

Biochemistry of Photosynthesis and Respiration

Unit 1 Topic Note · Biology · Secondary 4

This unit covers how plants make food (photosynthesis) and how living things release energy from food (respiration), including how gases move in and out of both plants and animals.

Sections in this Unit

- 1.1 Necessity of chlorophyll, light energy and carbon dioxide for photosynthesis
- 1.2 Limiting factors for photosynthesis
- 1.3 Internal structure of the leaf and its adaptations to photosynthesis
- 1.4 Importance of photosynthesis
- 1.5 The process of photosynthesis
- 1.6 Chemical compounds which constitute living organisms
- 1.7 Respiration
- 1.8 Respiratory system in animals
- 1.9 Respiration in other animals
- 1.10 Gaseous exchange in human beings and plants
- 1.11 Gaseous exchange in plants

1.1 Why Plants Need Light, Chlorophyll, and Carbon Dioxide to Make Food

Before this: You should already know that photosynthesis is how green plants make their own food, and that this happens inside the leaf.

Why this matters: Every meal you eat traces back to a plant that photosynthesized. Three conditions must be present at the same time, or photosynthesis stops completely.

Key Vocabulary

- **Photosynthesis:** the process by which green plants make their own food using light, CO₂, and water
- **Chlorophyll** (the green colouring in leaf cells that captures light energy)
- **Limiting factor** (a condition whose shortage slows the whole process down)

The Three Requirements

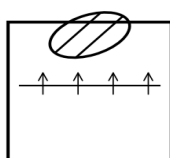
Requirement	Why it's needed	What happens if it's missing
Chlorophyll	Traps light energy from the sun	Cells without chlorophyll cannot make starch, regardless of light or CO ₂
Light energy	Powers the whole reaction	In darkness, even a healthy green leaf makes no starch
Carbon dioxide	Combines with water to build glucose	Sealed off from air, a leaf cannot photosynthesize even in bright light

Overall word equation: **Carbon dioxide + Water → (light, chlorophyll) → Glucose + Oxygen**

Experiment — Testing for Starch

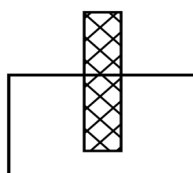
1. Pick a leaf that has been in sunlight for several hours.
2. Soften it by dipping it briefly in boiling water.
3. Remove the green colour using ethanol in a hot water bath (this doesn't kill the leaf — boiling water already did — it only extracts chlorophyll).
4. Rinse and flatten the leaf, then flood it with iodine solution.
5. Blue-black = starch present; brown = no starch, no photosynthesis occurred.

1. Boil in water
(softens leaf)



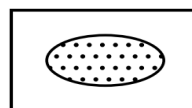
leaf in boiling water

2. Boil in ethanol
(removes green colour)
leaf + ethanol



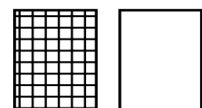
water bath (hot)

3. Rinse + flatten
(prepare for test)



white tile

4. Add iodine
(read colour change)



starch present (dark + hatched) no starch (plain/light)

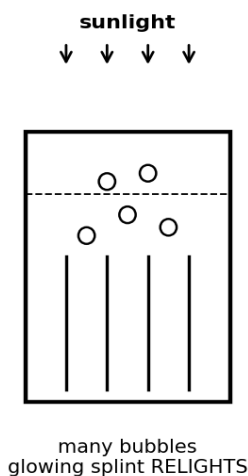
Diagram: the four steps of the starch test. Starch-positive areas are shown with cross-hatching rather than colour alone.

Experiment — Testing for Gas Release

1. Place local aquatic/soft-stem plant material (e.g. water spinach stems or pond weed) in two jars of water.
2. Put Jar A in sunlight, Jar B in a dark box, for several hours.
3. Check both for bubbles; test any collected gas with a glowing splint.

4. Jar A: bubbles form and the splint relights (oxygen). Jar B: little or no gas, no change.

Jar A — placed in sunlight



Jar B — placed in darkness

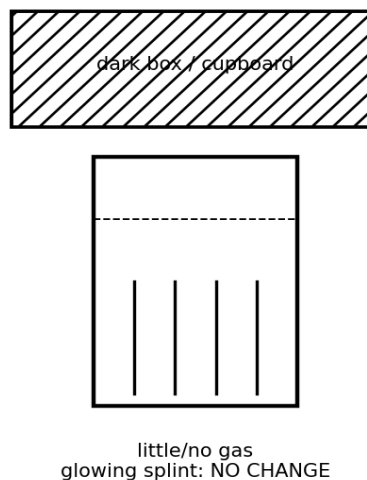


Diagram: Jar A (sunlight) produces oxygen; Jar B (darkness) does not. Only light differs between them.

Local Example — Cassava Leaf

A farmer in Yambio notices cassava leaves with pale yellow blotches (chlorophyll damage from nutrient deficiency or virus). Iodine testing shows green areas turn blue-black while blotches stay brown — proof damaged patches cannot photosynthesize.

Key Takeaways & Common Pitfalls

- **Must-remember:** all three conditions must be present simultaneously.
- **Common mistake:** ethanol does not kill the leaf — boiling water does; ethanol only removes chlorophyll.
- **Second mistake:** bubbles alone aren't proof of photosynthesis — only a glowing-splint test confirming oxygen counts.

Practice Questions

Easy

Q: What colour does iodine turn when starch is present?

A: **Blue-black.** This colour change only happens where starch has actually been made.

Medium

Q: A leaf is kept in darkness for two days, then tested with iodine. Predict and explain the result.

A: **It stays brown.** Light is missing, so photosynthesis cannot occur even with chlorophyll and CO₂ present.

Hard

Q: Half a leaf is covered in black paper for a day, then the whole leaf is iodine-tested. Explain the result and why this is a fair test.

A: **Covered half stays brown; uncovered half turns blue-black.** Both halves share the same leaf (same chlorophyll, water, CO₂) — light is the only variable, so it alone explains the difference.

Research & Discussion

- Find a local plant with naturally variegated or discoloured leaves. Investigate whether it's a natural trait or a sign of stress.

- Some farmers cover seedlings with dark cloth at night, believing it helps growth. Based on what you know, could this be true? How would you test it at home?
- Ask an elder what traditional signs they use to judge if a crop is healthy. Do any relate to chlorophyll or photosynthesis?

1.2 Limiting Factors for Photosynthesis

Before this: You should know the three basic requirements for photosynthesis — chlorophyll, light, and carbon dioxide.

Why this matters: A crop can have healthy green leaves and full sun and still grow slowly — because one single condition in short supply can hold back the whole process, even if everything else is abundant.

Key Vocabulary

- **Limiting factor** (whichever condition is in shortest supply relative to what's needed) — it controls the rate, no matter how much of the other conditions are available
- **Rate of photosynthesis** (how quickly a plant makes food, often measured by oxygen bubbles or starch produced per unit time)

The Three Main Limiting Factors

Factor	Effect on rate	Real-world trigger
Light intensity	Rate rises with more light, then flattens once another factor becomes limiting	Cloudy days in the rainy season slow crop growth even with plenty of water
CO ₂ concentration	Rate rises as CO ₂ increases, then plateaus	Air is only about 0.04% CO ₂ — crops grown close together may compete for it
Temperature	Rate rises to an optimum, then falls sharply as enzymes are damaged	Very hot midday sun in the dry season can slow, not speed up, plant growth

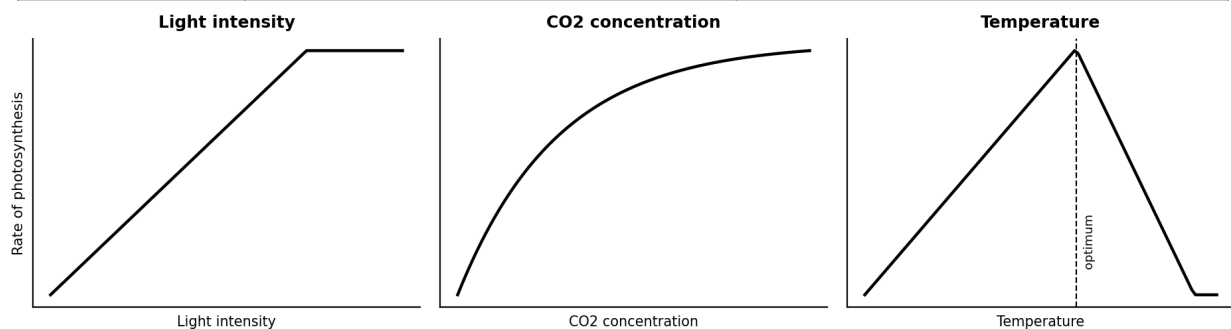


Diagram: three original graphs showing how rate of photosynthesis responds to light intensity, CO₂ concentration, and temperature. Each shape is different and labelled — not colour-dependent.

Experiment — Counting Bubbles Under Different Light Distances

1. Place a short length of a local aquatic weed in a jar of water with a pinch of baking soda dissolved in it (adds CO₂).
2. Position a lamp at four different distances from the jar (e.g. 10cm, 20cm, 40cm, 80cm), testing one distance at a time.
3. Count bubbles released per minute at each distance.
4. Record results in a simple table and plot distance against bubble count.
5. Closer light (higher intensity) should give more bubbles per minute, up to a point where it levels off.

Local Example — Maize Field Spacing

A farmer plants maize too close together. Even with good soil and rain, the crowded plants shade each other, cutting the light reaching lower leaves. Growth slows — not from lack of water or nutrients, but because light has become the limiting factor for the shaded plants.

Key Takeaways & Common Pitfalls

- **Must-remember:** only the scarcest factor controls the rate at any given moment — adding more of a factor that isn't scarce won't help.
- **Common mistake:** students think increasing light always increases photosynthesis rate — but once light is no longer scarce, another factor (CO₂ or temperature) takes over as the limit.

Practice Questions

Easy

Q: What is a limiting factor?

A: A condition in short supply that controls the rate of a process. Even if every other requirement is abundant, the scarcest one sets the pace.

Medium

Q: A greenhouse owner increases light intensity but sees no change in plant growth. Suggest why.

A: Light was not the limiting factor. Something else — likely CO₂ concentration or temperature — was already limiting the rate, so adding more light made no difference.

Hard

Q: A field of crops grows well in the morning but visibly wilts and slows growth by early afternoon on hot days, despite full sun and watered soil. Explain, using the concept of limiting factors.

A: Temperature has moved past the optimum. In the morning, temperature is favourable and light/CO₂ may be limiting. By afternoon, high heat begins denaturing enzymes involved in photosynthesis, so temperature becomes the new limiting factor — even though light and water are both still plentiful.

Research & Discussion

- Observe crops in your area planted very close together versus more spaced out. Do the crowded ones look different? Why might that be?
- Ask a farmer in your community what time of day they consider best for watering crops, and why. Does it relate to temperature and photosynthesis?
- Think about a greenhouse or shaded nursery bed you've seen. What limiting factor might the shading be addressing?

1.3 Internal Structure of the Leaf and Its Adaptations to Photosynthesis

Before this: You should know the three requirements for photosynthesis and that it happens inside leaf cells.

Why this matters: A leaf's shape and internal layers are not random — every layer is built to maximize light capture and gas exchange, the two things photosynthesis depends on most.

Key Vocabulary

- **Palisade mesophyll** (tightly packed column-shaped cells just under the upper surface, containing most of the leaf's chloroplasts)
- **Spongy mesophyll** (loosely packed cells with air spaces between them, allowing gases to move around)
- **Stomata** (tiny pores, usually on the leaf underside, that let gases in and out)

Layers of the Leaf and Their Adaptations

Layer	Adaptation	Why it helps photosynthesis
Cuticle + epidermis	Thin and transparent	Lets light pass through with minimal blocking
Palisade mesophyll	Tall, tightly packed cells with many chloroplasts near the top surface	Captures the most light where it's strongest
Spongy mesophyll	Loosely arranged with large air spaces	Allows CO ₂ and O ₂ to circulate freely between cells
Stomata + guard cells	Pores that open and close	Controls gas exchange and water loss
Vascular bundle (xylem + phloem)	Runs through the leaf as veins	Delivers water/minerals in, carries food out

Cross-section through a leaf (original schematic)

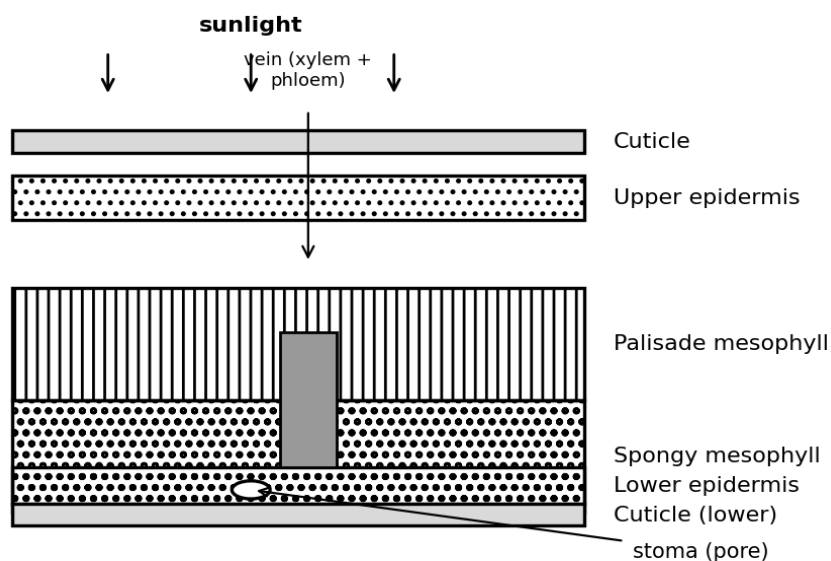


Diagram: original schematic cross-section of a leaf showing the main layers and a stoma. Layers distinguished by pattern, not colour.

Experiment — Comparing Upper and Lower Leaf Surfaces

1. Collect a broad leaf common in your area (e.g. a mango or banana leaf).
2. Smear a thin layer of petroleum jelly on the upper surface of one leaf, and on the lower surface of a second, identical leaf.
3. Leave both in the sun for a few hours, alongside an untreated control leaf.
4. Compare wilting: the leaf coated on the underside should wilt faster, since most stomata (and therefore most water loss) are on the lower surface.

Local Example — Broad vs Narrow Leaves

Compare a broad leaf like banana with a narrow one like grass. The banana leaf's larger surface area captures more light per leaf, but also loses more water — which is part of why banana plants need consistently moist soil, while grasses tolerate drier conditions.

Key Takeaways & Common Pitfalls

- **Must-remember:** palisade cells are positioned near the top specifically because that's where light is strongest.
- **Common mistake:** students often think stomata are evenly spread on both leaf surfaces — most land plants have far more on the underside, reducing water loss from direct sun exposure.

Practice Questions

Easy

Q: Which leaf layer contains the most chloroplasts?

A: **The palisade mesophyll.** Its cells are packed with chloroplasts and positioned near the upper surface to absorb the most light.

Medium

Q: Explain why the spongy mesophyll has large air spaces.

A: **To allow gases (CO₂ and O₂) to move freely between cells and the stomata.** Tightly packed cells would slow gas diffusion, limiting how quickly the leaf could take in CO₂ for photosynthesis.

Hard

Q: A plant grown in deep shade often develops thinner leaves with a less-developed palisade layer than the same species grown in full sun. Suggest why.

A: **In low light, investing heavily in a thick palisade layer wastes resources,** since there isn't enough light to make full use of many tightly packed, light-hungry cells. A thinner leaf with less palisade tissue is more resource-efficient for the amount of light actually available, though it will photosynthesize more slowly overall than a sun leaf.

Research & Discussion

- Compare leaves from a plant grown in full sun with the same species grown in shade (if available near you). Note differences in thickness, size, or colour.
- Look at leaves in your area with unusually thick, waxy surfaces (e.g. succulents). Discuss with classmates why that adaptation might exist.
- Ask a family member which local plants wilt fastest in the dry season and which don't. What might explain the difference?

1.4 Importance of Photosynthesis

Before this: You should understand what photosynthesis produces — glucose and oxygen — and where it happens.

Why this matters: Photosynthesis isn't just a process plants use for themselves — nearly every form of life, and much of human economic activity, depends on it directly or indirectly.

Key Vocabulary

- **Primary producer** (an organism, usually a green plant, that makes its own food and forms the base of a food chain)
- **Carbon cycle** (the ongoing movement of carbon between the atmosphere, living things, and the environment)

Main Areas of Importance

Area	Role of photosynthesis
Food chains	Plants are primary producers — nearly all food chains begin with photosynthesis, directly (crops) or indirectly (grazing animals)
Oxygen supply	The oxygen released as a by-product is what most living things, including humans, need for respiration
Carbon cycle regulation	Photosynthesis removes CO ₂ from the air, balancing what respiration and burning add back
Raw materials	Wood, cotton, natural fibres, and some medicines all come from materials plants build through photosynthesis
Economic importance	Agriculture, forestry, and fuel-wood industries in South Sudan all depend on plant growth driven by photosynthesis

Local Example — The Sorghum Food Chain

Sorghum photosynthesizes to build grain. A family eats some of that grain directly, and feeds some to goats, which are later eaten or sold. Every step in that chain — the grain, the goat's meat, the milk — ultimately traces back to sorghum's photosynthesis in the field.

Key Takeaways & Common Pitfalls

- **Must-remember:** photosynthesis affects far more than plant growth alone — it underlies food security, the air we breathe, and much of the local economy.
- **Common mistake:** students sometimes think only farmers/plants 'benefit' from photosynthesis — but every animal that breathes oxygen or eats any part of a food chain depends on it too.

Practice Questions

Easy

Q: Why are green plants called primary producers?

A: Because they make their own food through photosynthesis, forming the base that food chains are built on.

Medium

Q: Explain two ways photosynthesis benefits organisms that cannot photosynthesize themselves.

A: It provides food (directly through plant material, or indirectly through animals that eat plants) and it releases oxygen, which non-photosynthesizing organisms like humans and animals need for respiration.

Hard

Q: A region experiences large-scale deforestation for farmland. Using what you know about the importance of photosynthesis, predict two consequences beyond the loss of trees themselves.

A: (1) Less CO₂ is removed from the atmosphere, disrupting the carbon cycle balance, and (2) local food chains and oxygen production drop as fewer primary producers remain. Both consequences extend well beyond simply losing wood or shade — they affect air quality, climate, and the food web supporting local wildlife.

Research & Discussion

- List three products in your home that come from plants (beyond food). Trace each one back to photosynthesis.
- Discuss with classmates: how might cutting down a large area of forest near your community affect the air quality or local food chain?
- Ask an elder what crops or trees were more common in the area years ago. Have any disappeared, and might that affect the local food chain?

1.5 The Process of Photosynthesis

Before this: You should know the overall word equation for photosynthesis and the three requirements it needs.

Why this matters: Photosynthesis isn't one single reaction — it's two linked stages, each happening in a different part of the chloroplast, working together to turn light into stored food energy.

Key Vocabulary

- **Photolysis** (the splitting of a water molecule using light energy)
- **ATP** (adenosine triphosphate — a high-energy molecule cells use to power reactions, like a rechargeable battery for cellular energy)
- **NADPH** (a molecule that carries hydrogen from the light stage to the dark stage)
- **Carbon fixation** (turning carbon dioxide gas into a solid carbon-containing sugar molecule)
- **RuBisCO** (the enzyme that attaches CO₂ onto a 5-carbon molecule to begin the Calvin cycle — considered the most abundant enzyme on Earth)
- **Calvin cycle** (the named cycle of reactions making up the dark stage, where CO₂ is fixed and glucose is built)

Two Stages of Photosynthesis

Stage	Location	What happens
Light-dependent stage	Thylakoid membranes, within the grana	Chlorophyll absorbs light; water splits into hydrogen ions, electrons, and oxygen (photolysis); the light energy drives ATP synthase to produce ATP, and NADP ⁺ is reduced to NADPH
Light-independent stage (Calvin cycle)	Stroma	RuBisCO fixes CO ₂ onto a 5-carbon molecule (RuBP); using ATP and NADPH from the light stage, this is reduced through several steps into glucose, and RuBP is regenerated to keep the cycle running

Both stages happen continuously in daylight, in different parts of the same chloroplast — they are linked by ATP and NADPH, which the light stage produces and the Calvin cycle consumes.

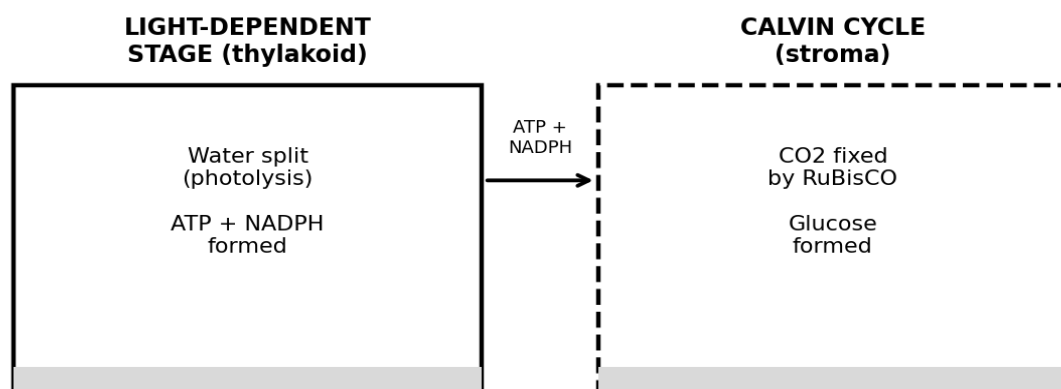


Diagram: original schematic showing the light-dependent stage feeding NADPH and ATP into the Calvin cycle, where glucose is built.

Demonstration — Modelling the Two Stages

1. Using two labelled boxes or hoops on the ground/floor (one marked 'Light Stage — Thylakoid', one 'Calvin Cycle — Stroma'), assign small groups of students roles: water molecules, light energy, NADPH/ATP carriers, CO₂ molecules, RuBisCO, and glucose.
2. Walk through the sequence physically: 'water' students split into 'hydrogen/electron' carriers and 'oxygen' in the Light Stage box (photolysis).
3. 'NADPH' and 'ATP' students carry themselves into the Calvin Cycle box.
4. In the Calvin Cycle box, a 'RuBisCO' student attaches a 'CO₂' student onto a 'RuBP' student, and the 'NADPH'/'ATP' students power its conversion into 'glucose'.
5. Discuss as a class: which stage needed light directly, and which one used the light stage's products (ATP, NADPH) instead?

Key Takeaways & Common Pitfalls

- **Must-remember:** the Calvin cycle doesn't need light directly, but it cannot run without the ATP and NADPH the light stage supplies — the two stages are linked, not independent.
- **Common mistake:** students often think the 'dark stage'/Calvin cycle only happens at night. It actually happens continuously in daylight too, at the same time as the light-dependent stage, inside a different part of the chloroplast.
- **Second common mistake:** RuBisCO is often skipped over, but it is the specific enzyme that fixes CO₂ onto RuBP — without it, carbon fixation could not begin.

Practice Questions

Easy

Q: Which two products of the light-dependent stage are needed to power the Calvin cycle?

A: ATP and NADPH. Both are produced during the light stage and carry energy and hydrogen into the Calvin cycle.

Medium

Q: Explain why the Calvin cycle cannot continue if the light-dependent stage suddenly stops.

A: The Calvin cycle depends on a continuous supply of ATP and NADPH produced during the light stage. Without these, RuBisCO can still fix CO₂ briefly, but the cycle soon runs out of the energy and hydrogen it needs to convert fixed carbon into glucose and regenerate RuBP.

Hard

Q: A student claims: 'the dark stage happens only at night.' Using what you know about the two stages, explain why this claim is incorrect.

A: The Calvin cycle happens continuously during daylight, at the same time as the light-dependent stage — it is called 'dark' only because it doesn't use light directly, not because of when it occurs. In fact, if the light stage stopped supplying ATP and NADPH (as would happen at actual night), the Calvin cycle would also stop shortly after, since RuBisCO's carbon-fixation step depends on those products to keep running.

Research & Discussion

- Using items around your home (bottle caps, seeds, stones), build your own simple model showing the two stages of photosynthesis and present it to a family member.
- Discuss with a classmate: why might scientists have originally named one stage 'dark' even though it happens during the day?

1.6 Chemical Compounds Which Constitute Living Organisms

Before this: You should know that glucose, made during photosynthesis, is a type of carbohydrate.

Why this matters: Everything a living body is built from and runs on — muscle, energy stores, cell walls — comes down to a small set of chemical compound types, each built for a different job.

Key Vocabulary

- **Organic compound** (a compound built mainly from carbon, hydrogen, and oxygen, often found in living things)
- **Monosaccharide** (a single sugar unit — e.g. glucose, fructose)
- **Disaccharide** (two monosaccharides joined together — e.g. sucrose, maltose)
- **Polysaccharide** (many monosaccharides joined in a long chain — e.g. starch, glycogen, cellulose)
- **Amino acid** (the building block of proteins, joined to each other by peptide bonds)
- **Peptide bond** (the chemical bond linking amino acids together to form a protein chain)
- **Fatty acid** and **glycerol** (the two building blocks that join to form a lipid)
- **Condensation reaction** (joining two smaller molecules into one larger one, releasing water)
- **Hydrolysis** (breaking a larger molecule apart by adding water — the reverse of condensation)

Main Compound Groups

Compound group	Building blocks	Named examples
Carbohydrates	Monosaccharides joined by condensation	Monosaccharide: glucose. Disaccharide: sucrose (table sugar), maltose. Polysaccharide: starch (cassava, sorghum), glycogen (stored in animal liver/muscle), cellulose (plant cell walls)
Proteins	Amino acids joined by peptide bonds	Structural: keratin, collagen. Functional: enzymes (e.g. amylase, which breaks down starch); haemoglobin (carries oxygen in blood)
Lipids	Glycerol + 3 fatty acids (triglyceride) or glycerol + 2 fatty acids + a phosphate group (phospholipid)	Triglycerides: groundnut oil, animal body fat. Phospholipids: a main component of every cell membrane

Experiment — Testing Foods for Starch and Protein

1. Collect small samples of local foods (e.g. cassava, groundnuts, boiled egg white, sorghum flour paste).
2. Add a few drops of iodine solution to a portion of each — blue-black indicates starch.
3. For a separate portion, gently heat with a little vinegar and observe curdling/texture changes typical of protein denaturing (do this only under teacher supervision, away from open flame).
4. Record which foods tested positive for starch and which showed protein-like behaviour when heated.

Local Example — Groundnuts as a Lipid Source

Groundnuts (peanuts) are pressed to extract oil — a lipid. This is why a handful of roasted groundnuts feels much more energy-dense than the same weight of boiled cassava (mostly carbohydrate): lipids store roughly twice as much energy per gram as carbohydrates.

Key Takeaways & Common Pitfalls

- **Must-remember:** condensation builds molecules (with water released); hydrolysis breaks them apart (with water added) — they are opposite processes.
- **Common mistake:** students sometimes confuse monosaccharides with polysaccharides — a monosaccharide is one sugar unit (glucose); starch, cellulose, and glycogen are all polysaccharides made of many linked glucose units, but with different bonding patterns that give them different properties (e.g. cellulose is rigid and indigestible to humans; starch and glycogen are digestible energy stores).
- **Second common mistake:** students often forget that lipids come in two related but distinct forms — triglycerides (energy storage) and phospholipids (cell membrane structure) — both built from glycerol and fatty acids, but combined differently.

Practice Questions

Easy

Q: Name the three main elements found in carbohydrates.

A: **Carbon, hydrogen, and oxygen.** These three elements combine in different ratios to form sugars and starches.

Medium

Q: Explain the difference between a condensation reaction and hydrolysis, using starch as your example.

A: **Condensation joins glucose units together into starch, releasing water at each new bond; hydrolysis uses water to break those same bonds, splitting starch back down into individual glucose molecules.** They are reverse processes of each other, and hydrolysis is exactly what happens when the enzyme amylase digests starch in the body.

Hard

Q: Starch, glycogen, and cellulose are all polysaccharides made entirely of glucose units, yet they behave very differently in living things. Suggest why.

A: **Although all three are built from the same glucose monomer, the type of bond linking the glucose units and the way the chains are arranged differ between them.** Starch's coiled arrangement makes it compact for energy storage in plants; glycogen is similarly built for animal energy storage but is more highly branched for faster breakdown; cellulose's bonding produces straight, tightly bundled chains that make it strong and rigid, which is why it forms plant cell walls and is not digestible by human digestive enzymes.

Research & Discussion

- List five foods eaten in your household and classify each as mainly carbohydrate, protein, or lipid based on what you now know.
- Ask a family member which local foods they consider most 'energy-giving' for physical work. Do these tend to be higher in lipids or carbohydrates?

1.7 Respiration

Before this: You should know that respiration releases energy from food, and that it is the reverse process of photosynthesis in terms of gases used.

Why this matters: Every cell in every living thing needs a constant supply of usable energy — respiration is how that energy is actually released from food, whether or not oxygen is available.

Key Vocabulary

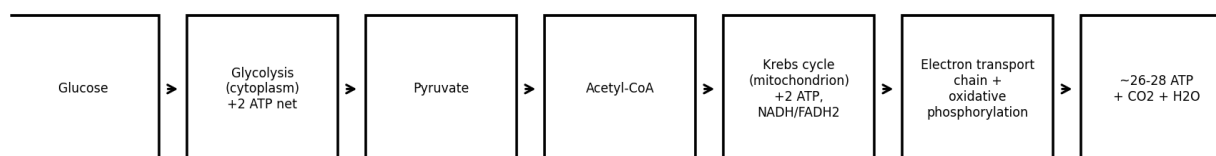
- **Aerobic respiration** (respiration that requires oxygen, releasing a large amount of energy)
- **Anaerobic respiration** (respiration without oxygen, releasing much less energy)
- **Glycolysis** (the first step of respiration, splitting glucose into two pyruvate molecules, happening in the cytoplasm; produces a small net gain of ATP directly)
- **Acetyl-CoA** (the 2-carbon molecule formed when pyruvate is converted before entering the Krebs cycle)
- **Krebs cycle** (a cycle of reactions in the mitochondrion that breaks down acetyl-CoA fully, releasing CO₂ and generating electron carriers)
- **NADH and FADH₂** (electron carrier molecules produced during glycolysis and the Krebs cycle, which deliver electrons to the electron transport chain)
- **Electron transport chain** (a series of proteins in the mitochondrial membrane that uses electrons from NADH/FADH₂ to pump hydrogen ions, ultimately powering ATP synthase)
- **Oxidative phosphorylation** (the process of generating ATP using the electron transport chain and oxygen as the final electron acceptor — this is where most ATP from respiration is produced)

Aerobic vs Anaerobic Respiration

Feature	Aerobic	Anaerobic
Oxygen needed?	Yes — final electron acceptor in the electron transport chain	No
Energy released	Large: roughly 30–32 ATP per glucose molecule overall	Small: only 2 ATP per glucose molecule (from glycolysis alone)
Breakdown of glucose	Complete, down to CO ₂ and water	Incomplete — stops after glycolysis
By-products	CO ₂ + water	CO ₂ + ethanol (plants/yeast) or lactic acid (animals)
Where it occurs	Glycolysis in cytoplasm; Krebs cycle + electron transport chain in the mitochondrion	Cytoplasm only

ATP yield breakdown (aerobic, per glucose molecule): glycolysis produces a net 2 ATP directly; the Krebs cycle produces 2 more ATP directly; the electron carriers generated by both stages (NADH and FADH₂) then feed into the electron transport chain, where oxidative phosphorylation produces the remaining ~26–28 ATP — making the electron transport chain responsible for the large majority of the total energy yield.

Aerobic respiration pathway (original schematic)



Oxygen is required as the final electron acceptor in the electron transport chain

Diagram: original flow of aerobic respiration from glucose through glycolysis (cytoplasm), the Krebs cycle (mitochondrion), and oxidative phosphorylation to final products.

Experiment — Yeast Fermentation (Anaerobic Respiration)

1. Mix a spoon of sugar and a spoon of dry yeast into a bottle of warm water.
2. Stretch a balloon over the bottle's mouth and seal with a rubber band.
3. Leave in a warm place for 30–60 minutes.
4. Observe the balloon slowly inflating — this is CO₂ gas produced by the yeast respiring anaerobically (fermenting) the sugar.
5. Smell (carefully, from a distance) for a faint alcohol-like odour, another anaerobic by-product.

Local Example — Muscle Fatigue After Fieldwork

After carrying heavy loads of water or firewood for a long distance, a person's leg muscles may feel a burning tiredness. When muscles work harder than the blood can supply oxygen for, they briefly switch to anaerobic respiration, producing lactic acid — the source of that burning, tired feeling.

Key Takeaways & Common Pitfalls

- **Must-remember:** glycolysis happens in both aerobic and anaerobic respiration — the pathways only differ after that step, at the point where oxygen either is or isn't available.
- **Common mistake:** students often think anaerobic respiration produces no energy at all — it does produce ATP (2 per glucose from glycolysis), just far less than the ~30–32 ATP aerobic respiration produces.
- **Second common mistake:** the Krebs cycle itself only directly produces a small amount of ATP — its real contribution is generating the NADH and FADH₂ that the electron transport chain then uses to produce the bulk of the ATP.

Practice Questions

Easy

Q: What gas is required for aerobic respiration, and at which stage is it used?

A: Oxygen, used at the electron transport chain as the final acceptor of electrons. Without it, the chain backs up and cells must rely on anaerobic respiration instead, which releases far less energy.

Medium

Q: Explain why anaerobic respiration releases far less energy than aerobic respiration, referring to specific stages.

A: Anaerobic respiration only completes glycolysis (yielding 2 ATP), stopping there because pyruvate cannot be converted to acetyl-CoA and enter the Krebs cycle without oxygen. **Aerobic respiration continues through the Krebs cycle and the electron transport chain**, which together generate the large majority of the total ~30–32 ATP — energy that anaerobic respiration simply never accesses.

Hard

Q: A person begins sprinting suddenly after standing still. Explain, in terms of respiration type and ATP yield, what happens in their leg muscles in the first few seconds versus after a minute of continuous running.

A: In the first few seconds, the muscles briefly rely more on anaerobic respiration, because the heart and lungs cannot immediately increase oxygen delivery fast enough to match the sudden demand — glycolysis alone supplies a fast but small 2 ATP per glucose, and lactic acid builds up as a by-product. **After a minute of continuous running, breathing and heart rate increase**, delivering enough oxygen for pyruvate to enter the Krebs cycle and electron transport chain, shifting the muscles back toward aerobic respiration and its far larger ATP yield — more sustainable for continued activity, even though it responds more slowly to sudden demand.

Research & Discussion

- Ask someone in your community who does heavy physical work (farming, carrying water) whether they experience muscle burning during hard tasks. Relate their answer to what you've learned about anaerobic respiration.
- If you have access to any local fermented food or drink (e.g. fermented sorghum porridge), discuss with family members how it's made and which organism might be respiring anaerobically to produce it.

1.8 Respiratory System in Animals

Before this: You should know the difference between aerobic and anaerobic respiration.

Why this matters: Different animals have evolved very different structures to get oxygen into their bodies, depending on their size, environment, and body design.

Key Vocabulary

- **Respiratory surface** (the specific body part where gas exchange with the environment happens)
- **Gaseous exchange** (the movement of oxygen in and carbon dioxide out of an organism)

Respiratory Organs Across Animals

Animal group	Respiratory organ	Common feature of all respiratory surfaces
Unicellular (e.g. amoeba)	Cell membrane	Large surface area, thin, moist, good blood/fluid supply
Earthworm	Skin	Same as above
Fish	Gills	Same as above
Insects	Spiracles + tracheae	Same as above
Humans, birds	Lungs	Same as above

Demonstration — Comparing Surface Area to Volume

1. Cut one potato into a single large cube and a second, identical-sized potato into 8 small cubes.
2. Estimate (or measure with string/paper) the total outer surface area of the single cube versus the combined surface area of all 8 small cubes.
3. Notice the 8 small cubes have far more total surface area for the same total volume.
4. Relate this to why small or thin organisms (or those with folded/branched respiratory surfaces like alveoli or gills) can exchange gases efficiently, while large solid bodies could not rely on their outer skin alone.

Local Example — Fish in the Nile and Its Tributaries

Fish caught in South Sudan's rivers rely entirely on gills to extract dissolved oxygen from water. This is why fish quickly become distressed when removed from water — even though air contains far more oxygen than water, gills are adapted specifically to extract oxygen dissolved in water, not from air.

Key Takeaways & Common Pitfalls

- **Must-remember:** every respiratory surface, whatever the animal, shares the same three features — large surface area, thin walls, good blood or fluid supply.
- **Common mistake:** students sometimes think insects breathe through their mouths — insects actually exchange gases through spiracles (small openings) along their body, connected to internal tracheae.

Practice Questions

Easy

Q: Name the respiratory organ used by fish.

A: **Gills.** They extract dissolved oxygen from water and release carbon dioxide into it.

Medium

Q: List two features common to all respiratory surfaces, and explain why each is necessary.

A: **(1) Large surface area** — increases how much gas can be exchanged at once; **(2) thin walls** — allows gases to diffuse across quickly without a long distance to travel.

Hard

Q: An earthworm relies on its moist skin for gas exchange rather than lungs. Explain why an earthworm's skin can work as a respiratory surface, and suggest one risk this creates for the worm.

A: **The earthworm's skin is thin, kept moist, and well supplied with blood vessels close to the surface** — meeting all three requirements of a respiratory surface even without specialised lungs. **The risk is that if the skin dries out** (e.g. during a hot, dry spell), gas exchange can no longer take place effectively, which is why earthworms are typically found in damp soil and become inactive or die in very dry conditions.

Research & Discussion

- Observe an insect in your area (e.g. a grasshopper) closely. Can you find the small openings (spiracles) along its body?
- Ask a fisherman or someone familiar with fishing in your area what happens to fish soon after they're taken out of the water, and relate it to how gills work.

1.9 Respiration in Other Animals

Before this: You should know the common features shared by all respiratory surfaces.

Why this matters: The very simplest animals show that a whole respiratory system isn't always needed — sometimes diffusion through a single cell membrane is enough, as long as the organism stays small.

Key Vocabulary

- **Diffusion** (the natural movement of a substance from where it is in high concentration to where it is in low concentration, with no energy needed)

Respiration in Amoeba (a Single-Celled Organism)

Amoeba is a single-celled organism living in water. It has no lungs, gills, or skin — its entire outer cell membrane acts as the respiratory surface. Oxygen dissolved in the surrounding water diffuses directly into the cell, and carbon dioxide produced by respiration diffuses back out, both simply following the concentration gradient.

Demonstration — Modelling Diffusion Without a Pump

1. Fill a clear glass with water and let it settle completely still.
2. Carefully drop a small amount of food colouring or hibiscus (karkade) tea concentrate into one spot without stirring.
3. Observe over several minutes as the colour spreads outward on its own, with no stirring or pumping.
4. Relate this to how oxygen and CO₂ move in and out of amoeba — no heart or pump is needed, just diffusion along a concentration difference.

Local Example — Why Amoeba-Sized Organisms Don't Need Lungs

A single-celled organism has a very large surface area compared to its tiny volume, so diffusion alone can supply all the oxygen its one cell needs. A human, by contrast, has a huge volume of cells relative to outer skin surface — which is exactly why humans and other large animals need lungs with a much bigger internal surface area than their outer body size alone could provide.

Key Takeaways & Common Pitfalls

- **Must-remember:** diffusion alone is only sufficient for very small organisms, because small size keeps the surface-area-to-volume ratio high.
- **Common mistake:** students sometimes think amoeba 'doesn't respire' since it has no visible organs — it does respire, just through simple diffusion across its cell membrane rather than through specialised structures.

Practice Questions

Easy

Q: What structure does amoeba use for gas exchange?

A: Its cell membrane. Gases diffuse directly across it, since amoeba has no specialised respiratory organs.

Medium

Q: Explain why diffusion alone is enough to supply amoeba with oxygen, but would not be enough for a large animal.

A: Amoeba is extremely small, giving it a large surface area relative to its volume, so oxygen can diffuse to every part of the cell quickly. **A large animal has a far greater volume relative to its outer surface,** so diffusion alone would be too slow to reach all its internal cells — it needs specialised respiratory organs and a transport system instead.

Hard

Q: If an amoeba-like organism grew significantly larger while keeping the same simple round shape, explain what problem it would encounter with gas exchange, and why.

A: As an organism grows larger while keeping the same shape, its volume increases faster than its surface area (volume grows roughly with the cube of size, while surface area grows roughly with the square). This means the surface-area-to-volume ratio drops, so diffusion across the outer membrane would become too slow to supply oxygen to the organism's now-much-larger interior — it would need to evolve specialised respiratory structures or a different body shape to keep gas exchange efficient.

Research & Discussion

- Look for small pond or puddle water samples in your area (with permission and care) and see if you can identify very small organisms with a hand lens or simple microscope, if available at school.
- Discuss with classmates: why do you think very large animals like elephants or hippos need lungs, while tiny organisms in a drop of water may not?

1.10 Gaseous Exchange in Human Beings and Plants

Before this: You should know that lungs are the human respiratory organ, and that a good respiratory surface is thin, moist, and has a large surface area.

Why this matters: Breathing is only the first half of getting oxygen to your cells — the actual exchange of gases happens at a microscopic structure deep inside the lungs, built specifically to maximize that exchange.

Key Vocabulary

- **Trachea** (windpipe — the main airway connecting the throat to the lungs, held open by rings of cartilage)
- **Bronchi** (the two branches of the trachea, one entering each lung) and **bronchioles** (the many smaller branches the bronchi divide into inside each lung)
- **Alveolus** (tiny air sac at the end of a bronchiole, where gas exchange with the blood actually happens; plural: alveoli — the human lungs contain several hundred million of them)
- **Inhalation** (breathing in) and **exhalation** (breathing out) — together called ventilation
- **Diaphragm** (a dome-shaped muscle below the lungs that helps drive breathing) and **intercostal muscles** (muscles between the ribs that help move the rib cage during breathing)

Airway route: air travels trachea → bronchi → bronchioles → alveoli. Each branching point creates smaller, more numerous tubes, ending in millions of tiny alveoli — this branching is itself an adaptation, since it creates an enormous total surface area for gas exchange within the limited space of the chest.

Breathing Mechanism (Humans)

Phase	Diaphragm	Rib cage	Result
Inhalation	Contracts, flattens	Moves up and out	Chest volume increases, air rushes in
Exhalation	Relaxes, domes upward	Moves down and in	Chest volume decreases, air is pushed out

Gas exchange at the alveolus (original schematic)

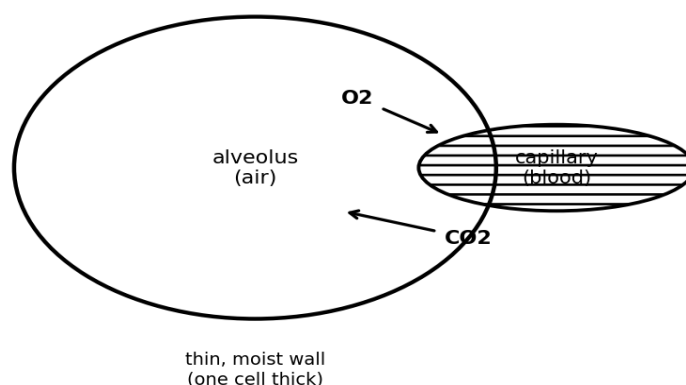


Diagram: original schematic of gas exchange at the alveolus — oxygen diffuses into the blood, carbon dioxide diffuses out, across a thin, moist wall.

Demonstration — Modelling the Breathing Mechanism

1. Cut the neck off a small balloon and stretch it tightly over the open bottom of a plastic bottle with its base removed.
2. Insert a smaller balloon through the bottle's mouth, sealing around the neck with a straw or tube so air can only move in/out through the balloon.
3. Pull the stretched balloon (representing the diaphragm) downward — observe the inner balloon (representing a lung) inflate.
4. Push the stretched balloon upward — observe the inner balloon deflate.
5. Relate: pulling down = diaphragm contracting = inhalation; pushing up = diaphragm relaxing = exhalation.

Local Example — Breathlessness at High Exertion

Someone carrying heavy jerry cans of water uphill breathes faster and deeper than at rest. Faster, deeper breathing increases the volume of air reaching the alveoli per minute, keeping the oxygen diffusion gradient high enough to meet the muscles' increased demand for oxygen.

Key Takeaways & Common Pitfalls

- **Must-remember:** breathing (ventilation) and gas exchange are two separate steps — breathing moves air in and out, while exchange is the actual diffusion of gases between air and blood at the alveoli.
- **Common mistake:** students often think the lungs actively 'pump' themselves — lungs have no muscle tissue and only expand/contract due to pressure changes caused by the diaphragm and rib muscles.

Practice Questions

Easy

Q: What happens to the diaphragm during inhalation?

A: It contracts and flattens. This increases the volume of the chest cavity, drawing air into the lungs.

Medium

Q: Explain why the alveolus is well suited to gas exchange.

A: It has a large surface area (many millions of alveoli), thin walls (one cell thick), a moist lining, and a rich blood supply — all four features together allow oxygen and carbon dioxide to diffuse quickly between air and blood.

Hard

Q: A person with a lung condition that thickens the alveolar walls often experiences breathlessness even at rest. Explain, in terms of gas exchange, why this happens.

A: Thickened alveolar walls increase the distance gases must diffuse across, slowing the rate of oxygen entering the blood and carbon dioxide leaving it. Even though breathing (ventilation) may still bring air in and out normally, the actual exchange step is impaired, so the body doesn't get enough oxygen — causing breathlessness even without physical exertion.

Research & Discussion

- Time how many breaths you take per minute at rest, then again right after a short period of exercise (e.g. running on the spot for one minute). Discuss why the number changes.
- Ask an older family member if they know anyone affected by smoke (e.g. from indoor cooking fires) and whether it seems to affect their breathing. Relate this to what you've learned about the alveoli.

1.11 Gaseous Exchange in Plants

Before this: You should know what stomata are and that they are found mostly on the underside of leaves.

Why this matters: Unlike animals, plants don't have lungs or a single breathing rhythm — gas exchange happens continuously and passively through small pores, and even changes direction between day and night.

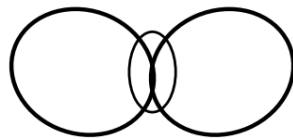
Key Vocabulary

- **Guard cells** (a pair of cells surrounding each stoma that control whether it is open or closed)
- **Lenticels** (small raised pores on woody stems that allow gas exchange through the bark)

Gas Exchange: Day vs Night

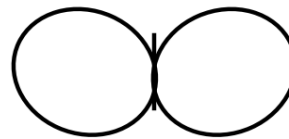
Time	Process(es) occurring	Net gas exchange in leaves
Daytime	Photosynthesis (uses CO ₂ , releases O ₂) + respiration (uses O ₂ , releases CO ₂)	O ₂ diffuses out overall; CO ₂ diffuses in overall (photosynthesis outweighs respiration)
Night-time	Only respiration occurs (no light for photosynthesis)	O ₂ diffuses in; CO ₂ diffuses out

Guard cells: open



pore open
(gases move freely)

Guard cells: closed



pore closed
(gas exchange blocked)

Diagram: original schematic of guard cells controlling an open versus closed stoma. Shown structurally (pore visible or blocked), not by colour.

Experiment — Observing Stomata Under a Hand Lens

1. Paint a small patch of clear nail polish on the underside of a fresh leaf and allow it to dry fully.
2. Once dry, press a small piece of clear tape onto the patch and peel it away gently, lifting a thin layer of the leaf's outer cells.
3. Stick the peeled layer onto a clear surface or slide.
4. Examine under a hand lens or microscope, looking for small paired guard cells with a gap (the stoma) between them.

Local Example — Water Loss in the Dry Season

During South Sudan's dry season, many trees partly close their stomata during the hottest part of the day to reduce water loss through transpiration — even though this also slightly reduces how much CO₂ can enter for photosynthesis. It's a trade-off between conserving water and maximizing food production.

Key Takeaways & Common Pitfalls

- **Must-remember:** the net direction of gas exchange in a leaf actually reverses between day and night, because photosynthesis only happens in daylight while respiration happens all the time.
- **Common mistake:** students often think plants 'only' release oxygen and 'only' take in CO₂ — at night, with no photosynthesis happening, the net exchange is the opposite: CO₂ out, O₂ in, exactly like respiration in animals.

Practice Questions

Easy

Q: What structures surround and control a stoma?

A: **Guard cells.** They change shape to open or close the pore between them.

Medium

Q: Explain why the net gas exchange in a leaf is different during the day compared to at night.

A: **During the day, photosynthesis (which uses CO₂ and releases O₂) is occurring alongside respiration**, and photosynthesis's gas use outweighs respiration's, so the net exchange is CO₂ in, O₂ out. **At night, with no photosynthesis happening, only respiration continues**, reversing the net exchange to O₂ in, CO₂ out.

Hard

Q: A farmer notices that a certain drought-resistant tree in their field keeps its leaves tightly curled and its stomata mostly closed throughout the hottest hours of the day, even though this must slow its photosynthesis. Explain why this could still benefit the plant overall.

A: **Closing stomata during the hottest, driest hours reduces water loss through transpiration**, which matters more to the plant's survival than a temporary reduction in photosynthesis rate. **The tree effectively trades a lower rate of food production for a much lower risk of fatal water loss** — a worthwhile trade-off during South Sudan's dry season, when water conservation can be more urgent than maximizing growth.

Research & Discussion

- Observe a tree or crop near your home in the early morning versus the hottest part of a dry-season afternoon. Do the leaves look different (e.g. curled, drooping)? Discuss possible reasons with a family member.
- Look for raised bumps or rough patches on the bark of a tree trunk near you — these may be lenticels. Discuss with classmates what role they might play.