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Natural Selection

IB Biology - Revision Notes

Natural Selection & Evolution

Natural Selection & 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

- Scientist **Charles Darwin** came up with the theory of evolution by natural selection after a five-year expedition around the world during which he observed an incredible variety of organisms
- **Natural selection** is the process that drives evolution. It 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

On the Origin of Species

- Darwin published his book "On the Origin of Species" in 1859
- It contained the following statements and deductions
  - The **increased survival chances** of individuals with **advantageous alleles** mean that advantageous characteristics are **more likely to be passed down** through the generations because those individuals **reproduce more**
  - 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 through 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

NOS: Darwin's theory provided a convincing mechanism and replaced Lamarckism. Students should understand the meaning of the term "paradigm shift"

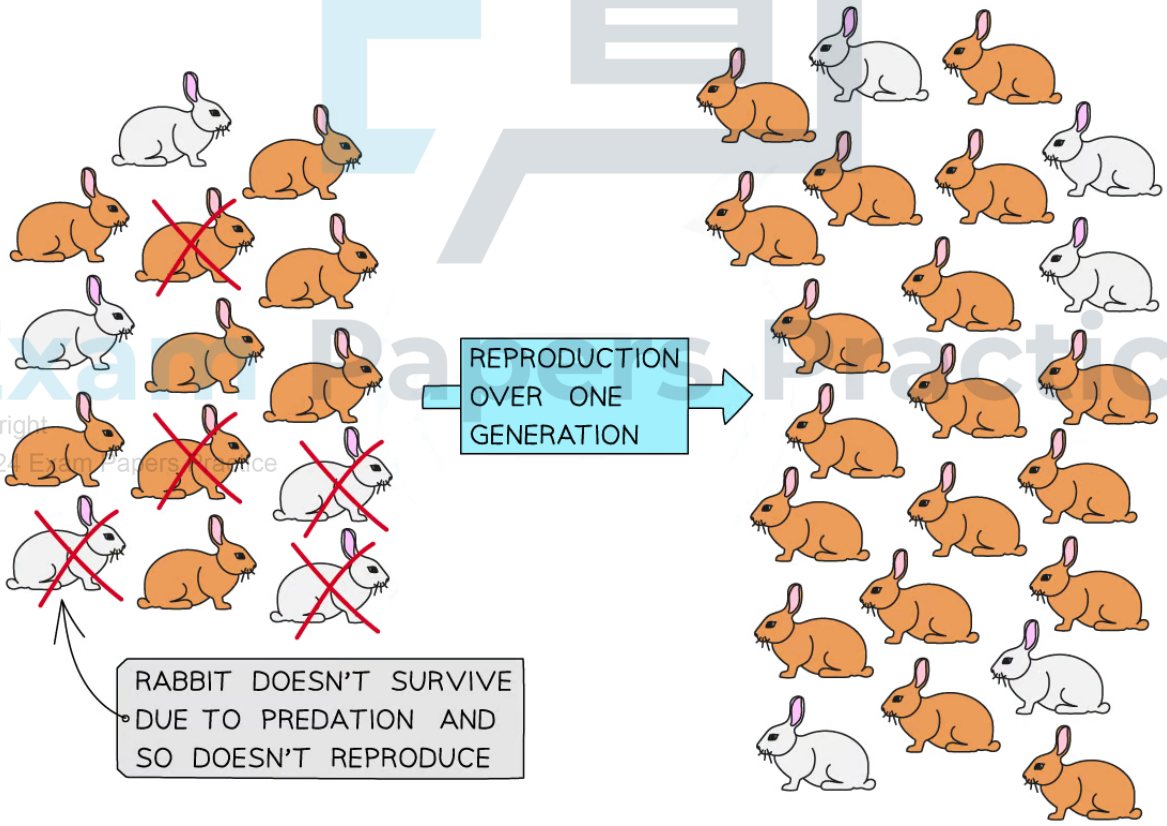
- Darwin's theory was seen as very controversial at the time, it is said to have caused a **paradigm shift**
  - Paradigm shifts occur when scientific research contradicts previous assumptions
  - Darwin's theory replaced Lamarckism

    - This was the idea that an organism could pass on physical characteristics they acquired during their lifetime to their offspring
- Nearly 200 years of genetic research backs up Darwin's theory of evolution by natural selection

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 in a rabbit population diagram



Selection pressures act 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

Generating Variation: Mutation & Sexual Reproduction

- **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
- **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

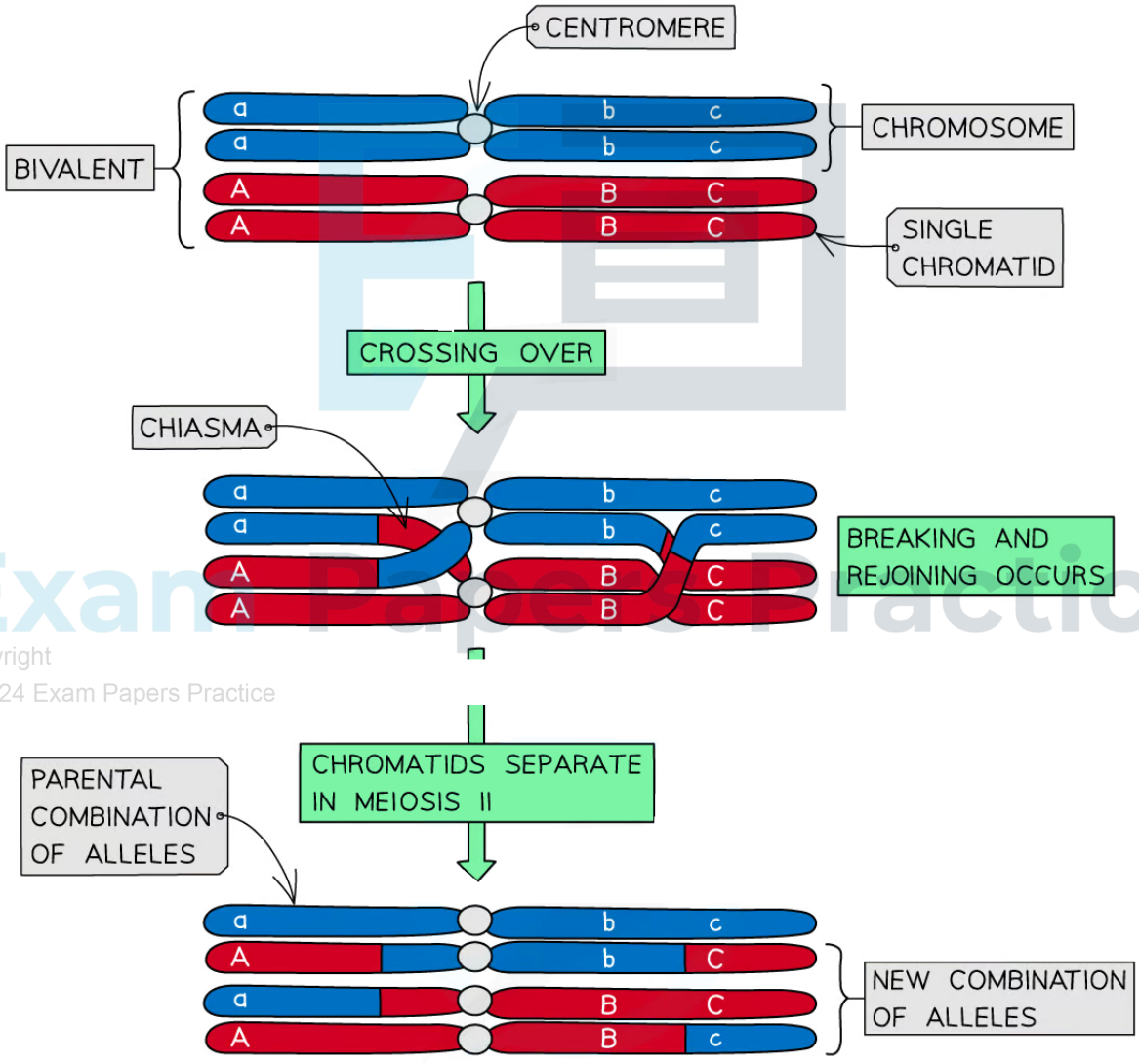
- The original source of genetic variation is **mutation**
  - A mutation is a change in the **DNA base sequence** that results from a copying error during DNA replication
- Mutation results in the **generation of new** alleles
- Mutations that take place in the **dividing cells of the sex organs** lead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

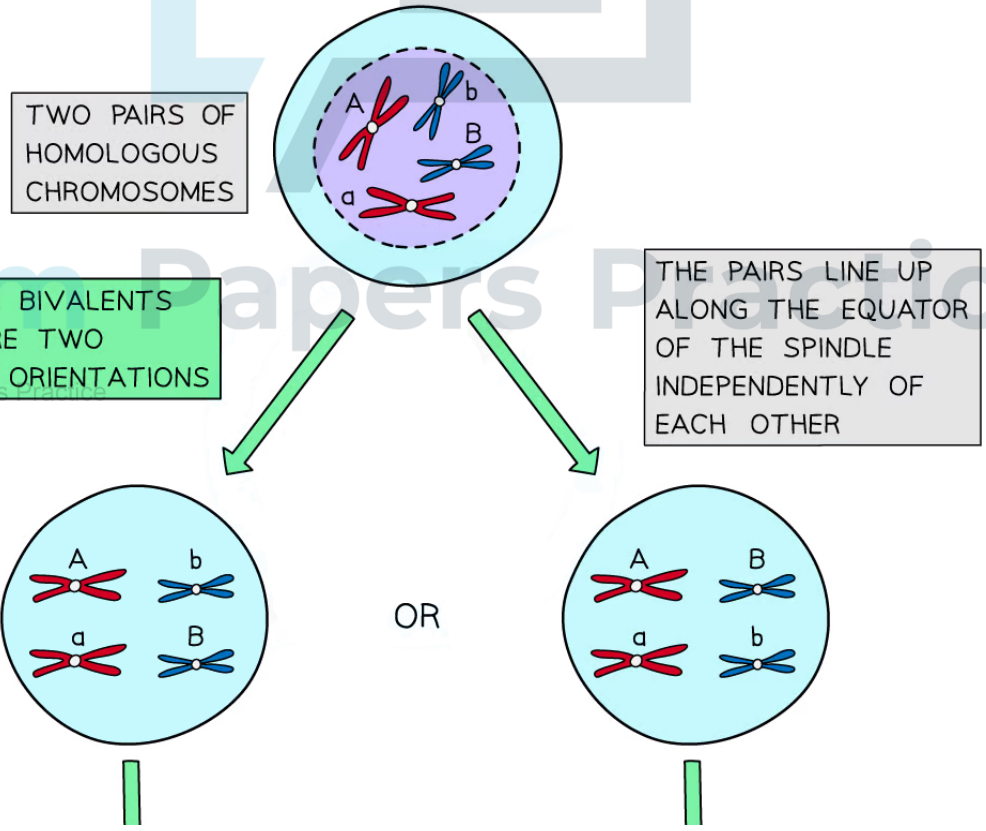
Chromosomes crossing over diagram

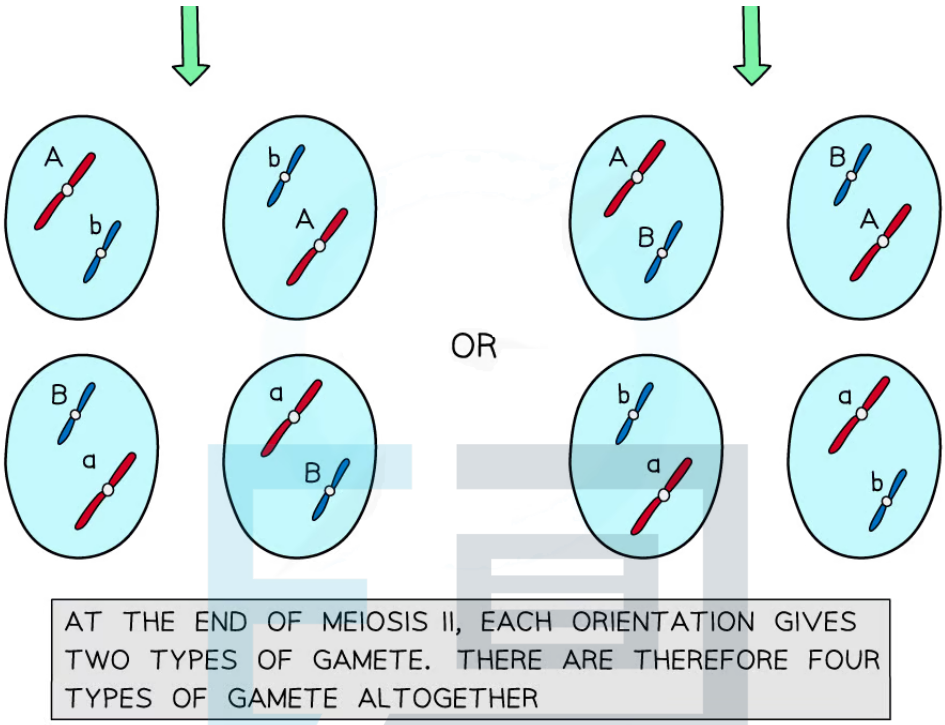


The process of crossing over can result in new combinations of alleles

- **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 diagram



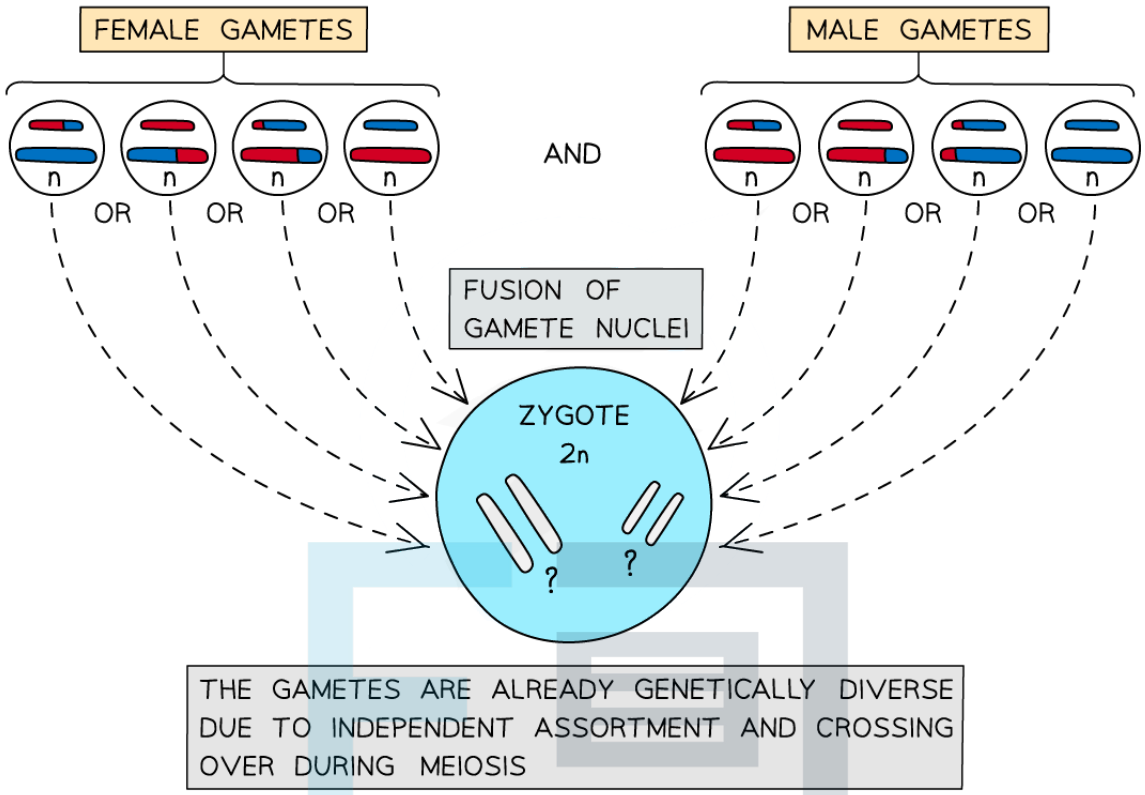


Random orientation of chromosomes

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

Fusion of gametes during fertilisation diagram



The random fusion of gametes during fertilisation

Sources of genetic variation table

Overproduction of Offspring & Competition

- 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**
- There are often **more offspring produced than can be supported** by the surrounding environment
  - Darwin noticed this, and named the phenomenon '**overproduction of offspring**'
- The **overproduction** of offspring within a population leads to **competition** for resources as population size is naturally limited by environmental factors
  - E.g. availability of food, space and light
- These environmental factors limit the carrying capacity of a species' population
  - An insufficient amount of resources means that a large number of offspring fail to survive and reproduce
- Overproduction of offspring and competition for resources promote natural selection

Intraspecific Competition & Natural Selection

- Habitats have limited resources
- When individuals within a habitat fight over or try to obtain a limited resource they are said to be "competing"
- Competition can occur between individuals of different species (interspecific competition) and between individuals of the **same** species (intraspecific competition)
- **Intraspecific** competition plays a greater role in evolution because:
  - Individuals are **more likely to interact** with members of their own species
  - Individuals of the same species share the same niche
  - They are affected by the same abiotic and biotic factors

How does intraspecific competition promote natural selection?

- Variation is present within the species population
- Some individuals 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 and 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.

Heritable Traits & Evolutionary Change

- 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

Selection Pressures

Selection Pressures: Abiotic Factors

- In Biology, 'abiotic' means **non-living**
- An abiotic factor is a non-living factor within an ecosystem
  - Some abiotic factors are **density-independent**
    - E.g. temperature or rainfall
- Abiotic factors can act as **selection pressures**
  - They affect the survival of individuals in a population, causing the population size to fluctuate

Selection Pressures: Sexual Selection

- Sexual selection is another type of selection pressure that can affect the evolution of **animal** species
- It can be defined as:
  - A form of selection that occurs due to the **preference of one sex for certain characteristics** in individuals of the **other sex**
- In order for a selection pressure to have an effect, there needs to be **variation** within the population
  - Within the male cohort of a population, there will be **variation in physical and behavioural traits** which are visible to the female cohort (and vice versa)
- These differences are sometimes viewed as indicators of overall fitness by the females within the population
- As a result, they can affect an individual's success in attracting a mate and drive the evolution of an animal population

What are the effects of sexual selection?

- Sexual selection within a population can cause:
  - Reproductive isolation
  - Sexual dimorphism

What is reproductive isolation?

- **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
- For example, certain alleles may result in changes in male courtship behaviour meaning they are no longer attractive to females
  - The females no longer choose to mate with these males, creating reproductive isolation

What is sexual dimorphism?

- Sexual dimorphism is the distinct **difference in size or appearance** between the **sexes** of an animal species
- Sexual dimorphism is commonly seen in **Birds of Paradise**
  - The male birds are brightly coloured and can perform intricate courtship displays
  - The female's plumage consists of greys and browns

How does sexual dimorphism occur?

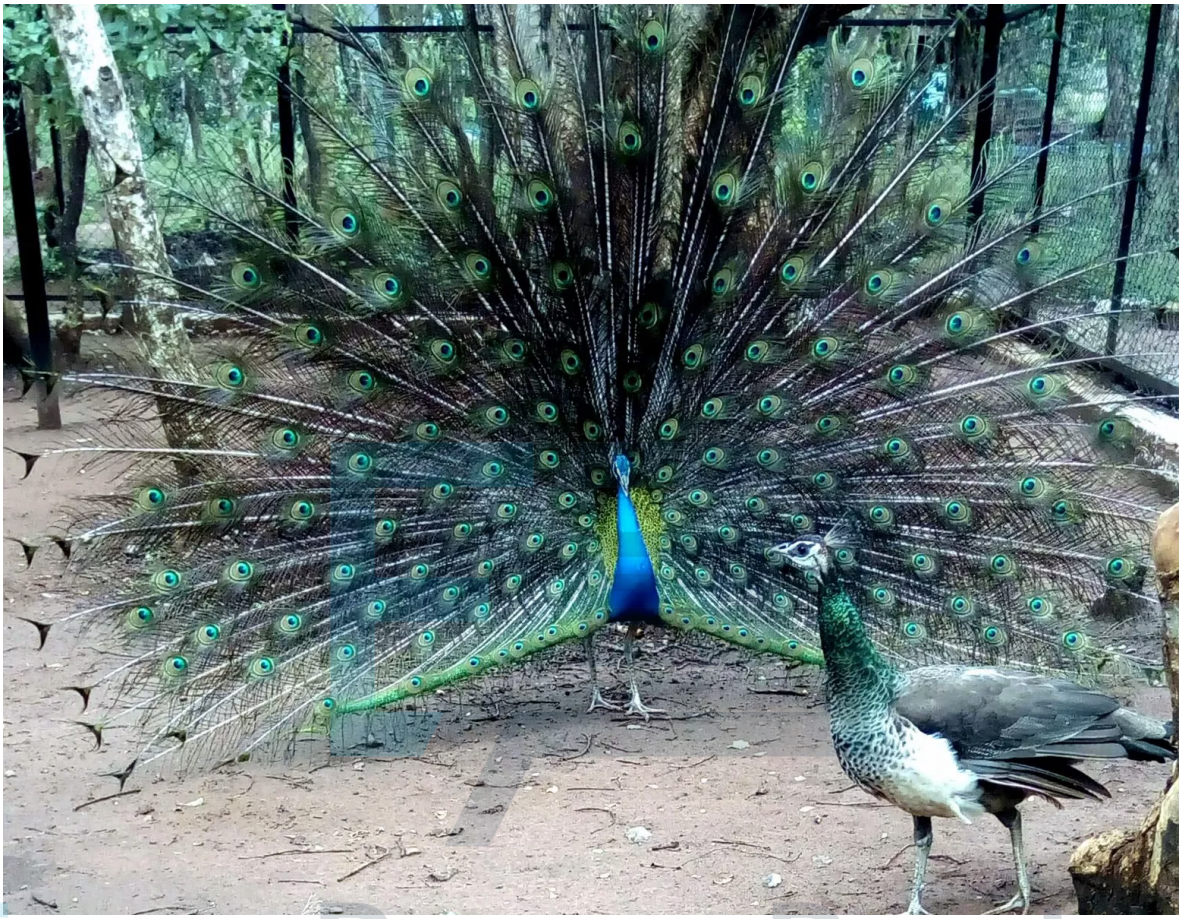
- A physical and/or behavioural trait within the male phenotype is used as an indicator of fitness by the females in the population
  - E.g. a male peacock with vibrant, healthy tail feathers is likely to have a lower disease burden compared to a male with dull, sparse tail feathers
- Females are more likely to be attracted to and mate with males that display the desired traits

- Over time, the genes associated with these traits are inherited by subsequent generations and they become more prominent within the species
- As a result, sexual selection can impact mating success, driving the evolution of an animal population

What is the difference between natural selection and sexual selection?

- Natural selection occurs due to competition for **resources** whereas sexual selection occurs due to competition for **mates**
  - On islands where resources are plentiful and predators rare, females are often the primary selection pressure which determines how males evolve
- Sexual selection results in animals with enhanced mating success whereas natural selection tends to result in populations of individuals that are well-adapted to their environment
- Sexual selection **does not result in individuals that are well-adapted** to their environment
  - E.g. Peacocks possess iridescent tail feathers with a specific eye-spot pattern which are used heavily during courtship displays to females
  - Over time, sexual selection in peacocks has resulted in males with longer tail feathers and more elaborate patterns
  - These traits actually make the bird more prone to predation, reducing their chances of survival
    - A long tail reduces agility, ability to fly and makes the bird easier to spot
- Sexual selection can be a more prominent evolutionary force than natural selection as variation in mating success can:
  - Amplify selection
  - Maintain new genetic variation among individuals
- Both of which can result in rapid evolutionary change

Peacock and Peahen



https://commons.wikimedia.org/wiki/File:Peacock_with_peahen.jpg

A male peacock proudly displays his elaborate tail feathers in an attempt to attract a female mate

- The concept of sexual selection is viewed as Darwin's second-greatest insight
- Darwin was aware that the existence of traits that were not favoured by natural selection needed a reasonable explanation

Selection Pressures: Skills

Modelling Sexual & Natural Selection

Guppies in Trinidad and Tobago

- Guppies are a species of fish found in the mountain forest streams of Trinidad and Tobago
- They exhibit variation in colouration and patterning as well as sexual dimorphism
  - Similar to the Birds of Paradise the males tend to be **brightly coloured**, while the females are duller
- The colouration (specifically the spots) of Guppies provides them with **camouflage from predators**
- Their spots mimic the gravel of the streambeds in their native streams
  - Some streambeds are finer and sandier while others are coarser and more pebble-like
- Certain streams provide more natural protection through hiding spots from predators

John Endler's Experiments with Guppies

- In the 1970s a scientist named John Endler observed the guppies in Trinidad and noticed that their colour patterning changed with **predation pressure**
- As a result of these observations, he conducted lab and field research on guppy populations to investigate the effects of **natural and sexual selection** on the evolution of the guppies
- Endler came up with several hypotheses to try and explain the varying levels of male colouration:
  - When predators are present, the **substrate type** of the streambed impacts survival causing spot brightness to change
  - When there is a **low** predation rate, spot brightness on male guppies **increases** due to **sexual selection**
  - As predation increases, the brightness of the spots **decreases**

Laboratory experiment

- Endler used a **greenhouse** to recreate a **tropical** environment
- Prior to the experiment, the guppies were living in large tanks and breeding freely for six months with no predation
  - These guppies exhibited a wide range of spot size and number (reflecting the range of streams and predator content they were taken from)
  - Endler counted and measured the spots on all of the guppies
  - During this time they were randomly assigned to go into ten ponds
- He set up the ten ponds inside the greenhouse
  - Five ponds had **coarse** gravel
  - Five ponds had **fine** gravel
- The ponds were exposed to three different levels of predation

- A number of dangerous and weak predators were used to mimic the density of predators in the wild:
  - Two ponds had **no predation**
    - One with fine and one with coarse gravel
  - Four ponds contained a **dangerous predator** e.g. pike cichlid
    - Two with fine and two with coarse gravel
  - Four ponds contained a **weak predator** e.g. the killifish
    - Two with fine and two with coarse gravel
- Once the predators were introduced, the experiment was allowed to run for **five months**
- After the five-month mark, Endler **counted and measured** the spots on all of the guppies
- Then the experiment was allowed to run for a further **nine months**, after which more data was collected

- His prediction was that:
  - A **high** predation rate would cause the populations to **diverge** from each other
    - So the guppies in ponds with coarse gravel should have different patterns/colouration to those in ponds with fine gravel
  - A **low** predation rate would allow the male guppies to become **more conspicuous**
    - The brightness of their spots would help them to attract females

- It is worth noting that prior to the introduction of predators (when the guppies were living in the large tanks for six months) there was an increase in the number of spots
  - Likely due to sexual selection
- When predators were introduced there were significant changes in the guppies:
  - In ponds with a high predation rate, the mean number of spots decreased
  - In ponds with a low predation rate, the number of spots continued to increase
  - In ponds with coarse gravel, guppies tended to have larger spots whereas in the ponds with finer gravel guppies tended to have smaller spots
    - This was true of both ponds with a low or high predation rate
    - This can be interpreted as spot size mimicking gravel size
  - In ponds with no predation, the opposite was observed. Fine gravel ponds favoured large spots on male guppies while coarse gravel ponds favoured small spots
    - It was thought that not matching their background make males more conspicuous which can help to attract females

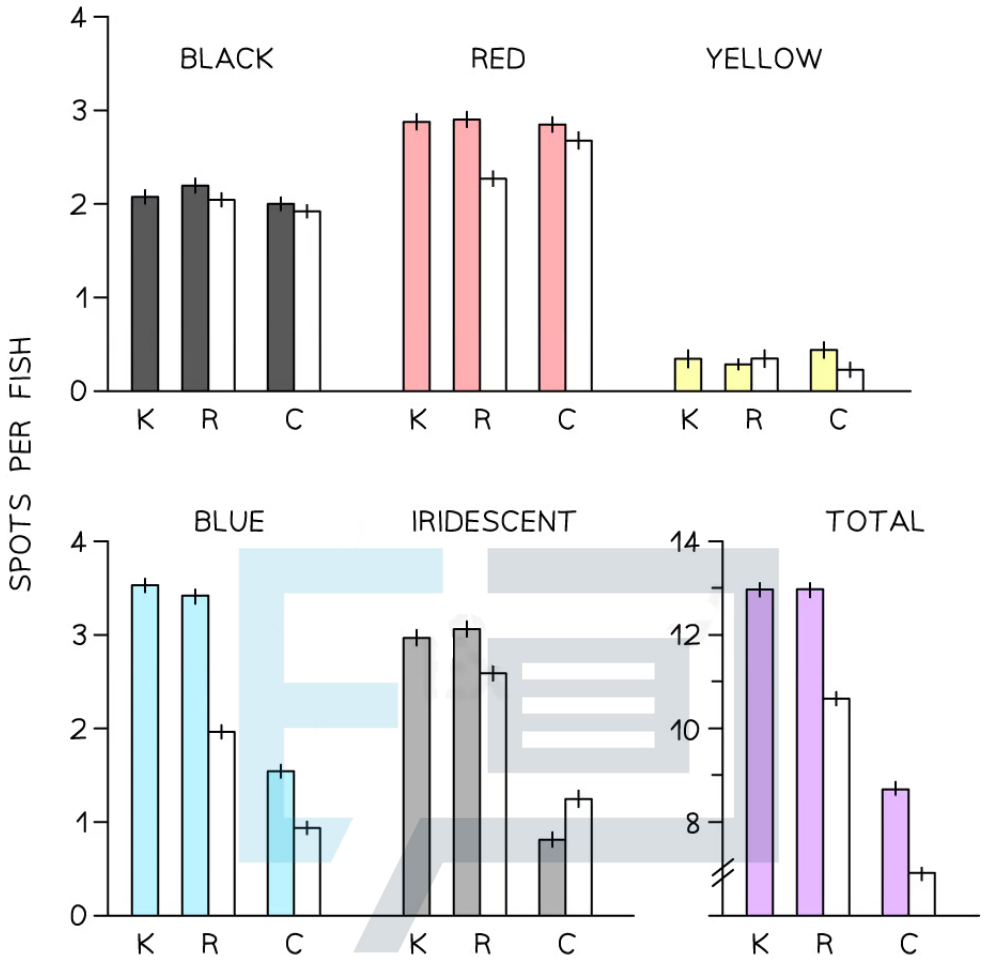
Field experiment

- Endler transferred a number of **dull male guppies** from an area of high predation to an area of low predation
- He left them there for 15 guppy generations (two years) before returning to observe any changes
- When he returned he noticed that the male guppies had more colourful patterning
  - This was likely due to **sexual selection** and the absence of strong predation

Interpreting results

- The lab and field experiments that Endler carried out demonstrated that the evolution in the guppy populations isn't clear cut
  - It is a dynamic process of **natural and sexual selection**
- Natural selection occurs in guppies due to **competition** for food and avoidance of predators
  - Predators can spot brightly coloured males more easily, reducing their survival chances
  - This leads to selection for less highly coloured/spotted individuals within the population
- Sexual selection occurs as some traits (e.g. bright colouration) provide a **reproductive advantage**
  - Males with brighter and bigger spots are more likely to obtain a mate, reproduce and pass on their alleles that code for these specific characteristics
- As a result, a **trade-off** between these two types of selection occurs
  - Although in areas with high predation rates, brightly coloured males are less likely to survive, regardless of their reproductive advantage

Endler's results graph



Endler's experimental data from the lab and field are presented in several graphs. The colour of the guppies was evaluated by counting the colour, brightness and number of spots.

Exam Tip

Take some time to look at the graphs containing Endler's data. Can you decipher the trends and results mentioned earlier?

It is an important exam skill to be able to pick out key information from confusing graphs like those above! The most useful part of the image is the bottom right-hand graph, you could spend a long time looking at the others but this one summarises the key trends between ponds with different predation levels and the brightness/number of spots.