



# DP IB Biology: HL



Your notes

## 5.1 Evolution & Natural Selection

### Contents

- \* 5.1.1 Evolution
- \* 5.1.2 Evolution: Evidence
- \* 5.1.3 Variation
- \* 5.1.4 Natural Selection
- \* 5.1.5 Natural Selection Examples



Your notes

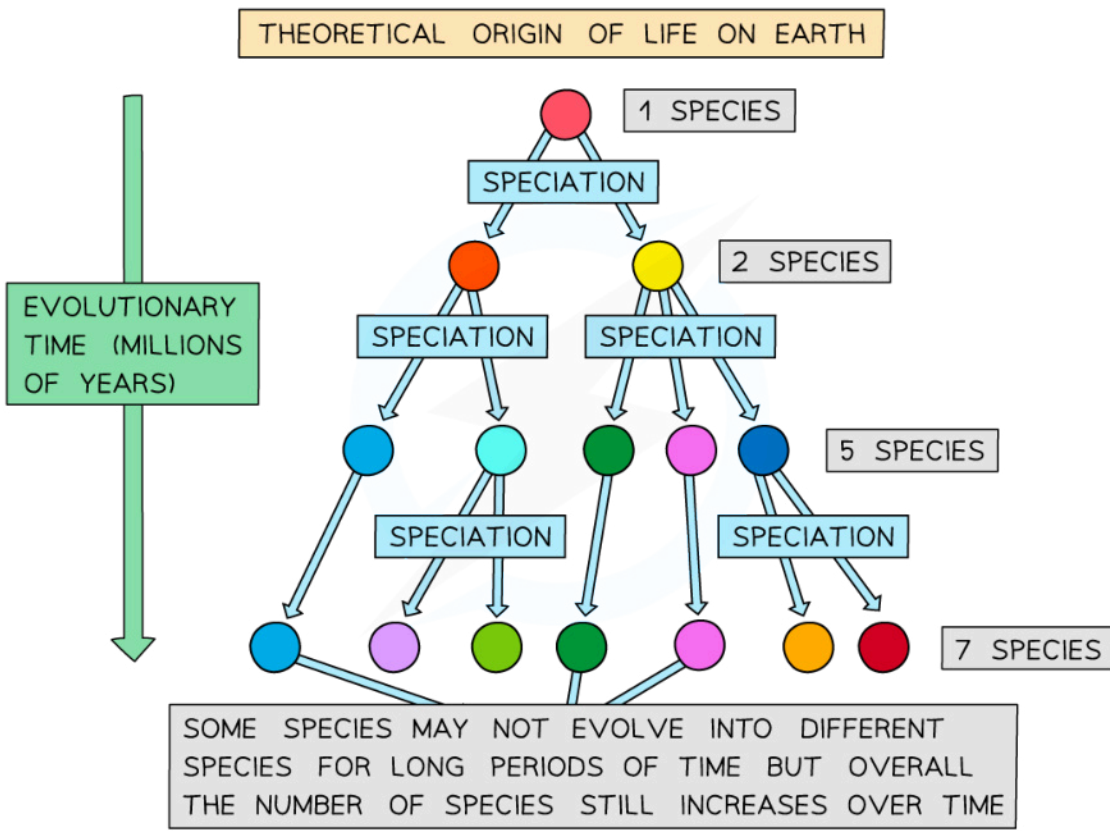
## 5.1.1 Evolution

### 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



Your notes



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



Your notes

## Speciation

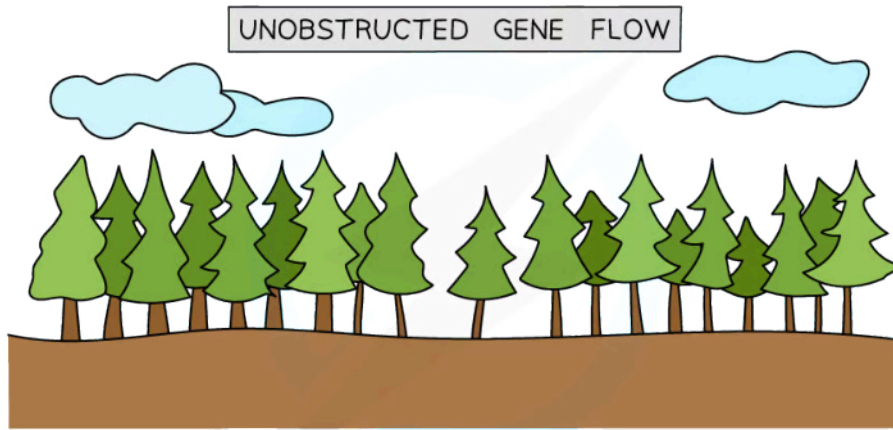
- The **theory of evolution** states that species **do not stay the same**, but change over time; this can lead to the process of **speciation**
- Speciation can be defined as:
  - **The development of new species from pre-existing species over time**
- Speciation can result from **geographical isolation**
  - 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

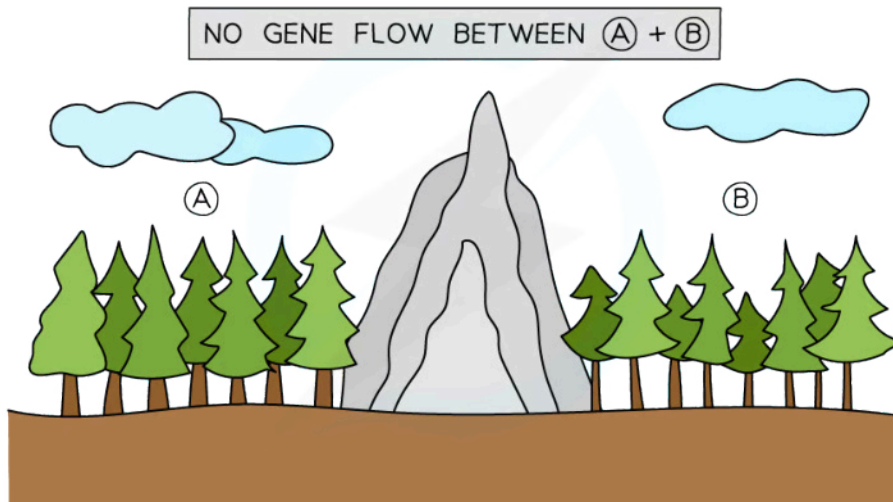
- A population of trees exists in a mountainous habitat
- A new mountain range forms that **divides the species** into **two populations**
- The geographical barrier prevents the two populations from **interbreeding**, so there is **no gene flow** between them
- The two populations experience **different 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



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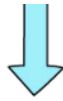
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SELECTION PRESSURES AND GENETIC DRIFT CAUSE DIVERGENCE BETWEEN (A) + (B) UNTIL SPECIATION OCCURS



POPULATION (A) AND (B) CAN NO LONGER INTERBREED: THEY ARE DIFFERENT SPECIES

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

 **Examiner 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!



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## 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



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## 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

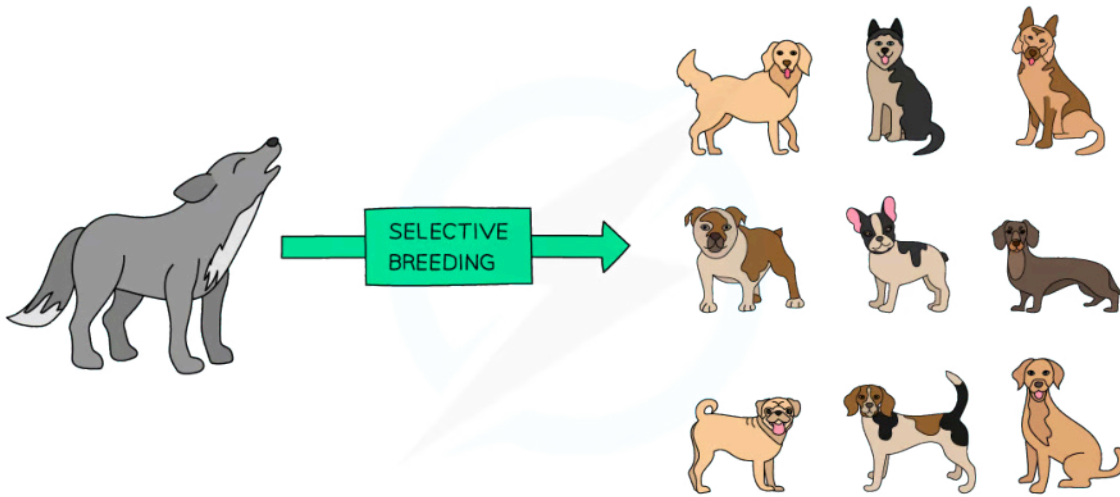
### The process of selective breeding

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





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



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## Evidence for Evolution: Homologous Structures

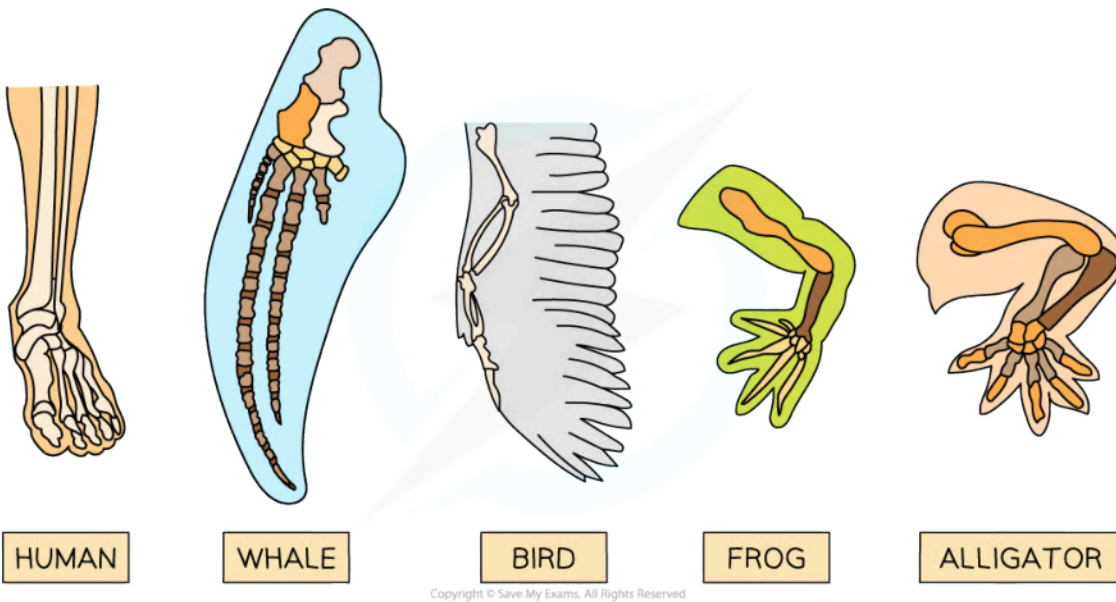
- **Homologous structures** are body parts that may **look and function very differently** but share **structural similarities**
- The limbs of animals are a good example of this; animals have many different mechanisms of motion and limb use, but the **basic arrangement of bones** in many different types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



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*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**



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## Evidence for Evolution: Continuous Variation Between Populations

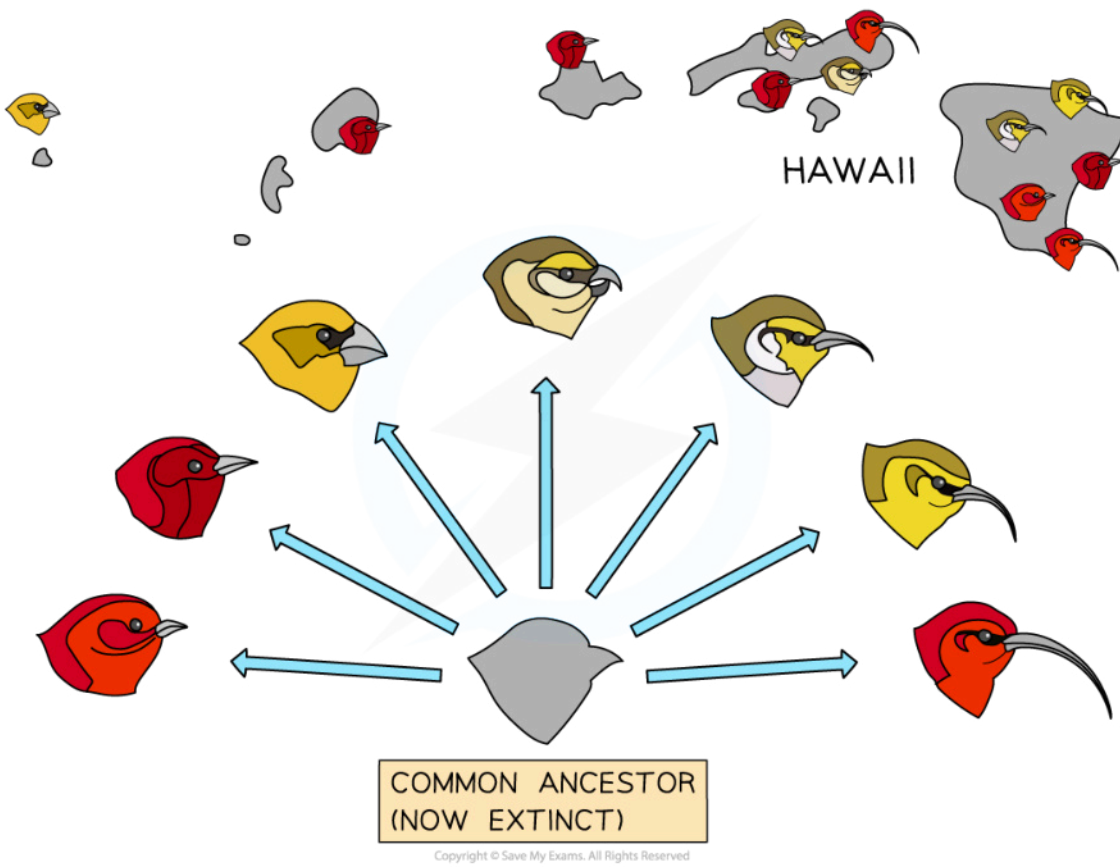
- Different populations of a species may show small amounts of variation between each population e.g. a few mm in beak length between bird populations
  - Beak length is an example of continuous variation
- The presence of **continuous variation** between populations **across their geographical range** 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



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**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

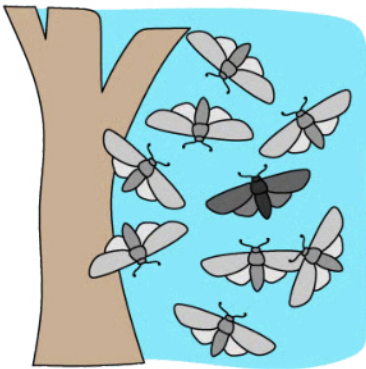


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- Because evolution generally happens over **millions of years**, it is difficult to see it taking place, and we often have to rely on evidence from the **fossil record**, and evidence of **common ancestry** such as **homologous structures** and **continuous 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**

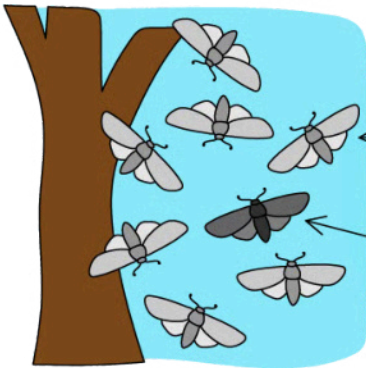


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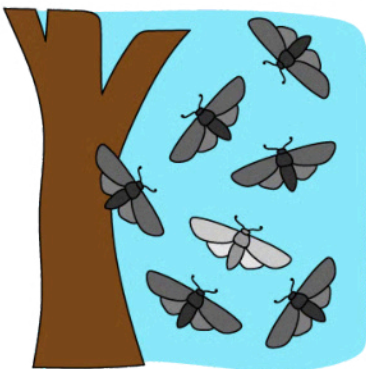
1 THERE IS VARIATION WITHIN THE PEPPERED MOTH POPULATION – SOME HAVE ALLELES FOR MELANISM, AND SOME DO NOT

2 IN INDUSTRIALISED AREAS WHERE AIR POLLUTION IS HIGHER, LICHENS ARE KILLED, CAUSING TREE BARK TO APPEAR DARKER IN COLOUR



3 NON-MELANISTIC MOTHS ARE NOW MORE LIKELY TO BE EATEN BY BIRDS, AND LESS LIKELY TO REPRODUCE

4 MELANISTIC MOTHS ARE NOW MORE LIKELY TO SURVIVE AND REPRODUCE, PASSING ON THEIR ALLELES FOR MELANISM TO THEIR OFFSPRING



5 OVER TIME, THERE IS A GRADUAL INCREASE IN THE FREQUENCY OF MELANISTIC MOTHS IN INDUSTRIALISED AREAS

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



## 5.1.3 Variation



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### 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



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## 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

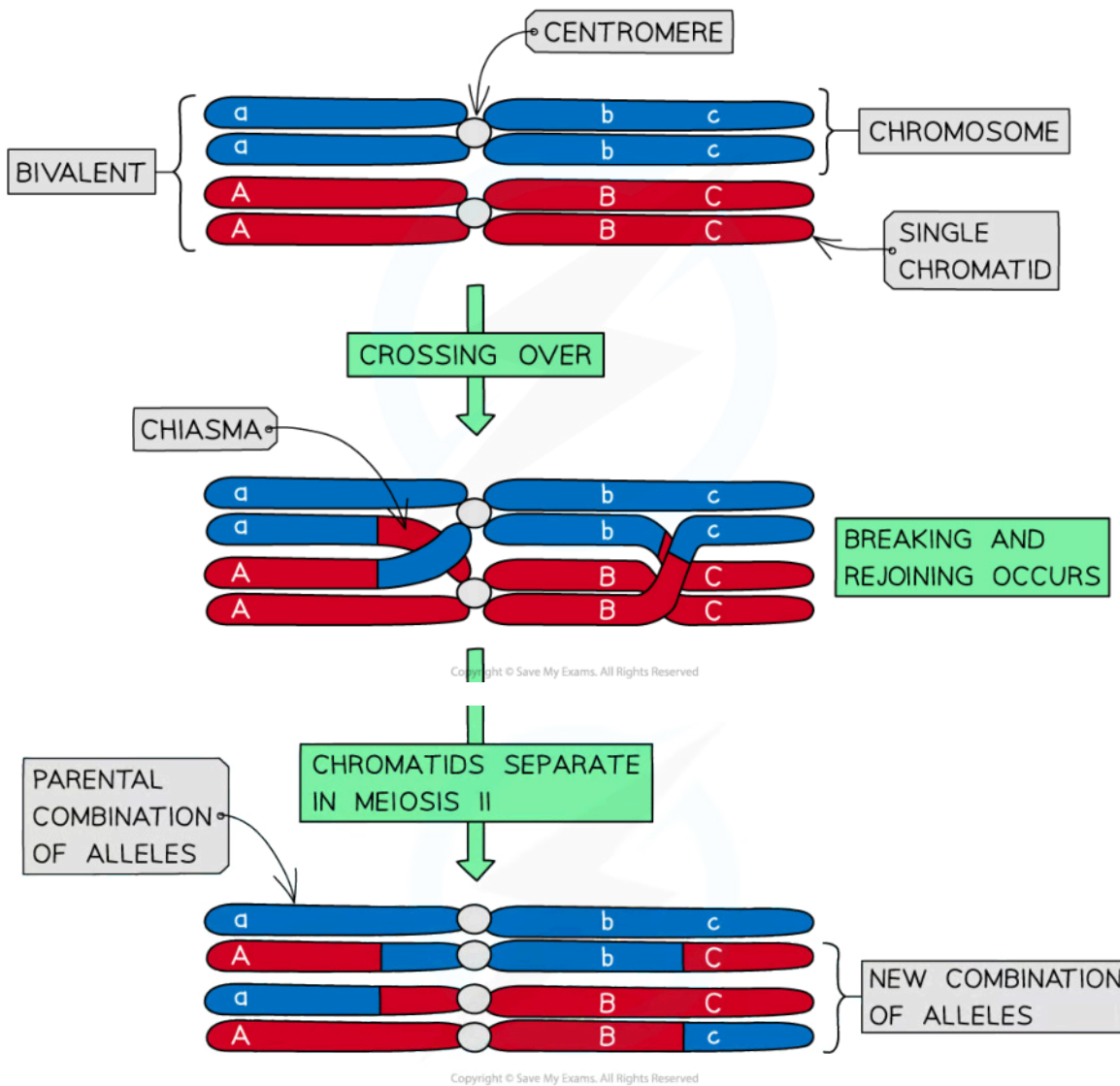
- The original source of genetic variation is **mutation**
  - A mutation is a change in the **DNA base sequence** that results from a copying error during DNA replication
- Mutation results in the **generation of new** alleles
- Mutations that take place in the **dividing cells of the sex organs** lead 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



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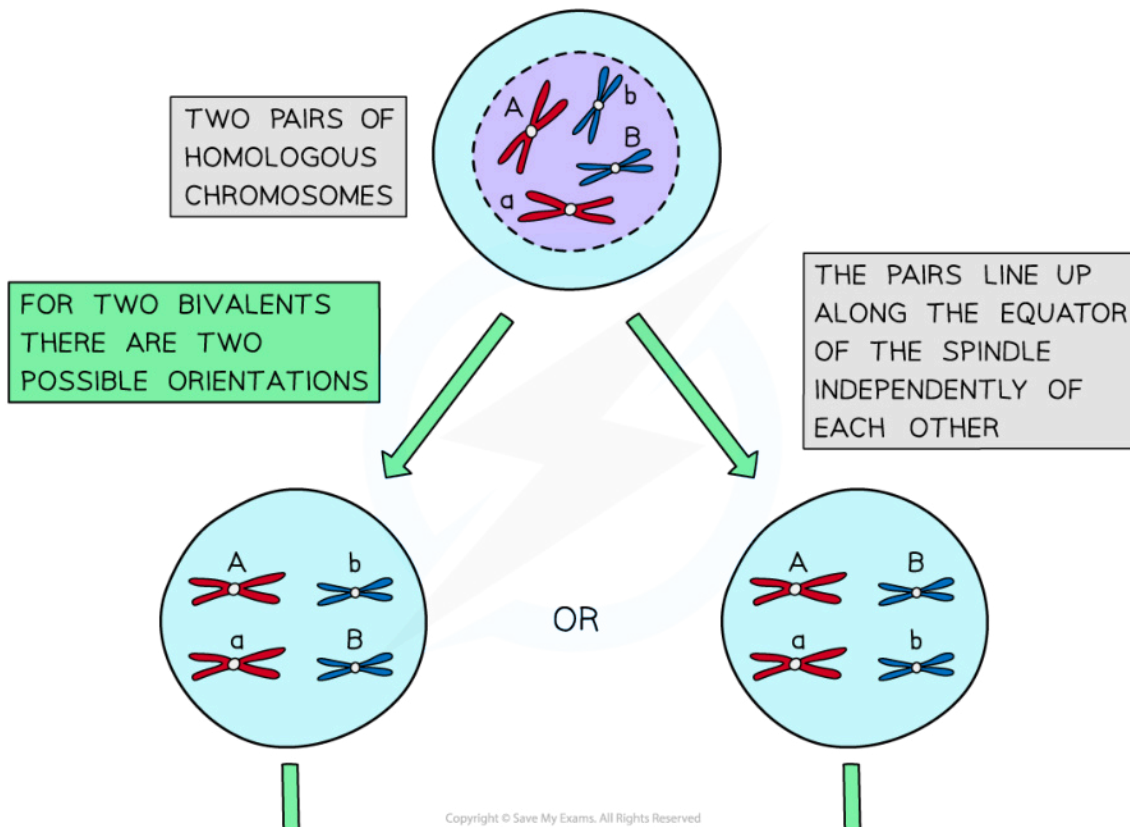
*The process of crossing over can result in new combinations of alleles*

- **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**



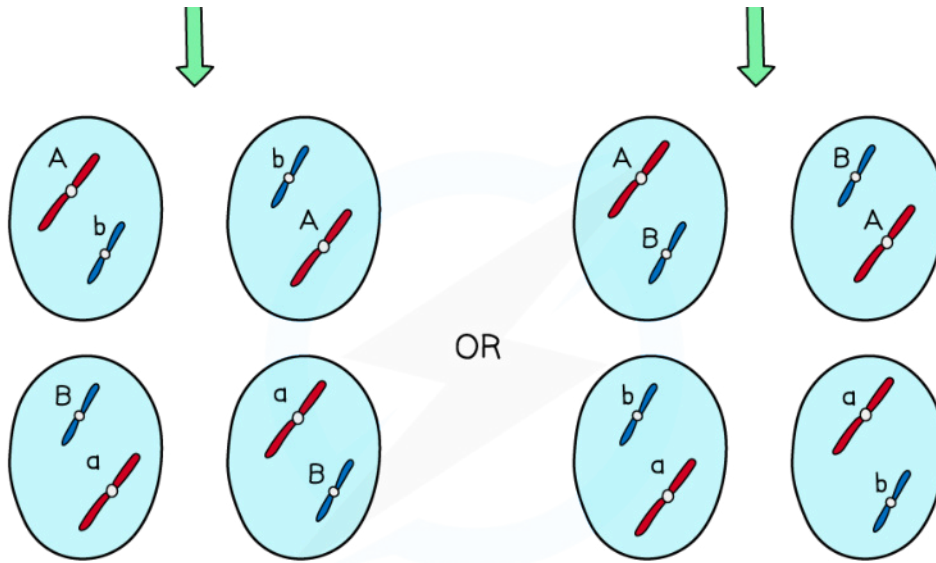
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- The homologous chromosomes on the equator of the cell are **pulled apart** to different poles, and will each end up in a separate daughter cell
- The combination of alleles that end up in each daughter cell depends on **how the pairs of homologous 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





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AT THE END OF MEIOSIS II, EACH ORIENTATION GIVES TWO TYPES OF GAMETE. THERE ARE THEREFORE FOUR TYPES OF GAMETE ALTOGETHER

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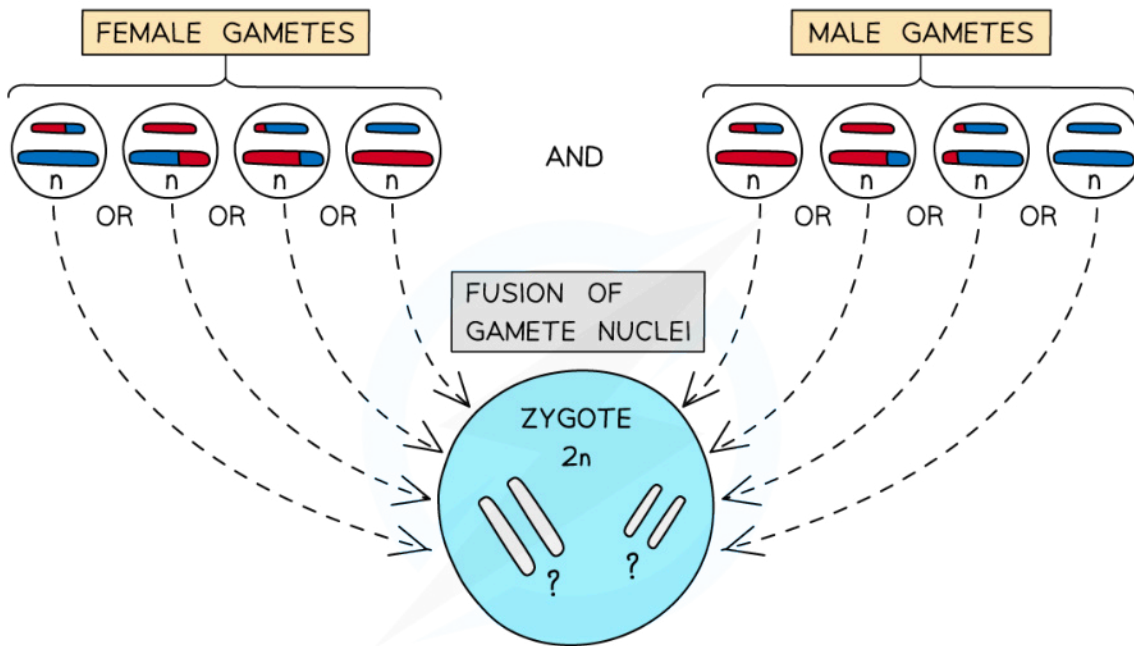
**Random orientation of chromosomes**

**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



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*The random fusion of gametes during fertilisation*

Sources of Genetic Variation Table



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Process	Mechanism	Consequences
<b>Independent assortment of homologous chromosomes during metaphase I</b>	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
<b>Crossing over of non-sister chromatids during prophase I</b>	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
<b>Random fusion of gametes during fertilization</b>	Any male gamete is able to fuse with any female gamete (Random mating in a species population)	Genetic variation between zygotes and resulting individuals
<b>Mutation</b>	Random change in the DNA base sequence results in the generation of a new allele. Mutation must exist within gametes for it to be passed onto future generations	Genetic variation between individuals within a species population

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## 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**

### Examiner 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.



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## 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

#### Examiner 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



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## Change in Frequency of Characteristics

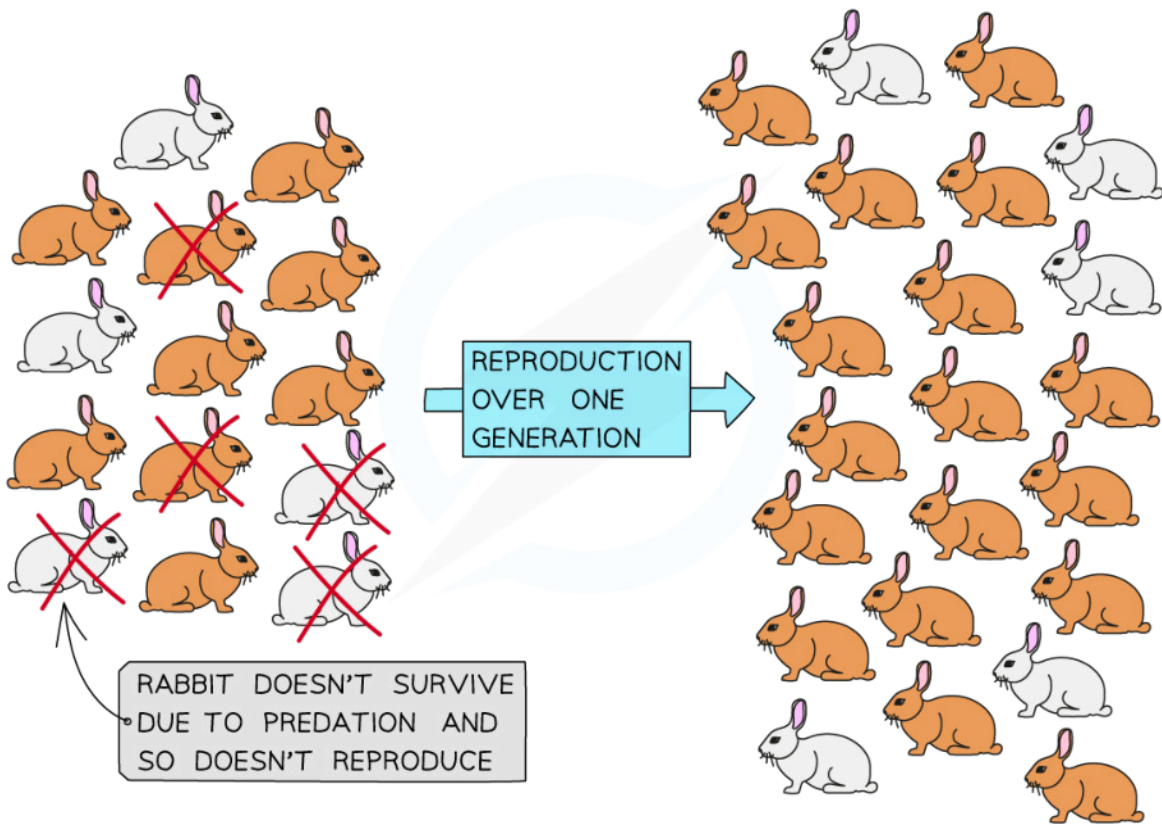
- **Natural selection** can be defined as
  - **The process by which organisms that are better adapted to their environment survive, reproduce, and pass on their advantageous alleles, causing advantageous characteristics to increase in frequency within a population**
- The **increased survival chances**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



Your notes



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**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**



Your notes

## 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**



Your notes

*Geospiza magnirostris*



*Geospiza fortis*



*Geospiza parvula*



*Geospiza olivacea*



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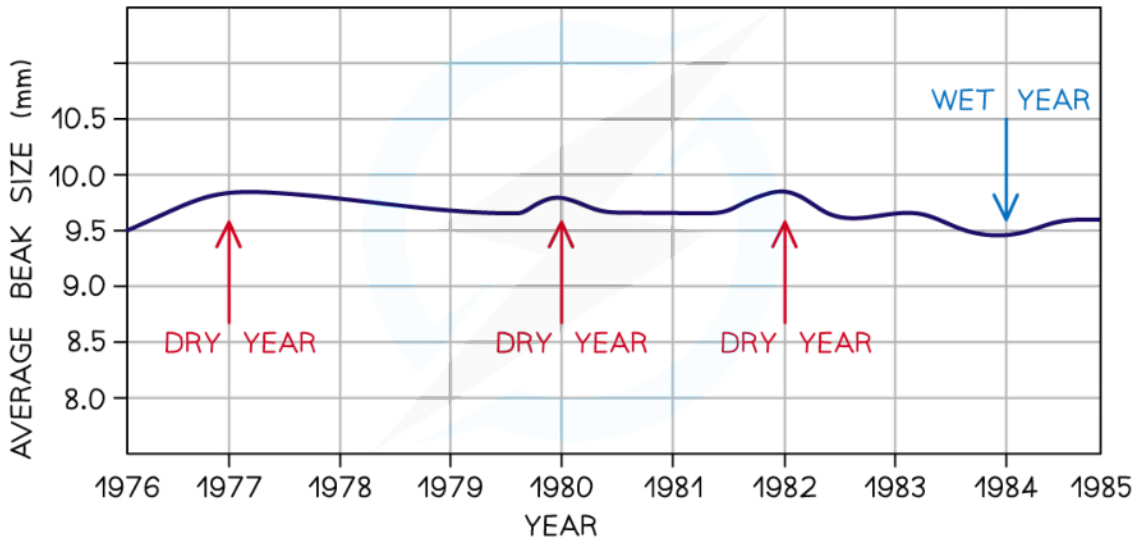
**Darwin noticed that Galapagos finches had beaks that were perfectly adapted to the food sources available on the island on which they lived**

- 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



Your notes

- 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**



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*Peter and Rosemary Grant found that average beak size in *G. fortis* on Daphne Major increased in drought years when seeds became larger and tougher, and decreased in wet years when seeds became smaller and softer*

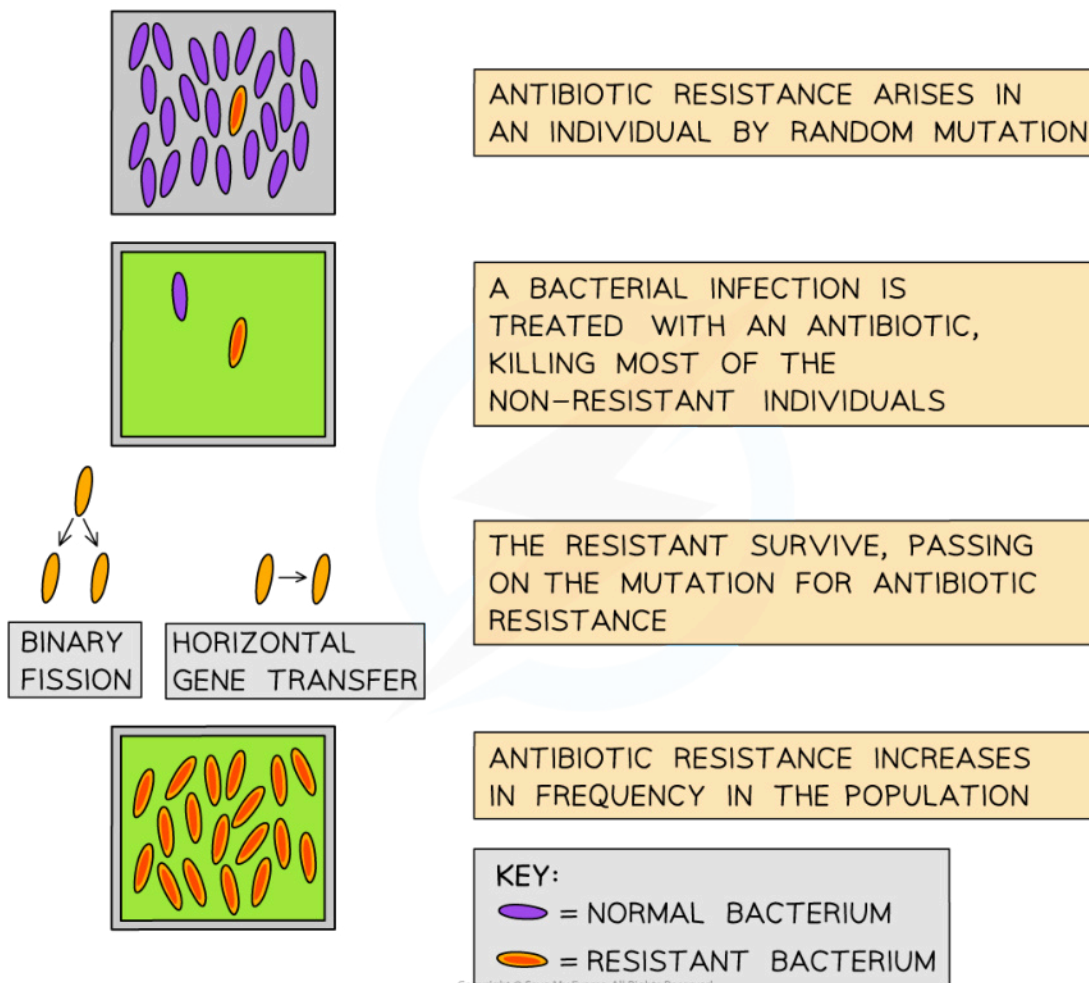
### Antibiotic resistance in bacteria

- **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



Your notes

- 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**



Your notes

- 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

 **Examiner 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**



Your notes