# SL IB Biology

Your notes

## Evolution & Speciation

### Contents

# Evolution

Your notes

## Evolution

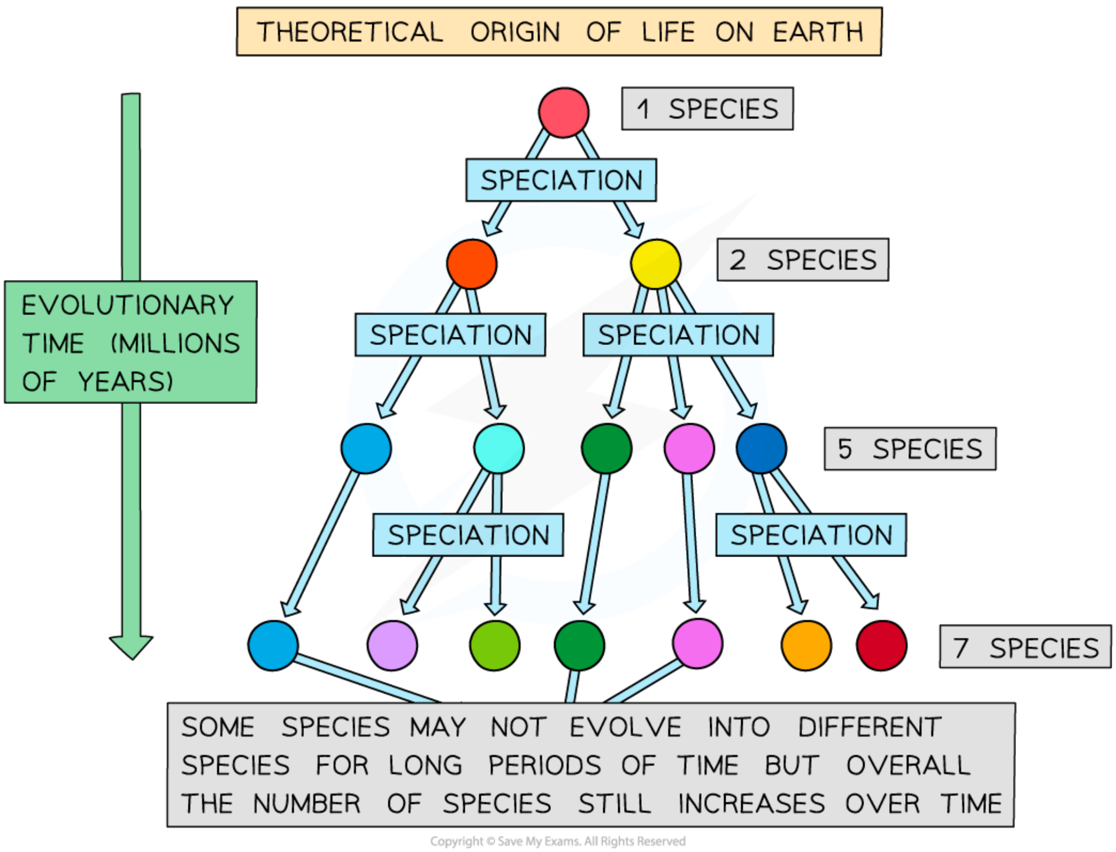
- Species **do not stay the same over time**; the species that we see around us today have developed over millions of years
  - This process of species change is known as **evolution**
- Evolution can be defined as:

**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**

Your notes

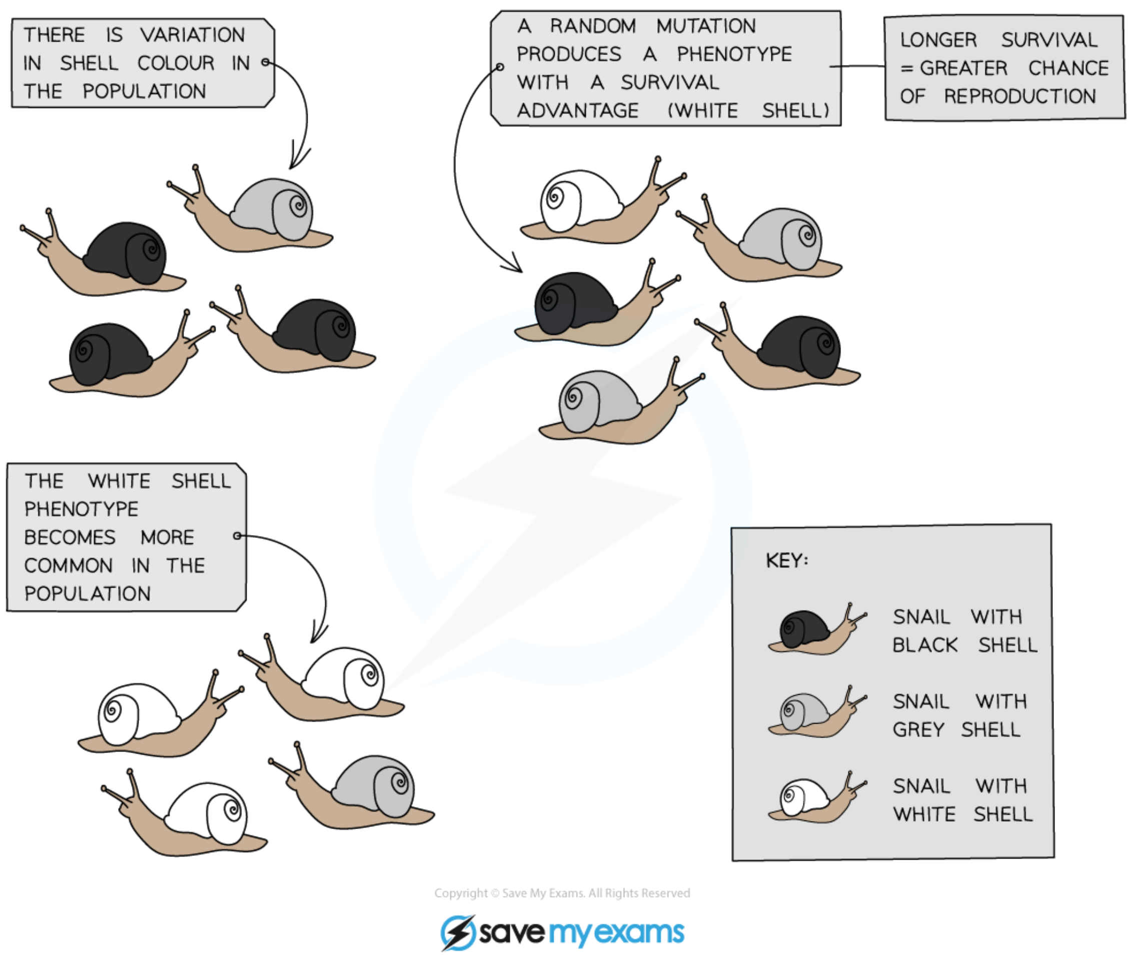



***Evolutionary change over a long period of time has resulted in a great diversity of species***

## Darwinian evolution

- 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**



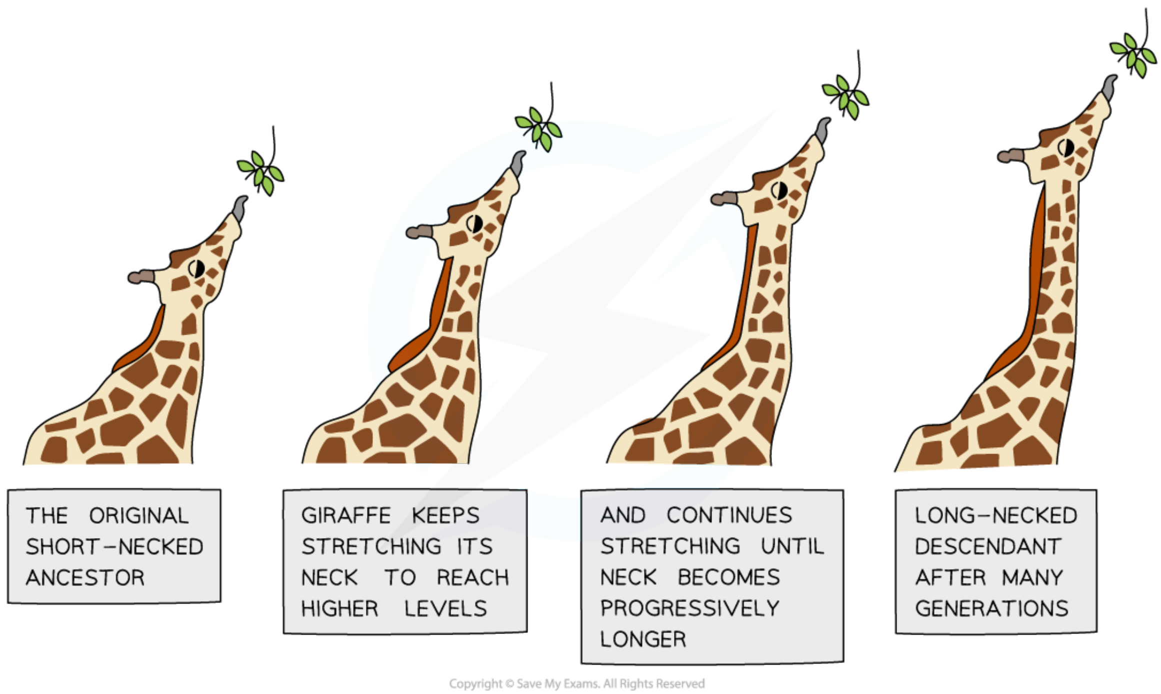

***Natural selection acts on genetic variation in populations. Here the allele for white shells is advantageous, so becomes more frequent in the population over time.***

## 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

**Lamarckian evolution diagram**




***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

Your notes

  - 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'

# Evidence of Evolution

Your notes

## Sequence Data

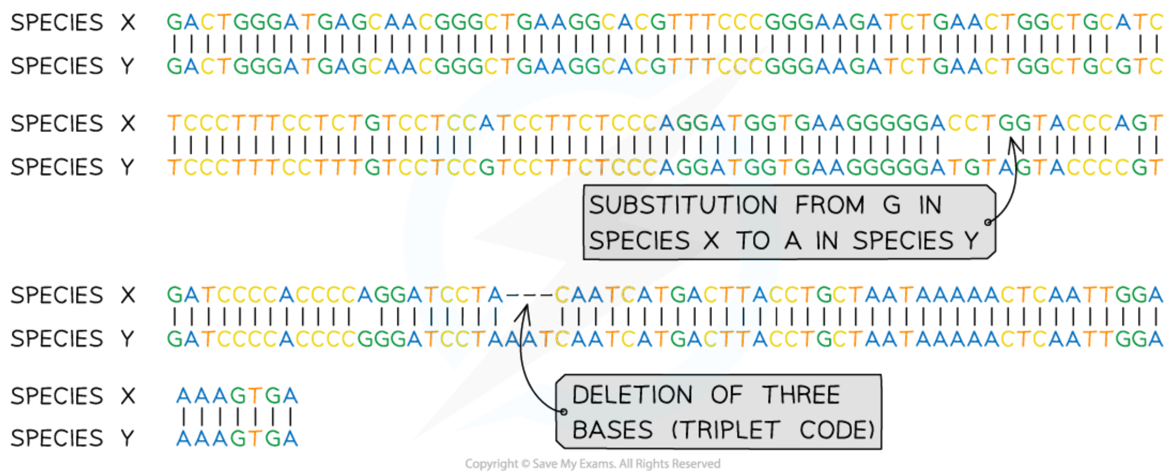
- Sequence data can be obtained from:
  - DNA
    - The **base sequence of DNA** found in the nucleus, mitochondria and chloroplasts of cells can be determined
  - RNA
    - RNA is the product of transcription, and the **RNA base sequence** provides information about the DNA base sequences of genes that 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**

Your notes




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

## Selective Breeding



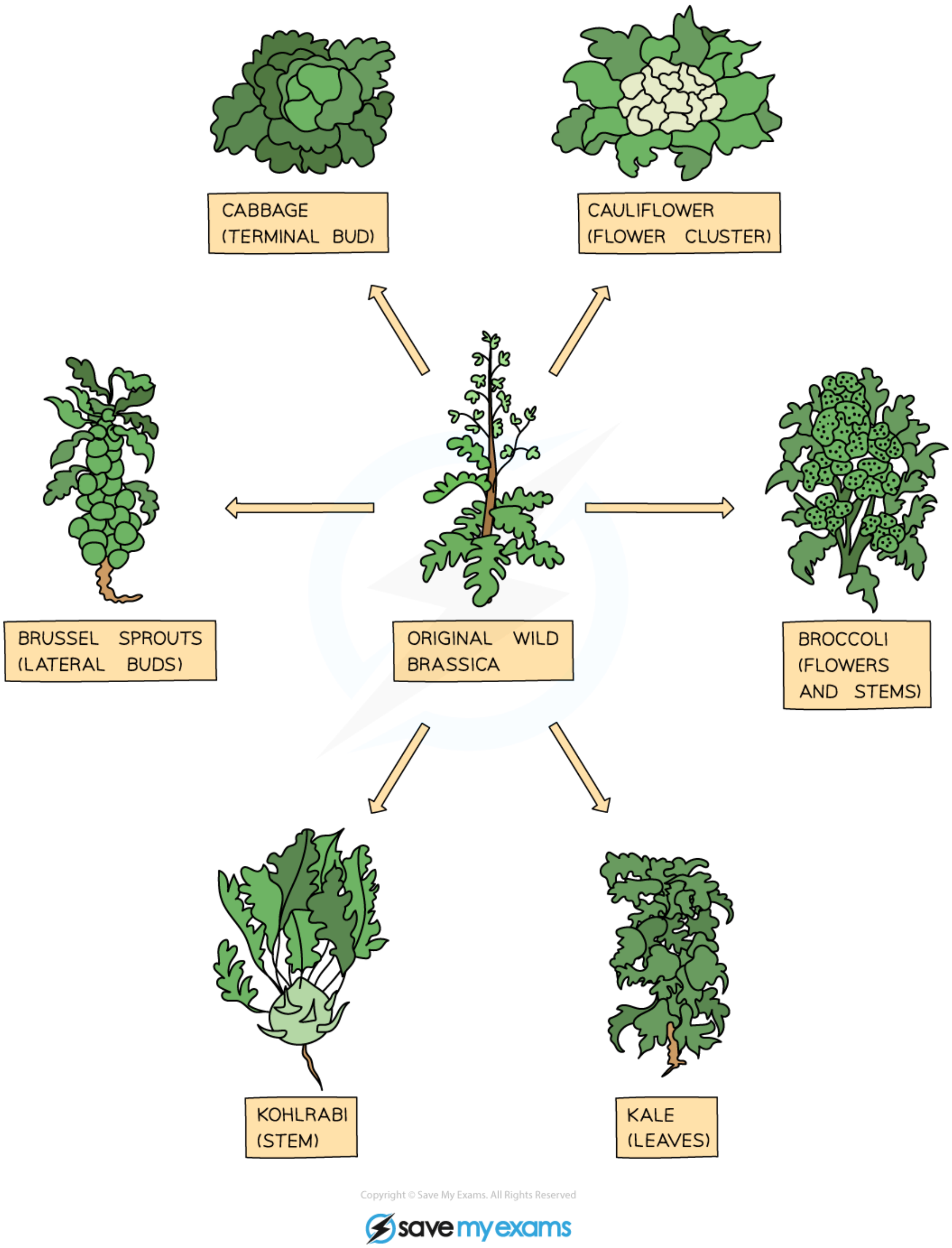
- Selective breeding is a process in which **humans choose** organisms with **desirable characteristics** and **breed them together repeatedly** to increase the expression of these characteristics over **many generations**
  - The process of selective breeding has enabled humans to take advantage of **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**

Your notes




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

Your notes

## Homologous Structures

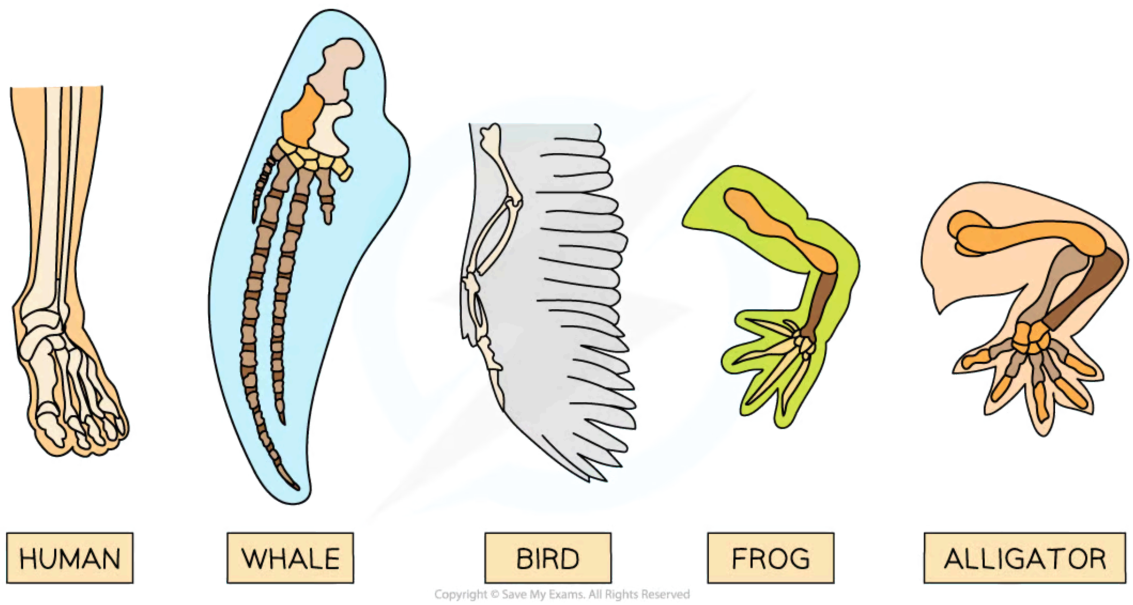
- **Homologous structures** are body parts that may **look and function very differently** but share **structural similarities**
- The limbs of animals are a good example of this; animals have many different mechanisms of motion and limb use, but the **basic arrangement of bones** in many different types 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**

**Homologous structures diagram**

Your notes




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

# Convergent Evolution

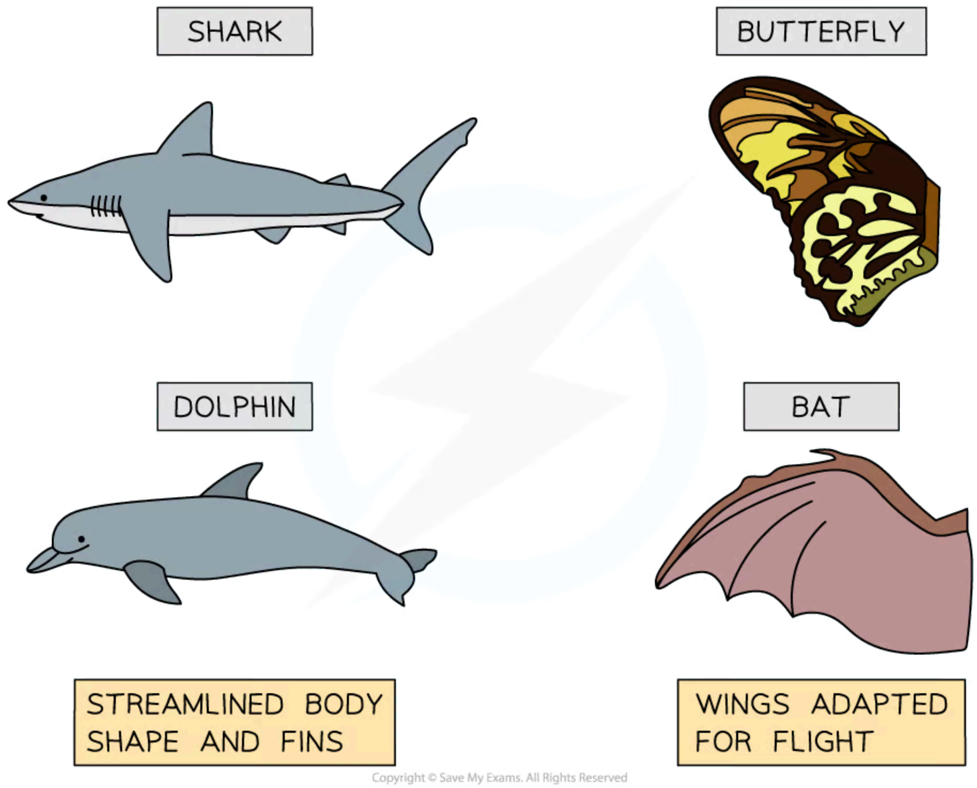
Your notes

## 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**




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

### Examiner Tip

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

Your notes

# Speciation

Your notes

## Speciation

### Speciation increases diversity

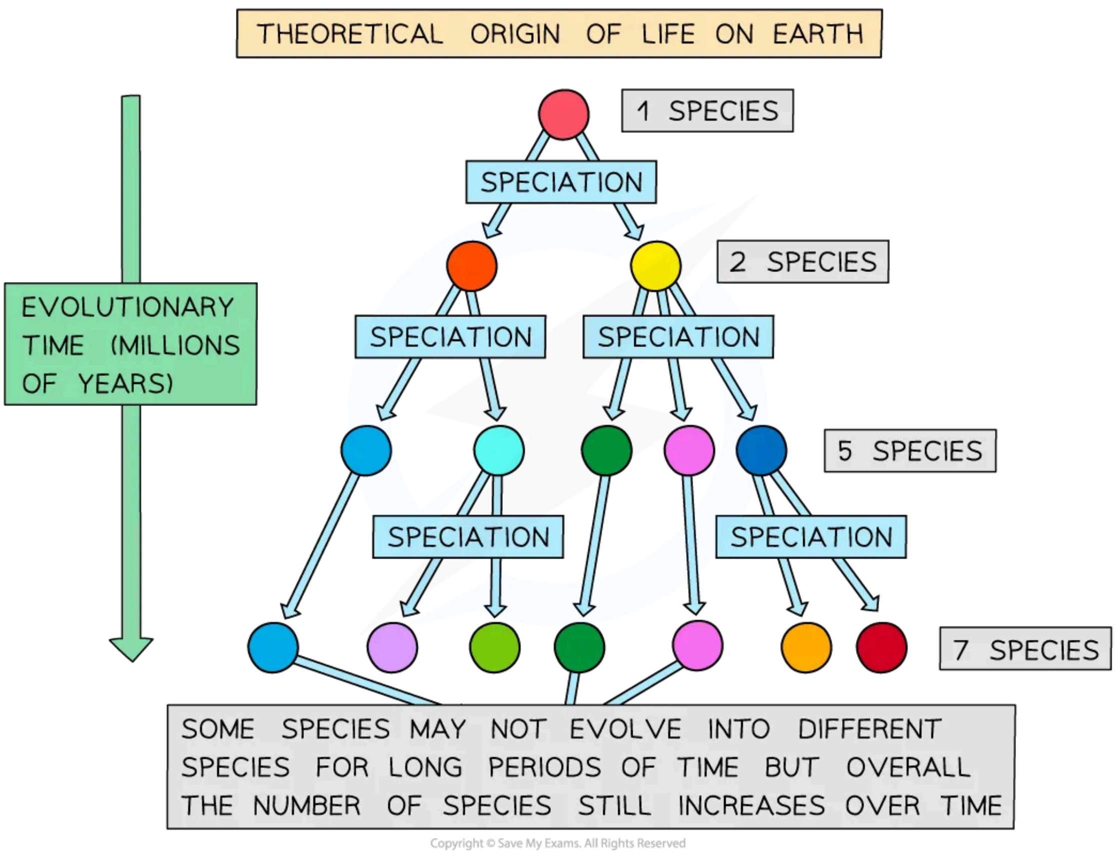
- The theory of evolution states that **species do not stay the same**, but change over time; this can lead to the process of **speciation**
- Speciation can be defined as

**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**

Your notes




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

## Extinction reduces diversity

- 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

Your notes

## Reproductive isolation

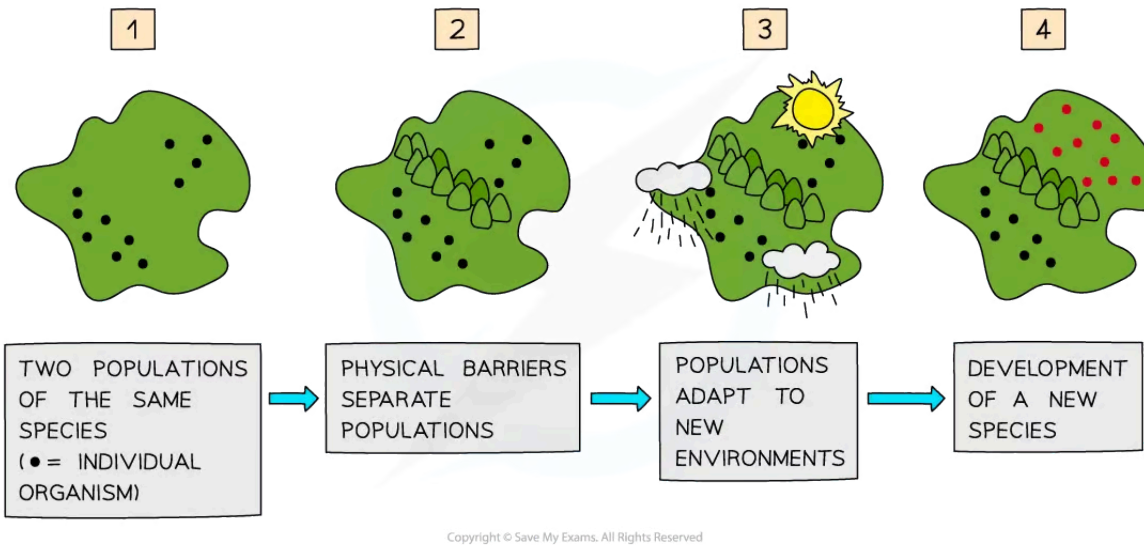
- Organisms that belong to the same species share the same characteristics and are able to **breed together to produce fertile offspring**
- **Reproductive isolation** occurs when changes in the alleles and phenotypes of some individuals in a species **prevent them from successfully breeding** with other 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**

Your notes




***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**
  - **Different 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

### Examiner 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 **can no 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*