

Variation and selection

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Read first: [Chromosomes, genes and proteins](#), [Monohybrid inheritance](#), [Transport in plants](#)

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What you need to know

This topic explains why living things of one species are not all the same, where new alleles come from, and how selection (by nature or by farmers) changes a population over many generations. It comes up on every paper: one-mark multiple-choice questions on Papers 1 and 2, and parts of longer questions on Papers 3 and 4, often built around a graph, a photograph of an organism, a table of stomata or a farming story. Outcomes marked **Extended only** are tested on Papers 2 and 4 only. By the end of this topic you should be able to:

Variation

1. Describe **variation** as the **differences between individuals of the same species**.
2. State that **continuous variation** gives a **range of phenotypes between two extremes**, for example body length and body mass.
3. State that **discontinuous variation** gives a **limited number of phenotypes with no intermediates**, for example ABO blood groups, and seed shape and seed colour in peas.
4. State that discontinuous variation is **usually caused by genes only**, and continuous variation is caused by **both genes and the environment**.
5. **Investigate and describe** examples of continuous and discontinuous variation: collect measurements, then draw and read the right kind of graph.
6. Describe a **mutation** as a **genetic change**.
7. State that mutation is **the way new alleles are formed**.
8. State that **ionising radiation** and **some chemicals increase** the rate of mutation.
9. **Extended only**: describe a **gene mutation** as a **random change in the base sequence of DNA**.
10. **Extended only**: state that **mutation, meiosis, random mating** and **random fertilisation** are the sources of genetic variation in populations.

Adaptive features

11. Describe an **adaptive feature** as an **inherited feature that helps an organism to survive and reproduce in its environment**.
12. Use photographs, drawings or other information about a species to **describe its adaptive features**.
13. **Extended only**: explain the adaptive features of **hydrophytes** (plants that live in water) and **xerophytes** (plants of dry places) to their environments.

Selection

14. Describe **natural selection** using five ideas: genetic variation within the population; production of many offspring; a struggle for survival, including competition for resources; a greater chance of reproducing for the individuals that are better adapted; and these individuals passing on their alleles to the next generation.
15. Describe **selective breeding**: humans select individuals with the features they want, cross them to produce the next generation, then select the offspring that show those features.
16. Outline how selective breeding (**artificial selection**) is repeated over many generations to improve crop plants and farm animals, and apply this to a new example.
17. **Extended only**: describe **adaptation** as the **process**, resulting from natural selection, by which **populations** become more suited to their environment over many generations.
18. **Extended only**: describe how strains of **antibiotic-resistant bacteria** develop, as an example of natural selection.
19. **Extended only**: outline the **differences between natural and artificial selection**.

Alleles, dominant and recessive, and genetic diagrams are in Monohybrid inheritance; genes and DNA are in Chromosomes, genes and proteins; stomata and transpiration are in Transport in plants. This note uses all three.

Understand it

Variation: no two alike

Look at any class of students: different heights, different masses, different blood groups, different eye colours. These **differences between individuals of the same species** are **variation**. (Differences between two species, such as a cat and a dog, are not what the word means here.)

Some of the differences come from the **genes** an individual inherited, and some come from its **environment**: what it eats, how much light or water a plant gets, disease, exercise, and so on.

Continuous variation

Some features can take **any value in a range**: height, body mass, body length, hand span, foot length, leaf length, the mass of a potato. There is a smallest and a largest value (the two **extremes**), and every value in between is possible. This is **continuous variation**.

These features are controlled by **genes and the environment** together. Your genes set a range for your height, and your diet and health decide where in that range you end up. Many genes add small effects, so most people are near the middle and few are at the extremes.

To show continuous data, measure each individual, sort the values into **classes** of equal width (for example 17.0–17.9 cm), count the individuals in each class, and draw a **histogram**: bars that touch, because the classes run straight on from one another. It is usually highest in the middle and lower on both sides, a hump

often called a bell shape.

For example, a class of 40 students measured their hand spans:

Hand span / cm	16.0–16.9	17.0–17.9	18.0–18.9	19.0–19.9	20.0–20.9	21.0–21.9
Number of students	2	5	9	12	8	4

The total is $2 + 5 + 9 + 12 + 8 + 4 = 40$ students. The class with the most students, the **modal class**, is 19.0–19.9 cm.

Discontinuous variation

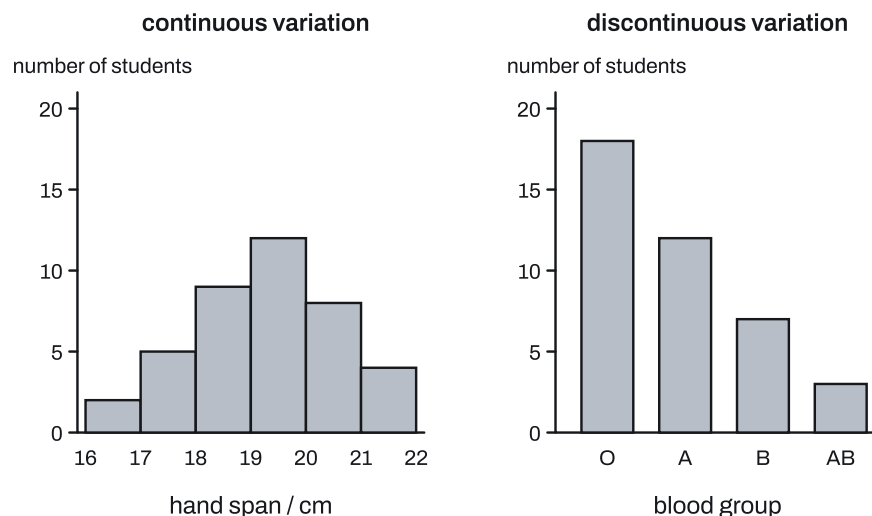
Other features fall into **a few separate groups with nothing in between**. A person's ABO blood group is A, B, AB or O; there is no "half-way between A and B". A pea seed is round or wrinkled, and yellow or green. Sex, tongue rolling, dimples, wet or dry ear wax and attached or free ear lobes are more examples. This is **discontinuous variation**: a **limited number of phenotypes with no intermediates**.

These features are **usually caused by genes only**: a few alleles of one gene decide them, and the environment doesn't change them. Your blood group is the same whatever you eat.

Show discontinuous data as a **bar chart**: one bar for each category, with **gaps between the bars**, because the categories are separate. The blood groups of the same 40 students were:

Blood group	O	A	B	AB
Number of students	18	12	7	3

The total is again $18 + 12 + 7 + 3 = 40$.



The shapes of the two graphs are how questions often test this: touching bars with a hump in the middle mean **continuous**; separate bars for named categories mean **discontinuous**.

Mutation: where new alleles come from

A **mutation** is a **genetic change**. It is the **only way new alleles are formed**: without mutation, a species would only ever reshuffle the alleles it already has.

Mutations happen by chance, all the time, at a low rate. Two things **increase** the rate:

- **ionising radiation**, such as X-rays and gamma rays, and the radiation from radioactive substances;
- **some chemicals**, such as some of the chemicals in tobacco smoke.

Most mutations make no difference or are harmful; a few give a feature that helps. Only mutations in cells that make gametes (or in a single-celled organism such as a bacterium) are passed to offspring.

Extended only: a **gene mutation** is a **random change in the base sequence of DNA**. The base sequence of a gene is the code for a protein, so a changed sequence can give a changed protein, and that is a new allele. Note that the change is in the **bases** of DNA, not in amino acids: DNA doesn't contain amino acids.

Extended only: the **sources of genetic variation** in a population are:

- **mutation**, which makes new alleles;
- **meiosis**, which gives every gamete a different mix of the parent's chromosomes;
- **random mating**, because any individual may breed with any other;
- **random fertilisation**, because any one of millions of sperm (or pollen nuclei) may fuse with the egg.

Mitosis and asexual reproduction make genetically **identical** cells, so they are **not** sources of variation.

Adaptive features

An **adaptive feature** is an **inherited** feature that helps an organism to **survive and reproduce** in its environment. All three parts matter: a scar is not inherited, so it is not an adaptive feature, and a feature that helps survival must also make reproduction more likely.

To describe adaptive features from a photograph or data, name a feature you can see (or read), then say how it helps in **that** environment:

Feature	How it helps
Colours and shape like a leaf or twig	camouflage : hidden from predators, or from prey
Large spots like eyes on the wings	startle or scare off predators
Bright warning colours	predators learn to avoid it
Forward-facing eyes, sharp teeth or claws	judging distance and catching prey (predators)
Eyes on the sides of the head	wide field of view to spot predators (prey animals)
Large ears with many blood vessels (desert fox)	lose heat

Feature	How it helps
Concentrated urine, little sweating	keep water in a dry habitat
Short life cycle, flowering quickly	reproduce in a short growing season, such as on a snowy mountain

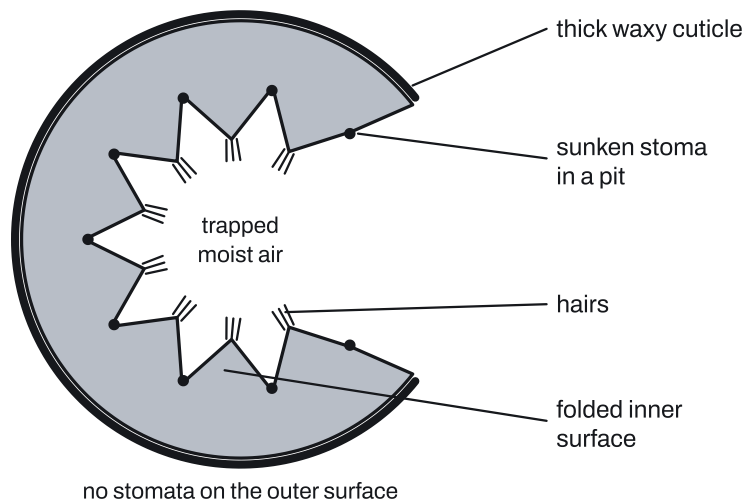
Xerophytes: plants of dry places

Extended only. A **xerophyte** lives where water is scarce: deserts, sand dunes, windy dry places. Its problem is that it loses water vapour by transpiration through its stomata, and it can't replace much from the soil. Its adaptive features either **reduce water loss**, **store water** or **take up more water**.

Most of the water lost from a leaf **diffuses out through the stomata** as water vapour, down a gradient from the moist air spaces inside the leaf to drier air outside. So most leaf features work by keeping **moist air** next to the stomata, which makes the **water vapour diffusion gradient** shallower and slows the loss.

Feature	How it reduces water loss
Thick waxy cuticle	waterproof layer: less evaporation from the leaf surface
Few stomata , often only on the lower or inner surface	fewer places for water vapour to escape
Sunken stomata (stomata in pits)	moist air is trapped in the pit, so the diffusion gradient is smaller
Hairs on the leaf surface	trap a layer of moist air and reduce air movement next to the stomata
Rolled or curled leaves , with the stomata on the inside	trap moist air inside the roll; less surface exposed to wind and sun
Folded inner surface	the grooves hold still, moist air around the stomata
Small leaves, or leaves reduced to spines (cactus)	small surface area for transpiration
Swollen, fleshy (succulent) stem or leaves	store water for dry periods
Green stem	the stem photosynthesises instead of the (reduced) leaves
Shallow roots spread widely near the surface	absorb rain quickly, before it evaporates or drains away
Very deep roots	reach water deep underground
Stomata open at night , closed in the day	take in carbon dioxide when it is cool, so less water is lost

Marram grass, which grows on sand dunes, shows most of the leaf features in one section:

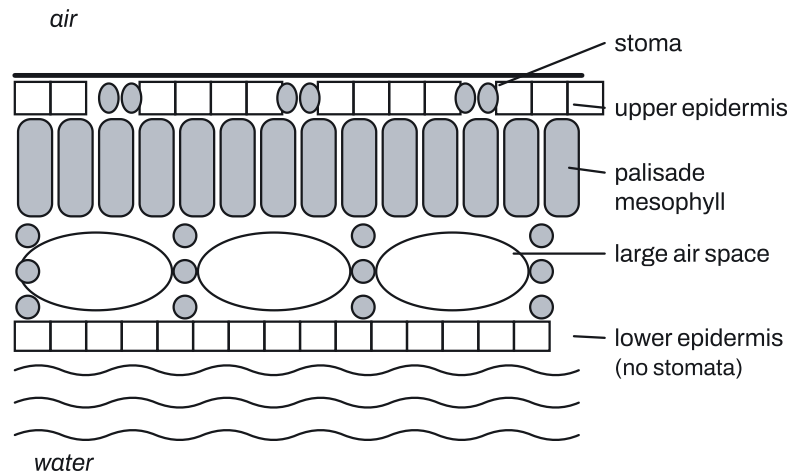


The thick walls of a xerophyte's epidermis cells, like all plant cell walls, are made of **cellulose**. Measurements this small are given in micrometres: $1 \text{ mm} = 1000 \text{ }\mu\text{m}$, so a wall $3.5 \text{ }\mu\text{m}$ thick is $3.5 \div 1000 = 0.0035 \text{ mm}$.

Hydrophytes: plants in water

Extended only. A **hydrophyte** lives in water, such as a water lily or pondweed. Water is never short, so the problems are different: getting enough **light** and **gases**, and staying afloat.

Feature	Why it suits life in water
Stomata on the upper surface only (floating leaves)	the upper surface is in the air, so gases can diffuse in and out; the lower surface is in water
No stomata at all (submerged leaves, such as pondweed)	gases diffuse into the leaf straight from the water
Large air spaces in the leaves and stems	make the leaves float (buoyancy) near the light, and store oxygen and carbon dioxide
Thin cuticle, or none	no need to stop water loss; lets gases and light in easily
Little xylem , weak stems	the water supports the plant and water is all around it
Large, flat floating leaves	absorb as much light as possible



Stomatal counts are often given **per mm²**. 1 cm = 10 mm, so 1 cm² = 10 × 10 = 100 mm². To change per mm² into per cm², **multiply by 100**: 480 stomata per mm² is 480 × 100 = 48 000 stomata per cm². (The number gets **bigger**, because a cm² is a bigger area.)

Natural selection

In every population there is **genetic variation**: individuals have different alleles. Natural selection works like this:

1. **Variation.** Individuals differ, partly because of their alleles.
2. **Many offspring.** Organisms produce more offspring than the environment can support.
3. **Struggle for survival.** Offspring **compete** for resources such as food, water, light, space and mates, and face predators and disease. Many die.
4. **Better adapted survive.** Individuals whose inherited features suit the environment are more likely to survive **and reproduce**.
5. **Alleles passed on.** They pass their **alleles** to the next generation.
6. **Over many generations** the helpful allele, and the feature it gives, becomes more common in the population.

Nobody chooses anything: the environment "selects", because some individuals leave more offspring than others.

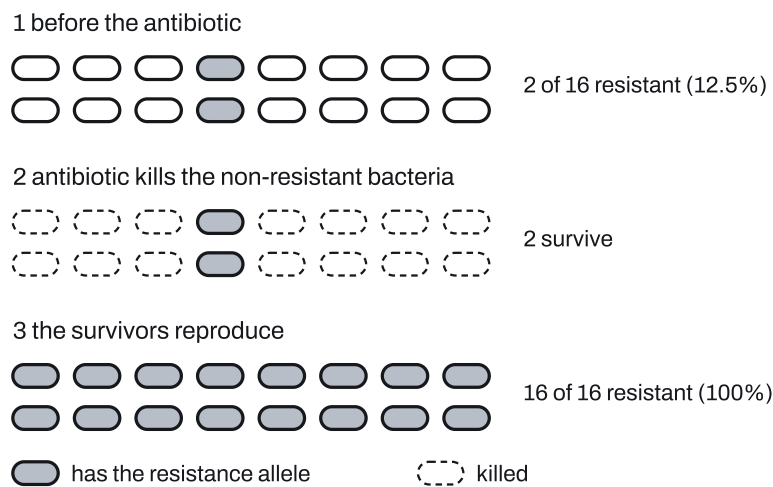
For example, a moth usually has pale wings, which hide it on pale tree bark. A few moths have dark wings because of a mutation. If the bark becomes dark with soot, dark moths are harder for birds to see, so more dark moths survive and breed, and pass on the allele for dark wings. After many generations most of the moths are dark.

Extended only: this change over many generations, by which a **population** becomes more suited to its environment, is called **adaptation**. An individual cannot adapt in this sense during its life: a giraffe does not grow a longer neck by stretching. Giraffes with longer necks (because of their alleles) reached more leaves, survived and bred more, and passed those alleles on.

Antibiotic-resistant bacteria

Extended only. Antibiotic resistance is natural selection that you can watch happen in a few years, because bacteria reproduce very quickly.

1. In a large population of bacteria, a **random mutation** gives a few bacteria an allele for **resistance** to an antibiotic. The antibiotic did **not** cause this mutation; it was there already.
2. When the antibiotic is used, it **kills the bacteria that are not resistant**. The **resistant bacteria survive**.
3. The survivors no longer compete with the others, and they **reproduce** (by binary fission, very quickly).
4. Their offspring **inherit the resistance allele**.
5. The **proportion** of resistant bacteria in the population rises, until the antibiotic no longer works: a **resistant strain** has developed.



In the diagram, 2 of 16 bacteria start resistant: $2 \div 16 \times 100 = 12.5\%$. After the antibiotic and a few divisions, all 16 are resistant: 100%. To slow this down, doctors prescribe antibiotics only when they are needed (never for viruses), patients finish the whole course, and farmers use fewer antibiotics on animals.

Selective breeding (artificial selection)

Humans have changed crops and farm animals enormously by choosing which ones breed. This is **selective breeding**, also called **artificial selection**:

1. **Select** individuals with the **desirable feature** (the most milk, the largest grains, resistance to a disease, drought tolerance).
2. **Cross** (breed) them together to produce the next generation.
3. From the offspring, **select** those that show the desirable feature most strongly.
4. Breed **those** together.
5. **Repeat for many generations**, until all the offspring reliably show the feature.

It takes many generations because each one only moves the feature a little, and the wanted alleles have to become common in the whole group.

Examples: cows and goats that give more milk; sheep with more wool; chickens that grow faster or lay more eggs; wheat, rice and maize with higher yields, shorter stems or resistance to pests and disease; crops that tolerate drought; broccoli, cauliflower and cabbage, all bred from one wild plant; dogs of many breeds.

Extended only: natural and artificial selection compared.

	Natural selection	Artificial selection
What selects	the environment	humans
Which features spread	ones that help survival and reproduction	ones useful or wanted by humans , whether or not they help survival
Competition or struggle for survival	yes	no : humans choose who breeds and provide food and shelter
Speed	usually slow	usually faster
Result	organisms better adapted to their environment	organisms with the features people want

What they share: there is variation to start with; **only certain individuals reproduce**; their **alleles are passed on** to the offspring; and the change builds up over **many generations**.

Genetic engineering is **not** selective breeding: it moves a gene from one organism into another directly, in a laboratory, in one step.

Key facts and formulas

There is no formula list in the IGCSE Biology exam, so everything below must be learnt. "Learn it" means you must remember it.

Formula or fact	Status
Continuous: range of phenotypes between two extremes; genes and environment; histogram	Learn it
Discontinuous: limited number of phenotypes, no intermediates; usually genes only ; bar chart	Learn it
Mutation = genetic change; the way new alleles are formed; rate increased by ionising radiation and some chemicals	Learn it
Extended only : gene mutation = random change in the base sequence of DNA	Learn it
Extended only : sources of genetic variation = mutation, meiosis, random mating, random fertilisation	Learn it
Adaptive feature = inherited feature that helps an organism to survive and reproduce in its environment	Learn it

Formula or fact	Status
Percentage change = $\frac{\text{new value} - \text{original value}}{\text{original value}} \times 100$	Learn it
Mean = $\frac{\text{sum of the values}}{\text{number of values}}$	Learn it
$1 \text{ cm}^2 = 100 \text{ mm}^2$, so $\text{per mm}^2 \times 100 = \text{per cm}^2$	Learn it
$1 \text{ mm} = 1000 \mu\text{m}$, so $\mu\text{m} \div 1000 = \text{mm}$	Learn it
Total stomata = stomata per unit area $\times$ area (in the same units)	Learn it

How to do it

We tagged 154 questions for this topic (2021–2025, Papers 1–4). 23 of them mix types, so the counts add up to 182.

Question type	Questions
Continuous and discontinuous variation	38
Xerophyte and hydrophyte adaptations	33
Mutation and sources of genetic variation	25
Natural selection	22
Selective breeding	20
Adaptive features	17
Natural versus artificial selection	10
Working with variation data	10
Antibiotic resistance	7

1. Continuous and discontinuous variation (38 questions)

- Decide the type.** Ask: can the feature take any value in a range (continuous), or does it fall into a few named groups (discontinuous)?
- Give the cause** that goes with it: continuous = genes **and** environment; discontinuous = **usually genes only**.
- Give an example** if asked. Safe ones: continuous = height, body mass, body length, hand span, leaf length; discontinuous = ABO blood group, sex, pea seed shape or colour, tongue rolling.

4. **"Explain how the data show ..."**: quote the graph or table. For discontinuous: "there are only four blood groups / distinct categories, and **no intermediates** between them". For continuous: "the values form a **range** between two extremes (from 12.0 to 19.9 cm), and any value in between is possible".

Variations you will meet:

- **Multiple choice rows** such as "type / caused by / example". Check all three columns: most wrong options pair the right type with the wrong cause (for example "continuous, genes only") or the wrong example (body mass is never discontinuous).
- **Which graph?** Touching bars in classes, highest in the middle = continuous. Separate bars for named categories = discontinuous.
- **Tick tables:** "no intermediate phenotypes" and "usually caused by genes only" = discontinuous; "range of phenotypes between two extremes" and "caused by genes and environment" = continuous.
- **Define variation:** differences between individuals **of the same species**. Not "between species", and not "an alternative form of a gene" (that is an allele).
- **Which variation can be inherited?** Variation caused by genes can be inherited; variation caused by the environment (a scar, a language learned, big muscles from training) cannot.
- **Extended only:** ABO blood group is discontinuous because it is controlled by a single gene with three alleles (two of them codominant), so only four phenotypes are possible.

2. Xerophyte and hydrophyte adaptations (33 questions)

Extended only.

1. **Name the feature**, using the photograph, diagram or data (rolled leaf, hairs, sunken stomata, thick cuticle, spines, swollen stem, large air spaces, stomata on the upper surface).
2. **Say what it does**, in terms of water, gases, light or floating. For xerophytes link it to water loss: "traps moist air, so the water vapour diffusion gradient is reduced" or "waterproof layer, so less evaporation".
3. **Link it to the habitat:** "because water is scarce in the desert", or "because the lower surface of the leaf is in the water".

Variations you will meet:

- **Multiple choice "which leaf is adapted to hot, dry places?"**: few stomata, thick waxy cuticle, small surface area. Any option with "many stomata", "thin cuticle" or "large leaves" is wrong for a xerophyte.
- **Stomata tables.** A plant with **no stomata** on either surface is submerged; one with stomata **only on the upper surface** has floating leaves (water lily); one with few stomata, mostly on the lower surface, is a xerophyte; a land plant that isn't a xerophyte has many stomata, most on the lower surface. Explain each with gases (upper surface in the air) or water loss.
- **Convert units.** Per mm² to per cm²: $\times 100$. For example 573 per mm² is $573 \times 100 = 57\,300$ per cm². Micrometres to mm: $\div 1000$.
- **Total stomata on a leaf.** Put the density and the area in the same units first, then multiply: 25 stomata per mm² on a leaf of 6 cm² is $25 \times 100 \times 6 = 15\,000$ stomata.

- **Root systems.** Shallow roots spread wide near the surface: absorb water straight after rain. A long, deep root: reaches water deep in the ground. Talk about **water**, not anchorage or minerals.
- **Stems.** Swollen or succulent (stores water), green (photosynthesis), thick waxy cuticle. Don't give leaf or root features when the question asks about the stem, and spines "against herbivores" are not a dry-habitat adaptation.
- **Graphs of gas exchange over a day** (such as a desert plant that takes in carbon dioxide at night): stomata open in the cool night and close in the hot day, so less water is lost.

3. Mutation and sources of genetic variation (25 questions)

1. **Define it:** mutation is a **genetic change**. It is how **new alleles** are formed.
2. **Causes** of a higher rate: **ionising radiation** and **some chemicals**. They **increase** the rate (a common wrong option says "decrease").
3. **Extended only:** a gene mutation is a **random** change in the **base sequence of DNA**.
4. **Extended only:** the four sources of genetic variation: **mutation, meiosis, random mating, random fertilisation**.

Variations you will meet:

- **Gap-fill sentences** from a word list: "A mutation is a **genetic** change. It is the way new **alleles** are formed. The rate is increased by **ionising** radiation and some chemicals."
- **"State two other sources of genetic variation"** (after one is given in the question): choose from the four. Mitosis, asexual reproduction, growth and "sexual reproduction" on its own are not accepted.
- **"Explain how new alleles are formed"**: by mutation, a random change in the base sequence of DNA (of a gene); the rate is increased by ionising radiation or some chemicals.
- **Multiple choice traps:** "a change in the amino acid sequence of DNA" (wrong: DNA has bases), "mutation is caused by phenotypic variation" (wrong way round), "an increase in the number of chromosomes" (that is not a gene mutation).

4. Natural selection (22 questions)

1. Start with **variation**: individuals differ because of their **alleles** (for example, some have darker fur).
2. **Many offspring** are produced, so there is **competition** for resources (food, mates, space) or a **struggle for survival** (predators, disease).
3. The individuals with the helpful feature are **better adapted**, so they are **more likely to survive and reproduce**.
4. They **pass on their alleles** to their offspring.
5. **Over many generations**, the allele and the feature become **more common** in the population.
6. Name the process: **natural selection**.

For an open 3–4 mark question, apply every step to the organism in the question. For example, a white crab living in dark caves: a mutation stopped pigment being made; in the dark, colour gives no advantage, and not making pigment saves energy and materials; crabs without pigment were at least as likely to survive and

reproduce, and passed on the allele; over many generations the whole population became white.

Variations you will meet:

- **Gap-fill sentences** about an animal in a photograph (spots that match coral, a lizard's tail, an insect shaped like a leaf).
- **Put the statements in order:** variation → overproduction → competition → survival of the better adapted → reproduction → alleles passed on → more common over generations.
- **Graphs that shift over time**, such as beak lengths in 2000 and 2020: the peak has moved, so the environment favoured one end of the range.
- **"What is needed for natural selection?":** variation in the population, more offspring than can survive, and competition. Not "plenty of resources", and not identical offspring.
- **Extended only:** use **allele** (not "trait" or "gene for a characteristic") and mention that the variation came from **mutation**. Use the word **adaptation** for the change in the population.

5. Selective breeding (20 questions)

1. **Choose parents** that show the **desired feature** most strongly (the heaviest chickens, the most drought-tolerant plants).
2. **Breed** (cross) them together.
3. **Select the offspring** that show the feature best.
4. **Breed these** together.
5. **Repeat for many generations.**

Variations you will meet:

- **"Complete the steps"** when step 1 is given: write steps 2–5, not step 1 again.
- **Put the steps in order** or fill in a flow chart.
- **Name the process:** selective breeding (artificial selection is also accepted). Not "genetic engineering", not "natural selection".
- **Why would a farmer want this feature?** Think money and supply: animals that mature faster produce eggs or meat sooner and bring in profit sooner; higher yield meets demand; pest resistance means less crop is lost and less pesticide is bought.
- **Plants:** cross-pollinate by hand (transfer pollen from one chosen plant to another) and cover the flowers with bags so no other pollen gets in.
- **Extended only:** say it happens **over many generations**, and link the feature to its **alleles** (the wanted alleles become more common).

6. Adaptive features (17 questions)

1. **Define it** with both key parts: an **inherited** feature that helps an organism to **survive and reproduce** in its environment.

2. **From a photograph or data:** name a feature you can **see**, then explain how it helps that organism in that place.

Variations you will meet:

- **Gap-fill definition:** "An adaptive feature is an **inherited** feature that helps an organism to **survive** and **reproduce** in its environment." Many students write only "survive" and lose the mark.
- **Camouflage and warning** (leaf insects, sea-dragons that look like seaweed, butterflies with eye-spots): hidden from predators or prey, or scares predators.
- **Predator or prey?** Forward-facing eyes, sharp teeth and claws suit predators (secondary consumers); eyes on the side of the head suit prey.
- **Extreme places:** a desert fox (large ears to lose heat, little water lost in urine), alpine plants that flower quickly in a short summer.
- **Extended only:** "Describe the meaning of **adaptation**": the **process**, resulting from natural selection, by which **populations** become more suited to their environment over many generations. Don't confuse it with "adaptive feature".

7. Natural versus artificial selection (10 questions)

1. **Who selects?** Humans = artificial; the environment = natural.
2. **Which features?** Artificial: useful to humans. Natural: help survival and reproduction.
3. **Struggle for survival?** Only in natural selection.

Variations you will meet:

- **Classify the example.** Antibiotic-resistant bacteria, dark moths, long-necked giraffes, beak shapes: **natural**. Cows that give more milk, broccoli and cauliflower from a wild plant, disease-resistant wheat crossed with high-yield wheat: **artificial**. Insulin made by modified bacteria is **genetic engineering**, neither.
- **"Which is true of both?":** only certain individuals reproduce; alleles are passed on to offspring; it takes many generations; it needs variation.
- **Extended only, 2–3 marks "explain how natural selection differs from artificial selection":** write matched pairs, for example "In natural selection the environment selects, but in artificial selection humans select. Natural selection favours features that help survival, but artificial selection favours features humans want. There is a struggle for survival only in natural selection. Artificial selection is usually faster."

8. Working with variation data (10 questions)

1. **Totals:** add every class (check you haven't missed one).
2. **Modal class** ("most frequent"): the class with the tallest bar or the biggest number. Give the class with its unit, for example "19.0–19.9 cm".
3. **Count above or below a value:** add the classes on that side.

4. **Mean**: add the values and divide by how many there are. Give it to the accuracy asked, with the unit. For example leaf lengths of 42, 45, 39, 48 and 41 mm: $215 \div 5 = 43$ mm.
5. **Extended only: percentage change**: $\frac{\text{new} - \text{original}}{\text{original}} \times 100$. Divide by the **original** (earlier or starting) value. For example a wheat yield that rose from 1.2 to 3.0 tonnes per hectare: $\frac{3.0 - 1.2}{1.2} \times 100 = 150\%$. A fall gives a negative answer: 80 down to 60 is $\frac{60 - 80}{80} \times 100 = -25\%$.
6. **Round last**, to the number of significant figures asked (the mark scheme gives a mark for the data, one for the calculation and one for the rounding).

9. Antibiotic resistance (7 questions)

Extended only.

1. **Mutation**: some bacteria have (by random mutation) an allele that makes them **resistant**.
2. The antibiotic **kills the non-resistant bacteria**; the **resistant bacteria survive**.
3. The resistant bacteria **reproduce**, with less competition.
4. They **pass on the allele** for resistance.
5. Over time the **proportion** of resistant bacteria increases: a resistant strain.
6. This is **natural selection**.

Variations you will meet:

- **Order the events**: antibiotic used → non-resistant bacteria killed → resistant bacteria survive and reproduce → population mostly resistant.
- **A graph of % resistant rising** over time: caused by natural selection (not artificial selection, not meiosis).
- **How to reduce it**: use antibiotics only when needed, not for viral infections, complete the full course, use fewer antibiotics in farming.
- **"Why are antibiotics used so much in intensive farming?"**: many animals are kept close together, so bacterial diseases spread easily.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
 - **A1** accuracy mark: for a correct answer; it needs the M mark before it.
 - **B1** mark for a correct result on its own, with no method needed.
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Example 1

A student measured the foot length of 50 students.

Foot length / cm	20.0–21.9	22.0–23.9	24.0–25.9	26.0–27.9	28.0–29.9
Number of students	3	9	17	14	7

(a) Show that 50 students were measured. **[1]**

(b) State the modal class. **[1]**

(c) How many students had a foot length of 26.0 cm or more? **[1]**

(d) State the type of variation shown by foot length, and explain how the data show this. **[2]**

(e) State one example of the other type of variation in humans, and what causes that type. **[2]**

(a) $3 + 9 + 17 + 14 + 7 = 50$ **B1**

(b) 24.0–25.9 cm **B1**

(c) $14 + 7 = 21$ students **B1**

(d) Continuous variation **B1**. The foot lengths form a range between two extremes (20.0 cm to 29.9 cm), with any value in between possible, and they are grouped in classes that follow on from each other **B1**.

(e) ABO blood group (or sex, or tongue rolling) **B1**; usually caused by genes only **B1**.

Example 2

A farmer keeps goats for milk. Twenty years ago the mean milk yield of her herd was 1.6 litres per goat per day. It is now 4.4 litres per goat per day.

(a) Calculate the percentage change in the mean milk yield. **[2]**

(b) Describe how the farmer could use selective breeding to increase the milk yield. **[3]**

(c) Suggest why it took many years to reach this yield. **[1]**

(a) $\frac{4.4 - 1.6}{1.6} \times 100$ **M1** = 175% **A1**

(b) Choose the goats with the highest milk yield (and a male from a high-yielding mother) **B1**. Breed them together **B1**. Select the offspring with the highest milk yield, breed them, and repeat over many generations **B1**.

(c) Each generation only increases the yield a little, and goats take a long time to grow up and breed, so many generations are needed **B1**.

Example 3

The table shows the number of stomata per mm² on the leaves of two plants. One is a xerophyte.

Plant	Upper surface	Lower surface
P	60	220
Q	0	35

(a) Estimate the total number of stomata on the lower surface of a leaf of plant Q with a lower surface area of 4 cm². [2]

(b) Using the data, explain which plant is the xerophyte. [3]

(c) Describe two other features of xerophyte leaves and explain how each reduces water loss. [4]

(a) $4 \text{ cm}^2 = 4 \times 100 = 400 \text{ mm}^2$ **M1**; $35 \times 400 = 14\,000$ stomata **A1**

(b) Plant Q **B1**. It has far fewer stomata (35 per mm² in total, against $60 + 220 = 280$ for P), so fewer places for water vapour to diffuse out **B1**. It has none on the upper surface, which is hotter and more exposed to the sun and wind, so less water evaporates **B1**.

(c) Any two, each feature **B1** + explanation **B1**:

- A thick waxy cuticle: a waterproof layer, so less water evaporates from the surface.
- Sunken stomata (in pits): moist air is trapped around the stomata, so the water vapour diffusion gradient is smaller.
- Hairs: trap moist air and reduce air movement over the stomata.
- Rolled leaves: the stomata are inside the roll, where moist air is trapped.

Example 4

The number of infections caused by bacteria resistant to one antibiotic rose from 34 to 57 per 1000 people in a town.

(a) Calculate the percentage increase. Give your answer to two significant figures. [3]

(b) Explain how a population of bacteria becomes resistant to an antibiotic. [4]

(c) State two differences between the process in (b) and selective breeding. [2]

(a) Uses 57 and 34 **B1**; $\frac{57 - 34}{34} \times 100 = 67.647 \dots$ **M1**; = 68% **A1**

(b) Any four:

- A random mutation gave some bacteria an allele for resistance **B1**.
- The antibiotic kills the non-resistant bacteria, but the resistant ones survive **B1**.
- The resistant bacteria reproduce **B1**.

- They pass on the allele for resistance to their offspring **B1**.
- Over time the proportion of resistant bacteria in the population increases **B1**.
- This is natural selection **B1**.

(c) In (b) the environment (the antibiotic) selects, but in selective breeding humans select **B1**. In (b) there is a struggle for survival, but in selective breeding there is not (or: (b) favours features that help survival, selective breeding favours features humans want) **B1**.

Common mistakes

- **Writing only "survive" for an adaptive feature.** The definition needs **inherited**, **survive** and **reproduce**. Examiner reports say "reproduce" and "inherited" are the words most often left out.
- **Mixing up the cause of each type of variation.** Discontinuous = usually genes **only**; continuous = genes **and** environment. Multiple-choice options often swap them.
- **Describing the graph instead of answering.** "Explain how the data show discontinuous variation" wants "separate categories with no intermediates", with the graph quoted, not a list of the bar heights.
- **Saying the antibiotic causes the mutation**, or that bacteria "change to adapt" or "become immune". The mutation is random and already there; the antibiotic only kills the others. Immunity and antibodies belong to your body, not to bacteria.
- **Writing "traits" or "characteristics are passed on".** Mark schemes want **alleles** (or genes) passed on.
- **Thinking antibiotics kill resistant bacteria.** They kill the non-resistant ones; that is the whole point.
- **Saying selective breeding involves a struggle for survival.** It doesn't: humans choose, and that is exactly how it differs from natural selection.
- **Giving selective breeding when the question is about genetic engineering**, or the other way round. Selective breeding is crossing and choosing over generations; genetic engineering is moving a gene in a laboratory.
- **Dividing a stomata density the wrong way.** Per mm² to per cm² makes the number **bigger** ($\times 100$), because a cm² is a bigger area.
- **Rounding when asked to convert.** "Convert 1.276 μm to mm" wants 0.001276 mm, not a rounded number.
- **Giving a leaf or root feature when the question asks about the stem**, or anchorage and minerals when the question is about water uptake by roots in a desert.
- **Calling the air spaces "spongy mesophyll" or "air gaps"**, or giving xerophyte features (sunken stomata, hairs) for a hydrophyte. Use the syllabus terms: "air spaces".
- **Dividing by the new value in a percentage change**, or not rounding to the significant figures asked.
- **Counting "sexual reproduction", mitosis or asexual reproduction as sources of variation.** The four accepted sources are mutation, meiosis, random mating and random fertilisation.

How to get the marks

- **"State" or "name"** wants one word or a short phrase: "selective breeding", "natural selection", "mutation", "continuous".
- **"Describe"** a process (selective breeding, natural selection) wants the steps in order. Each step is usually one mark, so a 3-mark question wants three separate steps, ending with "repeat over many generations".
- **"Explain"** an adaptive feature wants the feature **and** how it helps **and** the link to the habitat, for example "sunken stomata trap moist air, which reduces the water vapour diffusion gradient, so less water is lost in the dry desert".
- **"Using Fig. ..." or "Using the data"** wants you to quote what you see or the numbers. A feature not visible in the photograph earns nothing.
- **Key words earn the marks:** alleles, mutation, competition, struggle for survival, survive and reproduce, pass on, many generations, proportion, diffusion gradient, air spaces, buoyancy.
- **Calculations:** show the numbers you took from the table or graph, the working, then the rounding asked for (significant figures, a whole number, or with a unit). Each is usually a separate mark, and later marks follow through from a wrong earlier step.
- **Tick boxes:** read the instructions. "One tick in each row" or "tick the correct statements" — an extra wrong tick can cancel a correct one.
- **Multiple choice:** read every column of a row. One wrong entry makes the whole row wrong.

Quick check

1. For each feature, state whether it shows continuous or discontinuous variation: (a) human height (b) sex (c) tongue rolling (d) length of a leaf.
2. Complete: A mutation is a _____ change. Mutation is the way new _____ are formed. The rate of mutation is increased by _____ radiation and some _____.
3. **Extended only.** (a) A water lily leaf has 520 stomata per mm² on its upper surface. Convert this to stomata per cm². (b) A cuticle is 2.8 µm thick. Convert this to mm.
4. **Extended only.** In a population of rabbits, 12% had thick fur. Twenty years later, after a run of cold winters, 45% had thick fur. Calculate the percentage change, and name the process that caused it.
5. Put these statements about natural selection in order: (A) the better-adapted individuals survive and reproduce; (B) individuals in a population show variation; (C) there is competition for food; (D) alleles are passed to the next generation; (E) more offspring are produced than can survive.
6. **Extended only.** Explain why a floating water lily leaf has its stomata on the upper surface only.

Answers

1. (a) continuous (b) discontinuous (c) discontinuous (d) continuous.
2. genetic; alleles; ionising; chemicals.
3. (a) $520 \times 100 = 52\,000$ stomata per cm^2 . (b) $2.8 \div 1000 = 0.0028$ mm.
4. $\frac{45 - 12}{12} \times 100 = 275\%$. Natural selection: rabbits with the allele for thick fur were more likely to survive the cold and reproduce.
5. B, E, C, A, D.
6. The upper surface is in the air, so oxygen and carbon dioxide can diffuse in and out through the stomata. The lower surface rests on the water, where stomata could not exchange gases with the air.

Past questions to try

- **0610/31/O/N/24 Q6:** define variation, sort statements, and mutation.
- **0610/43/O/N/23 Q6:** adaptation, a cactus and a stomata table with a total.
- **0610/43/M/J/24 Q4:** new alleles, selective breeding of wheat, natural versus artificial selection.
- **0610/42/M/J/23 Q3:** percentage change and how bacteria become resistant.