



EXPANDED STUDY MATERIAL

# CHAPTER 13

## Earth as a System: Energy, Matter, and Life

Earth's connected spheres, cycles, climate and human impacts

### INSIDE THIS BOOKLET

Detailed theory notes • Key definitions • Formula and concept boxes • Worked examples • One full page of practice questions • Answer key at the end

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Learn clearly. Practise consistently. Improve every rank.

Use these notes alongside your prescribed textbook and classroom teaching. Scientific terms and examples are explained in student-friendly language for revision and practice.

# THEORY NOTES

## 1. Earth as an interconnected system

Earth is not a collection of isolated parts. Its air, water, land, living organisms and internal processes interact continuously. A change in one component can trigger changes in others. For example, clearing a forest affects soil, runoff, river flow, local temperature, carbon storage and habitats.

A **system** is a set of connected parts that interact. Earth receives energy mainly from the Sun and also has internal heat. Matter such as water, carbon, nitrogen and minerals cycles through the system. Energy flows through the system and is eventually radiated to space, while matter is reused in cycles.

Scientists divide Earth into interacting spheres to study these connections. The atmosphere is the layer of gases around Earth; the hydrosphere includes liquid water; the cryosphere includes frozen water; the geosphere includes rocks, soil and Earth's interior; and the biosphere includes living organisms and the regions where life exists.

## 2. Energy flow: Sun, Earth and climate

Sunlight drives photosynthesis, warms land and oceans, powers evaporation and helps create differences in air pressure that generate winds. The Sun is therefore the main energy source for most surface processes and nearly all food webs. Earth's internal heat drives processes such as mantle convection, volcanism and plate movement.

Incoming solar radiation is partly reflected by clouds, ice, aerosols and bright surfaces, and partly absorbed by the atmosphere, land and oceans. Earth emits energy back toward space as infrared radiation. The balance between incoming and outgoing energy influences global temperature.

The **greenhouse effect** is a natural process in which gases such as water vapour, carbon dioxide and methane absorb and re-emit some outgoing infrared radiation, warming the lower atmosphere and surface. Human activities have increased concentrations of several greenhouse gases, strengthening the effect and causing global warming.

Climate differs from weather. Weather describes short-term atmospheric conditions; climate describes patterns and averages over longer periods. Climate is affected by solar energy, latitude, altitude, ocean circulation, atmospheric circulation, landforms, vegetation and greenhouse gases.

## 3. Atmosphere and winds

The atmosphere is a mixture of gases, mostly nitrogen and oxygen, with smaller amounts of argon, carbon dioxide, water vapour and other gases. It protects life from much harmful radiation, helps regulate temperature and provides gases needed by organisms.

Uneven heating creates temperature and pressure differences. Warm air tends to rise, while cooler, denser air tends to sink; air moves from high-pressure toward lower-pressure regions, creating wind. Earth's rotation deflects large-scale moving air through the Coriolis effect, helping form global wind belts and circulation patterns.

Land and water heat and cool at different rates. During the day, land often warms more quickly than the sea, creating a sea breeze toward land; at night, land often cools faster, and a land breeze may develop. Local topography and weather conditions can modify these patterns.

Monsoons are seasonal wind systems associated with large-scale differences in heating between land and ocean, along with shifting pressure patterns and other atmospheric processes. The South Asian summer monsoon brings moisture-laden winds and rainfall to much of India, but its timing and intensity vary from year to year.

## 4. The water cycle and ocean circulation

The **water cycle** moves water among oceans, atmosphere, land and living organisms. Solar heating drives evaporation from water surfaces and transpiration from plants. Water vapour cools and condenses into droplets or ice crystals, forming clouds; precipitation returns water to the surface as rain, snow or hail.

After precipitation, water may infiltrate soil, recharge groundwater, flow over land into streams and rivers, be stored in lakes and glaciers, or return to the atmosphere through evaporation and transpiration. Vegetation slows runoff and helps water enter soil. Deforestation and soil compaction can increase rapid runoff and erosion in some settings.

Oceans store and transport large amounts of heat. Surface currents are driven mainly by winds and shaped by continents and Earth's rotation. Deep-ocean circulation is also influenced by differences in water density related to temperature and salinity. Ocean currents redistribute heat, influence coastal climates and affect marine ecosystems.

Warmer ocean water can increase evaporation and supply moisture to the atmosphere. Its influence on a regional monsoon depends on broader pressure systems, winds, land-sea temperature contrasts and ocean-atmosphere interactions; a single factor rarely explains a monsoon's behaviour by itself.

## 5. Carbon, nitrogen and nutrient cycles

The **carbon cycle** moves carbon among the atmosphere, living organisms, oceans, soils and rocks. Plants take in carbon dioxide during photosynthesis and use carbon to build organic molecules. Respiration, decomposition and combustion release carbon dioxide. Oceans exchange carbon with the atmosphere, and some carbon is stored for long periods in sediments and fossil fuels.

Burning fossil fuels and clearing forests transfer carbon to the atmosphere faster than many natural processes can remove it. Forests store carbon in wood and soil; when forests are cut or burned, some stored carbon is released and future carbon uptake may decline. Carbon-cycle changes affect atmospheric carbon dioxide and climate.

The **nitrogen cycle** moves nitrogen through air, soil and organisms. Most organisms cannot use atmospheric nitrogen gas directly. Nitrogen-fixing bacteria convert it into forms that plants can use; other microbes transform nitrogen compounds through nitrification, decomposition and denitrification. Plants absorb usable nitrogen from soil, animals obtain it by feeding, and decomposition returns nitrogen to the environment.

Phosphorus and other nutrients also cycle through rocks, soil, water and organisms. Unlike carbon and nitrogen, phosphorus has no major gaseous phase in its common cycle. Excess nutrients from fertilisers and sewage can enter waterways, promote algal blooms and reduce dissolved oxygen as the algae decompose.

## 6. Geosphere, soil and living systems

The geosphere includes rocks, minerals, landforms and Earth's interior. Weathering breaks rocks into smaller particles; erosion transports material by water, wind, ice or gravity; deposition lays it down elsewhere. These processes shape landscapes and help form soil.

Soil contains mineral particles, organic matter, water, air and living organisms. Healthy soil supports plant growth, stores carbon, filters water and provides habitat for many organisms. Plant roots bind soil, while leaf litter adds organic matter. Removing vegetation from slopes can increase erosion and sediment entering rivers.

The biosphere interacts with all other spheres. Plants use sunlight, water, carbon dioxide and minerals; animals depend directly or indirectly on plants and other organisms; decomposers recycle nutrients. Ecosystem health depends on flows of energy and matter as well as the diversity and abundance of organisms.

Glaciers and ice sheets store freshwater and reflect a large amount of sunlight. When ice melts, it can contribute to sea-level rise, while reduced reflective ice can increase absorption of solar energy. Sea level also rises as ocean water warms and expands. Coastal impacts depend on local land movement, storms, tides and adaptation measures.

## 7. Human impacts and sustainability

Human actions can change Earth-system processes rapidly. Fossil-fuel combustion adds greenhouse gases and air pollutants. Deforestation alters carbon storage, water movement and habitats. Intensive agriculture can cause soil erosion and nutrient pollution. Urbanisation changes surface reflectivity, drainage and local temperatures.

Effects can combine and reinforce each other. For example, forest removal can reduce interception of rainfall, increase runoff and erosion, carry more sediment into rivers, damage aquatic habitats and reduce carbon uptake. A warming climate can intensify some heat extremes and change precipitation patterns, but local outcomes vary.

Sustainable management aims to meet human needs while maintaining ecosystem functions for the future. Approaches include energy efficiency, low-carbon energy, protection and restoration of forests and wetlands, soil conservation, water efficiency, waste reduction, public transport and careful use of fertilisers.

Earth-system thinking asks not only 'What changes?' but also 'What other parts are connected, over what time scale, and with what feedbacks?' A feedback can amplify an initial change (positive feedback) or oppose it (negative feedback). For example, loss of reflective ice can amplify warming; some plant growth responses to carbon dioxide may partly offset atmospheric increases but are limited by water, nutrients and temperature.

## 8. Worked examples

**Example 1 — Water runoff:** If a forested slope is cleared, less rain may be intercepted and roots no longer bind soil as effectively. Runoff and erosion may rise, carrying sediment into streams.

**Example 2 — Carbon:** Photosynthesis removes carbon dioxide from the atmosphere and stores carbon in organic matter; respiration and decomposition return some carbon dioxide.

**Example 3 — Sea level:** Melting land ice adds water to the ocean, while warming seawater expands. Both processes contribute to sea-level rise.

## QUICK REVISION SUMMARY

### Key ideas to retain

Earth's spheres interact. The Sun drives most surface processes; matter cycles while energy flows. Water, carbon and nitrogen cycles link atmosphere, water, soil and organisms. Human activities can change climate, ecosystems and land/water processes.

## PRACTICE QUESTIONS

Attempt all questions before checking the answer key. Show working for numerical questions and write full sentences for explanation questions.

1. Name five interacting Earth-system spheres and give one example of an interaction.
2. Explain the difference between energy flow and matter cycling in the Earth system.
3. What drives the water cycle? Describe its main stages.
4. Explain how uneven heating of Earth's surface creates winds.
5. What is the greenhouse effect, and how do human activities strengthen it?
6. Distinguish between weather and climate.
7. Describe two ways forests influence the water cycle and soil.
8. Explain the role of ocean currents in Earth's climate.
9. Outline the carbon cycle and identify two human activities that alter it.
10. Why is nitrogen fixation important for plants and food webs?
11. Explain how excess fertiliser can damage aquatic ecosystems.
12. How can melting ice contribute to sea-level rise and further warming?
13. Define positive feedback and give an Earth-system example.
14. Give four practical measures that can reduce human pressure on Earth systems.
15. A forest is cleared on a steep slope. Predict two effects on nearby rivers and explain the links.

### Before you submit

Check calculations, include units where appropriate, define important terms clearly and support explanations with examples.

## ANSWER KEY

Use the answers to check your understanding. For explanation questions, equivalent scientifically correct wording is acceptable.

1. Atmosphere, hydrosphere, cryosphere, geosphere and biosphere. Example: plants in the biosphere take water from soil and carbon dioxide from the atmosphere.
2. Energy enters mainly from the Sun and flows through processes before leaving as heat; matter such as water and carbon is reused through cycles.
3. Solar energy drives evaporation and transpiration; vapour condenses, precipitation falls, then water infiltrates, runs off, is stored or evaporates again.
4. Different surfaces heat unevenly, creating pressure differences; air moves from higher toward lower pressure, forming wind.
5. Greenhouse gases absorb and re-emit infrared radiation; fossil-fuel burning, deforestation and some agriculture increase greenhouse-gas concentrations.
6. Weather is short-term atmospheric condition; climate is long-term patterns and averages.
7. Forests intercept rain and promote infiltration; roots bind soil and reduce erosion; vegetation slows runoff.
8. Currents transport heat and influence coastal temperature, rainfall patterns and marine ecosystems.
9. Photosynthesis removes CO<sub>2</sub>; respiration, decomposition and combustion release it; oceans and rocks store carbon. Fossil-fuel burning and deforestation alter the cycle.
10. It converts atmospheric nitrogen into usable compounds that plants need to build proteins and nucleic acids.
11. Nutrient runoff can cause algal blooms; decomposition consumes dissolved oxygen and can harm aquatic organisms.
12. Melting land ice adds water to oceans; loss of reflective ice reduces albedo and can amplify warming. Warming seawater also expands.
13. A change that reinforces itself; loss of reflective ice increases absorption of sunlight, causing more warming and further ice loss.
14. Use low-carbon energy, protect forests/wetlands, conserve water, improve efficiency, reduce waste, prevent soil erosion and use fertiliser carefully.
15. Runoff and erosion may increase; rivers can carry more sediment, become muddier or shallower, and aquatic habitats may be damaged.

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Revise the theory, practise without looking at the answers, and revisit any question you could not explain in your own words.

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