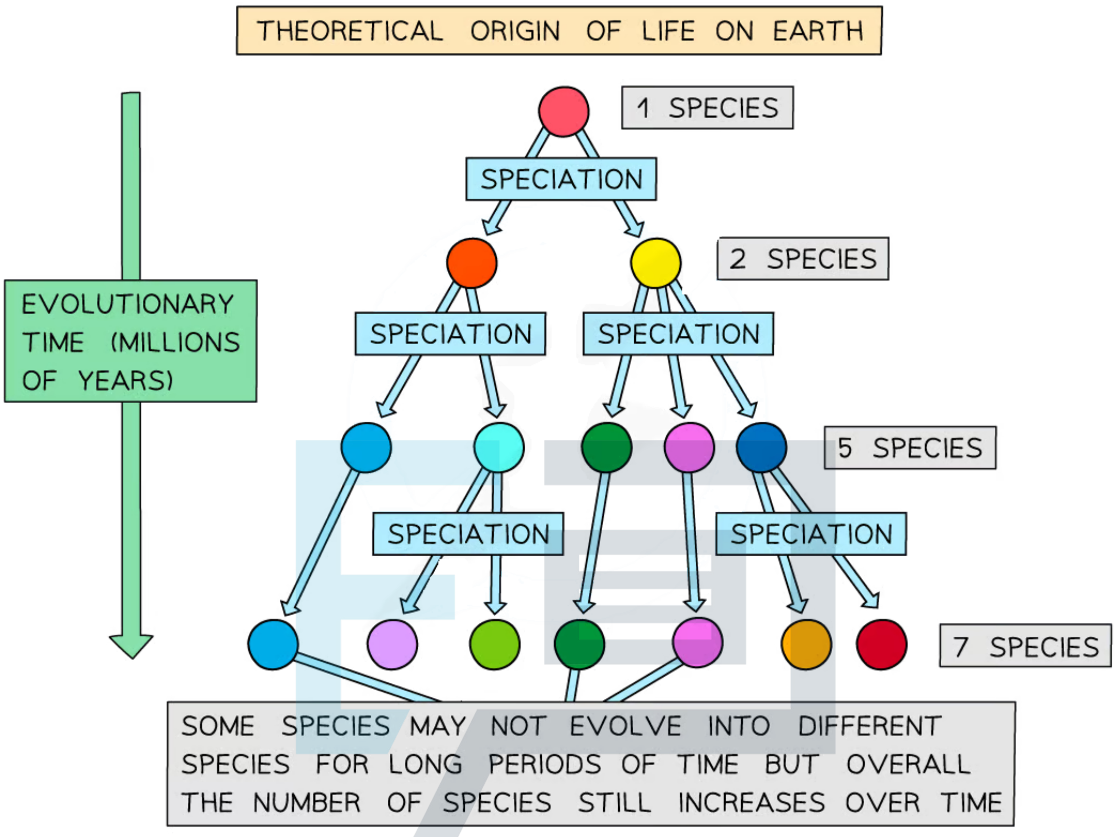
5.1 Evolution & Natural Selection

IB Biology - Revision Notes

5.1.1 Evolution

Evolution Defined

- 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



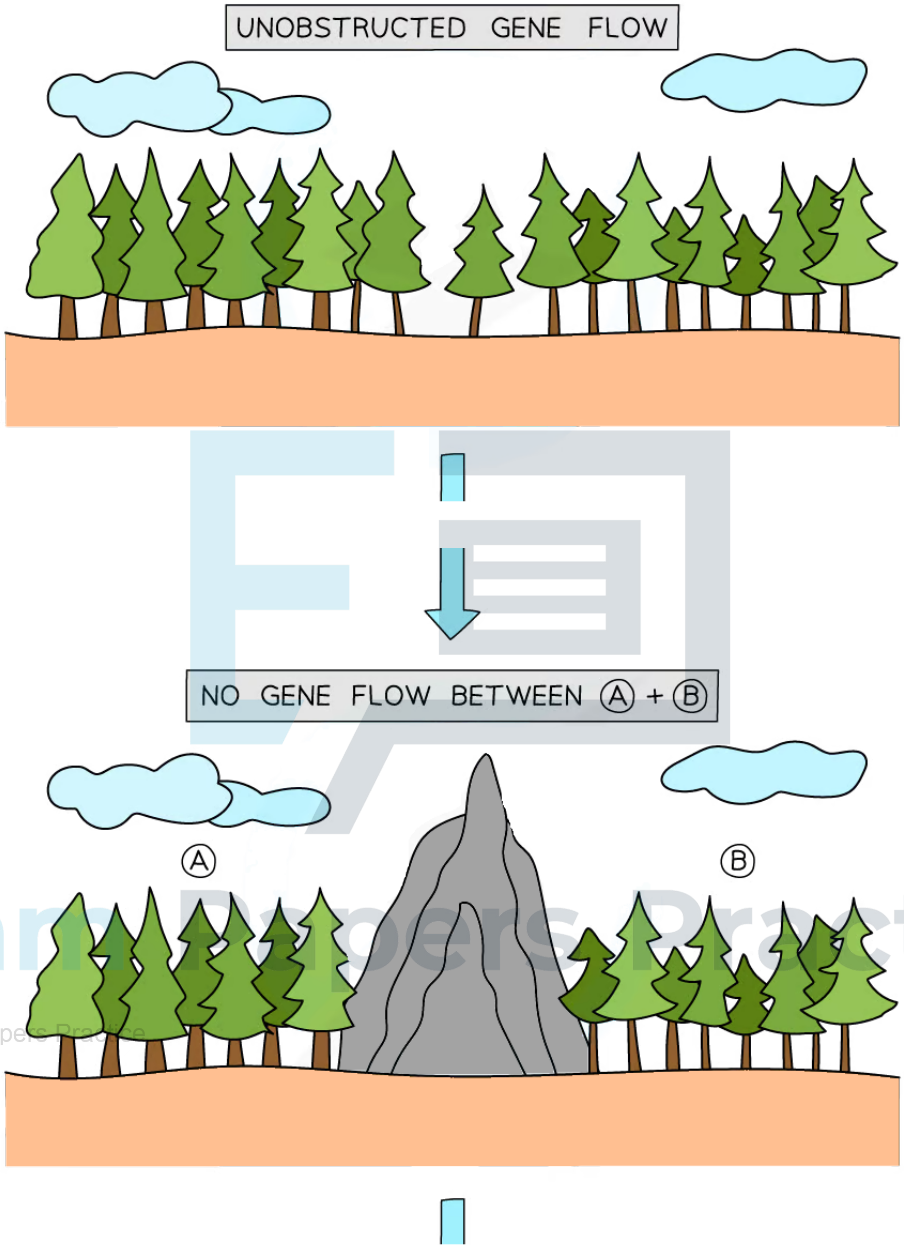
Evolutionary change over a long period of time has resulted in a great diversity of species

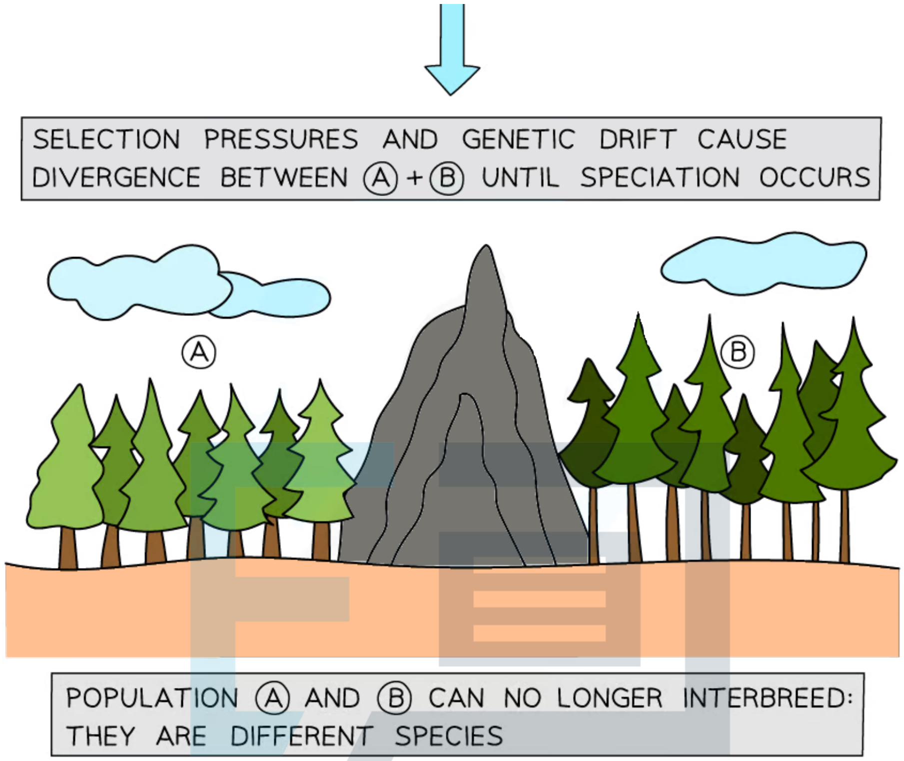
Speciation

- 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 can result from **geographical isolation**
  - This means that a species is separated into two populations by e.g. being on different islands or different sides of a mountain range
    - The ocean and the mountains in these examples are **geographical barriers**
- This creates two populations of the same species who cannot interbreed due to being in different places; as a result, **no exchange of genes,** or **gene flow,** will occur between them
- The different environmental conditions for the two populations might mean that **different alleles are advantageous**, so different alleles are more likely to be passed on and become more frequent in each population; this is the process of **natural selection**
  - The allele frequencies in the two populations change over time
  - Genetic drift can also affect allele frequencies
- Over time, the two populations may begin to differ **physiologically**, **behaviourally** and morphologically to such an extent that they can no longer interbreed to produce **fertile offspring**; speciation has occurred

Example: speciation in trees

- A population of trees exists in a mountainous habitat
- A new mountain range forms that **divides the species** into **two populations**
- The geographical barrier prevents the two populations from **interbreeding**, so there is **no gene flow** between them
- The two populations experience **different environments**, so different **alleles** become **advantageous**
- Different alleles are therefore more likely to be **passed on** in each population
- Different alleles become **more frequent** in each population
- Over thousands of years, the divided populations **form two distinct species** that can no longer interbreed to produce fertile offspring


UNOBSTRUCTED GENE FLOW
NO GENE FLOW BETWEEN A + B
A
B



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

Exam Tip

Speciation commonly occurs after a species **expands its range** to new geographical areas. This phenomenon is evidenced by the large number of endemic species found on islands such as the Hawaiian honeycreepers; a group of more than 50 bird species found in the Hawaiian archipelago!

5.1.2 Evolution: Evidence

Evidence for Evolution: Fossils

- Fossils are the **preserved remains** of organisms, or the traces left by organisms, such as footprints, burrows and faeces
  - These remains can be **preserved,** e.g. in **rocks,** by the process of petrification, during which the tissues of organisms are replaced with minerals
  - The fossil record is small in relation to the number of organisms that have ever lived, due to the **conditions for fossilisation** being so **rare**

- We can tell from fossils that organisms have **changed significantly over millions of years**
  - Fossils, as well as the rocks they are found in, can be **dated**, allowing us to accurately put fossil organisms into a **sequence** from oldest to youngest, and therefore see how organisms have changed through **evolutionary time**
  - The fossil record shows the kind of **progression** that the theory of evolution would lead us to expect, with older fossils showing **simpler life forms** and **complexity increasing with time**
  - The sequence of fossils aligns with **ecology groups**:
    - Plant fossils appear earlier in the fossil record than animals
    - Plants with the ability to be pollinated by insects appear before insect pollinators

  - Fossils can show evidence for **transitional species**, showing how one species could evolve into another e.g. *Ambulocetus* is a fossil that links amphibians with early whale-like organisms, and *Archaeopteryx* appears to link reptiles with birds

Evidence for Evolution: Selective Breeding

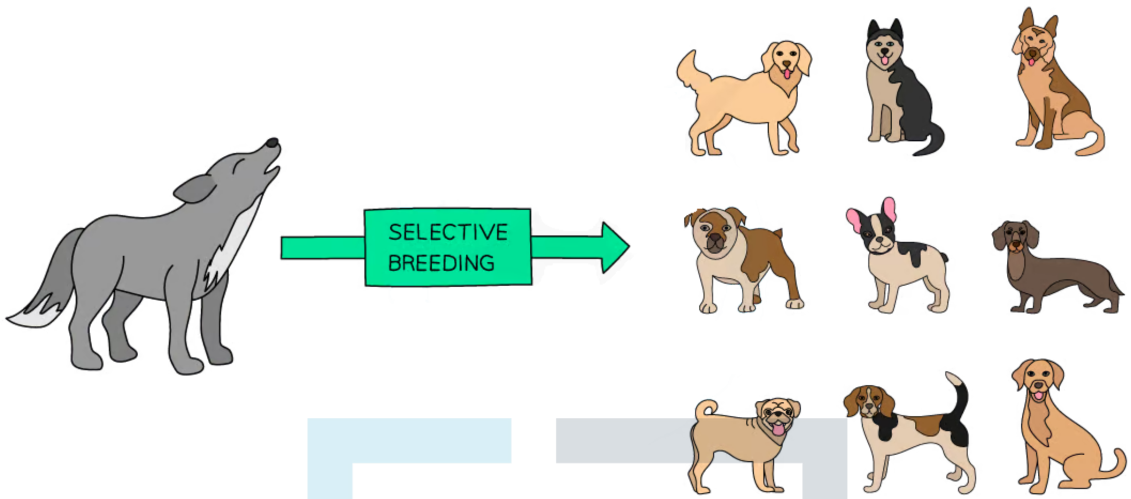
- **Selective breeding** is a process in which **humans choose** organisms with **desirable characteristics** and **breed them together** to increase the expression of these characteristics over **many generations**
  - The process of selective breeding has enabled humans to produce **desirable crop varieties** and **livestock with exaggerated characteristics** from **wild varieties and species,** e.g.
    - Desirable crop varieties include those with a high yield and disease resistance
    - Exaggerated characteristics in livestock include thick, heavy wool in sheep, and large volumes of milk produced in dairy cattle

- Selective breeding involves **changes to** heritable **characteristics over many generations**, and so it is an example of **evolution in action**
- 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

- Humans have been selectively breeding organisms for thousands of years, long before scientists understood genes and alleles

The process of selective breeding

1. The population shows **variation;** there are individuals with different characteristics
2. Breeders select **individuals with the desired characteristics;** selected individuals should not be closely related to each other
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



The wolf was bred selectively over thousands of years to produce a wide variety of domesticated dog breeds.

Evidence for Evolution: Homologous Structures

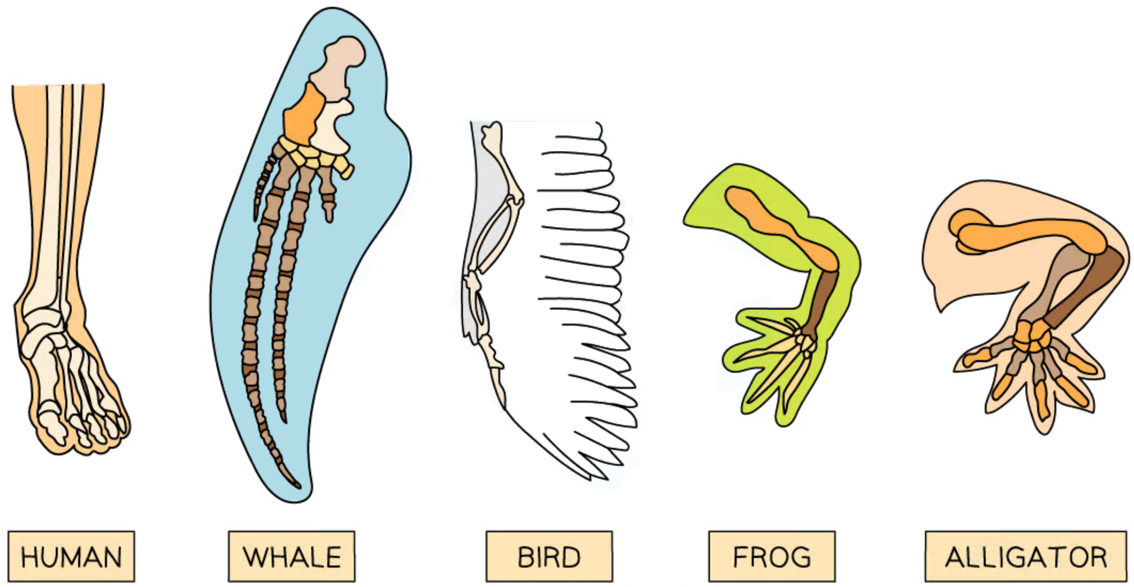
- **Homologous structures** are body parts that may **look and function very differently** but share **structural similarities**
- The limbs of animals are a good example of this; animals have many different mechanisms of motion and limb use, but the **basic arrangement of bones** in many different types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



The bone structure of the pentadactyl limb of a human, whale, bird, frog, and alligator; they all have the same basic layout despite having evolved for different functions

Vestigial structures

- Note that **vestigial structures**, while different in nature from homologous structures, **can also be explained by common ancestry**
  - Vestigial structures are those that **no longer have a function** in an organism
    - E.g. pelvis bones in snakes and whales and wings in flightless birds

- These structures tend to be **homologous to structures that perform a function** in other species
- The presence of vestigial structures suggests a **shared ancestry** with those species that possess a **fully functioning equivalent** of the same structure
- Vestigial structures are considered to be 'evolutionary leftovers'; they **would have had a function in an ancestral organism**, but a change in the environment led to **loss of use** e.g. a group of fish trapped in a dark cave would have no use for eyes
  - The presence of vestigial structures **does not harm** the species in which they are found, so there is no advantage to be gained by losing them completely; hence their persistence

NOS: Looking for patterns, trends and discrepancies; there are common features in the bone structure of vertebrate limbs despite their varied use

- When **patterns** and **trends** are observed in nature, scientists seek to find **explanations** that fit with these observations

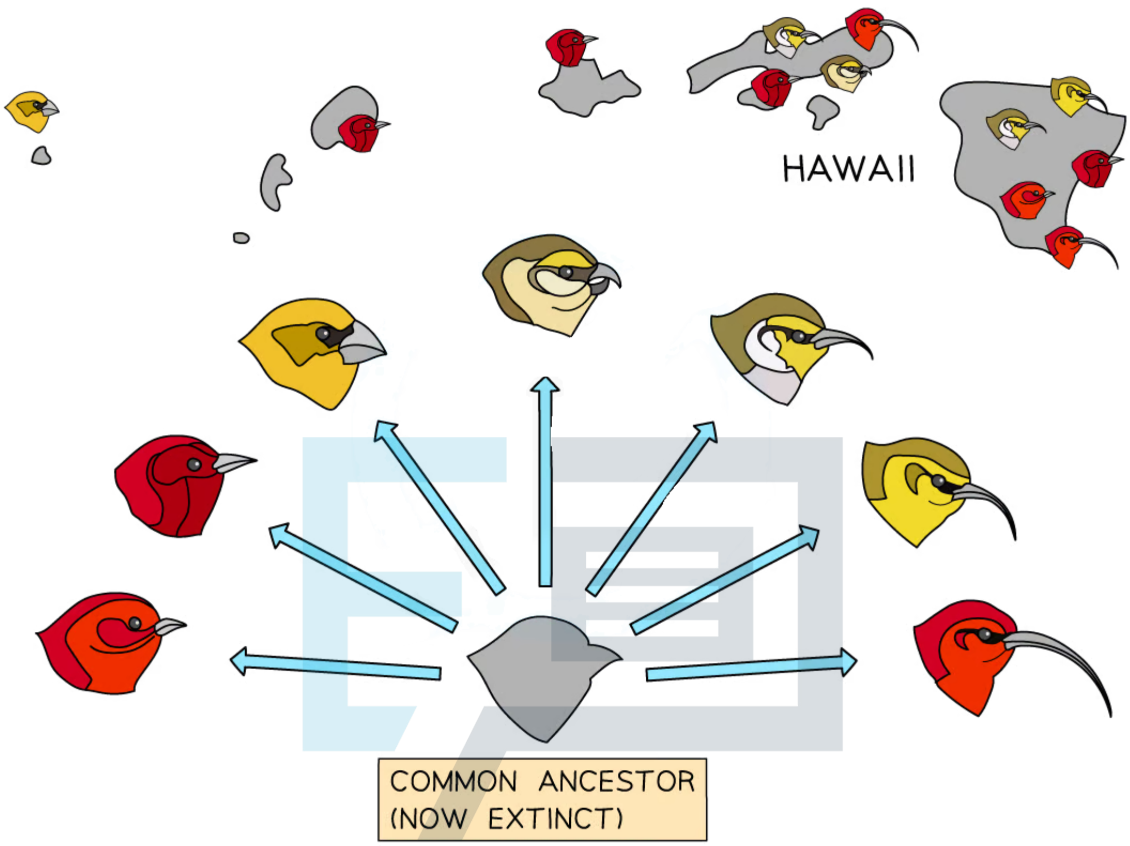
  - Here, scientists have observed a **pattern** in the limb structure of animals; despite **differences in appearance and function**, the **general structure** of the pentadactyl limb is **repeated** throughout the animal kingdom
  - The **explanation** that best fits this **observation** is that all animals evolved from a **common ancestor** that itself had a pentadactyl limb, in the process of **adaptive radiation**
    - This is the only explanation so far that makes sense of the **pattern of homologous structures** seen in nature, and it supports the theory that **organisms evolve over time**

Evidence for Evolution: Continuous Variation Between Populations

- Different populations of a species may show small amounts of variation between each population e.g. a few mm in beak length between bird populations
  - Beak length is an example of continuous variation
- The presence of **continuous variation** between populations **across their geographical range** can lead to **gradual divergence**
  - The term **divergence** refers to the species becoming **separate;** this is the process of speciation
- It can sometimes be difficult to make decisions about the point at which populations showing **continuous variation** have **diverged into different species**, and biologists sometimes **disagree** over whether separate populations are the same species, different subspecies, or separate species
  - E.g. Orca, or killer whale, populations can show different body shapes and markings, and there is debate among scientists around whether there is only one species of orca, several subspecies, or several species

Evidence for gradual divergence

- There are several examples around the world of groups of species found in a **particular geographical location** where the **differences between those species are small**, e.g.
  - Darwin's finches; many species of small bird observed by Darwin in the Galapagos islands
  - Hawaiian honeycreepers; a group of more than 50 bird species found in the Hawaiian archipelago
- The presence of **continuous variation** like this, between species, and **across their geographical range,** suggests that these species evolved by **gradual divergence** as a result of continuous variation between historical populations
- For example, Hawaiian honeycreepers show **continuous variation across their geographical range**; because of this, they are thought to have **evolved** from a **series of ancestral populations,** from which **gradual divergence** gave rise to many different species



The Hawaiian honeycreepers show continuous variation across their geographical range, suggesting that they diverged gradually from a common ancestor

Evidence for Evolution: Melanistic Insects in Polluted Areas

- Because evolution generally happens over **millions of years,** it is difficult to see it taking place, and we often have to rely on evidence from the **fossil record,** and evidence of **common ancestry** such as **homologous structures** and **continuous variation** between species
- There are, however, some examples of evolution, on a small scale, that show changes in heritable characteristics in a short time frame
  - E.g. in insects and bacteria
  - Examples like this rely on **short generation times**

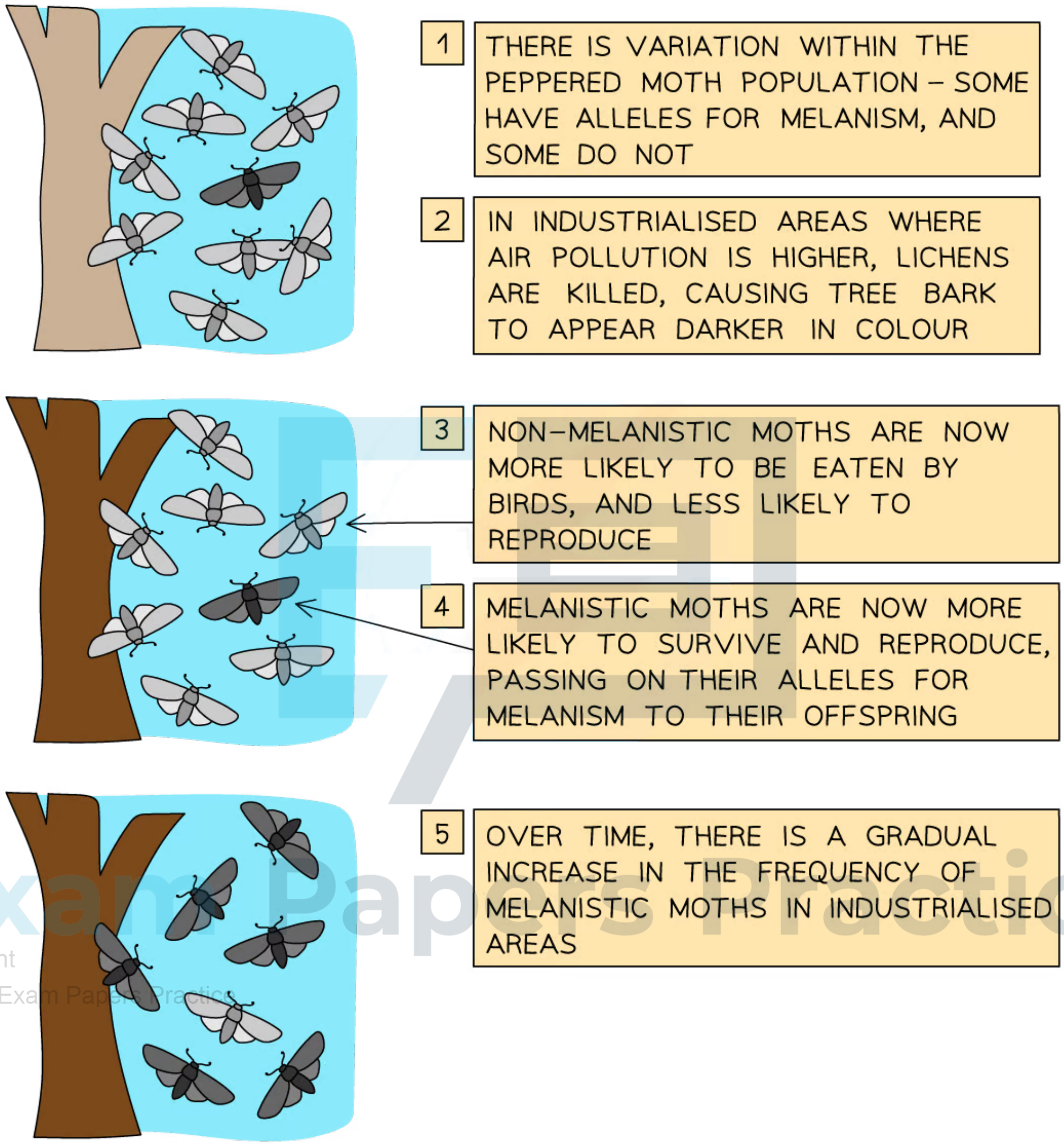
- A famous example of evolution taking place in insects is that of the **peppered moth** and **industrial melanism**
  - **Melanin** is a dark pigment produced in the cells; the more melanin is produced, the more **melanistic** an individual is said to be, and the darker it will be in colour

- It has been noted that **melanistic peppered moths** have become **more common** than non-melanistic individuals in industrialised parts of the UK where **air pollution has increased**
  - Air pollution kills organisms called **lichens** that grow on the **bark of trees**
  - In areas with clean air, lichens grow on tree bark, causing tree trunks and branches to appear **paler in colour**
    - In these areas, **non-melanistic moths** are **well camouflaged** against the trees, and therefore **more likely to survive** and **pass on the alleles** for non-melanism

  - In polluted areas, lichens are killed, causing tree trunks and branches to appear **darker in colour**
    - Here, **melanistic moths** are well camouflaged, increasing their chances of surviving and passing on the alleles for melanism

  - The frequency of **non-melanistic individuals therefore increases in non-polluted areas**, and the frequency of **melanistic individuals increases in polluted areas**

- This **change in the heritable characteristic** of melanin production **over generations** of moths shows **evolution taking place**



In areas with higher levels of air pollution the frequency of melanistic moths increases

5.1.3 Variation

Variation

- **Differences** exist between organisms of the same species
  - These differences are known as **variation**
  - Examples of variation include:
    - Coat colour in mammals
    - Body length in fish
    - Flower colour in flowering plants

- The process of natural selection can **only take place** when there is **variation in a population**
  - If every organism in a population is identical then no individual will be favoured over another
  - There will be no **advantageous characteristics** leading to **increased survival** and **chances of reproduction**, and so there would be no increased likelihood of passing on those **advantageous** alleles
  - In this situation, a population's characteristics would remain **the same over time** and it would be **unable to adapt** to any environmental changes

Causes of Variation

- **Variation** results from small differences in **DNA base sequences** between individual organisms within a population
- There are several sources of these differences in DNA base sequences:
  - Mutation
  - Meiosis
  - Random fertilisation during sexual reproduction

Mutation

- The original source of genetic variation is **mutation**
  - A mutation is a change in the **DNA base sequence** that results from a copying error during DNA replication

- Mutation results in the **generation of new** alleles
- Mutations that take place in the **dividing cells of the sex organs** lead to changes in the alleles of the gametes that are passed on to the next generation
  - A new allele may be **advantageous, disadvantageous** or have **no apparent effect**
  - An advantageous allele is **more likely to be passed on** to the next generation because it increases the chance that an organism will survive and reproduce
  - A disadvantageous mutation is **more likely to die out** because an organism with such a mutation is less likely to survive and reproduce

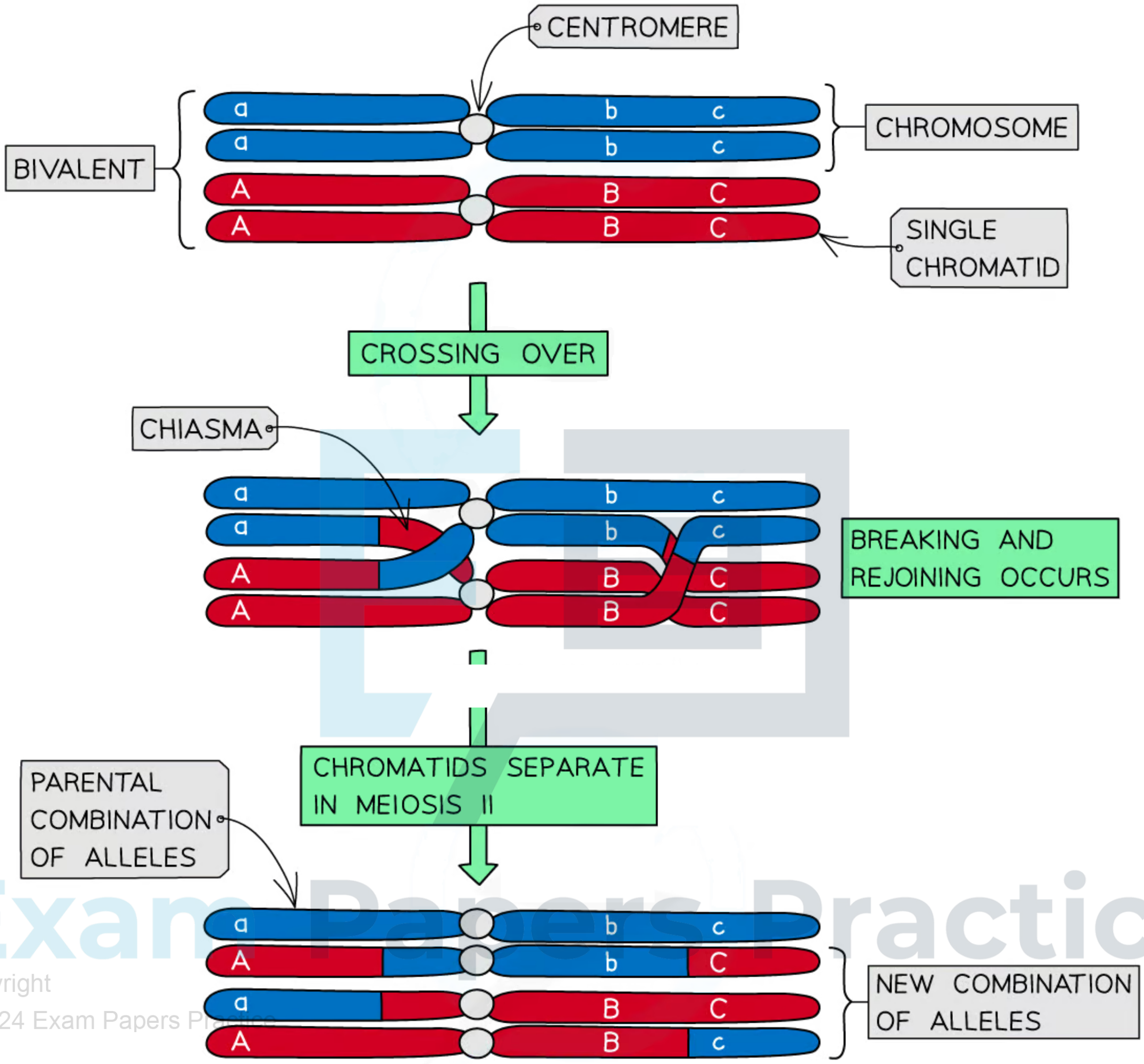
- Note that a mutation taking place in a body, or somatic, cell will **not be passed on to successive generations**, and so will have no impact on natural selection
- Mutation is the only source of variation in asexually reproducing species

Meiosis

- There are two main events during the process of **meiosis** that **generate variation**
  - Crossing over
  - Random orientation

- **Crossing over** is the process by which **homologous chromosomes** exchange alleles
  - During meiosis I homologous chromosomes pair up
  - The **non-sister** chromatids **can cross over** and get entangled
  - As a result of this, a section of chromatid from one homologous chromosome may **break and rejoin** with the chromatid from the other chromosome

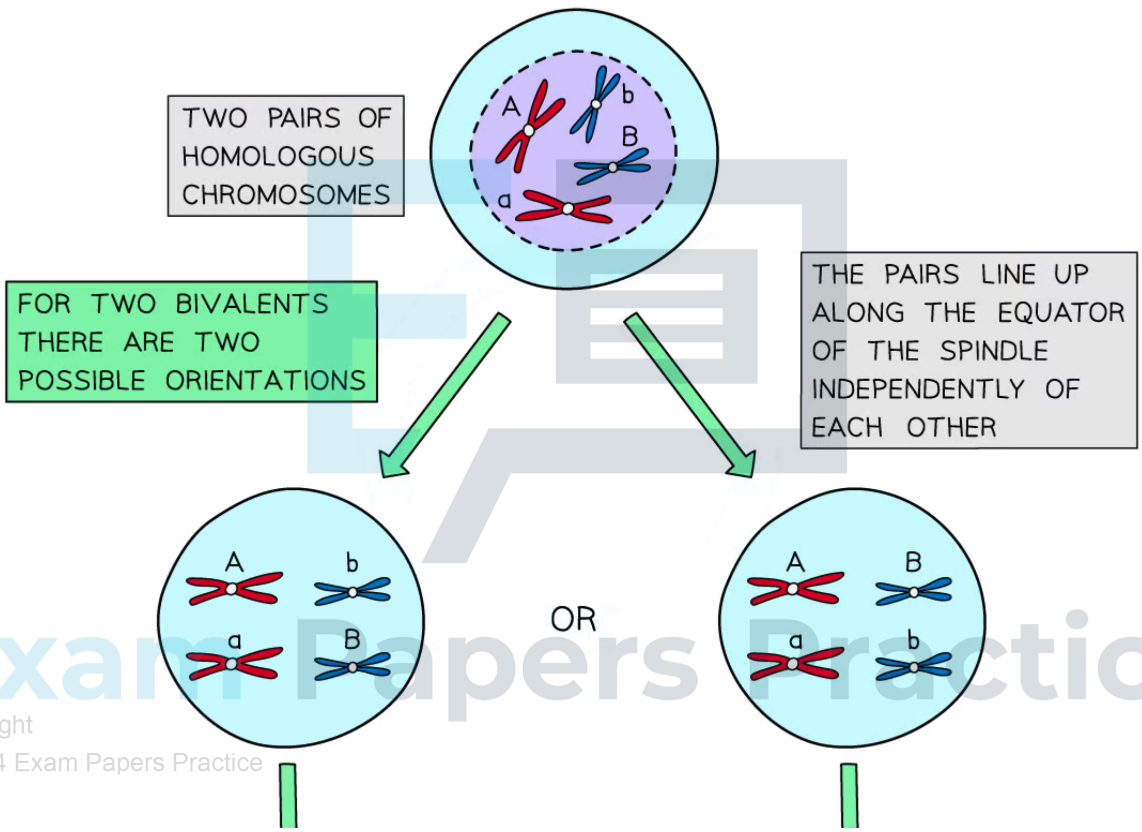
- This swapping of alleles is significant as it can result in a **new combination of alleles** on the two homologous chromosomes

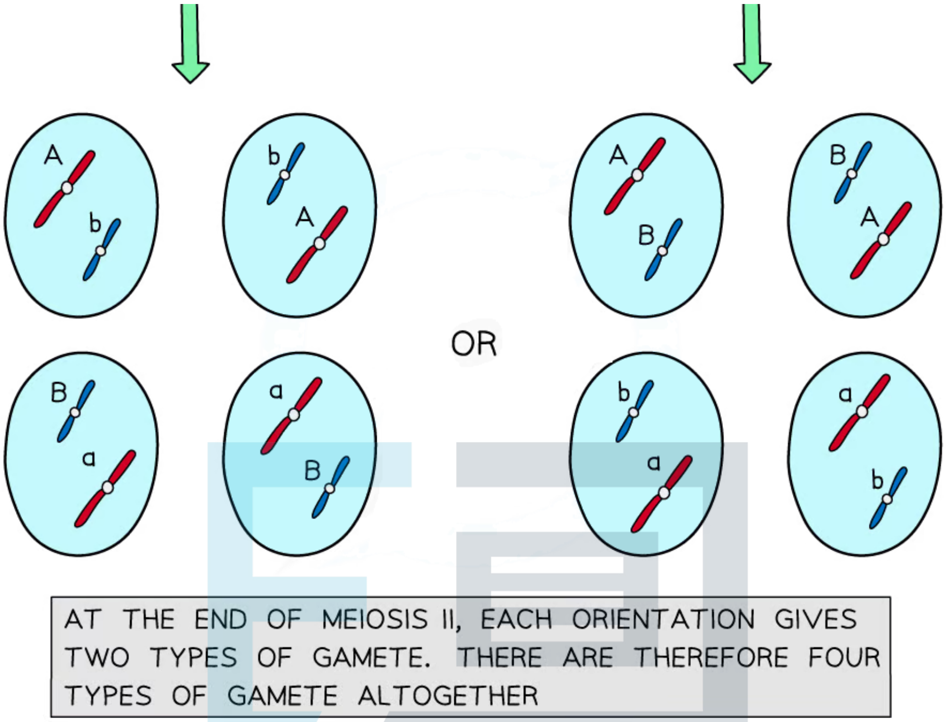


The process of crossing over can result in new combinations of alleles

- **Random orientation** occurs due to the **independent arrangement** of homologous pairs along the equator of the cell during metaphase I
  - **Each pair can be arranged with either chromosome on either side of the cell;** this is completely random
  - The **orientation of one homologous pair is independent**, or unaffected by the orientation of any other pair
  - This is sometimes described as **independent assortment**

- The homologous chromosomes on the equator of the cell are **pulled apart** to different poles, and will each end up in a separate daughter cell
- The combination of alleles that end up in each daughter cell depends on **how the pairs of homologous chromosomes were lined up**
- To work out the number of different possible chromosome combinations the formula 2^n can be used, where n corresponds to the number of chromosomes in a haploid cell
  - E.g. for humans this is 2^{23} which calculates as 8,324,608 different combinations

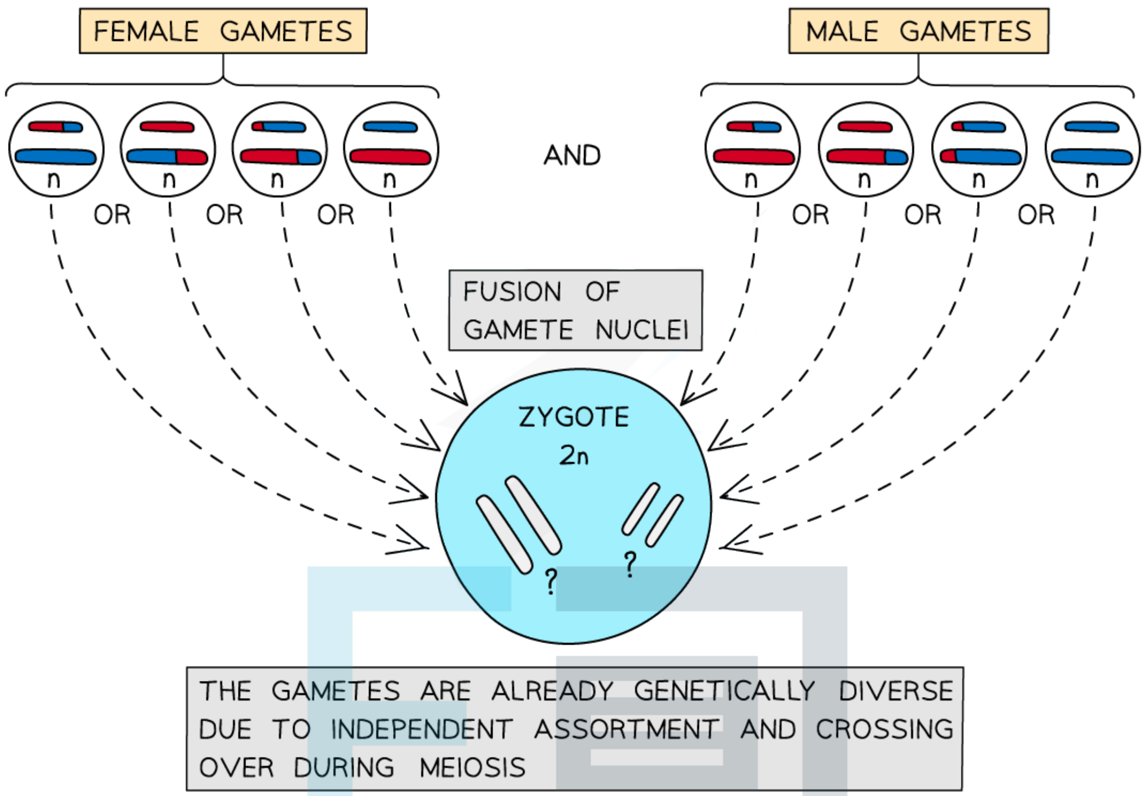




Random orientation of chromosomes

Random fertilisation during sexual reproduction

- **Meiosis** creates genetic variation between the gametes through **crossing over** and **independent assortment**
- This means each gamete carries substantially **different alleles**
- During fertilisation any male gamete can fuse with any female gamete to form a zygote
- This **random fusion of gametes** at fertilisation creates genetic variation **between zygotes** as each will have a unique combination of alleles
- There is an almost zero chance of individual organisms resulting from successive sexual reproduction being genetically identical



The random fusion of gametes during fertilisation

Sources of Genetic Variation Table

Process	Mechanism	Consequences
Independent assortment of homologous chromosomes during metaphase I	Random alignment of chromosomes results in different combinations of chromosomes and different allele combinations in each gamete	Genetic variation between gametes produced by an individual
Crossing over of non-sister chromatids during prophase I	Exchange of genetic material between non-sister chromatids leads to new combinations of alleles on chromosomes. It can also break linkage between genes	Genetic variation between gametes produced by an individual
Random fusion of gametes during fertilization	Any male gamete is able to fuse with any female gamete (Random mating in a species population)	Genetic variation between zygotes and resulting individuals
Mutation	Random change in the DNA base sequence results in the generation of a new allele. Mutation must exist within gam-etes for it to passed onto future generations	Genetic variation between individuals within a species population

Adaptations

- Adaptations can be defined as:
  - **Characteristics that cause individuals to be well suited to their environment and methods of living**

- When describing an adaptation it is always a good idea to relate the **structure** of a characteristic to its **function**, e.g.
  - Fish gills are an adaptation for survival underwater; they have a very **large surface area**, enabling them to **maximise oxygen absorption** from water
  - The thick fur of a polar bear is an adaptation for survival in a cold environment; it is **thick**, trapping a layer of warm air next to the polar bear's body and **providing insulation**
  - Different beak shapes in birds enable the consumption of different types of food; some species of finch have **short, cone-shaped beaks** that enable them to **crack nuts and seeds**

- Adaptations arise in species gradually by **evolution** through the **process of natural selection**
  - In a **slowly changing environment**, populations are able to **adapt** by natural selection and survival continues
  - If an **environment changes quickly**, the process of **natural selection is too slow** and adaptation cannot occur fast enough; in this situation, a population must **migrate** to a different environment or it will go **extinct**

Exam Tip

Remember that adaptation occurs as a result of **natural selection**; a process that acts on **randomly occurring variation**, and does not occur as a direct, purposeful response to an environment; avoid any statements that imply that adaptations occur 'so that' an organism can survive in its environment. Instead, it is correct to say that adaptations occur by **natural selection** as a result of **random variation** in populations.

5.1.4 Natural Selection

Overproduction of Offspring

- The **number of offspring**, or young, produced in each breeding event **differs between species**
  - Some species produce **small numbers** of young, e.g. elephants usually give birth to just one baby per pregnancy
  - Some species produce **many offspring** e.g. some species of ant can lay 3-4 million eggs in one go

- It is more usual for organisms to produce **multiple offspring**, to the extent that there are **more offspring produced than can be supported** by the surrounding environment
  - Darwin noticed this, and named the phenomenon '**overproduction of offspring**'

- Overproduction of offspring means that there is **always competition** for resources

Survival of the Fittest

- In any habitat there are **environmental factors** that **affect survival chances**
  - E.g. predation, competition for food, and disease
  - Environmental factors that influence survival chances are said to act as **selection pressures**
- In any population, due to the variation present, some individuals will have **characteristics** that make them **better adapted** for survival
  - For example, lions that are stronger and faster are more likely to be able to catch prey and therefore more likely to survive
  - This is sometimes described as '**survival of the fittest**'
- Individuals that are well adapted and **survive into adulthood** are **more likely to find a mate** and **reproduce**, producing **many offspring**
- Individuals that are less well adapted **do not survive long** into adulthood are likely to **reproduce less often** than those that survive for longer, so producing **fewer offspring**
  - These individuals may not reach adulthood and so do **not get the chance to reproduce** at all

Exam Tip

When answering exam questions, be careful not to imply that organisms better adapted to their environments are guaranteed to survive. Instead, you should say that they are **more likely** to survive. Organisms that are less suited to an environment are still able to survive and potentially reproduce within it, but their chance of survival and reproduction is lower than their better-adapted peers.

Inheritance

- Many of the **characteristics** that affect an individual's chances of survival are determined by the alleles of genes present in their DNA
- Characteristics that are **determined by alleles** are heritable
  - Heritable characteristics can be **physical** e.g. the length of a giraffe's neck, or **behavioural** e.g. the innate behaviour of a woodlouse moving towards a dark hiding place
- Individuals with characteristics that **increase their chances of survival** are likely to produce **more offspring**
- This means that they are more likely to **pass on the alleles** that code for these **advantageous characteristics** to their offspring
- Note that **non-heritable characteristics are not passed on to offspring**
  - Non-heritable characteristics are those **acquired during the lifetime** of an organism e.g. gaining weight after eating lots of nuts and berries in autumn, or being injured by a predator

Change in Frequency of Characteristics

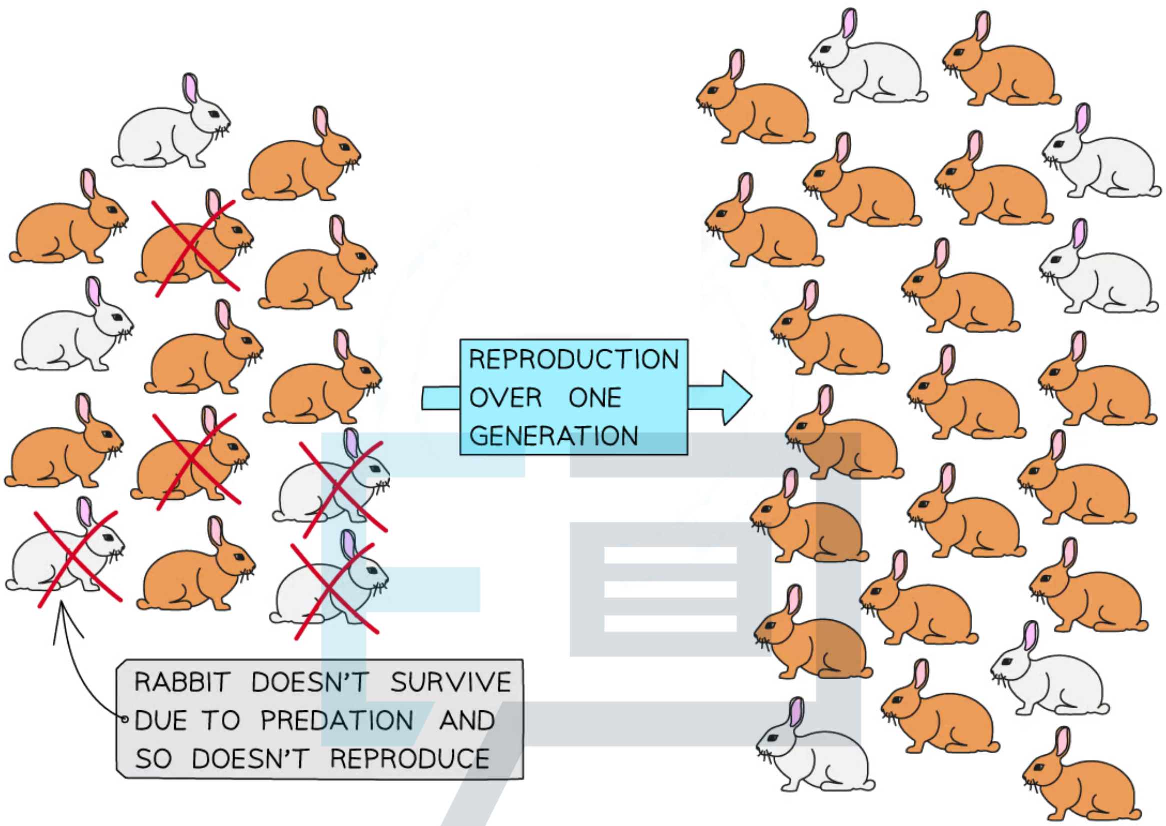
- **Natural selection** can be defined as
  - **The process by which organisms that are better adapted to their environment survive, reproduce, and pass on their advantageous alleles, causing advantageous characteristics to increase in frequency within a population**

- The **increased survival chances** of individuals with **advantageous alleles** mean that advantageous characteristics are **more likely to be passed down** through the generations
- The number of individuals in a population with a particular favourable characteristic will increase over time; the characteristic is said to **increase in frequency**
- Eventually this favourable characteristic will become the **most common** of its kind in the population; the population can be said to have **adapted** to its environment by the process of **natural selection**
- While favourable characteristics increase in frequency by natural selection, **unfavourable characteristics decrease in frequency** by the same process
  - Individuals with unfavourable characteristics are less likely to survive, reproduce, and pass on the alleles for their characteristics, so unfavourable characteristics are eventually lost from the population

An example of natural selection in rabbits

- **Variation** in fur colour exists within a rabbit population
  - One allele codes for **brown fur** and another for **white fur**

- Rabbits have natural predators such as foxes which act as a **selection pressure**
- The brown rabbits are **more likely to survive** and **reproduce** due to having more effective camouflage
- When the brown rabbits reproduce they **pass on their alleles** to their offspring
- The frequency of brown fur alleles in the population will increase
- **Over many generations,** the **frequency** of **brown** fur will **increase** and the frequency of white fur will decrease



Selection pressures acting on a rabbit population for one generation; predation by foxes causes the frequency of brown fur in rabbits to increase and the frequency of white fur in rabbits to decrease

5.1.5 Natural Selection Examples

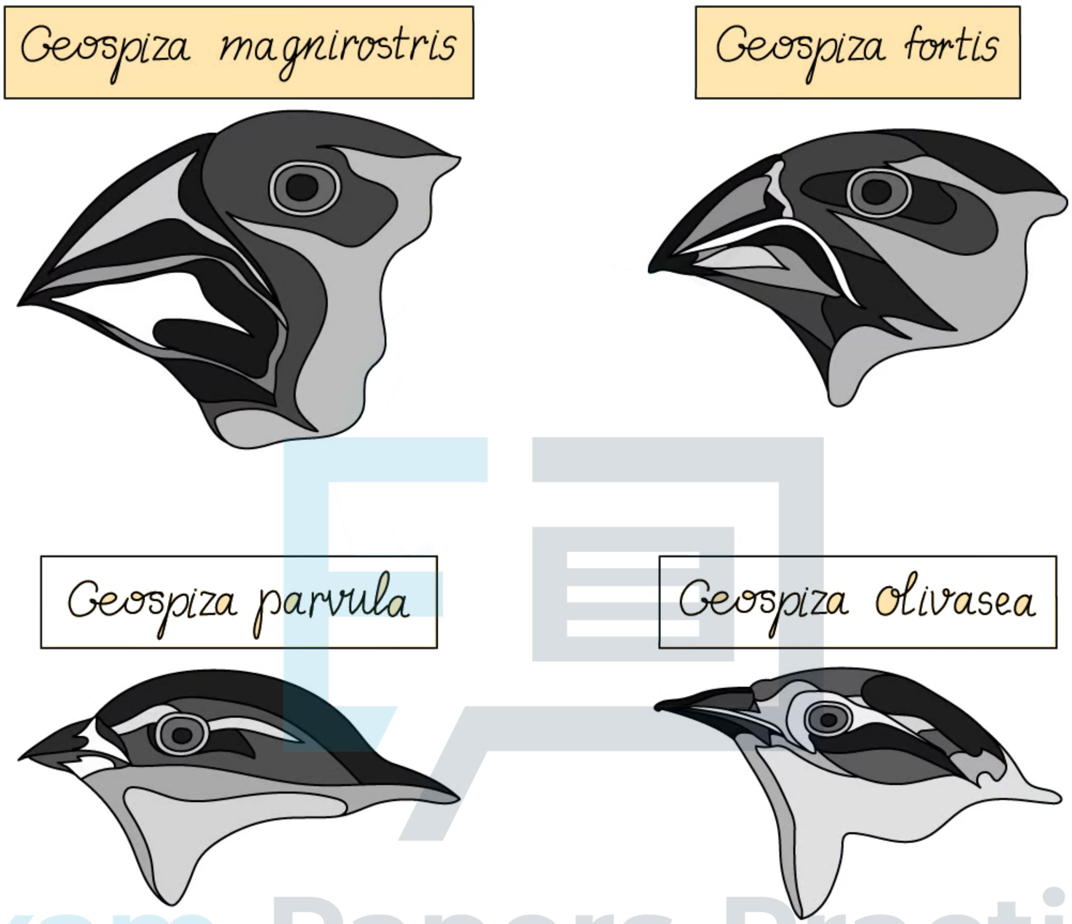
Examples of Natural Selection

- Because evolution by natural selection generally happens over **millions of years**, it is difficult to see it taking place, and we often have to rely on evidence from the **fossil record**, and evidence of **common ancestry** such as homologous structures and continuous variation between species
- There are, however, some examples of evolution, on a small scale, that show changes in heritable characteristics in a **short time frame**, e.g.
  - Finches on Daphne Major
  - Antibiotic resistance in bacteria

Finches on Daphne Major

- **Daphne major** is an island in the Galapagos, the wildlife of which inspired **Charles Darwin** to come up with his **theory of evolution by natural selection**
- He noticed that some of the birds of the Galapagos, identified as **finches**, bore a strong resemblance to each other, but that they also showed **differences that were specific to each island**
  - Scientists now know that Darwin's famous finches are not technically finches at all, but they are usually still referred to as 'Darwin's finches'

- In particular, finch **beak shape** and **size** corresponded to the **diet available** to them on **each island**



Darwin noticed that Galapagos finches had beaks that were perfectly adapted to the food sources available on the island on which they lived

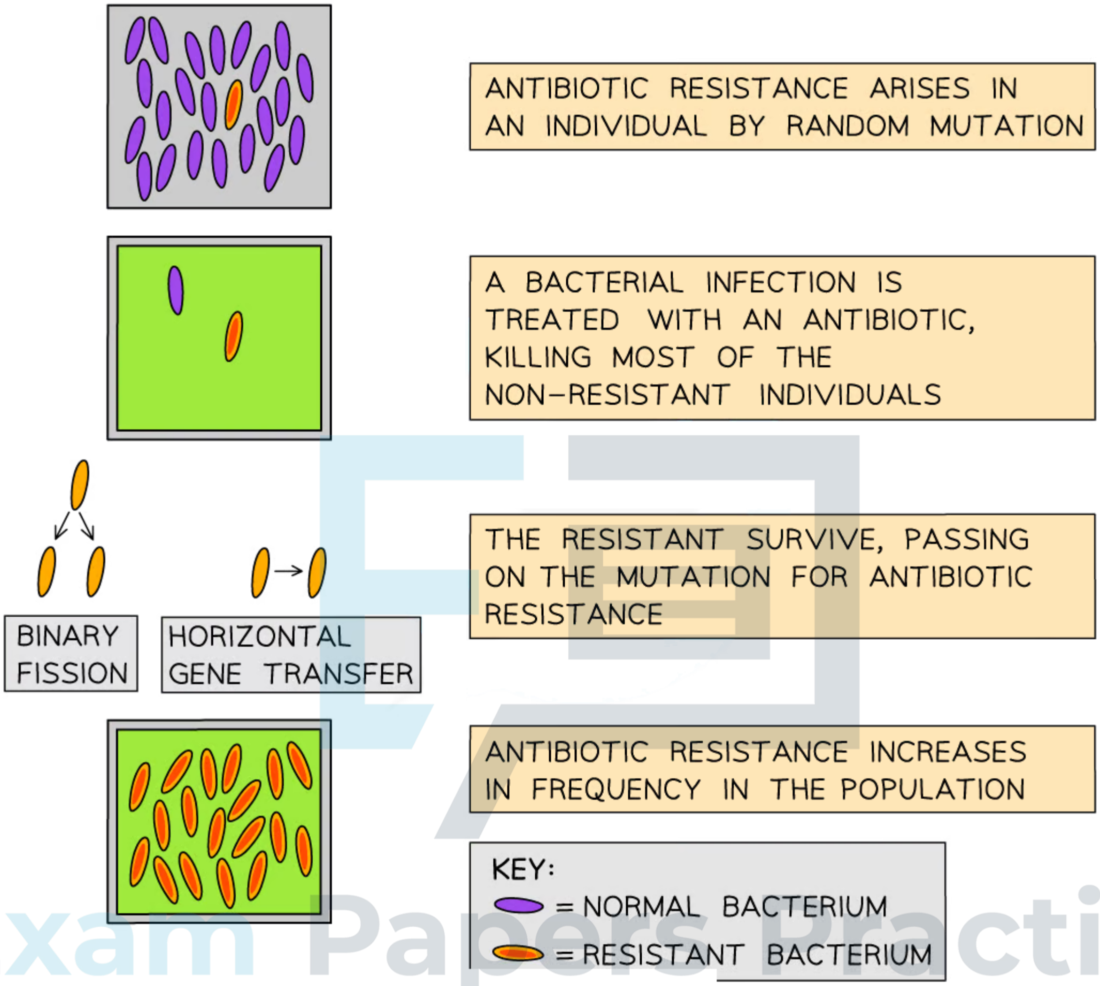
- Since Darwin, many **evolutionary biologists** have studied the wildlife of the Galapagos
- Scientists **Peter** and **Rosemary Grant** carried out a long-term study on the finch species *Geospiza fortis* on the island of **Daphne Major**
- *G. fortis'* diet consists of seeds, which when **weather conditions are normal** are **plentiful, small,** and **soft,** but which become **fewer, larger,** and **tougher** during **times of drought**
- The Grants observed a **wide range of beak sizes** in *G. fortis* when weather conditions were normal, but found that during periods of drought **beak size increased**
  - When seeds were plentiful, small, and soft, there was **no advantage** for individuals with larger beaks, and so alleles for different beak sizes were **passed on** to *G. fortis* offspring **in equal proportions**
  - When seeds were fewer, larger, and tougher, finches with larger beaks had an **advantage** when competing for food, and were therefore more likely to **survive** and **pass on the alleles**

for large beak size, leading to an **increase in frequency of large beaks** in the population

- The observation that finches with larger beaks produce large-beaked offspring while finches with smaller beaks produce smaller-beaked offspring suggests that beak size is **largely determined by genes**, and so is heritable
- The heritable nature of beak size means that *G. fortis* can **adapt to a changing environment** by the process of **natural selection**

Antibiotic resistance in bacteria

- **Antibiotics** are chemical substances made by some **fungi** or **bacteria** as a defence mechanism
- They **kill bacteria** by targeting processes and structures that are specific to bacterial cells
  - Antibiotics are **effective against bacteria** but **not against viruses**, and usually have **no effect on animal cells**
- The use of antibiotics has **increased significantly** since they were first introduced in the 1930s, **saving millions of lives**
- Since their discovery and widespread use **antibiotic resistance** has developed in many different types of bacteria
  - Antibiotic resistant bacteria are not killed by antibiotics
- Antibiotic resistance is a **heritable** characteristic and so develops in bacterial populations by the process of **natural selection**
  - Bacteria, like all organisms, have mutations in their DNA that give rise to **variation**
  - A mutation may give rise to **resistance to a particular antibiotic** in an individual bacterial cell
  - If a bacterial infection is treated with that antibiotic, a bacterial individual with the mutation for resistance is likely to **survive**
    - The antibiotic in this situation acts as a **selection pressure** in the same way that a predator would in a rabbit population
  - The bacterial cell with the resistance mutation will **reproduce** by binary fission, **passing on the mutation** and causing antibiotic resistance to **increase in frequency** in the population
    - Bacterial cells are also able to transfer genes to each other by a process called horizontal gene transfer, further increasing the number of individuals with the resistance mutation
- Note that if antibiotic use stops, an **antibiotic resistance mutation will no longer be advantageous**, and it will not be passed on to offspring **any more often than the original non-resistant form of the gene**
  - Antibiotics should not be used any more often than necessary so that a **selection pressure** is not provided; this will reduce the likelihood of an antibiotic resistant population developing



Antibiotic-resistant bacterial populations can evolve by natural selection

- Natural selection takes place very quickly in bacterial populations because
  - Bacterial populations contain **many individuals**, so the **chances of an advantageous mutation appearing are higher** than in other types of organisms
  - They can **reproduce very quickly**, meaning that generation times are short and any mutations that do arise can be **passed on to many offspring in a very short time**
    - Bacteria can reproduce as often as every 20 minutes
  - Bacteria can **transfer genes horizontally**, further increasing the rate at which advantageous mutations can spread
- Antibiotic resistance is a huge problem; antibiotics have been revolutionary in the treatment of disease, and losing them as a medical tool would be devastating

- Scientists are looking for ways to **reduce the rate at which resistance evolves** e.g. by reducing the use of antibiotics and the spread of infection, as well as seeking out **alternatives to current antibiotics** e.g. new antibiotics and other types of antibacterial agent

NOS: Use theories to explain natural phenomena; the theory of evolution by natural selection can explain the development of antibiotic resistance in bacteria.

- Scientists can gather information about the world by **observing events**, or **phenomena**
- They **formulate theories** that seek to explain observed events
- In the case of antibiotics, it has been **observed** that antibiotic resistance in bacteria is on the increase
  - In particular it has been noticed that once an antibiotic starts to be used to treat a particular infection, resistance rates begin to rise

- Scientists use the **theory** of natural selection to **explain this observation**
  - Antibiotics act as a selection pressure
  - Resistant individuals are 'selected' when non-resistant bacteria are killed by treatment
  - Resistant individuals survive, reproduce, and pass on the resistance characteristic
  - Resistant individuals increase in frequency

- **Understanding the mechanism** by which resistance evolves means that scientists have a better chance of **solving** or **reducing the problem**
  - E.g. by reducing the selection pressure, i.e. the use of antibiotics, natural selection can be slowed down

Exam Tip

While you are expected to know the examples of natural selection described above, you could also be given an unfamiliar example, so make sure that you can describe the **process of natural selection**:

- Within a species, there is always **variation** in **heritable** characteristics due to chance mutation
- Populations will have **selection pressures** acting on them
- Individuals with advantageous characteristics are more likely to **survive** and **reproduce**
- Heritable advantageous characteristics are **passed on** to offspring
- The advantageous characteristic **increases in frequency**