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Evolution & Speciation



IB Biology - Revision Notes

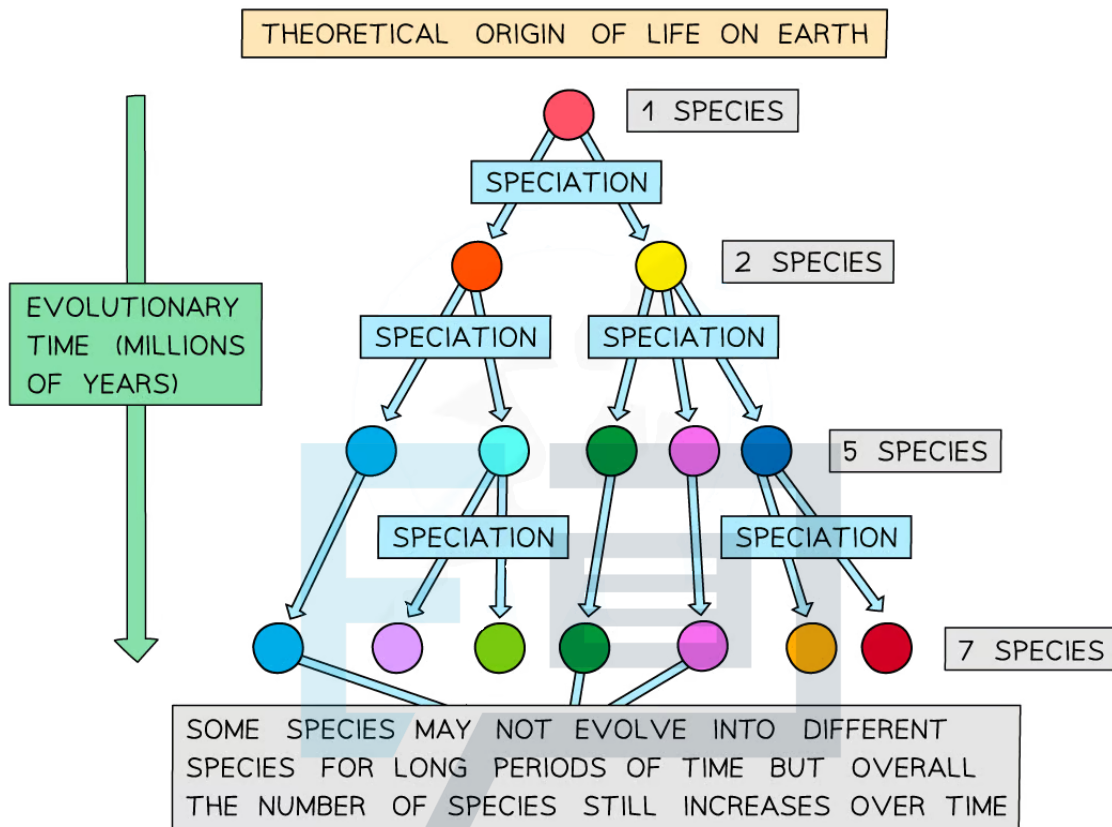
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Evolution

Evolution

- Species **do not stay the same over time**; the species that we see around us today have developed over millions of years
 - This process of species change is known as **evolution**
- Evolution can be defined as:
Changes in the heritable characteristics of organisms over generations
- **Heritable** characteristics are those that can be **inherited by**, or **passed on to**, the next **generation**
 - Changes in characteristics that are not inherited, e.g. a plant having its leaves eaten, do not lead to evolution
 - Heritable characteristics are determined by the alleles of genes that are present in an individual
 - Alleles may change as a result of **random** mutation, causing them to become more or less advantageous
- Heritable characteristics that are **advantageous** are **more likely to be passed on** to offspring, leading to a **gradual change** in a species over time
 - This is the process of **natural selection**
- Changes in the heritable characteristics of organisms can also lead to the development of completely **new species**
- The formation of new species via the process of evolution has resulted in a **great diversity of species** on Earth
 - Theoretically, at the origin of life on Earth, there would have been just **one** single species
 - This species evolved into **separate new species**
- These species would then have **divided** again, each forming new species once again
- Over millions of years, evolution has led to countless numbers of these speciation events, resulting in the millions of species now present on Earth

Evolution diagram



Evolutionary change over a long period of time has resulted in a great diversity of species

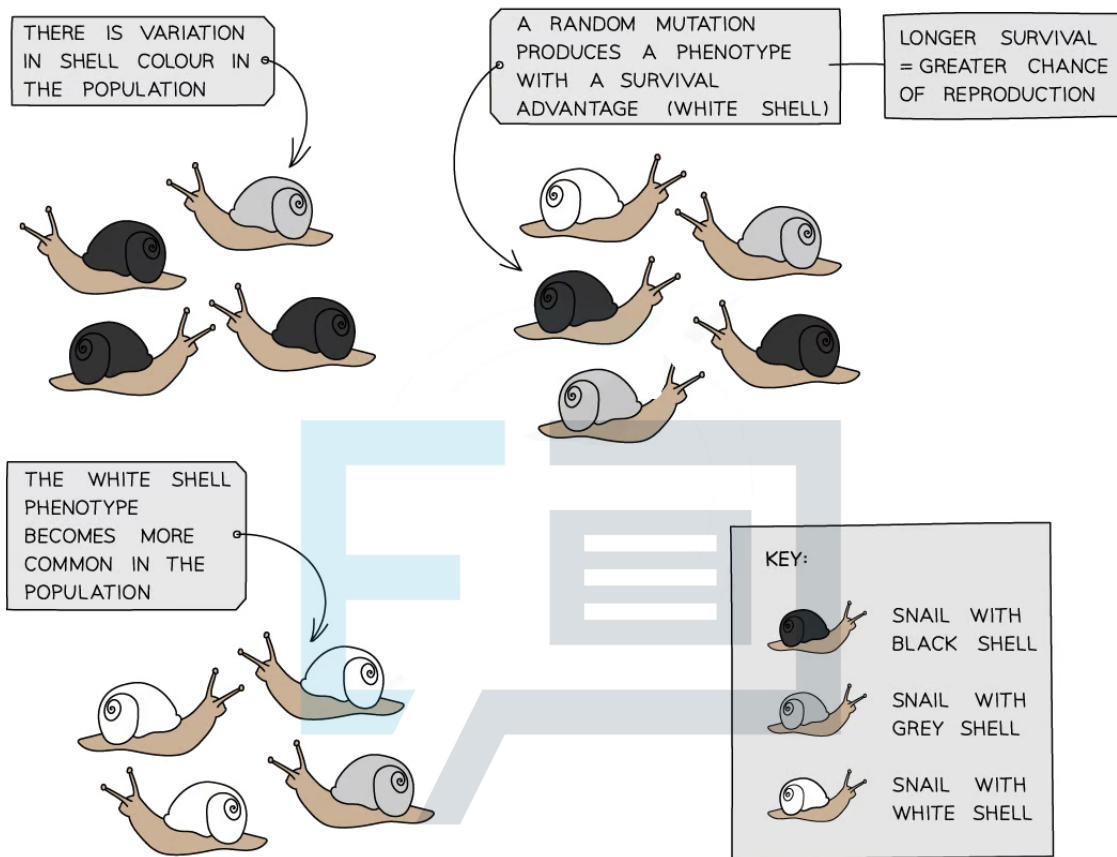
Darwinian evolution

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- Charles Darwin, as a result of **observations** on a round-the-world expedition, and backed by years of experimentation and discussion, proposed the **theory of evolution by natural selection**
- Darwin's theory is as follows:
 - Individuals in a species show a wide range of **variation** due to **random mutations** in their DNA
 - Individuals within a population must compete for survival due to selection pressures
 - Individuals with characteristics most suited to the environment have a **higher chance of survival** and so are **more likely to reproduce**
 - Advantageous **alleles** are passed down to offspring
 - Over many generations the advantageous alleles become more frequent in a population
- Darwinian evolution by natural selection requires that characteristics are **heritable**

Natural selection diagram



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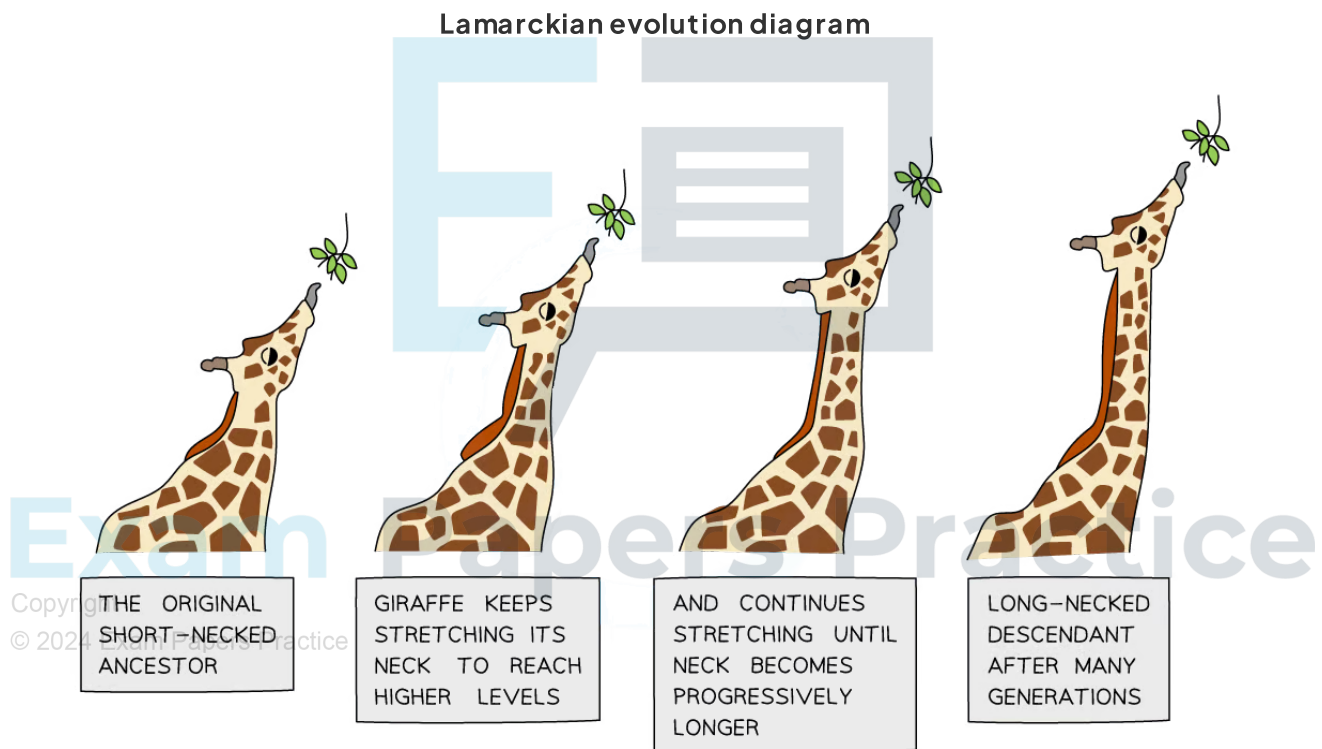
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© 2018 *Natural selection acts on genetic variation in populations. Here the allele for white shells is advantageous, so becomes more frequent in the population over time.*

Lamarckian evolution

- Another theory of evolution, developed at the start of the 19th century (before Darwin announced his theory), was that of French scientists **Jean-Baptiste Lamarck**
- Lamarck's theory was based mainly on the idea that changes that occur in an organism **during its lifetime** can be inherited
 - Such changes are known as **acquired characteristics**
- His theory is as follows:
 - A characteristic that is used frequently by an organism becomes better and stronger, whereas a characteristic that isn't used gradually disappears
 - The beneficial **characteristics that are used frequently are passed to offspring**

- For example, Lamarck suggested that:
 - Giraffes had a short-necked ancestor that would frequently stretch its neck to reach the high branches so it could feed on the leaves
 - This repeated stretching could very slowly elongate the giraffe's neck and this **elongated neck would be passed to the giraffe's offspring**
 - Over time and many generations, the giraffe would evolve to have the very long neck it has today
- Lamarck's ideas were incorrect because they lack the component of heritability; **acquired characteristics are not passed on to offspring**
 - The new science of **epigenetics** may provide an exception to this rule, but changes like these are unlikely to be major drivers of natural selection



Lamarck proposed that characteristics acquired during an organism's lifetime could be passed on to offspring

NOS: The theory of evolution by natural selection predicts and explains a broad range of observations and is unlikely to ever be falsified

- Scientists can gather information about the world by **observing events**
- They formulate **theories** that seek to explain observed events



- The theory of natural selection **explains many observations**, and is **widely accepted** as a correct explanation of observed events; no other reasonable theories have ever been proposed, and so this theory is **likely to remain** as the scientific explanation for species change over time
 - It is worth noting that there are some minor aspects of Darwin's original theory that have been falsified since they were proposed:
 - 'Evolution by natural selection is always slow'
 - We know that, e.g. antibiotic resistance can evolve in bacteria very quickly
 - 'The fossil record cannot provide evidence for evolution'
 - There are multiple examples of fossils that appear to show intermediate species
 - These errors have resulted in **updates** to Darwin's theory, but not to its falsification
- Due to the geological time periods over which evolutionary change has occurred, it is **not possible to formally prove** that natural selection has given rise to the species that we see today, hence the continued use of the term 'theory'



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Evidence of Evolution

Sequence Data

- Sequence data can be obtained from:
 - DNA
 - The **base sequence of DNA** found in the nucleus, mitochondria and chloroplasts of cells can be determined
 - RNA
 - RNA is the product of transcription, and the **RNA base sequence** provides information about the DNA base sequences of genes that are expressed in a cell
 - Proteins
 - The **amino acid sequence** of expressed proteins can be determined
- Similarities between sequence data in different species suggest that **all species share a common ancestor**
- The sequences for comparison must come from the same part of the DNA, and are often taken from regions of DNA that are **highly conserved**, meaning that they have **changed very little over time**; this is important for several reasons:
 - Like needs to be compared with like**; comparing two completely different regions of DNA will not yield useful information
 - There are likely to be relatively few differences, so **similarities and differences can be easily identified**
 - Conserved sequences are also more likely to exist in a **wide range of species**
- Examples of conserved sequences are those that **code for essential proteins**, e.g. haemoglobin, or enzymes involved in respiration

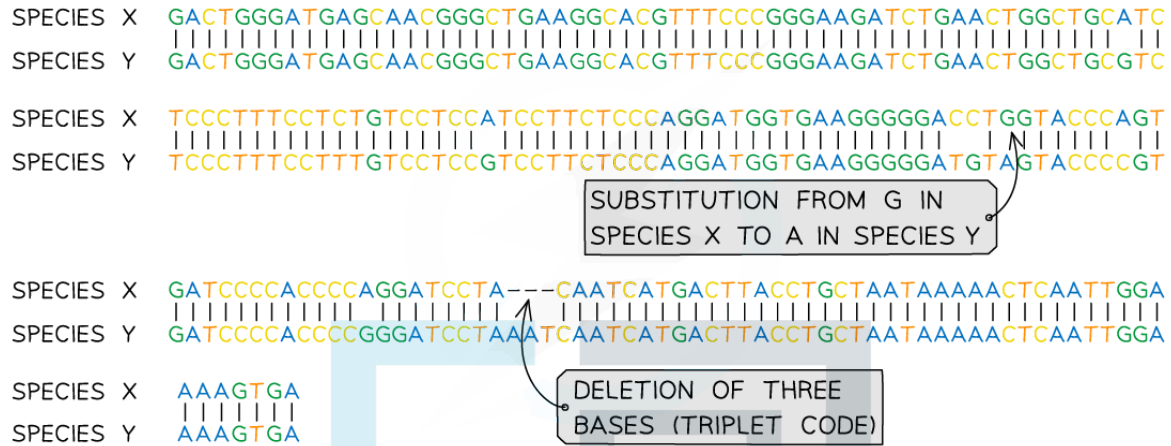
Comparing DNA sequences

- DNA is **extracted from cells**
 - DNA can be extracted from blood or skin samples from **living organisms** or from **fossilised remains**
- 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 relationship**
 - The **more similarities** there are in the DNA base sequence, the **more closely related** members of different species are
 - E.g. 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
- Data from **multiple sources**, e.g. several different genes, are compared to increase the level of certainty



- The data gained from comparing sequence data can be used to build an **evolutionary tree**

Comparing DNA sequences diagram



Similarities and differences between the DNA of two species provide information about their divergence from a common ancestor

Selective Breeding

- Selective breeding is a process in which **humans choose** organisms with **desirable characteristics** and **breed them together repeatedly** to increase the expression of these characteristics over **many generations**
 - The process of selective breeding has enabled humans to take advantage of **naturally occurring variation**, e.g.
 - Variation between individuals in plants means that some individuals may have a higher food yield or disease resistance
 - Variation between individuals in domestic animal varieties means that some individuals may have thick, heavy wool, or large volumes of milk production
 - Humans have been able to develop desirable crop and domestic animal varieties from individuals with desirable characteristics
- This practice is also known as **artificial selection**
 - It makes use of the **principles of** natural selection, but is carried out by humans
 - In natural selection, **advantageous** alleles are more likely to be passed on because they increase an organism's chances of survival
 - In artificial selection, or selective breeding, **desirable alleles** are more likely to be passed on because humans decide which individuals will be used for breeding
- Selective breeding involves **changes to heritable characteristics** over **many generations**, and so it is an example of **evolution in action**
 - Selective breeding leads to **faster change** than natural selection; this is because **only the selected individuals are allowed to breed** together, while in natural selection there will still be some breeding between individuals with less favourable alleles
- Selective breeding provides evidence that evolution occurs due to the **accumulation of small changes to the DNA** of organisms over time

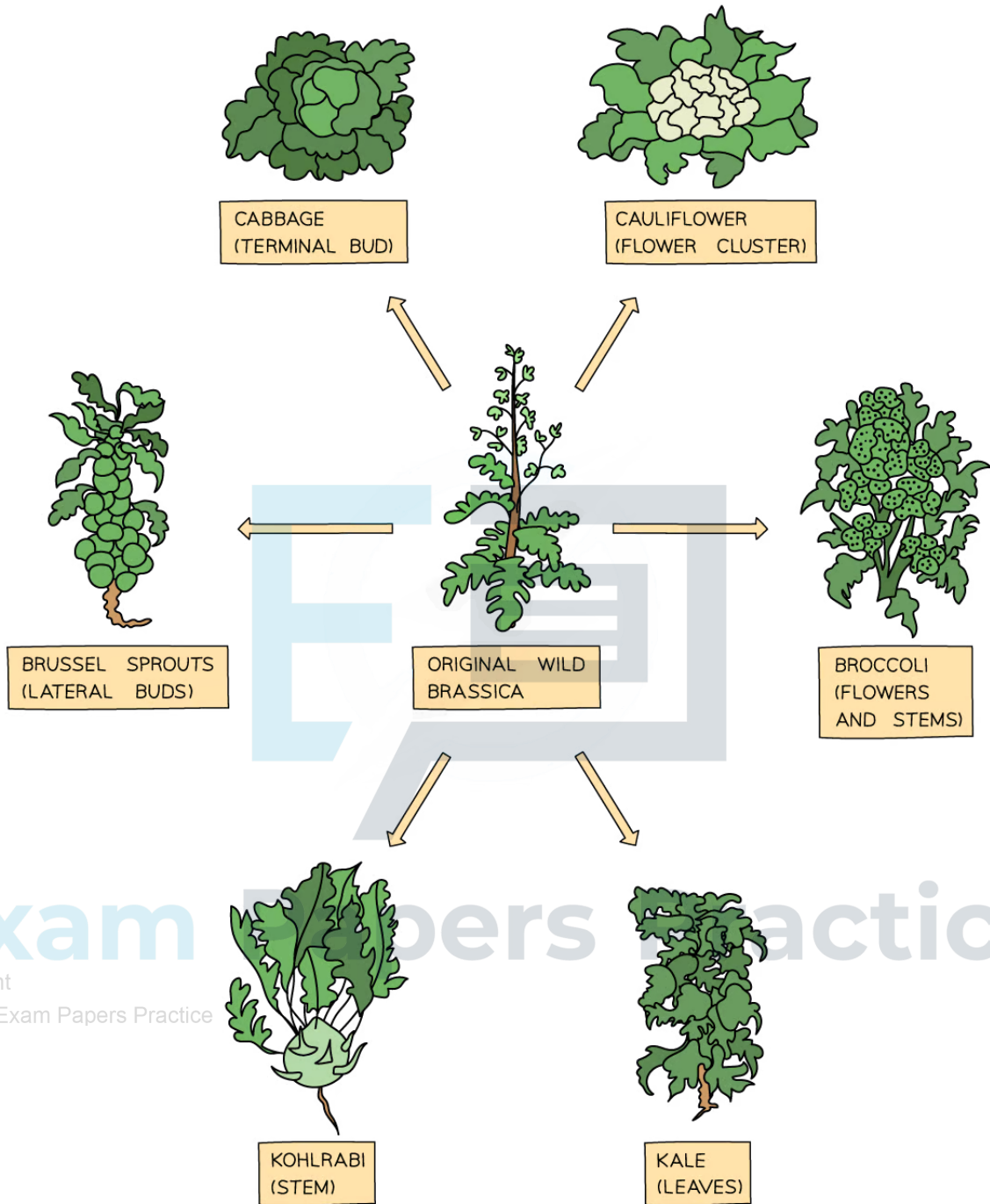
The process of selective breeding

1. The population shows **variation**; there are individuals with different characteristics
2. Breeders select **individuals with the desired characteristics**
3. Two selected individuals are **bred together**
4. The offspring produced reach maturity and are then **tested for the desirable characteristics**; those that display the desired characteristics to the greatest extent are selected for **further breeding**
5. The process is **repeated over many generations**; the best individuals from the offspring are continually chosen for breeding until all offspring display the desirable characteristics

Selective breeding diagram

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Variation in wild brassica plants allowed humans to selectively breed many of the crop plants that we eat today

Homologous Structures

- **Homologous structures** are body parts that may **look and function very differently** but share **structural similarities**
- The limbs of animals are a good example of this; animals have many different mechanisms of motion and limb use, but the **basic arrangement of bones** in many different types of limbs is **very similar**
 - E.g. The limbs of birds, bats, crocodiles, whales, horses, and monkeys are used very differently and are visually very different, but are structurally **very similar** to each other
- One explanation for the surprising similarities of these different limbs is that of **adaptive radiation**; the idea that organisms with homologous structures have all **evolved from a shared, common ancestor** but have **adapted to different environments** in the process
 - Note that adaptive radiation does not provide **proof** that these organisms have evolved from a common ancestor, but it is a good explanation for the existence of homologous structures

A homologous structure: the pentadactyl limb

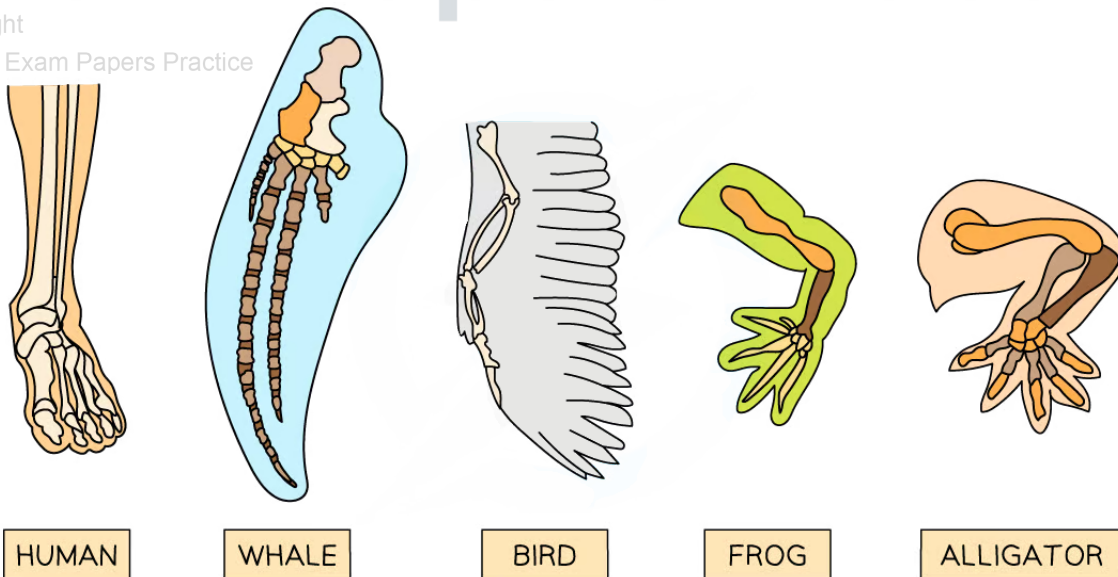
- A **pentadactyl limb** is any limb that has **five digits**, i.e. five fingers or toes
- Pentadactyl limbs are present in **many species** from **many groups of organisms**, including mammals, birds, amphibians, and reptiles
- In different species, the pentadactyl limb has a **similar bone structure** but can enable an animal to move in a very different way
 - The **human foot** evolved for **upright walking and running**
 - **Whale flippers** enable them to **propel** themselves through a **marine environment**
 - **Bird wings** are usually highly adapted for **flight**
 - The **limbs of frogs** allow them to **walk, jump and swim**
 - **Alligator limbs** enable them to **walk and swim**
- Although the **individual bones** of the pentadactyl limb in these example animals are **very different shapes and sizes** due to their different mechanisms of **locomotion**, their **layout** is almost **exactly the same**

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Homologous structures diagram

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The pentadactyl limbs of humans, whales, birds, frogs, and alligators all have the same basic layout despite having evolved for different functions

Convergent Evolution

Convergent Evolution

Convergent evolution

- **Analogous structures** are characteristics with **similar form and function, but with different evolutionary origin**
 - Such structures have historically caused some confusion for scientists working in the field of taxonomy
- While homologous structures provide evidence of shared ancestry, analogous structures come about as the result of **convergent evolution**
 - Analogous structures provide **evidence for the passing on of advantageous characteristics** during natural selection
- Convergent evolution can occur when two distantly related species live in habitats with similar selection pressures, meaning that similar characteristics provide a survival advantage
 - **Advantageous characteristics evolve separately**, rather than as the result of a single mutation
- Examples of similarities that have arisen due to convergent evolution include:
 - Dolphins and sharks
 - These are both groups of aquatic animals that **share a similar body shape**, but they in fact belong to different classes
 - Dolphins are mammals and sharks are fish
 - Their streamlined body shapes **evolved separately** rather than originating in one common ancestor
 - Cacti and euphorbia
 - These are two groups of desert plants recognisable by their spiny leaves and branching, succulent stems
 - They belong to different orders of plants
 - Cacti are found in the deserts of the Americas, while euphorbias are found in Africa
 - They evolved separately, but **adapted to similar environments**

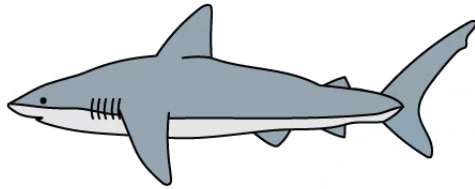
Analogous structures diagram

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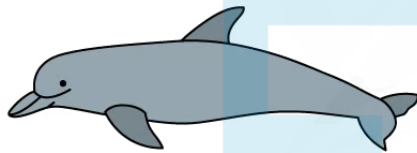
SHARK



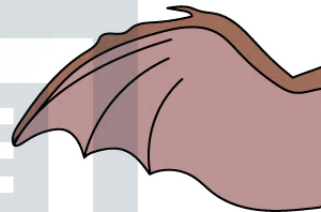
BUTTERFLY



DOLPHIN



BAT



STREAMLINED BODY
SHAPE AND FINS

WINGS ADAPTED
FOR FLIGHT

Analogous structures, such as body shape in sharks and dolphins, and wings in butterflies and bats, occur as the result of convergent evolution

 **Exam Tip**

Make sure that you learn **at least one example** of analogous structures

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Speciation

Speciation

Speciation increases diversity

- The theory of evolution states that **species do not stay the same**, but change over time; this can lead to the process of **speciation**

- Speciation can be defined as

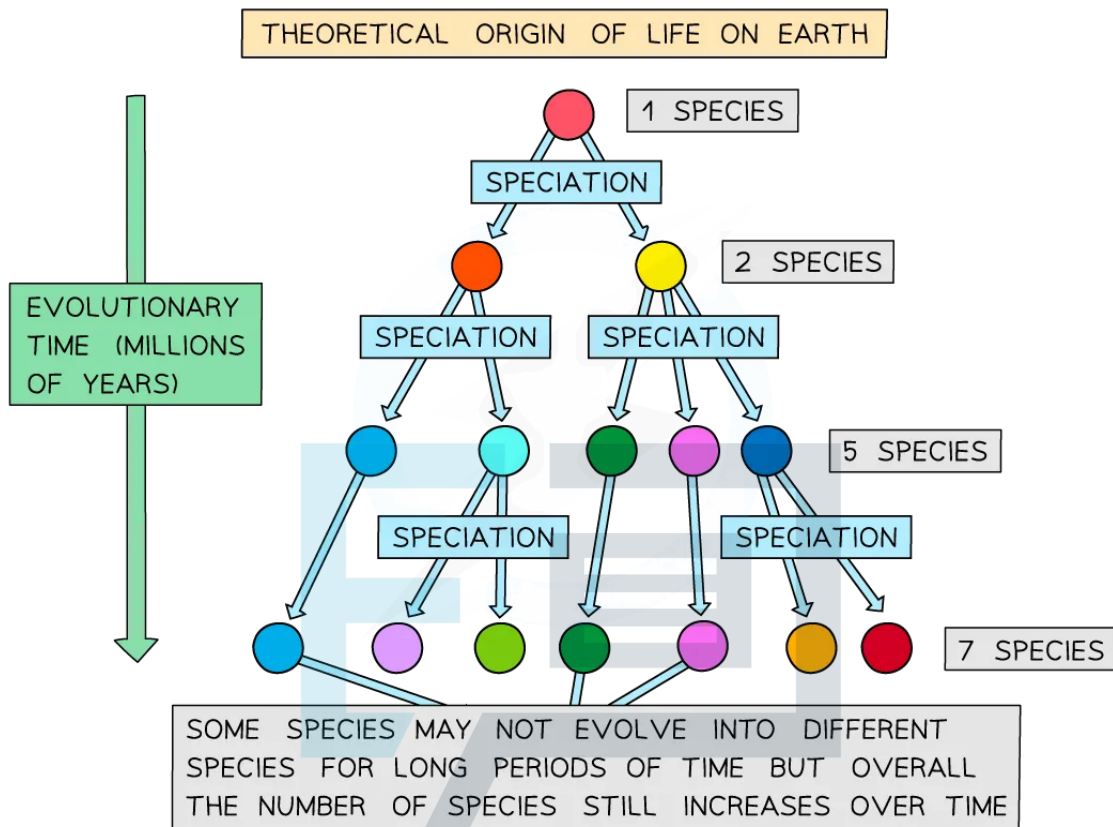
The development of new species from pre-existing species over time

- Speciation has resulted in a **great diversity of species** on Earth
 - Theoretically, at the origin of life on Earth, there would have been just one single species
 - This species evolved into separate new species
 - These species would then have divided again, each forming new species once again
 - Over millions of years, evolution has led to countless numbers of these speciation events, resulting in the millions of species now present on Earth
- Speciation can occur when the exchange of genes, or **gene flow**, between populations of a species is prevented, e.g. due to them being separated on different islands
 - When gene flow stops, **genetic differences can accumulate** between the two populations
 - This may happen faster if different selection pressures are acting on the two populations
- A speciation split has occurred when the two populations **can no longer interbreed to produce fertile offspring**; at this point the two populations are said to be **reproductively isolated** from each other
 - Note that in order for speciation to have occurred, **there must be reproductive isolation**; gradual evolutionary change alone is not enough

Speciation diagram

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Speciation is thought to have given rise to the huge diversity of species on Earth

Extinction reduces diversity

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- While speciation increases the number of species on Earth, not all of the species that have evolved over evolutionary time still exist today; many species have gone **extinct**, meaning that **they no longer exist**
 - E.g. The passenger pigeon and the woolly mammoth
 - Extinction **reduces the number of species** on Earth

Reproductive Isolation & Differential Selection

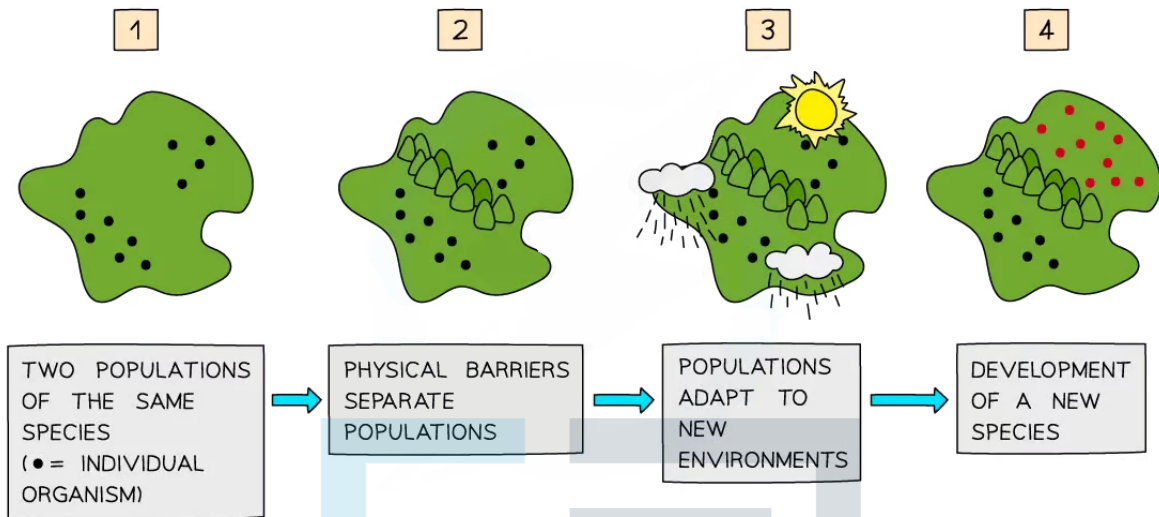
Reproductive isolation

- Organisms that belong to the same species share the same characteristics and are able to **breed together to produce fertile offspring**
- Reproductive isolation** occurs when changes in the alleles and phenotypes of some individuals in a species **prevent them from successfully breeding** with other individuals that don't have these changed alleles or phenotypes
- Examples of allele or phenotype changes that can lead to reproductive isolation include:
 - Seasonal changes
 - Some individuals may develop different mating or flowering seasons, becoming sexually active at different times of the year
 - Behavioural changes
 - Some individuals in a population may develop changes in their courtship behaviours, meaning they can no longer attract individuals of the opposite sex for mating
- These changes can occur as a result of **geographical isolation of populations**

Geographical isolation

- Reproductive isolation can occur when populations of a species become separated from each other by **geographical barriers**
 - The separated populations are said to be **geographically isolated** from each other
- Geographical barriers can include
 - Naturally occurring barriers such as a body of water, or a mountain range
 - Man-made barriers, such as a motorway
- Geographical isolation creates two populations of the same species between which **no gene exchange** can occur
- The two populations may be affected by **different selection pressures**, meaning that natural selection may act differently on the two populations
- This is known as **differential selection**
- Over time, the two populations may become so different that they are **reproductively isolated**, and speciation has occurred

Geographical isolation diagram



A mountain range can lead to geographical isolation, and eventually reproductive isolation

Bonobos & chimpanzees

- An example of a speciation event that has resulted from geographical isolation is the evolution of bonobos (*Pan paniscus*) and chimpanzees (*Pan troglodytes*)
- Chimpanzees are found to the north of the Congo river, and bonobos to the south
 - This suggests that at some point in their evolutionary past the river caused two populations of their ancestor species to become **geographically isolated**
 - **Differential selection pressures** would have acted on the two populations, so **differential selection** occurred, resulting in differences between the two populations, e.g.
 - Chimpanzees tend to be more behaviourally aggressive than bonobos; this could have arisen due to more intense competition for resources
 - Chimpanzees have male-dominated social structures while bonobos have dominant females
 - Eventually the two groups became **reproductively isolated**, and were two separate species

Exam Tip

Be careful not to confuse geographical isolation with reproductive isolation. Geographical isolation **prevents gene flow**, but may be temporary (i.e. if the two populations came back together again then successful breeding could occur) while reproductive isolation means that **speciation has occurred** and that the two species **cannot longer breed together successfully**, even if they live in the same habitat.

Note that you **do not** need to use binomial Latin names in an exam, e.g. it is fine to refer to bonobos rather than *Pan paniscus*