Evolution

Unit 4

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4.5 The evolution of humans (page 213)	• Explain how humans have evolved. • Construct an evolutionary tree of human evolution. • Explain the importance of Lucy and Ardi in the study of human evolution. • Discuss some of the controversies surrounding human evolution.

4.1 The origin of life

By the end of this section you should be able to:

- Explain what biologists generally understand by the term 'evolution'.
- Describe and compare some of the different theories that seek to explain the origin of life on Earth, including special creation theory, spontaneous generation theory, eternity of life theory, cosmozoan theory and biochemical origin theory.
- Describe some of the evidence supporting the biochemical origin theory, including the work of Oparin and Miller.
- Appreciate the quest by humans for knowledge of their origins.

What is evolution?

When we talk of **evolution** we usually 'know what we mean' but, actually, it can be quite difficult to define. We usually think of the whole process – the whole 'course of evolution' starting with the origin of life and ending with the current biodiversity – with some notion that there must have been extinctions along the way. We think of new species arising and the biodiversity of the planet increasing and also, as evolution has progressed, there has been a general trend towards larger and more complex organisms. And we often put ourselves right at the pinnacle of evolution, as though things 'could not get any better than this'. We have something like the summary shown in figure 4.1 in mind.

KEY WORD

evolution *the theory of evolution describes how the various forms of life on Earth (including humans) emerged and developed*

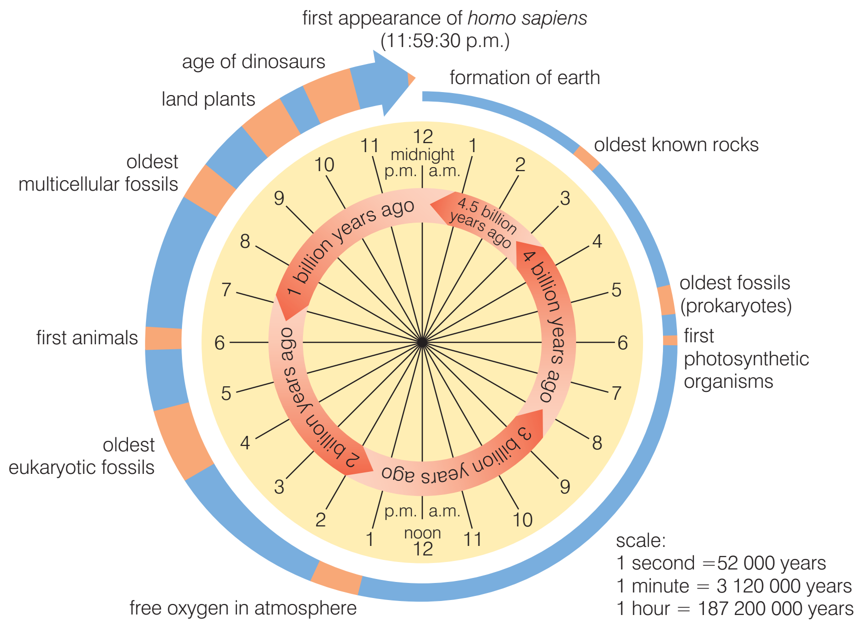


Figure 4.1 *A summary of the course of evolution*

But what is happening? How did all these millions of new species appear? We need a working definition of evolution which will take into account what is happening. Obviously, change is important when trying to explain evolution. Organisms have changed over time – they have evolved; we almost use the two words interchangeably. But why would an organism change? And would it matter if just one organism changed? For new species to appear, groups of organisms – populations – have to change, not just single organisms. For them to change, their genes must change, as the genes define what they will be by controlling protein synthesis (see unit 3).

So we can come up with a working definition of the process of evolution as:

The change in genetic composition of a population over successive generations, which may be caused by meiosis, hybridisation, natural selection or mutation. This leads to a sequence of events by which the population diverges from other populations of the same species and may lead to the origin of a new species.

What theories are there about the origin of life on Earth?

There are five main theories of the origin of life on Earth:

- special **creationism**
- spontaneous generation
- eternity of life
- cosmozoan theory
- biochemical origin

How does special creationism account for the origin of life?

Special creation is nearly always linked to religion, whereas an acceptance of evolution is linked to scientific thinking. There are fundamental differences between the two that mean it is unlikely that the difference between the scientific theory of evolution and special creation will ever be resolved. Science describes the natural world around us using a means of observation and empirical testing using instruments. These observations then result in the development of scientific theories. There is no attempt on the part of science to give opinions about morality or purpose.

Religion mainly focuses on spiritual matters that, by their very nature, cannot be seen, touched or measured effectively. Religion deals with philosophical matter that relates to morality and concerns between humans and their God. Religion is less concerned with empirical observable facts and testable hypotheses but rather with faith, the belief in things that cannot be proven.

Science relies on provable events; religion relies on believing in that which cannot be proven. The two views are very, very different from each other even though each is a valid worldview in its own context.

Special creation states that at some stage, some supreme being created life on Earth. There are many different versions of special creation, linked with different religions. Often, there is considerable variation as to how rigidly the special creation theory is interpreted within a religion.

Young Earth creationism

This form of creationism today suggests that the Earth is only a few thousand years old. Young Earth creationists often believe the Earth was created in six 24-hour days. While they agree that the Earth is round and moves around the Sun, they interpret all geology in the light of Noah's flood.

Old Earth creationism

There are several types of creationism that are considered Old Earth. They vary in different aspects of how they explain the age of the Earth while still holding to the story found in Genesis. Those who believe in Old Earth creationism accept the evidence that the Earth is very old but still maintain that all life was created by God.

Day-age and gap creationism

These are similar in that each interprets the beginnings of the creation story as actually having taken much longer than six Earth days.

- Gap creation discusses a large gap between the formation of the Earth and the creation of all the animals and humans. The gap could be millions or billions of years. This gets around the scientific evidence that the Earth is several billion years old without having to believe in the process of evolution itself.

KEY WORD

creationism *(or special creationism) a theory claiming that the different forms of life on Earth were created by a supreme being*

Activity 4.1

Work in groups. Each group takes one theory of how life on Earth began and researches into it. Within your group discuss the theory and consider any scientific evidence which supports the theory. Plan a presentation to the rest of the class.

KEY WORDS

intelligent design *a theory claiming that life developed due to a combination of natural forces and the intervention of a supernatural being*

spontaneous generation *a theory that claimed that some types of organism could come into being almost instantly from non-living materials*

- Day-age creationism is similar in the length of time but talks about each of the six 'days' as really meaning a billion years or so of geologic time; the 'days' are just symbolic.

Progressive creationism

This type of creationism accepts the Big Bang as the origin of the Universe. It accepts the fossil record of a series of creations for all of the organisms catalogued. However, it does not accept these as part of a continuing process; each is seen as a unique creation. Modern species are not seen as being genetically related to ancient ones.

Theistic evolution/Evolutionary creationism

This view of evolution maintains that God 'invented' evolution and takes some form of an active part in the ongoing process of evolution. It also invokes the role of God in areas not discussed by science, like the creation of the human soul. Theistic evolution is promoted by the Pope for the Catholic Church and is also espoused by most mainline Protestants.

Intelligent design

This is the newest version of creationism and maintains that God's handiwork can be seen in all of creation if one knows where to look. Advocates of **intelligent design** offer sophisticated arguments, often based on cell biology and mathematics, to give the impression of complex scientific arguments and to create equal stature with mainstream scientific thought. These arguments attack different parts of evolutionary theory, with the idea that if one part of evolutionary theory can be found to be incorrect then it follows that all of evolution must be incorrect. The term intelligent design is used to mask the fact that it's a form of creationism cloaked in scientific-sounding ideas.

How does spontaneous generation seek to explain life on Earth?

Spontaneous generation suggests that life can evolve 'spontaneously' from non-living objects. It was only a few hundred years ago that people still believed this to be true. For example, people believed that rotting meat turned into flies and that wine produced bacteria as it went sour.

It took the work of Francisco Redi to disprove the idea of rotting meat producing flies and the work of Louis Pasteur to finally show that not even micro-organisms could be produced by spontaneous generation.

In Redi's experiment, illustrated in figure 4.2, flies only appeared in the jars where flies had access in the first place. Exclude the flies, as he did with some jars, and the meat does not produce either maggots or flies.

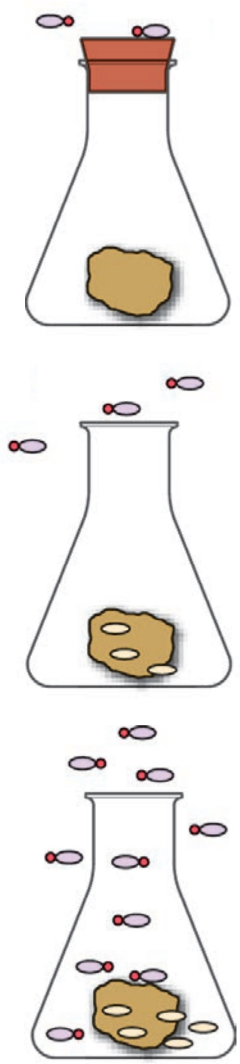


***Figure 4.2** Redi's experiment*

Louis Pasteur showed that broth (or wine) only went sour if micro-organisms were allowed to enter. Also no micro-organisms appeared in the broth unless they were allowed to enter from the outside – they were not formed from the broth itself.

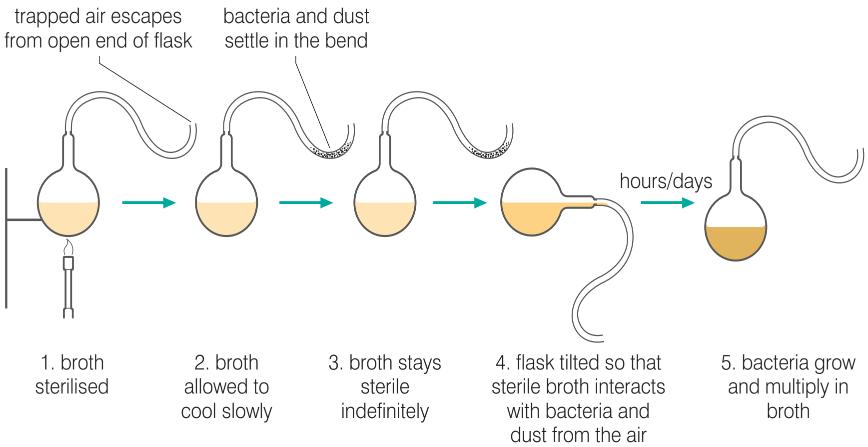


Figure 4.3 *Louis Pasteur finally disproves spontaneous generation*

These two scientists showed that both macro-organisms (Redi) and micro-organisms (Pasteur) can only arise from pre-existing organisms, disproving the theory of spontaneous generation.

But what about the first ever cell? Unless we believe that life is eternal, with no beginning and no end, there had to be a first cell. And it could not have come from a pre-existing cell because it was the first.

As we shall see later, scientists have proposed a method whereby the necessary components of life could be formed and believe that, somehow, they managed to assemble themselves into a primitive cell. This is a kind of spontaneous generation.

How does the eternity of life theory seek to explain life on Earth?

In this theory of life, there is no beginning and no end to life on Earth and so it neither needs special creation nor does it need to be generated from non-living matter. Supporters of this theory believe that life is an inherent property of the Universe and has always existed – as has the Universe. At the time when such theories were being propounded, many eminent scientists – including Albert Einstein – believed that the Universe was unchanging. They reasoned that 'if life is found today in an unchanging Universe, then it must always have been there'.

How does the cosmozoan theory seek to explain life on Earth?

According to this theory, life has reached this planet Earth from other cosmological structures, such as meteorites, in the form of highly resistant spores.

This idea was proposed by Richter in 1865 and supported by Arrhenius in 1908 and by other contemporary scientists. The

Activity 4.2

Write a report describing briefly the theory of spontaneous generation. Explain carefully how we now know that spontaneous generation is not possible and does not happen.

KEY WORDS

eternity of life theory *claims that the Universe has always existed and that there has always been life in the Universe.*

cosmozoan theory *claims that life on Earth originally came from elsewhere in the Universe (possibly from another planet)*

Figure 4.4 *Did meteorites bring life to Earth?*

theory did not gain any significant support as it lacks evidence. It is strongly linked to the 'eternity of life' theory of the origin of life on Earth.

In the nineteenth century, Hermann Richter put forward the idea that life has always existed in the Universe, propagating itself from one place to another by means of '**cozmozoa**' (germs of the cosmos). In this theory, life has existed and will exist for all eternity across the Universe, and so there is no need for an explanation of its origin. Two other eminent scientists of the time – Lord Kelvin and Herman von Helmholtz – also took the same view.

In 1908, the Swedish physical chemist Svante Arrhenius put forward a new version of the cosmozoan theory, and gave it the name panspermia. Arrhenius' contribution was a new theory of the mechanism by which life could be transported between planets; he proposed that bacterial spores were propelled through inter-planetary space by radiation pressure. Previous versions of the theory had assumed transport was by means of meteorites or by comets. However, the very high temperatures that meteorites create on entering the Earth's atmosphere seemed to rule this out. In Arrhenius' version of the theory, spores arriving at the Earth (possibly attached to grains of interstellar dust) could fall slowly to the ground without being subjected to high temperatures due to air friction.

One of the motivations for Arrhenius' panspermia theory was that it also seemed to provide a solution to the disproof by Louis Pasteur's experiments of spontaneous generation in bacteria. If there was no way in which the origin of life could be explained, it was reasonable to suppose that life was an inherent property of the Universe and had always existed. Arrhenius' theory was dropped by most scientists when it became apparent that the bacterial spores would be subject to UV radiation and X-radiation, zones of charged particles, which would inevitably destroy them.

However, another version of the cosmozoan theory or panspermia does have some evidence to back it up. This version – called weak panspermia or pseudo-panspermia – is the theory that organic compounds arrived from outer space and added to the chemicals on Earth that gave rise to the first life. In 1969 a meteorite landed in Australia that was 12% water and contained traces of 18 amino acids. This evidence points not only to the presence of organic compounds in outer space, but also to the capacity of such compounds to reach Earth. Also, complex organic molecules have been detected in star-forming clouds, further adding to the evidence for organic molecules in space.

DID YOU KNOW?

The steady state theory of the Universe

Scientists now generally accept that the Universe began with a 'Big Bang' and will either expand for ever or will eventually contract again, ending in a 'Big Crunch'. However, for the early part of the twentieth century, a number of eminent astronomers and physicists believed that the Universe was in a 'steady state'. It had always existed the way it was and always would. The eternity of life theory is strongly linked to this theory of the Universe.

Figure 4.5 *Clouds of inter-stellar gas have been shown to contain organic molecules.*

KEY WORD

biochemical theory *suggests that life on Earth originated as a result of a number of biochemical reactions producing organic molecules which associated to form cells*

How does the biochemical theory seek to explain life on Earth?

The current ideas we have about how life may have evolved on Earth as a result of biochemical reactions (sometimes called abiogenesis) owe much to two biologists working early in the twentieth century:

- **Aleksandr Oparin**, a Russian biologist who first put forward his ideas in 1924, and
- **John Haldane**, an English biologist independently put forward almost identical ideas in 1929 (before Oparin's book had been translated into English).

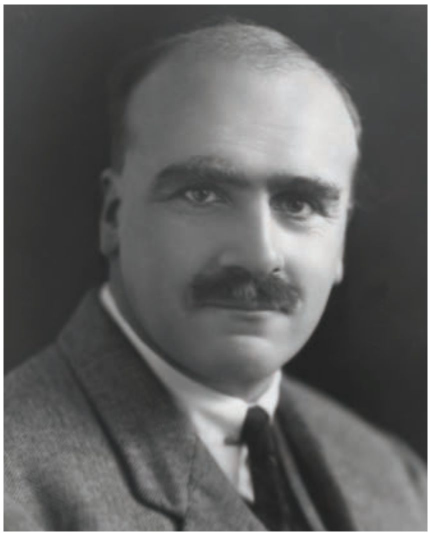


Figure 4.6 *J B S Haldane and A I Oparin*

They both suggested that:

- the primitive atmosphere of the Earth was a reducing atmosphere with no free oxygen – as opposed to the oxygen-rich atmosphere of today
- there was an appropriate supply of energy, such as lightning or ultraviolet light, and
- this would provide the energy for reactions that would synthesise a wide range of organic compounds, such as amino acids, sugars and fatty acids.

Oparin suggested that the simple organic compounds could have undergone a series of reactions leading to more and more complex molecules. He proposed that the molecules might have formed colloidal aggregates, or 'coacervates', in an aqueous environment. The coacervates were able to absorb and assimilate organic compounds from the environment in a way similar to the metabolism of cells. These coacervates were the precursors of cells and would be subject to natural selection, eventually leading to the first true cells. Figure 4.7 shows some coacervate droplets containing amino acids and small polymers of one of the nitrogenous bases in DNA.

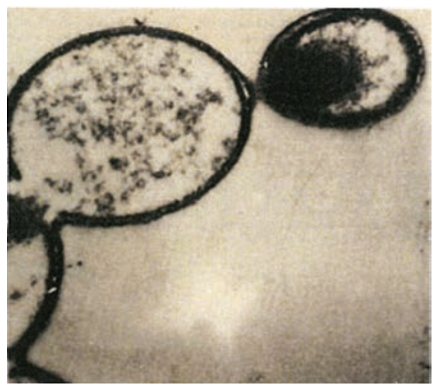


Figure 4.7 *Coacervate droplets – pre-cells?*

Haldane's ideas about the origin of life were very similar. He proposed that the primitive sea served as a vast chemical laboratory powered by solar energy. As a result of all the reactions powered by solar energy, the sea became a 'hot dilute soup' of organic monomers and small polymers. Haldane called this the 'prebiotic soup', and this term came to symbolise the Oparin–Haldane view of the origin of life.

But is there any evidence for the theory? In 1953, **Stanley Miller** conducted his now-famous spark-discharge experiment. In this investigation, he passed electric sparks repeatedly through a mixture of gases that were thought to represent the primitive atmosphere of the Earth. These gases were methane (CH_4), ammonia (NH_3), water (H_2O) and hydrogen (H_2). The equipment he used is shown in figure 4.8.

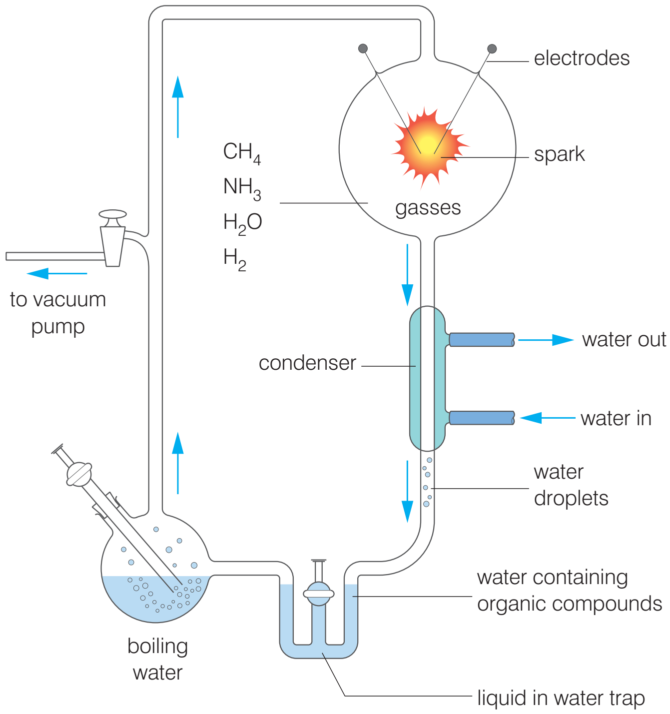


Figure 4.8 *Stanley Miller's spark-discharge experiment*

KEY WORDS

prokaryote *an organism consisting of a prokaryotic cell. All bacteria are prokaryotes*

eukaryote *an organism consisting of one or more eukaryotic cells. All organisms other than bacteria are eukaryotes*

archaebacterium *the first bacteria (and thus the first living organisms) to develop on Earth. They are now only found in extreme conditions*

eubacterium *any bacteria that is not an archaebacterium is a eubacterium*

photosynthesis *the use of light energy to drive reactions that synthesise organic molecules; it occurs in plants, algae and some bacteria*

When he analysed the liquid in the water trap, he found it contained a number of simple organic molecules – hydrogen cyanide (HCN) was one of them.

He found that by leaving the equipment for longer periods of time, a larger variety and more complex organic molecules were formed including:

- amino acids – essential to form proteins
- pentose sugars – needed to form nucleic acids
- hexose sugars – needed for respiration and to form starch and cellulose
- hydrogen cyanide again – but it has been shown that the nitrogenous bases found in nucleotides can be synthesised in the laboratory using HCN as a starting point

There is then considerable evidence to support the Oparin–Haldane hypothesis. But it is not without its problems. These include:

- Why are only 'left-handed' amino acids found in living things when both left-handed and right-handed types are possible?
- Although nitrogenous bases can be synthesised in the laboratory, purines (adenine and guanine) are not synthesised under the same conditions as pyrimidines (thymine, uracil and cytosine); this is quite a serious problem for the theory.

- Although Miller was able to demonstrate the formation of monomers in his investigation, he was unable to demonstrate the next significant step of polymerisation of these monomers.

Recently, progress has been made in all of these areas. In 2009, John Sutherland, a chemist at the University of Manchester in England, found that, instead of making the nitrogenous base and sugar separately from chemicals likely to have existed on the primitive Earth, under the right conditions the base and sugar could be built up as a single unit (a nucleotide), and so did not need to be linked.

It has also been shown that polymerisation can occur under appropriate conditions and a solution is in sight for the 'handedness' problem.

The biologist John Desmond Bernal suggested that there were a number of clearly defined 'stages' in explaining the origin of life:

- Stage 1: the origin of biological monomers
- Stage 2: the origin of biological polymers
- Stage 3: the evolution from molecules to cell

Bernal suggested that evolution may have commenced at some time between stages 1 and 2.

The first two stages have been demonstrated as being possible in the conditions of the primitive Earth, and research on stage 3 is well advanced.

DID YOU KNOW?

Other ideas on the biochemical theory

Professor William Martin Dusseldorf and Dr Michael Russell Glasgow claim that cells came before the complex organic molecules. Not living cells but inorganic ones made of iron sulphide, formed not at the Earth's surface but at the bottom of the oceans. In their theory, a fluid rich in compounds such as hydrogen, cyanide, sulphides and carbon monoxide emerged from the Earth's crust at the ocean floor. It then reacted inside the tiny metal sulphide cavities. They provided the right microenvironment for chemical reactions to take place. That kept the building blocks of life concentrated at the site where they were formed rather than diffusing away into the ocean. The iron sulphide cells are where life began.

Activity 4.3: Debating the origin of life

Your teacher will divide the class into groups with the following names:

- The Creationists
- The Spontaneous Generationists
- The Eternalists
- The Cosmozoans
- The Abiogenesists

Each group must prepare a 'case' for their theory of the origin of life.

Once this is done, each group will, in turn, then start a debate by announcing: This house believes that only … (Creationism, for example,) can truly account for the origin of life.

The group will have five minutes to put their case to the rest of the class.

The group starting the debate will then face five minutes of questions from a second group made up of one member from each of the other four groups.

At the end of this time, those members not involved directly in this debate will vote as to who they think has won the debate – the group proposing the theory or the group questioning the theory.

You must try to vote only on the debate, not on your personal views.

DID YOU KNOW?

Archaebacteria are found in extreme conditions

Thermophilic means 'heat-loving' and these bacteria are found at temperatures that would kill other cells. Very few cells can live in high concentrations of methane as can the methanobacteria or salt as can the halobacteria.

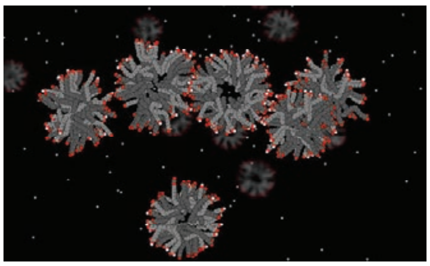


Figure 4.9 *Could pre-cells have looked like this when they were dividing?*

KEY WORDS

autotroph *an organism that produces organic molecules from inorganic material*

aerobic respiration *a means by which cells release energy from organic molecules using oxygen*

How did autotrophs evolve on Earth?

However the first organisms appeared – about 4 billion years ago – they were **prokaryotes**. They had no true nucleus. It seems likely also that they had RNA rather than DNA as their genetic material. It seems likely that they gave rise to three distinct lines of evolution leading to:

- **archaebacteria** – prokaryotes including thermophilic sulphobacteria, methanobacteria and halophilic bacteria
- **eubacteria** – prokaryotes; ordinary bacteria and cyanobacteria (blue-green bacteria and sometimes known as blue-green algae)
- **eukaryotes** – eventually evolving into protoctistans, fungi, plants, animals (nearly all are aerobic)

One great change that affected the evolution of early life forms was the shift from the reducing atmosphere to an atmosphere containing oxygen. This took place about 2.4 billion years ago. Where did this oxygen come from?

There is only one process we know of that can have produced it – **photosynthesis**.

The fossil record shows that cyanobacteria had been producing oxygen by photosynthesis from about 3.5 billion years ago but that for almost 1 billion years the levels in the atmosphere did not rise because the oxygen was absorbed by the vast amount of iron in the Earth – it rusted!! But, by 2.4 billion years ago, the concentration began to rise and the rate of increase accelerated from 2.1 billion years ago. Cyanobacteria are photo-autotrophs; they use light as a source of energy, and CO_2 as a source of carbon (photosynthesis). They are among the earliest of **autotrophs**, using, not chlorophyll, but another pigment, phycocyanin (which gives them their blue-green appearance), to capture light energy. You can see from figure 4.11 that phycocyanin absorbs different wavelengths of light from both chlorophyll a and chlorophyll b.

Other primitive autotrophs used not light as a source of energy but chemical reactions and are called chemo-autotrophs. Chemo-autotrophs use the energy from chemical reactions to synthesise all

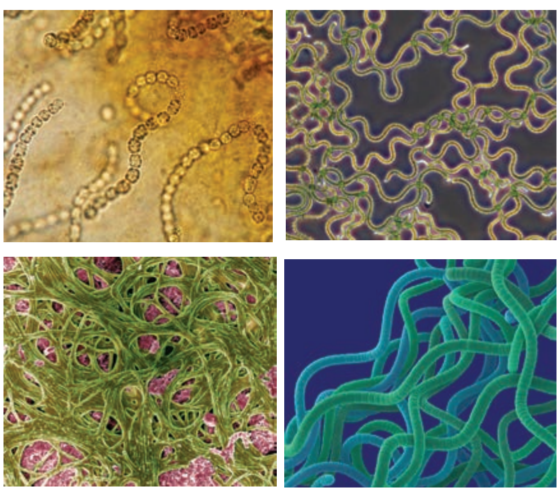


Figure 4.10 *Cyanobacteria have been around for a long time*

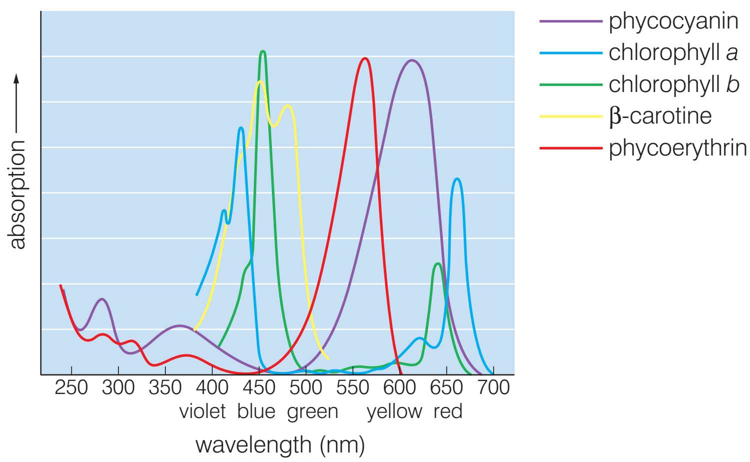


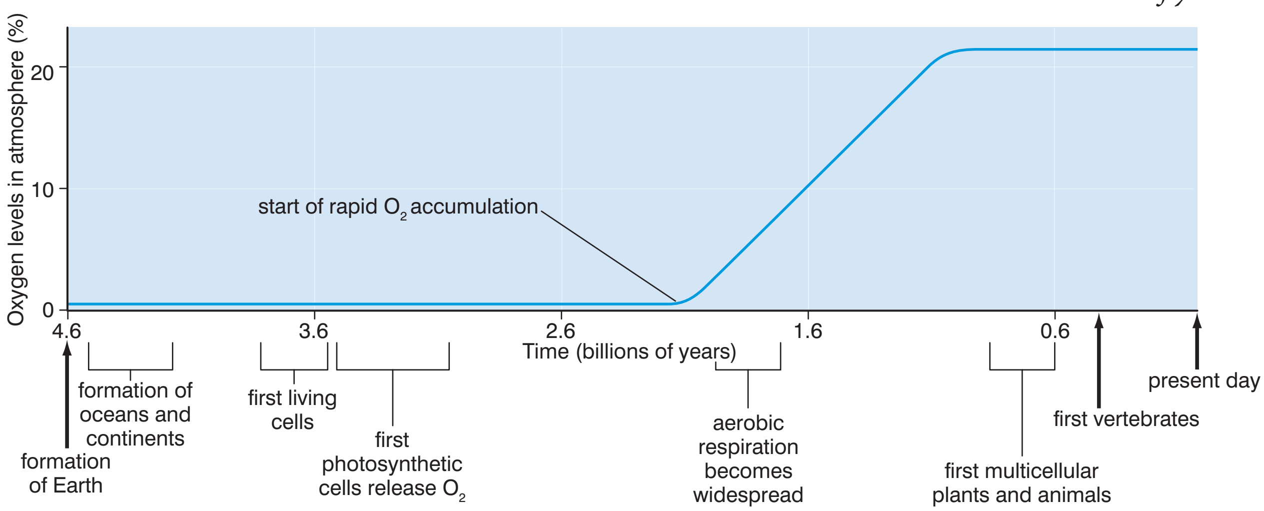
Figure 4.11 *Phycocyanin absorbs different wavelengths of light from chlorophyll*

necessary organic compounds, starting from carbon dioxide. They generally only use inorganic energy sources. Most are bacteria or archaea that live in hostile environments such as deep sea vents and are the primary producers in ecosystems on the sea beds. Scientists believe that the some of first organisms to inhabit Earth were chemo-autotrophs.

The primitive sulphobacteria use hydrogen sulphide as the energy source. Hydrothermalism, particularly in deep sea vents, maintains the bacterial life of sulphobacteria and/or methanobacteria. Bacteria are the only life forms found in the rocks for a long time, 3.5 to 2.1 billion years ago. Eukaryotes became numerous 1.9 to 2.1 billion years ago and fungi-like organisms appeared about 0.9 billion years ago. The oxygen produced by the photo-autotrophs had made it possible for **aerobic respiration** to evolve as an energy-releasing pathway. As this process releases far more energy than does the anaerobic pathway more active organisms could now evolve – the animals, perhaps 600 to 700 million years ago.

Figure 4.12 *Was the first animal like this comb jelly?*

Figure 4.13 *Life on Earth has evolved over billions of years*



Activity 4.4: Class discussion 'The origin of life'

This topic can arouse quite strong emotions. People with a deep religious belief can be easily offended by those who deny the existence of any supreme being who created live and the universe. Equally, those who accept the biochemical origin of life often cannot understand how anyone could believe in a supreme being. During this activity, everyone will have the chance to put their point of view, but it is as much about listening as it is about making your own point. You must accept that other points of view are possible and listening carefully may make you revise your own position.

The activity will follow the following procedure:

- Your teacher will summarise the various theories on the origin of life.
- Your teacher will ask you for your opinions. You may then make your point of view but, during this stage, it is important that:
- you do not interrupt anyone else; they also have the right to put their point of view
- you only put your point of view when your teacher allows you to – the discussion cannot degenerate into a row!
- At the end of the discussion, your teacher will summarise the views of the class.
- You will write a summary of the main views held by different people in the group and why they hold those views. Do not comment on their views and reasons for holding them; just record them.

Review questions

Choose the correct answer from A to D.

1. Evolution is best described as:
   A a genetic change in an individual
   B a genetic change in an individual that is passed on through successive generations
   C a genetic change in a population
   D a genetic change in a population that is passed on through successive generations
2. Special creationism always suggests that:
   A evolution is a tool of a supreme being
   B a supreme being created everything in its present state
   C a supreme being is somehow involved in the creation of life
   D none of the above
3. In the past spontaneous generation has suggested that:
   A life can be created from non-living matter
   B micro-organisms can be created from non-living matter
   C flies can be created from rotting meat
   D all of the above
4. The eternity of life theory suggests that:
   A all life forms are eternal
   B life has always existed and always will
   C life will go on forever
   D all of the above
5. All forms of the cosmozoan (panspermia) theory suggest that:
   A life forms arrived on Earth from other celestial bodies
   B life forms arrived on Earth due to radiation pressure
   C organic molecules arrived on Earth in meteorites
   D other celestial bodies have been important in the origin of life on Earth
6. All forms of the biochemical theory (abiogenesis) suggest that:
   A life evolved from non-biological molecules which reacted together and eventually formed pre-cells
   B life evolved from non-biological molecules which reacted together using solar or electrical energy at the surface of the oceans and eventually formed pre-cells
   C life evolved from non-biological molecules which reacted together using heat energy deep beneath the sea and eventually formed pre-cells
   D life evolved from non-biological molecules which reacted together in small pools and eventually formed pre-cells
7. The first photo-autotrophic organisms were likely to have been:
   A green algae
   B sulphur bacteria
   C plants
   D blue-green bacteria
8. From the time when oxygen was first produced on the planet, it took approximately how many years for the levels to begin to rise?
   A 1 000 000
   B 10 000 000
   C 100 000 000
   D 1 000 000 000
9. Which of the following is the best definition of a chemo-autotroph?
   A An organism that uses chemical reactions as a source of energy.
   B An organism that uses chemical reactions as a source of energy to absorb its food.
   C An organism that uses chemical reactions as a source of energy to synthesise its own food.
   D An organism that uses chemical reactions as a source of energy to synthesise organic molecules, using carbon dioxide as a starting point.

10. The scientists who developed the theory of abiogenesis were:
    A Miller and Bernal
    B Miller and Oparin
    C Bernal and Haldane
    D Oparin and Haldane

4.2 Theories of evolution

By the end of this section you should be able to:

- Appreciate that there have been several attempts to explain how evolution takes place.
- Describe the theory proposed by Jean-Baptiste Lamarck.
- Describe the theory proposed by Charles Darwin.
- Compare these two theories.
- Explain how our knowledge of genetics, behaviour and molecular biology has modified Darwin's ideas into a form called neo-Darwinism.
- State the neo-Darwinian ideas of evolution.

What theories of evolution are there?

In section 1 we arrived at a definition of evolution as:

The change in genetic composition of a population over successive generations, which may be caused by meiosis, hybridisation, natural selection or mutation. This leads to a sequence of events by which the population diverges from other populations of the same species and may lead to the origin of a new species.

But how does it happen? What drives the population to become a new species? Over time there have been many theories that have attempted to explain this. In this section we shall look at some of them.

We owe much of our current thinking on natural selection to the ideas of Charles Darwin, who put forward the idea to the Royal Society in 1858. His paper suggested that those organisms that were best adapted to their environment would have an advantage and be able to reproduce in greater numbers than other types, and pass on the advantageous adaptations. Because he knew nothing of genetics, he was unable to suggest how this might take place.

For many years in Europe, the Christian belief had been that the Earth and all species had been created about 6000 years ago. In the mid 1700s, George Buffon challenged this idea, suggesting that:

- the Earth was much older than this, and that
- organisms changed over time in response to environmental pressures and random events.

KEY WORD

Lamarckism *the theory developed by the French biologist Jean-Baptiste Lamarck that claimed that organisms passed on to subsequent generations traits acquired during their lifetime*

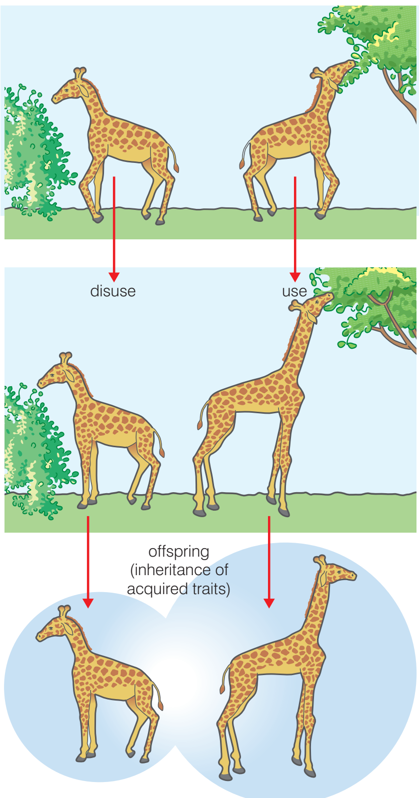


Figure 4.14 *Lamarck's ideas of use and disuse and the inheritance of acquired traits of evolution*

DID YOU KNOW?

Epigenetics is a relatively new branch of genetics. One of its important findings is that the way a gene expresses itself may become altered during an individual's lifetime. These changed genes may be passed on to the next generation. Is this the inheritance of acquired traits after all? Well, maybe, but certainly not in the way that Lamarck meant it.

Whilst we now accept these ideas almost without a second thought, at the time Buffon had no evidence to back them up and, as a result, could not convince people.

At the start of the nineteenth century, Lamarck, having read Buffon's ideas, made what is now considered to be the first major advance towards modern evolutionary thinking because he proposed a mechanism by which the gradual change in species might take place. In 1809 he published a paper entitled 'Philosophie Zoologique', in which he described a two-part mechanism by which change was gradually introduced into the species and passed down through generations. His theory is called the 'theory of transformation' or, more usually, simply '**Lamarckism**'. The two parts of his theory are:

- Use and disuse, and
- Inheritance of acquired traits.

Use and disuse

In this part of his theory, Lamarck suggests that by continually using a structure or process, that structure or process will become enlarged or more developed. Conversely, any structure or process that is not used or is little used will become reduced in size or less developed.

The classic example he used to explain the concept of use and disuse is the elongated neck of the giraffe. According to Lamarck, a given giraffe could, over a lifetime of straining to reach high branches, develop an elongated neck. However, Lamarck could not explain how this might happen. He talks about a 'natural tendency towards perfection' – but this is not really an explanation. Another example Lamarck used to illustrate his idea was the toes of water birds. He suggested that from years of straining their toes to swim through water, these birds gained elongated, webbed toes to improve their swimming.

These two examples demonstrate how use could change a trait. He used the wings of penguins as an example to illustrate what might happen to a structure with disuse. Their wings would have become smaller than those of other birds because penguins do not use them to fly.

Inheritance of acquired traits

Lamarck believed that traits changed or acquired during an individual's lifetime could be passed on to its offspring. Giraffes that had acquired long necks would have offspring with long necks rather than the short necks their parents were born with. This type of inheritance, sometimes called Lamarckian inheritance, has since been disproved by the discoveries of genetics.

However, Lamarck did believe that evolutionary change takes place gradually and constantly. He studied ancient seashells and noticed that the older they were, the simpler they appeared. From this, he concluded that species started out simple and consistently moved towards complexity, or, as he termed it, closer to perfection. These ideas we still retain today.

Just 50 years later, in 1858, Charles Darwin published his famous paper on Natural Selection. He had developed the idea some twenty years earlier, but was afraid of the ridicule the idea might receive. In 1858, another biologist, Alfred Russell Wallace, had come to similar conclusions and they jointly published the scientific paper to the Linnean Society of London that would change our thinking on the origin of species for ever.

Some of Darwin's evidence came from a visit to the Galapagos Islands. These are a small group of islands in the Pacific Ocean about 600 miles off the coast of Ecuador in South America.

Darwin visited five of the Galapagos Islands and made drawings and collected specimens. In particular, Darwin studied the finches found on the different islands and noted that there were many similarities between them, as well as the obvious differences. He concluded that the simplest explanation was that an 'ancestral finch' had colonised the islands from the mainland and, in the absence of predators, been able to adapt to the different conditions on the islands and, eventually, evolve into different species. Some of the finches had, he suggested, evolved into insect eaters, with pointed beaks. Others had evolved into seed eaters with beaks capable of crushing the seeds. One hundred and fifty years later on and geneticists have been able to confirm Darwin's ideas and even produced a 'family tree' based on the similarity of their DNA. Figure 4.16 shows this family tree.

Figure 4.15 Charles Darwin as a young man

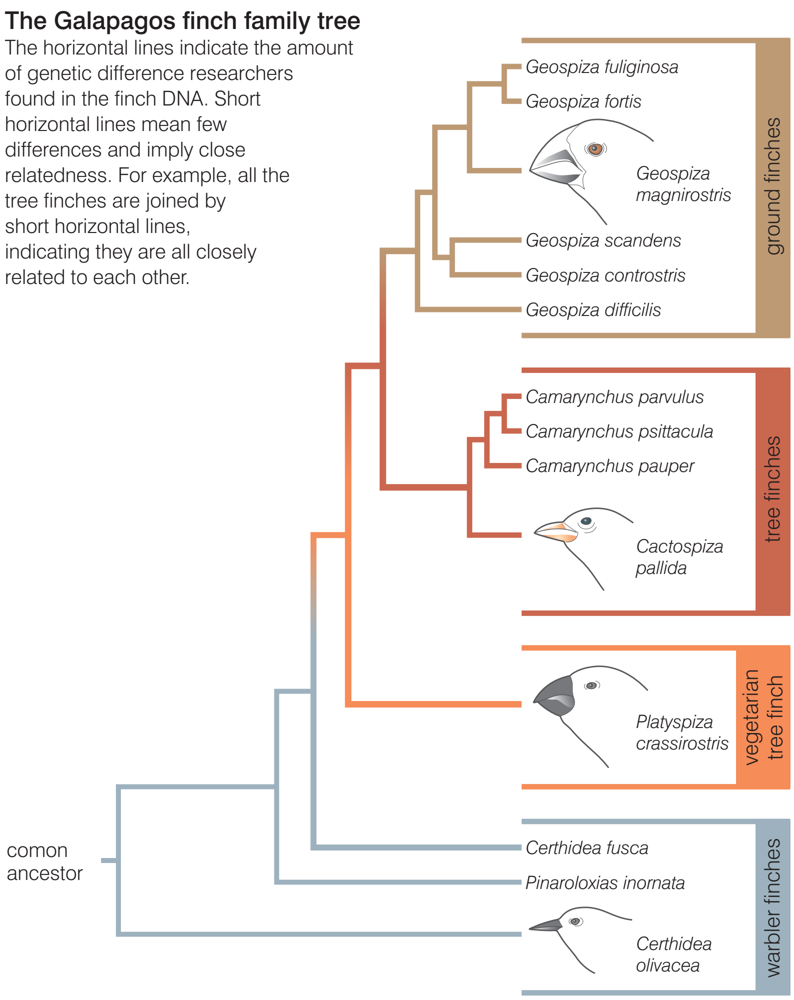


Figure 4.16 Genetic similarities in 'Darwin's finches'

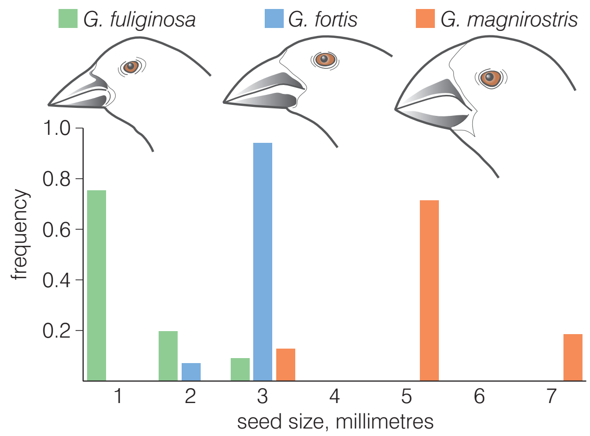


Figure 4.17 *The different sizes of seeds eaten by three species of ground finch from the Galapagos Islands*

Biologists wanted to test how well the finches were adapted to their 'niche'. They analysed the sizes of the seeds eaten by three different ground finches. Figure 4.17 shows what proportion of each species ate the different sized seeds.

As you can see, although there is a little overlap, each finch eats seeds of a different size and their beaks are adapted to obtain and crush these different-sized seeds.

At the time, Darwin called this 'descent with modification' and believed it to be key evidence in support of his theory of natural selection. We now call this 'adaptive radiation'.

Darwin summarised his observations in two main ideas:

- all species tend to produce more offspring than can possibly survive
- there is variation among the offspring

From these observations he deduced that:

- There will be a 'struggle for existence' between members of a species (because they over-reproduce, and resources are limited).
- Some members of a species will be better adapted than others to their environment (because there is variation in the offspring).

Combining these two deductions, Darwin proposed:

Those members of a species which are best adapted to their environment will survive and reproduce in greater numbers than others less well adapted.

This is his now-famous theory of natural selection, and can be summarised in the flow chart below.

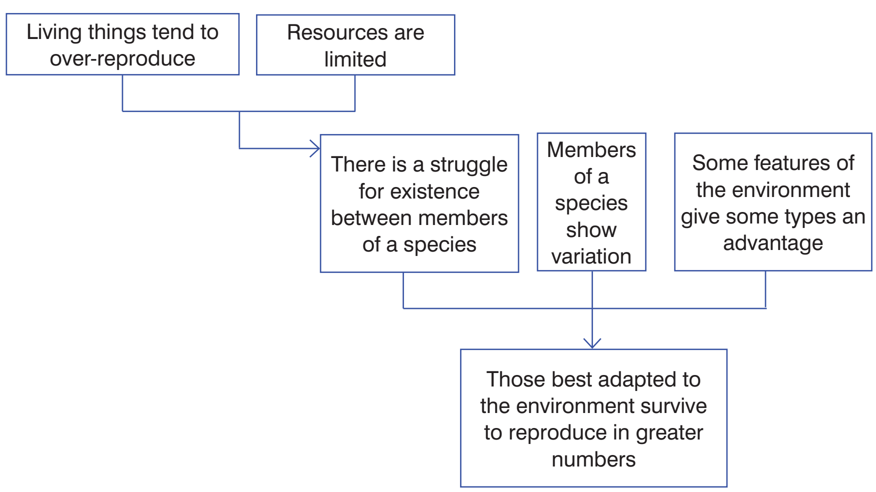


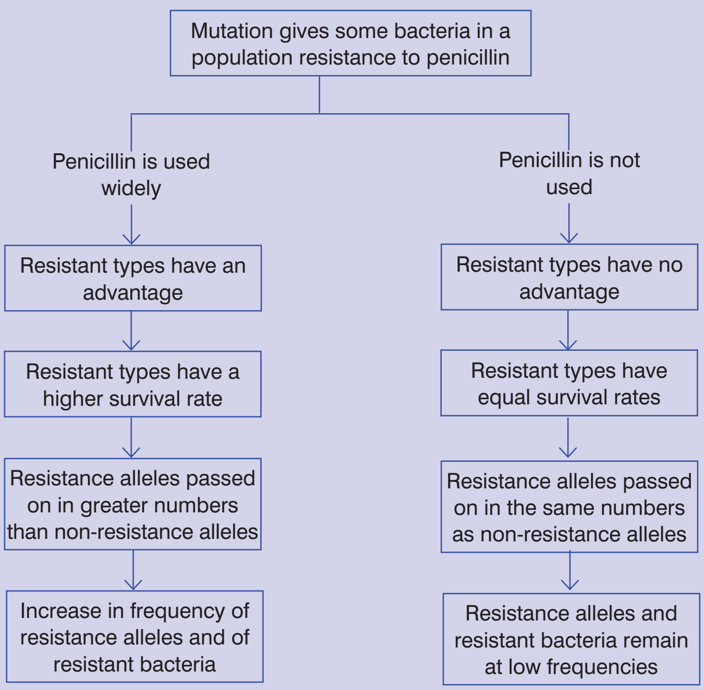
Table 4.1 *Comparison of Lamarck's theory of use and disuse with Darwin's theory of natural selection*

Aspect of theory	Lamarck's theory of use and disuse	Darwin's theory of natural selection
Variation	Environment changes, creating a need for the organism to change	There is a natural variation in features and the variations are heritable
Survival	Development of new features (e.g. longer neck) in order to survive	Environment selects in favour of those traits that adapt the organism to the environment and against those that do not
Inheritance	New features acquired during lifetime of an individual are passed to the offspring	Individuals with advantageous variations of traits survive in greater numbers and pass on these advantageous variations to their offspring
Evolution	New species over time	New species over time

DID YOU KNOW?

About antibiotic resistance – a modern example of selection in action

Mutations in bacteria can make them resistant to an antibiotic, for example, penicillin. If they are resistant to penicillin, it will have no effect on their growth and reproduction. What happens next depends on whether the bacterial population is exposed to the antibiotic, or not. This is summarised in the flow chart.



KEY WORD

neo-Darwinism *a revised version of Darwin's theory of evolution by means of natural selection. This theory, which is now accepted by most biologists, combines Darwin's original theory, genetic theory and theories about animal behaviour*

Activity 4.5

Some people have suggested that breeding animals and plants for use on farms is very similar to natural selection. Working in small groups, discuss this idea and make lists of the ways in which breeding farm animals and plants is similar to and different from natural selection.

What is neo-Darwinism?

Charles Darwin knew very little of genetics. Mendel had not carried out his ground-breaking work on inheritance at the time Darwin published his book *On the Origin of Species*. However, we can now incorporate our knowledge of genes and gene action into the theory of natural selection to give a better understanding of what drives evolution.

Genes or, more accurately, alleles of genes determine features. But when we think about how a population might evolve into a new species, we need to think not just in terms of the alleles each individual might carry, but also in terms of all the alleles (of all the genes) present in the population. We call this the gene pool of the population.

Suppose an allele determines a feature that gives an organism an advantage in its environment. The following will happen:

- Those individuals with the advantageous allele of the gene will survive to reproduce in greater numbers than other types.
- They will pass on their advantageous allele in greater numbers than the other types pass on their alleles of the same gene.
- The frequency of the advantageous allele in the gene pool of the population will be higher in the next generation.
- This process repeats over many generations and the frequency of the advantageous allele in the gene pool increases with each generation that passes.

Mutations are important in introducing variation into populations. Any mutation could produce an allele which:

- confers a selective advantage; the frequency of the allele will increase over time
- is neutral in its overall effect; the frequency may increase slowly, remain stable or decrease (the change in frequency will depend on what other genes/alleles are associated with the mutant allele)
- is disadvantageous; the frequency of the allele will be low and could disappear from the population.

But **neo-Darwinism** doesn't just take into account our knowledge of genetics. It also encompasses our understanding of animal behaviour – sometimes referred to as ethology. Many ethologists and also evolutionary psychologists believe that it is not just physical features that can confer an advantage, but that behaviour patterns can also be advantageous – or not. As such, a behaviour pattern that confers a survival advantage will be selected for, whilst those that do not will be selected against. An example of an advantageous behaviour is imprinting in geese. Young geese (goslings) 'imprint' upon the first moving object that they see after hatching, and follow it everywhere. Since this will almost certainly be 'mother goose' there is a very obvious survival advantage in following her; the young goslings will be fed and protected. Any goslings that do not show this behaviour pattern are much less likely to survive.

Review questions

Choose the correct answer from A to D.

1. A gene pool is:
   - A all the genes in an individual
   - B all the alleles in an individual
   - C all the alleles in a population
   - D all the genes in a population
2. As a result of natural selection, those most adapted to an environment survive to reproduce in the greatest numbers because:
   - A resources are limited
   - B resources are limited and there is a natural variation between members of a population
   - C resources are limited, there is a natural variation between members of a population and living things tend to over-reproduce
   - D none of the above
3. New alleles arising from mutations in a population will:
   - A increase in frequency if they are beneficial in their effect and decrease in frequency if they are neutral in their effect
   - B increase in frequency if they are neutral in their effect and decrease in frequency if they are harmful in their effect
   - C increase in frequency if they are beneficial in their effect and increase in frequency if they are neutral in their effect
   - D increase in frequency if they are beneficial in their effect and decrease in frequency if they are harmful in their effect
4. Bacterial populations can develop a resistance to antibiotics. Which of the factors listed below does NOT contribute to the development of antibiotic resistance?
   - A random mutations in the bacterial population
   - B the repeated use of the same antibiotic on a bacterial population
   - C careful selection of the most effective antibiotic to use on a bacterial population
   - D people not completing a course of antibiotics so that some bacteria survive
5. In comparing Darwin's theory of evolution with Lamarck's, it is true to say that:
   - A Darwin based his theory on natural selection whilst Lamarck based his on use and disuse

B Lamarck believed that variation arose out of a need to change whereas Darwin suggested that variations were already present in populations

C both suggested that new species could evolve eventually

D all of the above

6. Darwin's finches were able to evolve into 14 different species from one ancestral type because:

A there were many different habitats and niches on the Galapagos islands

B there was variation in the population of ancestral finches that colonised the islands

C there was little competition for the niches

D all of the above

7. Neo-Darwinism is a modification of Darwin's original theory that takes into account:

A the inheritance of acquired characteristics and ethology

B behavioural psychology and molecular genetics

C genetics and ecology

D genetics and ethology

8. Although now discredited, Lamarck's work is regarded as important because he attempted to explain:

A how new species could appear over a long period of time

B how an individual could acquire new characteristics

C how a gene pool could change over time

D how mutations could appear

9. Darwin's theory of natural selection was based on the observations that:

A all things tend to over-reproduce and there is a struggle for existence

B there is variation in populations and there is a struggle for existence

C some members of a population are better adapted than others and there is a struggle for existence

D all things tend to over-reproduce and there is variation in populations

10. Which of the following statements does not describe why imprinting by goslings is adaptive behaviour (has survival value)?

A it helps makes sure the goslings will be protected

B it helps make sure the goslings will be fed

C it helps them solve abstract problems

D it helps make sure the goslings stay together and so are less likely to be predated

4.3 The evidence for evolution

By the end of this section you should be able to:

- Explain how the following support the theory of evolution: palaeontology (the fossil record), comparative anatomy, comparative embryology, comparative biochemistry, plant and animal breeding experiments.
- Describe examples of each of these types of evidences.

How does palaeontology support the theory of evolution?

The word 'palaeontology' refers to the study of ancient life and comes from the Greek words *palaios* (ancient) and *logos* (study). Fossils form the basis of this science as they are the main direct evidence about past life.

Fossils (this word is derived from the Latin word *fossus*, meaning 'having been dug up') are the remains or traces of animals, plants and other organisms from the remote past. We can group fossils into two categories:

Category 1: the remains of the dead animal or plant or the imprint left from the remains, including:

- bones
- teeth
- skin impressions
- hair
- the hardened shell of an ancient invertebrate such as a trilobite or an ammonite
- an impression of an animal or plant, even if the actual parts are missing

Category 2: something that was made by the animal while it was living that has since hardened into stone; these are called trace fossils and include:

- footprints
- burrows
- coprolite (animal faeces)

Type I fossils can be the actual organism or part of an organism, like a piece of bone or hair or feather as it actually was. For example, this spider has been trapped, completely unchanged, inside the amber for millions of years. Amber is fossilised resin from trees. This spider probably became stuck inside the sticky resin and could not escape. As the amber became fossilised, the spider was protected from micro-organisms and air which would have led to its decomposition. In many fossils like this, the soft parts of the body

Figure 4.18 *A spider preserved in amber*

have been lost, but the exoskeleton is perfectly preserved. In some cases, however, the entire body remains.

However, when we think of fossils, we usually think of imprints of whole organisms or parts of organisms – the last two examples of category 1 fossils. So how do these fossils form? Clearly death of the organism, for some reason or other, is the first stage. But death is nearly always associated with decomposition – which obviously doesn't happen when fossils are formed. So how is this prevented and just how do fossils form? There are four main stages:

1. Death without decomposition

   To start with, an animal or plant must die in or so close to water that it is covered by water immediately after, or shortly after, death. The water insulates the remains from many of the elements that contribute to decomposition. Bacteria will still decay the soft body parts over a long period but leave any hard body parts unaltered.

2. Sedimentation

   As time passes, sediments (tiny particles of solid matter settling out of the water) bury the remaining hard parts of the organism. Fossilisation is more likely if this happens quickly than if it happens slowly. Sudden landslides and mudslides into the water help. Sedimentation further insulates the organism from complete decay.

   The nature of the sediments themselves influences the nature and quality of the fossil. Very fine-grained particles, like clays, will create a more detailed fossil than coarser-grained sediments like sand. The chemical make-up of the sediments affects the colour the fossil will be. Iron-rich sediments could give the rock (and the fossil) a reddish colour. Phosphates may darken the rock so that it is grey or black.

3. Permineralisation

   As the sediments accumulate, the lower layers become compacted by the weight of the layers on top. Over time, this pressure turns the sediments into rock. If water rich in minerals percolates (seeps) through the sediments, the mineral particles stick to the particles of sediment, effectively gluing them together into a solid mass. An important point here is that these minerals are probably not the same minerals that make up the sediments (now rock).

   Over the course of millions of years, these mineral particles dissolve away the original hard parts of the organism, replacing the molecules of exoskeleton with molecules of calcite (calcium carbonate) or another mineral. In time, the entire shell is replaced by mineral particles and these also are compressed into rock in the shape of the original organism. As this rock is not the same as the surrounding rock, it is visible as a fossil in the exact shape of the original organism. Figure 4.19 shows how a dinosaur fossil may form.

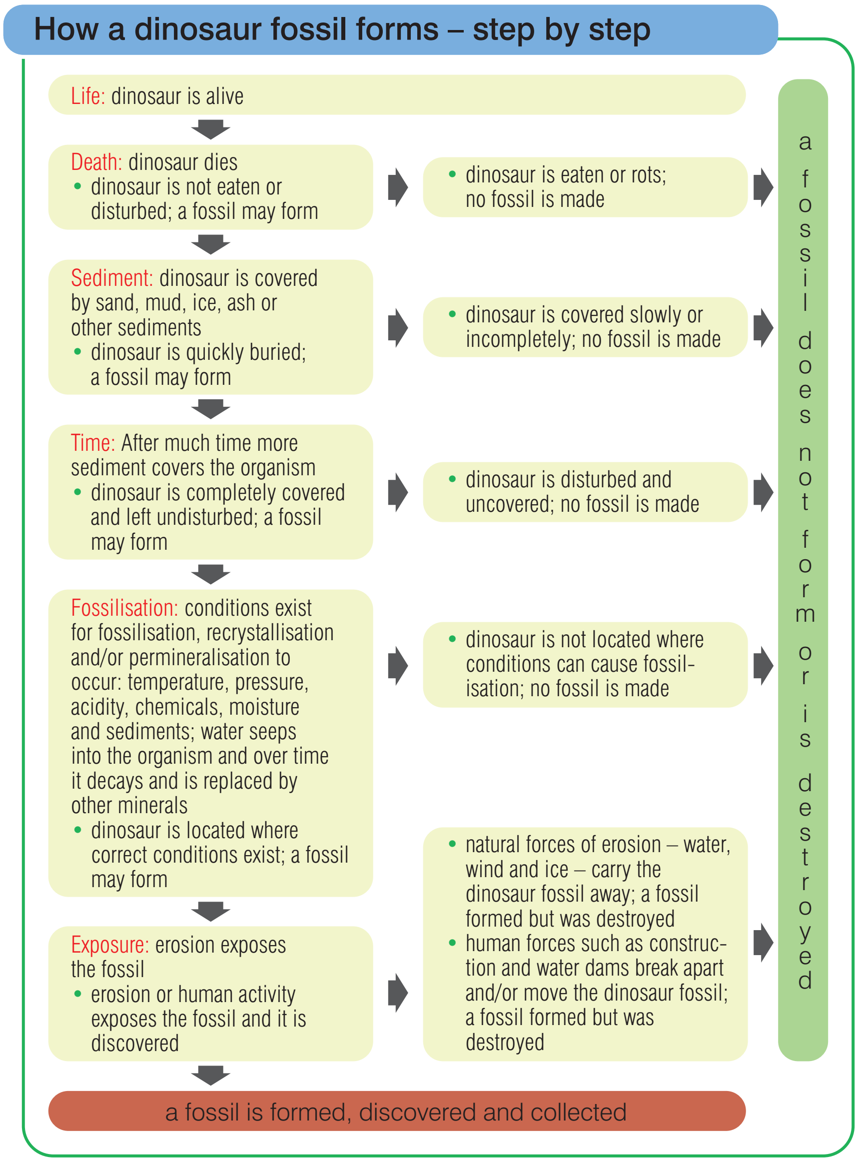


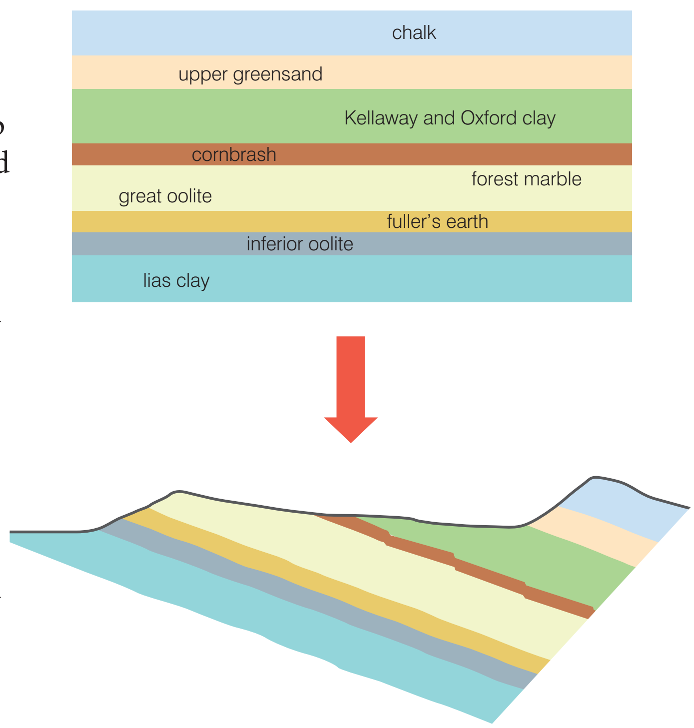
Figure 4.19 How a dinosaur fossil may form

4. Uplift

As the continental plates move around the Earth, colliding with each other, mountains are formed. What were sea floors are lifted up and become dry land. Now the fossil is buried under hundreds or even thousands of feet of rock in different strata. A stratum is a layer of sediment (or sedimentary rock) that is the same throughout the layer, but different from layers above and below.

Other Earth movements cause rocks to slip and parts of different strata to become exposed. When this happens, rock that contains fossils becomes lifted to the Earth's surface. Rain, wind, earthquakes, freeze and thaw erode rock and may expose a fossil. You just need to know where to look!

Figure 4.20 Earth movements may expose rocks that were deep beneath the surface.



KEY WORD

half-life *the time needed for half the atoms of a radioactive substance to decay. After two half-lives, three quarters of the atoms will have decayed, and so on*

How can we date fossils?

Because sedimentary rocks are laid down in layers (strata) we can use the sequence of the strata and the fossils that occur in them to deduce how the organisms have changed over time. This is called stratigraphy. The oldest strata, and therefore the oldest fossils, will be in the lowest layers and more recent rocks and fossils in layers above them, with the most recent being nearest to the surface. Figure 4.21 represents the sequence of the strata at a site in southern England. The depth of the strata is related to their age. The thickness of each stratum (shown in the diagram) is a measure of the time period during which that stratum was formed. The names 'Tertiary', 'Cretaceous' and 'Jurassic' are the names of some of the geological periods of time. But how do we actually date the rocks? How do we find out how old each layer is?

To do this, we biologists use one of two techniques:

- radiocarbon dating, or
- potassium–argon dating.

Both these techniques rely on the principle that radioactive atoms decay into other atoms over time. Radioactive carbon atoms (C^{14}) decay into non-radioactive nitrogen atoms (N). Radioactive potassium atoms (K^{40}) decay into argon atoms (A^{40}). Each has what is known as a **half-life**. During this period, half of the radioactive atoms decay. So, starting with a certain number of radioactive potassium atoms, after one half-life, 50% will still be radioactive. After a second half-life, 50% of this 50% will have decayed and 25% of the original number will still be radioactive.

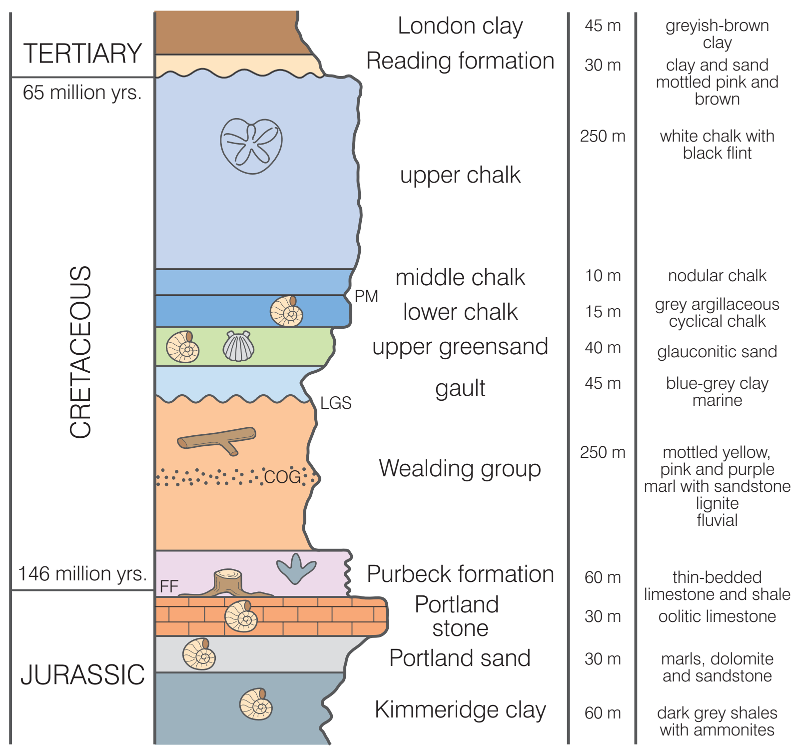


***Figure 4.21** Stratigraphy allows us to deduce the relative age of fossils.*

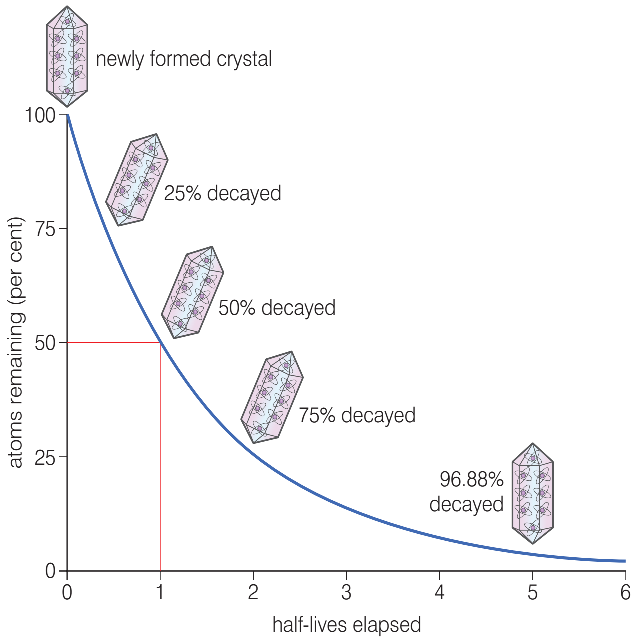


Figure 4.22 *Half-life of a radioactive element*

Activity 4.6

Carry out research into the 22 million year old fossils found in Ethiopia in 2010 and explain why these fossils are thought to be so important.

The ratio of carbon 14 (radioactive carbon) to carbon 12 (ordinary carbon) in living things is about 1 to 1 trillion and we believe that this ratio has always been the same. During their lives, living things lose carbon 14 (as carbon dioxide and other excretory products) and also gain it in the food they eat (or make in the case of autotrophs).

But when living things die, the carbon 14 starts to decay into non-radioactive nitrogen and, clearly, is not replaced. So after 5730 years (one half-life of carbon 14), only 50% of the original carbon 14 atoms will remain and the ratio of carbon 14 to carbon 12 will be 1 to 2 trillion (or 0.5 to 1 trillion). After 11 460 years, 25% of the original carbon 14 atoms remain and the ratio is 1 to 4 trillion (or 0.25 to 1 trillion). The percentage of carbon 14 atoms and the ratio of carbon 14 to carbon 12 keeps halving with each half-life that passes. This is shown in figure 4.23.

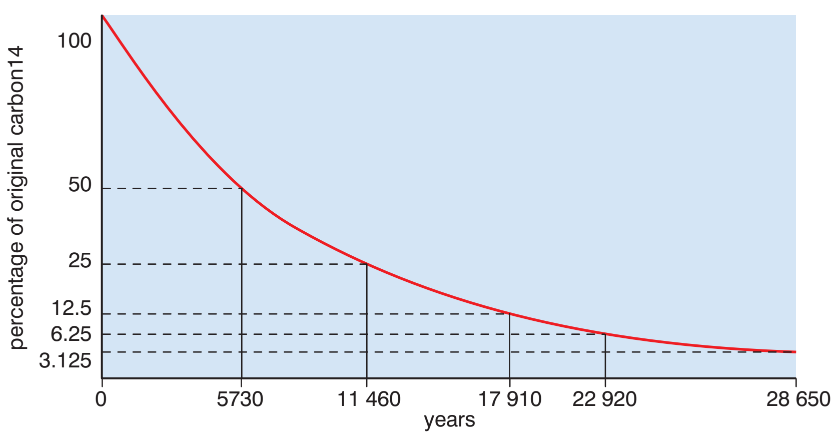


Figure 4.23 *Converting the percentage of carbon 14 in a fossil to an age*

So, if we analysed a fossil and found that it had only 6.25% of its original carbon 14 atoms, we would know that it was 22 920 years old.

Potassium–argon dating works in the same way, but the half-life in this case is 1.3 million years. This makes potassium–argon dating suitable for dating rocks millions of years old, whereas radiocarbon dating is really only accurate with rocks up to 60 000 years old.

Putting together information from stratigraphy and radiometric dating, the fossil record for animals gives the picture shown in figure 4.24.

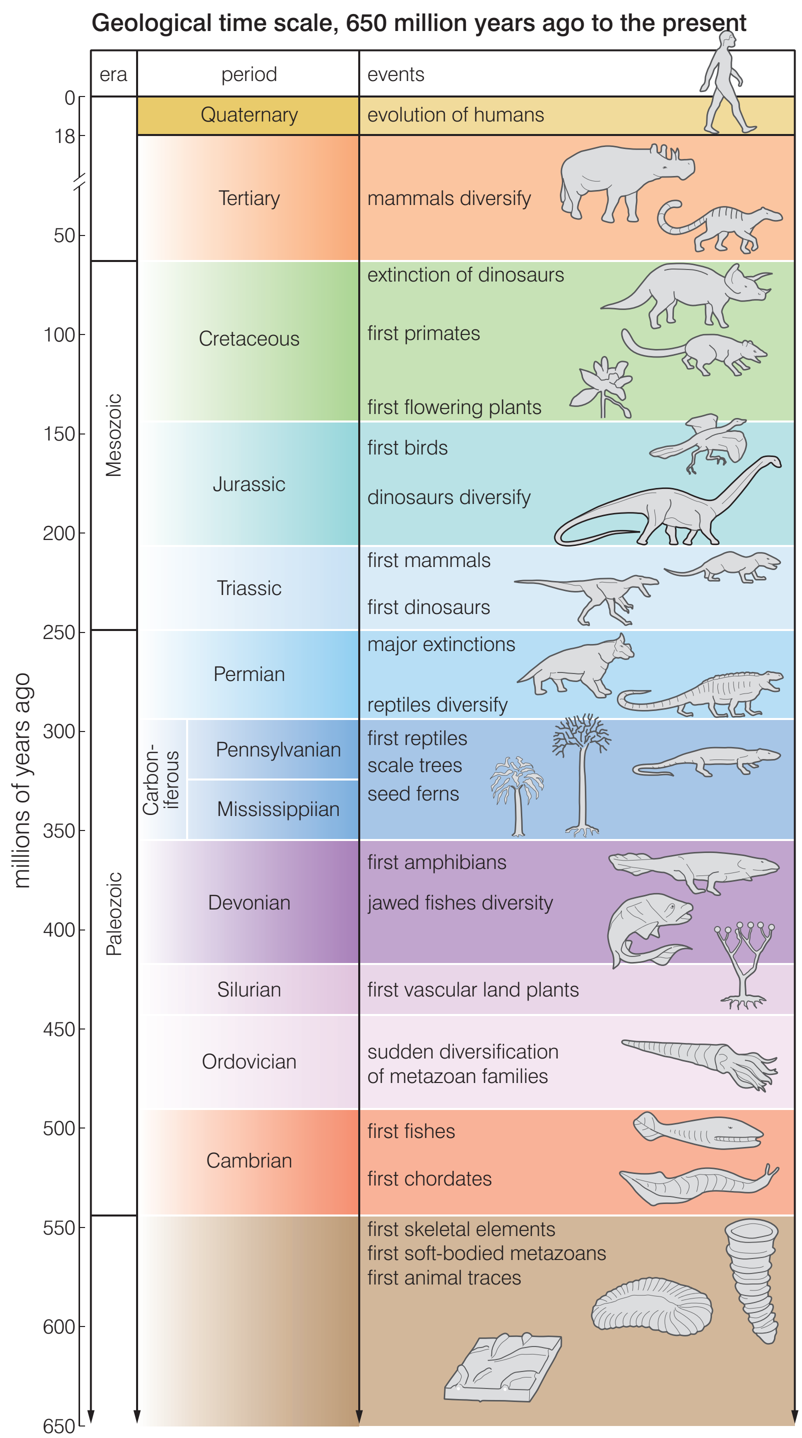


__Figure 4.24__ Key events in the fossil record of animal evolution

Activity 4.7: Dating fossils

Use the graph in figure 4.23 to work out the following:

- the age of a fossil containing 25% of the original carbon 14 atoms
- the age of a fossil containing 3.125% of the original carbon 14 atoms
- the approximate age of a fossil containing 20% of the original carbon 14 atoms
- why radiocarbon dating becomes less accurate with older fossils

How does comparative anatomy support the theory of evolution?

This is one of the strongest forms of evidence for evolution. Comparative anatomy looks at structural similarities of organisms and uses these to determine their possible evolutionary relationships. It assumes that organisms with similar anatomical features are closely related evolutionarily, and that they probably share a common ancestor.

Some organisms have anatomical structures that are very similar in form, but very different in function. We call such structures **homologous structures**. Because they are so similar, they indicate an evolutionary relationship and a common ancestor of the species that possess them. Perhaps the best-known example of homologous structures is the forelimb of mammals. When examined closely, the forelimbs of humans, whales, cats and bats are all very similar in structure, as figure 4.25 shows.

KEY WORD

homologous structures *structures with the same basic anatomy and a common evolutionary origin but having a different function*

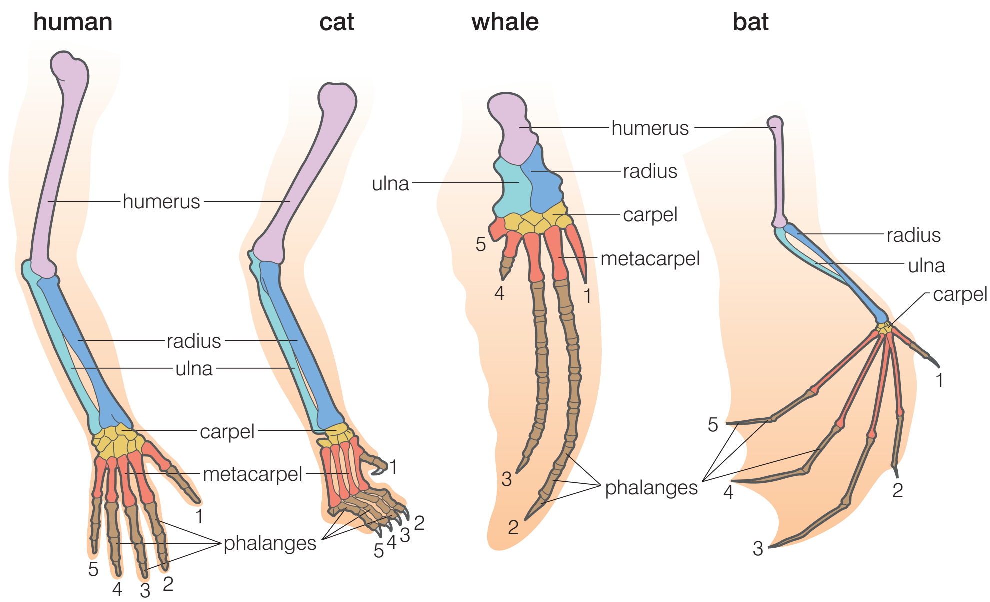


Figure 4.25 *The forelimbs of mammals are homologous structures*

Each possesses the same number of bones, arranged in almost the same way, while they have different external features and they function in different ways:

- arm for manipulation in humans
- leg for running in cats
- flipper for swimming in whales
- wing for flying in bats

By comparing the anatomy of these limbs, scientists have determined that the basic pattern (called a **pentadactyl limb**) must have evolved just once and that all organisms with this kind of limb are descended from that original type – they share a common ancestor.

However, comparative anatomy needs to be used carefully as evidence for evolution. Sometimes organisms have structures that function in very similar ways. However, morphologically and developmentally these structures are very different. We call these **analogous structures**. Because they are so different structurally, even though they have the same function, they cannot indicate that two species share a common ancestor.

For example, although the wings of a bird and a mosquito both serve the same function their anatomies are very different. The bird wing has bones inside and is covered with feathers, while the mosquito wing has neither of these. They are analogous structures and have evolved separately.

How does comparative embryology support the theory of evolution?

Comparative embryology studies the way in which the embryos of vertebrates develop before they hatch or are born. This development shows similarities which supports a common ancestry. For example,

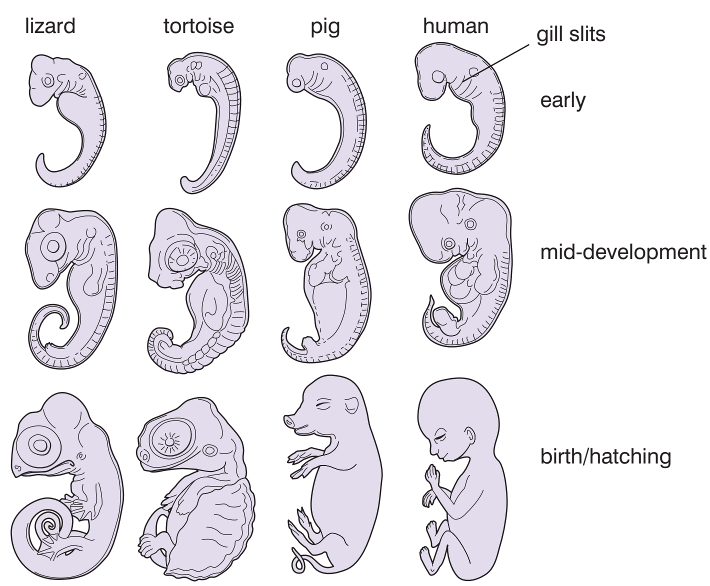


Figure 4.26 *Similarities in development of embryos*

DID YOU KNOW?

Pentadactyl means 'five-fingered'. The basic 'plan' of a pentadactyl limb is (starting from the 'body' and working outwards):

- a single long bone (the humerus)
- a pair of long bones (the radius and ulna)
- a cluster of small bones (the carpals – in the wrist)
- five sets of meta-carpals and digits (the fingers)

KEY WORDS

pentadactyl limb *a limb with five digits*

analagous structures *struactures having the same function but different anatomy and different evolutionary origin* early in development, all vertebrate embryos (including you) have gill slits and tails, shown in figure 4.26. However, the 'gill slits' are not gills; they connect the throat to the outside, but in many species they close later in development. However, in fish and larval amphibians they contribute to the development of gills.

The embryonic tail does not develop into a tail in all species. In humans, it is reduced during development to the coccyx, or tailbone. The more similar the pattern of embryonic development, the more closely related species are assumed to be. The similarity in the pattern of development of vertebrates suggests, again, a common ancestor.

You must be careful when describing what comparative embryology shows. It does not show that an embryo is retracing its evolutionary history, as some people, mistakenly, believe.

How does comparative biochemistry support the theory of evolution?

Various chemicals have been studied in order to find evidence of evolutionary relationships. The idea behind this is that if organisms share very similar molecules and biochemical pathways, then they must be closely related evolutionarily. Chemicals that have been used in such analyses include:

- DNA – the base sequences of DNA from different organisms is compared
- proteins such as:
  - cytochrome c (found in the electron transport chain of respiration) and
  - haemoglobin

which are compared in terms of amino acid sequences.

Species that are closely related have the most similar DNA and proteins; those that are distantly related share fewer similarities. A comparison of DNA sequences shows that it is 99.9% certain that chimpanzees are humans' closest relatives (98% of our DNA is the same as that of chimpanzees).

To measure the similarity of one species' DNA with another species, we use a technique called DNA hybridisation. The technique measures the extent to which a strand of DNA from one species can bind with (or hybridise with) a strand of DNA from another species. In this technique, the double helix of the DNA molecule is heated to separate it into single strands and then the single-stranded DNA (ssDNA) from both species is mixed and the mixture cooled. Although the ssDNA from species A and species B will hybridise (bind) as it cools, it will not do so along all its length. There will be regions that are mismatched (the base pairs are not complementary) and so do not bind and there are techniques available to measure the percentage of this mismatching. The information can then be used to calculate the percentage similarity of the DNA samples.

DID YOU KNOW?

Vertebrates have similar patterns of embryological development

All vertebrates have a basic set of genes (called the homeobox genes) that define the basic body plan of a vertebrate. These operate early in development to ensure that a backbone and skull etc. develop. Later, other genes (which are different in different groups) define the development of those features that will make them the species that they are.

DID YOU KNOW?

We may share 98% of our DNA with chimpanzees, but we share 50% of our DNA with bananas!

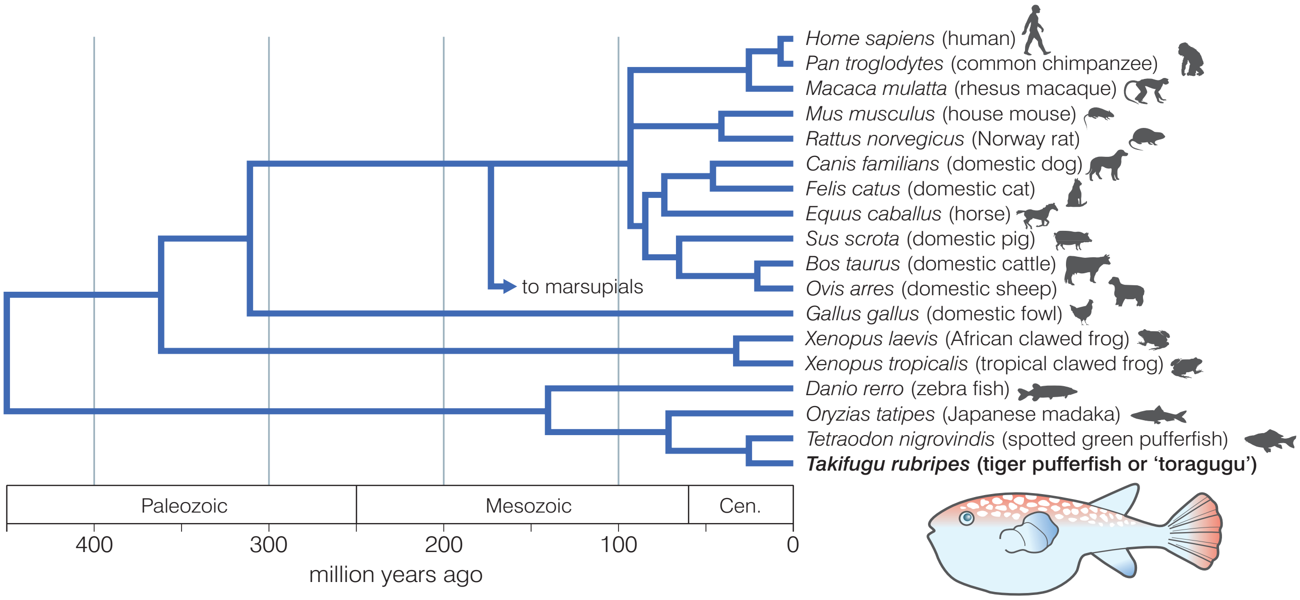


Figure 4.27 A phylogenetic (evolutionary) tree of some animals based on differences in DNA

KEY WORD

***haemoglobin** the molecule found in red blood cells that carries oxygen to where it is needed*

DID YOU KNOW?

Differences in DNA are largely due to mutations. By using estimates of mutation rates, biologists can calculate how long it might have taken for a certain number of differences in DNA to have arisen.

The **haemoglobin** molecule is similar in all animals that possess it, but there are differences. For example, the haemoglobin of the lamprey (a primitive fish-like animal) has only one polypeptide chain, not four. Most animals have haemoglobin with four chains, but the chains do vary. Figure 4.28 shows the differences in the amino acid sequences of the α chains of human and several other animals. The diagram is presented in such a way as to show when the different animals may have diverged from the evolutionary line that led to humans.

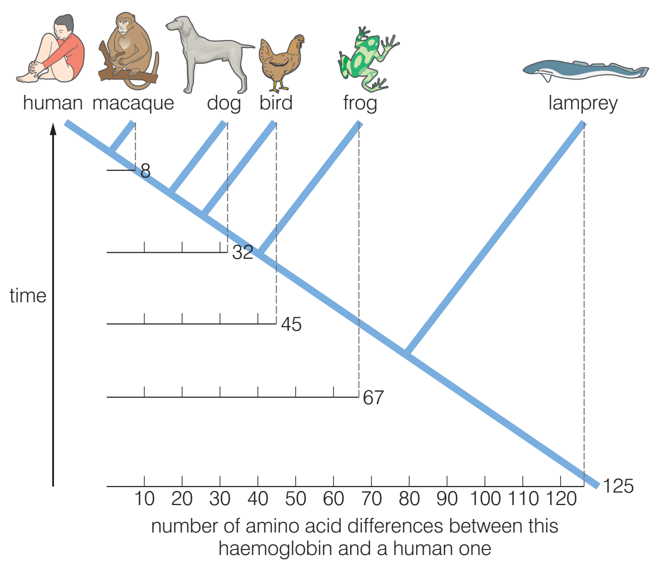


Figure 4.28 The evolutionary relationships of some animals shown by differences in haemoglobin

Differences in the amino acid sequence of cytochrome c give a similar picture.

The molecules that are used to show evolutionary relationships are those that are common to large numbers of organisms. But, clearly, haemoglobin analysis cannot be used to include plants and algae in any phylogenetic tree.

How does plant and animal breeding support the theory of evolution?

For thousands of years, humans have been trying to improve the yields of their crop plants and stock animals. They have done this by **selective breeding**, in which:

- those animals (or plants) that show the desired trait (for example, high milk yield or large number of seeds per pod) are selected and mated, and
- the offspring are monitored carefully and, again, only those with the desired trait are allowed to breed.

Over many generations, selective breeding can bring about significant changes to the organisms involved. One example of this is the modification by selective breeding of the wild pig (wild boar) into the many different varieties of the domestic pig.

If new varieties can be produced by selective breeding (in which humans choose which individuals will 'survive to breed') then natural selection (in which environmental pressures select which will survive to breed) should also be able to produce new varieties and, eventually, new species.

KEY WORD

selective breeding *a technique used to produce organisms with a desired trait by allowing only those organisms with that trait to reproduce*


Figure 4.29 *The wild boar has been selectively bred to produce the domestic pig*

Activity 4.8: The evidence for evolution

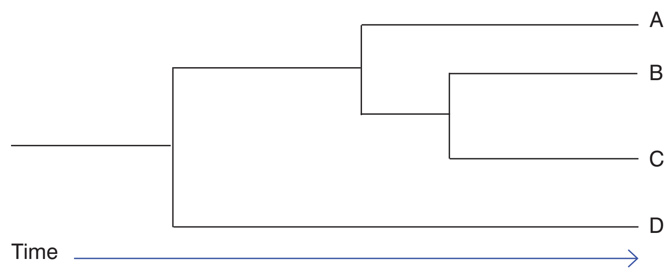
Your teacher will divide the class into groups with the following names:
- The Palaeontologists
- The Anatomists
- The Embryologists
- The Biochemists
- The Breeding experts

Each group will:
- research its own particular area of expertise and try to find four or five pieces of evidence that support the theory of evolution
- make a poster of the results of their research
- all the posters will form a display 'The evidence for evolution'

Review questions

Choose the correct answer from A to D.

1. In DNA hybridisation, the similarity between DNA of two species is determined by:
   A the extent to which strands of the different ssDNA hybridise (bind) on heating
   B the extent to which strands of the different ssDNA hybridise (bind) on cooling
   C the extent to which strands of the different ssDNA separate on heating
   D the extent to which strands of the different ssDNA separate on cooling
2. The diagram shows a phylogenetic tree of four organisms:



   Which of the following is false?
   A Species A is most closely related to species D.
   B Species C is most closely related to species B.
   C Species B and C are equally related to species A.
   D Species A is most distantly related to species D.
3. The theory behind using protein biochemistry to classify organisms is:
   A the more similar the proteins, the more closely related the organisms
   B the extent of the similarity of proteins measures how long ago species diverged
   C similar organisms will have similar proteins because they have similar DNA
   D all of the above

4. A fossil can be:
   A an imprint of part of an organism
   B an imprint of a whole organism
   C a footprint
   D all of the above
5. Homologous structures:
   A have a different structure
   B have a different evolutionary origin
   C often have a different function
   D develop differently in the embryo
6. Comparative embryology provides evidence of evolution because:
   A the embryos retrace their evolutionary history
   B very different embryos show similarities in their early development
   C all the embryos have gills
   D none of the above
7. The sequence of events in fossil formation by permineralisation is:
   A organism dies – falls into water – is covered with sediment – is compressed by pressure – hard parts of organism replaced by minerals
   B organism dies – is covered with sediment – is compressed by pressure – falls into water – hard parts of organism replaced by minerals
   C organism dies – is covered with sediment – falls into water – hard parts of organism replaced by minerals – is compressed by pressure
   D organism dies – falls into water – hard parts of organism replaced by minerals – is compressed by pressure – is covered with sediment
8. Plant and animal breeding provide evidence of evolution because:
   A they create new species
   B they show that natural selection can produce variation
   C they show that selective breeding can produce new varieties
   D they create organisms with a better yield

9. Analogous structures:
   A have the same function
   B have different internal structures
   C develop differently
   D all of the above
10. Fossils over 10 million years old are best dated by:
   A carbon^{14} dating
   B stratigraphy
   C potassium–argon dating
   D none of the above

4.4 The processes of evolution

By the end of this section you should be able to:

- Define natural selection.
- Explain the role in evolution of natural selection (including directional selection, stabilising selection and disruptive selection), isolation and speciation, adaptive radiation (divergent evolution) and convergent evolution.
- List, describe and give examples of the different types of natural selection.

KEY WORDS

natural selection *the theory that explains the origin of species in terms of survival of those best adapted to a specific environment*

species *a group of related organisms that can reproduce with each other so that they produce fertile offspring*

speciation *the process by which a new species evolves*

What are the different types of natural selection?

The modern view of **natural selection** is stated briefly below:

Those members of a species which are best adapted to their environment will survive and reproduce in greater numbers than others less well adapted. They will pass on their advantageous alleles to their offspring and, in successive generations, the frequency of these alleles will increase in their gene pool. The advantageous types will, therefore, increase in frequency in successive generations.

Natural selection is the 'driving force' behind evolution. It is the process that brings about changes (over time) in populations that can, eventually, lead to different populations of the same **species** becoming different species.

To appreciate how natural selection can eventually lead to **speciation** (the formation of new species), we must be clear what we mean by a species. Obviously humans are a different species from chimpanzees. But the different races of humans are all members of the same species. Why?

Our current definition of a species is:

A group of similar organisms with a similar biochemistry, physiology and evolutionary history that can interbreed to produce offspring that are fertile.

This explains why all humans are members of the same species, but belong to a different species from the chimpanzee.

So how can there be different types of natural selection? All types of natural selection work in the same manner (as described above), but their influence on a population is different. The different types of selection include:

- **directional selection**
- **stabilising selection**
- **disruptive selection**

Are you clear about what makes a different species?

The key is not just that organisms can breed, but that their offspring are fertile (can also breed). A horse and a donkey can breed to produce a hybrid we call a mule. However, mules are almost always sterile – they cannot produce offspring. So horse and donkey must belong to different species.

What is directional selection?

A feature may show a range of values. Individuals at one extreme could have a disadvantage whereas those at the other extreme have an advantage. For example, thicker fur (longer hair) in foxes is an advantage in a cold climate. Thinner fur in foxes is an advantage in a hot climate. If the environment were to change so that it became significantly colder, or a group of the foxes were to establish a population in a new, colder environment, there would be a selection pressure in favour of the foxes with long fur and against those with short fur.

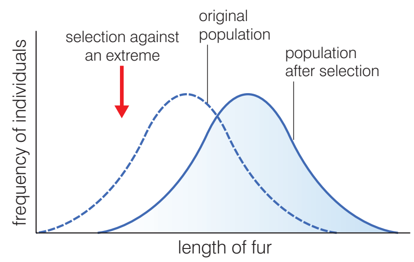


Figure 4.30 *Directional selection*

Over time, selection operates against the disadvantaged extreme and in favour of the other extreme. The mean and range of values shift towards the favoured extreme. The frequency of the alleles causing longer fur will increase.

If you look at the graph carefully, you will see that the whole distribution has shifted. As we might expect, there are now no foxes with the very shortest fur – they could not survive in the new environment. But there are foxes with fur lengths that are longer than any of those in the original distribution. Where have they come from? They must be the result of either:

- new mutations, or
- new combinations of alleles.

In either case, if they had existed in the original population, they would have been disadvantageous as they would prevent the foxes from being able to cool themselves effectively and so would have died.

What is stabilising selection?

In a stable environment, individuals at both ends of the range of values for a feature are the least well adapted. Selection often operates against both these extremes to reduce the variability in the population and to make the population more uniformly adapted.

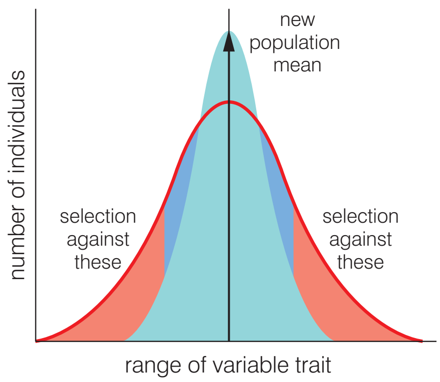


Figure 4.31 *Stabilising selection*

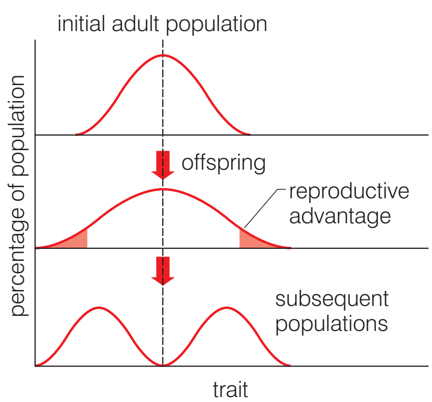


Figure 4.32 *Disruptive selection*

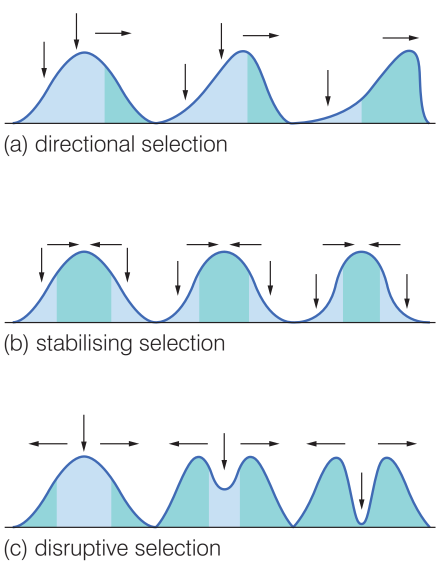


Figure 4.33 *A summary of the different types of selection*

Birth mass in humans is an example. Babies who are very heavy or very light show a higher neonatal mortality rate (die more frequently at, or just after, birth) than those of medium mass. Over time selection is operating to reduce the numbers of heavy and light babies born. Figure 4.31 illustrates the effect of stabilising selection on a trait.

What is disruptive selection?

Disruptive selection is, in effect, the converse of stabilising selection. In this instance, individuals at both extremes of a range have some advantage over those displaying the mean value. As a result, the frequency of those individuals at the extremes of the range will increase over time and those in the middle of the range will decrease over time.

This is part of the explanation of the evolution of Darwin's finches. A finch with an 'average' length beak may not be able to obtain insects out of cracks in the bark of trees as well as one with a longer beak. It may also not be able to crush seeds as well as one with a shorter, more powerful beak. Over time, those with the thinner, longer beaks and those with the shorter, more powerful beaks will increase in numbers, whilst those with average length beaks will decrease in numbers.

Figure 4.33 summarises the different types of selection.

How can natural selection lead to the formation of new species?

Natural selection provides a mechanism by which new populations of a species can arise. But at what point can these populations be considered as distinct species? We have described a species as:

A group of similar, interbreeding organisms that produce fertile offspring.

If two populations become so different that individuals from different populations cannot interbreed to produce fertile offspring, then we must think of them as different species. There are a number of ways in which this can occur. The two main ways are:

- **allopatric speciation**, and
- **sympatric speciation**.

As long as two populations are able to interbreed, they are unlikely to evolve into distinct species. They must somehow go through a period when they are prevented from interbreeding. Both allopatric and sympatric speciation involve isolating mechanisms that prevent different populations from interbreeding for a period of time. During this period, mutations that arise in one population cannot be passed to the other. As a result of this, and different selection pressures in the different environments, genetic differences between the two populations increase. Eventually, the two populations will become so different that they will be unable to interbreed and, at this point, we say that they are 'reproductively isolated'. Effectively, they will have become distinct species.

What is allopatric speciation?

In allopatric speciation, the species become isolated by some physical feature. Examples of this could include:

- a river changing course
- a mountain range being created
- a land mass separating two bodies of water

This is a type of **geographical isolation**. Interbreeding between the populations becomes impossible and speciation could result.

An example of allopatric speciation occurred in the shrimp population of the Caribbean Sea and the North Pacific Ocean, which were once joined. About 3 million years ago, the isthmus of Panama (shown in green in figure 4.34) was formed and separated them, and at the same time created two populations of shrimps, one on either side of the isthmus.

The shrimps from either side of the isthmus still look remarkably similar, but they do not interbreed with each other. They are also extremely aggressive to each other. Two distinct species have evolved from one original species as a result of geographical isolation and allopatric speciation.

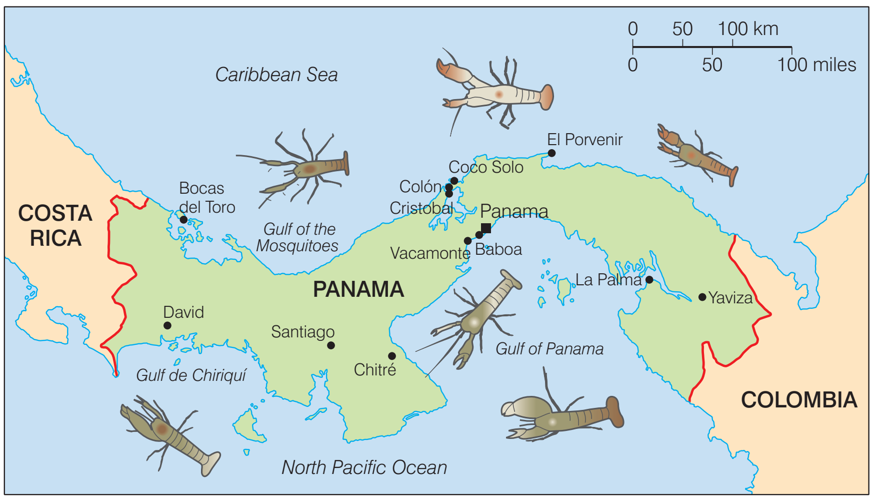


Figure 4.34 *Allopatric speciation in the shrimp population of the North Pacific Ocean and the Caribbean Sea*

What is sympatric speciation?

Speciation need not involve physical separation. The two diverging populations may inhabit the same area, but be prevented from breeding in a number of ways, including:

- **seasonal isolation** – members of the two populations reproduce at different times of the year
- **temporal isolation** – members of the two populations reproduce at different times of the day
- **behavioural isolation** – members of the two populations have different courtship patterns

Speciation following any of these methods of isolation is referred to as **sympatric speciation**.

KEY WORDS

allotropic speciation *occurs when a population from an existing species becomes geographically isolated and the isolated population develops into a new species*

sympatric speciation *occurs when a population from an existing species develops into a new species without becoming geographically isolated from other members of the original species*

DID YOU KNOW?

An **isthmus** is a narrow strip of land connecting two larger land masses, in this case North and South America.

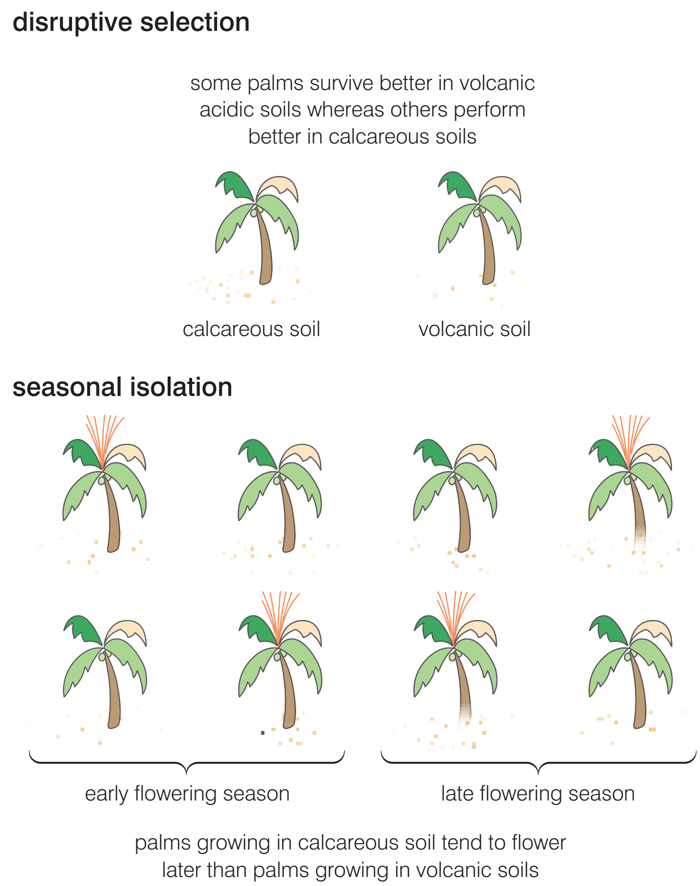


Figure 4.35 *Sympatric speciation in the palms of Lord Howe Island*

An example of sympatric speciation is found in palm trees growing on Lord Howe Island off the east coast of Australia. The soil on the island is in parts volcanic and in other parts calcareous. Palms growing on the different soils developed different breeding seasons (as a result of nutrient availability at different times). As a result they were reproductively isolated and developed into two different species. Interestingly, the process also involves disruptive selection. Plants in the original population showed tolerance to a range of pH values. However, since the soil was either alkaline (the calcareous soil) or acidic (the volcanic soil), plants at the extremes of the pH tolerance range were at an advantage and were selected for.

What is polyploidy and why is it important in plant evolution?

You have already met the terms diploid (chromosomes in pairs – there are two sets of chromosomes in a cell) and haploid (chromosomes are single – there is just one set of chromosomes in a cell). Poly- means many. **Polyploid** cells have many sets of chromosomes per cell – sometimes four sets, sometimes eight or more. Some human liver cells have 92 chromosomes per cell – they are **tetraploid** – they have four sets of chromosomes per cell.

KEY WORDS

polyploidy *occurs when an organism has more than two sets of homologous chromosomes*

tetraploid *a tetraploid organism has four sets of homologous chromosomes*

Polyploidy has been important in plant evolution because it has allowed otherwise infertile hybrids to become fertile again. When different species form hybrids, very often the hybrid cannot produce offspring because all the chromosomes cannot form bivalents (homologous pairs) in meiosis. So they cannot form sex cells and cannot reproduce. If the chromosome number were to double, then all chromosomes are able to form homologous pairs. Meiosis and sex-cell formation can take place and the hybrid is now fertile. Hybridisation and polyploidy have both been important in the evolution of modern wheat from wild grasses. Figure 4.36 shows how.

Hybrid B is infertile because each cell contains one set of chromosomes (7) that came from *Aegilops squarrosa* and one set of chromosomes (14) that came from *Triticum durum*. Clearly, with 21 chromosomes per cell, there are not enough chromosomes for them all to form homologous pairs – even if they were homologous. But when the hybrid doubled its chromosome number, there were two of each chromosome. Now homologous pairs can form in meiosis and the hybrid is fertile.

Triticum vulgare is one form of modern wheat. Polyploidy, in addition to restoring fertility to infertile hybrids, often results in bigger plants with more and bigger seeds.

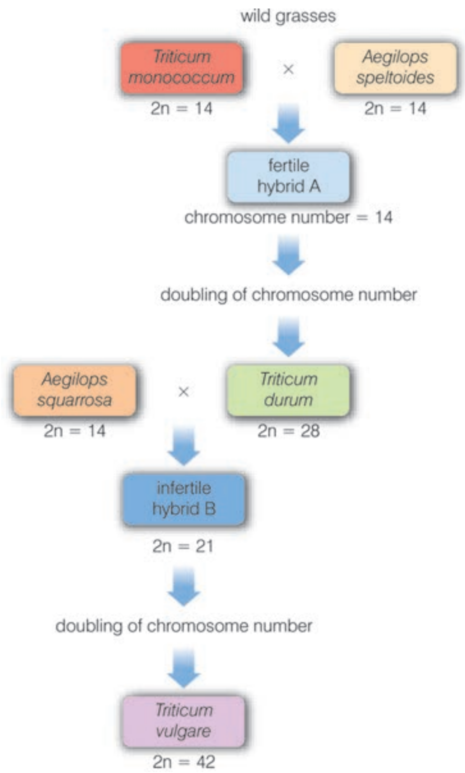


***Figure 4.36** Hybridisation and polyploidy in the evolution of modern wheat*

What are divergent evolution and convergent evolution?

We have looked so far at mechanisms that drive speciation. Now we shall turn our attention to the situations that dictate the lines along which speciation progresses in a given situation.

What is divergent evolution?

Divergent evolution is another name for a process we have already met – adaptive radiation. In divergent evolution, a basic type 'diverges' along different lines because of different selection pressures in different environments.

If different selection pressures are placed on populations of a particular species, a wide variety of adaptive traits may result. If only one structure on the organism is considered (such as a limb), these changes can either improve the original function of the structure, or they can change it totally. Divergent evolution leads to the development of a new species.

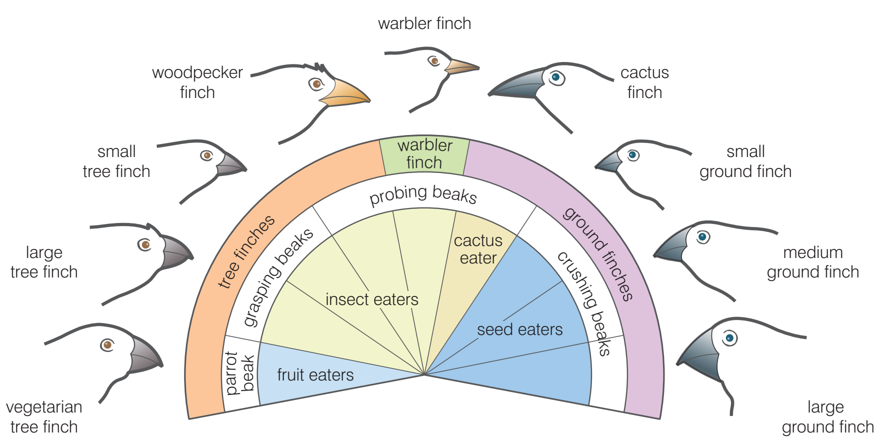


***Figure 4.37** Divergent evolution of finches on the Galapagos Islands*

Examples of divergent evolution (adaptive radiation) include:

- the evolution of the different species of finches on the Galapagos Islands
- the evolution of the different forms of the pentadactyl limb

What is convergent evolution?

KEY WORD

convergent evolution *the process by which unrelated organisms evolve similar structures, adapted for the same function*

Convergent evolution takes place when different organisms occupy similar niches. The selection pressures on the populations are the same and so similar adaptations evolve over time. One example is the convergent evolution of the giant armadillo, giant pangolin, giant anteater and spiny anteater.

They are not related evolutionarily, but all feed on ants and must obtain the ants from narrow cracks in the ground. The similarity between the four is the result of convergent evolution. The same selection pressures result in similar structures appearing in unrelated organisms. Convergent evolution is also responsible for the wings of a bird, a bat and the extinct pterodactyl.

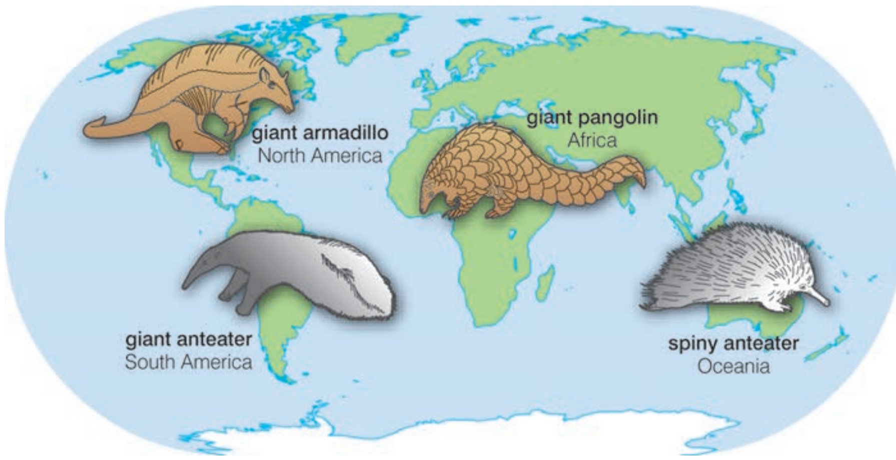


Figure 4.38 Convergent evolution in anteaters

Activity 4.9: Making a fossil

You will need:

- a small, light plastic container to make the fossil in, such as a yoghurt pot or something similar
- a sponge; natural and synthetic are both fine, but sponges with more holes work better
- some fine sand, enough to half fill your container
- magnesium sulphate
- a saucer or small tray

Carry out the following:

1. Create a shape for your fossil by cutting it out from the sponge – it could be a leaf, a shell, a bone or a whole animal.
2. Cut two or three small holes in the bottom of your container. Place it on the saucer/tray.
3. Put sand in the container to a depth of 1 cm.
4. Place your sponge shape on top and cover with another 2 cm of sand.
5. Mix four spoons of bath magnesium sulphate in four spoons of warm water and pour into your container.
6. Allow the mix to sink through the sand then leave it somewhere safe and warm (for example, a window ledge).
7. Add more of the water and salt mix at least once a day for at least five days. The longer you leave it the more 'fossilised' it becomes! (The holes in the sponge trap the salts, mineralising the sponge; as they dry out they solidify to create a fossil. How crumbly this fossil is depends on the consistency of your local sand.)
8. After this time, leave the sand to dry out for two days before removing the 'fossil' sponge. If it is still a little wet, leave the fossil for a few days before handling it.
9. If you have access to a camera, take a photograph of your fossil.

Activity 4.10: Apes to humans

Your teacher will divide the class into pairs. Each pair will be given an assignment from the list below:

1. Tools and tool use by early hominids before *Homo sapiens*
2. Culture of early hominids before *Homo sapiens*
3. Who's who on the *Homo sapiens* evolutionary tree
4. Life and culture of one of the great apes
5. The preservation of non-human primates in the wild
6. Primates in captivity
7. The common ancestor of humans and chimpanzees
8. The importance of an opposable thumb

Each pair must research their topic and make a presentation to the rest of the class.

Review questions

Choose the correct answer from A to D.

1. Allopatric speciation involves:
   - A a period when individuals of two populations are prevented from interbreeding
   - B geographical isolation
   - C a period of increasing genetic diversity of two populations
   - D all of the above
2. In directional selection, the selection pressure operates:
   - A in favour of those individuals showing the mean values for a feature
   - B in favour of those individuals at one extreme of the range of values for a feature
   - C in favour of those individuals at both extremes of the range of values for a feature
   - D none of the above
3. Sympatric speciation involves:
   - A a period when individuals of two populations are prevented from interbreeding
   - B geographical isolation
   - C a period of decreasing genetic diversity of two populations
   - D all of the above

Activity 4.11

Work in groups to plan an activity, an experiment or a game which would simulate the events of natural selection. You need to think of the organisms involved, the changes that take place in the environment and the way in which natural selection takes place.

An alternative activity would be to make a big chart summarising the different ways in which natural selection can operate to bring about the evolution of a new species.

4. In stabilising selection, the selection pressure operates:
   - A in favour of those individuals showing the mean values for a feature
   - B in favour of those individuals at one extreme of the range of values for a feature
   - C in favour of those individuals showing both extremes of the range of values for a feature
   - D none of the above
5. Convergent evolution can occur when:
   - A different organisms inhabit different environments
   - B different organisms inhabit similar environments
   - C similar organisms inhabit similar environments
   - D similar organisms inhabit different environments
6. Divergent evolution is an alternative name for:
   - A allopatric speciation
   - B adaptive radiation
   - C sympatric speciation
   - D disruptive selection
7. In disruptive selection, the selection pressure operates:
   - A in favour of those individuals showing the mean values for a feature
   - B in favour of those individuals at one extreme of the range of values for a feature
   - C in favour of those individuals at both extremes of the range of values for a feature
   - D none of the above
8. In sympatric speciation, the isolating mechanism could be:
   - A temporal
   - B seasonal
   - C behavioural
   - D any of the above
9. Fertile polyploid organisms could have:
   - A two sets of chromosomes per cell
   - B one set of chromosomes per cell
   - C three sets of chromosomes per cell
   - D four sets of chromosomes per cell
10. The wings of a bird and a pterodactyl are the result of:
    - A convergent evolution
    - B directional selection
    - C stabilising selection
    - D divergent evolution

4.5 The evolution of humans

By the end of this section you should be able to:

- Explain how humans have evolved.
- Construct an evolutionary tree of human evolution.
- Explain the importance of Lucy and Ardi in the study of human evolution.
- Discuss some of the controversies surrounding human evolution.

Who are we and where have we come from?

There is often a lot of very loose language used in describing human evolution. You will hear people say 'we evolved from monkeys' or 'we evolved from apes' or 'we evolved from chimpanzees'. None of these statements are accurate. There has been a 'line of evolution' for millions of years that has given rise to old world monkeys, new world monkeys, the great apes and the different species of humans that have lived. But, we are *Homo sapiens* and we are the latest of several humans to live on the planet. We have two features in particular that distinguish us from other primates. These are:

- a very large brain, and
- bipedalism – the ability to truly walk on just two legs.

There was a lot of debate amongst biologists as to which of these came first and also about exactly how this 'evolutionary tree' has given rise to the various groups. But although they may disagree

KEY WORD

Homo sapiens *the species that all humans alive today belong to*

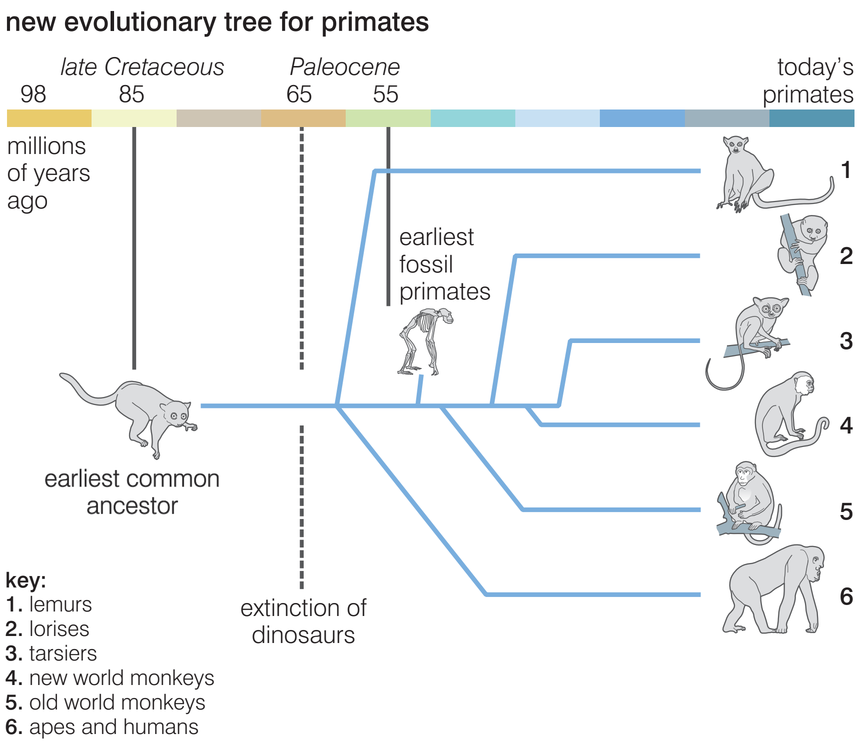


Figure 4.39 *The evolutionary tree for modern primates*

over the details, they are all agreed about the idea – a line of evolution that has branched to give the different groups of primates (including apes and humans) that exist today and have existed in the not too distant past. Figure 4.40 shows the part of the evolutionary tree of humans and the living great apes in more detail.

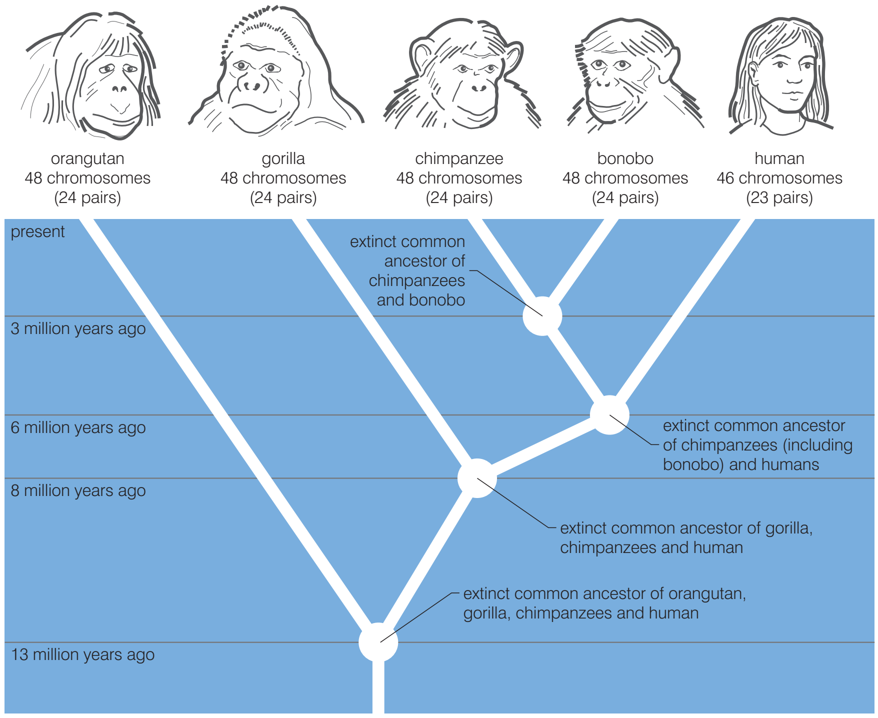


Figure 4.40 *The evolutionary tree of humans and the great apes*

KEY WORDS

genus (plural **genera**) *a group of closely related species*

hominin *any member of the genus* Homo*. This includes modern humans (*Homo sapiens*), neanderthals and* Homo erectus

hominid *a group of species that includes all the species belonging to the genus* Homo *along with other species such as* Ardipethecus ramidus *and* Australopithecus afarensis *(Lucy)*

You can see that at several points there are 'common ancestors'. These represent branching points in the evolutionary tree. At these points it is assumed that an ancestral type became divided into at least two populations which subsequently evolved along different lines. You can see from this evolutionary tree why statements like 'humans evolved from chimpanzees' are inaccurate. Humans and chimpanzees both evolved from a common ancestor that lived about 6 million years ago.

So far in this section, we have talked about 'humans' rather than the one specific type of human (ourselves – *Homo sapiens*) that now inhabits the planet. There were other humans before us and, before them, what we might call 'pre-humans'. All humans belong to the **genus** *Homo*.

Figure 4.41 shows a timeline for the major **hominin** and **hominid** species according to currently available fossil evidence.

Looking carefully at figure 4.41, you begin to see just how important Ethiopia has been in the evolution of humans. Fossils of many of the species along the early part of the timeline were found in Ethiopia. It is indeed the 'cradle of mankind'.

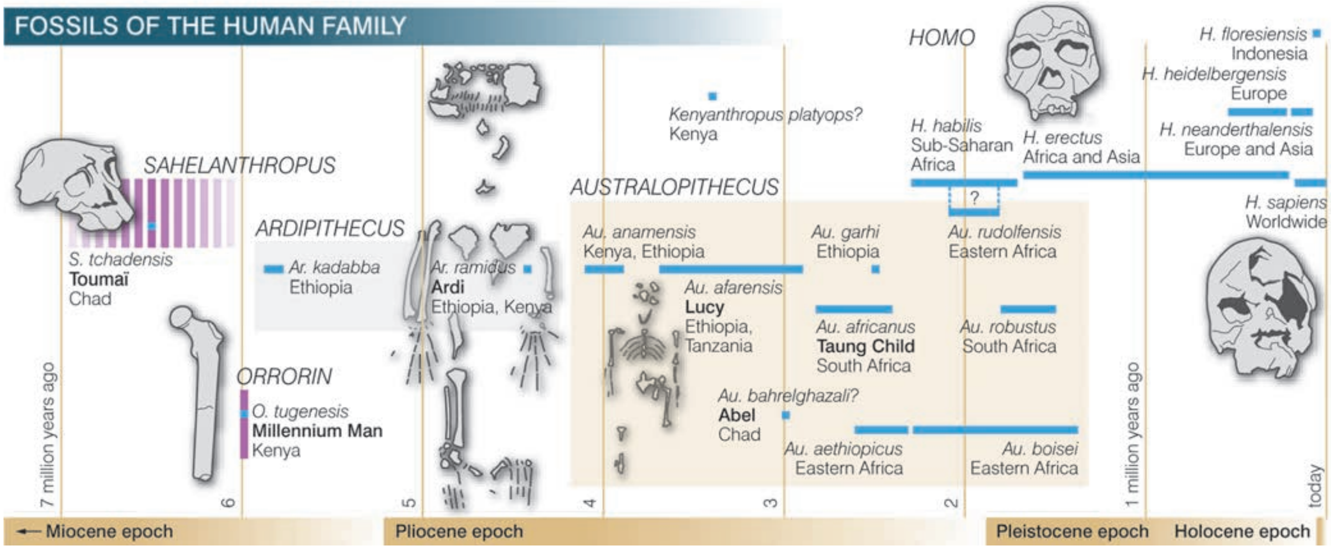


Figure 4.41 *A timeline for the major hominin and hominid species*

What is significant about Lucy and Ardi?

Both Lucy and Ardi are important fossils in explaining the evolution of modern humans and chimpanzees from a common ancestor. Lucy was discovered by Donald Johanson and Tom Gray in 1974 at Hadar in Ethiopia. Lucy is a fossil dated at about 3.2 million years. She was an adult female of about 25 years and belonged to the species *Australopithecus afarensis*.

Her skeleton was about 40% completed, an unusually high proportion for a fossil skeleton. Her pelvis, femur (the upper leg bone) and tibia show that she was bipedal (could walk upright on two legs). However, there is also evidence that Lucy was also partly arboreal (tree-dwelling). She was about 107 cm (3′6″) tall and about 28 kg (62 lbs) in weight. At the time she was discovered, Lucy represented one of the oldest fossil hominins. The proportions of her humerus and femur were mid-way between those of modern humans and chimpanzees.

DID YOU KNOW?

At the time of the discovery, a Beatles song was playing … 'Lucy in the Sky with Diamonds'. The fossil was named Lucy after the song.

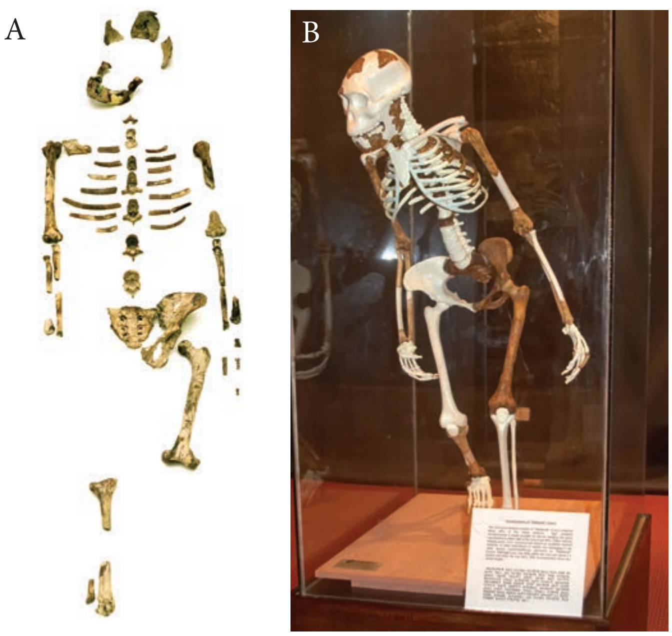
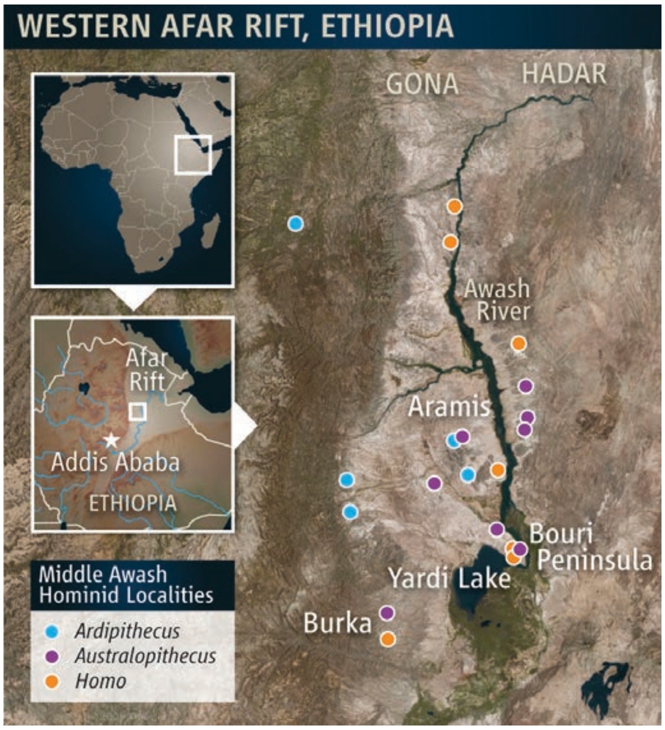


Figure 4.42 *A – The original Lucy fossil; B – The Lucy display including reconstructed parts*

Lucy had a brain about the same size as that of a chimpanzee, so her discovery was able to settle a debate amongst biologists at the time – which came first, large brain or bipedalism? Clearly bipedalism came before big brains.

The Ardi fossil (together with many other similar fossils) was first discovered in 1992, in the Afar dessert in Ethiopia, but it was only in 2009, after many years' analysis, that research papers were finally published that gave Ardi a unique position in human evolution.

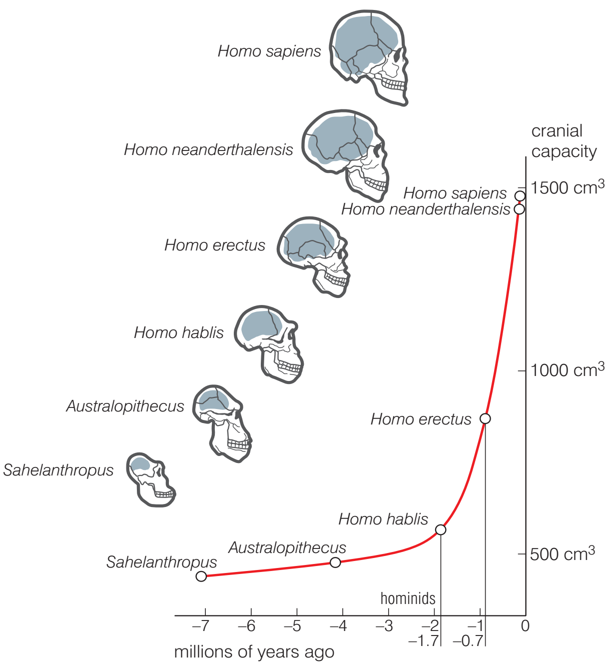


Ardi was 1.2 million years older than Lucy, was also female and belonged to the species *Ardipithecus ramidus*. One significant feature about Ardi was that she was also bipedal. At 4.4 million years old, Ardi is the nearest fossil to the 'common ancestor' of humans and chimpanzees that has so far been found. This find finally proves that the common ancestor of humans and chimpanzees could not have resembled a chimpanzee, as chimpanzees are not truly bipedal.

Figure 4.43 *Map showing the area where Ardi was found*

How has brain size changed during human evolution?

Figure 4.44 *Brain size in different hominids*



During the course of human evolution, the brain has got bigger. We know from comparing fossils that the cranial capacity has increased with each new hominid species that evolved.

However, that is not the whole story. Besides becoming bigger overall, the brain has increased in size as a proportion of body mass. Whereas species of *Australopithecus* have a brain that is between 0.7% and 1.0% of their body mass, modern humans have a brain that is between 1.8% and 2.3% of their body mass. The brain of *Homo sapiens* uses 25% of the resting energy requirement, compared with 8% in the great apes.

A larger brain allows humans to:

- run faster and in a more upright posture
- plan in advance to avoid attack
- develop and use tools and weapons

These abilities clearly also depend on other physical adaptations such as longer legs, more nimble fingers and a straighter spine, but, without the larger brain to co-ordinate the activities, the physical changes would not confer the same advantage.

Are we still evolving?

Homo sapiens (modern humans) first appeared in Africa and have since migrated to all other parts of the world. Figure 4.45 shows these migratory patterns together with the time (in thousands of years before present) when they took place.

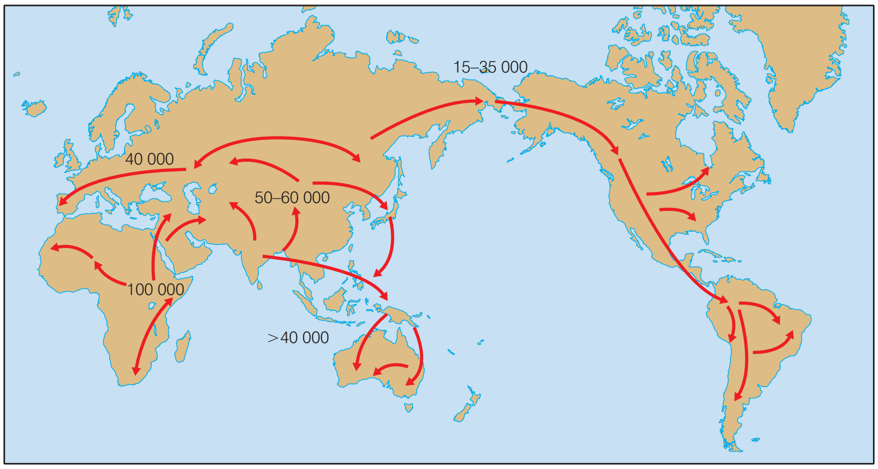


Figure 4.45 *The migration of modern humans out of Africa – it all begins near Ethiopia. Numbers indicate the time (in years) since each stage of the migration.*

As humans moved from Africa into different areas of the world, they encountered different environments. Different selection pressures in the different environments resulted in the different human populations evolving along different lines.

For example, as humans encountered colder climates, body features that gave a survival advantage by helping to conserve heat were selected for. These included:

- a shorter, squatter body shape; this reduces the surface-area-to-volume ratio and so reduces the rate of heat loss by radiation
- an increased layer of adipose tissue under the skin to act as insulation
- increased hairiness; this reduces heat loss by convection

Humans have been evolving into different 'races' for thousands of years. The classification of these races is difficult and there is some disagreement about their exact nature. One classification is given below. In this there are three main races with several subdivisions. This is based on a recent genetic analysis of the different races.

- **African** (Negroid), 100 million people from Africa and Melanesians of the South Pacific.
- **Eurasian** (Caucasoid), 1000 million people with variable skin colour ranging from white to dark brown. Three subdivisions exist:
  – Nordic – often tall, blonde and narrow-headed; includes people from Scandinavian and Baltic countries, Germany, France, Britain

Figure 4.46 *Example of African features*

Figure 4.47 *Example of Eurasian features*

Figure 4.48 *Example of East Asian features*

  - Mediterranean – usually lighter in body build, dark and narrow-headed; includes people from Southern France, Spain, Italy, Wales, Egypt, Jews, Arabs, Afghanistan, Pakistan, India
  - Alpine – usually broad-headed, square jaws, olive skin, brown hair; includes people from countries from the Mediterranean to Asia
- **East Asian** (Mongoloid), most numerous of the present-day populations and split into three groups:
  - Eastern Siberians, Eskimos and the Northern American Indians
  - Japanese, Koreans and Chinese
  - Indonesians and Malays

However, this classification does not include the Central African pigmies, the Bushmen and the Australoids.

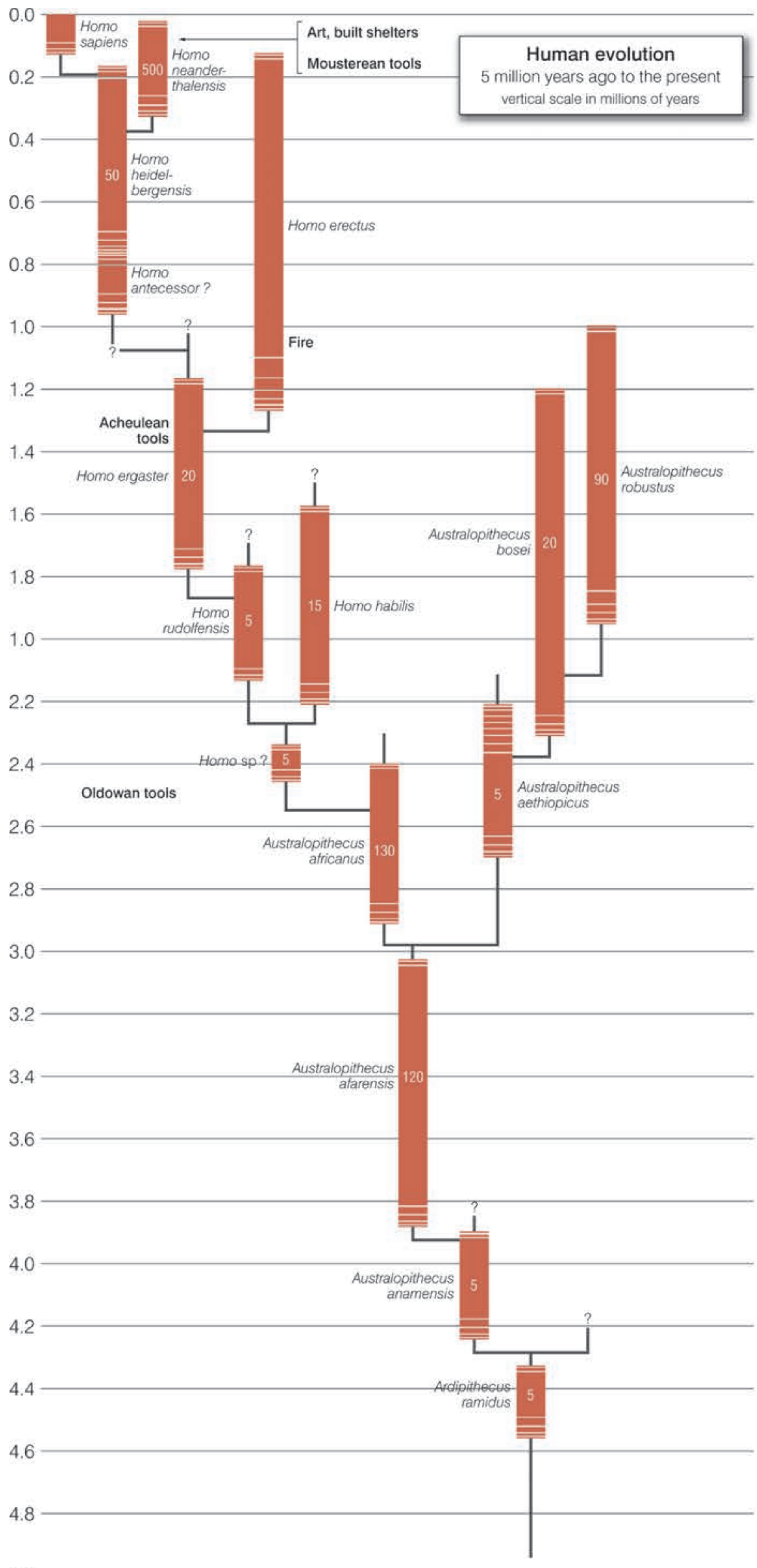
It seems that some thousands of years ago the human populations or races might have been beginning to evolve into separate species. Certainly physical and genetic differences were emerging between the different races. However, our large brain has intervened in two major ways, described below.

- We developed the skill to design and manufacture all kinds of things from buildings to tools to clothes. This effectively allowed us to become able to modify our environment, rather than having to evolve to adapt to it. Anyone can now live perfectly easily in Sweden or any other Nordic country. They must simply wear the right clothes.
- We developed global travel. This has allowed humans of all races to interbreed, throwing many of the genetic differences that have evolved into a huge human melting pot.

We may still evolve into diverse species, but, at the moment, the mechanisms that usually drive speciation have been modified by our large brains.

Figure 4.49 gives a 'best guess' as to the evolution of hominids from 5 million years ago to the present day.

There are more species of *Homo* and *Australopithecus* shown in this diagram than have been discussed in the text. You could do a library search to find out about some of them.



Activity 4.12: Internet search

The origin of modern humans is a fascinating topic and a vast amount has been written about it. You could carry out an internet search to see what else you could find out. You only need search 'human evolution' and you will get a large number of websites to visit. The links printed below will give you a start, if you are uncertain where to go first.

Your teacher may wish you to research a particular aspect of human evolution, in which case you will need to refine your search instruction accordingly.

http://www.talkorigins.org/faqs/homs/lucy.html

http://iho.asu.edu/

http://www.time.com/time/health/article/0,8599,1927200,00.html

http://www.telegraph.co.uk/science/6251024/New-fossil-moves-story-of-mankind-back-one-million-years.html

http://www.becominghuman.org/

Figure 4.49 *Hominid evolution from five million years ago to the present day*

Activity 4.13

Ethiopia plays a central role in the story of human evolution. Using this text book, other books and the internet if you have access to it, do as much research as you can on the discovery and importance of Lucy in the story of human evolution. Put together a big classroom display on Lucy based on your findings.

Review questions

Choose the correct answer from A to D.

1. It is true to say that:
   - A modern humans evolved from chimpanzees
   - B modern humans evolved from *Homo erectus*
   - C modern humans and chimpanzees evolved from a common ancestor
   - D modern humans evolved from *Australopithecus robustus*
2. Lucy belonged to the genus:
   - A *Homo*
   - B *Ardepithecus*
   - C *Australopithecus*
   - D *Pan*
3. The fact that Ardi was bipedal disproves the idea that:
   - A there was a common ancestor of modern humans and chimpanzees
   - B the common ancestor of modern humans and chimpanzees was like a chimpanzee
   - C the common ancestor of modern humans and chimpanzees was intelligent
   - D there was no common ancestor of modern humans and chimpanzees
4. A larger brain gave modern humans an increased ability to:
   - A run faster with a more upright posture
   - B develop and use weapons and tools
   - C plan in advance to avoid attack
   - D all of the above
5. A recent genetic analysis of human populations suggests that there are:
   - A five distinct human races
   - B five human races with some subdivisions
   - C three human races with some subdivisions
   - D three distinct human races
6. As humans migrated from Africa to colder climates, adaptations that would confer a survival advantage include:
   - A a longer, thinner body shape
   - B a less hairy body
   - C less adipose tissue
   - D a shorter, squatter body shape

7. During hominid evolution, brain size has:
   - A increased overall but decreased as a proportion of body mass
   - B decreased overall and decreased as a proportion of body mass
   - C decreased overall but increased as a proportion of body mass
   - D increased overall and increased as a proportion of body mass
8. The human races are now less likely to evolve into separate species because:
   - A humans are able to travel freely across the globe
   - B interbreeding between different races occurs quite frequently
   - C we are able to modify our environments
   - D all of the above
9. It is true to say that modern humans are:
   - A hominins
   - B hominids
   - C primates
   - D all of the above
10. The common ancestor of modern humans and chimpanzees lived about:
    - A 2 million years ago
    - B 4 million years ago
    - C 6 million years ago
    - D 8 million years ago

Summary

In this unit you have learnt that:

- Evolution can be defined as:
  The change in genetic composition of a population over successive generations, which may lead to a population diverging from others of the same species and may lead to the origin of a new species.
- Theories that seek to explain the origin of life on Earth include:
  – special creation theory, in which a ‘supreme being’ is believed to have created life or directs its creation and evolution

  - spontaneous generation theory, in which life is believed to arise from non-living matter; this was finally disproved by the experiments of Francisco Redi and Louis Pasteur
  - eternity of life theory, in which life is believed to have existed forever and will continue to exist forever and so no origin is required
  - cosmozoan theory, in which either life forms or the organic molecules needed for the origin of life are believed to have been brought to Earth by meteorites and comets
  - biochemical origin theory, in which life is believed to have originated as a result of biochemical reactions creating first the necessary organic molecules which then became assimilated into 'pre-cells', which eventually evolved into cells
- Miller's 'spark discharge' experiment showed that the organic molecules essential for life could be synthesised in the conditions on Earth 4.5 billion years ago.
- The oldest photo-autotrophs are the cyanobacteria and they were largely responsible for the increase in free oxygen in the atmosphere.
- In 1809, Lamarck proposed a two-part theory to explain evolution based on:
  - use and disuse
  - inheritance of acquired characteristics
- In 1859 Darwin proposed the theory of natural selection based on:
  - a struggle for existence
  - natural variation in the offspring
- Darwin's theory of natural selection stated that *'Those members of a species which are best adapted to their environment will survive and reproduce in greater numbers than others less well adapted'*.
- Neo-Darwinism takes into account our knowledge of genetics, biochemistry and ethology to modify Darwin's original theory to include the effect of selection on allele frequency and frequency of behaviour patterns.
- Evidence supporting the theory of evolution comes from many areas, including:
  - palaeontology (the fossil record)
  - comparative anatomy
  - comparative embryology
  - comparative biochemistry
  - plant and animal breeding experiments

- Fossils can be dated using:
  - stratigraphy – analysing the sequence and thickness of different layers (strata) of rocks
  - radioactive carbon (C^{14}) dating – measuring the ratio of radioactive carbon to normal carbon – is suitable for fossils up to 60 000 years old
  - potassium–argon dating – measuring the ratio of potassium to argon – is suitable for much older fossils
- Homologous structures are evidence of a common origin and divergent evolution.
- Analogous structures are evidence of a different origin and convergent evolution.
- Similar patterns of embryological development in vertebrates suggest a common origin.
- The extent of differences in molecules common to many species (for example, DNA, cytochrome c, haemoglobin) is a measure of their relatedness.
- Selective breeding experiments have shown that genetic and physical modification of species is possible and so should be possible as a result of natural selection (rather than human selection).
- A species can be defined as *'a group of similar organisms with a similar biochemistry, physiology and evolutionary history that can interbreed to produce offspring that are fertile'.*
- The gene pool is the sum of all the alleles of all the genes in a population or species.
- The gene pool is constantly changing as a result of mutations introducing new genes into the population and disadvantageous alleles being lost through natural selection.
- In natural selection:
  - individuals with an advantageous allele survive to reproduce in greater numbers than other types
  - they pass on their advantageous allele in greater numbers than other types
  - the frequency of the advantageous allele in the population increases in the next generation
  - the process repeats over many generations, with the frequency of the advantageous allele increasing in each generation
- In directional selection one extreme of a range of values for a feature has a survival advantage; the range of values for the population shifts towards the extreme with the selective advantage.

- In stabilising selection, the two extremes are at a selective disadvantage compared to those showing the mean values for a particular feature; the range is compressed around the mean.
- In disruptive selection, both extremes have a selective advantage compared with the mean; two distinct types begin to emerge showing the extreme values of the original population.
- If two populations of the same species are isolated for sufficient time, they may become so different genetically as to evolve into separate species.
- Speciation involving geographical separation is called allopatric speciation.
- Speciation involving separation within one area which is a result of different breeding strategies is called sympatric speciation; the different strategies can involve:
  - temporal isolation – reproduction at different times of the day
  - seasonal isolation – reproduction during different seasons
  - behavioural isolation – for example, different courtship/mating behaviours
- Divergent evolution involves adaptive radiation and is the evolution of one basic 'type' into several different 'types' as a result of different selection pressures. Examples include:
  - the divergent evolution of the pentadactyl limb into flippers, legs, wings, etc.
  - the divergent evolution of the beaks (and other features) of Darwin's finches on the Galapagos Islands
- Convergent evolution is the evolution of similar 'types' with similar adaptations from several different original 'types'. Examples include:
  - the elongated 'snouts' (and other features) of the different anteaters of the world
  - the wings of birds, insects, pterodactyls, etc.
- Modern humans and other primates have evolved from a common primate ancestor that lived before the dinosaurs became extinct.
- Modern humans and chimpanzees have evolved from a common ancestor that lived about 6 million years ago.
- Two distinctive features of modern humans are:
  - large brains
  - true bipedalism
- The fossil Lucy was significant because it showed that bipedalism evolved before large brains.

- The fossil Ardi was significant because it showed that the common ancestor of humans and chimpanzees cannot have resembled a chimpanzee.
- Brain size has increased as hominids have evolved.
- Modern humans evolved in Africa, in and near Ethiopia, and have since migrated to all parts of the world.
- Humans evolved into different 'races' because natural selection favoured different features in different environments.
- The three main races of humans are:
  - African
  - Eurasian
  - East Asian
- Despite genetic differences between the races, it seems unlikely that they will evolve into distinct species because of:
  - increasing interbreeding between the races as a result of increased travel
  - increasing ability to modify the environment

End of unit questions

1. Copy the table below.

Theory	Point(s) in favour of theory	Point(s) against theory
Special creation		
Spontaneous generation		
Eternity of life		
Cosmozoan (panspermia)		
Biochemical (abiogenesis)		

   For each of the theories of the origin of life, list at least one point in favour of the theory and at least one point against the theory. You may have to imagine yourself as a 'person of the times' in some cases.

2. (a) Explain what is meant by each of the following terms:
   (i) evolution
   (ii) convergent evolution
   (iii) divergent evolution
   (b) How does the fossil record provide evidence for evolution?

3. Both Lamarck and Darwin put forward theories of how evolution may have occurred.

   (a) Copy and complete the table below to compare the two theories.

Aspect of evolution	Lamarck's explanation	Darwin's explanation
How differences emerge		
Inheritance of features		
Why certain types survive		

   (b) Explain how neo-Darwinism has modified Darwin's original theory of natural selection.

4. Biologists investigated populations of stinging nettles in two areas of a large National Park in Japan. Stinging nettles have hairs on their leaves that secrete a chemical when crushed that gives a stinging sensation to animals. There had been a large population of deer in one area for more than 1200 years. The other area had only rarely had deer in it.

   Plants from the nettle population in the area that contained the deer were found to have, on average, 100 times more stinging hairs than the nettle plants in the other area. When seeds from these plants were grown in the laboratory, they developed into plants that also had high numbers of stinging hairs. Seeds from the plants with low numbers of stinging hairs, when germinated, grew into plants that also had low numbers of stinging hairs.

   (a) Explain the evidence that suggests:

      (i) the numbers of stinging hairs per leaf is controlled genetically

      (ii) the difference in the number of stinging hairs on the leaves of the nettles in the two populations is a result of natural selection.

   (b) Despite their differences, the two populations have not evolved into different species. Suggest why not.

5. (a) In each of the following examples of natural selection, identify:

   - the selection pressure (feature of the environment that is selecting for some types and against others), and
   - the type within the population that is best adapted.

   (i) wildebeest hunted by lions

   (ii) bacteria in a hospital where penicillin is widely used

   (iii) nettle plants with different-sized leaves in a shaded woodland area.

(b) Allopatric speciation and sympatric speciation are two processes by which new species can evolve. Explain:

(i) one similarity between the two processes

(ii) one difference between the two processes

6. (a) Explain what is meant by the term 'species'.

(b) King cheetahs have a different pattern of spots from ordinary cheetahs. At first it was thought that they might be a different species. Suggest how:

(i) the difference in spot pattern might have arisen

(ii) biologists have been able to show that king cheetahs are members of the same species as other cheetahs

7. The amino acid sequences of one of the polypeptide chains of haemoglobin from nine animals were determined. The results are shown in the table.

Type of haemoglobin	**Number of amino acids different from human haemoglobin**
Human	0
Gorilla	1
Gibbon	2
Rhesus monkey	8
Horse	25
Chicken	45
Frog	67
Sea slug	127

(a) Use the information to draw a phylogenetic tree of the organisms.

(b) Cytochrome c can also be used to study evolutionary relationships between organisms. Explain why.

(c) It is possible to use DNA hybridisation to suggest relationships between species. Explain why.

8. (a) Explain the importance of each of the following in speciation:

- isolation of different populations
- mutation
- selection pressures
- reproductive isolation

(b) Describe and explain three ways in which selection pressures in a cold environment could have altered the physical appearance of migrating humans colonising a colder environment.

9. (a) Describe how the experiments of Redi and Pasteur were able to disprove the theory of spontaneous generation.

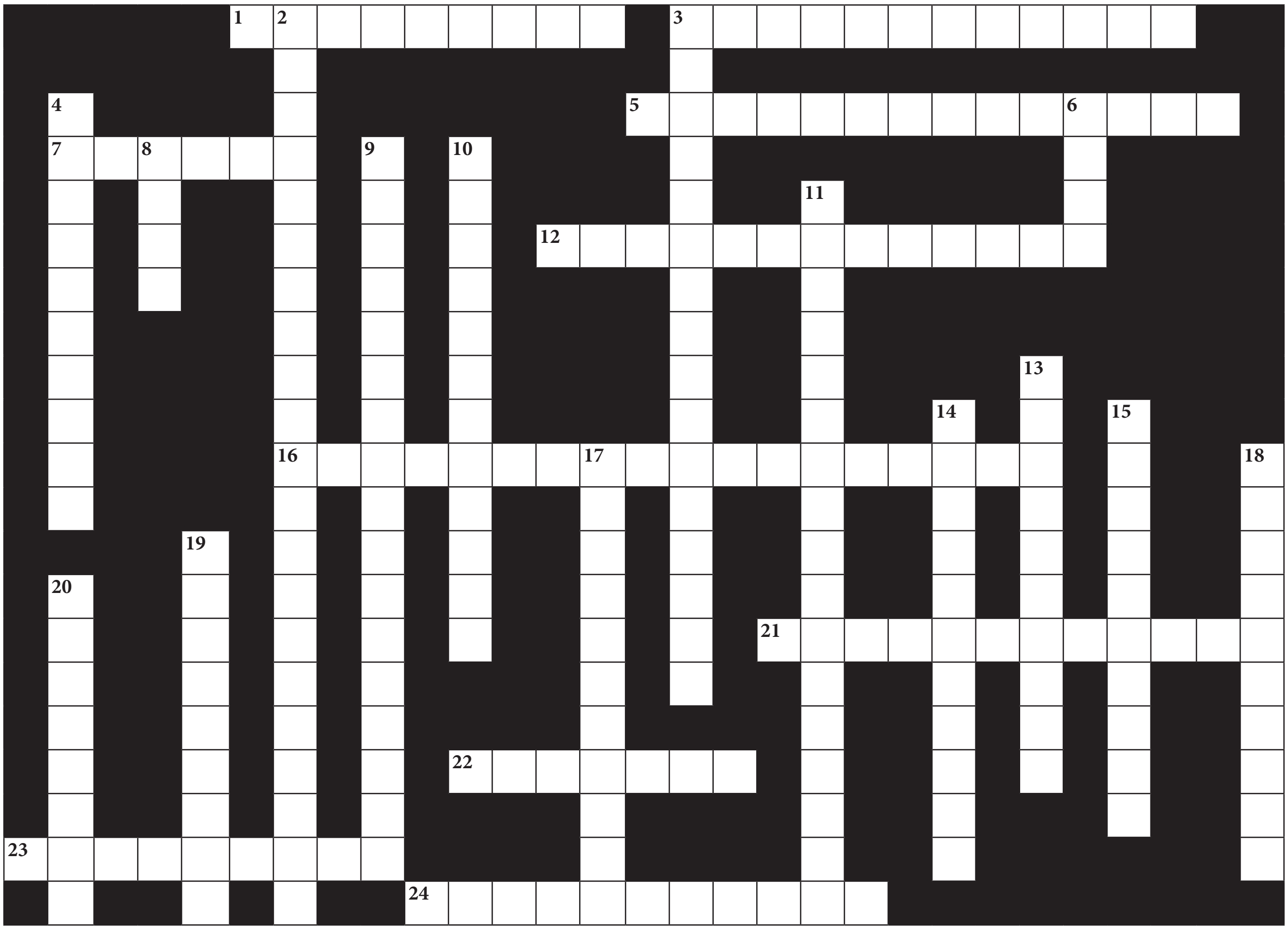
(b) (i) Describe the Oparin/Haldane theory of abiogenesis (the biochemical origin of life).

(ii) Describe three pieces of evidence that support this theory.

10. Write a short essay on human evolution. Include the following aspects of human evolution in the essay:

- the idea of a common ancestor with chimpanzees
- some of the early humans that have existed
- the importance of bipedalism and large brain size
- the significance of the Lucy and Ardi fossils
- the evolution of different races of humans

Copy the crossword puzzle below into your exercise book (or your teacher may give you a photocopy) and solve the numbered clues to complete it.



Across

1. Something that prevents two populations from interbreeding is an … mechanism (9)
3. Modification of Darwin's theory to take account of genetics and ethology (3–9)
5. Theory of origin of life on Earth that states life has always existed in the Universe and always will (8, 2, 4)
7. Russian biologist who, with Haldane, suggested the theory of abiogenesis (6)
12. The study of ancient life forms, mainly based on the study of fossils (13)
16. Theory of the origin of life that involves a supreme being (7, 11)
21. The dating of a fossil using its position in a sequence of rock strata (12)
22. French biologist who proposed a theory of evolution based on 'use and disuse' and 'the inheritance of acquired characteristics' (7)

23. The theory of the origin of life that suggests that life arrived on Earth from elsewhere in the Universe (9)
24. Modern man (4, 7)

Down

2. Theory of the origin of life which states that life can arise from non-living matter (11, 10)
3. Theory of the origin of species proposed by Charles Darwin (7, 9)
4. Type of evolution that results in totally unrelated species evolving similar structures as a result of occupying similar niches (10)
6. A fossil Australopithecine found in Ethiopia in 1974 (4)
8. A fossil Ardipithecine found in Ethiopia in 1991 (4)
9. Process by which one species evolves into many to fill available niches (8, 9)
10. The comparison of the same molecule in different species is comparative … (12)
11. Form of creationism that tries to disprove evolution by using cell biology and mathematical models (11, 6)
13. Structures with the same basic anatomy but with different functions are said to be … (10)
14. The type of natural selection in which one extreme is favoured and the other is selected against (11)
15. The process by which new species evolve (10)
17. Droplets that could have been the first 'pre-cells' (11)
18. The study of how embryos develop (10)
19. A process resulting from genetic change in a population over generations leading to the formation of new species (9)
20. All the alleles of all the genes of a population (8)