HL IB Biology

Your notes

Natural Selection

Contents

Natural Selection & Evolution

Your notes

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"

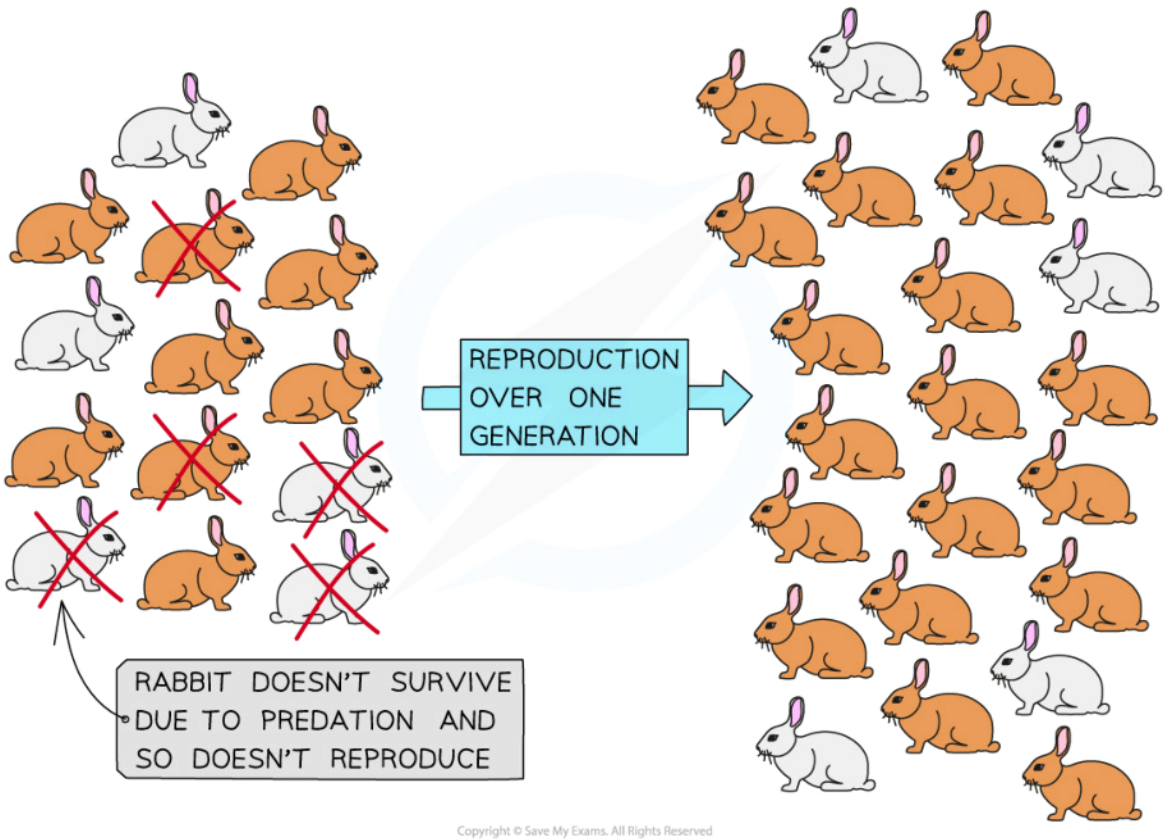
- Darwin's theory was seen as very controversial at the time, it is said to have caused a **paradigm shift**
  - Paradigm shifts occur when scientific research contradicts previous assumptions
  - Darwin's theory replaced Lamarckism
    - This was the idea that an organism could pass on physical characteristics they acquired during their lifetime to their offspring
- Nearly 200 years of genetic research backs up Darwin's theory of evolution by natural selection

Your notes

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

Your notes

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

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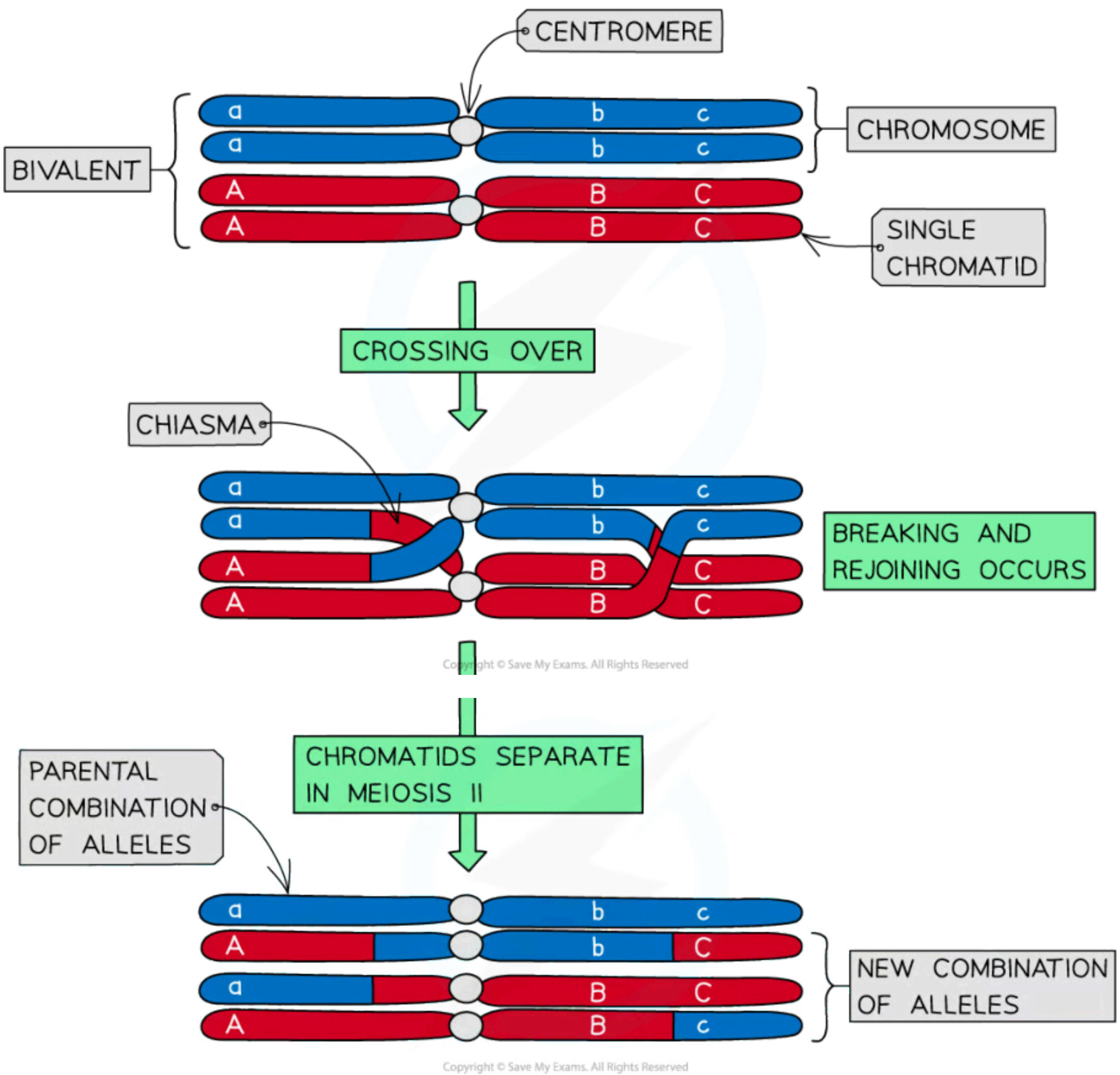
- The **non-sister** chromatids **can cross over** and get entangled
- As a result of this, a section of chromatid from one homologous chromosome may **break and rejoin** with the chromatid from the other chromosome
- This swapping of alleles is significant as it can result in a **new combination of alleles** on the two homologous chromosomes

Chromosomes crossing over diagram



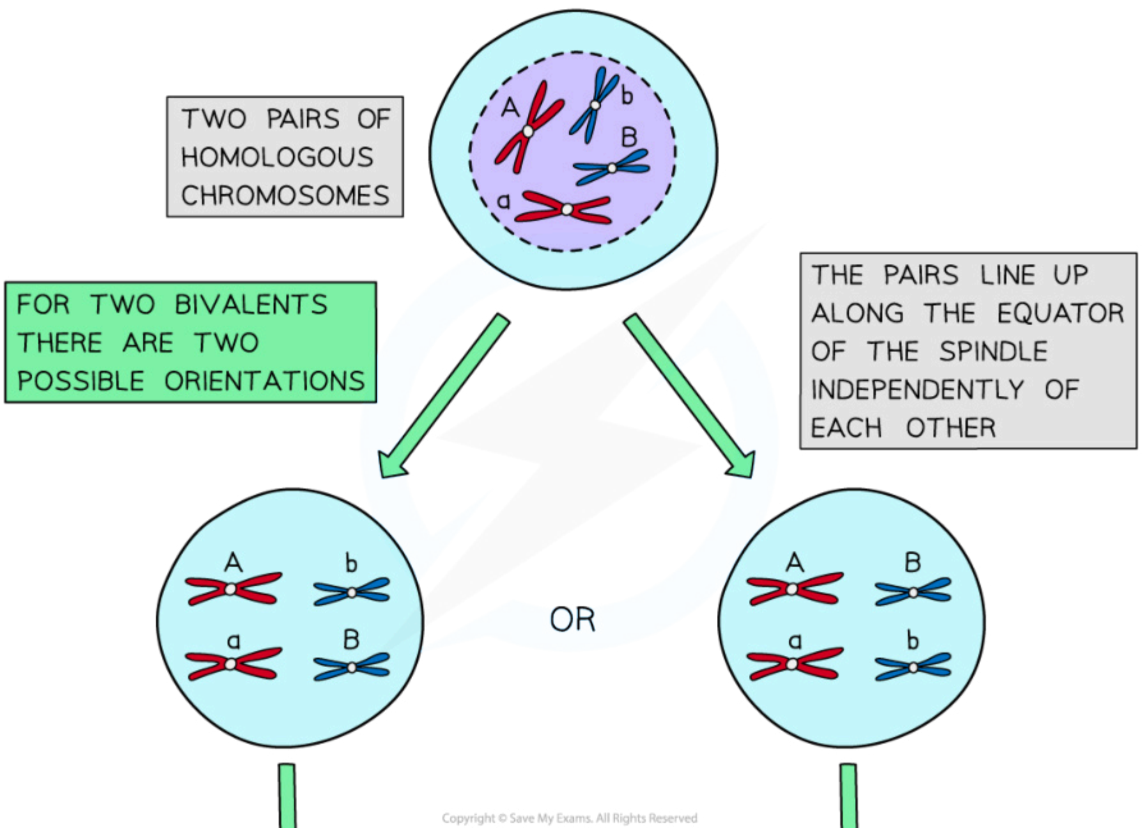
The process of crossing over can result in new combinations of alleles

- **Random orientation** occurs due to the **independent arrangement** of homologous pairs along the equator of the cell during metaphase I

Your notes

    - **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



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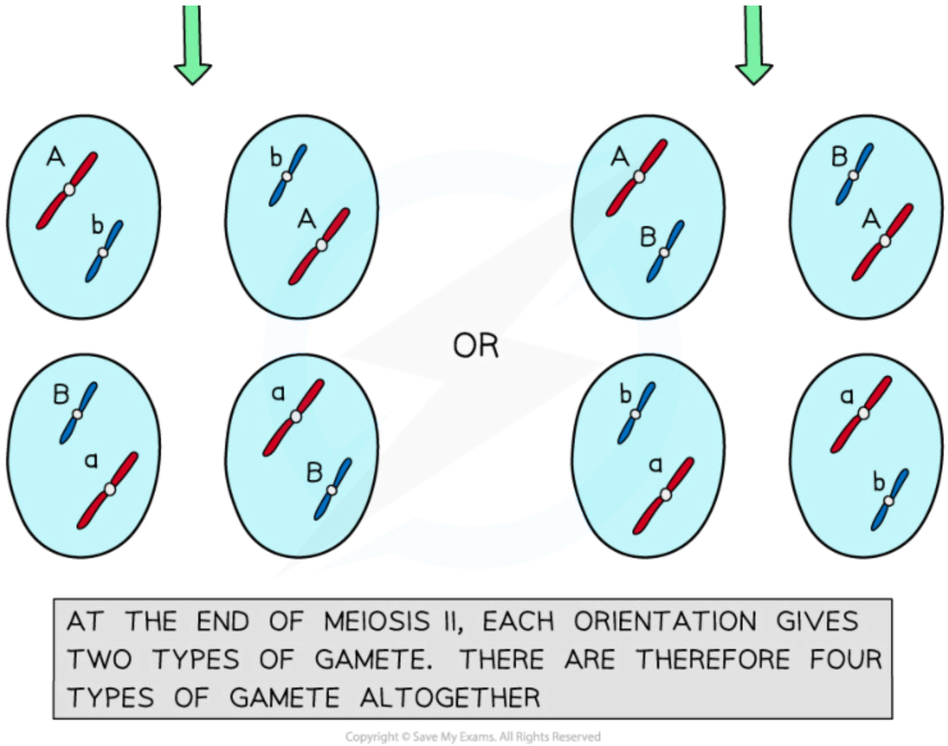
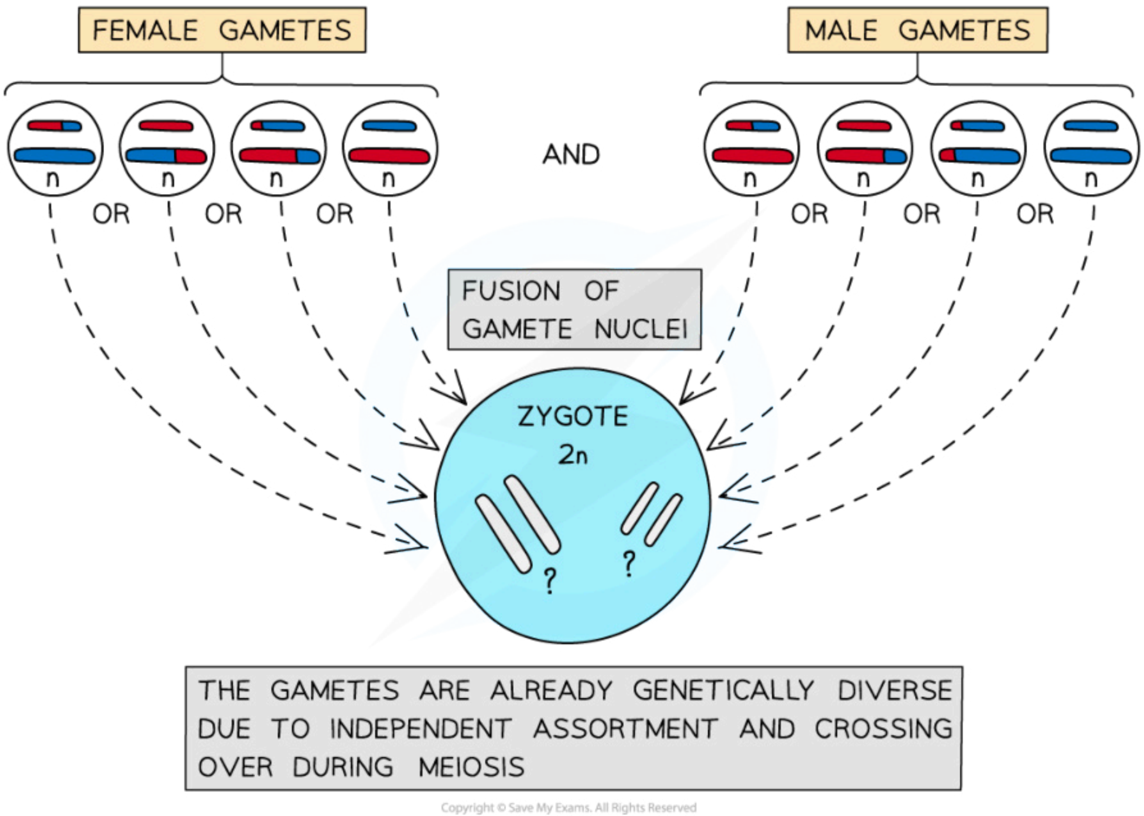


Random orientation of chromosomes

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

Fusion of gametes during fertilisation diagram



The random fusion of gametes during fertilisation

Sources of genetic variation table

Your notes

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

Your notes

Overproduction of Offspring & Competition

Your notes

- 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

Your notes

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

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.

Heritable Traits & Evolutionary Change

Your notes

- 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

Your notes

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

Abiotic Factors Table

Your notes

ABIOTIC FACTOR	HOW ABIOTIC FACTOR AFFECTS COMMUNITY
LIGHT INTENSITY	LIGHT IS NEEDED BY PLANTS FOR PHOTOSYNTHESIS. MORE LIGHT LEADS TO AN INCREASE IN RATE OF PHOTOSYNTHESIS AND AN INCREASE IN PLANT GROWTH RATE
TEMPERATURE	AFFECTS THE RATE OF PHOTOSYNTHESIS IN PLANTS
MOISTURE LEVELS	PLANTS AND ANIMALS REQUIRE WATER TO SURVIVE
SOIL pH AND MINERAL CONTENT	DIFFERENT SPECIES OF PLANTS ARE ADAPTED TO DIFFERENT SOIL pH LEVELS AND NUTRIENT CONCENTRATION LEVELS
WIND INTENSITY AND DIRECTION	WIND SPEED AFFECTS TRANSPIRATION RATE IN PLANTS. TRANSPIRATION AFFECTS THE RATE OF PHOTOSYNTHESIS AS IT ENSURES WATER AND MINERAL IONS ARE TRANSPORTED TO THE LEAVES
CARBON DIOXIDE LEVELS FOR PLANTS	CO_2 IS REQUIRED FOR PHOTOSYNTHESIS IN PLANTS. CO_2 CONCENTRATION AFFECTS THE RATE OF PHOTOSYNTHESIS
OXYGEN LEVELS FOR AQUATIC ANIMALS	SOME AQUATIC ANIMALS (SUCH AS FISH) CAN ONLY SURVIVE IN WATER WITH HIGH OXYGEN CONCENTRATIONS

Selection Pressures: Sexual Selection

Your notes

- 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?

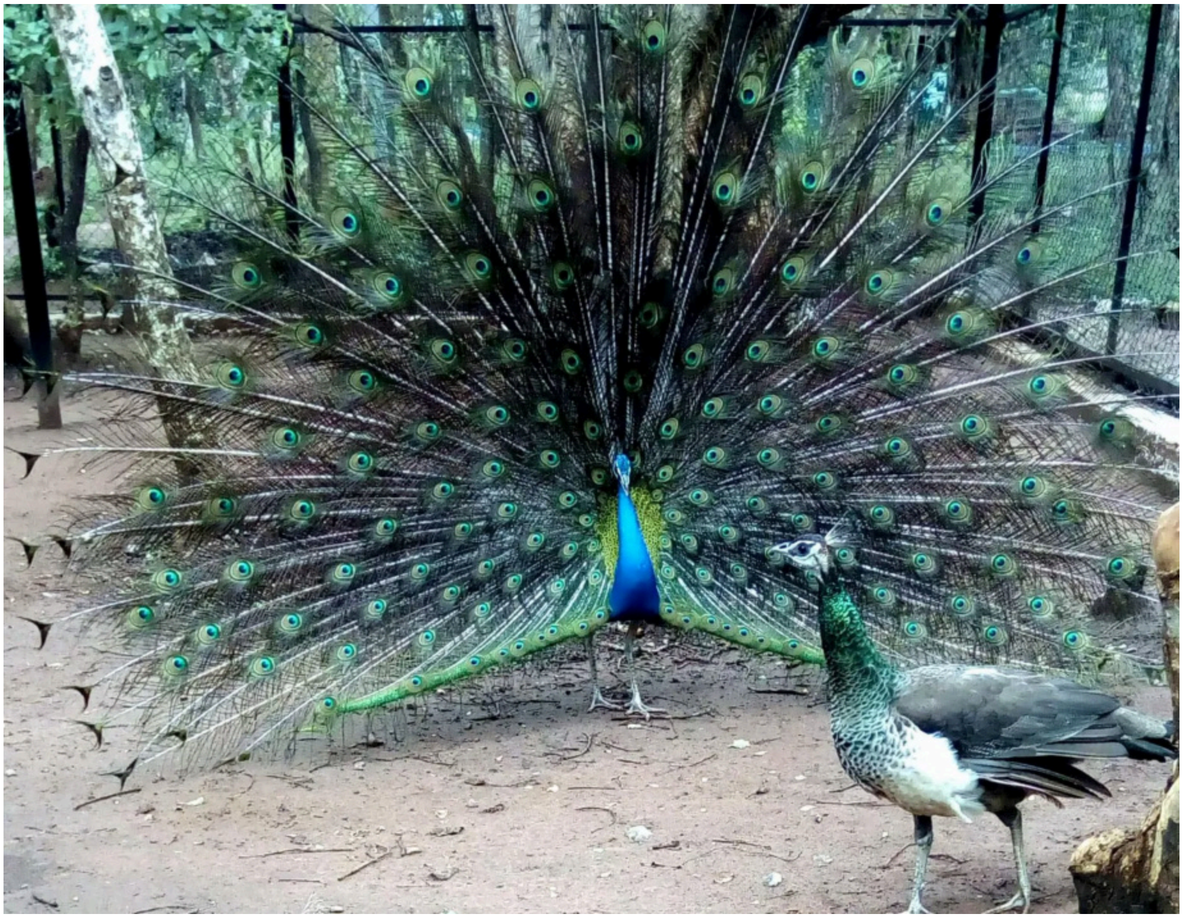
- A physical and/or behavioural trait within the male phenotype is used as an indicator of fitness by the females in the population
  - E.g. a male peacock with vibrant, healthy tail feathers is likely to have a lower disease burden compared to a male with dull, sparse tail feathers
- Females are more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

Your notes



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

Your notes

Modelling Sexual & Natural Selection

Selection in guppies

- Guppies are a species of fish found in the mountain forest streams of Trinidad and Tobago
- They exhibit variation in colour and pattern, as well as sexual dimorphism
  - Males tend to be **brightly coloured** while females are dull in colour
- 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 guppies in Trinidad and noticed that their colour patterning changed with **predation pressure**
- 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:
  - When predators are present, the **substrate type** of the streambed impacts survival, causing spot brightness to change
  - When predation rate is **low** 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
- Endler counted and measured the spots on all of the guppies
- Guppies were then randomly assigned to go into 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:
  - 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**
- Endler then **counted and measured** the spots on all of the guppies
- The experiment was allowed to run for a further **nine months**, after which more data was collected

Your notes

Results

- Endler **predicted** 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
- Endler **found** that 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 ponds with a low and 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

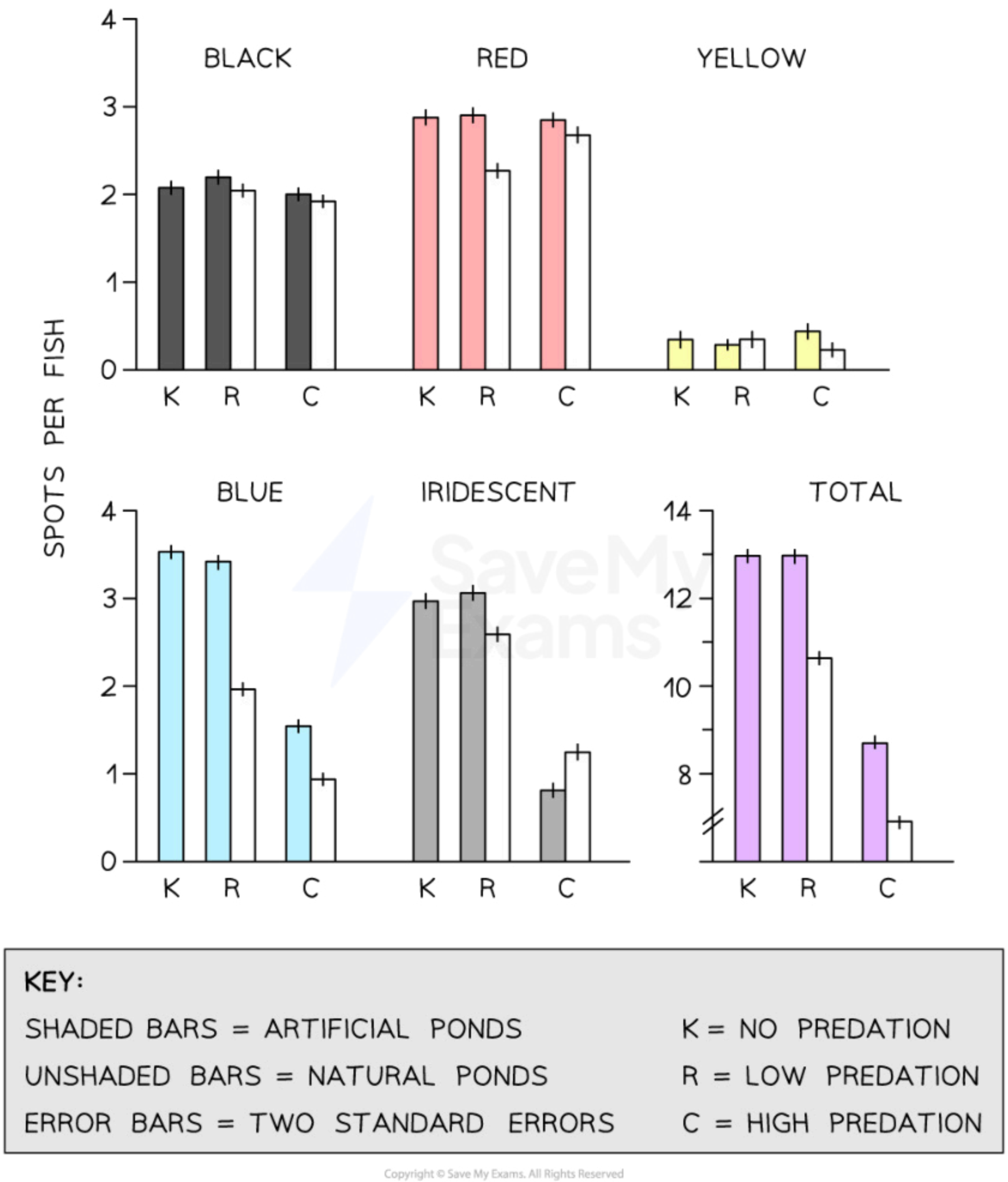
Field experiment

- 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
- 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.

Examiner Tip

You need to be able to interpret the graphs containing Endler's data; you should be able to match the results described in the text above with the data shown in the graphs.

It is an important exam skill to be able to pick out key information from confusing graphs. The most useful part of the image is the bottom right-hand graph; this one summarises the key trends between ponds with different predation levels and the brightness/number of spots.

Your notes

Gene Pools (HL)

Your notes

Gene Pools

- A gene pool consists of all the genes and their different alleles, present in an interbreeding population
- A consideration of all the genes (and alleles thereof) in a population is important as that will govern the **genomes of the next generation**
- Some populations of the same species are geographically isolated from each other
  - So **multiple gene pools** can exist for a species

Stable gene pools

- Populations retain a **stable** gene pool under the following conditions
  - The population is **large**
  - Each individual in the population has an **equal chance of mating**
  - That matings are **random**
  - There are **no selection pressures** acting upon individuals based on their phenotype
- A stable gene pool means that a population is **not evolving**

Changes in Allele Frequency

- Darwin came up with the theory of evolution by natural selection without any knowledge of genetics or DNA
- His theory has been further developed by modern scientists through the integration of genetics
  - This is often referred to as **neo-Darwinism**
- Modern science has allowed evolution to be understood at a molecular level
  - Changes in allele frequency in the gene pool occur due to processes such as **natural selection**, **sexual selection** and **genetic drift**

Your notes

Allele Frequencies: Skills (HL)

Allele Frequencies in Isolated Populations

Comparison of allele frequencies of geographically isolated populations

- Allele frequency is a term that assigns a **relative frequency** of an allele at a particular gene locus
  - Alleles can vary from each other by as little as one nucleotide
- When a degree of geographic **separation** exists between two populations, this can cause differences in the frequencies of alleles to emerge
- Human allele frequencies vary by **geography** and **ethnicity**
  - Examples of clear-cut allele frequency differences are rare in human populations because of the ease of **travel** and **interbreeding**
  - This leads to a scarcity of **truly isolated** populations
- If there is more than one allele in existence for a particular gene, the respective **allele frequencies must add up to 1**
- Online databases list the frequencies of human alleles
- Alleles are sometimes referred to as **polymorphisms** which just means many (poly-) different forms (-morphisms) of a gene
  - The most common type is called a **single nucleotide polymorphism** (SNP)
- Mathematical formulae such as the **Hardy-Weinberg formula** can be used to calculate phenotype frequencies from allele frequencies and *vice versa*
- Comparing allele frequencies can provide information for
  - Identifying **genetic associations** with particular diseases
  - Estimating the **number of individuals with disease susceptibility** within a population
  - Estimating the level of **drug resistance** in a population
  - Performing **evolutionary and anthropological studies** (e.g. tracing the history of humans through time)

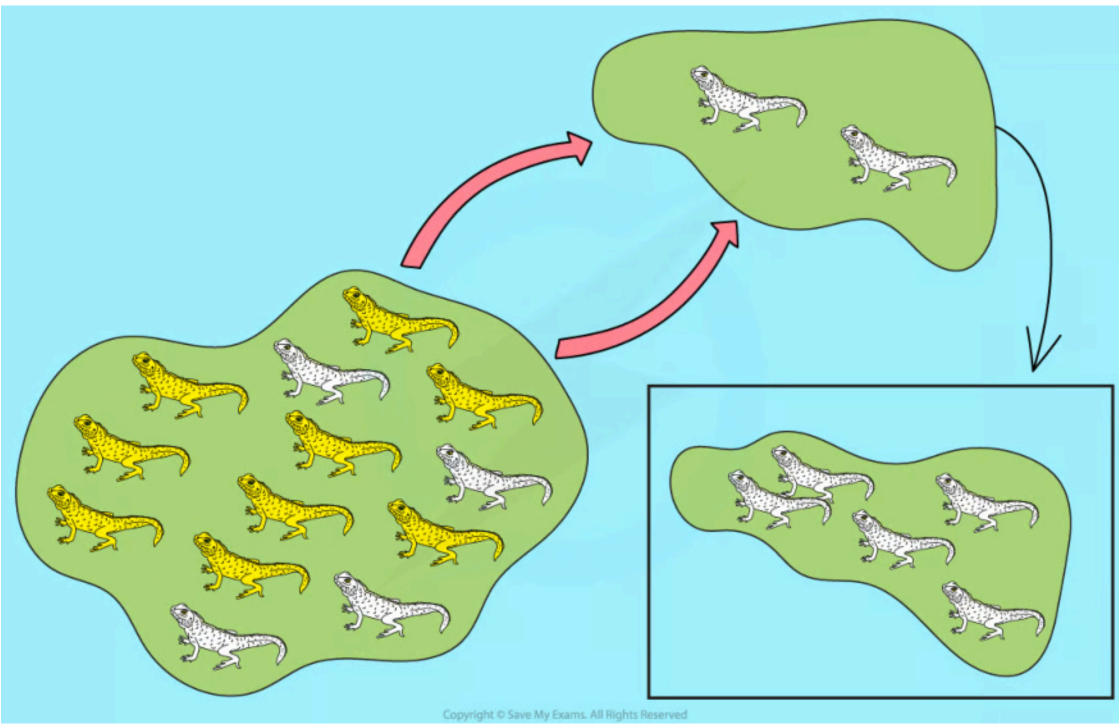
Basis of allele frequency analysis

- For any polymorphism, each individual carries **two alleles per locus**
  - One is inherited from the mother, the other from the father
  - Exception - this does not apply to alleles present on the X or Y chromosome
- Within a population, there are **twice as many total alleles** as there are individuals
- **Homozygous** individuals each contribute **two** of that allele to the total number of that particular allele
- **Heterozygous** individuals each contribute **one** of a particular allele to the total number of that allele
  - For example, if there are eight individuals with the **ZZ** genotype, they contribute 16 **Z** alleles
  - Thirty-four **Zz** heterozygous individuals contribute a total of 34 **Z** alleles and 34 **z** alleles to the total

Your notes

Worked example

Consider the following isolated island populated by a certain species of lizard. On this island, the ratio of white lizards to yellow lizards is 4:9. The yellow pigmentation is caused by a dominant allele, **Y**. Lizards possessing the homozygous recessive genotype (**yy**) are white in colour.



Distribution of lizards on the island before and after the geological event

Two of these lizards found themselves on a floating log that was carried in an ocean current to another island. Their migration is shown by the red arrows in the image. Fortunately, these were male and female and they were able to begin the colonisation of the new island.

Calculate the allele frequencies of **Y** and **y** on the old island **and** the new island.

Solution:

Mathematical formulae such as the **Hardy-Weinberg formula** can be used to calculate allele frequencies from phenotype frequencies (and vice versa)

$$p + q = 1$$

Where:

- The letter ***p*** represents the frequency of the dominant allele **(Y)**
- The letter ***q*** represents the frequency of the recessive allele **(y)**

Your notes

Step 1: Calculate the phenotype frequencies on the old island

If 4/13 are the white lizards, the phenotype frequency of **yy** is 4 ÷ 13 = 0.3077

Step 2: Calculate the allele frequency of y (from the phenotype frequency in Step 1)

The probability of two y alleles coming together through fertilisation is given by (**q** x **q**) or $\mathbf{q}^2$
Therefore, **q** is the square root of the white phenotype frequency

$$q = \sqrt{\frac{4}{13}} = 0.5547$$

Step 3: Subtract this from 1 to find the allele frequency of the dominant allele, Y

1 - 0.5547 = 0.4453

Frequency of **Y** allele on the old island = 0.4453 or 44.5%
Frequency of the **y** allele on the old island = 0.5547 or 55.5%
Frequency of **Y** allele on the new island = 0 or 0%
Frequency of the **y** allele on the new island = 1.0 or 100%

Examiner Tip

Mathematical derivations of allele frequencies are not required for your exams, although it helps to appreciate that the sum total of all the allele frequencies must add up to 1, in order to appreciate the variation within a species.

Types of Natural Selection (HL)

Your notes

Types of Natural Selection

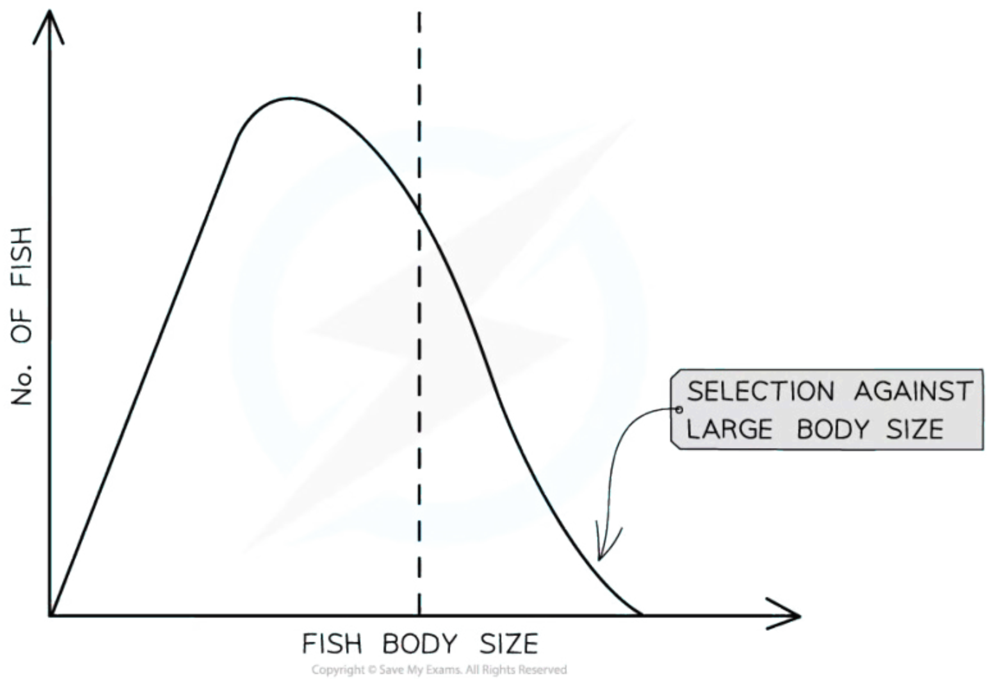
- There are three main types of selection:
  - Directional
  - Stabilising
  - Disruptive

Directional selection

- The population changes **towards one extreme** of a range of variation
  - As that extreme becomes better adapted
- This tends to happen when **environmental conditions change**
- For example, a **fall in average temperatures** can affect plants that are not resistant to **frosts** (spells where the air temperature falls below 0°C)
- If there is no allele that can give the species a degree of frost resistance, then the species will **become extinct** in that habitat if cold temperatures endure for more than one generation
- If an allele exists that gives a degree of frost protection, then the species will be able to
  - Survive the frost
  - Go on to reproduce successfully
- Such an allele may code for a new protein that can lower the freezing point of water/cell contents by a few degrees and prevent the formation of damaging ice crystals
- The species has developed a **selective advantage** over other species
- A disadvantageous allele **does not have to be fatal** to an individual organism
- However, it must **prevent the individual from reproducing successfully**
  - Which is effectively the same thing from an evolutionary point of view
  - Because the allele will disappear from the gene pool as the reproductively unsuccessful individuals die
- The species can **change its genome abruptly** by directional selection

Directional selection diagram

Your notes



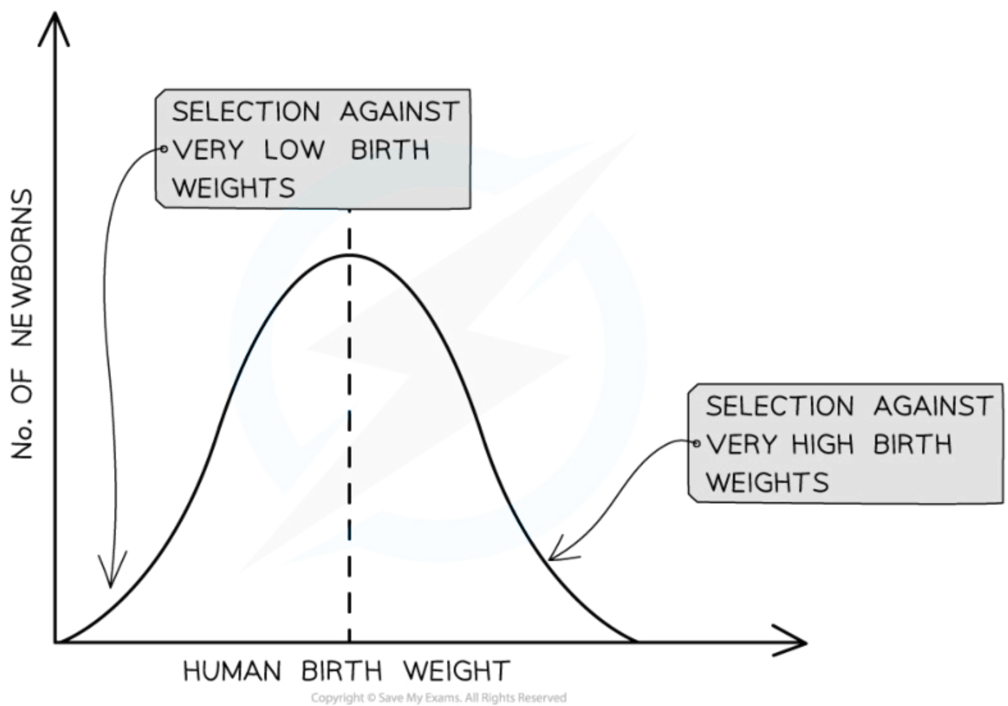
Directional selection acting on fish body size. Increases in ocean temperatures are selecting for smaller body sizes in fish. Warmer seas cause fish metabolism to speed up and so increase their need for oxygen (oxygen levels are lower in warmer seas). Larger fish have greater metabolic needs than smaller fish, and so they feel the effect of increased temperatures more strongly.

Stabilising selection

- Selects **in favour of the average individual** in a population
- Occurs when environmental conditions are stable / do not change
- Selection tends to favour individuals with a range of alleles whose characteristic is the **most advantageous**
- Stabilising selection is the **most common form** of natural selection
- An example is the coat colour of mice
  - The colour stabilises as the one which gives the most camouflage against the surroundings e.g. brown fur versus a forest floor
- Birth mass is also an example
  - Where a **normal distribution** clusters around a mean birth mass
  - Too low and too high can lead to problems of survival for an infant
- Stabilising selection
  - Discards **extreme** phenotypes
  - And instead favours the **majority of the population** that is well adapted to their local environment
  - **Decreases diversity** within a population
  - Works mostly on traits that are **polygenic**
  - Is often characterised by a **normal distribution** (a bell-shaped curve)

Your notes

Stabilising selection diagram



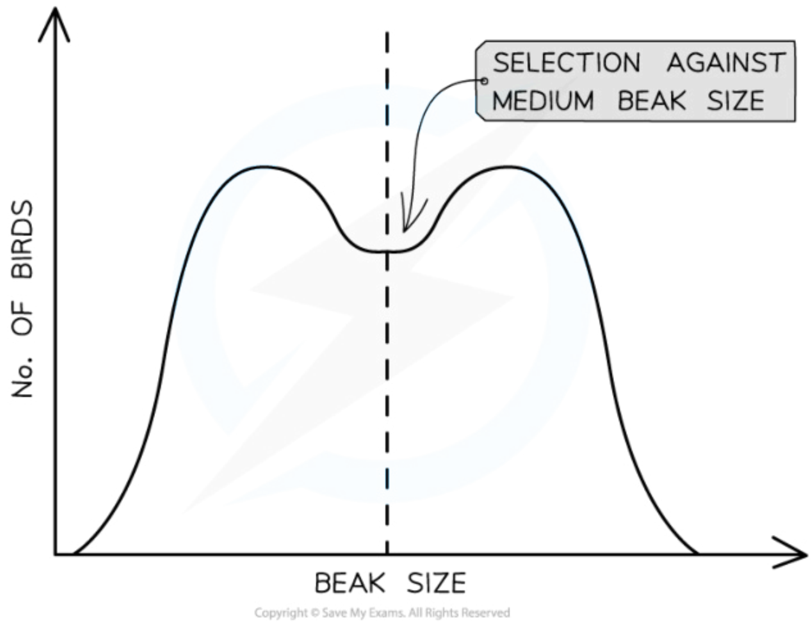
Stabilising selection on human birth weight

Disruptive selection

- Selects **against the average individual** in a population
- Is the rarest of the three forms of natural selection
- Like directional selection, disruptive occurs when **habitats or resources undergo a change**
- Disruptive selection can lead to the **formation of an entirely new species** (speciation)
  - For this reason, is sometimes referred to as '**diversifying** selection'
- **Darwin's finches** in the Galápagos Islands are one of the best-known examples
- Fifteen different species evolved from a common ancestor
- **Multiple types of beaks** have adapted to different food sources over time
- On one island, Santa Cruz
  - Ground finches eat more seeds and some arthropods
  - Tree finches eat more fruits and arthropods
  - Vegetarian finches feed on leaves and fruit
  - Warblers typically eat more arthropods
- When food is **abundant**, their **diets can overlap**
- When food is scarce, these specialisations give each species the ability to compete for a certain type of food better than other species
- This helps each species to occupy its own niche

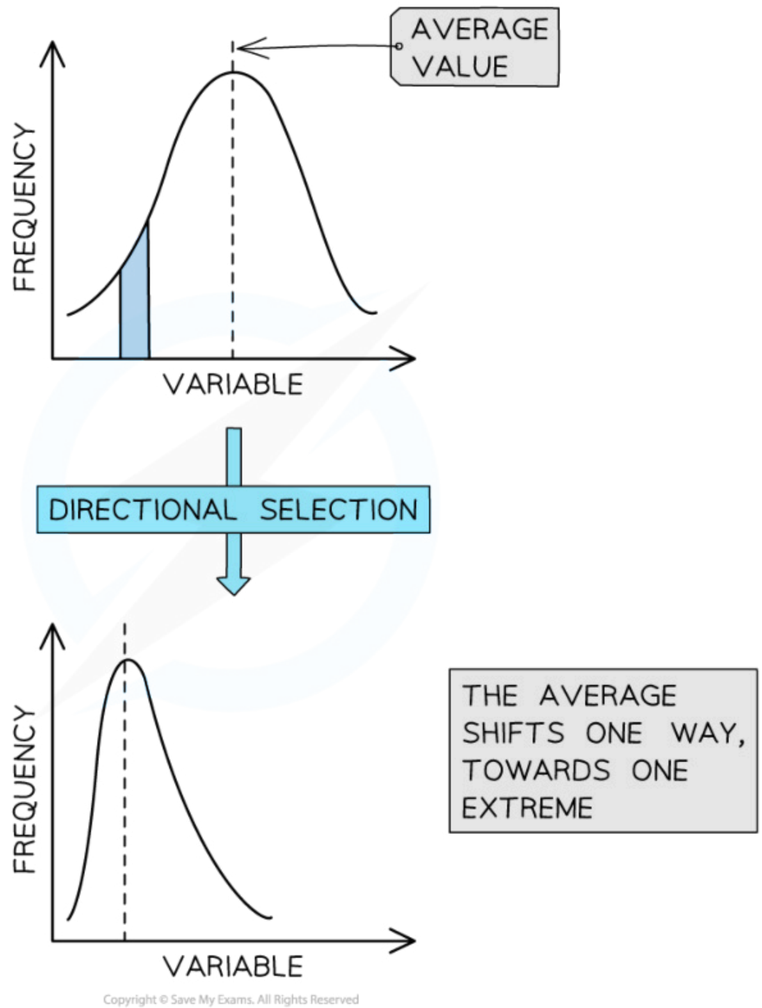
Disruptive selection diagram

Your notes



Disruptive selection acting on beak size in a bird population

Types of natural selection overview diagram


AVERAGE VALUE
FREQUENCY
VARIABLE
DIRECTIONAL SELECTION
FREQUENCY
VARIABLE
THE AVERAGE SHIFTS ONE WAY, TOWARDS ONE EXTREME
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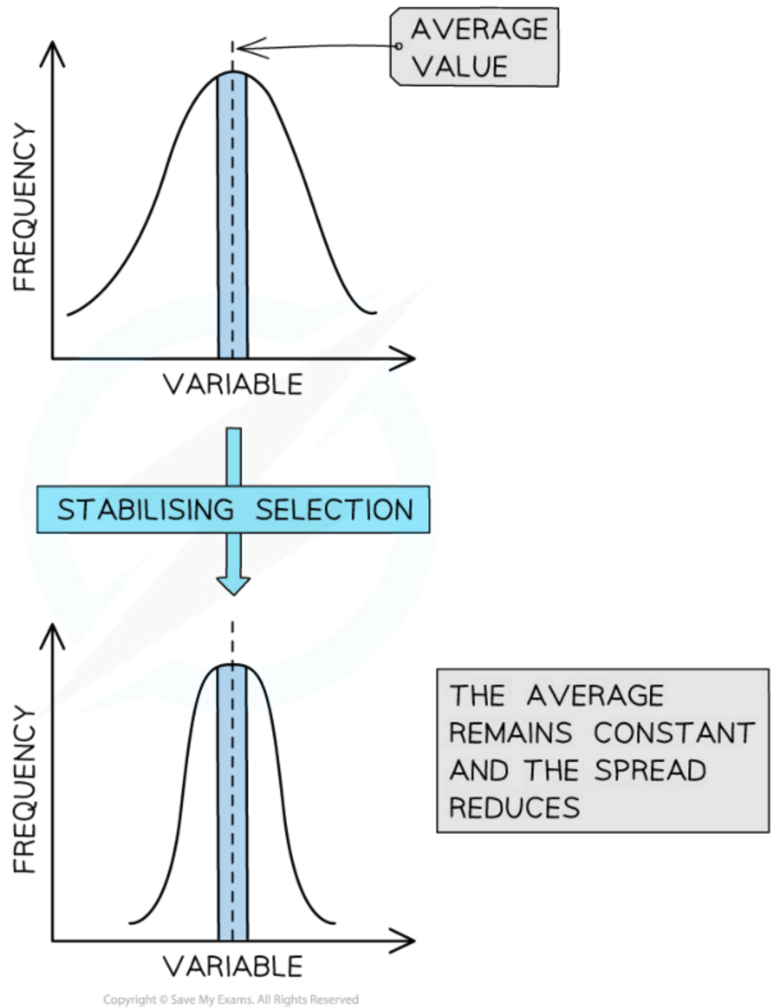
AVERAGE VALUE
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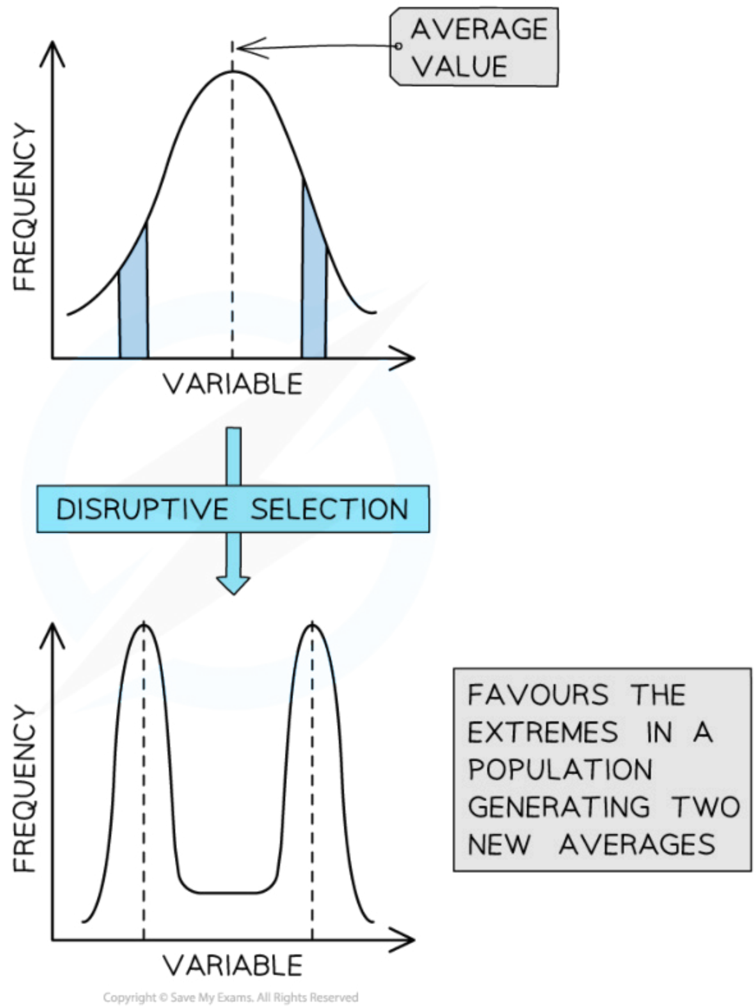


Summary of the three main forms of natural selection and their effects on the average phenotype of a population

Examiner Tip

Become familiar with the shapes of the graphs above. They can help you answer questions about the type of selection that is occurring in a population.

Hardy-Weinberg Principle (HL)

Your notes

Hardy-Weinberg Equation

- The Hardy-Weinberg principle states that if certain conditions are met then the **allele frequencies of a gene within a population will not change from one generation to the next**
- There are seven **conditions or assumptions** that must be met for the Hardy-Weinberg principle to hold true
- The Hardy-Weinberg **equation** allows for the **calculation of allele and genotype frequencies** within populations
- It also allows for predictions to be made about how these frequencies will change in future generations

Hardy-Weinberg equations

- If the phenotype of a trait in a population is determined by a single gene with only two alleles (we will use **B / b** as examples throughout this section) then the population will consist of individuals with three possible genotypes:
  - Homozygous dominant **(BB)**
  - Heterozygous **(Bb)**
  - Homozygous recessive (**bb)**
- When using the Hardy-Weinberg equation frequencies are represented as **proportions** of the population; a proportion is a number out of 1
  - For example if every individual in the population has the homozygous dominant genotype BB then its frequency will be 1, while if half of the population show this genotype then the frequency will be 0.5
- **Frequency of alleles** can be represented; this is the proportion of all of the alleles in a population that are of a particular form
  - The letter ***p*** represents the frequency of the dominant allele **(B)**
  - The letter ***q*** represents the frequency of the recessive allele **(b)**
  - As there are only two alleles at a single gene locus for a phenotypic trait in the population:

$$p + q = 1$$

  - E.g. in a population of 100 individuals there would be 200 alleles because every individual has two versions of each gene
    - If 120 of those alleles were the dominant allele then the frequency of the dominant allele would be 120/200
    - It could be said that $p = 120 \div 200 = 0.6$
    - If $p = 0.6$ then $q = 1 - 0.6 = 0.4$
- **Frequency of genotypes** can also be represented; this is the proportion of all of the individuals with a particular genotype
  - The chance of an individual being homozygous dominant is p^2
    - The offspring would inherit dominant alleles from both parents so $p \times p = p^2$
  - The chance of an individual being heterozygous is $2pq$

Your notes

  - Offspring could inherit a dominant allele from the father and a recessive allele from the mother (***p*** x ***q***) **or** offspring could inherit a dominant allele from the mother and a recessive allele from the father (***p*** x ***q***) so **2*pq***
- The chance of an individual being homozygous recessive is q^2
  - The offspring would inherit recessive alleles from both parents so $q \times q = q^2$
- As these are all the possible genotypes of individuals in the population the following equation can be constructed:

$$p^2 + q^2 + 2pq = 1$$

Your notes

Worked example

In a population of birds 10% of the individuals exhibit the recessive phenotype of white feathers. Calculate the frequencies of all genotypes.

Answer:

- We will use F / f to represent dominant and recessive alleles for feather colour
- Those with the recessive phenotype must have the homozygous recessive genotype, **ff**
- Therefore $q^2 = 0.10$ (as 10% of the individuals have the recessive phenotype and q^2 represents this)

To calculate the frequencies of the homozygous dominant (p^2) and heterozygous ($2pq$):

Step 1: Find q

$$\sqrt{q^2} = \sqrt{0.1} = 0.32$$

Step 2: Find *p* (the frequency of the dominant allele F). If q = 0.32, and p + q = 1

$$p + q = 1$$

$$p = 1 - 0.32$$

$$p = 0.68$$

Step 3: Find p^2 (the frequency of homozygous dominant genotype)

$$0.68^2 = 0.46$$

$$p^2 = 0.46$$

Step 4: Find 2*pq* = 2 x (p) x (q)

$$2 \times (0.68) \times (0.32) = 0.44$$

Step 5: Check calculations by substituting the values for the three frequencies into the equation; they should add up to 1

$$p^2 + 2pq + q^2 = 1$$

$$0.46 + 0.44 + 0.10 = 1$$

In summary:

- Allele frequencies:
  - *p* = **F** = 0.68
  - *q* = **f** = 0.32
- Genotype frequencies:

- p^2 = **FF** = 0.46
- q^2 = **ff** = 0.10
- $2pq$ = **Ff** = 0.44

Your notes

Examiner Tip

When you are using Hardy-Weinberg equations you must always start your calculations by determining the proportion of individuals that display the **recessive phenotype;** this is the only phenotype from which you can immediately work out its genotype as it will always be **homozygous recessive** (the dominant phenotype is seen in both homozygous dominant and heterozygous individuals).

In Hardy-Weinberg questions it is a good idea to begin by establishing what information you have been given in the question (i.e. do you know q^2, or do you know p?), and then establishing what the question wants you to work out (i.e. are you calculating $2pq$?). You can then work out how to get from one to the other.

Don't mix up the **Hardy–Weinberg equations** with the **Hardy–Weinberg principle**. The **equations** are used to **estimate** the allele and genotype **frequencies** in a population. The **principle** suggests that there is an **equilibrium** between allele frequencies and that there is no change in this between generations.

Hardy–Weinberg Conditions

Conditions for the Hardy–Weinberg principle

- For the Hardy-Weinberg principle to be correctly applied to a population a series of conditions, or assumptions, need to be met
  - Organisms are **diploid**
  - Organisms reproduce **by sexual reproduction** only
  - There is **no overlap** between generations, i.e. parents do not mate with offspring
  - **Mating** is **random**
  - The **population** is **large**
  - There is **no migration**, **mutation,** or **selection**
    - This would mean no individuals entering the population (immigration) or leaving (emigration)
    - Selection refers to both natural and artificial selection
  - Allele **frequencies** are **equal** in both sexes
- If genotype frequencies in a population do not fit the Hardy-Weinberg equation, it indicates that one or more of these conditions is not being met
- The Hardy-Weinberg principle can be useful when building models and making predictions, but the assumptions listed are very rarely, if ever, all present in nature

Your notes

Artificial Selection (HL)

Artificial Selection

- **Artificial selection** is the process by which **humans choose** organisms with **desirable traits** and **selectively breed** them together to enhance the expression of these desirable traits over time and over many generations
  - This practice is also known as **selective breeding**
- Humans have been selectively breeding organisms for thousands of years, long before scientists understood the genetics behind it
- Knowledge of the alleles that contribute to the expression of the desired traits are not required as individuals are selected by their **phenotypes,** and **not their genotypes**
- As the genetics is not always understood, breeders can accidentally **enhance other traits that are genetically linked** to the desirable trait
  - These other traits can sometimes **negatively affect** the organism's **health**

The process of artificial selection

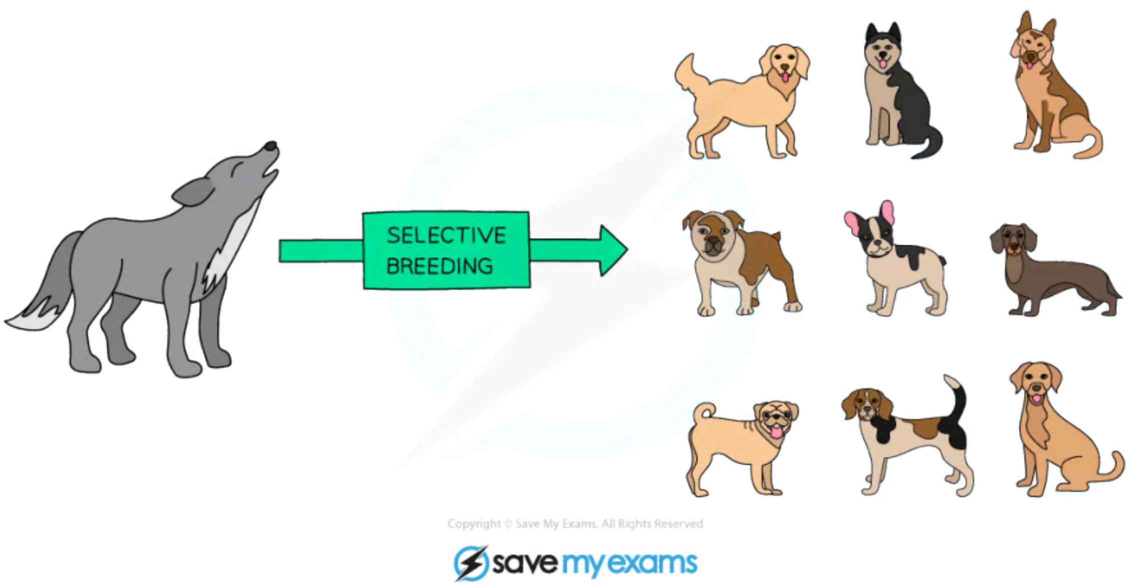
1. The population shows **phenotypic variation** - there are individuals with different phenotypes (i.e. different characteristics)
2. A breeder (the person carrying out the artificial selection) selects an individual with the **desired phenotype**
3. Another individual with the desired phenotype is selected. The two selected individuals **should not be closely related to each other**
4. The two selected individuals are **bred together**
5. The offspring produced reach maturity and are then **tested for the desirable trait.** Those that display the desired phenotype to the greatest degree are **selected** for **further breeding**
6. The process continues for **many generations**: the best individuals from the offspring are chosen for breeding until **all offspring display the desirable trait**

Selective breeding in animals

- Animals are selectively bred for various characteristics, including:
  - Cows, goats and sheep that produce a higher yield of **milk** or **meat**
  - Chickens that lay large **eggs**
  - Domestic dogs that have a gentle nature
  - Sheep with good quality wool
  - Horses with fine features and a very fast pace
- An example of an animal that has been selectively bred by humans in many ways to produce breeds with many different characteristics is the domestic dog, all breeds of which are descended from wolves

Selective breeding in dogs diagram

Your notes



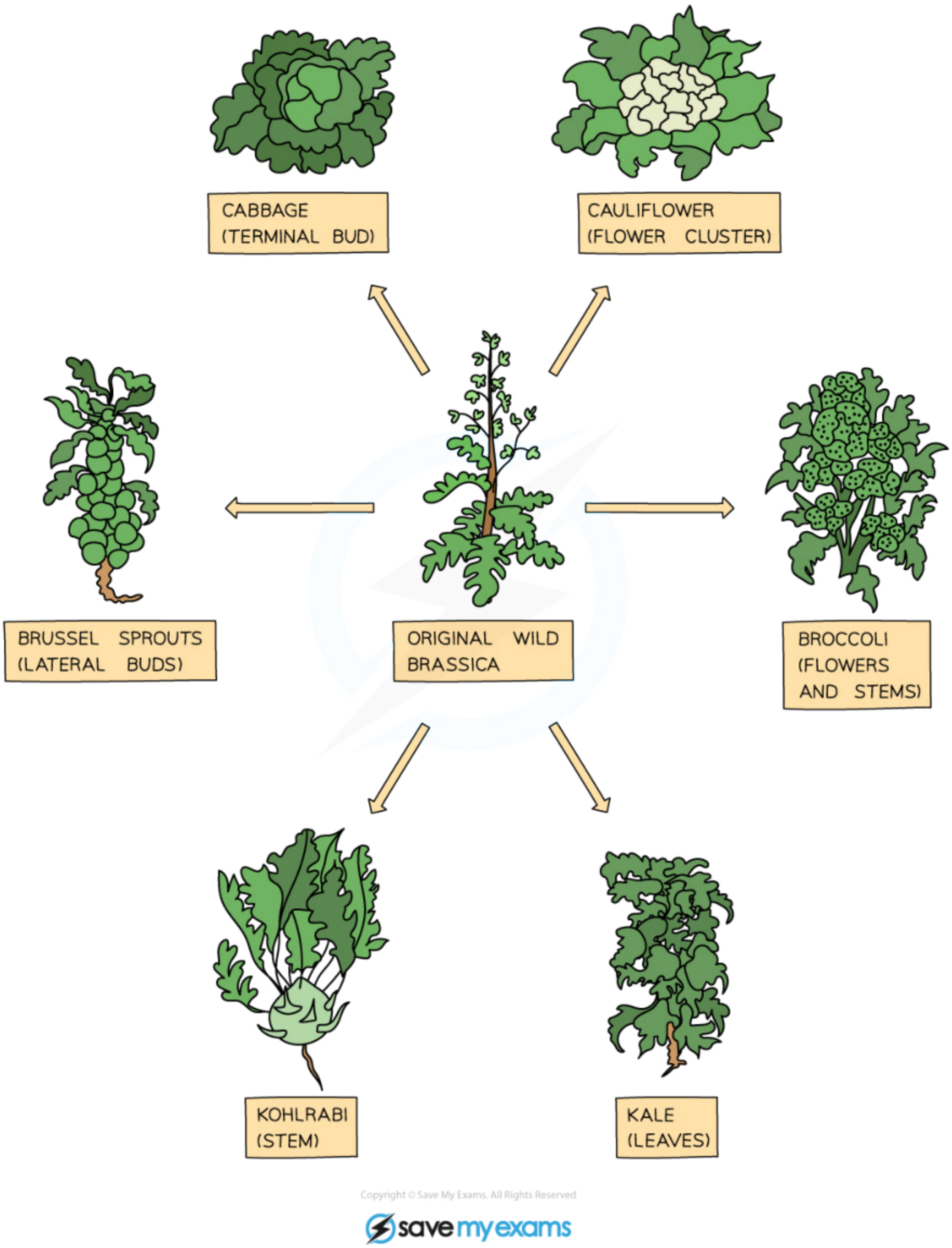
Selective breeding has produced many different breeds of domestic dog

Selective breeding in plants

- Selective breeding of plants takes place in the same way as selective breeding of animals
- Plants are selectively bred by humans for development of many characteristics, including:
  - **Disease resistance** in food crops
  - **Increased crop yield**
  - **Hardiness to weather conditions** (eg. drought tolerance)
  - Better tasting fruits
  - Large or unusual flowers
- An example of a plant that has been selectively bred in multiple ways is wild brassica, which has given rise to cauliflower, cabbage, broccoli, brussel sprouts, kale and kohlrabi

Selective breeding in plants diagram

Your notes



An example of selective breeding in plants

What is the difference between natural and artificial selection?

- Artificial selection involves a **deliberate choice of traits** by humans whereas natural selection does not
- For example, the evolution of resistant bacteria from the overuse of antibiotics in humans is due to natural selection
  - Humans did not deliberately use antibiotics in order to produce resistant bacteria; it was an unintended consequence
- Natural selection results in an animal better adapted to their environment
- Artificial selection can result in animals poorly suited to their environment

Your notes