassing**. Today, the source of atmospheric nitrogen is **denitrification**, while the sink is **nitrogen fixation**.
4. The major source of oxygen for the atmosphere is photosynthesis. The sinks for oxygen are respiration, decomposition, combustion, and oxidation.
5. In the short-term carbon cycle, the sources are respiration, decomposition, and combustion, while the sink is photosynthesis. In the long-term carbon cycle, the sources are volcanism and weathering of organic carbon, while the sink is silicate weathering. Carbon dioxide is a **greenhouse gas**. The carbonate-silicate cycle controls the amount of carbon dioxide in the atmosphere. Therefore, it is thought that this cycle may have been an important regulator of the climate throughout most of Earth's history.
6. Water vapour is the most variable of the atmospheric gases; it is also a greenhouse gas. Water exists in all three phases at normal Earth temperatures, and it absorbs and releases **latent heat** as it changes phase.
7. The **residence time** for ozone in the atmosphere is very short because it is continually created and destroyed by photochemical reactions in the stratosphere. In the process, most of the sun's ultraviolet radiation is absorbed, preventing it from reaching Earth's surface. Ozone is also a greenhouse gas and a pollutant.
8. Atmospheric **aerosols** are solid or liquid particles that can remain suspended in the atmosphere. The sources of aerosols are numerous and diverse; they come from the land and the ocean, they result from life processes, and they are produced by human activities. **Primary aerosols** are emitted directly into the atmosphere, while **secondary aerosols** form in the atmosphere.
9. Earth's primitive atmosphere was high in water vapour and carbon dioxide, and low in nitrogen. There was no oxygen. As water vapour condensed, it left the atmosphere in the form of precipitation and formed in the oceans. Some of the carbon dioxide dissolved in rain water and was removed by rock weathering. Much of the rest of the carbon dioxide was removed by photosynthesis and subsequent burial of organic carbon. As a result of both processes, most of Earth's carbon is now stored in rocks. As the originally dense atmosphere thinned, nitrogen became the most abundant gas. Even though oxygen was being produced by photosynthesis as far back as 3.5 billion years ago, this gas did not begin to accumulate in our atmosphere until about 2 billion years ago. Some of the oxygen in the atmosphere reacted to form the ozone layer.
10. Comparison of Earth's atmosphere to those of Venus and Mars suggests why Earth is habitable while the other two planets are not. Earth's distance from the sun, combined with its size, prob-

ably caused its atmosphere to evolve quite differently from those of the other two planets. Once life established itself on Earth, it seems to have played an important role in further shaping the atmosphere.

Key Terms

Aerosols Tiny solid or liquid particles suspended in the atmosphere (p. 33).

Anaerobic decomposition A process of decay that occurs when oxygen is unavailable (p. 26).

Biogeochemical cycle The various pathways that chemical elements repeatedly follow as they flow through the atmosphere, rocks, water, ice, and life of Earth (p. 22).

Carbon cycle The biogeochemical cycle in which carbon is transferred between the various reservoirs of the Earth system (p. 26).

Carbonate-silicate cycle The inorganic part of the carbon cycle, in which carbon dioxide is removed from the atmosphere as silicate rocks weather, and returned to the atmosphere hundreds of thousands to millions of years later by volcanic eruptions (p. 28).

Condensation The process by which a substance, usually water, changes phase from a gas to a liquid (p. 31).

Constant gases Gases that have consistent concentrations across the atmosphere, up to a height of about 80 km (p. 20).

Denitrification The process by which bacteria convert nitrogen in the soil to nitrogen gas or nitrous oxide gas (p. 24).

Flow The rate of movement of substances into and out of a reservoir in a system (p. 22).

Evaporation The process by which a substance, usually water, changes phase from a liquid to a gas (p. 31).

Haze A reduction of visibility caused by the scattering of visible radiation in the atmosphere (p. 34).

Heterosphere The upper atmosphere, in which the heaviest molecules are on the bottom and the lightest are on the top (p. 33).

Homosphere The lower atmosphere, in which the constant gases are thoroughly mixed (p. 33).

Hydrologic cycle The biogeochemical cycle in which water is transferred between the various reservoirs of the Earth system (p. 31).

Latent heat The energy associated with phase changes (p. 30).

Nitrogen cycle The biogeochemical cycle in which nitrogen is transferred between the various reservoirs of the Earth system (p. 24).

Nitrogen fixation The process by which nitrogen gas is removed from the atmosphere and converted to a soluble form of nitrogen that can be taken up by plants (p. 24).

Outgassing The release of gases dissolved in rock (p. 38).

Oxidation The addition of oxygen to a compound, which is accompanied by a loss of electrons (p. 26).

Photodissociation A process in which a molecule is split apart by the absorption of radiation (p. 24).

Primary aerosols Aerosols that are emitted directly into the atmosphere (p. 34).

Reservoir A storage place (p. 22).

Residence time The average amount of time that a substance might be expected to remain in a reservoir of the Earth system (p. 23).

Secondary aerosols Aerosols that form in the atmosphere (p. 34).

Sink A process by which a substance leaves a reservoir (p. 22).

Source A process by which a substance enters a reservoir (p. 22).

Steady state A condition that exists when the inflows to a reservoir are equal to the outflows from the reservoir (p. 22).

Stock The amount of a substance in a reservoir of a system (p. 22).

Transpiration The process by which water vapour is returned to the atmosphere through the stomata in the leaves of plants (p. 31).

Ultraviolet radiation Radiation with wavelengths ranging from 0.1 to 0.4 μm (p. 32).

Variable gases Gases that have different concentrations in different areas of the atmosphere and at different times (p. 20).

Volatile organic compounds (VOCs) Carbon containing compounds that easily vaporize (p. 35).

Answers to Selected Review Questions (p. 43)

1. **What is the difference between constant gases and variable gases? Give an example of each. How is residence time an important determinant of whether or not a gas will be constant or variable?**

   Constant gases have consistent concentrations throughout the atmosphere up to a height of about 80 km. Variable gases have different concentrations depending on when, or where, a sample of air is taken. Nitrogen, oxygen, and the inert gases are all constant gases. Carbon dioxide, ozone, and water vapour are examples of variable gases.
   Residence times are associated with biogeochemical cycles—cycles in which elements (e.g., carbon, nitrogen, and oxygen) and compounds (e.g., water) are continuously transferred between the atmosphere and the rocks, water, and life of our planet.

3. **How can photosynthesis lead to a) short-term carbon storage and b) long-term carbon storage?**

   Photosynthesis leads to short-term carbon storage when carbon dioxide is quickly returned to the atmosphere by decomposition or respiration. b) Under circumstances in which decomposition cannot occur, carbon will be stored for the long term in the rocks of the lithosphere.

5. **How does production and destruction of stratospheric ozone protect life on Earth from ultraviolet radiation?**

   The production and destruction of stratospheric ozone absorbs harmful ultraviolet radiation and prevents it from reaching the Earth's surface. Oxygen molecules absorb ultraviolet radiation splitting the oxygen molecules into oxygen atoms. Then, the newly formed oxygen atoms collide with oxygen molecules, forming ozone.

7. **What are the differences between primary aerosols and secondary aerosols? Give examples of each.**

   Primary aerosols are emitted into the atmosphere. Secondary aerosols form in the atmosphere. Salt particles, dust, seeds, pollen, spores, bacteria, viruses, volcanic ash, and soot are all examples of primary aerosols. Sulphate and nitrate aerosols are examples of secondary aerosols.

9. **How is the composition of the troposphere similar to and different from that of the stratosphere?**

   In both the troposphere and the stratosphere, mixing dominates and constant gases are therefore evenly distributed. The residence times in the troposphere are lower than in the stratosphere due to precipitation removing aerosols from the troposphere.

11. **What evidence do we have that oxygen did not begin to accumulate in the atmosphere until about 2 billion years ago?**

    When oxygen enters the atmosphere, it reacts with iron released by the weathering of rocks making the iron insoluble so that it accumulates in soils, forming iron deposits known as redbeds. Researchers have found that there are no redbeds older than about 2 billion years old.

13. **What is the significance of the following to the evolution of Earth's atmosphere: a) distance from the sun, b) life, c) plate tectonics, d) Earth's size, and e) the solubility of carbon dioxide in water?**

    a) Earth's distance from the sun provides Earth with a temperature that allows water to become liquid. b) The presence of liquid water made life possible. c) Plate tectonics results in volcanic eruptions which contributed carbon dioxide and water vapour to the primitive atmosphere. d) If Earth were a smaller planet, it would have a smaller gravitational field, which would make it easier for gases to escape from the atmosphere. e) As water rained down, it dissolved atmospheric carbon dioxide and removed it from the atmosphere keeping the Earth from getting too hot as the sun's output increased.

Study Questions

For suggested answers, see below.

1. How would Earth be different if it did not have a greenhouse effect?

2. What is the carbonate-silicate cycle? Explain it. How it is a negative feedback mechanism?

3. What is the difference between the homosphere and the heterosphere?

4. What are the three steps involved in removing aerosols from the atmosphere through precipitation? Briefly explain each step.

5. What is the Gaia hypothesis?

Answers to Study Questions

1. Without a greenhouse effect, Earth would have an average surface temperature of about –18°C instead of about 15°C. It would be less suited to supporting life. (p. 26)

2. In the carbonate-silicate cycle, carbon dioxide is removed from the atmosphere as silicate rocks weather and is returned to the atmosphere by volcanic eruptions. This is a negative feedback mechanism because carbon dioxide in the atmosphere from volcanism will increase temperatures and, therefore, weathering rates. As weathering rates increase, the amount of carbon dioxide in the atmosphere will decline. The will cause temperatures to decrease. (p. 28)

3. The homosphere is the lowest 80 km of the atmosphere, in which the constant gases are thoroughly mixed. The heterosphere is the upper atmosphere (located above 80 km), in which the heaviest molecules are on the bottom and the lightest are on top. (p. 33)

4. First, atmospheric water vapour condenses on the surface of larger aerosols which thus form the centres of cloud droplets. Second, more water vapour moves toward these cloud droplets, pulling additional aerosols along with it. Third, once the cloud droplets grow into rain drops, they fall, picking up still more aerosols. (p. 36)

5. The Gaia hypothesis is based on the observation that Earth's atmosphere would be different if there was no life on the planet. It proposes that the various parts of the Earth system—the lithosphere, the atmosphere, the biosphere, and the hydrosphere—operate together as a self-regulating system. (p. 41)