

# Energy Flow, Ecosystems and the Environment

## revision notes

Energy Flow, Ecosystems and the Environment is topic 5 of Pearson Edexcel International A Level Biology (YBI11) and is examined in Unit 4. It covers photosynthesis, productivity and energy transfer, ecosystems and succession, climate change and its effects, the effect of temperature on enzymes, and evolution and speciation. It includes core practicals 10, 11 and 12.

For Pearson Edexcel International AS Biology XBI11 and International A Level Biology YBI11, **A Level only** is IA2 content (Units 4 to 6), not needed for the International AS.

### 1 Photosynthesis **Spec 5.1–5.8** **A Level only**

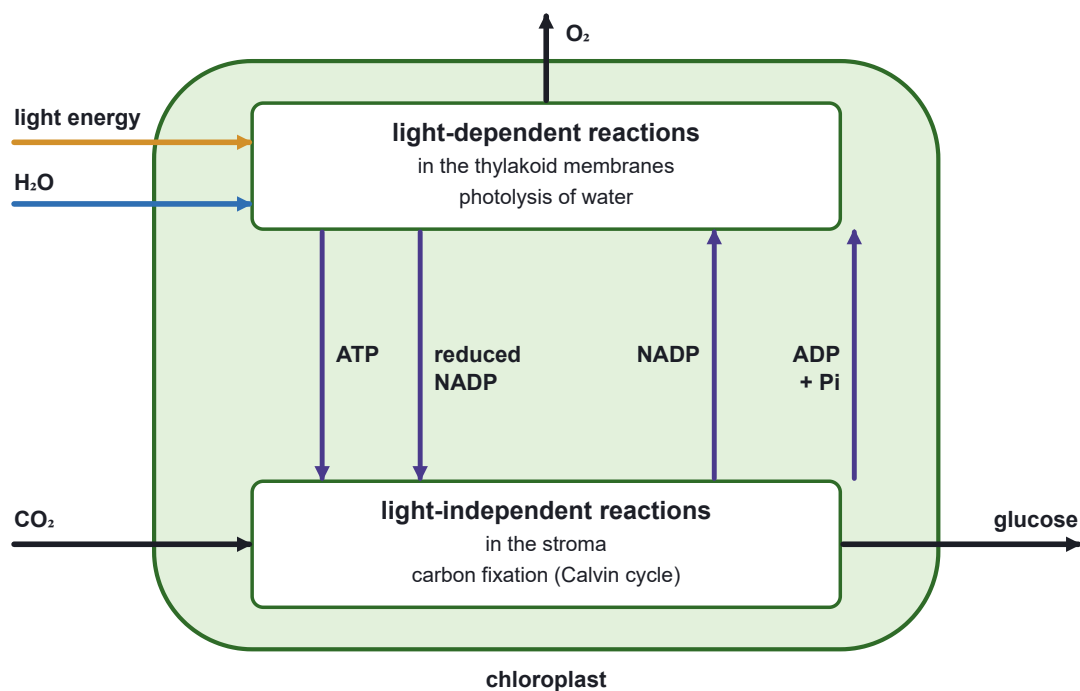
#### The overall reaction and the role of ATP **Spec 5.1, 5.2**

The overall reaction is a **redox reaction**. Light energy is used to break the strong bonds in water molecules (photolysis). The hydrogen from the water is stored in a fuel, **glucose**, by combining it with carbon dioxide. Oxygen is released into the atmosphere as a by-product.



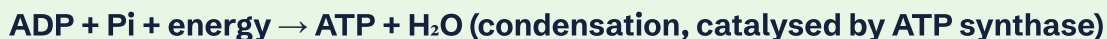
Carbon dioxide is reduced (it gains hydrogen) and water is oxidised (it loses hydrogen and electrons). The oxygen released comes from water, not from carbon dioxide. This can be shown by supplying plants with water labelled with the isotope oxygen-18: the oxygen gas given off is labelled, but the glucose is not. The summary equation above hides this, because 6 water molecules hold only 6 of the 12 oxygen atoms in  $6\text{O}_2$ . A more accurate equation is  $6\text{CO}_2 + 12\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 + 6\text{H}_2\text{O}$ , in which all the oxygen gas comes from water.

The reaction is not carried out in one step. Light energy is first used in the **light-dependent reactions** to make ATP and reduced NADP. These are then used in the **light-independent reactions** to reduce carbon dioxide to sugars.



The **light-dependent reactions** make ATP and **reduced NADP** (a hydrogen carrier) and release oxygen from water; the **light-independent reactions** use them to fix carbon dioxide into glucose.

ATP (adenosine triphosphate) is the immediate source of energy for biological processes. When the terminal phosphate bond is hydrolysed, ATP becomes ADP and inorganic phosphate (Pi) and a small, usable amount of energy is released. This is done in one step, catalysed by ATP hydrolase (ATPase), so energy is available quickly and in amounts the cell can use.



In photosynthesis, the ADP is converted to ATP by **photophosphorylation**: the addition of phosphate to ADP using light energy. This requires energy because the reaction  $\text{ADP} + \text{Pi} \rightarrow \text{ATP}$  is endergonic. The ATP made in the light-dependent reactions is hydrolysed in the light-independent reactions to power the reduction of carbon dioxide.

*Exam tip: Say that photophosphorylation uses light energy to add phosphate to ADP. Do not say that ATP stores or 'makes' energy: it releases energy when it is hydrolysed.*

## The light-dependent reactions Spec 5.3

The light-dependent reactions take place on the **thylakoid membranes** of the chloroplast. Chlorophyll and other pigments are arranged in two groups called photosystems: photosystem I (PSI) and photosystem II (PSII). Each photosystem traps light energy and passes it to a reaction centre containing chlorophyll a.

### How light energy is trapped

When a photon of light hits chlorophyll, an electron in the chlorophyll is raised to a higher energy level. The electron is said to be **excited**. It leaves the chlorophyll molecule and is passed to an electron carrier. The chlorophyll has been oxidised (it has lost an electron).

## Non-cyclic photophosphorylation

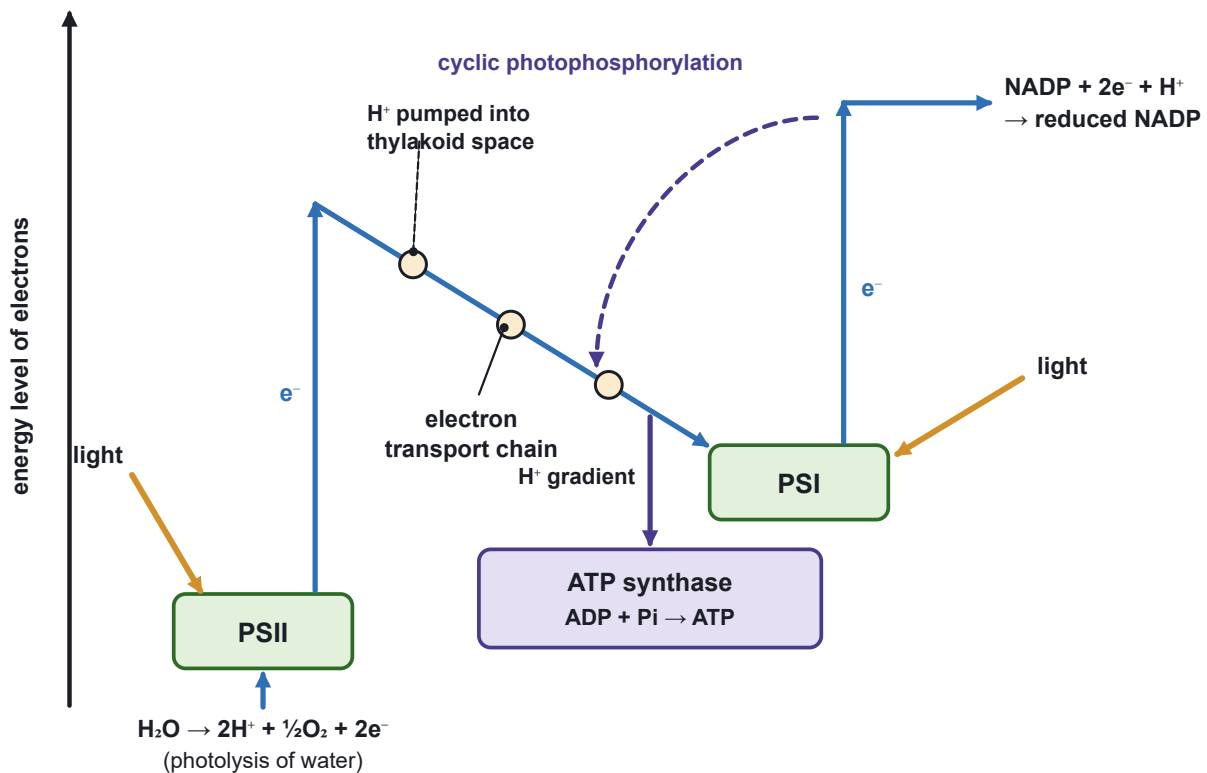
1. Light energy excites two electrons in chlorophyll in photosystem II. They leave the chlorophyll and are taken up by the first electron carrier in the electron transport chain.
2. The electrons pass down the electron transport chain from carrier to carrier, losing energy at each step in a series of redox reactions.
3. The energy lost is used to pump protons ( $H^+$ ) from the stroma into the thylakoid space. This builds up a proton gradient across the thylakoid membrane.
4. Protons flow back down their concentration gradient into the stroma through ATP synthase. This is **chemiosmosis**. The flow drives the synthesis of ATP from ADP and  $P_i$  (photophosphorylation).
5. Light also excites electrons in photosystem I. These electrons are passed to NADP, which also accepts a proton ( $H^+$ ) from the stroma, and is reduced to **reduced NADP**.
6. The electrons lost from photosystem II are replaced by electrons from water. The enzyme-catalysed **photolysis** of water splits it:  $2H_2O \rightarrow 4H^+ + 4e^- + O_2$ . The electrons replace those lost from chlorophyll. The  $H^+$  ions contribute to the proton gradient and are used to reduce NADP. The oxygen is a waste product, and diffuses out of the leaf or is used in respiration.

Because electrons flow in one direction, from water through the two photosystems to NADP, this is called non-cyclic photophosphorylation. Its products are ATP, reduced NADP and oxygen.

## Cyclic photophosphorylation

In cyclic photophosphorylation only photosystem I is used. Excited electrons leave chlorophyll, pass along an electron transport chain and return to the same chlorophyll molecule. Energy lost along the chain is used to make ATP by chemiosmosis. No NADP is reduced, no water is split and no oxygen is made. The electrons are recycled, so no replacement electrons are needed.

| Cyclic and non-cyclic photophosphorylation |                      |                                         |
|--------------------------------------------|----------------------|-----------------------------------------|
| Feature                                    | Non-cyclic           | Cyclic                                  |
| <b>Photosystems used</b>                   | Photosystem II and I | Photosystem I only                      |
| <b>Source of electrons</b>                 | Water (photolysis)   | The same chlorophyll (electrons return) |
| <b>ATP made</b>                            | Yes                  | Yes                                     |
| <b>Reduced NADP made</b>                   | Yes                  | No                                      |
| <b>Oxygen made</b>                         | Yes                  | No                                      |



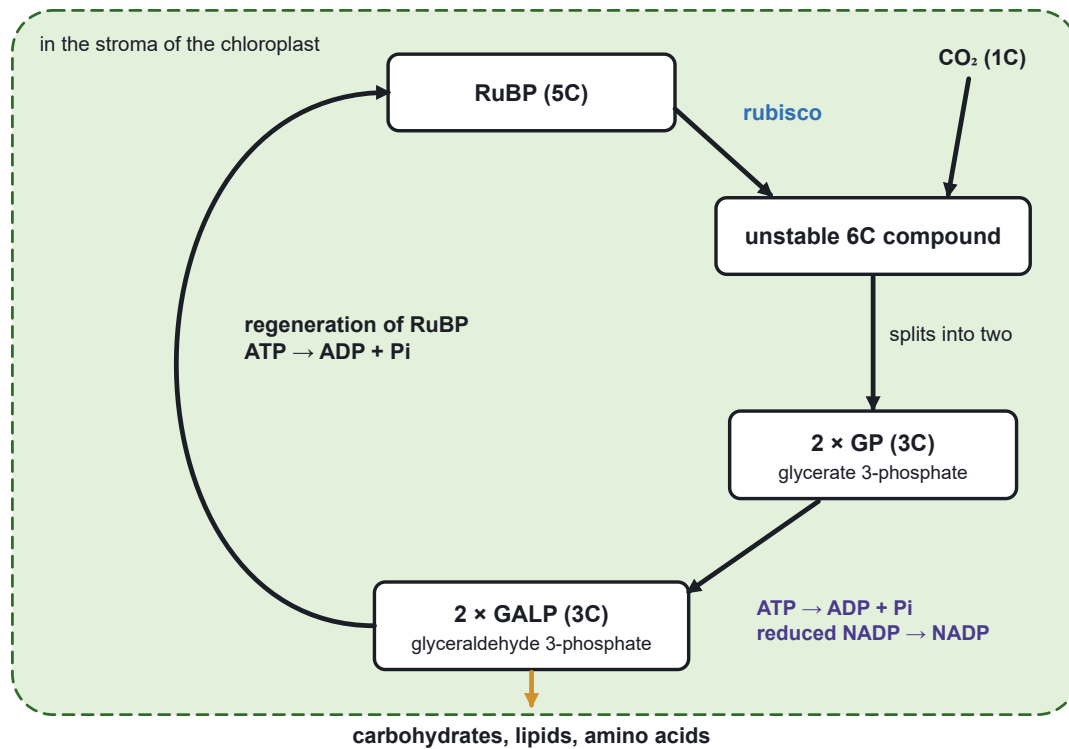
The **Z-scheme** of the light-dependent reactions: electrons are raised to a higher energy level twice, with ATP made as they pass down the chain.

**Common mistake: Photolysis is not the splitting of carbon dioxide. Oxygen released in photosynthesis comes from water.**

## The light-independent reactions (Calvin cycle) Spec 5.4

The light-independent reactions are a cycle of enzyme-controlled reactions called the **Calvin cycle**. They take place in the **stroma** of the chloroplast. They do not need light directly, but they depend on the ATP and reduced NADP made in the light-dependent reactions, so they stop soon after the light is switched off.

1. **Carbon fixation**: carbon dioxide diffuses into the stroma and combines with the five-carbon compound ribulose biphosphate (**RuBP**). The reaction is catalysed by the enzyme ribulose biphosphate carboxylase-oxygenase (**rubisco**). The unstable six-carbon compound formed splits immediately into two molecules of the three-carbon compound glycerate 3-phosphate (**GP**).
2. **Reduction**: GP is reduced to glyceraldehyde 3-phosphate (**GALP**, a triose phosphate) using hydrogen from reduced NADP and energy from ATP. Reduced NADP is oxidised back to NADP, and ATP to ADP and  $\text{P}_i$ , which return to the light-dependent reactions.
3. **Regeneration**: most of the GALP (five of every six molecules) is used, with energy from ATP, to regenerate RuBP so that the cycle can continue.
4. **Synthesis**: the remaining GALP is used to make glucose and other organic molecules. Two GALP molecules are needed to make one hexose sugar, so the cycle must turn six times to fix the six carbon atoms needed for one glucose molecule.



The **Calvin cycle**: carbon fixation by rubisco, reduction of GP to GALP, and regeneration of RuBP.

### Uses of the products (5.4(ii))

The products of photosynthesis are **simple sugars**. These are used by plants, animals and other organisms in respiration, to release energy, and in the synthesis of new biological molecules.

| Biological molecules made from the products of photosynthesis |                                                                                                                                                    |
|---------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| Molecule made                                                 | How the products of the Calvin cycle are used                                                                                                      |
| <b>Polysaccharides</b>                                        | Glucose is made from GALP, then joined by condensation to make starch (storage) and cellulose (cell walls)                                         |
| <b>Lipids</b>                                                 | Glycerol is made from GALP, and fatty acids from GP (via acetyl CoA), then combined to form triglycerides                                          |
| <b>Amino acids and proteins</b>                               | GP provides the carbon skeletons. Nitrogen comes from nitrate ions absorbed from the soil. Amino acids are joined by condensation to form proteins |
| <b>Nucleic acids</b>                                          | Sugars provide the pentose sugars (ribose, deoxyribose) and carbon for bases. Phosphate groups come from phosphate ions in the soil                |

Animals and other organisms (such as fungi and many microorganisms) obtain these sugars and the molecules made from them by feeding, and use them in the same ways.

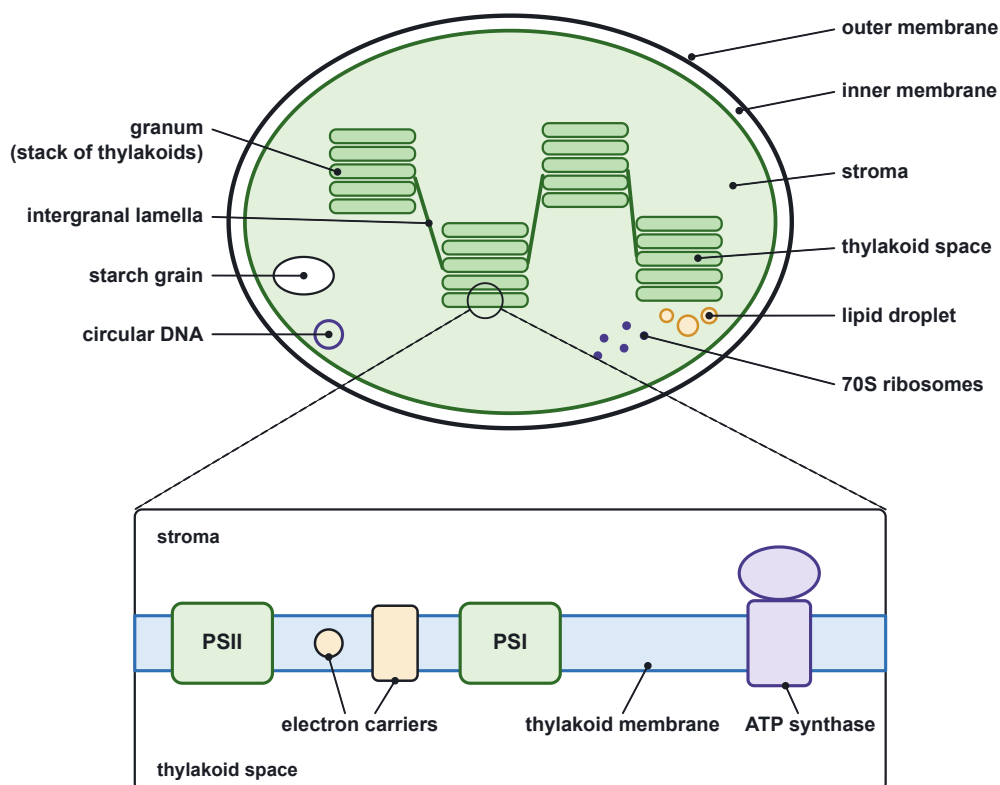
*Exam tip: If asked what happens to GP and RuBP levels when conditions change, work through the cycle. In darkness, ATP and reduced NADP run out, so GP cannot be reduced; GP rises and RuBP falls. With less carbon dioxide, RuBP cannot be used; RuBP rises and GP falls.*

### Chloroplast structure and function Spec 5.5

Chloroplasts are found mainly in palisade mesophyll cells. They are biconvex discs about 2 to 10 µm long. Each is surrounded by a **chloroplast envelope** of two phospholipid membranes, which controls the entry and exit of substances such as carbon dioxide, ATP and sugars.

## Chloroplast structure related to function

| Structure                            | Description                                                | Role in photosynthesis                                                                                                                                                                                 |
|--------------------------------------|------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Thylakoid membranes</b>           | Flattened fluid-filled sacs, with a thylakoid space inside | Contain chlorophyll and other pigments in photosystems, electron carriers and ATP synthase. Site of the light-dependent reactions. The small space inside allows a proton gradient to build up quickly |
| <b>Grana (singular granum)</b>       | Stacks of thylakoids                                       | Give a very large surface area for pigments, so more light is absorbed. Stacks are arranged to capture light efficiently                                                                               |
| <b>Intergranal lamellae</b>          | Thylakoid membranes joining one granum to the next         | Link grana, and keep them in position                                                                                                                                                                  |
| <b>Stroma</b>                        | Colourless fluid-filled matrix surrounding the grana       | Contains the enzymes (including rubisco) for the light-independent reactions, starch grains, lipid droplets, and the chloroplast's own DNA and ribosomes                                               |
| <b>Starch grains</b>                 | Insoluble stores in the stroma                             | Temporary store of the sugars made in the Calvin cycle                                                                                                                                                 |
| <b>Chloroplast DNA and ribosomes</b> | A small circular DNA molecule and 70S ribosomes            | Allow chloroplasts to make some of their own proteins, for example some rubisco subunits                                                                                                               |



A chloroplast, with a magnified view of the **thylakoid membrane** where the light-dependent reactions happen.

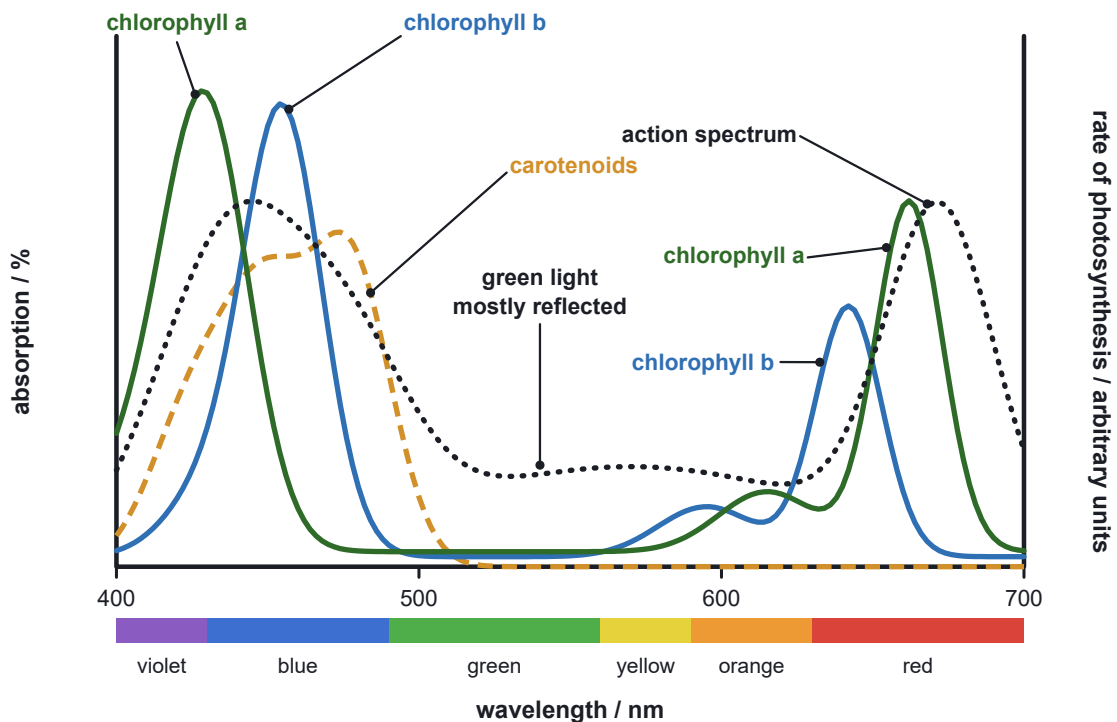
The two stages of photosynthesis are in different places but close together. The ATP and reduced NADP made on the thylakoid membranes are used straight away in the stroma next door, so little energy is lost in transport.

## Pigments, spectra and chromatography Spec 5.6, 5.7

|                            |                                                                                                                                        |
|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| <b>Absorption spectrum</b> | A graph showing how much light of different wavelengths is absorbed by a pigment (or by a leaf extract).                               |
| <b>Action spectrum</b>     | A graph showing the rate of photosynthesis (for example oxygen released or carbon dioxide taken up) at different wavelengths of light. |

Chloroplasts contain a mixture of photosynthetic pigments. **Chlorophyll a** and **chlorophyll b** absorb mostly red and blue-violet light, and reflect green light. Carotenoids (for example carotene and xanthophyll) absorb mostly blue-violet and blue-green light. Different pigments absorbing different wavelengths mean that more of the available light is used.

The action spectrum has a similar shape to the combined absorption spectra of the pigments. This shows that the wavelengths that are absorbed are the ones used in photosynthesis. The action spectrum is not identical to the absorption spectrum, because some light absorbed by accessory pigments is passed on to chlorophyll a with some loss of efficiency, and not all absorbed light is used in photosynthesis.



Absorption spectra of the pigments and the **action spectrum** share the same peaks in blue-violet and red light.

**Common mistake:** Do not say that an action spectrum shows how much light is absorbed. It shows the rate of photosynthesis.

### Separating pigments by chromatography (5.7)

1. Grind fresh leaves with a little propanone (or ethanol) and sand to extract the pigments.
2. Draw a pencil line (the origin) about 2 cm from the bottom of a chromatography paper strip (or a thin-layer chromatography plate). Use pencil because ink would also dissolve in the solvent.
3. Apply a small spot of extract on the line and let it dry. Repeat several times to build up a concentrated spot.
4. Stand the paper in a container with a shallow layer of solvent (a mixture such as petroleum ether and propanone) below the origin line. Cover the container.

5. When the solvent front is near the top, remove the paper and mark the solvent front at once with a pencil before it evaporates.
6. Measure the distance from the origin to the centre of each pigment spot and from the origin to the solvent front.

The pigments separate because they have different solubilities in the solvent and different affinities for the paper (or plate). A pigment that is more soluble in the solvent, and sticks less strongly to the paper, travels further.

$$R_f = \text{distance moved by the pigment} \div \text{distance moved by the solvent front}$$

The  $R_f$  value has no units and is always less than 1. The same pigment gives the same  $R_f$  value in the same solvent and under the same conditions, so  $R_f$  values can be compared with published values to identify pigments. Carotene travels furthest (highest  $R_f$ ), followed by xanthophyll, then chlorophyll a, then chlorophyll b (lowest  $R_f$  of the four).

#### Calculating an $R_f$ value

A pigment spot is 5.4 cm from the origin. The solvent front is 7.2 cm from the origin. Calculate the  $R_f$  value of the pigment.

1.  $R_f = \text{distance moved by the pigment} \div \text{distance moved by the solvent front}$
2.  $R_f = 5.4 \div 7.2$

**Answer:**  $R_f = 0.75$  (no units)

*Maths skill: Measure to the centre of each spot, and measure both distances from the same origin line.  $R_f$  has no unit, and a value above 1 means a measuring slip.*

*Exam tip: If asked about risks or good practice in chromatography: handle propanone and other solvents in a well-ventilated area away from flames, wear eye protection, and keep the lid on the container so the atmosphere in the tank stays saturated with solvent vapour.*

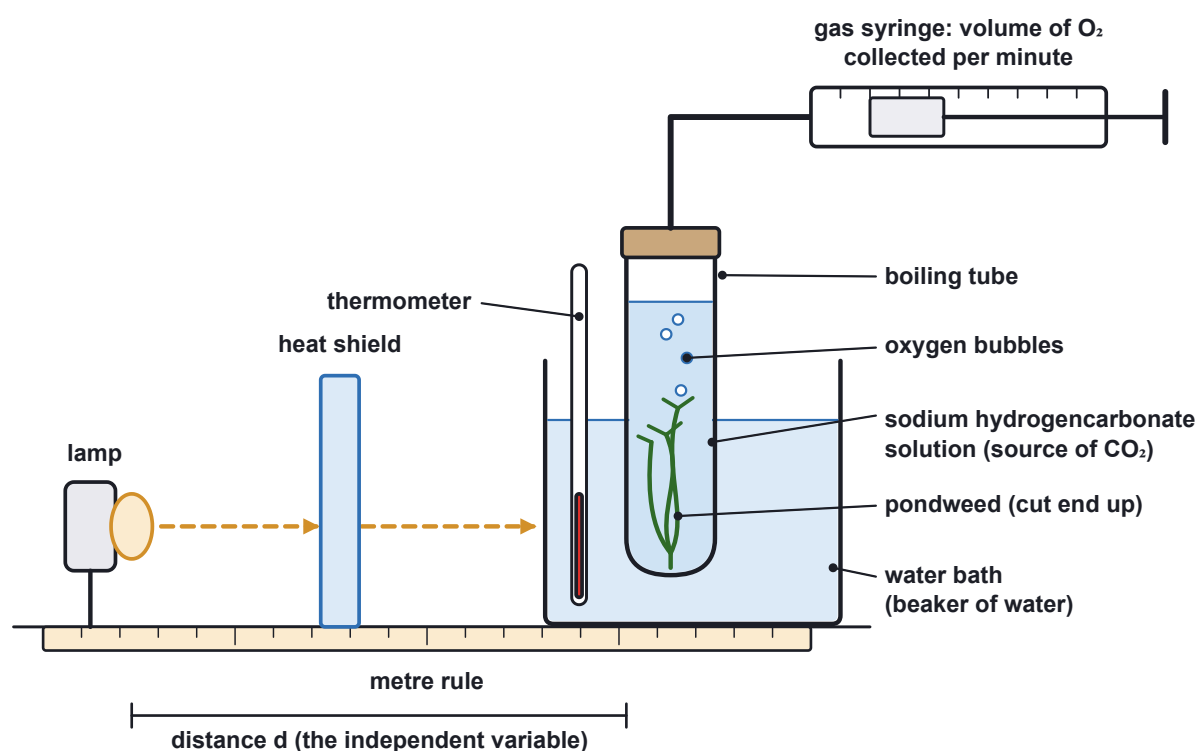
### Core practical 10: factors affecting the rate of photosynthesis Spec 5.8

*Core practical: Core practical 10: investigate the effects of light intensity, light wavelength, temperature and availability of carbon dioxide on the rate of photosynthesis using a suitable aquatic plant.*

A piece of aquatic plant (for example *Cabomba* or *Elodea*) is cut at the stem under water and placed in a boiling tube or beaker with the cut end upwards. Oxygen released in photosynthesis forms bubbles at the cut end. The **rate of photosynthesis** is estimated from the number of bubbles per minute, or more accurately from the volume of gas collected in a capillary tube or gas syringe in a set time.

## Variables in the investigation

| Factor<br>(independent<br>variable) | How it is varied                                                                                                                                  | What must be controlled                                                                                                                    |
|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Light intensity</b>              | Move a lamp to different measured distances from the plant (intensity is proportional to $1 \div \text{distance}^2$ )                             | Temperature (place a heat shield, such as a beaker of water, between lamp and plant), carbon dioxide concentration, plant mass, wavelength |
| <b>Light wavelength</b>             | Use coloured filters, or LEDs of different colours, at a fixed distance                                                                           | Light intensity (check it with a light meter), temperature, carbon dioxide concentration                                                   |
| <b>Temperature</b>                  | Use a water bath at several set temperatures (for example 10 to 40 °C), checked with a thermometer                                                | Light intensity, carbon dioxide concentration, plant mass; allow the plant to equilibrate before counting                                  |
| <b>Carbon dioxide availability</b>  | Use sodium hydrogencarbonate solutions of different concentrations (for example 0.00 to 0.10 mol dm <sup>-3</sup> ), which release carbon dioxide | Light intensity, temperature, plant mass, volume of solution                                                                               |



Measuring the rate of photosynthesis as the volume of oxygen collected per minute at different lamp distances  $d$  (the water bath and heat shield keep the temperature constant).

## Method and good practice

- Leave the plant under the lamp for a few minutes to adjust to each new condition (equilibrate), then count bubbles or measure gas volume for a fixed time such as 2 or 5 minutes.
- Repeat at least three times at each value of the independent variable and calculate a mean, ignoring anomalous results.
- Use the same plant (or pieces cut to the same length and mass) throughout, and the same volume of solution in the tube.

- A control with no plant, or with a plant in the dark, shows that bubbles come from the plant's photosynthesis.

## Processing results

Rate = volume of oxygen collected  $\div$  time, in  $\text{cm}^3 \text{ min}^{-1}$ . Plot rate against the independent variable. Light intensity can be plotted against  $1 \div \text{distance}^2$ , because intensity is inversely proportional to the square of the distance from a point source. A graph that levels off shows that another factor has become limiting.

### Calculating a rate and a mean

In three trials at 20 cm from the lamp, a plant gave off 0.9, 1.0 and 1.1  $\text{cm}^3$  of oxygen in 5 minutes. Calculate the mean rate of photosynthesis in  $\text{cm}^3 \text{ min}^{-1}$ .

1. Mean volume =  $(0.9 + 1.0 + 1.1) \div 3 = 1.0 \text{ cm}^3$
2. Rate = volume  $\div$  time =  $1.0 \div 5$

**Answer:**  $0.20 \text{ cm}^3 \text{ min}^{-1}$

*Maths skill: Quote the unit of rate ( $\text{cm}^3 \text{ min}^{-1}$ ), and say how many readings the mean was calculated from.*

Risks: the lamp and mains electricity are used near water, so keep the socket and lamp away from spills. The lamp can get hot; allow it to cool before moving it. Wash hands after handling plants and pond water.

*Exam tip: Light, temperature and carbon dioxide can each be limiting. In an exam, say which factor is limiting at the point where a graph levels off, and why the other factors are not.*

### Quick check

1. Where does the oxygen released in photosynthesis come from?
2. Name the enzyme that catalyses the fixation of carbon dioxide by RuBP.
3. Which stage of photosynthesis makes reduced NADP?
4. What is the formula for the  $R_f$  value?

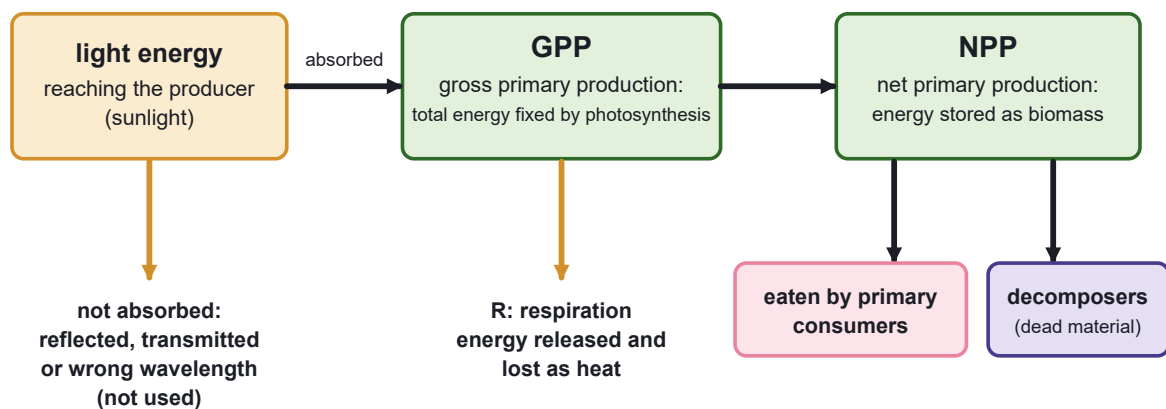
## 2 Productivity and ecosystems Spec 5.9-5.15 A Level only

### Gross and net primary productivity Spec 5.9

|                                         |                                                                                                                                                                |
|-----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Gross primary productivity (GPP)</b> | The total chemical energy fixed by photosynthesis in a given area in a given time (for example $\text{kJ m}^{-2} \text{ year}^{-1}$ ).                         |
| <b>Net primary productivity (NPP)</b>   | The chemical energy remaining in plant biomass after the energy lost in respiration has been taken away. It is the energy available to the next trophic level. |

$$\text{NPP} = \text{GPP} - \text{R} \text{ (R = energy lost in plant respiration)}$$

Plants use some of the sugars they make in respiration, to release energy for growth, active transport and other processes. This energy is eventually lost as heat. Only the remainder is stored in new plant material (growth), which is the biomass that can be eaten by herbivores or decomposed. Productivity is measured as a **rate**, for example  $\text{kJ m}^{-2} \text{ year}^{-1}$  for energy or  $\text{g m}^{-2} \text{ year}^{-1}$  for dry mass of biomass.



$$\text{NPP} = \text{GPP} - \text{R}$$

all measured in  $\text{kJ m}^{-2} \text{ year}^{-1}$  (energy) or  $\text{g m}^{-2} \text{ year}^{-1}$  (dry mass)

From sunlight to biomass:  $\text{NPP} = \text{GPP} - \text{R}$ .

#### Calculating NPP

A field of grass fixes  $12\,500 \text{ kJ m}^{-2} \text{ year}^{-1}$  of energy by photosynthesis. The grass loses  $4\,100 \text{ kJ m}^{-2} \text{ year}^{-1}$  in respiration. Calculate the net primary productivity and express it as a percentage of GPP.

1.  $\text{NPP} = \text{GPP} - \text{R}$
2.  $\text{NPP} = 12\,500 - 4\,100 = 8\,400 \text{ kJ m}^{-2} \text{ year}^{-1}$
3.  $\text{Percentage} = 8\,400 \div 12\,500 \times 100$

**Answer:**  $\text{NPP} = 8\,400 \text{ kJ m}^{-2} \text{ year}^{-1}$  (67.2 % of GPP)

*Maths skill: You may be given any two of GPP, R and NPP and asked for the third. Rearrange the equation first and give the unit ( $\text{kJ m}^{-2} \text{ year}^{-1}$  or  $\text{g m}^{-2} \text{ year}^{-1}$ ).*

*Common mistake: Do not say that GPP is the energy absorbed from the Sun. Most light is not absorbed, and only a small percentage of the light energy that reaches the leaf is fixed.*

## Efficiency of biomass and energy transfers Spec 5.10

**efficiency of transfer (%) = (energy or biomass in the next trophic level ÷ energy or biomass in the previous trophic level) × 100**

Use the same units for both trophic levels. Energy transfer is usually measured in  $\text{kJ m}^{-2} \text{ year}^{-1}$ , and biomass transfer as dry mass in  $\text{g m}^{-2} \text{ year}^{-1}$ . Dry mass is used because water content varies and water holds no chemical energy.

### Calculating efficiency of energy transfer

Grass in a meadow has an NPP of  $8\,400 \text{ kJ m}^{-2} \text{ year}^{-1}$ . Rabbits feeding on the grass gain  $840 \text{ kJ m}^{-2} \text{ year}^{-1}$  of energy in their biomass. Calculate the efficiency of transfer from grass to rabbits.

1.  $\text{efficiency} = \text{energy in rabbits} \div \text{energy in grass} \times 100$

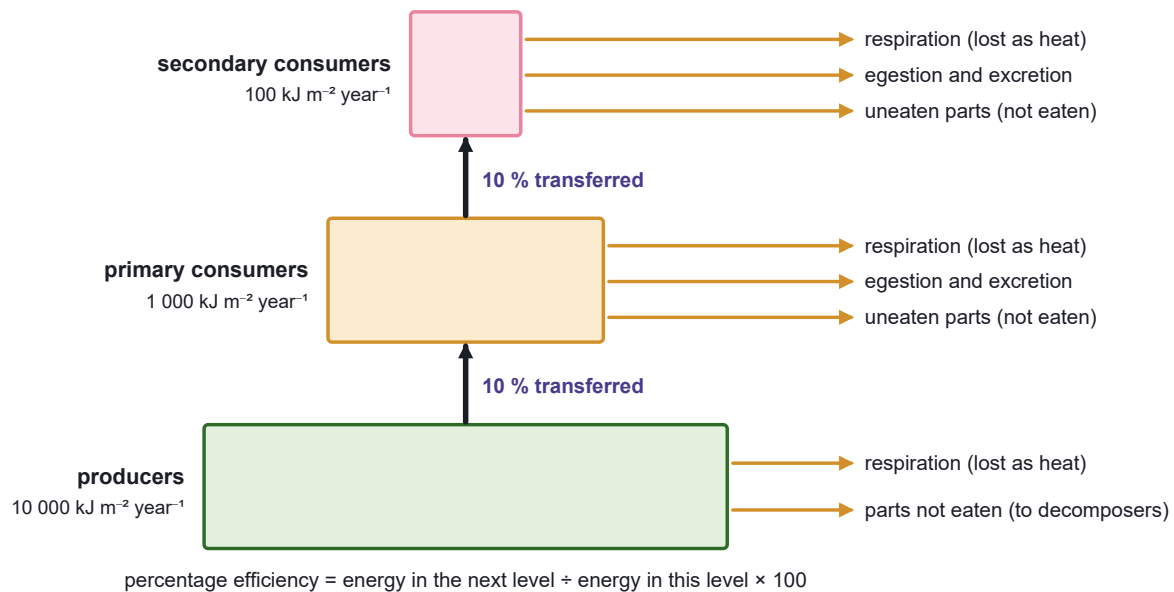
2.  $= 840 \div 8\,400 \times 100$

**Answer:** 10 %

### Why transfers are inefficient

- Not all of the organism is eaten: bones, roots, shells, hair and other parts are left uneaten.
- Some of what is eaten is not digested and is lost in faeces (**egestion**).
- Some absorbed material is lost as excretory products such as urea (**excretion**), which contains energy.
- Energy is lost as heat from **respiration** in the consumer, to power movement, active transport and other processes (and, in birds and mammals, to maintain body temperature). This energy is not available to the next trophic level.
- Not all individuals are eaten: some die of disease or old age and pass to decomposers.

Because of these losses, the biomass and energy at each trophic level are lower than in the level before it. This is why food chains rarely have more than four or five trophic levels, and why pyramids of energy are always pyramid-shaped. Transfers are often less efficient from producer to primary consumer (plants contain indigestible cellulose and lignin) and are higher for carnivores (whose food is easier to digest).



A **pyramid of energy**: each level holds less energy because of losses at every transfer.

*Exam tip: When explaining energy loss, name the process (respiration, egestion, excretion) and say what happens to the energy (lost as heat; held in material that passes to decomposers). Marks are rarely given for 'energy is lost' on its own.*

## Population, community, habitat and ecosystem; biotic and abiotic factors Spec 5.11, 5.12

|                   |                                                                                                                                     |
|-------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| <b>Population</b> | All the organisms of one species living in a habitat at the same time.                                                              |
| <b>Community</b>  | All the populations of different species living and interacting in a habitat.                                                       |
| <b>Habitat</b>    | The place where an organism, population or community lives, with its own set of environmental conditions.                           |
| <b>Ecosystem</b>  | A community of organisms together with the non-living (abiotic) components of their environment, and the interactions between them. |

For example, in a pond the population of frogs, the population of pondweed and the populations of all the other species make up the community. The pond water, sediment, light, dissolved oxygen and temperature are abiotic parts of the ecosystem.

### Biotic and abiotic factors

The **numbers** and **distribution** of organisms in a habitat are controlled by both kinds of factor. Distribution describes where organisms are found, and abundance how many there are.

| Biotic and abiotic factors |                                                                                                                                        |                                                                                                                                                                 |
|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                            | Biotic factors                                                                                                                         | Abiotic factors                                                                                                                                                 |
| <b>Meaning</b>             | Factors caused by living organisms                                                                                                     | Non-living physical and chemical factors                                                                                                                        |
| <b>Examples</b>            | Competition (for food, light, space, mates), predation, parasitism and disease, grazing, availability of food                          | Temperature, light intensity, water availability, pH, salinity, oxygen concentration, mineral ions, wind speed, humidity                                        |
| <b>Effects</b>             | Intraspecific competition limits population size; interspecific competition and predation can exclude a species from part of a habitat | Set the range of conditions in which a species can survive and reproduce, for example plants that are not tolerant to salt are limited to areas of low salinity |

Biotic factors are often **density-dependent**: their effect increases as the population gets larger, for example disease and competition. Abiotic factors such as a severe frost affect a population regardless of its size.

*Exam tip: In a data question, say whether the factor is biotic or abiotic, and then link it to the effect on numbers or distribution, for example 'an increase in predators lowers prey numbers' rather than just 'predation'.*

## The concept of niche Spec 5.13

### Niche

The role of a species within its habitat, including its interactions with the biotic and abiotic components of the environment (for example its food, its habitat, its time of activity and its position in the food web).

Each species has a unique niche. Within a habitat, the niche of a species is shaped by its adaptations: where it feeds, what it feeds on, the abiotic conditions it tolerates, when it is active and how it reproduces.

### How niche accounts for distribution and abundance

- A species is found only where the biotic and abiotic conditions of its niche are met, which explains its **distribution**.
- If two species have very similar niches, they compete for the same resources. This **interspecific competition** reduces the population of both, or one species outcompetes the other and is excluded from the habitat (the competitive exclusion principle).
- Coexisting species usually have slightly different niches, for example feeding at different heights, on different foods or at different times of day. This reduces competition and allows more species to live in the habitat.
- Within a species, **intraspecific competition** for the resources of its niche limits the population size, so the amount of the resources in the habitat sets the abundance of the species.

For example, two species of birds may both eat insects from the same tree. If one feeds mainly on the trunk and the other on the outer twigs, their niches differ enough for both to survive, and the abundance of each reflects the food in its part of the tree.

*Common mistake: Habitat and niche are not the same. A habitat is where an organism lives; a niche is what it does there and how it interacts with its environment.*

## Core practical 11: a study of the ecology of a habitat Spec 5.14

*Core practical: Core practical 11: carry out a study of the ecology of a habitat, such as using quadrats and transects to determine the distribution and abundance of organisms, and measuring abiotic factors appropriate to the habitat.*

### Choosing the sampling method

| Quadrats and transects                      |                                                                                                                                  |                                                                                                                                                                            |
|---------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Method                                      | Use                                                                                                                              | How it is done                                                                                                                                                             |
| <b>Random sampling with quadrats</b>        | To estimate the abundance (and mean density or percentage cover) of organisms across an area, avoiding bias                      | Lay out two tape measures at right angles to form a grid. Use random numbers (from a calculator or table) as coordinates for each quadrat. Place the quadrat at each point |
| <b>Systematic sampling along a transect</b> | To show how the distribution of organisms changes along an environmental gradient (for example from the sea shore or up a slope) | Stretch a tape measure along the gradient. Place a quadrat at regular intervals (an interrupted belt transect) or record species touching the line (a line transect)       |

A quadrat is a square frame, often 0.25 m<sup>2</sup> or 1 m<sup>2</sup>. In each quadrat, record the **abundance** of each species. Use percentage cover for plants that are difficult to count as individuals, such as grass, and count individuals for animals and larger plants. A frequency measure counts how many of the squares in a gridded quadrat contain the species.

**mean number per m<sup>2</sup> = total number counted ÷ (number of quadrats × area of one quadrat in m<sup>2</sup>)**

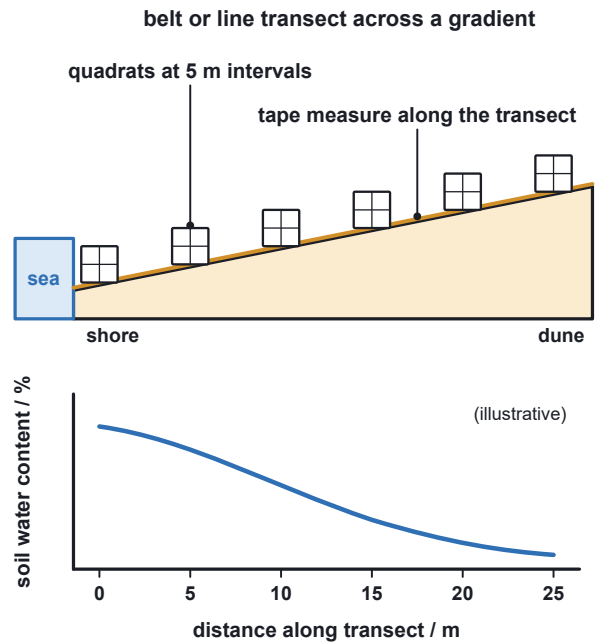
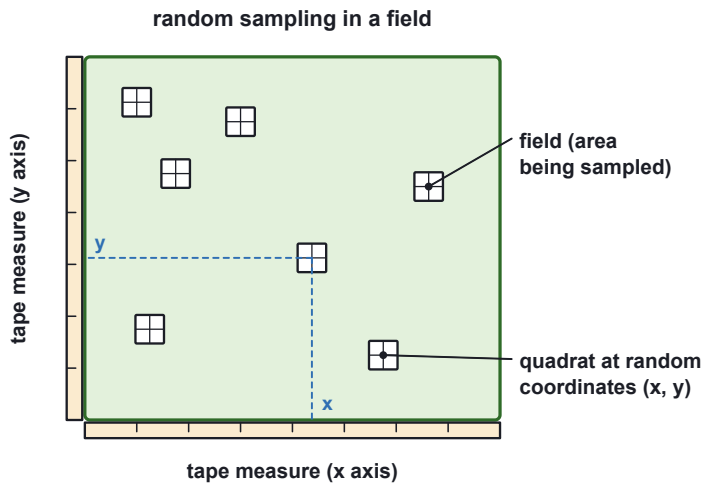
**estimated population size = mean number per m<sup>2</sup> × total area of habitat in m<sup>2</sup>**

#### Estimating a population

Ten 0.25 m<sup>2</sup> quadrats were placed randomly in a field of area 2 000 m<sup>2</sup>. A total of 35 daisy plants were counted in the quadrats. Estimate the population size of daisies in the field.

1. Total area sampled = 10 × 0.25 = 2.5 m<sup>2</sup>
2. Mean per m<sup>2</sup> = 35 ÷ 2.5 = 14
3. Population = 14 × 2 000

**Answer:** 28 000 daisy plants



**Random sampling** with coordinates (left) and a **transect** across a gradient with an abiotic factor measured at each quadrat (right).

## Measuring abiotic factors

Measure abiotic factors at each quadrat so that distribution can be linked to environment. The factors chosen depend on the habitat. Examples are light intensity (light meter), soil or water pH (pH meter or probe), soil moisture (moisture meter, or mass lost on drying), temperature (thermometer or probe), wind speed (anemometer), and salinity or dissolved oxygen (probe). Take several readings and calculate a mean.

## Reliability, safety and ethics

- Use a large enough sample (for example 10 to 30 quadrats) so that the mean is representative. Sample size is large enough when the running mean stops changing.
- Identify species using a key; use the same sampling effort and the same person where possible, and record the time of day and the season.
- Link the distribution of a species to an abiotic factor by plotting both against distance on a graph, and use a statistical test (for example a correlation test) to find whether the relationship is significant. Correlation does not by itself show cause.
- Risks: slips and trips, sun, ticks, contaminated water, sharp objects. Wear suitable clothing and footwear, check weather and tides, work in pairs and wash hands.
- Cause as little damage as possible to the habitat: take quadrats carefully, do not trample the vegetation more than needed, return any animals, and obtain permission to sample.

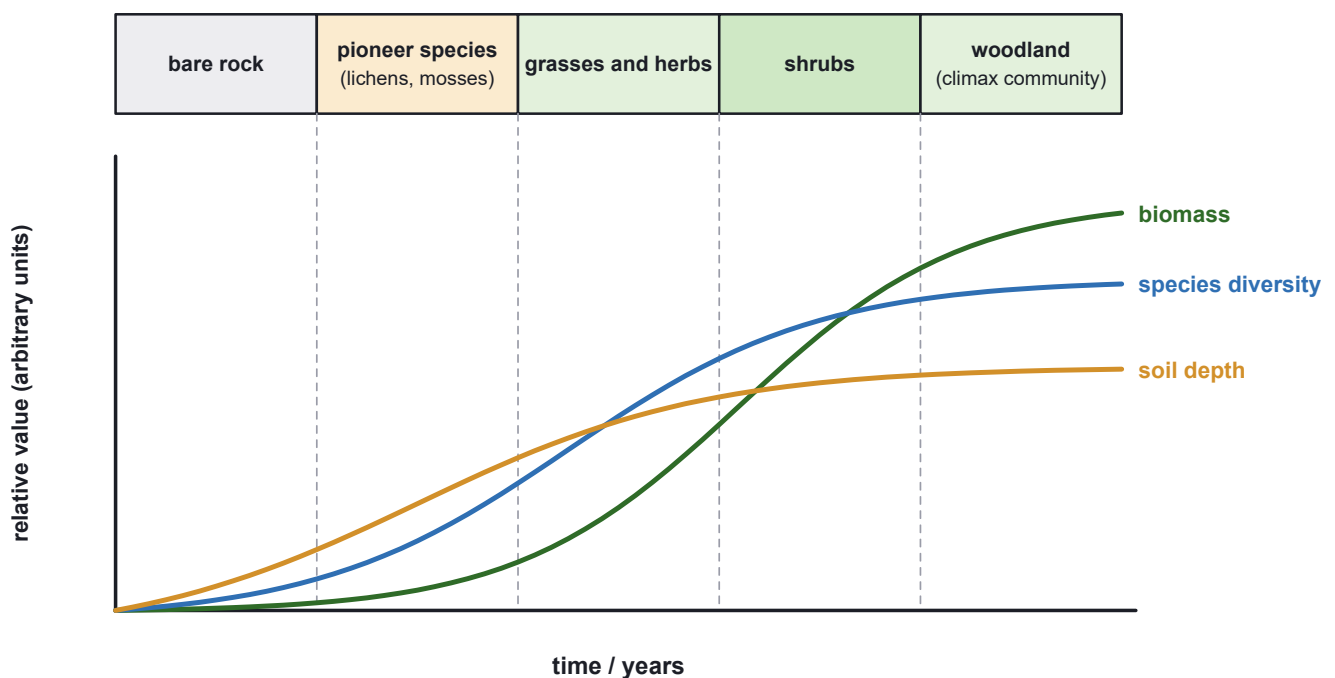
*Exam tip: If asked why sampling is random, say it avoids bias in choosing where to place quadrats. If asked why a transect is used, say it samples across a gradient, so changes in distribution can be linked to a change in an abiotic factor.*

## Succession Spec 5.15

**Succession** is the process by which an ecosystem changes over time, with one community of species replacing another. **Primary succession** starts on bare, newly formed land such as rock or sand dunes,

where there is no soil. **Secondary succession** happens where soil is already present, for example after a forest fire or when farmland is abandoned.

1. **Colonisation**: pioneer species such as lichens, mosses or algae arrive, often as wind-blown spores or seeds. They are adapted to tolerate harsh abiotic conditions, such as low nutrients and water availability, and can photosynthesise or fix nitrogen.
2. Pioneers change the abiotic environment. They weather rock, trap dead material and, when they die and are decomposed, add organic matter and minerals, which form a thin soil that holds more water.
3. The conditions become less hostile, so new species such as grasses and small herbs can germinate and grow. They outcompete the pioneers, which are replaced. Each community changes the conditions and allows the next to colonise (shrubs, then trees).
4. As succession proceeds, soil depth, nutrients and water retention increase. Species diversity and biomass rise, and food webs become more complex.
5. Eventually a stable **climax community** forms, in which the species are in balance with the abiotic environment (especially the climate) and no further net change in species occurs. The climax community is usually dominated by a few large, long-lived species, such as woodland trees in temperate climates.



Primary succession: biomass, species diversity and soil depth all increase and level off at the **climax community**.

| Early and late stages of succession |                                  |                                       |
|-------------------------------------|----------------------------------|---------------------------------------|
| Feature                             | Pioneer stage                    | Climax community                      |
| <b>Species diversity</b>            | Low                              | High (but dominated by a few species) |
| <b>Soil depth and nutrients</b>     | Thin soil or none; few nutrients | Deep, rich soil                       |
| <b>Abiotic conditions</b>           | Harsh and variable               | Stable, less extreme                  |
| <b>Biomass</b>                      | Low                              | High                                  |
| <b>Food webs</b>                    | Simple                           | Complex                               |
| <b>Size of dominant plants</b>      | Small                            | Large                                 |

*Exam tip: The key idea is that each stage changes the environment, making it more suitable for the next. Say what the species change (the abiotic conditions such as soil) and what that allows.*

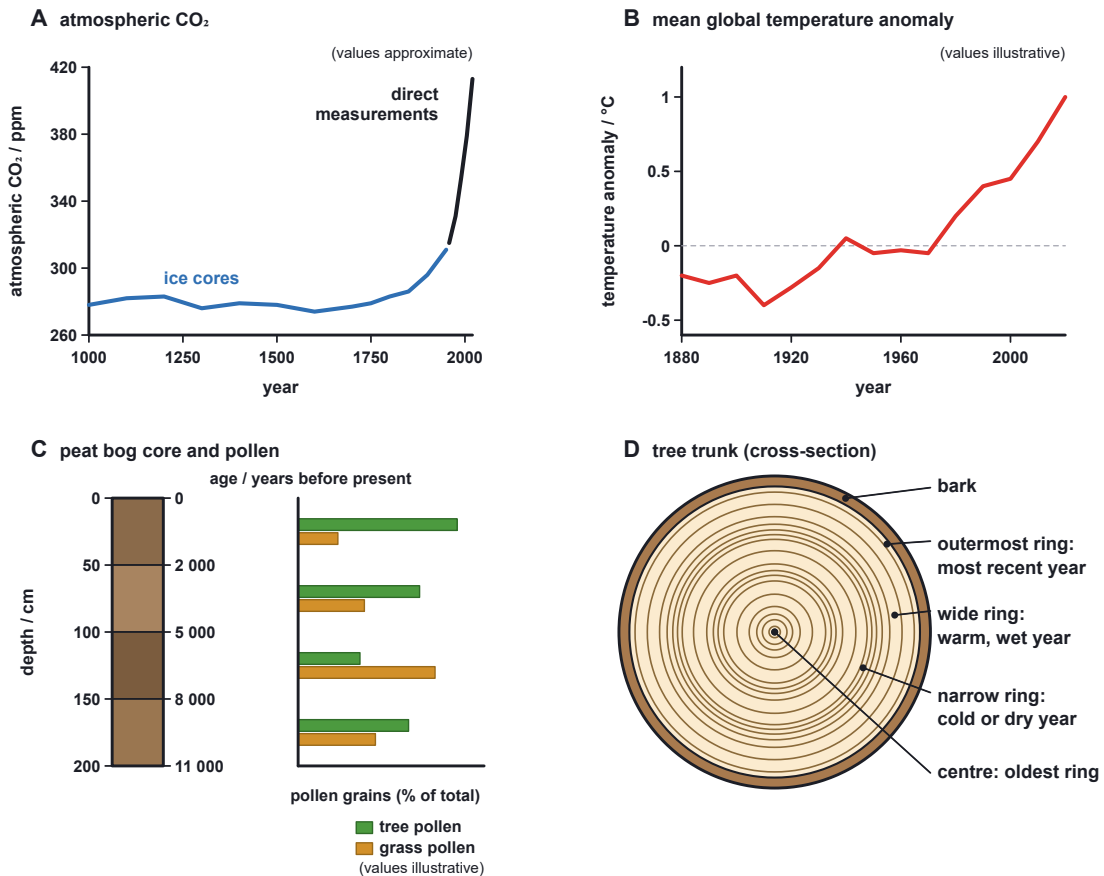
### Quick check

1. Write the equation linking NPP, GPP and R.
2. Give two ways in which energy is lost between trophic levels.
3. What is a niche?
4. Why are quadrats placed at random?
5. What is a climax community?

### 3 Climate change Spec 5.16–5.20, 5.25–5.26 A Level only

#### Evidence for climate change Spec 5.16

| Evidence for climate change          |                                                                                                                                                                                |                                                                                                                                                        |                                                                                                                                                   |
|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| Evidence                             | What is measured                                                                                                                                                               | What it shows                                                                                                                                          | Limitations                                                                                                                                       |
| <b>Carbon dioxide records</b>        | Direct measurement of atmospheric CO <sub>2</sub> (for example continuous measurements since the 1950s); CO <sub>2</sub> in air bubbles trapped in ice cores for earlier times | A rise in atmospheric CO <sub>2</sub> concentration, with a steep rise since the industrial revolution; ice cores cover hundreds of thousands of years | Ice-core values are indirect and become less precise further back; local sources can affect some records                                          |
| <b>Temperature records</b>           | Thermometer readings from weather stations, ships and satellites; earlier temperatures estimated from other evidence                                                           | Mean global temperature has risen, especially since about 1950                                                                                         | Coverage of early records is patchy; local effects such as urban heating; different measurement methods                                           |
| <b>Pollen in peat bogs</b>           | Pollen grains preserved in the acidic, anaerobic (waterlogged) layers of peat. Layers are dated (for example by radiocarbon dating) and the pollen is identified and counted   | The species of plants present at different times. Each species has a climate it tolerates, so the pollen record shows what the climate was like        | Pollen can be blown from elsewhere; plants respond to other factors, such as soil and human activity; identification to species level can be hard |
| <b>Dendrochronology (tree rings)</b> | Counting and measuring the width of annual rings in trees. Overlapping patterns of ring widths from living and dead trees extend the record                                    | Wide rings suggest warm, wet years with good growth; narrow rings suggest cold or dry years. Gives precise dates for past conditions                   | Growth is also affected by disease, competition and nutrients; only tells about local conditions; limited to areas where trees grow               |



Four types of evidence: ice cores, temperature records, pollen in peat and tree rings.

## Correlation and causation

Data from different sources can be compared on one graph. A **correlation** exists where two variables change together, for example atmospheric CO<sub>2</sub> concentration and mean global temperature. A correlation alone does not show that one causes the other: both could be caused by a third factor. A **causal relationship** is supported when there is also a known mechanism (here the greenhouse effect), the correlation is seen repeatedly in many independent data sets, and the cause comes before the effect.

*Exam tip: In data questions say 'there is a positive correlation between ...' and then discuss whether it shows cause. Use evidence such as a known mechanism and data from several independent sources to support a causal link.*

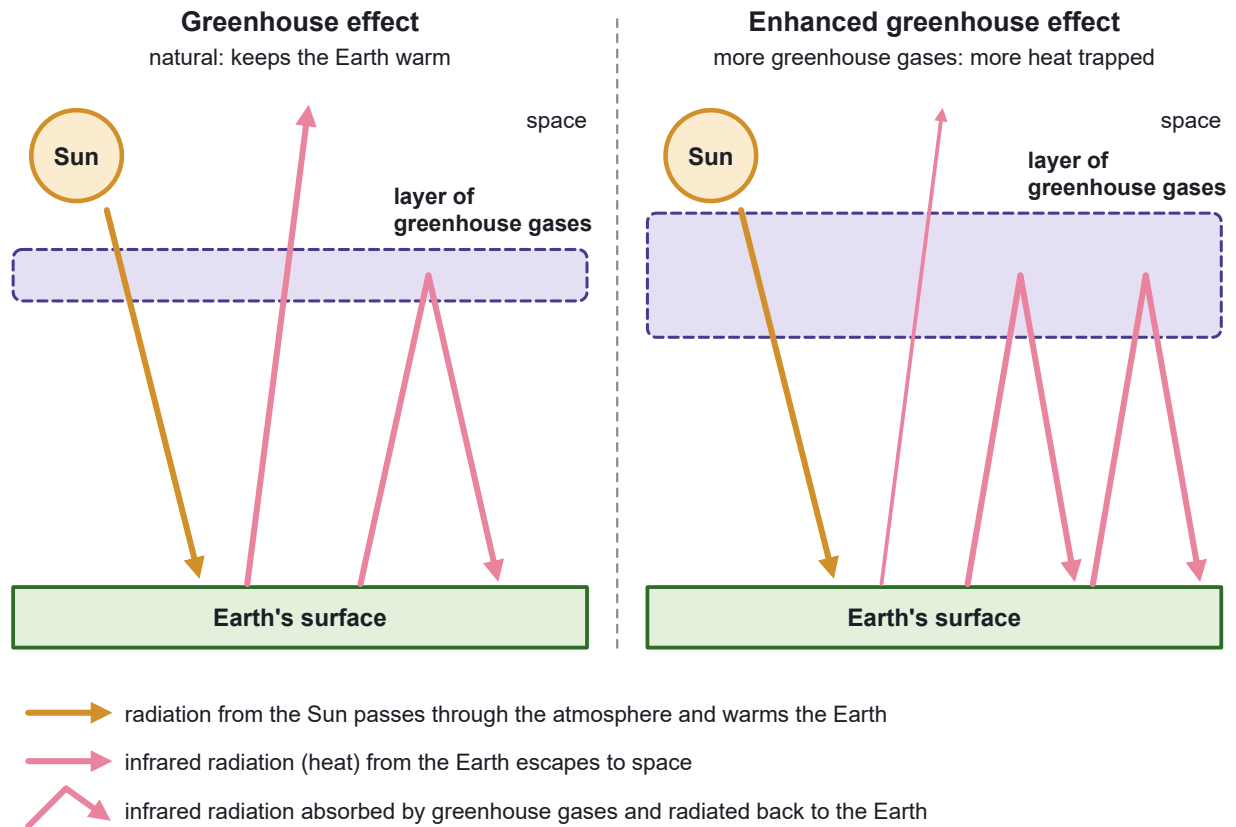
## Causes of anthropogenic climate change and the greenhouse effect Spec 5.17

### The greenhouse effect

1. Short-wavelength radiation (visible light) from the Sun passes through the atmosphere. Some is reflected, and the rest is absorbed by Earth's surface and warms it.
2. The warmed surface emits radiation at longer wavelengths, as infra-red radiation (heat).
3. **Greenhouse gases** in the atmosphere absorb some of this infra-red radiation and re-radiate it in all directions, including back towards Earth's surface.
4. This traps heat, and keeps the lower atmosphere warmer than it would be otherwise. This natural process keeps average temperatures suitable for life.

The main greenhouse gases are carbon dioxide, methane, water vapour, nitrous oxide and CFCs. They differ in how long they stay in the atmosphere and in how effective they are at absorbing infra-red

radiation: for each molecule, methane is more effective than carbon dioxide, but carbon dioxide is far more abundant.



**Greenhouse gases:** carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), CFCs and water vapour

The greenhouse effect and the **enhanced greenhouse effect**: more greenhouse gases trap more infrared radiation.

## Anthropogenic causes

**Anthropogenic** means caused by humans. Since the industrial revolution, human activities have increased the concentrations of greenhouse gases, an **enhanced greenhouse effect** that has led to global warming.

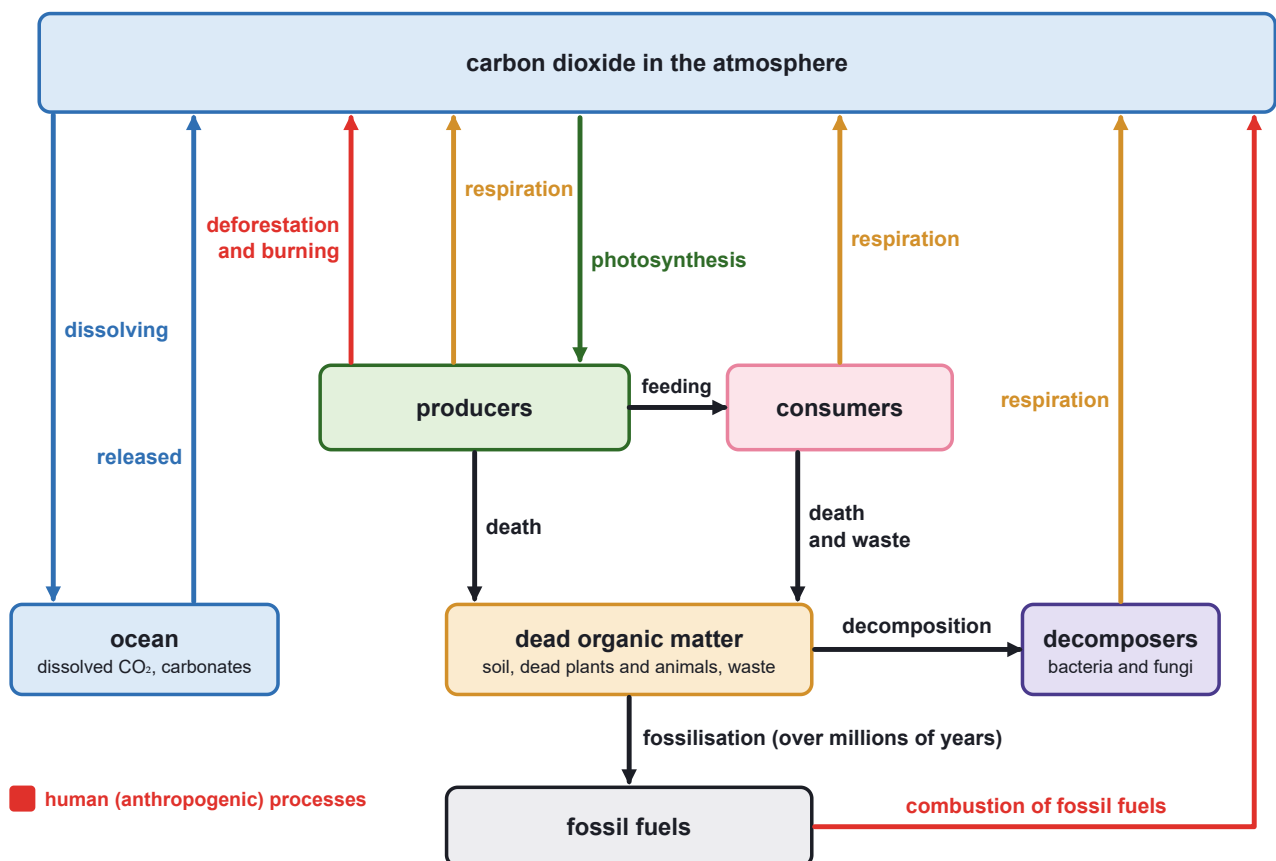
| Human activities and greenhouse gases                                                  |                         |                                                                                                            |
|----------------------------------------------------------------------------------------|-------------------------|------------------------------------------------------------------------------------------------------------|
| Human activity                                                                         | Greenhouse gas affected | Effect                                                                                                     |
| <b>Burning fossil fuels (coal, oil, gas) in power stations, transport and industry</b> | Carbon dioxide          | Releases carbon that has been locked up in fossil fuels for millions of years                              |
| <b>Deforestation, especially by burning</b>                                            | Carbon dioxide          | Burning and decay release stored carbon; fewer trees remove less carbon dioxide by photosynthesis          |
| <b>Cattle and sheep farming; rice paddies; landfill</b>                                | Methane                 | Ruminants release methane from digestion; waterlogged soils and rotting waste give anaerobic decomposition |
| <b>Use of nitrogen fertilisers</b>                                                     | Nitrous oxide           | Released by denitrifying bacteria in the soil                                                              |
| <b>Use of refrigerants and aerosol propellants (CFCs)</b>                              | CFCs                    | Absorb infra-red radiation strongly (CFCs also damage the ozone layer)                                     |

*Common mistake: The greenhouse effect itself is natural and essential. It is the enhanced greenhouse effect, caused by extra greenhouse gases, that leads to climate change. The ozone layer is a different issue.*

## The carbon cycle and reducing atmospheric carbon dioxide Spec 5.18

The **carbon cycle** describes how carbon moves between the atmosphere, oceans, living organisms, soil and rocks. Carbon is held in **sinks** such as plants, soil, oceans and fossil fuels, and moves between them in the following processes.

| Carbon cycle processes                                  |                                                                                 |
|---------------------------------------------------------|---------------------------------------------------------------------------------|
| Process                                                 | Effect on atmospheric CO <sub>2</sub>                                           |
| <b>Photosynthesis</b> (plants, algae, cyanobacteria)    | Removes CO <sub>2</sub> and stores carbon in organic molecules                  |
| <b>Respiration</b> (all organisms)                      | Returns CO <sub>2</sub> to the atmosphere                                       |
| <b>Feeding</b>                                          | Transfers carbon compounds along food chains                                    |
| <b>Decomposition by bacteria and fungi</b>              | Returns CO <sub>2</sub> to the atmosphere (and methane in anaerobic conditions) |
| <b>Fossilisation (when decomposition is incomplete)</b> | Locks carbon in peat, coal, oil and gas for millions of years                   |
| <b>Combustion (fossil fuels and biomass)</b>            | Rapidly returns stored carbon as CO <sub>2</sub>                                |
| <b>Dissolving in oceans; formation of carbonates</b>    | Removes CO <sub>2</sub> from the atmosphere and stores it in the ocean          |



The **carbon cycle**, with human (anthropogenic) processes in red.

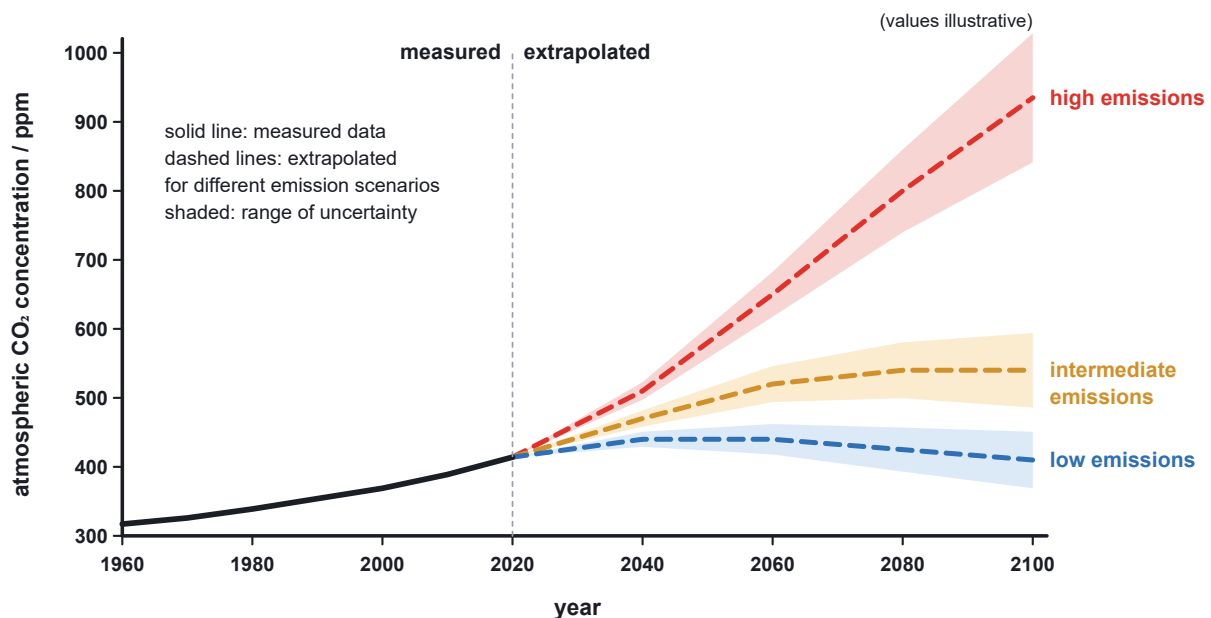
## Applying knowledge of the cycle to reduce atmospheric CO<sub>2</sub>

- **Afforestation and reforestation**: planting trees increases photosynthesis, so more CO<sub>2</sub> is removed from the atmosphere and held in wood. It works only while the trees grow, and carbon is released again if the wood is burnt or the forest destroyed.
- **Protecting existing forests, peat bogs and wetlands**: these are large carbon sinks. Draining peat or burning forests releases stored carbon. Preventing deforestation keeps this carbon locked up.
- Reducing the combustion of fossil fuels: using renewable energy (wind, solar, hydroelectric) and energy efficiency reduces the transfer of carbon from the fossil store to the atmosphere.
- Using **biofuels** in place of fossil fuels: the carbon dioxide released on burning was recently absorbed by the plants, so the process may be close to carbon neutral (see 5.26 for conflicts).
- Reducing decomposition and respiration of soils and returning organic matter to the soil, for example by minimal tillage, keeps carbon in the soil.
- Carbon capture and storage: carbon dioxide from power stations is collected and stored underground. It does not change the cycle itself but reduces the flow to the atmosphere.

*Exam tip: Always link a method to a stage of the cycle: 'planting trees increases photosynthesis, which removes CO<sub>2</sub> from the atmosphere' scores; 'trees absorb CO<sub>2</sub>' on its own may not.*

## Predicting climate change: extrapolation and models Spec 5.19

**Extrapolation** means extending a line or curve beyond the measured data to predict what might happen in the future. Predictions are used in **models** of future climate change, which use data on greenhouse gas concentrations, temperature, ice cover and ocean currents to estimate how much warming might occur under different assumptions (for example scenarios of high or low emissions).



**Extrapolating** measured CO<sub>2</sub> data to 2100 under different emission scenarios (values illustrative).

## Limitations of models

- The climate is a **complex system** with many interacting factors (oceans, clouds, ice, vegetation, volcanic activity), and it is not possible to include them all accurately.
- Models contain **feedback loops**, which are hard to represent. Positive feedback increases the change: for example, melting ice exposes darker surfaces that absorb more heat; warming thaws

permafrost and releases methane. Negative feedback reduces change: for example, more CO<sub>2</sub> may increase plant growth.

- Data may be incomplete or unreliable, especially for the past and for remote areas, and small errors in the data are amplified in the predictions.
- Extrapolation assumes that the trend continues as it has done, which may not be true. Predictions depend on assumptions about future human behaviour, such as emissions and population growth, which cannot be known.
- Different models give different predictions, so there is uncertainty. A model can be tested by checking whether it reproduces known past climates.

*Exam tip: A 'limitation' needs a reason. Write 'the model may not predict accurately because it cannot include all the variables, such as feedback from melting ice' rather than just 'models are not accurate'.*

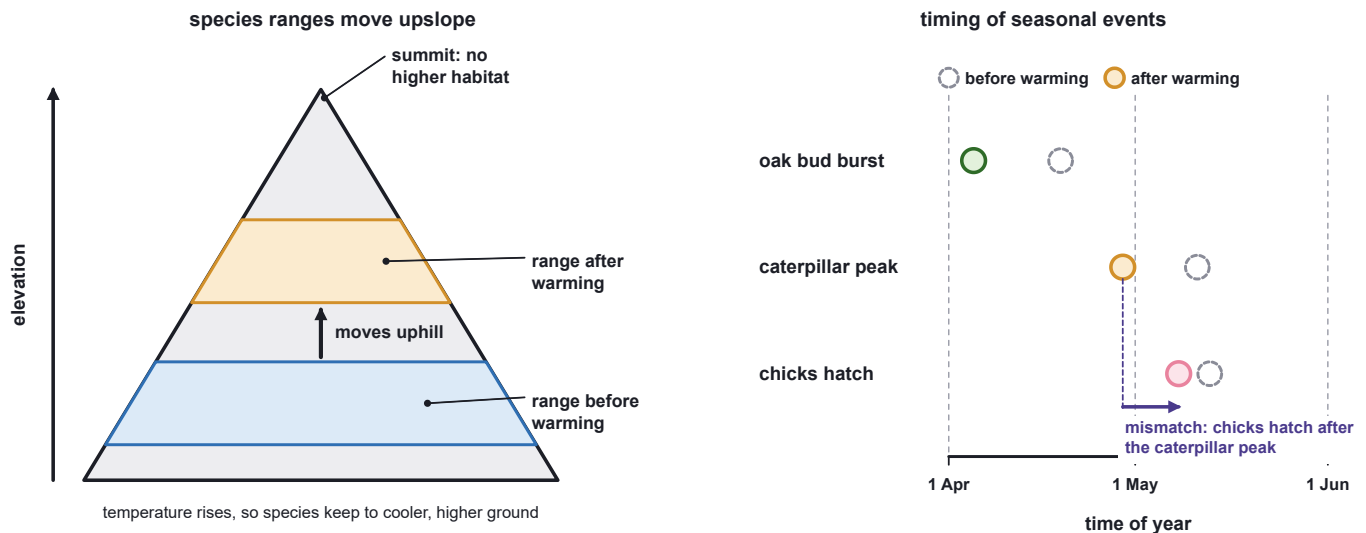
## Effects of climate change on plants and animals Spec 5.20

### Distribution of species

Each species survives within a range of abiotic conditions. As temperatures and rainfall change, the area that meets these conditions moves. Species move **towards the poles** or **to higher altitude** if they can, or their range contracts if they cannot. Examples include warm-adapted species such as some insects and plants spreading into new areas, and cold-adapted species in the Arctic and on mountain tops losing habitat. Changes in rainfall alter water availability, so drought-tolerant species can replace others, and species may become isolated when habitats change.

### Development and life cycles

- Higher temperatures speed up enzyme-controlled reactions in ectotherms, so some insects complete their life cycle faster and may produce more generations per year.
- Seasonal events occur earlier: leaves open, plants flower, insects emerge and eggs hatch earlier in spring, and some animals migrate at different times or stop migrating.
- Species that depend on one another may respond differently, so timing may no longer match. For example, if caterpillars emerge earlier but the birds that feed their chicks on them lay at the same time as before, there is less food when chicks hatch and fewer survive.
- Changes in rainfall affect the timing of germination and breeding in species that depend on wet or dry seasons.
- Changes in the length and warmth of the growing season affect plant growth, seed production and crop yields.



Climate change shifts where species live and **phenology**, and unequal shifts cause a mismatch.

*Exam tip: Always say what has changed (for example temperature or rainfall) and then how it affects the organism (for example faster development or a shifted range). Use named examples if you can, but the explanation matters more than the example.*

## Evaluating scientific conclusions on controversial issues Spec 5.25

Climate change is a controversial issue because the actions needed have economic, political and social consequences. The scientific evidence may be the same, but the conclusions drawn can depend on **who is reaching them** and why.

- **Vested interest**: an organisation that profits from fossil fuels may emphasise uncertainty, while an organisation that campaigns for the environment may emphasise the worst predictions.
- **Funding**: who paid for the research may influence which questions are asked and how results are reported.
- **Selection of data**: a conclusion may use only the data that support it (a narrow time period, or one region), or compare different measurements.
- **Qualifications and expertise**: a conclusion from experts in climate science is more reliable than one from people without relevant expertise.
- **Peer review**: research that has been checked by other independent scientists before publication is more reliable than claims that have not.
- **Media and politics**: reports in the media may simplify, exaggerate or present a balanced debate as if scientists were equally divided.
- **Different assumptions**: governments and countries weigh economic costs, development and fairness differently, so they may disagree on actions even when they agree on the science.

*Exam tip: To evaluate a source, ask: who wrote it, who funded it, what evidence is used, is it from a peer-reviewed source, is the data selected, and is the conclusion supported by the data? Then give a judgement.*

## Reforestation, sustainable resources and biofuels Spec 5.26

There is a conflict between human needs (energy, wood, farmland, food) and **conservation** of ecosystems and biodiversity. **Sustainable** use meets present needs without reducing the ability of future generations to meet theirs.

## Managing the conflict between human needs and conservation

| Approach                                                                                                                                                                           | How it helps                                                                                                                         | Possible problems                                                                                                                                                                       |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Reforestation (replanting trees, for example after logging) and sustainable forestry (felling only as many trees as are replaced, replanting, selective felling, coppicing)</b> | Timber is still available; trees remove CO <sub>2</sub> by photosynthesis, store carbon, protect soil and provide habitats           | Planting a single species (monoculture) supports less biodiversity than natural forest; young forests store less carbon than mature forest; needs time and land                         |
| <b>Biofuels: fuels made from recently grown biomass, such as ethanol from sugar cane or maize and biodiesel from oil crops</b>                                                     | The CO <sub>2</sub> released on burning was taken in by the crop, so they may be close to carbon neutral; reduce use of fossil fuels | Growing crops needs land, which may be taken from forest or food crops; fertilisers, machinery and processing use energy and release greenhouse gases; monocultures reduce biodiversity |
| <b>Other sustainable resources (renewable energy, sustainably sourced timber and fish with quotas)</b>                                                                             | Reduce the use of finite resources and the release of greenhouse gases                                                               | Cost, land use, and impact on habitats must be balanced                                                                                                                                 |

The best management usually involves compromise: for example, using waste plant material or non-food crops grown on poor land for biofuels, rather than clearing rainforest to grow oil palm, and combining reforestation with the protection of mature forest.

*Exam tip: A good answer to an evaluation question gives one benefit and one drawback, and then a judgement about how well the conflict has been managed.*

### Quick check

1. Name two sources of indirect evidence for past climates.
2. What is an anthropogenic cause of climate change?
3. Which processes in the carbon cycle remove CO<sub>2</sub> from the atmosphere?
4. State one limitation of climate models.
5. Why might the conclusions about climate change differ between organisations?

## 4 Temperature, evolution and speciation

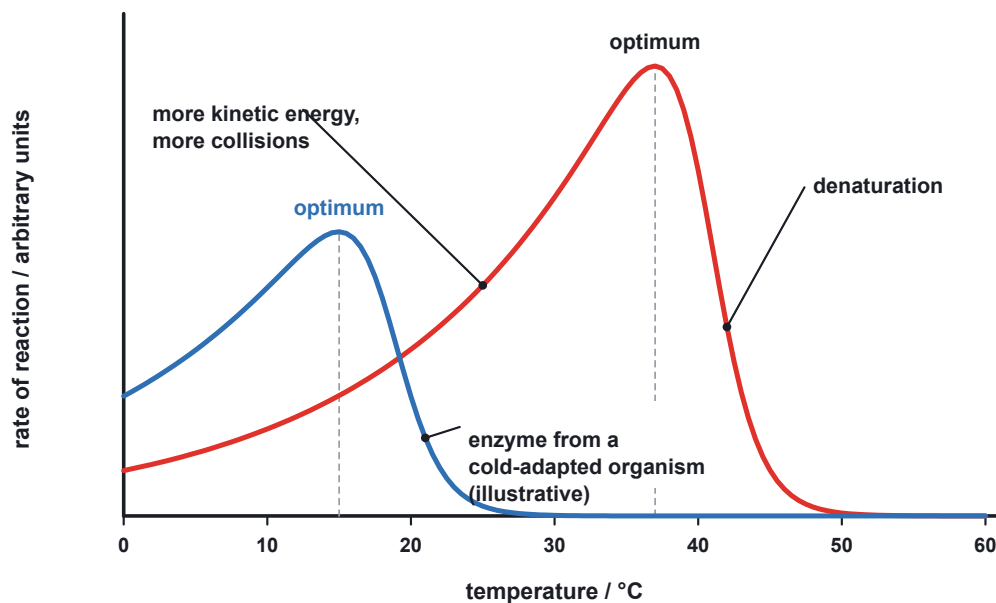
Spec 5.21-5.24

A Level only

### Temperature, enzyme activity and $Q_{10}$

Spec 5.21

As temperature rises, enzyme and substrate molecules gain kinetic energy, so they collide more often and with more energy. More enzyme-substrate complexes form per second, and the rate of reaction increases. Above the **optimum** temperature, hydrogen and other bonds that hold the tertiary structure break, the active site changes shape and the enzyme **denatures**, so the rate falls rapidly.



The effect of temperature on enzyme activity, with a second curve for an enzyme from a cold-adapted organism.

### The temperature coefficient, $Q_{10}$

$Q_{10}$

The factor by which the rate of a reaction (or process) increases when the temperature is raised by 10 °C.

$$Q_{10} = \text{rate of reaction at } (T + 10) \text{ °C} \div \text{rate of reaction at } T \text{ °C}$$

beyond the specification, for two temperatures not 10 °C apart:  $Q_{10} = (R_2 \div R_1)^{(10 \div (T_2 - T_1))}$

For many enzyme-controlled reactions  $Q_{10}$  is about **2**, meaning that the rate doubles for each 10 °C rise, below the optimum. A  $Q_{10}$  of 1 means that temperature has no effect, which is typical of processes limited by something other than temperature. Physical processes such as diffusion have a  $Q_{10}$  only a little above 1. A  $Q_{10}$  below 1 occurs above the optimum, as enzymes denature.

### Calculating $Q_{10}$

A seedling uses oxygen at a rate of  $12 \text{ mm}^3 \text{ min}^{-1}$  at  $15^\circ\text{C}$  and at  $30 \text{ mm}^3 \text{ min}^{-1}$  at  $25^\circ\text{C}$ . Calculate  $Q_{10}$  for oxygen consumption.

1. The two temperatures are  $10^\circ\text{C}$  apart, so  $Q_{10} = \text{rate at } 25^\circ\text{C} \div \text{rate at } 15^\circ\text{C}$
2.  $Q_{10} = 30 \div 12$

**Answer:**  $Q_{10} = 2.5$

### Extension (beyond the specification): $Q_{10}$ for a temperature difference other than $10^\circ\text{C}$

The rate of a reaction is 4.0 units at  $10^\circ\text{C}$  and 9.0 units at  $20^\circ\text{C}$ , then 11.0 units at  $30^\circ\text{C}$ . Calculate  $Q_{10}$  between 10 and  $30^\circ\text{C}$ .

1.  $Q_{10} = (R_2 \div R_1)^{(10 \div (T_2 - T_1))}$
2.  $R_2 \div R_1 = 11.0 \div 4.0 = 2.75$ ; exponent =  $10 \div 20 = 0.5$
3.  $Q_{10} = 2.75^{0.5}$

**Answer:**  $Q_{10} = 1.7$  (to 2 significant figures). This is an average over  $20^\circ\text{C}$ : the rise in rate is smaller between 20 and  $30^\circ\text{C}$  (a ratio of 1.2) because the rate is levelling off as the optimum is approached.

*Maths skill:  $Q_{10}$  has no unit. Check that you divide the higher temperature's rate by the lower temperature's rate, and make sure the temperature interval is exactly  $10^\circ\text{C}$ . If you are given a graph, read off the rates at two temperatures  $10^\circ\text{C}$  apart.*

### Impact on plants, animals and microorganisms

- Most plants, microorganisms and many animals (ectotherms, such as insects and reptiles) have a body temperature that follows the environment. A rise in environmental temperature increases metabolic rate, growth and development. Photosynthesis and respiration enzymes have optima, so above this the rate falls.
- Endotherms (birds and mammals) maintain a constant body temperature, so enzymes work at the optimum, but at a cost of energy.
- Microorganisms grow and reproduce faster as temperature rises to their optimum. This affects decomposition rates, the spread of pathogens and food spoilage.
- Extreme temperatures above the optimum denature enzymes, which can kill the organism. Organisms are adapted to their usual temperature range, and so can be put at risk by climate change.

*Exam tip: In a  $Q_{10}$  question, check that the interval is  $10^\circ\text{C}$ . Then link to the effect on the organism: higher rate of metabolic reactions, faster development, or denaturation above the optimum.*

### Core practical 12: temperature and the development of organisms Spec 5.22

*Core practical: Core practical 12: investigate the effects of temperature on the development of organisms (such as seedling growth rate or brine shrimp hatch rates), taking into account the ethical use of organisms.*

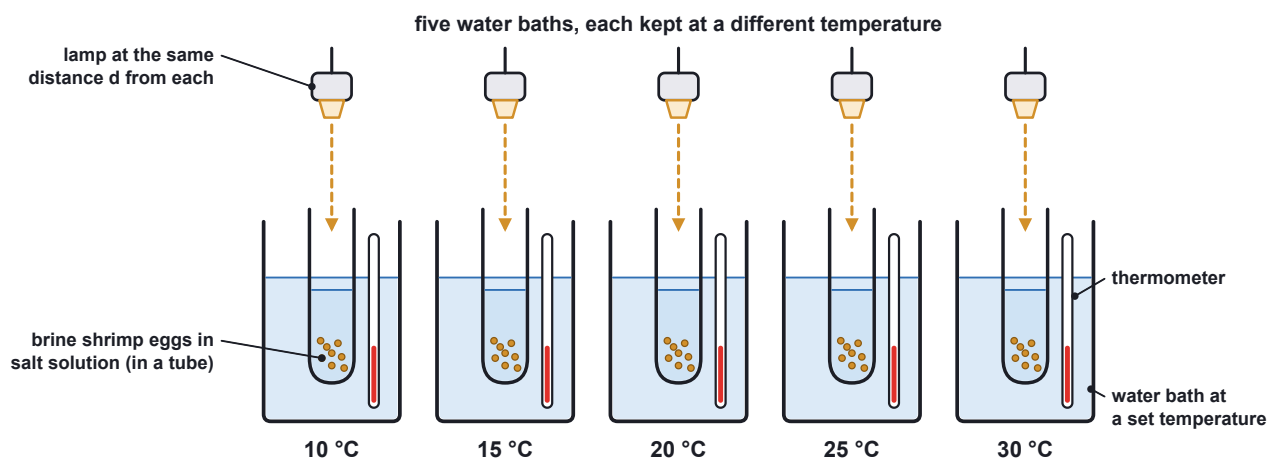
#### Brine shrimp hatching

1. Set up several water baths or incubators at different temperatures (for example  $15^\circ\text{C}$ ,  $20^\circ\text{C}$ ,  $25^\circ\text{C}$ ,  $30^\circ\text{C}$  and  $35^\circ\text{C}$ ), and check each with a thermometer.
2. Prepare salt solution of the same concentration for each (brine shrimp eggs need salt water). Add the same volume to each container, and equilibrate to the required temperature.
3. Add the same number (or mass) of brine shrimp eggs to each container.

- Keep all other conditions the same (light, salinity, volume, aeration).
- After a set time (for example 24 or 48 hours), count the number of hatched shrimp (nauplii) in a sample or the whole container, and calculate the percentage hatching. Repeat several times at each temperature.

### Seedling growth

Germinate the same number of seeds (for example cress or mustard) of one variety on damp filter paper at each temperature. Measure the length of the shoots (or their mass) at regular intervals, over several days. Calculate the rate of growth as  $\text{change in length} \div \text{time}$ . Keep light, water and seed mass the same.



| temperature / °C | number of eggs hatched | total number of eggs | hatching (%) |
|------------------|------------------------|----------------------|--------------|
|                  |                        |                      |              |
|                  |                        |                      |              |

Investigating temperature and the hatching of brine shrimp eggs: the lamp distance and all other variables are kept the same.

### Variables and processing

#### Variables in core practical 12

| Variable           | Detail                                                                                                                 |
|--------------------|------------------------------------------------------------------------------------------------------------------------|
| <b>Independent</b> | Temperature (°C)                                                                                                       |
| <b>Dependent</b>   | Number or percentage of eggs hatched in a set time, or rate of seedling growth ( $\text{mm day}^{-1}$ )                |
| <b>Controlled</b>  | Number and age of eggs/seeds, same batch of organisms, salinity or water volume, light, time, aeration, container type |

Calculate a mean from at least three replicates at each temperature. Plot hatching or growth rate against temperature. Calculate  $Q_{10}$  from values 10 °C apart on the rising part of the curve. Beyond the optimum the rate falls because enzymes denature, or the organisms die.

### Ethical use of organisms

- Use the minimum number of organisms needed to get valid results, and treat them humanely.
- Avoid temperatures that would cause unnecessary suffering or death: for animals, keep within a range they would naturally experience, and do not leave them at extreme temperatures for longer than necessary.
- Keep them in suitable conditions (salinity, oxygen, food). At the end, do not release brine shrimp into local waters (they may not be native); keep them or dispose of them humanely. Seedlings can be

disposed of in normal waste.

- Consider whether the use of living animals is justified, and whether seedlings (plants) could be used instead.

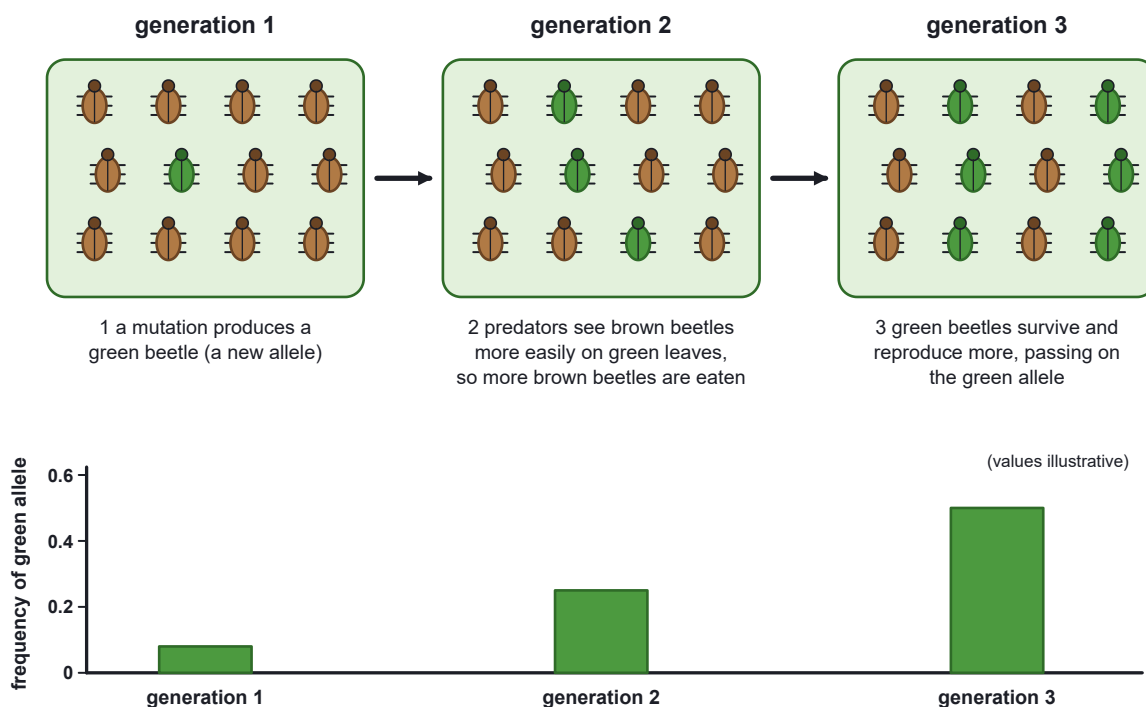
*Exam tip: If asked to justify the ethical approach, name the organism and the specific action, such as 'use the smallest number of shrimp and avoid temperatures above their tolerance'.*

## Evolution: mutation and natural selection Spec 5.23

|                         |                                                                |
|-------------------------|----------------------------------------------------------------|
| <b>Evolution</b>        | A change in allele frequency in a population over generations. |
| <b>Allele frequency</b> | How common an allele is in the gene pool of a population.      |

1. A **gene mutation** (a change in the base sequence of DNA) can produce a new allele. Mutations occur at random, and most are harmful or have no effect, but a few give an advantage in a particular environment.
2. There is variation in the population, so individuals differ in their alleles and phenotypes.
3. Organisms produce more offspring than can survive, and there is a **selection pressure** such as predation, disease, competition or an abiotic change.
4. Individuals with the advantageous allele are more likely to survive and reproduce (**natural selection**).
5. They pass the advantageous allele to their offspring, so the frequency of the allele increases in the next generation. Over many generations the frequency of the allele in the population changes, which is evolution.

For example, a mutation in a bacterium may give resistance to an antibiotic. When the antibiotic is used, non-resistant bacteria are killed, and resistant bacteria survive and reproduce, passing on the resistance allele. The frequency of the resistance allele in the population increases.



Natural selection over three generations: the frequency of the advantageous allele increases.

*Common mistake: Individuals do not evolve and organisms do not mutate 'in order to' survive. Mutations are random; selection favours the individuals that happen to have the advantageous allele, and the population changes.*

## Isolation and speciation Spec 5.24

A **species** is a group of organisms that can interbreed to produce fertile offspring. **Gene flow** is the movement of alleles between populations by interbreeding. **Speciation** is the formation of new species. It requires that gene flow between populations is reduced or stopped by isolation.

### Allopatric speciation

1. A population is divided by a geographical barrier such as a mountain range, river, sea or desert. The two populations can no longer interbreed, so there is no gene flow between them.
2. Mutations occur independently in each population, and the selection pressures differ between the two environments.
3. Allele frequencies in the two gene pools gradually diverge.
4. Eventually the populations are so different (for example in courtship behaviour, breeding time, or gamete compatibility) that if they came into contact again they could not interbreed to produce fertile offspring. They are now separate species.

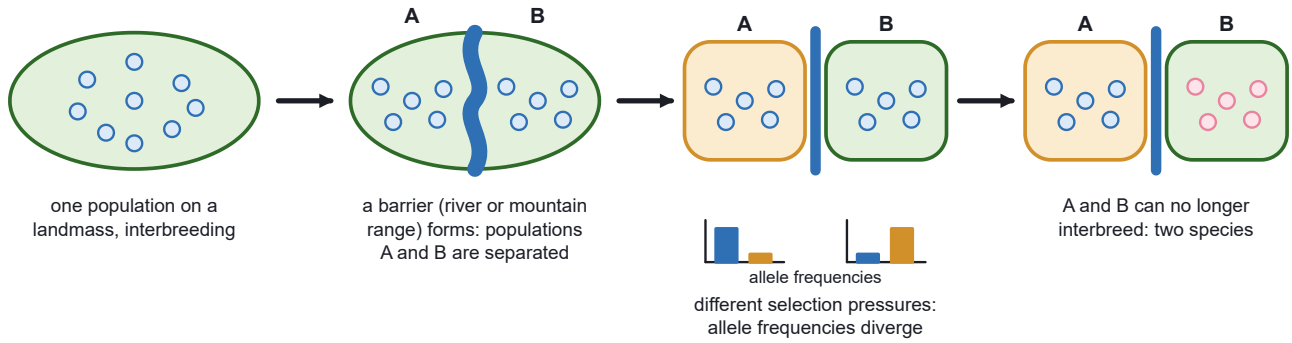
### Sympatric speciation

In **sympatric speciation**, new species form within the same geographical area, without a physical barrier. Reproductive isolation arises in other ways:

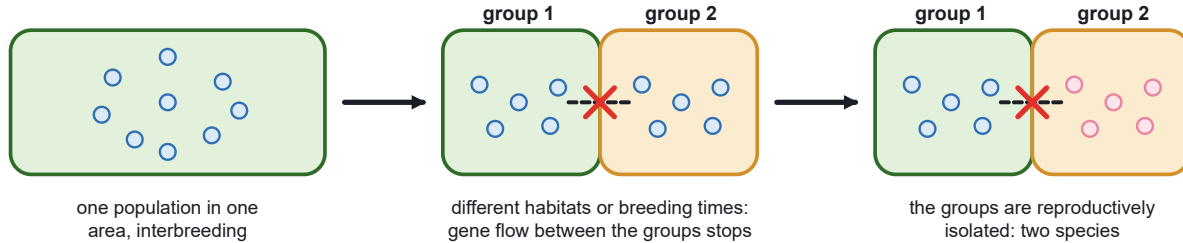
- Ecological or habitat isolation: groups use different parts of the habitat or different food sources.
- Temporal isolation: groups breed at different times of the year or day.
- Behavioural isolation: changes in courtship behaviour mean that individuals do not recognise each other as mates.
- Polyploidy (common in plants): an error in cell division (for example meiosis that produces gametes with two sets of chromosomes) doubles the number of chromosome sets. The polyploid plants cannot produce fertile offspring with the parent species (a cross gives sterile offspring), but they can reproduce with each other or by self-pollination.

| Allopatric and sympatric speciation |                                           |                                                      |
|-------------------------------------|-------------------------------------------|------------------------------------------------------|
| Feature                             | Allopatric                                | Sympatric                                            |
| <b>Location</b>                     | Populations in different areas            | Populations in the same area                         |
| <b>Cause of isolation</b>           | Geographical barrier                      | Ecological, temporal, behavioural or genetic changes |
| <b>Gene flow</b>                    | Stopped by the barrier                    | Reduced by reproductive isolation                    |
| <b>Outcome</b>                      | Different allele frequencies, new species | Different allele frequencies, new species            |

## 1 Allopatric speciation



## 2 Sympatric speciation



Allopatric and sympatric speciation.

*Exam tip: Always include the same logic: isolation, so no gene flow, so different mutations and selection, so allele frequencies diverge, so no interbreeding (reproductive isolation), so new species.*

### Quick check

1. Write the formula for  $Q_{10}$ .
2. Why does the rate of an enzyme-controlled reaction fall above the optimum temperature?
3. Define evolution.
4. What is the difference between allopatric and sympatric speciation?

## Quick check answers

### Photosynthesis

1. From the photolysis of water.
2. Rubisco (ribulose biphosphate carboxylase-oxygenase).
3. The light-dependent reactions (non-cyclic photophosphorylation).
4. Distance moved by the pigment  $\div$  distance moved by the solvent front.

### Productivity and ecosystems

1.  $NPP = GPP - R$ .
2. Respiration (heat), egestion, excretion, uneaten parts.
3. The role of a species in its habitat, including its interactions with biotic and abiotic factors.
4. To avoid bias in sampling.
5. The stable community at the end of succession, in balance with the abiotic conditions.

### Climate change

1. Pollen in peat bogs and tree rings (dendrochronology). Ice cores are also acceptable.
2. One caused by human activity, such as burning fossil fuels or deforestation.
3. Photosynthesis and dissolving in the oceans.
4. Climate is a complex system with feedback loops that cannot all be included accurately.
5. Vested interests, funding or selection of data can influence the conclusions.

### Temperature, evolution and speciation

1. Rate at  $(T + 10) ^\circ\text{C} \div$  rate at  $T ^\circ\text{C}$ .
2. The enzyme denatures: bonds break and the active site changes shape.
3. A change in allele frequency in a population over generations.
4. Allopatric involves geographical isolation. Sympatric occurs in the same area.