

Temperature, evolution and speciation

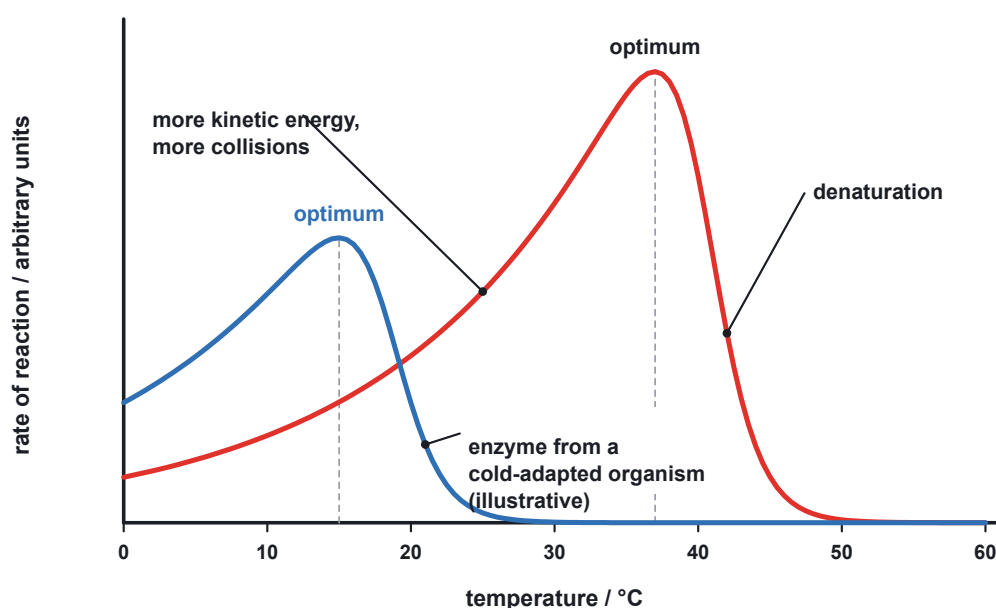
Revision notes · Temperature and enzyme activity (Q_{10}), the development core practical, evolution by mutation and selection, and allopatric and sympatric speciation.

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.

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 mm³ min⁻¹ at 15 °C and at 30 mm³ min⁻¹ at 25 °C. Calculate Q_{10} for oxygen consumption.

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

Answer: $Q_{10} = 2.5$

Extension (beyond the specification): Q_{10} for a temperature difference other than 10 °C

The rate of a reaction is 4.0 units at 10 °C and 9.0 units at 20 °C, then 11.0 units at 30 °C. Calculate Q_{10} between 10 and 30 °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 °C: the rise in rate is smaller between 20 and 30 °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 °C. If you are given a graph, read off the rates at two temperatures 10 °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 °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

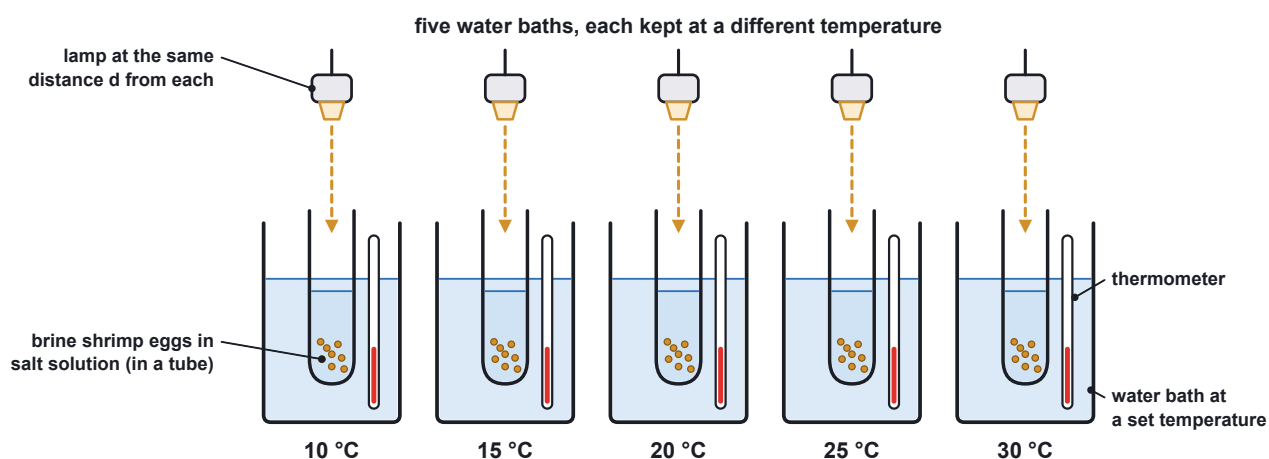
Core practical: Core practical 12: investigate the effects of temperature on the development of organisms (such as seedling growth rate or brine shrimp hatch rates), taking into account the ethical use of organisms.

Brine shrimp hatching

1. Set up several water baths or incubators at different temperatures (for example 15, 20, 25, 30 and 35 °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.
4. Keep all other conditions the same (light, salinity, volume, aeration).
5. 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 change in length $\div$ 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
Independent	Temperature (°C)
Dependent	Number or percentage of eggs hatched in a set time, or rate of seedling growth (mm day ⁻¹)
Controlled	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.

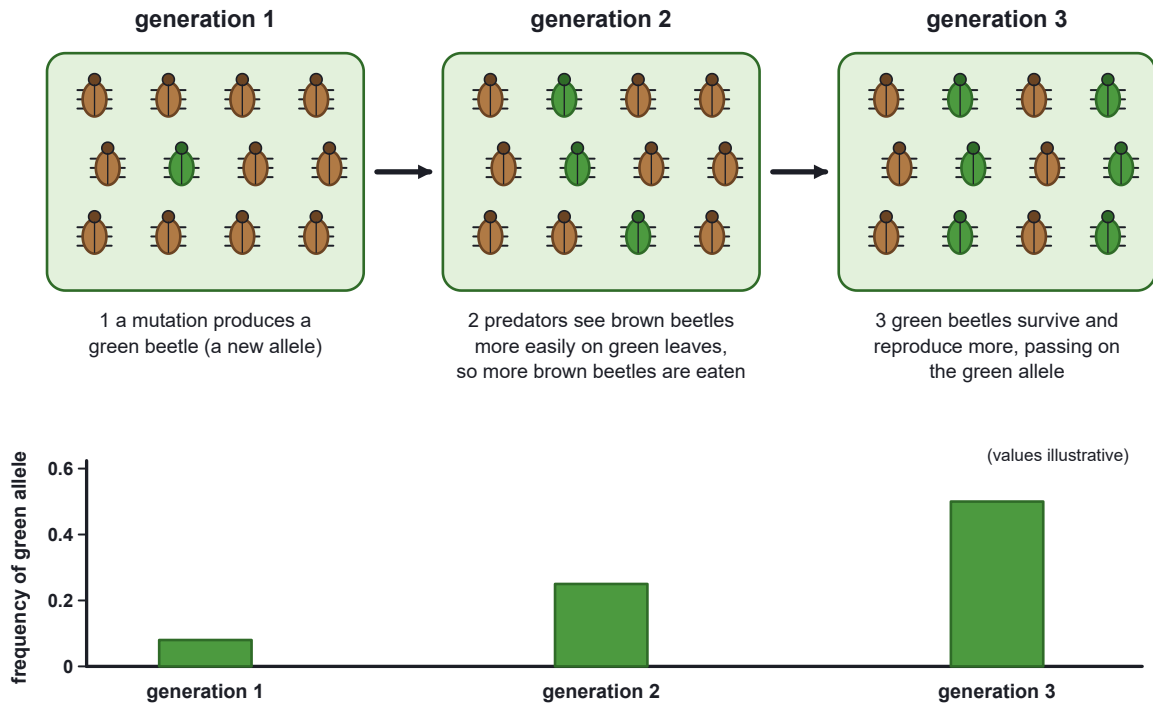
Exam tip: If asked to justify the ethical approach, name the organism and the specific action, such as 'use the smallest number of shrimp and avoid temperatures above their tolerance'.

Evolution: mutation and natural selection Spec 5.23

Evolution	A change in allele frequency in a population over generations.
Allele frequency	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

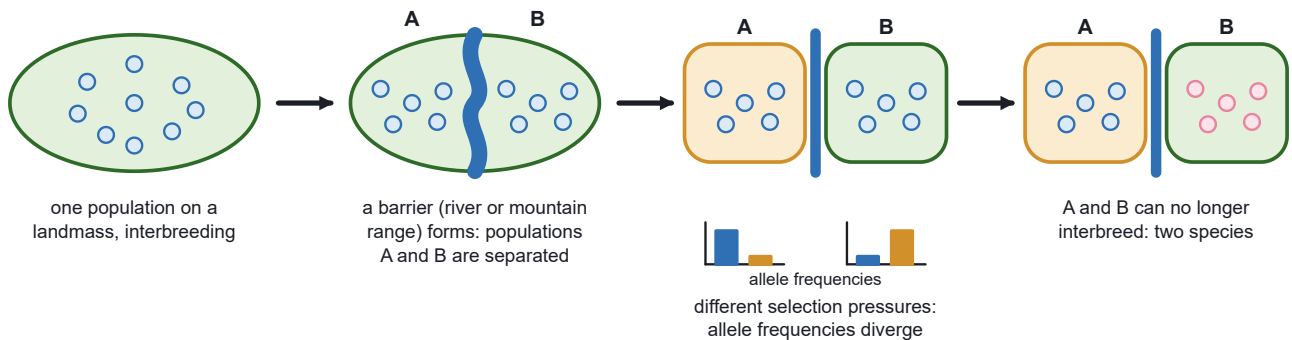
In **sympatric speciation**, new species form within the same geographical area, without a physical barrier. Reproductive isolation arises in other ways:

- 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

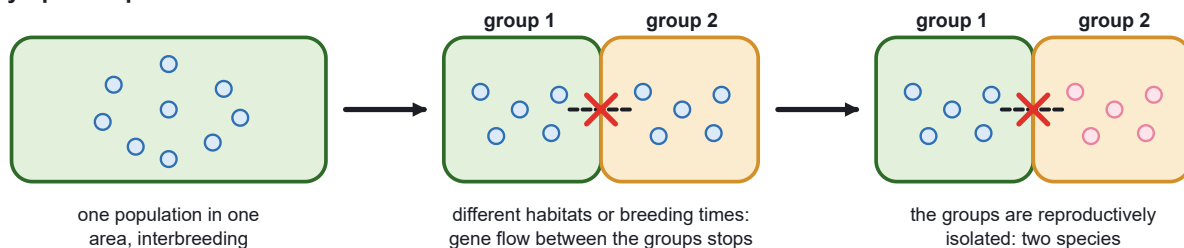
cannot produce fertile offspring with the parent species (a cross gives sterile offspring), but they can reproduce with each other or by self-pollination.

Allopatric and sympatric speciation		
Feature	Allopatric	Sympatric
Location	Populations in different areas	Populations in the same area
Cause of isolation	Geographical barrier	Ecological, temporal, behavioural or genetic changes
Gene flow	Stopped by the barrier	Reduced by reproductive isolation
Outcome	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

Temperature, evolution and speciation

1. Rate at $(T + 10) ^\circ\text{C} \div \text{rate at } T ^\circ\text{C}$.
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.