

Natural selection and genetic modification

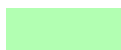
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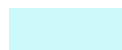
Revision notes for one topic, free to download.

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



Sub-topic headings

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Define Natural selection

- organisms with characteristics best suited to their environment survive, reproduce and pass on their alleles.

Define Mutation

- a random change in the DNA base sequence; the original source of new alleles.

Define Three domains

- Archaea, Bacteria and Eukarya; the top-level groups suggested by genetic analysis.

Define Genetic engineering

- modifying the genome of an organism to introduce desirable characteristics.

Define Sticky ends

- short, unpaired sections of bases left after a staggered cut by a restriction enzyme.

Define Vector

- a plasmid or virus used to carry a gene into a host cell.

Define Evolution

- the gradual change in the inherited characteristics of a population over many generations.

Define Variation

- differences in the characteristics of individuals of the same species.

Define Antibiotic resistance

- the ability of a bacterium to survive an antibiotic that would kill others of its species.

Define Selective breeding

- choosing parents with the desired characteristics and breeding them over many generations.

Define Restriction enzyme

- an enzyme that cuts DNA at a specific base sequence, leaving sticky ends.

Define Ligase

- an enzyme that joins two pieces of DNA by sealing the sugar-phosphate backbone.

Define GM organism

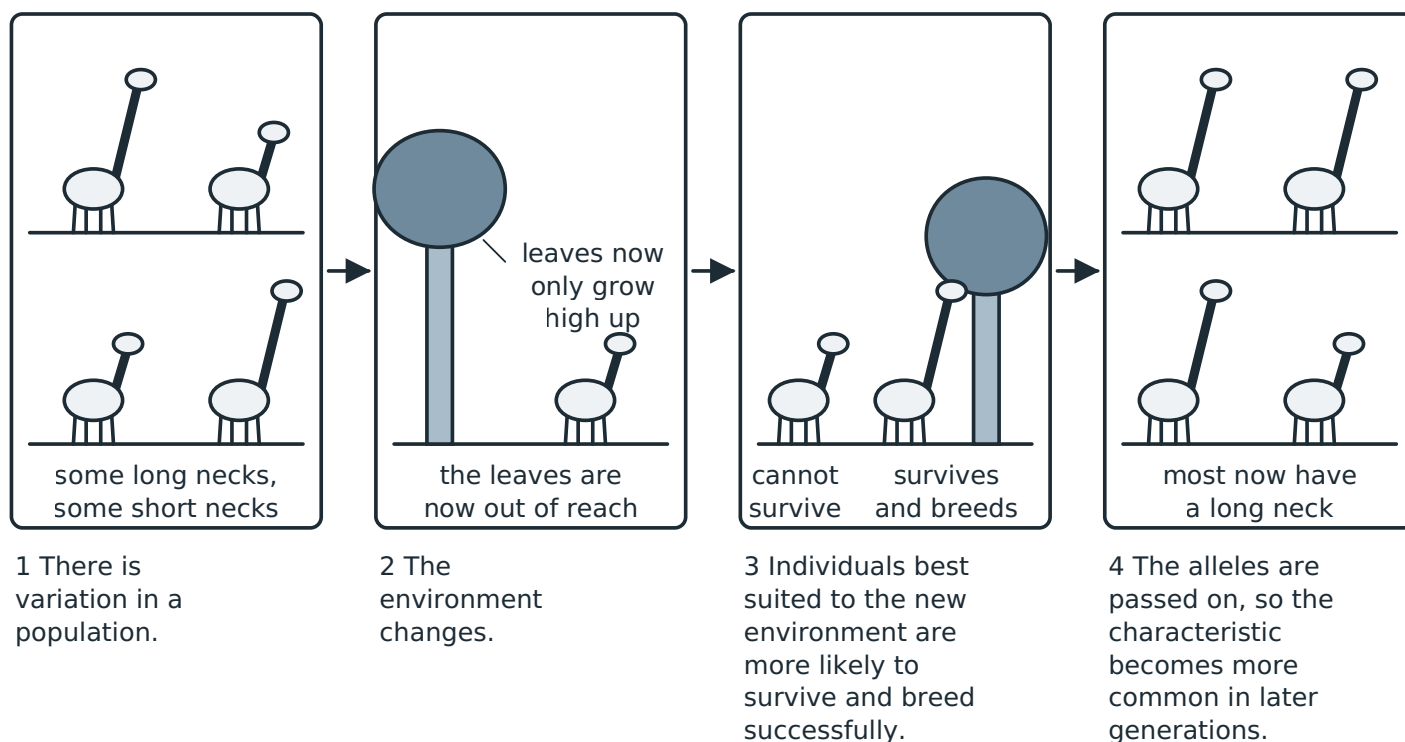
- an organism whose genome has been altered by genetic engineering.

4.1 The theory of evolution by natural selection (4.2)

1. There is **variation** within a population, caused by **mutations** and by sexual reproduction.
2. Organisms produce **more offspring than can survive**, so there is **competition** for limited resources such as food, water, territory and mates.
3. Individuals with characteristics **best suited to their environment** are more likely to survive — a **selection pressure** acts on the population.
4. The survivors **reproduce** and pass on the **alleles** for the advantageous characteristic to their offspring.
5. Over **many generations** the advantageous allele becomes more common in the population.
6. Over a very long time, especially if populations are isolated, the changes may be great enough that a **new species** forms.

This is **Charles Darwin's** theory, published in *On the Origin of Species* in 1859.

Evolution by natural selection



ANALOGY

Natural selection is a sieve the environment holds over every generation. The sieve does not *make* the variation — mutation already did that, at random. It only decides which variants get through and breed. Change the environment and you change the holes, so yesterday's disadvantage can be today's winner.

WATCH OUT

Organisms do **not** change during their lifetime to suit the environment and do not "try" to evolve. Never write "the giraffes stretched their necks" or "the bacteria decided to become resistant" — the variation comes first, by random mutation, and the environment then selects.

4.2 Evidence from resistant organisms (4.3)

Antibiotic resistance is powerful evidence for Darwin's theory because it can be **observed within a human lifetime**.

1. A random **mutation** occurs in the DNA of a single bacterium, giving it **resistance** to an antibiotic.
2. When the antibiotic is used the non-resistant bacteria are killed but the resistant one **survives** — the antibiotic is the selection pressure.
3. The resistant bacterium **reproduces rapidly by binary fission** (generation time as short as 20 minutes) with little competition left.
4. The allele is passed on, so the whole population becomes resistant. **MRSA** is a well-known resistant strain.

The same pattern is seen in **warfarin-resistant rats** and in pesticide-resistant insects. Resistance is made worse by over-prescribing antibiotics, using them for viral infections, and patients not completing the course.

ANALOGY

Antibiotic resistance is like a weedkiller that misses one dandelion. You did not create the survivor — you removed everything competing with it. Next time you look, the lawn is full of its descendants.

4.3 Evidence for human evolution from fossils (4.4)

Fossils of human ancestors show gradual change in **brain size**, **bipedalism** and **limb proportions**.

Fossil	Age and species	Key features
Ardi	4.4 million years ago, <i>Ardipithecus ramidus</i>	Brain about 350 cm ³ (chimp-sized); long arms, short legs; an ape- like divergent big toe for grasping branches, but foot and pelvis structure suggests it could walk upright on the ground.
Lucy	3.2 million years ago, <i>Australopithecus afarensis</i>	Brain about 400 cm ³ ; arched feet, no divergent big toe , so better adapted to walking upright; arm and leg lengths between ape and human.
Leakey's fossils	1.6 million years ago, <i>Homo erectus</i> ("Turkana Boy")	Found by Richard Leakey's team in 1984; brain about 900 cm³ ; short arms, long legs, arched feet, human-like skeleton — fully adapted to walking upright .

- The trend over 4.4 million years: brain volume increases, the big toe aligns with the others, the arms shorten relative to the legs and the skeleton becomes fully bipedal.
- Fossils are dated from the **rock layer (strata)** they are found in — deeper layers are older — and from radiometric dating of nearby volcanic ash.

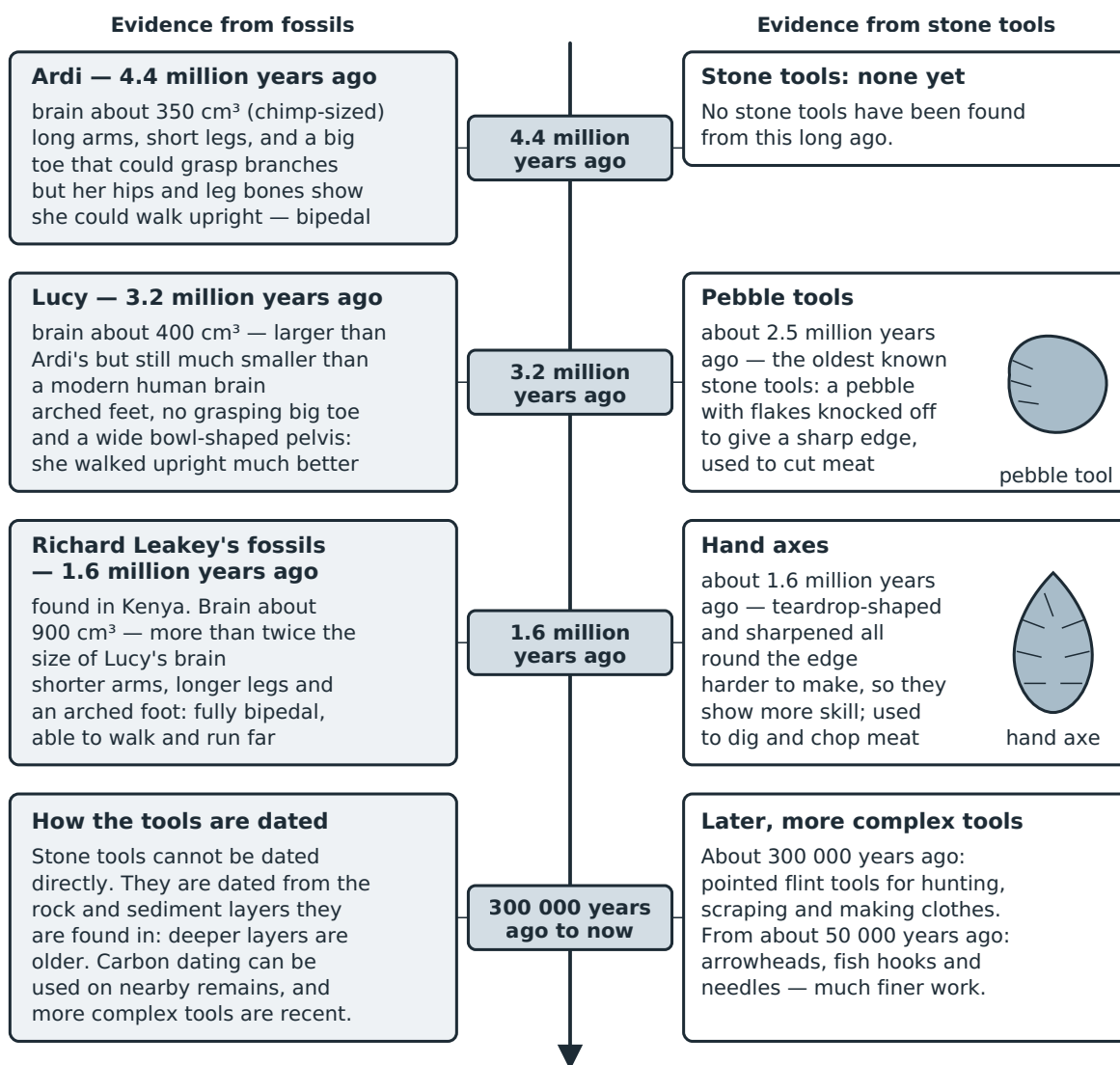
4.4 Evidence for human evolution from stone tools (4.5)

a — How stone tools developed over time

Approximate age	Species	Tool
2.5–2.6 million years	<i>Homo habilis</i>	Simple pebble tools with one struck sharp edge, for scraping and cutting
2.0–1.5 million years	<i>Homo erectus</i>	Hand axes , shaped on both sides and symmetrical, for hunting, digging and cutting meat
300 000–200 000 years	<i>Homo neanderthalensis</i>	Flint tools with finer, pointed edges , including spear points
50 000 years to present	<i>Homo sapiens</i>	Very fine flint work: arrowheads, needles, fish hooks

The tools become **more complex and more specialised** over time, suggesting increasing brain size and manual skill.

Fossil and stone-tool evidence for human evolution



b — How stone tools can be dated from their environment

- **Stratigraphy** — tools in deeper rock layers are older.
- **Rocks and volcanic ash** in the same layer can be dated radiometrically (potassium–argon dating).
- **Carbon-14 dating** of bone or charcoal found with the tools dates younger finds.
- **Fossils in the same layer** date the tools, and vice versa.

4.5 Classification: from five kingdoms to three domains (4.7)

- Traditional (Linnaean) classification sorts organisms by **observable characteristics** into kingdom, phylum, class, order, family, genus, **species**, with a two-word (binomial) name. The **five kingdoms** are animals, plants, fungi, protists and prokaryotes.
- Improved technology allowed **genetic analysis** — comparing DNA and ribosomal RNA base sequences — and biochemical analysis of membranes and cell walls. This showed that the organisms grouped together as "prokaryotes" fall into **two groups as different from each other as they are from all other life**.
- Classification was therefore changed to **three domains**:

Domain	Contains	Notes
Archaea	Primitive bacteria	Often in extreme environments (hot springs, salt lakes, deep-sea vents); cell wall, membrane chemistry and gene structure differ from bacteria
Bacteria	True bacteria	Prokaryotic cells, no nucleus
Eukarya	Protists, fungi, plants, animals	Cells have a nucleus and membrane-bound organelles

- The exam point: **as evidence improves, scientific models change**. Genetic evidence is more reliable than appearance, because unrelated organisms can look alike.

NOTE

The three-domain model was proposed by **Carl Woese** from work on ribosomal RNA. The specification asks only that you describe how genetic analysis led to three domains replacing five kingdoms.

4.6 Selective breeding (4.8)

Selective breeding (artificial selection) is choosing parents with the desired characteristic and breeding them together.

1. **Select** the parents from a mixed population that show the desired characteristic most strongly.
2. **Breed** them together.
3. **Select** the offspring with the best form of the characteristic and breed from them.
4. **Repeat** over many generations until all offspring show the characteristic.

Food plants are bred for larger yields of grain or fruit, disease resistance, hardiness and better taste. **Domesticated animals** are bred for high milk or meat yield, more eggs, thicker wool, gentle temperament, and appearance or behaviour in dogs and horses.

Impact

- Advantages — greater yields from the same land, and less need for chemicals where disease resistance is bred in.
- Disadvantages — inbreeding **reduces the gene pool and variation**, so the population is vulnerable to new disease or environmental change and rare harmful alleles are more likely to be inherited (e.g. hip dysplasia in some dogs). There are **ethical** concerns where a breed's welfare suffers.

4.7 Genetic engineering (4.10–4.11)

HIGHER TIER

- **Genetic engineering** is **modifying the genome of an organism to introduce desirable characteristics**, producing a **genetically modified (GM)**, or transgenic, organism. Examples: bacteria modified to make **human insulin**; crops modified for insect resistance or extra vitamins.

HT ONLY The main stages of genetic engineering (4.11)

1. **HT ONLY** A **restriction enzyme** cuts the desired gene out of the donor chromosome. The cut is **staggered**, leaving short sections of unpaired bases called **sticky ends**.
2. **HT ONLY** The **same restriction enzyme** is used to cut open a **vector** — usually a bacterial **plasmid**, or a virus. This leaves sticky ends with **complementary** bases.
3. **HT ONLY** The sticky ends of the gene and the plasmid pair up by **complementary base pairing**.
4. **HT ONLY** The enzyme **ligase** joins the sugar–phosphate backbones together, sealing the gene into the plasmid. The result is **recombinant DNA**.
5. **HT ONLY** The **vector** carries the gene into the **host cell**, for example a bacterium.
6. **HT ONLY** The host cell **divides**, copying the gene, and the population of cells expresses the gene to make the desired protein.

ANALOGY

Selective breeding is re-dealing a pack of cards and hoping for a good hand: you can only use alleles the species already has, and thousands of other genes come along for the ride. Genetic engineering is placing one chosen card into the hand in a single generation — and that card can come from a different pack entirely.

WATCH OUT

Restriction enzymes **cut** DNA; ligase **joins** it. Remember "restriction removes, ligase links".

4.8 Evaluating the benefits and the risks (4.14)

An **evaluate** question expects both sides and a conclusion.

- **Practical** — genetic engineering is fast and precise and can move a gene between species; selective breeding is slow and only uses alleles already in that species, but needs no specialist equipment.
- **Agriculture** — both raise yields; both **reduce genetic variation**, leaving crops and livestock vulnerable to new disease or climate change. GM crops can be given insect or herbicide resistance, cutting crop losses and pesticide use, but GM seed is expensive, genes may spread to wild plants by pollen and pests may evolve resistance.
- **Medicine** — genetic engineering produces pure human insulin, growth hormone and vaccines cheaply.
- **Ethical** — animal welfare, unknown long-term effects of releasing GM organisms, labelling and consumer choice, patenting living organisms.
- **Conclusion** — weigh the size and likelihood of each benefit and risk; do not simply list them.