IGCSE BIOLOGY 0610 · CHAPTER 13 NOTES · ~24 MIN READ

Inheritance, variation & selection

Chromosomes, genes and alleles, how mitosis and meiosis differ, how to work out monohybrid crosses with Punnett squares and pedigrees, why organisms vary, and how natural and artificial selection change populations.

Chromosomes & genes | Mitosis & meiosis | Monohybrid crosses | Variation | Mutation | Natural & artificial selection

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No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

IN 30 SECONDS

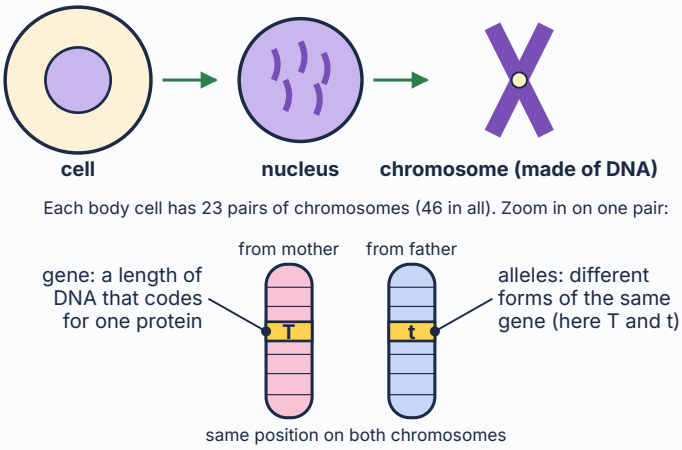
- **DNA** is the genetic code. A **gene** is a length of DNA that codes for a **protein**, and **alleles** are different versions of a gene. Humans have **46 chromosomes** (23 pairs) in every body cell.
- **Mitosis** makes **identical** cells for growth and repair. **Meiosis** makes **gametes** with **half** the chromosomes, all **genetically different**. **Punnett squares** predict the ratios, for example **3 : 1** and **1 : 1**.
- Offspring **vary** because of **genes** and the **environment**. **Mutation** makes new alleles. **Natural selection** (the environment) and **selective breeding** (humans) change which alleles are common.

BY THE END YOU CAN

- Define chromosome, gene and allele, and describe how sex is inherited in humans.
- Define haploid and diploid nuclei and state the chromosome number in human cells.
- Describe mitosis and meiosis and compare them, including why each is needed.
- Use the terms genotype, phenotype, homozygous, heterozygous, dominant, recessive and pure-breeding.
- Predict the results of monohybrid crosses (3 : 1 and 1 : 1) with Punnett squares, and interpret a pedigree.
- Compare continuous and discontinuous variation and say what causes variation.
- Define mutation and name factors that increase it.
- Describe adaptive features, natural selection and selective breeding.
- Explain how a gene codes for a protein, and how DNA controls cell function. EXT
- Describe stem cells. EXT
- Predict test cross, codominance (ABO) and sex-linked inheritance results. EXT
- Explain gene mutation, sources of variation and antibiotic resistance as natural selection. EXT
- Describe the adaptations of xerophytes and hydrophytes. EXT

1 DNA, genes and chromosomes

Chromosomes, genes and alleles



Each person has two alleles of every gene: one from each parent.

Chromosomes are made of DNA. A gene is a part of a chromosome. The two alleles of a gene sit at the same place on a pair of chromosomes.

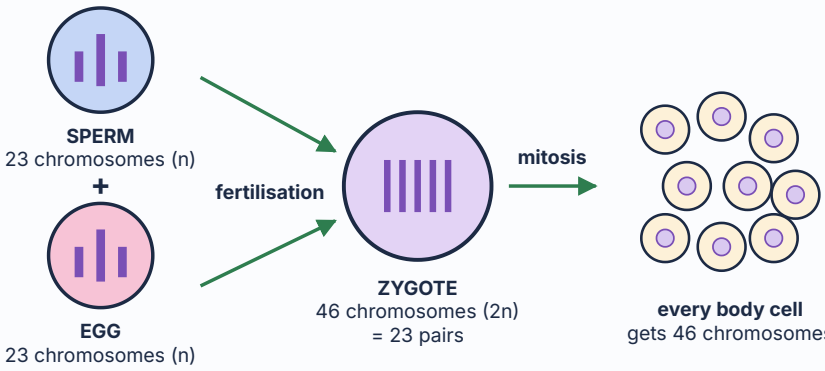
Chromosome — a thread-like structure of **DNA**, carrying genetic information in the form of **genes**.

Gene — a **length of DNA** that **codes for a protein**.

Allele — a **version** of a gene.

- Chromosomes are found in the **nucleus** (cells). **Human body cells have 46 chromosomes in 23 pairs.** One chromosome of each pair came from the **mother** and one from the **father**.
- Because the two chromosomes of a pair carry the **same genes** in the **same places**, a person has **two alleles of each gene**. They may be the **same** or **different**.

Haploid and diploid nuclei



HAPLOID (n) = one set of chromosomes: gametes (23).
DIPLOID (2n) = two sets, one from each parent: body cells (46).

Gametes are haploid (23). Fertilisation makes a diploid zygote (46), and mitosis copies it into every body cell.

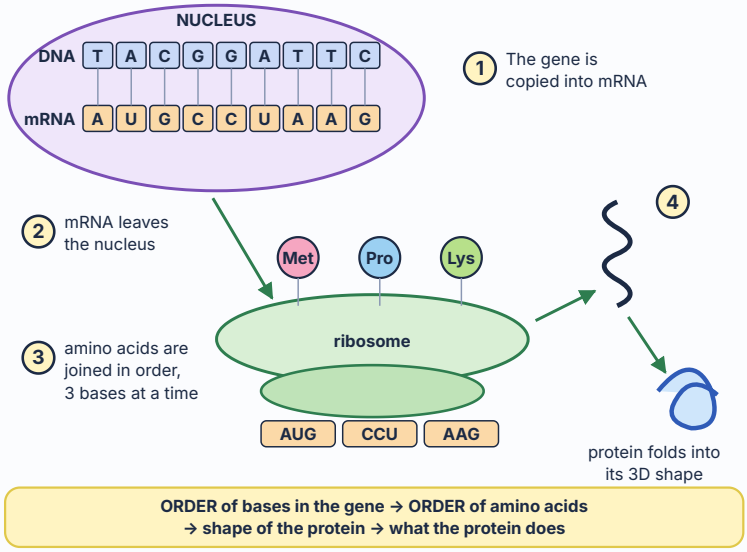
Haploid nucleus — a nucleus containing a **single set** of unpaired chromosomes (for example in a **gamete**).

Diploid nucleus — a nucleus containing **two sets** of chromosomes (for example in a **body cell**).

- **Humans:** body cells are **diploid (46)**, gametes are **haploid (23)**. Fertilisation **restores the diploid number**.

How a gene makes a protein

EXTENDED



EXT The sequence of bases in a gene decides the sequence of amino acids, which decides the shape and job of the protein.

- EXT **The code:** DNA has four bases (**A, T, C, G**). Every **three bases** in a gene code for **one amino acid**. The **sequence of bases** therefore decides the **sequence of amino acids** in the protein (proteins and enzymes).
- EXT **Protein shape = job.** The chain of amino acids **folds into a particular 3D shape**. A different amino acid sequence gives a **different shape**, so a different job (an **enzyme**, a **hormone** or **haemoglobin**).
- EXT **Protein synthesis in 4 steps:** (1) the **gene** in the nucleus is **copied** into **mRNA**, (2) the mRNA **leaves the nucleus**, (3) a **ribosome** in the cytoplasm **reads the mRNA** and joins **amino acids** in the right order, (4) the chain **folds** into the protein.
- EXT **DNA controls the cell** by controlling **which proteins are made**. **Different cells use different genes** (for example, only some pancreas cells make **insulin**), so cells become **specialised**.
- EXT The diagram shows the base pairing: DNA **T → A**, **A → U**, **C → G**, **G → C** in the mRNA. You do **not** need to learn which codon gives which amino acid.

How sex is inherited

eggs from mother (XX) \ sperm from father (XY)	X	Y
X	XX girl	XY boy
X	XX girl	XY boy

Every egg carries X. A sperm carries X or Y, so the SPERM decides the sex.
Result: 1 girl (XX) : 1 boy (XY), a 1 : 1 ratio, or 50% each.

Every egg carries X. The sperm carries X or Y and decides the sex.

- Humans have **23 pairs** of chromosomes. **22 pairs** are the same in both sexes. The **23rd pair** are the **sex chromosomes**: **XX in females** and **XY in males**.
- **Females** make eggs that all carry **X**. **Males** make **half** X sperm and **half** Y sperm. So the **sperm decides** the sex of the baby, and each baby has a **50% chance** of being a girl or a boy.

WORKED EXAMPLE

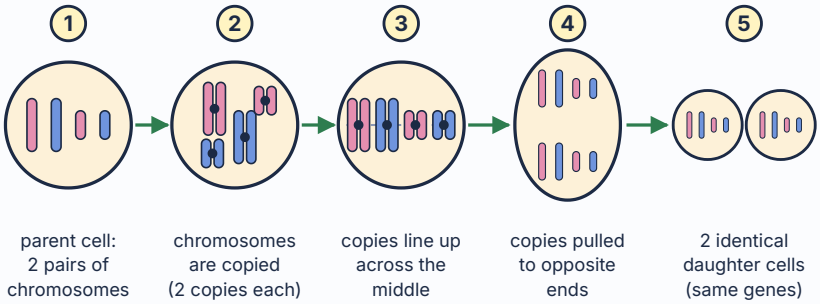
A couple already has four daughters. What is the probability that their fifth child is a boy?

1. each fertilisation is an **independent event**
2. the sperm that fertilises the egg is X or Y with **equal chance**
3. probability of a boy = **1/2 = 50%**
4. **the four daughters make no difference**

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2 Cell division

Mitosis



WHERE IS MITOSIS USED?

GROWTH	REPAIR	REPLACEMENT	ASEXUAL REPRODUCTION
more cells make the body bigger	heals cuts and broken bones	new skin and blood cells	offspring are clones

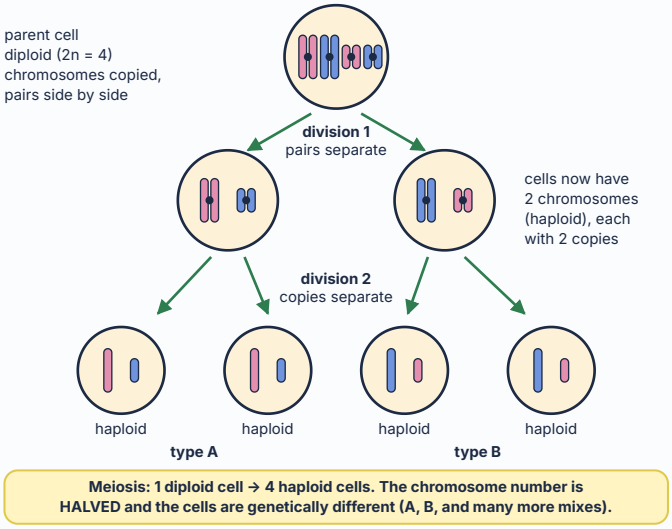
Mitosis: ONE cell → TWO identical cells, with the same number of chromosomes.

Mitosis: chromosomes are copied, lined up and pulled apart, giving two identical cells.

Mitosis — nuclear division giving rise to **genetically identical cells**.

- **Before** the cell divides, the **chromosomes are copied** (**replicated**). Then the copies are **separated** into **two nuclei**.
- Each daughter cell has the **same number of chromosomes** and the **same genes** as the parent cell. In a human, **46 → 46**.
- **Uses of mitosis: growth** (more cells), **repair** of damaged tissue, **replacement** of worn-out cells, and **asexual reproduction** (asexual reproduction).
- EXT **Stem cells** are **unspecialised cells** that **divide by mitosis** and can **become specialised** (differentiate). For example, **stem cells in bone marrow** make **new blood cells**.

Meiosis



Meiosis: 1 diploid cell → 4 haploid cells. The chromosome number is HALVED and the cells are genetically different (A, B, and many more mixes).

Meiosis: one diploid cell divides twice to make four haploid cells that differ from each other.

Meiosis — nuclear division giving rise to **genetically different cells**, with **half the number of chromosomes** (a **reduction division**).

- Meiosis happens in the **reproductive organs** (testes and ovaries, anthers and ovules) to make **gametes** (gametes).
- **One diploid cell makes four haploid cells.** In a human, **46 → 23**. Each gamete gets **one chromosome from each pair**, in a **random mixture**, so the gametes are **genetically different**.
- Fertilisation then **joins two haploid gametes** to make a **diploid zygote**, so the chromosome number stays the same from one generation to the next.

	Mitosis	Meiosis
where	most **body cells**	**reproductive organs** only
cells made	**2**	**4**
chromosome number	**stays the same** (46 → 46)	**halved** (46 → 23)
the cells are	**identical** to the parent	**different** from the parent and from each other
job	growth, repair, replacement, asexual reproduction	making **gametes**

WORKED EXAMPLE

A fruit fly body cell has 8 chromosomes. How many chromosomes are in (a) a cell made by mitosis, (b) a gamete, (c) a zygote?

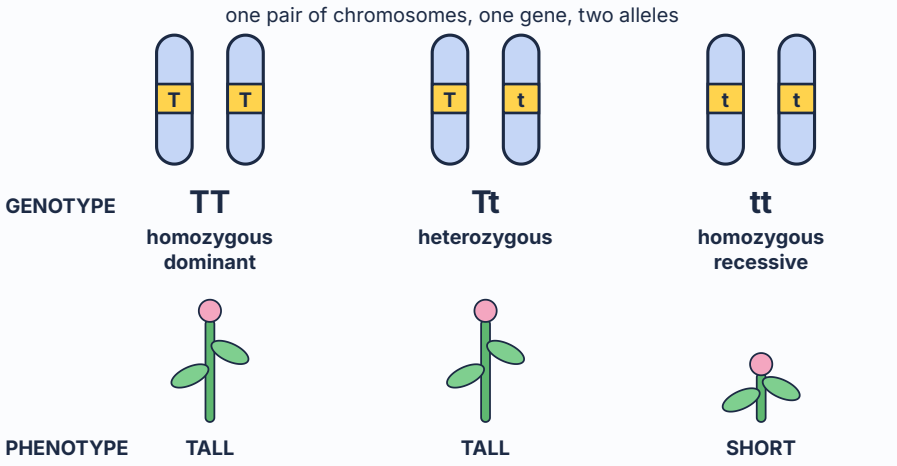
1. (a) mitosis keeps the number: **8**
2. (b) meiosis halves it: 8 ÷ 2 = **4**
3. **(c) two gametes fuse: 4 + 4 = 8**

MEMORY TRICK

MITOSIS = MIrror image (identical copies).
MEIOSIS = MEans half, and makes **gam**etes.

3 Monohybrid inheritance

Key terms



CAPITAL letter = dominant allele. Small letter = recessive allele.
A dominant allele shows even when only ONE copy is present.

One gene, two alleles. A dominant allele (capital) hides a recessive allele (small letter).

Term	Meaning
inheritance	the **passing on of genetic information** from one generation to the next
genotype	the **alleles** an organism has (for example **Tt**)
phenotype	the **observable features** of an organism (for example **tall**)
homozygous	**two identical alleles** of a gene (**TT** or **tt**)
heterozygous	**two different alleles** of a gene (**Tt**)
dominant	an allele that is **expressed even if only one copy** is present
recessive	an allele that is **expressed only if no dominant allele** is present
pure-breeding	**homozygous** for the feature, so it always **breeds true**

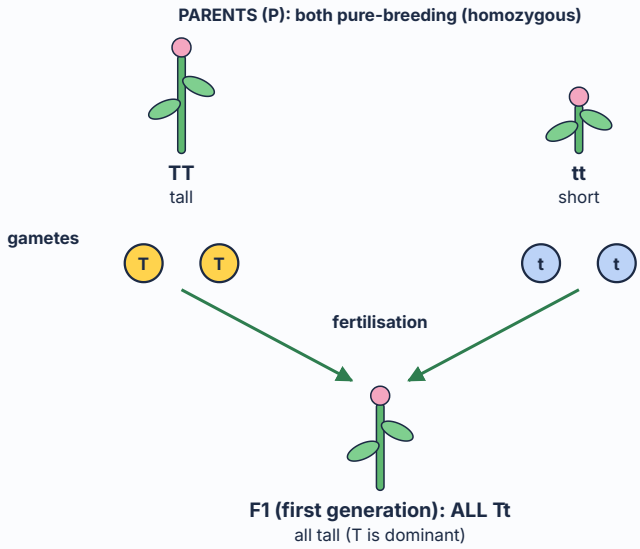
MEMORY TRICK

Homo = same (TT or tt). **Hetero** = different (Tt). **Geno**type = **gene** letters. **Pheno**type = what you **physically** see.

EXAM TIP

Use a **capital letter for the dominant allele** and the **same letter in small form** for the recessive allele. Choose a letter that looks **different** in both forms: **T and t** is clear, but **C and c** or **S and s** are easy to mix up.

From parents to the F1 generation



A cross between pure-breeding tall (TT) and short (tt) plants gives only Tt offspring, which are all tall.

- **P** = the **parents**. **F1** = the **first generation** of offspring. **F2** = the **second generation** (offspring of the F1).
- Each **gamete carries only one allele** of the gene. The TT parent makes only **T** gametes and the tt parent makes only **t** gametes, so **every F1 plant is Tt**.
- All F1 plants are **tall**, because **T is dominant**. The **t allele is still there**, hidden.

The F1 × F1 cross (3 : 1)

1. write the parents' genotypes: Tt × Tt
2. write the gametes along the edges
3. fill in the grid: one allele from each side
4. count the ratios from the grid

egg gametes from Tt plant \ pollen (gametes) from Tt plant	T	t
T	**TT** tall	**Tt** tall
t	**Tt** tall	**tt** short

GENOTYPE ratio: 1 TT : 2 Tt : 1 tt
PHENOTYPE ratio: 3 tall : 1 short (a 3 : 1 ratio)

Probability of a short plant (tt) = 1 in 4 = 25%.
Each offspring is an independent chance: 4 plants need not show exactly 3 : 1.

A Punnett square shows every possible combination of gametes. Tt × Tt gives 3 tall : 1 short.

- **Phenotype ratio 3 : 1. Genotype ratio 1 : 2 : 1.** The **short plant reappears** because the F1 plants **both carry t**.
- **The 1 : 1 ratio:** a **heterozygous** parent (**Tt**) crossed with a **homozygous recessive** parent (**tt**) gives **Tt, Tt, tt, tt**, which is **1 tall : 1 short**.

WORKED EXAMPLE

Cystic fibrosis is caused by a recessive allele (f). Two parents without the condition each carry one f (Ff × Ff). Find the probability that their child (a) has CF, (b) is a carrier, (c) is unaffected.

1. gametes from each parent: F or f
2. Punnett square gives **FF, Ff, Ff, ff**
3. (a) CF = ff = 1 out of 4 = **1/4 = 25%**
4. (b) carrier = Ff = 2 out of 4 = **1/2 = 50%**
5. **(c) unaffected = FF or Ff = 3 out of 4 = 3/4 = 75%**

WORKED EXAMPLE

In a Tt × Tt cross, 120 offspring are produced. How many would you expect to be short?

1. short plants are **tt** = 1/4 of the offspring
2. 120 × 1/4 = 120 ÷ 4 = **30** short
3. the other 120 − 30 = **90** are tall
4. **real results are close to, but not exactly, the expected ratio, because fertilisation is random**

COMMON MISTAKE

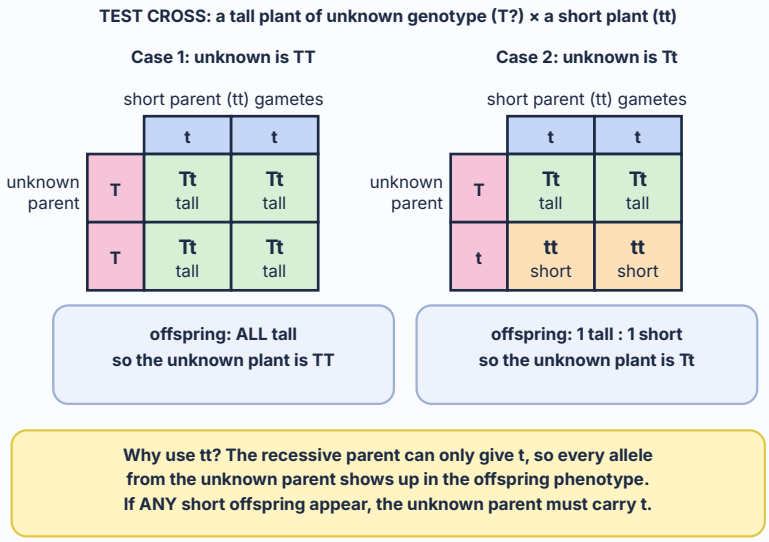
"A 3 : 1 ratio means that 3 of every 4 children will be tall." These are **probabilities**, not guarantees. Each child has a **3/4 chance** of being tall, whatever the earlier children were.

EXAM TIP

Four steps for every genetics question: (1) **key** (T = tall, t = short), (2) **parent genotypes**, (3) **gametes** then **Punnett square**, (4) read the **ratio**, then write the **phenotypes** in words.

Test cross

EXTENDED

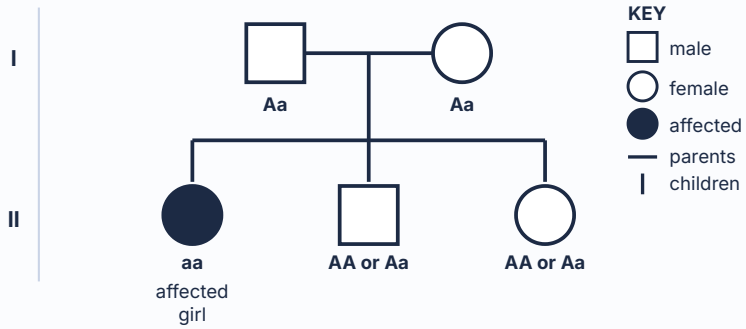


EXT Cross an organism of unknown genotype with a homozygous recessive one and look at the offspring.

Test cross — EXT a cross between an individual showing the **dominant phenotype** (unknown genotype) and a **homozygous recessive** individual, used to find the **unknown genotype**.

- EXT **All offspring show the dominant feature** → the unknown parent is **homozygous (TT)**.
- EXT **Some offspring show the recessive feature** (about **1 : 1**) → the unknown parent is **heterozygous (Tt)**.

Pedigrees



In a pedigree, squares are males, circles are females and shaded shapes are affected.

- **How to read it: horizontal line** = **parents**; **vertical line** down = **children**; **shaded** = **affected**; **open** = **unaffected**.
- **Clue for a recessive condition: two unaffected parents** have an **affected child**. The parents must be **carriers (heterozygous, Aa)** and the child is **aa**.
- **Clue for a dominant condition: two affected parents** have an **unaffected child**. The parents are **heterozygous** and the child has **no dominant allele**.

Codominance and the ABO blood groups

EXTENDED

BLOOD GROUPS AND THEIR GENOTYPES

A	I^AI^A or I^Ai
B	I^BI^B or I^Bi
AB	I^AI^B
O	ii

EXAMPLE CROSS: group A × group B
($I^Ai \times I^Bi$)

	I^B	i
I^A	I^AI^B group AB	I^Ai group A
i	I^Bi group B	ii group O

1 : 1 : 1 : 1 (all four groups possible)

CODOMINANCE: I^A and I^B are BOTH expressed in the heterozygote (group AB). i is recessive: it only shows when there are two copies (group O). Neither I^A nor I^B is dominant over the other, so use a capital I with a superscript letter for each allele, and a small i for the recessive allele.

EXT Alleles I^A and I^B are both expressed in group AB. The allele i is recessive.

Codominance — EXT when **both alleles** of a gene are **expressed** in the phenotype of a **heterozygote**.

- EXT The **ABO blood group** gene has **three alleles**: I^A, I^B and **i**. **I^A and I^B are codominant**, and **i is recessive** to both.
- EXT **Group A** = I^AI^A or I^Ai. **Group B** = I^BI^B or I^Bi. **Group AB** = I^AI^B. **Group O** = ii.

WORKED EXAMPLE

A woman is group O and her partner is group AB. Which blood groups can their children have?

1. mother = **ii**, father = **I^AI^B**
2. mother's gametes are all **i**; father's are **I^A** or **I^B**
3. children are **I^Ai (group A)** or **I^Bi (group B)**
4. **group A or group B in a 1 : 1 ratio, never O or AB**

Sex linkage

EXTENDED

The gene for colour vision is on the X chromosome. Males (XY) have only ONE X, so one recessive allele is enough to show it.

carrier mother × normal father
$X^NX^n \times X^NY$

	X^N	Y
X^N	X^NX^N normal girl	X^NY normal boy
X^n	X^NX^n carrier girl	X^nY colour-blind boy

N = normal vision (dominant) n = red-green colour blindness (recessive)

DAUGHTERS: all have normal vision (one half are carriers). SONS: 1 normal : 1 colour-blind. Overall: 1 in 4 children is colour-blind, and it is a boy. A carrier has the recessive allele but normal vision. Colour blindness is MORE COMMON IN MALES because they need only one copy of the recessive allele.

EXT A recessive allele on the X chromosome shows up more often in males, who have only one X.

Sex linkage — EXT the **association of a characteristic with the sex** of the individual, because the gene is on a **sex chromosome** (usually **X**).

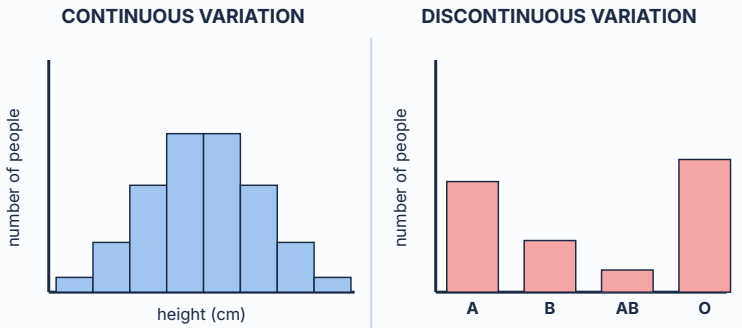
- EXT **Red-green colour blindness** is caused by a **recessive allele (X^n)** on the **X chromosome**. A woman needs **two copies** (X^nX^n) to be colour-blind, but a man needs **only one** (X^nY).
- EXT **More men than women** are colour-blind. A **carrier mother** (X^NX^n) and a **normal father** (X^NY) have **daughters with normal vision** and **sons with a 1 in 2 chance** of being colour-blind.

COMMON MISTAKE

"A father passes colour blindness to his sons." Sons get their **X from their mother** and a **Y from their father**, so sons inherit an X-linked allele from the **mother**.

4 Variation and mutation

Variation



Continuous: genes AND the environment (diet, exercise, sunlight).
Discontinuous: genes only, the environment has little or no effect.

Continuous variation gives a range (height). Discontinuous variation gives clear categories (blood group).

Variation — **differences** between **individuals of the same species**.

- **Causes: genes** (inherited alleles) and the **environment** (for example diet, exercise, sunlight). Many features are affected by **both**.

Feature	Continuous variation	Discontinuous variation
values	a **range** with all values in between	**distinct categories**
cause	**genes and environment**	usually **genes only**
examples	height, body mass, leaf length	blood group, tongue rolling, sex
graph	**histogram** (bars touch) or line graph	**bar chart** (gaps between bars)

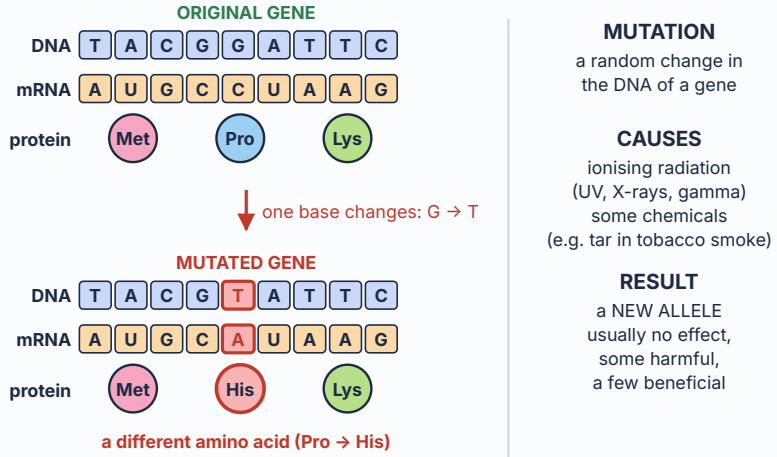
- **To investigate:** measure the feature in a **large sample** (50 or more), **group** the values and **draw a graph**. Continuous data gives a **bell-shaped** curve.

WORKED EXAMPLE

The lengths of five leaves from one tree are 42, 47, 45, 50 and 46 mm. Calculate the mean and the range.

1. mean = total ÷ number
2. total = 42 + 47 + 45 + 50 + 46 = **230**
3. mean = 230 ÷ 5 = **46 mm**
4. **range = largest – smallest = 50 − 42 = 8 mm**

Mutation



MUTATION
a random change in the DNA of a gene

CAUSES
ionising radiation (UV, X-rays, gamma)
some chemicals (e.g. tar in tobacco smoke)

RESULT
a NEW ALLELE
usually no effect,
some harmful,
a few beneficial

A new allele can make a different protein, and so a different feature.

Mutation is a random change in the DNA. A new allele can make a different protein.

Mutation — genetic change.

- Mutation is the **source of new alleles**. The **rate** of mutation is **increased** by **ionising radiation** (UV rays, X-rays, gamma rays) and by some **chemicals** (for example **tar in tobacco smoke**).
- EXT A **gene mutation** is a **random change in the sequence of DNA bases**. It may **change the amino acids** in a protein and so its **shape and function**. **Most are harmless**, **some are harmful** (for example **sickle-cell anaemia**, caused by a one-base change in the haemoglobin gene) and **a few are beneficial**.
- EXT **Sources of variation: mutation**, **meiosis** (a new mix of chromosomes in each gamete), **random mating** and **random fertilisation**.

EXAM TIP

Mutations are **random**. The environment does **not** cause a helpful mutation to appear. It only **selects** among the variation that is **already there**.

5 Selection and adaptation

Adaptive features

Adaptive feature — an **inherited feature** that **helps an organism survive and reproduce** in its environment.

- EXT **Fitness** is the **probability of an organism surviving and reproducing** in the environment where it lives.

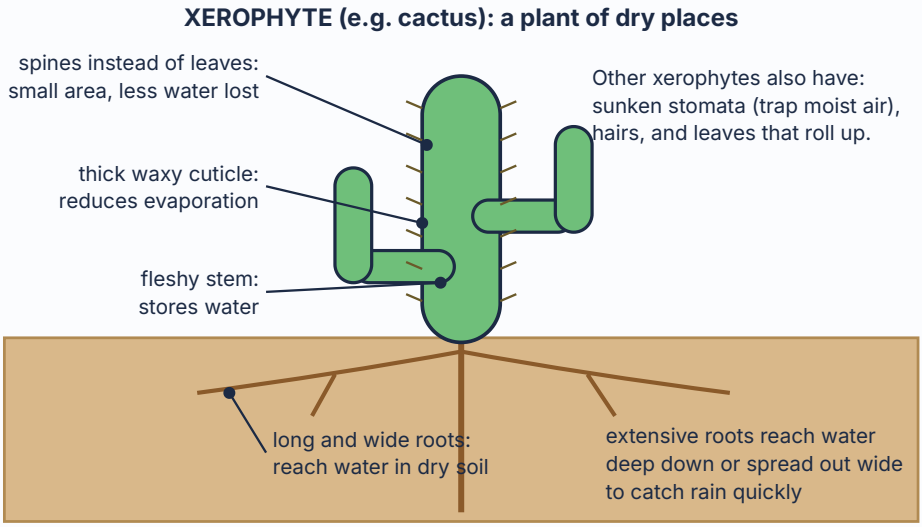
Organism	Adaptive feature	How it helps
polar bear	thick fur and a fat layer; white fur	**insulation** against the cold; **camouflage** in snow
camel	large flat feet; hump of fat; long eyelashes	**do not sink** into sand; **food store**; **keep sand out** of the eyes
cactus	spines; thick waxy stem	**less water lost**; **stores water**
water lily	large floating leaves	**catch lots of light** at the surface

EXAM TIP

In answers use the chain **feature → how it helps → survival and reproduction**. For example: "**White fur** hides the bear in the snow, so it can **catch more prey** and **survive to breed**."

Xerophytes

EXTENDED



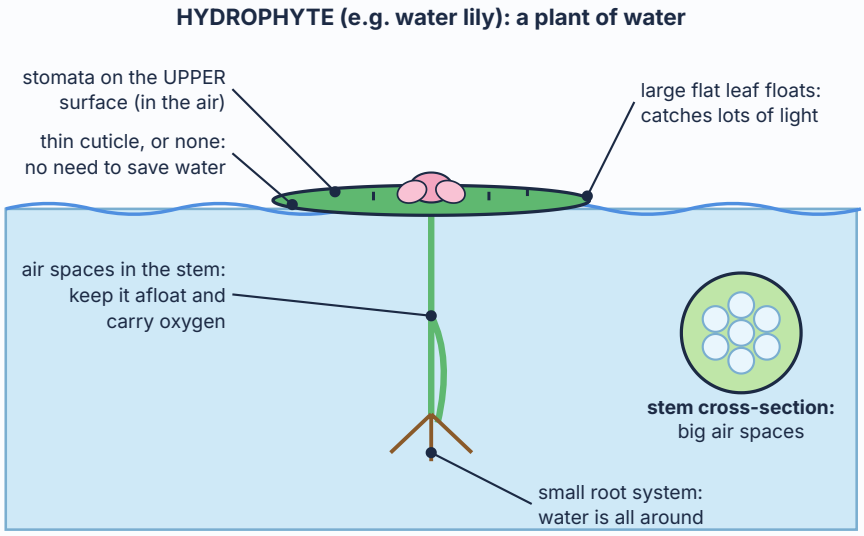
EXT Xerophytes are adapted to save water and to find water.

Xerophyte — EXT a plant **adapted to survive in dry habitats**.

- EXT **Less water lost: thick waxy cuticle**, **small leaves or spines** (small surface area), **sunken stomata** and **hairs** (trap moist air), and **rolled leaves**.
- EXT **Water stored** in **fleshy stems**. **Long or widely spread roots** reach water.

Hydrophytes

EXTENDED

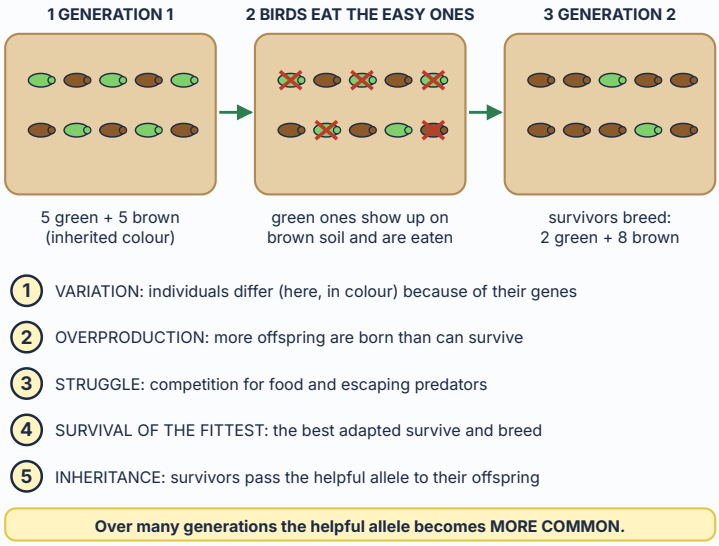


EXT Hydrophytes are adapted to life in water, where water loss is no problem but oxygen and light are.

Hydrophyte — EXT a plant **adapted to live partly or wholly in water**.

- EXT **Large, flat, floating leaves** catch light and have **stomata on the upper surface** (in the air).
- EXT **Air spaces** in the leaves and stems make the plant **float** and carry **oxygen to the roots**. **Thin (or no) cuticle**, **small roots** and a **flexible stem**.

Natural selection



Natural selection: the environment selects the best adapted individuals, which pass on their alleles.

Natural selection — the process in which organisms that are **better adapted** to their environment **survive and produce more offspring**, **passing on the alleles** for their adaptive features.

- **Five steps:** (1) there is **variation**, (2) **more offspring** are produced than can survive, (3) there is **competition** (food, mates, predators), (4) the **best adapted survive** and **breed**, (5) they **pass the helpful alleles** to their offspring, so these alleles become **more common** over generations.
- EXT This is **how populations become adapted** to their environment, and over a very long time **how new species can arise**.

COMMON MISTAKE

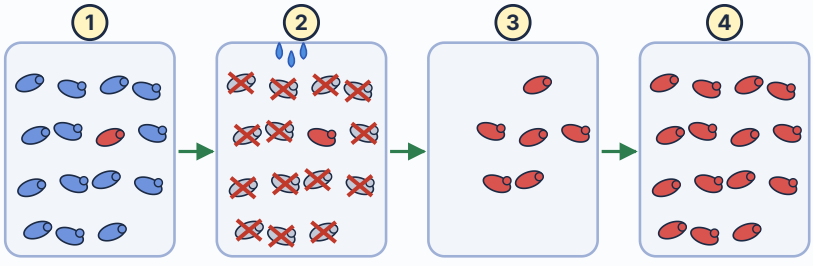
"Giraffes stretched their necks to reach leaves, so their babies had longer necks." **No.** Features gained during life are **not inherited**. The **alleles for long necks** were **already in the population** and were **selected**.

COMMON MISTAKE

"Organisms change because they need to." Organisms do **not** choose to change. Variation **already exists** and **selection** acts on it.

Antibiotic resistance

EXTENDED



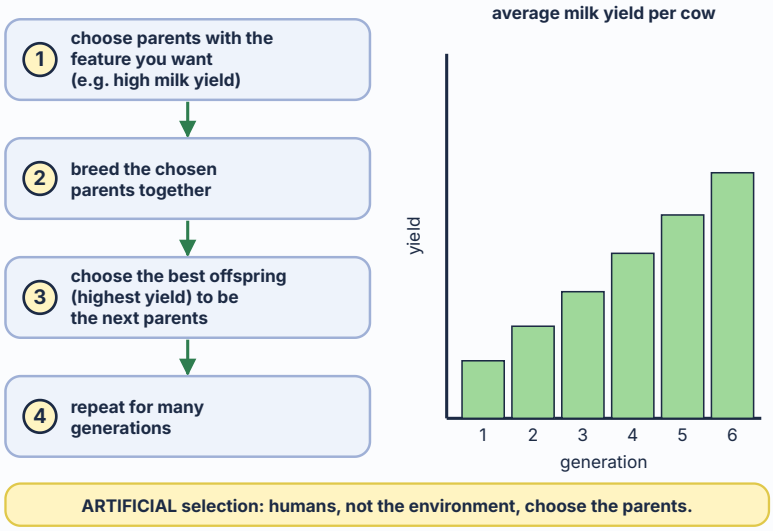
This is NATURAL SELECTION: the antibiotic is the selection pressure.
Slow it down: finish every course of antibiotics, and do not use them for viral infections such as colds and flu (antibiotics do not work on viruses).
Resistant bacteria such as MRSA are very hard to treat.

EXT The antibiotic kills the normal bacteria and selects the resistant one, which then multiplies.

- EXT A **random mutation** makes a bacterium **resistant** to an antibiotic. When the antibiotic is used, **non-resistant bacteria die** and **resistant bacteria survive and reproduce**. The **allele for resistance** becomes **common**: **natural selection**.
- EXT **Reduce the problem: complete the full course** of antibiotics, and **do not use them for viral infections**. (antibiotics)

Aiza Ma'am

Selective breeding



Selective breeding: choose the best parents, breed them, choose the best offspring, repeat for many generations.

Selective breeding — the **intentional breeding** of individuals with **desired features**, so that the features become **more common** in the population (**artificial selection**).

- **Examples:** cattle for **more milk or meat**, wheat and rice for **higher yield** and **disease resistance**, flowers for **colour and scent**.
- It usually takes **many generations**. A **disadvantage** is that the **variation in the population falls**, so one disease may harm all of them.

	Natural selection	Artificial selection
who chooses?	the **environment**	**humans**
what is selected?	features that help **survival and reproduction**	features that are **useful to people**
who benefits?	the **organism**	usually the **farmer or customer**

Aiza Ma'am

6 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. Define a gene.
2. What is an allele?
3. How many chromosomes are in a human body cell?
4. Which chromosomes make a human male?
5. What is mitosis?
6. Give two uses of mitosis.
7. How does meiosis change the chromosome number?
8. Define phenotype.
9. What does heterozygous mean?
10. What is the phenotype ratio of a Tt × Tt cross?
11. What is the phenotype ratio of a Tt × tt cross?
12. Give one example of continuous variation.
13. Name two factors that increase the rate of mutation.
14. What is an adaptive feature?
15. Define selective breeding.
16. EXT What do three bases in a gene code for?
17. EXT What is a stem cell?
18. EXT Why is a test cross done with a homozygous recessive?
19. EXT Which blood group has the genotype I^AI^B?
20. EXT Why are more men than women colour-blind?
21. EXT Name two adaptations of a xerophyte.

EXAM-STYLE

22. Describe how the sex of a baby is inherited. [3]
23. State three differences between mitosis and meiosis. [3]
24. Two heterozygous tall plants (Tt) are crossed. Use a Punnett square to show the genotypes and phenotype ratio of the offspring. [4]
25. Describe the difference between continuous and discontinuous variation. [3]
26. Describe how natural selection leads to a population becoming better adapted. [4]
27. Describe how selective breeding could be used to produce a cow that gives more milk. [4]
28. EXT Explain how a gene controls the production of a protein. [4]
29. EXT Explain how bacteria become resistant to an antibiotic. [4]
30. EXT A woman who is a carrier of colour blindness has children with a man with normal vision. Explain the chance that a son is colour-blind. [4]

Show answers

1. a length of DNA that codes for a protein
2. a version of a gene
3. 46 (23 pairs)
4. X and Y
5. nuclear division giving genetically identical cells
6. growth, repair, replacement of cells, asexual reproduction
7. it halves it (diploid to haploid)
8. the observable features of an organism
9. having two different alleles of a gene
10. 3 dominant : 1 recessive
11. 1 dominant : 1 recessive
12. height, body mass
13. ionising radiation (UV, X-rays), some chemicals such as tar
14. an inherited feature that helps survival and reproduction
15. the intentional breeding of organisms with desired features
16. one amino acid
17. an unspecialised cell that divides by mitosis and can become specialised
18. its gametes all carry the recessive allele, so the offspring show the unknown genotype
19. group AB (codominance)
20. the allele is recessive and on the X chromosome, and men have only one X
21. thick waxy cuticle, spines or small leaves, water-storing stem, long or wide roots
22. females have XX and males have XY
    eggs all carry X; sperm carry X or Y
    the sperm that fertilises the egg decides the sex (50% chance of each)
23. mitosis makes 2 cells and meiosis makes 4
    mitosis keeps the chromosome number and meiosis halves it
    mitosis gives identical cells and meiosis gives genetically different cells
24. gametes T and t from each parent
    offspring TT, Tt, Tt, tt
    1 TT : 2 Tt : 1 tt
    3 tall : 1 short
25. continuous has a range of values with no clear categories (e.g. height)
    discontinuous has distinct categories (e.g. blood group)
    continuous is caused by genes and environment; discontinuous mostly by genes only
26. there is variation in the population
    more offspring are born than can survive
    the best adapted survive and reproduce
    they pass on their alleles, so the allele becomes more common

27. choose a cow and a bull from parents with high milk yield
    breed them together
    choose the offspring that give the most milk
    repeat over many generations
28. the base sequence of the gene is copied into mRNA
    mRNA moves to a ribosome
    ribosome joins amino acids in the order set by the mRNA
    the amino acid sequence decides the shape of the protein
29. a random mutation makes a bacterium resistant
    the antibiotic kills the non-resistant bacteria
    the resistant bacterium survives and reproduces
    the resistance allele becomes common (natural selection)
30. mother is X^NX^n, father is X^NY
    the son gets Y from the father and an X from the mother
    the X from the mother is X^N or X^n with equal chance
    so there is a 1 in 2 (50%) chance that a son is colour-blind

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