

Inheritance, variation and evolution

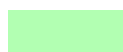
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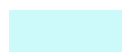
Revision notes for one topic, free to download.

These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Mnemonics



Analogies



Common confusions



Check yourself



Sub-topic headings

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Define Gamete

- a sex cell (sperm/egg in animals, pollen/egg cell in flowering plants) with a single set of chromosomes.

Define Gene

- a small section of DNA on a chromosome coding for a sequence of amino acids, to make a specific protein.

Define Recessive

- an allele only expressed if two copies are present.

Define Homozygous

- the two alleles for that trait are the same.

Define Genotype

- the alleles an organism has.

Define Genome

- the entire genetic material of an organism.

Define Variation

- differences in the characteristics of individuals in a population.

Define Species

- a group of organisms that can interbreed to produce fertile offspring.

Define Genetic engineering

- modifying the genome of an organism by introducing a gene from another organism.

Define Chromosome

- a structure in the nucleus made of a long DNA molecule, carrying many genes.

Define Allele

- a different form of the same gene.

Define Dominant

- an allele that is always expressed, even if only one copy is present.

Define Heterozygous

- the two alleles for that trait are different.

Define Phenotype

- the characteristics an organism shows.

Define Mutation

- a change in the DNA of an organism; all variants arise from mutations.

Define Evolution

- a change in the inherited characteristics of a population over time through natural selection.

Define Selective breeding

- breeding plants and animals for particular genetic characteristics (artificial selection).

Define Extinction

- when no individuals of a species remain alive.

6.1 Reproduction

6.1.1 Sexual and asexual reproduction

- **Meiosis** leads to **non-identical** cells being formed; **mitosis** leads to **identical** cells being formed.
- **Sexual reproduction** involves the joining (**fusion**) of male and female **gametes**: sperm and egg cells in animals; pollen and egg cells in flowering plants.
- Sexual reproduction **mixes genetic information**, giving **variety in the offspring**. Gamete formation involves meiosis.
- **Asexual reproduction** involves **one parent** and **no fusion of gametes**, so there is no mixing of genetic information and the offspring are genetically identical — **clones**. Only mitosis is involved.

	Sexual reproduction	Asexual reproduction
Parents	Two	One
Gametes	Fuse at fertilisation	None
Cell division	Meiosis, then mitosis	Mitosis only
Genetic information	Mixed from two parents	Not mixed
Offspring	Genetically different — variation	Genetically identical — clones

SAY IT

Two parents, two gametes, two sets mixed

Sexual reproduction: **two** parents, gametes fuse, genetic information is mixed, offspring vary. Asexual: **one** parent, no gametes, mitosis only, offspring are clones.

DON'T MIX UP

when variation helps and when it does not

Variation from sexual reproduction helps a population **survive a change** in the environment. Asexual reproduction is **faster** and needs no mate, which wins while conditions stay the same. Evaluation questions want both sides.

PICTURE IT

Sexual reproduction is shuffling two packs together and dealing a new hand every time. Asexual reproduction is a photocopier. *Where it breaks down:* a photocopy is perfect. Mitosis occasionally miscopies, which is where mutations in a clone come from.

CHECK YOURSELF

Cover the grey line before you answer.

1. Name the gametes in animals and in flowering plants.
Sperm and egg cells; pollen and egg cells.
2. Which type of cell division makes gametes?
Meiosis.
3. Why are the offspring of asexual reproduction called clones?
There is no mixing of genetic information, so they are genetically identical to the parent.

6.1.2 Meiosis

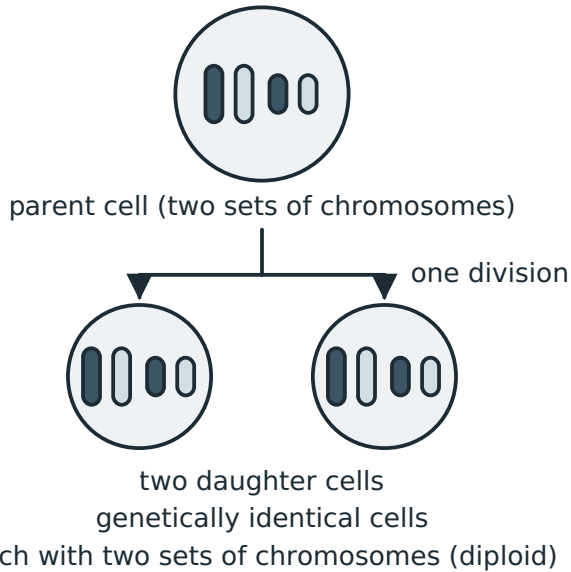
Meiosis **halves** the chromosome number in gametes; **fertilisation restores** the full number.

- Cells in the **reproductive organs** divide by meiosis to form gametes.
- When a cell divides to form gametes: copies of the genetic information are made; the cell **divides twice** to form **four gametes**, each with a **single set of chromosomes**; all gametes are **genetically different** from each other.
- Gametes **join at fertilisation** to restore the normal chromosome number. The new cell divides by **mitosis**, so cell number increases; as the embryo develops, cells **differentiate**.
- The **stages** of meiosis are **not required**.

	Mitosis	Meiosis
Divisions	One	Two
Cells produced	2	4
Chromosome number	Full set, as parent cell	Halved — single set
Daughter cells	Genetically identical	All genetically different
Where	Growth, repair, asexual reproduction	Reproductive organs — makes gametes

Mitosis and meiosis compared

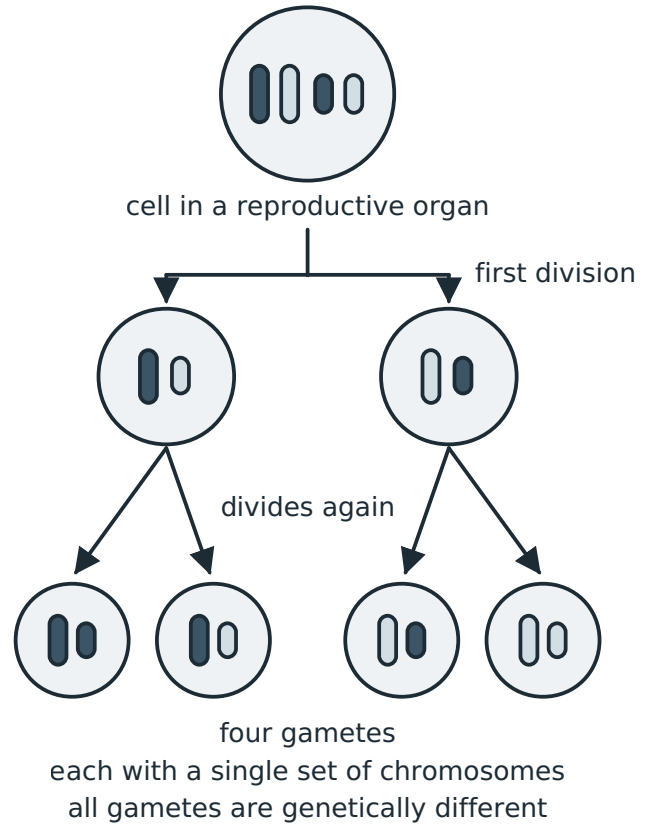
MITOSIS



dark = chromosome from one parent
 light = chromosome from the other parent

Asexual reproduction involves only mitosis, so the offspring are genetically identical (clones).

MEIOSIS



Knowledge of the stages of meiosis is not required.

WATCH OUT

Meiosis makes **gametes**, not embryos — after fertilisation the new cell grows by **mitosis**.

DON'T MIX UP

meiosis halves vs fertilisation restores

Meiosis **halves** the chromosome number so that fertilisation can **restore** it. Without the halving, the number would double every generation — that is the reason meiosis exists, and it is what an exam answer should say.

SAY IT

One copy, two divisions, four different gametes

The chromosomes are copied **once**, the cell divides **twice**, and the result is **four** gametes, each with a single set of chromosomes, all genetically different.

CHECK YOURSELF

Cover the grey line before you answer.

1. How many gametes does one cell produce by meiosis, and with how many sets of chromosomes?

Four gametes, each with a single set.

2. What happens immediately after fertilisation?

The new cell divides by mitosis, so cell number increases; as the embryo develops the cells differentiate.

3. Give two differences between mitosis and meiosis.

Mitosis: one division, two identical cells, full chromosome number, for growth and repair. Meiosis: two divisions, four different cells, half the chromosome number, in the reproductive organs.

6.1.3 DNA and the genome

- The genetic material in the **nucleus** is **DNA**: a **polymer** of **two strands** forming a **double helix**, held in structures called **chromosomes**.
- A **gene** is a small section of DNA on a chromosome, coding for a particular **sequence of amino acids** to make a **specific protein**.
- The **genome** is the **entire genetic material** of an organism. The whole **human genome** has now been studied, which will have great importance for medicine in the future.
- Why that matters (limited to these three): the search for genes linked to different types of disease; the **understanding and treatment of inherited disorders**; **tracing human migration patterns** from the past.

DON'T MIX UP gene vs allele

A **gene** is the instruction for a characteristic. An **allele** is one of its possible **versions**. You have the gene for eye colour; which alleles you have decides the colour.

HIGHER TIER

6.1.4 Genetic inheritance

- Some characteristics are controlled by a **single gene**, such as **fur colour in mice** and **red–green colour blindness in humans**. Each gene may have different forms called **alleles**.
- The alleles present (**genotype**) operate at a **molecular level** to develop characteristics expressed as the **phenotype**.
- Write **dominant** alleles as capitals and **recessive** as lower case; same pair = **homozygous**, different pair = **heterozygous**.
- Most characteristics result from multiple genes interacting, not a single gene.
- You must use **direct proportion and simple ratios** for the outcome of a cross, and **complete a Punnett square** and **interpret genetic crosses and family trees**. **HT ONLY** You must also **construct** a Punnett square diagram and use it to make predictions using the theory of probability.

ANALOGY

The genome is a **complete recipe book**. Each **gene** is one **recipe** — the instructions for a single protein — and a **chromosome** is one volume of the set. Change a recipe and you may change the dish; change an unimportant detail and the meal comes out exactly the same.

SAY IT

Base, Gene, Chromosome, Genome

Small to large. A **gene** is a section of DNA coding for a sequence of amino acids to make one protein. The **genome** is the entire genetic material of the organism.

CHECK YOURSELF

Cover the grey line before you answer.

1. Describe the structure of DNA.

A polymer of two strands forming a double helix, held in structures called chromosomes.

2. Define a gene.

A small section of DNA on a chromosome that codes for a particular sequence of amino acids to make a specific protein.

3. Give the three reasons the specification gives for studying the human genome.

The search for genes linked to disease; understanding and treating inherited disorders; tracing human migration patterns from the past.

Parents: Bb × Bb

both parents heterozygous, both with black fur

		gametes from parent 1	
		B	b
gametes from parent 2	B	BB black	Bb black
	b	Bb black	bb brown

Genotype ratio BB : Bb : bb = 1 : 2 : 1

Phenotype ratio black : brown = 3 : 1

B = dominant allele (black fur): always expressed

b = recessive allele (brown fur): needs two copies to be expressed

Probability of brown fur = 1 in 4 (25%)

ANALOGY

The two alleles are two people giving instructions. The **dominant** allele has a megaphone — one copy is enough to be heard. The **recessive** allele whispers, so it is only heard when **both** whisper and no megaphone is in the room.

	B	b
B	BB	Bb
b	Bb	bb

WATCH OUT

A ratio is a **prediction, not a promise**. A 3 : 1 cross does not guarantee three black and one brown in a litter of four — each birth is independent. Larger numbers get closer to the predicted ratio.

DON'T MIX UP

genotype vs phenotype

Genotype is the **genes** — the alleles present, such as Bb.
Phenotype is what you can see — the characteristic expressed.
Pheno and *photo* both start the same way: the phenotype is what shows up in the photograph.

6.1.5 Inherited disorders

Some disorders are **inherited** — caused by the inheritance of certain **alleles**.

- **Polydactyly** (extra fingers or toes) — a **dominant** allele, so one copy is enough and an affected person usually has an affected parent.
- **Cystic fibrosis** (a disorder of **cell membranes**) — a **recessive** allele, so two copies are needed and unaffected **carriers** can have affected children.

SAY IT

Homo is the Same, Hetero is Different

Homozygous — two of the **same** allele. **Heterozygous** — two **different** ones. Capital letter for dominant, lower case for recessive, and the same letter for both.

CHECK YOURSELF

Cover the grey line before you answer.

1. What does a Punnett square show?

The possible combinations of alleles in the offspring of a cross, and the ratio in which they are expected.

2. A cross gives 3 : 1 in the offspring. What were the parents' genotypes?

Both heterozygous — Bb × Bb.

3. Why is it wrong to say a 3 : 1 ratio means exactly 3 in every 4 offspring?

It is a probability, not a guarantee — the actual numbers vary, especially in small samples.

Inheritance of polydactyly and cystic fibrosis

Cystic fibrosis

caused by a recessive allele

Parents: Ff × Ff — both carriers
gametes

gametes		F	f
	F	FF unaffected	Ff carrier
	f	Ff carrier	ff affected

1 in 4 (25%) has cystic fibrosis
2 in 4 (50%) are carriers
1 in 4 (25%) is unaffected

F = dominant allele (unaffected)
f = recessive allele (cystic fibrosis)

Cystic fibrosis is a disorder of cell membranes.

Polydactyly

caused by a dominant allele

Parents: Dd × dd — one affected parent
gametes

gametes		D	d
	d	Dd affected	dd unaffected
	d	Dd affected	dd unaffected

2 in 4 (50%) have polydactyly
2 in 4 (50%) are unaffected
so a 1 in 2 chance of being affected

D = dominant allele (polydactyly)
d = recessive allele (unaffected)

Polydactyly is having extra fingers or toes.

	F	f
F	FF	Ff
f	Ff	ff

SAY IT

Polydactyly is Dominant, Cystic fibrosis is recessive

Polydactyly — Dominant, so one copy is enough and an affected person usually has an affected parent. Cystic fibrosis — recessive, so two copies are needed and unaffected **carriers** can have affected children.

Embryo screening. Embryos made by IVF can be screened for disorder alleles, and only unaffected embryos implanted. Make **informed judgements** on the **economic, social and ethical** issues:

- *For* — reduces suffering; lifelong treatment is expensive; parents can choose knowing the facts.
- *Against* — implies people with the disorder are less valuable; embryos are destroyed; costly when resources are limited; could lead to selection for non-medical characteristics.

Embryo screening and **gene therapy** may alleviate suffering, but the ethical issues they raise must still be considered.

DON'T MIX UP

a carrier vs an affected person

A **carrier** is heterozygous — they have one copy of the recessive allele and no symptoms. Two carriers can have an affected child. There are no carriers for a **dominant** disorder: if you have the allele, you have the condition.

CHECK YOURSELF

Cover the grey line before you answer.

1. Which of the two named disorders is caused by a dominant allele?

Polydactyly — extra fingers or toes.

2. Two unaffected parents have a child with cystic fibrosis. Explain how.

Both parents are carriers — heterozygous — and each passed on the recessive allele, so the child is homozygous recessive.

3. Give one argument for and one against embryo screening.

For: it reduces suffering, and lifelong treatment is expensive.

Against: it implies people with the disorder are less valuable, and embryos are destroyed.

6.1.6 Sex determination

- Ordinary human body cells contain **23 pairs of chromosomes. 22 pairs control characteristics only**; one pair carries the genes that determine sex.
- **Females XX** (the same); **males XY** (different).

Parents: XX × XY

mother — female (XX) father — male (XY)

		gametes from father	
		X	Y
gametes from mother —	X	XX female	XY male
	X	XX female	XY male

Ratio female : male = 1 : 1

2 in 4 (50%) female, 2 in 4 (50%) male

a 50 : 50 chance of a male or a female offspring

Ordinary human body cells contain 23 pairs of chromosomes.
22 pairs control characteristics only; one pair determines sex.

	X	Y
X	XX	XY
X	XX	XY

The **father's gamete determines the sex**, because only he can pass on a Y chromosome.

DON'T MIX UP

“the mother determines the sex” — what actually happens

The **father** determines it, because only he can pass on a Y.
Every egg carries an X. This comes up repeatedly and is reliably answered the wrong way round.

SAY IT

X marks the mother, Y comes from the father

Females are **XX** — the same. Males are **XY** — different. The mother can only pass on an X, so the father's gamete decides the sex.

CHECK YOURSELF

Cover the grey line before you answer.

1. How many pairs of chromosomes are in a human body cell, and how many carry the sex genes?

23 pairs; one pair determines sex, the other 22 control other characteristics.

2. Draw the cross for sex determination. What ratio does it give?

XX × XY gives XX, XX, XY, XY — a 1 : 1 ratio, so a 50 % chance of each sex.

3. Why does the father determine the sex of the child?

Only the father can pass on a Y chromosome; every egg carries an X.

6.2 Variation and evolution

SAY IT

Most none, some some, very few all

Of all mutations: **most** have **no** effect on the phenotype, **some** influence it, and **very few** determine it. That wording is what the specification asks for — use it.

DON'T MIX UP

genetic variation vs environmental variation

Genetic — from the alleles inherited. **Environmental** — from the conditions in which the individual developed. Most characteristics are **both**, and the safest exam answer says so.

6.2.1 Variation

- **Variation** may be due to the **genes inherited** (genetic causes), the **conditions in which individuals developed** (environmental causes), or a **combination** of both — the genome and its interaction with the environment influence the development of the **phenotype**.
- There is usually **extensive genetic variation** within a population of a species.
- **All variants arise from mutations: most have no effect** on the phenotype; **some influence** phenotype; **very few determine** phenotype.
- **Mutations occur continuously**. Very rarely one leads to a **new phenotype**; if that phenotype suits an environmental change, it can cause a **relatively rapid change in the species**.

CHECK YOURSELF

Cover the grey line before you answer.

1. Name the two causes of variation.

The genes inherited, and the conditions in which the individual developed — usually a combination of both.

2. Where does all genetic variation ultimately come from?

Mutations.

3. When can a single mutation change a species relatively rapidly?

When it produces a new phenotype that happens to suit a change in the environment.

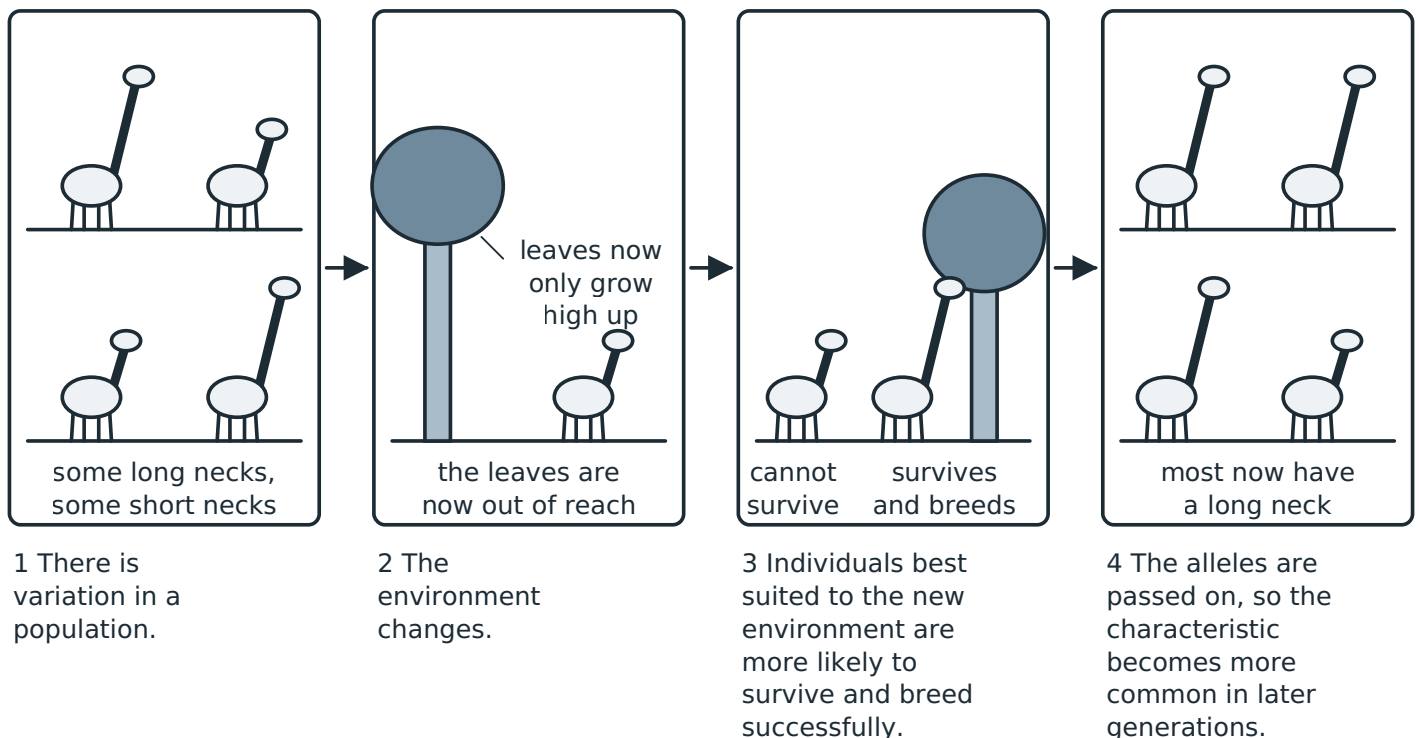
6.2.2 Evolution

- **Evolution** is a change in the inherited characteristics of a population over time, through the process of **natural selection**, which may result in the formation of a **new species**.
- The theory of evolution by natural selection states that all species have evolved from simple life forms that first developed **more than three billion years ago**.
- If two populations of one species become so different in phenotype that they can no longer interbreed to produce fertile offspring, they have formed **two new species**.

Natural selection — the steps to write in an exam answer

1. There is **variation** in the population, caused by **mutation**.
2. Individuals with the **phenotype best suited to the environment** are more likely to survive and breed successfully.
3. They **pass on the alleles** for that characteristic to their offspring.
4. Over **many generations** the proportion of the population with that characteristic **increases**.

Evolution by natural selection



ANALOGY

Natural selection is a **sieve, not a designer**. Mutation shakes out a random mixture and survival lets through whatever fits present conditions. Change the mesh (the environment) and different individuals get through.

DON'T MIX UP

"the animal adapts" — what actually happens

An individual does **not** adapt during its life. The **population** changes because better-suited individuals survive and reproduce more. Never write that an organism changed itself to suit its environment.

SAY IT

Choose, Breed, Select, Repeat

Choose parents with the characteristic, breed them, select the offspring that show it, and repeat **over many generations**. The last three words are often where the mark is.

DON'T MIX UP

selective breeding vs genetic engineering

Selective breeding works only with alleles the species already has, and takes many generations. **Genetic engineering** inserts a gene from a **different** organism, in one step.

6.2.3 Selective breeding

Selective breeding (artificial selection) is the process by which humans breed plants and animals for particular genetic characteristics — done for thousands of years, since food crops were first bred from wild plants and animals domesticated.

Method. Choose parents with the desired characteristic from a mixed population and **breed them together**; from the offspring, **breed together those showing the characteristic**; repeat **over many generations** until all offspring show it.

The characteristic can be chosen for **usefulness or appearance**: **disease resistance in food crops**; animals producing **more meat or milk**; domestic dogs with a **gentle nature**; **large or unusual flowers**.

Risk. Selective breeding can lead to '**inbreeding**', where some breeds are particularly **prone to disease or inherited defects**.

WATCH OUT

Individuals do not evolve — **populations** do. Write "individuals with longer necks survived and reproduced", never "giraffes stretched their necks to reach food".

SAY IT

Vary, Compete, Survive, Breed, Pass on

The five steps of natural selection, in the order an answer must give them: there is **variation**; organisms **compete**; those best suited **survive**; they **breed**; and they **pass on** the alleles for those characteristics.

CHECK YOURSELF

Cover the grey line before you answer.

1. Define evolution.

A change in the inherited characteristics of a population over time, through the process of natural selection, which may result in the formation of a new species.

2. When have two populations become two species?

When their phenotypes differ so much that they can no longer interbreed to produce fertile offspring.

3. Write out the five steps of natural selection.

Variation exists; competition for resources; those with advantageous characteristics survive; they reproduce; the alleles are passed to the next generation.

CHECK YOURSELF

Cover the grey line before you answer.

1. Describe how selective breeding is carried out.

Choose parents with the desired characteristic from a mixed population and breed them; from the offspring, breed together those showing the characteristic; repeat over many generations.

2. Give two characteristics breeders select for.

Disease resistance in food crops; more meat or milk from animals; a gentle nature in dogs; large or unusual flowers.

3. What is the main risk of selective breeding?

Inbreeding — some breeds become particularly prone to disease or inherited defects.

6.2.4 Genetic engineering

- **Genetic engineering** involves modifying the genome of an organism by introducing a gene from another organism to give a desired characteristic.
- **Plant crops** have been engineered to be **resistant to diseases** or **produce bigger, better fruits**; **bacterial cells** to make useful substances such as **human insulin** to treat diabetes.
- Genes from the chromosomes of humans and other organisms can be '**cut out**' and **transferred** to cells of other organisms. Crops modified this way are **genetically modified (GM) crops** — including ones resistant to insect attack or to herbicides — and generally show **increased yields**.
- **Concerns about GM crops**: the effect on populations of **wild flowers and insects**; some people feel the effects of **eating GM crops on human health** have not been fully explored. Modern medical research is exploring genetic modification to overcome some inherited disorders.

HT ONLY The main steps in genetic engineering

HT ONLY Enzymes are used to **isolate the required gene**.

1. **HT ONLY** The gene is **inserted into a vector**, usually a **bacterial plasmid** or a **virus**.
2. **HT ONLY** The vector inserts the gene into the required cells.
3. **HT ONLY** Genes are transferred to cells of animals, plants or microorganisms at an early stage of development, so they **develop with the desired characteristics**.

ANALOGY

Selective breeding is editing a book by repeatedly keeping only the sentences you like — slow, and limited to what the book already contains. **Genetic engineering** is copying a sentence from a *different* book and pasting it in — fast, and able to bring in something the species never had.

SAY IT

Cut, Insert, Transfer, Early

The steps of genetic engineering: the gene is **cut** out with enzymes, **inserted** into a vector (a plasmid or virus), **transferred** into the target cell, and this is done at an **early** stage of development so every cell of the adult carries it.

DON'T MIX UP

the gene **vs** the vector

The **gene** is the instruction being moved. The **vector** — a plasmid or a virus — is the vehicle that carries it in. Naming the vector is usually worth a mark on its own.

CHECK YOURSELF

Cover the grey line before you answer.

1. Define genetic engineering.
Modifying the genome of an organism by introducing a gene from another organism to give a desired characteristic.
2. Give one use in crops and one in bacteria.
Crops resistant to disease, insect attack or herbicides; bacteria engineered to make human insulin.
3. Give two concerns about GM crops.
The effect on populations of wild flowers and insects; and that the effects on human health of eating them may not have been fully explored.

6.3 The development of understanding of genetics and evolution

SAY IT

Genes, Fossils, Resistance

The three lines of evidence for evolution by natural selection: characteristics are passed on in **genes**; the **fossil** record; and antibiotic **resistance** evolving in bacteria, which can be watched happening.

CHECK YOURSELF

Cover the grey line before you answer.

1. Why was Darwin's theory only gradually accepted?
The mechanism of inheritance was not known at the time — the theory is now widely accepted because it has been shown that characteristics are passed on in genes.
2. Why is antibiotic resistance such good evidence?
It is natural selection happening fast enough to observe directly.

6.3.1 Evidence for evolution

- The theory of evolution by natural selection is now **widely accepted**. Evidence for **Darwin's theory** is now available, because it has been shown that characteristics are passed on to offspring in genes.
- There is further evidence in the **fossil record** and in how resistance to antibiotics evolves in bacteria.

CHECK YOURSELF

Cover the grey line before you answer.

1. Name the three ways fossils can form.

From parts that have not decayed because a condition for decay was absent; from parts replaced by minerals as they decay; and as preserved traces such as footprints, burrows and rootlet traces.

2. Why is the fossil record incomplete?

Many early forms of life were soft-bodied so left few traces, and those traces were mainly destroyed by geological activity.

SAY IT

Predator, Disease, Competition, Climate, Habitat, Catastrophe

Six causes of extinction. The first three are living pressures, the next two environmental, the last a single event.

CHECK YOURSELF

Cover the grey line before you answer.

1. Define extinction.

When there are no remaining individuals of a species still alive.

2. Name four factors that can cause extinction.

A new predator; a new disease; increased competition; environmental change such as climate change; destruction of habitat; a catastrophic event such as a volcanic eruption or asteroid collision.

SAY IT

No decay, Minerals, Traces

The three ways fossils form: parts that did **not decay** because a condition for decay was missing; parts **replaced by minerals** as they decayed; or preserved **traces** such as footprints, burrows and rootlets.

DON'T MIX UP

why the fossil record is incomplete

Many early life forms were **soft-bodied**, so left few traces, and most of those were destroyed by geological activity. That gap is precisely why scientists cannot be certain how life on Earth began.

6.3.2 Fossils

Fossils are the 'remains' of organisms from millions of years ago, found in rocks. They may form:

- from parts of organisms that have not decayed, because one or more **conditions needed for decay are absent**
- when parts of the organism are replaced by minerals as they decay as **preserved traces**, such as **footprints, burrows and rootlet traces**.

Why the record is incomplete. Many **early forms of life were soft-bodied**, so left **few traces**, and those were **mainly destroyed by geological activity** — which is why scientists cannot be certain how life began on Earth. Fossils do show how much or how little different organisms have changed as life developed, and you must extract and interpret information from charts, graphs and tables such as **evolutionary trees**.

6.3.3 Extinction

Extinction occurs when there are no remaining individuals of a species still alive. Contributing factors: a **new predator**; a **new disease**; **increased competition**; **environmental change** such as climate change; **destruction of habitat**; a **catastrophic event** such as a volcanic eruption or asteroid collision.

6.3.4 Resistant bacteria

- **Bacteria can evolve rapidly** because they **reproduce at a fast rate**.
- Mutations of bacterial pathogens produce new strains. Some are **resistant to antibiotics** and so are **not killed**; they **survive and reproduce**, so the **population of the resistant strain rises**.
- It then **spreads**, because **people are not immune to it** and there is **no effective treatment**. MRSA is resistant to antibiotics.

To reduce the rate of development of resistant strains

- **Doctors should not prescribe antibiotics inappropriately**, such as for non-serious or **viral** infections.
- **Patients should complete the course**, so **all bacteria are killed** and none survive to mutate into resistant strains.
- The agricultural use of antibiotics should be restricted.

Developing **new antibiotics is costly and slow**, and **unlikely to keep up** with new resistant strains.

CHECK YOURSELF

Cover the grey line before you answer.

1. Why can bacteria evolve resistance so quickly?
They reproduce at a very fast rate, so mutations arise and spread quickly.
2. Give three ways to slow the development of resistant strains.
Doctors not prescribing antibiotics inappropriately, such as for viral or non-serious infections; patients completing the course; restricting the agricultural use of antibiotics.
3. Why does completing the course matter?
So that all the bacteria are killed and none survive to mutate into resistant strains.

WATCH OUT

Bacteria do not become resistant *because* they meet an antibiotic. The **resistant mutation arises at random first**; the antibiotic then kills the non-resistant bacteria, leaving resistant ones to reproduce. The antibiotic is the **selection pressure**, not the cause of the mutation.

SAY IT

Mutate, Survive, Reproduce, Spread

A mutation produces a resistant strain; the antibiotic does not kill it; it **reproduces**; and it **spreads**, because people are not immune to it and there is no effective treatment.

DON'T MIX UP

"bacteria become resistant" — what actually happens

The antibiotic does not **teach** bacteria anything. A resistant strain already exists by chance mutation; the antibiotic kills everything else, so the resistant one is all that is left to reproduce. It is a sieve, not a training course.

6.4 Classification of living organisms

SAY IT

King Philip Came Over For Good Spaghetti

Kingdom, Phylum, Class, Order, Family, Genus, Species — largest group first, as Linnaeus set them out.

CHECK YOURSELF

Cover the grey line before you answer.

1. List the Linnaean groups from largest to smallest.
Kingdom, phylum, class, order, family, genus, species.
2. How is an organism named in the binomial system?
*By genus then species, for example *Homo sapiens* — capital for the genus, lower case for the species, both in italics.*
3. What did Linnaeus base his classification on?
Structure and characteristics.

DON'T MIX UP

genus **vs** species

In a binomial name the **genus** comes first with a **capital** letter and the **species** second in **lower case** — *Homo sapiens* — and both are italicised. Getting the capitalisation wrong is a common and avoidable loss.

The Linnaean system

- Traditionally, living things have been classified into groups depending on their **structure and characteristics**, in a system developed by **Carl Linnaeus**: kingdom, phylum, class, order, family, genus and species — largest group first.
- Organisms are named by the **binomial system of genus and species**, e.g. *Homo sapiens* — capital for the genus, lower case for the species, both in italics.

CHECK YOURSELF

Cover the grey line before you answer.

1. Who proposed the three-domain system, and on what evidence?

Carl Woese, from evidence from chemical analysis.

2. Name the three domains.

Archaea, bacteria and eukaryota.

3. What drove the change from the Linnaean system?

Improvements in microscopes revealing internal structures, and progress in understanding biochemical processes.

Evolutionary trees

- **Evolutionary trees** are a method used by scientists to show **how they believe organisms are related**, using **current classification data for living organisms** and **fossil data for extinct organisms**.
- To read one: **branch points** are **common ancestors**; the more recently two species branch apart, the **more closely related** they are, and a branch stopping before the present is an **extinct** species.

DON'T MIX UP

closely related vs **similar looking**

Relatedness is read from **where the branches split**, not from how similar two species look. Two species that look alike can sit on branches that parted long ago.

SAY IT

Archaea, Bacteria, Eukaryota

Woese's three domains, from chemical analysis. **Archaea** — primitive bacteria, usually in extreme environments. **Bacteria** — true bacteria. **Eukaryota** — protists, fungi, plants and animals.

DON'T MIX UP

why classification changed — both reasons

Better **microscopes** revealed internal structures, and understanding of **biochemical processes** improved. Both are needed for full marks — and the three-domain system came specifically from **chemical analysis**.

Developments in classification

- As evidence of internal structures became more developed through **improvements in microscopes**, and **understanding of biochemical processes progressed**, **new models of classification** were proposed.
- From evidence from **chemical analysis** there is now a '**three-domain system**' developed by **Carl Woese**, dividing organisms into:
- **archaea** — primitive bacteria, usually living in extreme environments
- **bacteria** — true bacteria
- **eukaryota** — including **protists, fungi, plants and animals**.

PICTURE IT

An evolutionary tree is a family tree read from the bottom up. Every fork is a shared ancestor; the later two lines split, the more closely related the species at the top. A branch that stops short of the top is a species that died out. *Where it breaks down*: a family tree names real individuals. The ancestors at the branch points are mostly inferred, not found.

CHECK YOURSELF

Cover the grey line before you answer.

1. What does a branch point on an evolutionary tree represent?
A common ancestor.
2. How do you tell which two species are most closely related?
The pair whose branches separate most recently.
3. What does a branch that stops before the present mean?
That species is extinct.