Cambridge (CIE) A Level Biology

Your notes

Evolution

Contents

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Theory of evolution

- A species can be defined as a group of organisms that are able to **interbreed** and **produce fertile offspring**
- Members of one species are **reproductively isolated** from members of another species
- In reality, it is quite hard to define 'species' and the determination of whether two organisms belong to the same species is dependent on investigation
- Individuals of the same species have similar behavioural, morphological (structural) and physiological (metabolic) features
- A common example used to illustrate this concept is mules; the infertile offspring produced when a male donkey and a female horse mate

The gene pool

- The phenotype of all organisms is dependent on its **genotype** and **environmental** influence on this
- Members of the same species will have the same genes, of which there may exist alleles (alternate versions)
- A **gene pool** is the collection of **genes** within an interbreeding population
- A **gene pool** can be thought of as the sum of all the alleles at all of the **loci** within the **genes** of a population of a single species or a population

Changes to the gene pool

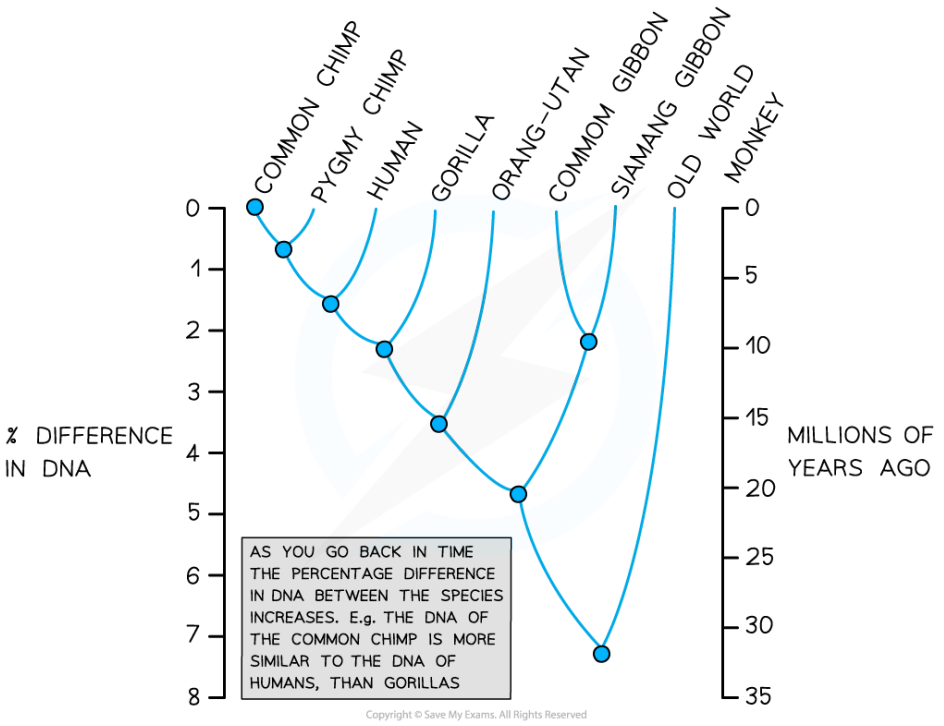
- The gene pool (or allele frequencies) in a species population can **change** over time due to processes such as:
  - Natural selection
  - Genetic drift
  - The founder effect
- When the **gene pool within a species population changes** sufficiently over time, the characteristics of the species will also change
- The **change can become so great that a new species forms**
  - This is **evolution**
- For a population to have evolved into a separate species it must be **genetically and reproductively isolated** from the pre-existing species population
  - **Reproductive isolation** can occur due to mutations that lead to the incompatibility of gametes or sex organs, or differences in breeding behaviour.

- When two populations are reproductively isolated, they can also be said to be **genetically isolated** from each other, meaning that they **do not exchange genes** with each other in the production of offspring

- Changes in the **allele frequencies** of isolated populations are not shared so they **evolve independently** of each other; this can lead to the formation of two groups that are no longer successfully able to interbreed and that are said to be separate species
  - The formation of new species in this way is known as **speciation**
- The evolution of a new species can take a **very long time** and many generations
- For organisms with a short generation time (such as bacteria), the evolution of new species can be observed far more quickly

Evidence of evolutionary relationships in DNA

- DNA found in the nucleus, mitochondria and chloroplasts of cells can be **sequenced** and used to show evolutionary relationships between species
- The **differences between the nucleotide sequences** (DNA) of different species can provide a lot of information:
  - The **more similar** the sequence the **more closely related** the species are
  - Two groups of organisms with very similar DNA will have separated into separate species more recently than two groups with less similarity in their DNA sequences
- DNA sequence analysis and comparison can also be used to create family trees (phylogenetic trees) that show the evolutionary relationships between species



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Example of a tree diagram showing the relationship between primate species

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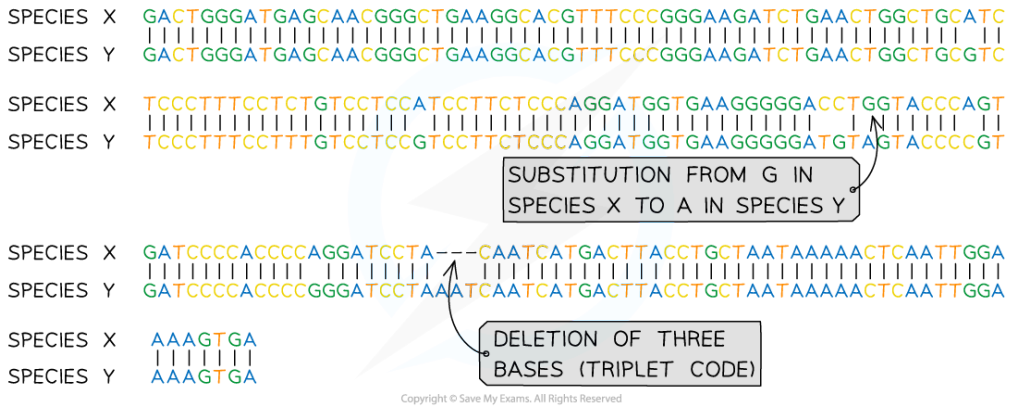
DNA analysis and comparison

- **DNA is extracted** from the nuclei of cells taken from an organism
  - DNA can be extracted from blood or skin samples from living organisms or from fossils
- The extracted DNA is processed, analysed and the **base sequence is obtained**
- The **base sequence is compared** to that of other organisms to determine evolutionary relationships
  - The **more similarities** there are in the DNA base sequence, the **more closely related** (in that the less distant the species separation) members of different species are
- In 2005, the chimpanzee genome was sequenced, and when compared to the human genome it was discovered that humans and chimpanzees share almost 99% of their DNA sequences, making them our closest living relatives
  - In 2012, the sequencing of the bonobo genome also revealed that humans and bonobos also share 98% of their genome (with slight differences from the differences seen in chimpanzees)



The DNA base sequences of two closely related species being compared – Species X is the ancestor of Species Y

Mitochondrial DNA

- When analysing DNA from the mitochondria, is important to remember that:
  - A zygote only contains the mitochondria of the egg and none from the sperm so **only maternal mitochondrial DNA is present in a zygote**
  - There is **no crossing over** that occurs in mtDNA so the base sequence can only change by mutation
- The lack of crossing over in mtDNA has allowed scientists to research the origins of species, genetic drift and migration events

- It has even been possible to estimate how long ago the first human lived and where
  - Mitochondrial Eve is thought to have lived in Africa ~200,000 years ago
  - The estimation of this date relies on the **molecular clock theory** which assumes there is a **constant rate of mutation** over time
  - The greater the number of differences there are between nucleotide sequences, the longer ago the common ancestor of both species existed
  - The molecular clock is calibrated by using **fossils and carbon dating**
  - A fossil of a known species is carbon-dated to estimate how long ago that organism lived
  - The mtDNA of this species is then used as a **baseline for comparison** with the mtDNA of other species
- Although for your exams you should say that only maternal mitochondrial DNA can be passed on or inherited by the zygote, recent research suggests that paternal mDNA may also be present in zygotes

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Allopatric & sympatric speciation

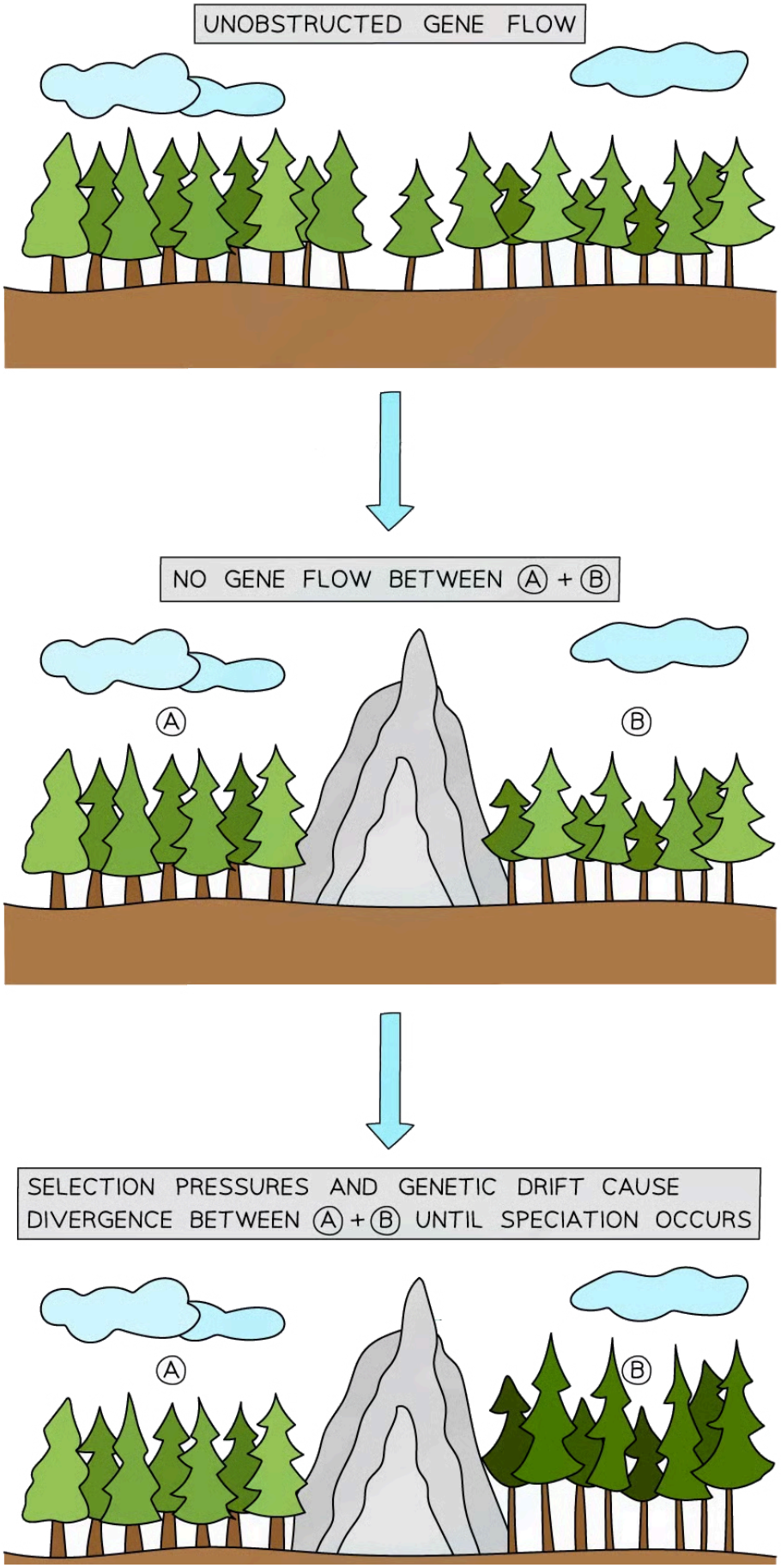
- **Evolution** causes **speciation**: the formation of **new species** from pre-existing species over time, as a result of **changes to gene pools** from generation to generation
- **Genetic isolation** between the new population and the pre-existing species population is necessary for speciation
- There are two different situations when speciation can take place:
  - Two groups within a species are separated by a **geographic** barrier
  - Two groups of species are **reproductively isolated** but still living in the same area (experiencing similar environmental selection pressures)

Allopatric speciation

- Allopatric speciation occurs as a result of **geographical isolation**
- It is the **most common type of speciation**
- A species population splits into one or more groups which then become separated from each other by geographical **barriers**
  - The barrier could be natural like a body of water, or a mountain range
  - It can also be man-made (like a motorway)
- This separation creates two populations of the same species who are isolated from each other, and as a result, **no genetic exchange** can occur between them
- If there is sufficient selection pressure or genetic drift acting to change the gene pools within both populations then eventually these populations will **diverge and form separate species**
  - The changes in the alleles/genes of each population will affect the phenotypes present in both populations
  - Over time, the two populations may begin to differ physiologically, behaviourally and morphologically (structurally)

Example of allopatric speciation in trees

- Imagine there is a population of trees that are all one species
- A new mountain range forms that divides the population into two
- The natural barrier prevents the two groups from interbreeding, so there is no gene flow between them
- The two populations experience **different selection pressures and genetic drift**
- Over thousands of years the divided populations **form two distinct species** that can no longer interbreed



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The natural geographical barrier of a mountain range can lead to allopatric speciation in trees

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Sympatric speciation

- Sympatric speciation takes place with **no geographical barrier**
- A group of the same species could be living in the same place but in order for speciation to take place there must exist two populations within that group and **no gene flow** occurs between them
- Something has to happen that splits or separates the population:
  - **Ecological** separation: Populations are separated because they **live in different environments within the same area**
    - For example, soil pH can differ greatly in different areas
    - Soil pH has a major effect on plant growth and flowering
  - **Behavioural** separation: Populations are separated because they have **different behaviours**
    - For example differences in feeding, communication or social behaviour

Example of sympatric speciation in fish

- A species of fish lives in a lake
- Some individuals within the population feed on the bottom while others remain higher up in the open water
- The different feeding behaviours separate the population into different environments
  - **Behavioural separation leads to ecological separation**
- The separated groups experience **different selection pressures**
  - Long jaws are advantageous for bottom-feeding whereas shorter jaws are advantageous for mid-water feeding
- Over time natural selection causes the populations to **diverge** and evolve **different courtship displays**
- They can no longer interbreed; they are separate species

Examiner Tips and Tricks

When looking at cases of sympatric speciation try not to confuse the factors that **originally caused a separation** between the populations vs the factors that then **prevent them from breeding** after genetic isolation. For the example of the fish: the difference in feeding behaviour is what originally causes separation but it is a difference in courtship displays (which is caused by genetic isolation) that prevents them from breeding together.

Also, do not forget that speciation is reliant on **mutation**! Without mutation, there are no new alleles or genes for selection to act on. The change in genetic material by mutation is important as it is what produces the differences in physiology, behaviour and morphology between species.

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