Section 1

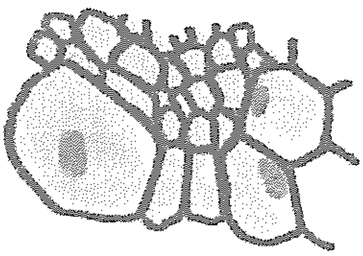
What you need to know before you begin

Throughout this book we try to avoid technical terms but we cannot avoid all of them. Important technical words, when first mentioned, will appear in bold type. More information about these terms is given in the Glossary. There are also a few facts that need to be understood before we can make sense of evolution. We can deal with these under four headings.

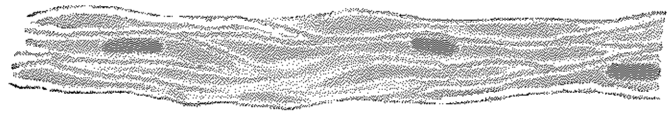
Cells

A cell is a small amount of living material enclosed in an extremely thin **plasma membrane**. Plasma membranes are part of the cell and are only two molecules thick so a stack of 10,000 would be thinner than a sheet of paper. Because of the chemistry of the molecules, they automatically come together to make this sort of membrane. Every known form of life exists in cells with plasma membranes. We all started life as a single cell (an egg) after it was fertilized by another single cell (a sperm). These special reproductive cells (eggs, sperms, pollen) can all be called **gametes** (pronounced gameets).

Plant cells, and some others but not animal cells, have a thick cell wall on the outside of the membrane. Cells divide into two to make more cells; that is how



Plant cells
Seen through a microscope in the cut end of a stem



Animal cells
Muscle cells of intestine seen through a microscope

living things grow. When cells divide they carry instructions for making further divisions. The instructions are carried in digital code formed by the make-up of some long, thin **molecules** known as **DNA.**

DNA, genes and gene pools

DNA is the stuff that genes are made of. A molecule of DNA is a bit like a long chain, with the links being made from particular combinations of four different chemical compounds. We don't need any details of the chemistry here, so we can just call the compounds A, T, C and G. Think of the four compounds as letters of the alphabet. The digital code is based on three-letter 'words' made from these four letters. There are 64 possible ways of arranging four letters in groups of three. The triplets of letters, the three-letter 'words', spell out the codes for other compounds called **amino acids**. About twenty amino acids, in different combinations, make up **proteins** that are the building blocks of life.

So, because of the mathematics of all this, a code of only four letters can carry the instructions for making billions and billions of different building blocks. What's more, with only tiny exceptions, every form of life on earth uses exactly the same code.

Each bit of the code that affects a particular feature, such as flower colour, eye colour or blood group, is called a **gene**. If you think of DNA as a chain, then there are commonly thousands of links in a single gene. Most characteristics are influenced by many genes, and some genes regulate other genes—telling them what to do, when to do it, and when to stop. The interactions between genes has been getting more complicated, minute by minute, for thousands of millions of years. Much DNA is non-coding. That is to say, no active genes have been found there, though it may be important in regulating gene activity elsewhere.

It is important to understand that although genes can interact with each other in complex ways, they always remain separate genes

If a DNA molecule were straightened out it would be even thinner than a cell membrane and could be several centimetres long. But DNA molecules do not lie straight. Instead, inside a cell, each DNA molecule is tightly packed in a bundle called a **chromosome**. Bacteria have only one chromosome. Other forms of life have more, with the number fixed for each species and contained in a special compartment of the cell called the **nucleus**. Nuclei are shown as dark patches in some of the cells on page 1.

Human Chromosomes

Humans have 46 chromosomes as 23 matching pairs. Most living things have between 10 and 50 chromosomes but there can be more or fewer. Mosquitoes have only 6 but silkworms have 56 and ducks have 80.

Living things that interbreed must share the same genes because the chromosomes are passed from male to female during sexual reproduction. Living things that interbreed and share the same genes are said to have the same **gene pool**. From now on, for want of a better word, we shall refer to living things as organisms.

The chromosome number in an organism is not doubled by sexual reproduction because the gametes carry only half the set of chromosomes from each parent. Chromosomes from egg and sperm (or pollen) combine at fertilization so the full set is restored in the offspring.

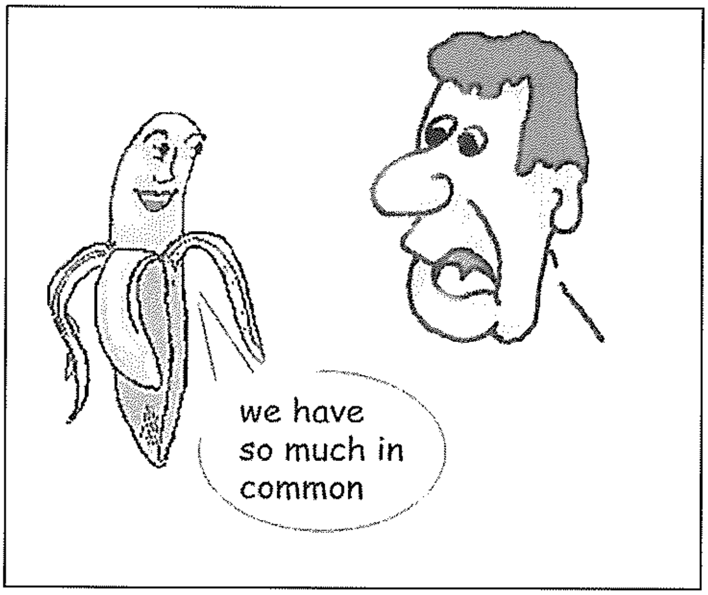
Heredity and mutations

Some things that are not living can seem to be alive. Flames move about, use up oxygen and give off waste. Crystals can grow and divide. But flames and crystals cannot pass on instructions for making more copies of themselves. The passing-on of genetic instructions is called **heredity** and it makes living organisms entirely different from non-living things such as flames and crystals.

Every organism on earth exists as one or more cells and has a mechanism for copying itself that we call heredity

When cells are dividing and copying their genetic instructions to the new cell, mistakes and other kinds of changes can occur so that genes get altered. The altered genes don't do quite the same thing that they did before. The changes, which are usually very small, are called **mutations**. The smallest mutations can affect only a few, or even a single one, of the gene's several thousand units ('links' in the DNA 'chain'). Altered genes can be passed on to offspring and so produce changes in the next generation of organisms (see **alleles**).

Genes that regulate the basic chemistry of life existed billions of years ago and have stayed much the same ever since. These ancient genes are still working in organisms alive today. They regulate processes such as cell division, cell growth and how cells react to other cells. That is why 21 per cent of human genes are found in all organisms, including bacteria. We share another 22 per cent of our genes with all other vertebrates.



Only one per cent of human genes have not been found in any other animal

The full set of genetic material in a species (see below) is the **genome** of that species.

Species

Scientific names of living things have two parts. The first is the genus and the second is the species. Lions and tigers are different species of animals but they are similar enough to be put together in the same genus (*Panthera*). So the lion's full name is *Panthera leo,* and the tiger is *Panthera tigris.* Domestic cats are also members of the cat family but they are not similar enough to lions and tigers to be put in the same genus. Scientific names are always written in italics, and the generic name always starts with a capital letter.

A species is a single type of organism that is normally interbreeding in nature. All living humans are the same species. Every other species in our genus has gone extinct.

Scientists classify all kinds of life into separate species but it is really just a convenient label. Some organisms may look similar but are genetically different and cannot interbreed. Others may look different but are genetically close enough to interbreed if they can be brought together. It can be impossible to know whether extinct types were interbreeding or not.

The naming of organisms is always an exercise in classification. For the purpose of this book you have all you need to know about it, but to illustrate the point, the picture on this page shows the hierarchy of main divisions in classifying two members of the animal kingdom - a person and a cat.

Kingdom ------		
Phylum --------	**Chordata** (see section 5)	**Chordata** (having a notochord)
Subphlum -----	**Vertebrata** (vertebrates)	**Vertebrata** (vertebrates)
Class ---------	**Mammalia** (mammals)	**Mammalia** (mammals)
Order ---------	**Primates** (primates)	**Carnivora** (carnivores)
Family ---------	**Hominidae** (apes, humans)	**Felidae** (cats)
Genus ---------	**Homo** (humans)	**Felis** (small cats)
Species---------	**H. sapiens** (recent humans)	**F. catus** (domestic cat)

Vertebrates are all those animals that have a backbone attached to a skull that encloses a brain. This group contains five classes— fish, amphibians, reptiles, birds and mammals. Clearly, cats and people are mammals and differ from the other four classes in having hair or fur (not scales or feathers), and suckling their babies on mother's milk.

But they don't have enough in common to be lumped together at the next level (order). Cats, like wolves and weasels, are hunters. They have teeth for killing and a gut for digesting meat. They are obviously carnivores (meat-eaters). People are quite different mammals. We have short snouts, eyes quite close together, fingernails instead of claws, wide collar-bones with shoulders and elbows able to rotate and move in all directions, good colour vision, only two teats for suckling, and many other features that show us to be primates.

Even specialists have difficulty in classifying all organisms systematically. But to some extent, evolutionary relationships are always taken into account

Section 1 Revision

True or false? Circle T or F:

1. Only living things can use oxygen — T F
2. Every gene has a separate gene pool — T F
3. Heredity is the passing of genetic information from one generation to a future generation — T F
4. Some genes are controlled by other genes — T F
5. Mutation is only another name for gene — T F
6. Animal cells have no cell wall — T F
7. There has only ever been one species of human — T F
8. Except for bacterial cells, chromosomes are found in the cell nucleus — T F
9. Bacteria have only one chromosome — T F
10. A genome is genetic material that contains no genes — T F

Try to answer the next three questions in a few words of your own:

11. Why do humans, carrots and microbes have some of the same genes?
12. Sexual reproduction passes on chromosomes, so how does the number of chromosomes stay the same in every generation?
13. Why have some very ancient genes not changed in billions of years?

Section 2

What causes evolution?

In just five points we can summarise why evolution happens. We will then consider some points in a bit more detail.

1. Every organism is able to produce more offspring than are needed to replace the parents.

2. Because of mutations, the offspring, even from a single cell, are not always genetically identical to the parents.

3. In nature, it is obviously impossible for all offspring to survive, grow and reproduce.

4. Sometimes, it may be just a matter of luck which individuals survive to reproduce, but in time, with large numbers of individuals, some of the genetic differences will have an effect on long-term survival.

5. Over time, it is the genes, or combinations of genes, that are passed on by survivors that become the most common ones. Inevitably, they come together in the same individuals. The genes, or combinations of genes, that keep being weeded out will become scarce or even disappear altogether from the gene pool. This change in genetic make-up, over generations, is what scientists have in mind when they talk about evolution.

Tiny changes can build up to become major changes, given enough time

Evolutionary biology is a big branch of science so there are a great many thick books on how it all works, and it can be quite mathematical. But the five simple points above will give you the general idea. We can now consider them in slightly more detail.

Reproduction

It is obviously impossible for all the offspring of any form of life to survive and reproduce. If that could happen it would not take long for all land and water to be packed solid with life! Numbers of the same kind of organism, living at the same time, are called **populations**. Populations can remain fairly steady, or there can be spectacular peaks and crashes in numbers as happens with locust and mouse plagues. But all populations have limits to growth. Populations may simply run out of the things they need—such as water, food, nesting places or some other essential. Individuals may die from disease, starvation, being eaten, dried out, flooded, burned in a bush fire, frozen, trampled, blown out to sea—or any other nasty end that you can think of. Some animals, such as certain species of fish, need to produce millions of young so that just a few will survive.

Mutations and other changes

Most gene alterations do no good. Many changes are detrimental, while other gene changes may make no difference and are said to be neutral. A few gene changes will help the organism in some way and are said to be beneficial. We will mention some examples later.

The particular genetic make-up of an individual, or a single cell, is its **genotype**. Identical twins, or cuttings from the same plant, will have the same genotype but they may develop differently if they grow up in different environments. A child raised on a starvation diet is not likely to make the same progress as an identical twin who is well nourished. Every gardener knows that identical plant cuttings will grow better in some situations than in others.

The outward appearance of an individual is its **phenotype**. So, in slightly more technical terms, the paragraph above means that the genotype determines the possibilities for development, but the phenotype will depend on how the environment allows the genotype to be expressed. The environment includes everything that affects development, both before and after birth or hatching.

Survival

With all the hazards of the natural world, it can be a matter of chance which individuals survive and which do not. But over a long period of time, it will generally be found that the individuals that survive to reproduce in a population are very well suited (adapted) to their particular way of life. The ones that get weeded out will more often have been at greater risk in some way. In other words, survival in the long term is not entirely random, it is selective. For this reason, beneficial mutations will tend to be preserved in survivors, while detrimental mutations will tend to be weeded out of populations. This is the process of **natural selection** and it is the main mechanism of evolution in the sense of adaptive change.

You may have heard the term 'survival of the fittest' in connection with evolution. This means much more than fitness in the athletic sense. It means being 'best fitted' or most well-adapted in every way, and it applies equally well to plants and microbes as well as animals.

Not every change of gene-types in a population is adaptive because neutral genes will get passed on at random. But neutral genes can become beneficial or detrimental at some future time if circumstances change (more about this in Section 3).

Despite the working of natural selection, It is also possible for genes to be lost at random from populations if the populations are very small. One event, such as a bush fire or storm, might just happen to kill all the individuals with a particular gene type. This process of genetic change caused only by random sampling is called **genetic drift**. It can be important when a species has been reduced to very small numbers. Similarly, if a small population got washed ashore on an island, it could be a matter of chance whether rare genes had been brought from the main population.

The genetic make-up of populations can change by chance, but only natural selection makes organisms better adapted to their environment

Now have a go at the questions for this section, then we'll move on to see how all this works in real life.

Section 2 Revision

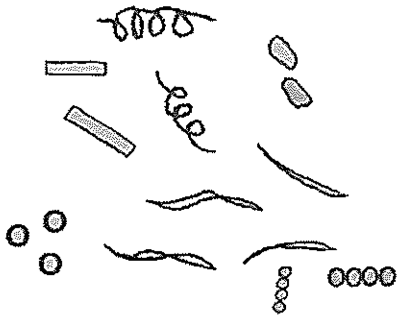
Think about the following questions and try to answer them in words of your own:

1. If you could change the way life works, what single change could you make that would stop evolution from happening?
2. Do you think sexual reproduction might make evolution work faster, slower, or should it make no difference?
3. If you learn to play a musical instrument, are your children likely to be better musicians? If not, why not?
4. If you are in charge of a nature reserve, when might you get worried about genetic drift?

Section 3

Natural selection in single cells

Life has now been continuous on earth for about 3.5 billion years. For nearly half that time, single cells in the form of bacteria were the only living things, although they were not the very first form of life. Nobody can be sure how life first got going but scientific evidence suggests that the chemistry of life first came together inside cells or 'bubbles' of some sort. At that time, the earth was very different from the way it is now and the atmosphere was without oxygen. The same chemical changes could not happen in the present atmosphere.



Bacteria exist in many shapes

Today, single celled organisms are still remarkably successful. Although you usually can't see them, they make up more than half the weight of life on earth and play a crucial role in the planet's ecology. Bacteria are still the most common form of life; a spoonful of soil commonly contains many millions of them in a great many kinds. Nobody knows how many kinds exist in total.

Bacteria have continued to evolve and are now adapted to an incredible number of specialized ways of life. In a human body, for instance, only about one tenth of the cells are human. Most are bacterial cells that invade our bodies soon after birth, and some of them help to keep us alive. Without the bacteria in our gut, we could not break down the thick cell walls of many plants that we eat.

Bacteria multiply by splitting in two. Most have a cell wall outside the plasma membrane

Like other cells, bacteria reproduce by splitting in two. Some bacteria divide every few minutes and can produce many generations in a single day. Bacteria have thousands of genes in their DNA and the genes can be copied in a matter of seconds. Mutations keep happening so their evolution can be very fast indeed. This makes them good subjects for evolutionary study, but it also has extremely important consequences for the welfare of other organisms, including humans.

Evolution and disease

Although most bacteria are harmless or beneficial to humans, some types do cause very serious diseases. These include tuberculosis, cholera, diphtheria, typhoid fever, typhus and bubonic plague. Some diseases, such as tuberculosis, can pass between humans and other mammals—both wild and domestic. Some serious plant diseases are also caused by bacteria.

In the past, bacterial diseases were a major cause of death among people who were crowded together in towns. In the fourteenth century, bubonic plague killed half the people of London. The bacteria lived in fleas that were carried about in cities on both rats and humans. In 1928, in London, Alexander Fleming discovered a substance from a fungus that could kill bacteria. He called it penicillin and it became the first of the **antibiotics** to be mass-produced as a medicine. At that time, nobody realised how fast evolution would work among bacteria.

The problem is that an antibiotic may not kill every single bacterium in a sick person (or domestic animal or plant), especially if the course of treatment is cut short. The least resistant bacteria are quickly weeded out, but the survivors have genes for better resistance. The survivors rapidly multiply so that more bacteria will be resistant to the next dose of antibiotics, and so on. Eventually, natural selection produces a **strain** of bacteria that is completely resistant to the antibiotic.

Many more antibiotics have been discovered since penicillin, and more and more kinds of bacteria have become resistant to them. Tuberculosis is now killing more people than it did thirty years ago, and, in some places, the best antibiotics have no effect. It is true to say that our dependence on antibiotics has become a race between medical science and bacterial evolution. Some people think evolution is winning.

A race against bacterial evolution

Where do resistant genes come from?

This is not a simple question because scientists may not know what a gene does until it shows up by doing something. For example, until antibiotics were used by doctors, nobody knew if bacteria had genes for resistance. In the same way, in insects, the genes for resistance to DDT and some other pesticides could have existed before the pesticides were invented. How is this possible?

Remember what you learned about neutral genes in Section 2. Gene pools can collect numbers of neutral genes. Many will not show up at all, others might make small differences that show up as part of natural variation in a species. Tiny variations in the chemistry of an insect's nervous system, for example, can affect the way an insect reacts to pesticides. So a gene that made very little difference to an insect's life might have become highly important when humans invented pesticides. When a gene turns out to be beneficial to an insect, natural selection can go to work on it and the gene will spread through the insect's breeding populations.

New genes for resistance can also arise by very tiny mutations, sometimes just affecting the smallest part of the DNA molecule. In summary, then, genes for resisting antibiotics and pesticides can arise from very small mutations, but they are often present to begin with.

Section 3 Revision

True or false? Circle T or F:

1.	Bacteria are always helpful to human digestion	T	F
2.	All bacteria normally live in soil	T	F
3.	Bacteria are too small to have genes	T	F
4.	When life began on earth there was no oxygen in the air	T	F
5.	All mutations are beneficial in the end	T	F

Circle the best answer:

6. Tuberculosis is caused by
   a. rats
   b. fleas
   c. bacteria

7. Antibiotics are
   a. a kind of fungus
   b. substances that kill bacteria
   c. types of penicillin

8. All bacteria are usually
   a. double cells
   b. harmful
   c. single cells

9. Bacteria
   a. were the first form of life
   b. are the commonest form of life
   c. make up half the weight of the human body

Try to answer the next two questions in words of your own:

10. Why is it foolish to take only part of a course of antibiotics?
11. Insects can get more resistant to pesticides in two ways. What are they?

Section 8

Problems with fossils

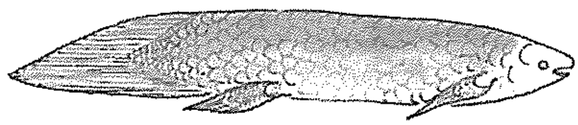
Fossils are the remains, or traces, of organisms that have been preserved after death and become part of the Earth's geology. For this to happen the organism must be buried, often in soft mud, so that it is protected while fossilization takes place. Over very long periods of time, the mud becomes rock and the remains of the organism can be seen as either an imprint in the rock, or as whole remains that have been mineralised and have themselves become rock. Fossils of hard parts, such as bone and shell, are much more common than those of soft tissues. Preserved remains are also found in amber, tar, peat and volcanic ash.

The time between about 540 and 490 million years ago is the Cambrian Period and fossils are abundant in rocks from that time. Nearly all the main groups of animals are represented in the Cambrian fossil record. The time before the Cambrian is known as the Precambrian Era, (Latin: *pre,* before). Animals with hard parts were thought not to exist then, so fossils were not expected to be found. Precambrian fossils have now been found and we know that there were animals such as sponges, jellyfish and worms in the seas of that time. Some fish had appeared by the end of the Precambrian.

> The earliest definite fossils from the Precambrian include some from Australia, and are dated between 550 and 670 million years old

Scientists are not sure how to explain such a big difference in fossil quantities between the Cambrian and Precambrian times. Were there simply a lot more creatures with hard parts to leave fossils in the Cambrian? Or was there a great spurt in evolution, or both?

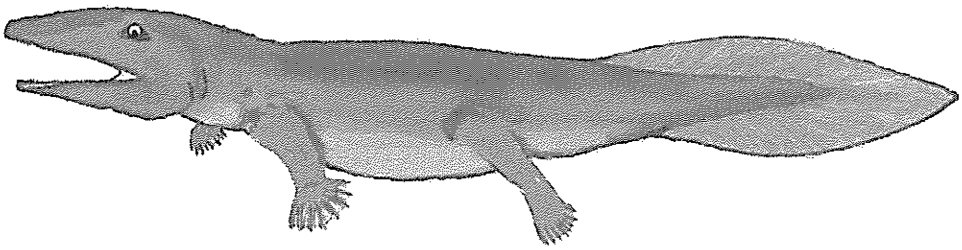
It is a question without a simple answer. The fossil record is plain to see but it is difficult to interpret. Some experts study rates of mutation in particular species and so calculate rates of evolution based on a sort of '**molecular clock**'. Their findings suggest that the major groups of animals had begun to separate in the Precambrian, even though the separations don't show up as fossils until later. Perhaps the picture will become clearer as more fossils come to light and more research is done at the molecular level.



Australian lungfish

In contrast, we have a rich fossil record from rocks that have been laid down since the Cambrian. Some of these fossils show evolutionary changes very clearly. There is a range of fossil types, for instance, that show details in the evolution of amphibians from lobe-finned fish (the modern lungfish is a lobe-finned fish). The many changes took place over tens of millions of years.

One creature from this range of fossils is called *Acanthostega*. It was about 60 cm long and lived in water. It had gills like a fish but had limbs with paddles on the ends that looked very like feet. There were eight 'fingers' and at least as many 'toes'. It is unlikely that the 'elbows' and 'knees' could bend very much. *Acanthostega* lived about 365 million years ago.



Acanthostega

It is obvious that, under similar conditions, big vertebrates will leave more fossils than do tiny ones. In Western Queensland, scientists are uncovering dinosaur fossils faster than they can get them ready to put on show. But this does not mean that the most abundant fossils must have been the most common animals of their time. It simply means that massive bones do not quickly disappear and so have more chance of becoming fossilized.

And yet, we do have some wonderfully detailed fossils of delicate structures such as leaves and feathers. This is amazing, given the extremely slim chance of such things being fossilized. Consider the fact that nobody has ever found the preserved bones of a passenger pigeon, although there were said to be billions of them in America when Europeans arrived nearly 400 years ago. It is now extinct.

Archaeopteryx

The best known fossil with feathers is the famous *Archaeopteryx* that lived about 150 million years ago. The first complete fossil was discovered in limestone in Germany in 1861.The very fine grain of the limestone shows the feathers in great detail. Six more *Archaeopteryx* fossils have since been found in the same area. These animals may have been capable of limited flapping flight as well as gliding.

During the past few years the fossils of similar creatures have been discovered in China. One of them (*Microraptor*) had flight feathers on all four limbs as well as the long tail. These little 'feathered dinosaurs' would have used their feathers for gliding rather than powered flight.

Section 8 Revision

Circle the best answer:

1. The Precambrian was the time before about
   a. 50 millions ago
   b. 5 million years ago
   c. 500 million years ago
   d. vertebrates

2. To understand the existing fossil record, scientists must
   a. know the ages of the rocks
   b. discover more soft fossils
   c. find fossils in limestone
   d. find Precambrian vertebrates

3. A 'molecular clock' is
   a. based on rates of mutation
   b. made of molecules from fossils
   c. another name for research
   d. used by geologists

Section 9

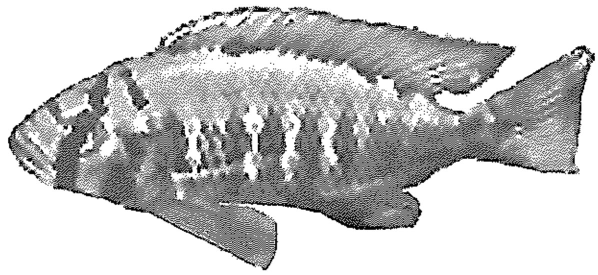
New species

We saw in Section1 that a species is a group of animals, plants or other organisms, that interbreed in nature. If, for any reason, some individuals are prevented from interbreeding with the rest, then a separate breeding group is formed. Mutations then begin to accumulate in two separate gene pools. In time, genetic changes can build up until the two groups are too different, genetically, to produce fertile offspring even if they come together again. In this way, a new species will have evolved. The process of evolving new species is called **speciation**.

The most obvious way in which populations can be separated is by physical barriers. Among vertebrates, speciation has often occurred on islands where populations have been separated by water for a long time. Similarly, different species can be found on either side of a mountain range or a river.

Sometimes, separated populations have evolved different ways of life that prevent them from interbreeding—even if they can get together again. They may have different flowering times, or breeding seasons, or courtship displays or simply live in different kinds of habitat.

In Africa's Lake Victoria, two types of fish are kept apart because they have evolved two different colour schemes. The males of one type have a blue colour pattern and the males of the other type are patterned in red. Females choose their mates by the colour.

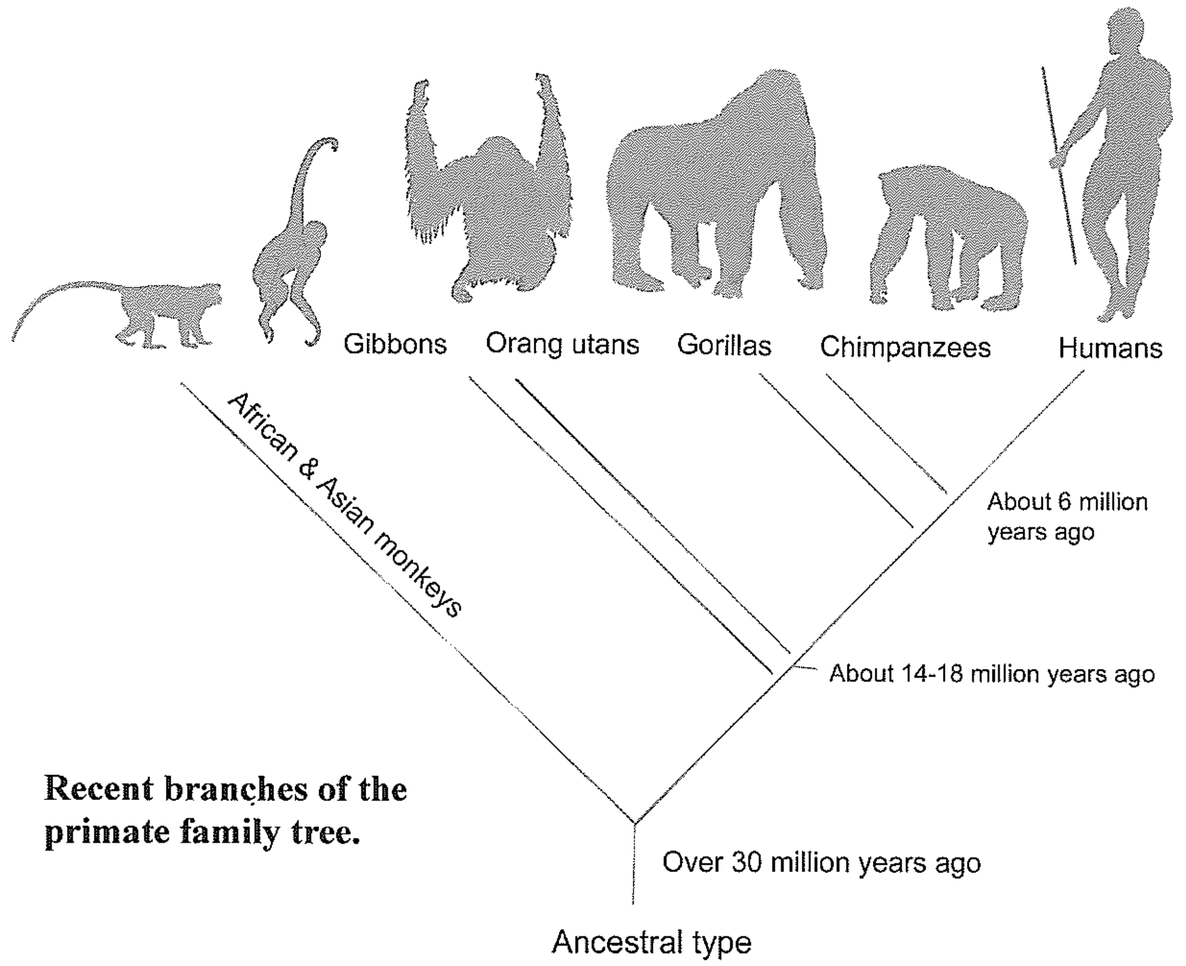


Pundamilia nyererei

But in an aquarium, in special light that does not show the colours, the females will mate with males of either colour. The offspring are fertile. This shows that nothing more than a mating preference is keeping two types apart. If the two remain separate for long enough they may drift further apart, genetically, and become unable to interbreed. On the other hand, if pollution of the lake makes it harder for the fish to see colour, then perhaps the two will join up again and the colour difference will be lost. The fish belong to the genus *Pundamilia* in the family Cichlidae. Many cichlids are popular aquarium fish.

Wild lions now survive only in Africa and one tiny part of India, so they do not normally meet any tigers. Lions and tigers are said to be different species. Yet in zoos, lions and tigers can mate and produce cubs. When the father is a lion, the cubs are called ligers; when the father is a tiger, the cubs are tigons. Male cubs are **sterile** but females can be fertile. In time, if lions and tigers do not go extinct in the wild, they may continue to evolve apart until they can not produce any fertile cubs even in zoos. Their genes will no longer match up well enough.

The species genetically closest to humans is the chimpanzee. Humans and chimps obviously had the same ancestor. With today's knowledge and technology, specialists on 'molecular clocks' estimate that the two species took more than four million years to separate. The final split, with no further interbreeding, occurred about six million years ago. It all sounds very recent, but it could have taken tens of thousands of years for small changes to show up. At that rate, if our pet cats were turning into big, horned monsters—we wouldn't notice a thing!



Recent branches of the primate family tree.

In this diagram of the primate family tree, only the main branches with living representatives are shown. Within the main branches there are many smaller branches leading to types that have become extinct. Scientists are working on the genomes of each living group. When they are completed it should be possible to put more precise times to the branching.

Humans, like cheetahs, are now a solitary species in a single genus. And it seems unlikely that we could separate into more than one species in the future. Certainly, in the world that we know, it would be practically impossible for part of our population to become isolated from the rest of the gene pool for the necessary length of time.

Cheetahs are also unlikely to speciate but for quite a different reason. They are almost extinct in Asia (a few remain in Iran) and have disappeared from much of their former range in Africa. The most probable outcome for isolated cheetah populations is extinction. About seven thousand are known to remain in total, compared with a human population of seven billion. We shall deal with population biology in the next book of this series.

Section 9 Revision

Circle the best answer:

1. Different species have different
   a. ancestors
   b. breeding seasons
   c. gene pools
   d. colours

2. Chimpanzees and humans had the same ancestor
   a. 6 thousand years ago
   b. 6 million years ago
   c. 6 generations ago
   d. 400,000 years ago

3. Sterile animals
   a. cannot produce offspring
   b. cannot mate
   c. are all males
   d. can only survive in zoos

4. Species may become separated by
   a. motherhood
   b. age
   c. water
   d. sterile males

5. Separated species
   a. can never rejoin
   b. might possibly rejoin
   c. must eventually rejoin
   d. are always sterile

Section 10

Evolution is blind

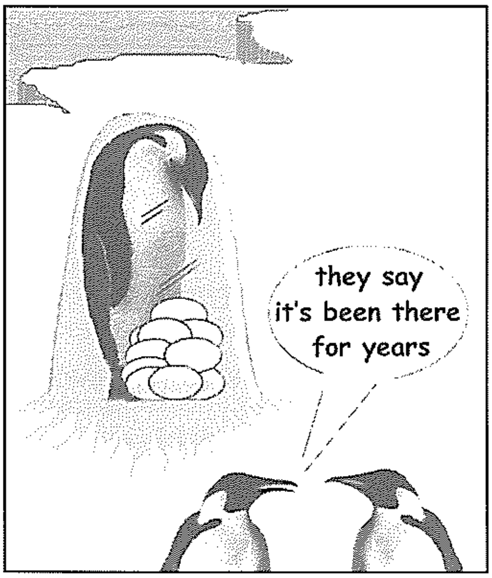
Natural selection can work only on what is already there so evolution cannot 'know' what might be coming next. The most successful genes from each organism just keep building up in the gene pool until, eventually, each type of organism is doing as well as can be, under the circumstances. Natural selection will then keep it that way. This is called **stabilizing selection**.

If you were to catch and examine hundreds of wild creatures in one area, you would probably find, for each species, that all the adults of the same sex would be quite similar in size and general appearance. Natural selection has settled on the most successful combination of features for all the existing circumstances. Stabilizing selection has been at work.

There are a few species that have changed very little when compared with their fossilized ancestors. Lungfish are good examples. They look much the same as some fossils from 200 million years ago. Perhaps these 'living fossils' have met very little change in living conditions, or perhaps they have not produced much genetic variation, or both. Six species of lungfish survive in muddy waters of Australia, South Africa and South America.

The ancestors of every living organism were obviously the survivors. Through evolutionary time they have come through all the hazards that have meant life or death to their kind. Genetically, they have proved to be the most successful mixture - all things considered. Everything that has made a difference to successful reproduction has been tested over time.

For example, some bird species lay only one or two eggs, while other species, such as wild ducks, may lay ten or more eggs in a clutch. We can be sure that clutch size is related to the parent birds' ability to incubate and care for the young. Baby ducks can feed themselves so more eggs can be an advantage to the species. At the other extreme, emperor penguins must balance a single egg on their feet until it hatches, and then find food for the chick in the freezing Antarctic. An emperor penguin, trying to care for ten eggs would hatch none at all.



Every plant, bird, or other organism that you see in the wild, is the result of its ancestors having passed on their genes successfully through evolutionary time

The cover of this book shows a human skeleton with the skull of a crocodile. It is, of course, nonsense. Even in fiction, such a combination would make no sense because the body and the head are obviously adapted for completely different ways of life. The primate neck could not support the massive reptile head, but if it could, the brain would be too small to deal with primate behaviour, the great jaws could not chew food and the eyes could not focus on the hands. Even science-fiction writers need to think about how evolution works.

When circumstances change

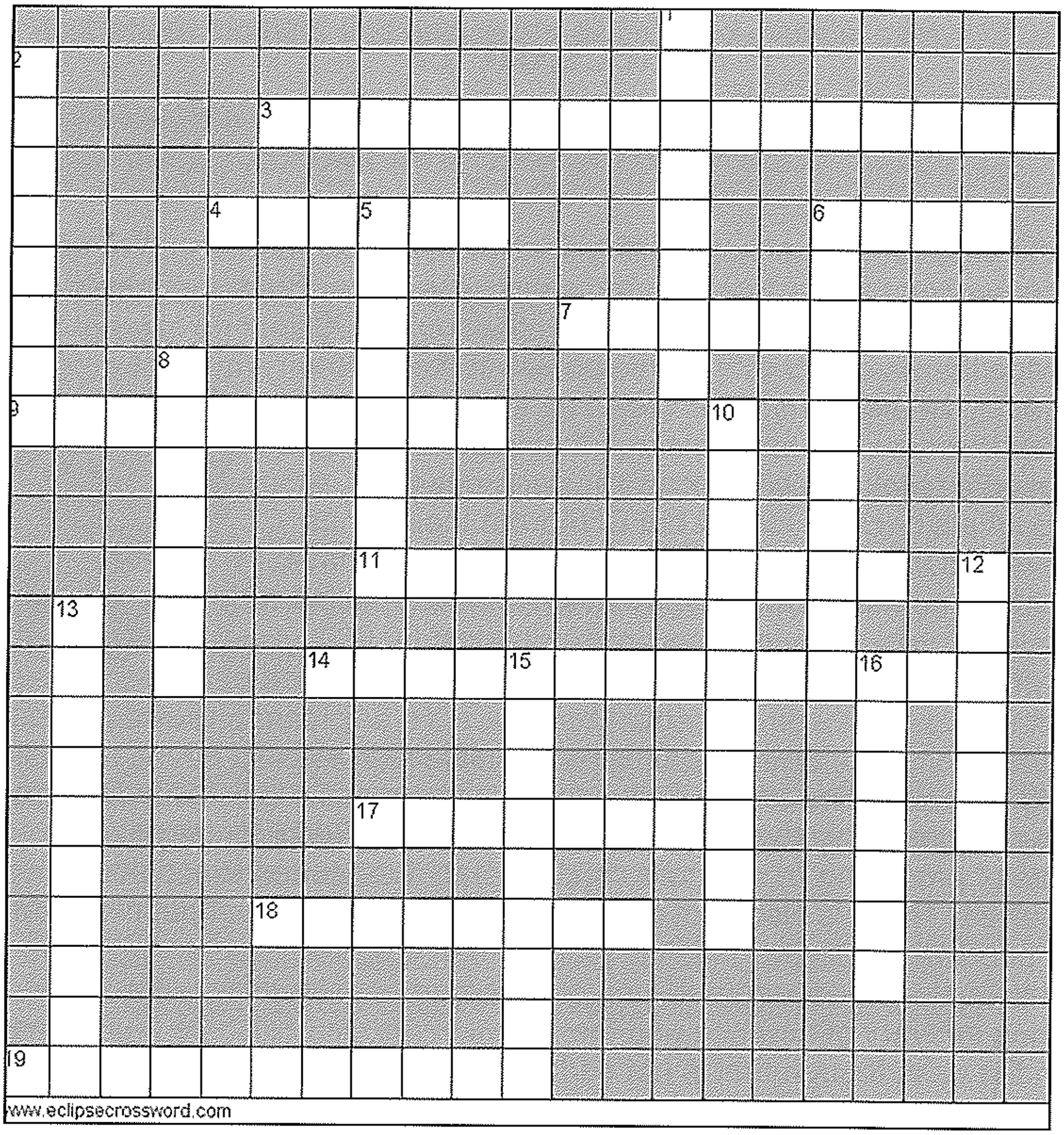
In nature, there is always change. Climates change, land masses move, volcanoes erupt, and now thousands of millions of human beings are having a tremendous impact on natural habitats. Adaptations that were most successful may become less successful under the new conditions. Different variations become more important. Perhaps individuals with more drought tolerance, or better camouflage, or particular disease resistance, may start to be more successful. Instead of an organism being stabilized by natural selection, it will then be changed in the direction of a type with a more successful set of adaptations. Natural selection will now be **directional** until it becomes stabilizing again. In Australia, cane toads have longer legs, on average, than they did thirty years ago. Cane toads were introduced to Australia from Hawaii. Under the changed circumstances, longer legs are proving beneficial.

If circumstances change quickly, then natural selection may not have time to work. The species will not become adapted to the changed conditions and will go extinct. This probably happened to the dinosaurs when a comet struck the Earth. It has certainly happened, and is still happening, to many species as a result of human activities.

Natural selection is always playing catch-up with environmental change

Section 10 Revision

It's time for some wider revision. Try the crossword.



Clues Across

3. When single cells get together (16)
4. A group within a species, may not be wild (6)
6. No life outside, as far as we know (4)
7. I stay with a sponge but others look like me and swim about (6, 4)
9. Penicillin is only one of them (10)
11. This type is not made of bones (11)
14. Plants do it, we depend on it (14)
17. The gene is not an exact copy (8)
18. Unique to living things (8)
19. They have a spine in common (11)

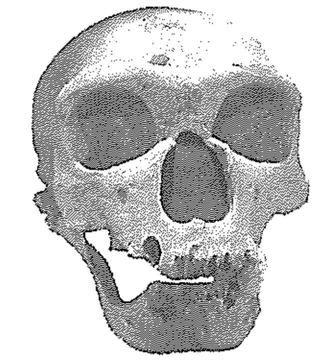
Clues Down

1. DNA is a particularly big one (8)
2. They never have a nucleus (8)
5. Natural selection favours such changes (8)
6. The DNA is all screwed up (10)
8. Winners, but might not be able to move (7)
10 Natural selection is favouring longer legs (11)
12. A combination of specialized cells (6)
13. Makes insects harder to poison (10)
15. Forms of life (9)
16. Humans are all the same (7)

Section 11

Evolution and humans

Human beings are the only surviving species in the genus *Homo.* We named our species *Homo sapiens*—which means 'wise man.' But human evolution did not stop after we came on the scene. Until about 30,000 years ago there were two or more species of the genus *Homo* living at the same time. We know that Neanderthal man lived alongside *H. sapiens* and that some interbreeding took place. We can't be sure why the Neanderthals became extinct but DNA from their bones has revealed that people from Europe and Asia still have some of their genes. Probably, there were other species or sub-species in the human mix within the last 80,000 years or so, before we became what we are today.



Neanderthal skull

So is that the end of the story, or is natural selection still operating on us? The reasons why evolution happens are listed in Section 2. Do the reasons apply to modern human societies? Certainly, people are capable of producing many more children than are needed to replace themselves. There is also a lot of variation between individual people. Indeed, within populations, the variation is greater than it was in the past because global travel has led to more mixing of ethnic groups. Mutations are still occurring in every generation and the mutation rate may also be higher than it was in the past, though that is not certain. But is natural selection working on any of these variations?

To put the question another way, are genetic differences in humans still having a selective influence on survival and the number of children that are being raised? It is difficult to get a measure of such things because humans have a long generation time and genetics is a relatively new science.

The structure of DNA was revealed in 1953— two human generations ago

Humans and natural selection

Before going any further, let's look at a well-known example of natural selection in humans. The average weight of a human baby at birth is 3.6 kg. This has been fixed by stabilizing selection. In earlier times, before we had doctors and hospitals, babies of about this weight had the best chance of surviving. Lighter babies are often premature, and heavier babies have more chance of being injured (or of injuring the mother) during birth. This is still true for people who live in places without medical help. But birth weight makes hardly any difference to survival where mothers and babies are given good medical care.

> Birth weight is just one example of the way in which modern medical science and technology can bring natural selection to a halt

Prevention of disease by hygiene and inoculations now saves the lives of millions of infants. Less than a century ago, these infants would not have survived to pass on their genes to children of their own. Many thousands of years ago, all humans lived by hunting and gathering among dangerous wild creatures. For those people, good eyes and ears would have been a great advantage. Today, as we hunt and gather in supermarkets, we survive just as well by wearing spectacles or hearing-aids. You can think of similar examples for yourself.

So, it does appear that modern humans have largely suspended natural selection and that family size is now determined mainly by personal choice and whether people have access to modern methods of birth control. Certainly, modern hygiene and medicine have allowed human numbers to explode from two billion to seven billion within a single human lifespan. But nobody knows what might happen in the future. We have no idea what combinations of genes will become important if conditions on earth become drastically changed. Remember the insects and DDT (Section 3).

> **Nobody knows what combinations of genes will become important if conditions on earth become drastically changed**

Why do we still have genetic disorders?

Some very serious medical conditions are caused by faulty genes. Why, then, were these harmful genes not selected out of existence in our evolutionary past? There are several reasons why natural selection can fail to weed out harmful genes. The following are just two examples.

Genes that do the same thing can exist in different versions (alleles). For example, a gene that gives a purple colour to the flowers of the garden pea also has a form that makes them white. In animals, one gene controls the passage of salt through cell membranes. A defective version of this gene causes cystic fibrosis in humans - which is the most common genetic disorder in people from Europe. If a child inherits the defective gene from one parent but not the other, then the disorder will not show up. In Europe, about one person in twenty-five has a copy of the defective gene and doesn't even know about it. The disease can only show up if a child inherits the defective gene from both parents.

In genetic terms, the good gene is said to be dominant over the defective version - which is recessive. Because people can carry this gene and remain perfectly healthy, it has not been possible for natural selection to eliminate it from human populations. Today, in Europe, about 1 in 2,500 babies inherits two defective forms of the gene and so develops cystic fibrosis.

A disorder called Huntington's disease provides another example of how harmful genes can be sheltered from natural selection. In this disease, the gene that is defective helps to regulate cells in the central nervous system. Sufferers develop tremors and convulsions. This defective gene is dominant over the healthy version so a baby inheriting it from only one parent will develop the illness. In this case, the disorder has not been selected out of existence because it does not show up until early middle-age. By that time, those with the defective gene can already have passed it on to their offspring.

These two examples are enough to remind us that evolution works at the genetic level and it has its limitations. It has produced organisms that are wonderfully adapted to their way of life but that does not mean they are perfect. In the case of genetic disorders, we must rely on medical science to improve on what nature has produced.

Section 11 Revision

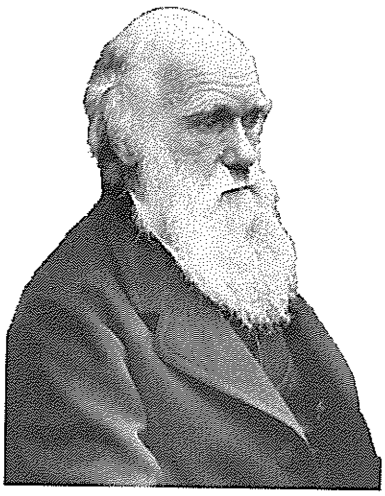
Circle the best answer:

1. In modern societies, natural selection Is not obvious because
   a. people don't have enough children
   b. technology compensates for genetic disadvantage
   c. harmful genes have mostly disappeared
2. It is difficult to study natural selection in humans because
   a. humans have stopped mutating
   b. people won't talk about it
   c. human generation time is so long
3. Average human birth weight has been fixed by
   a. stabilizing selection
   b. directional selection
   c. 3.6 kg
   d. none of the above
4. Harmful genes can avoid natural selection if they do not
   a. affect birth weight
   b. influence reproduction/survival
   c. come from both parents
   d. affect old age

Section 13

What about Charles Darwin?

The English naturalist, Charles Darwin, is regarded as the founder of evolutionary theory—which some people still call 'Darwinism.' It may seem odd not to have mentioned him before now, but Charles Darwin lived from 1809 to 1882, and much has been learned about evolution since he died. If you have read this book so far, you will already know some important things that Darwin did not, and could not, have known about evolution.



Charles Darwin. Photographed in 1869

What Darwin did

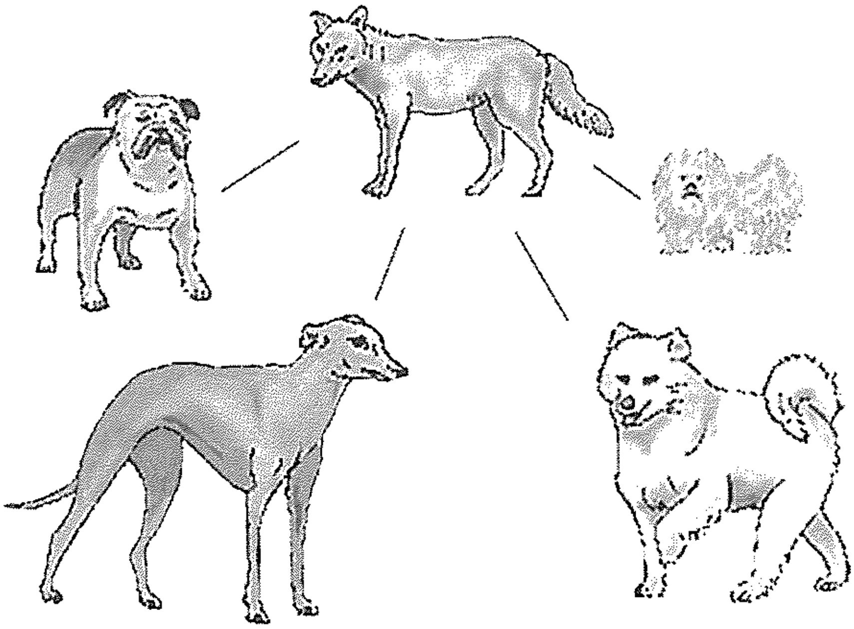
Before Darwin's time it was believed that the earth was only a few thousand years old, and that species had never been any different and could not change. During Darwin's life, geologists were finding rocks and fossils that suggested the earth must be at least hundreds of millions of years old. With this information, Darwin began to think about species in terms of very slow change. He was not the only person to be thinking that way, but by the time Darwin published his book—*The Origin of Species* (1859)— he had spent thirty years collecting masses of evidence to support his ideas. A few of the lines of evidence from his book can be summarised under the following headings:

Fossils

Compared with today, very few important fossils had been found in Darwin's time, but even from the collections known to him, he could see that there was a 'succession of types'. He correctly predicted that as more fossils were discovered, more links would be found between existing and extinct types.

Domestication

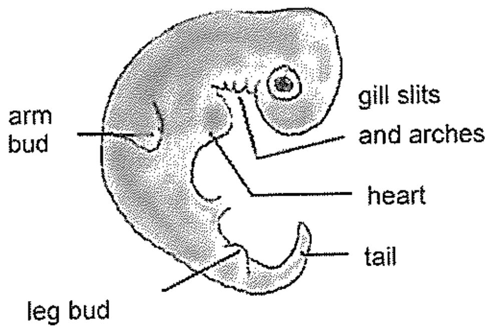
Darwin was impressed by the fact that a wild animal or plant can be selectively bred by humans to produce a wide range of different shapes, sizes and characteristics. He was interested in all the fancy pigeons that have been bred from one wild species. He marvelled at the very different-looking dog breeds that he thought must have come from a few wild types. He realised that although humans had done the selecting, all the variation must have come from nature. We now know that domestic dogs have only one wild ancestor—the wolf. Lapdogs, greyhounds, mastiffs and all the rest, have come from the genes of the wolf.



All breeds of dog can be traced back to the wolf

Embryos

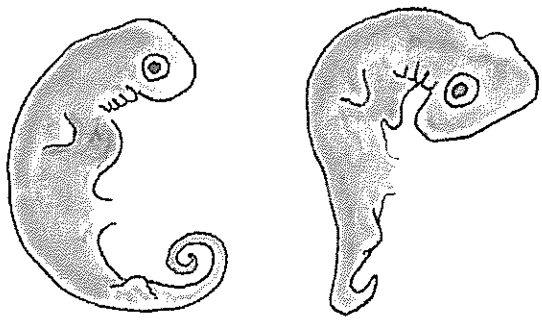
In some ways, the development of embryos shows the earlier stages of evolution. At the age of one month, a human embryo has gill slits and a tail and looks much the same as a fish, reptile or other vertebrate embryo.



Human embryo

This was well-known to Darwin and he saw it as evidence for a common ancestor. He reasoned that the changes which had evolved since the common ancestor were only showing up in later life, not in embryos. We now know that each kind of embryo continues to develop differently according to its inherited genetic programme. It is as though the later programmes are overwriting the earlier ones.

For example, certain bones remain in the gill arches of a modern fish just as they did in ancient times. But in reptiles and birds they develop as jaw bones, and in mammals they end up as tiny bones in the middle ear.



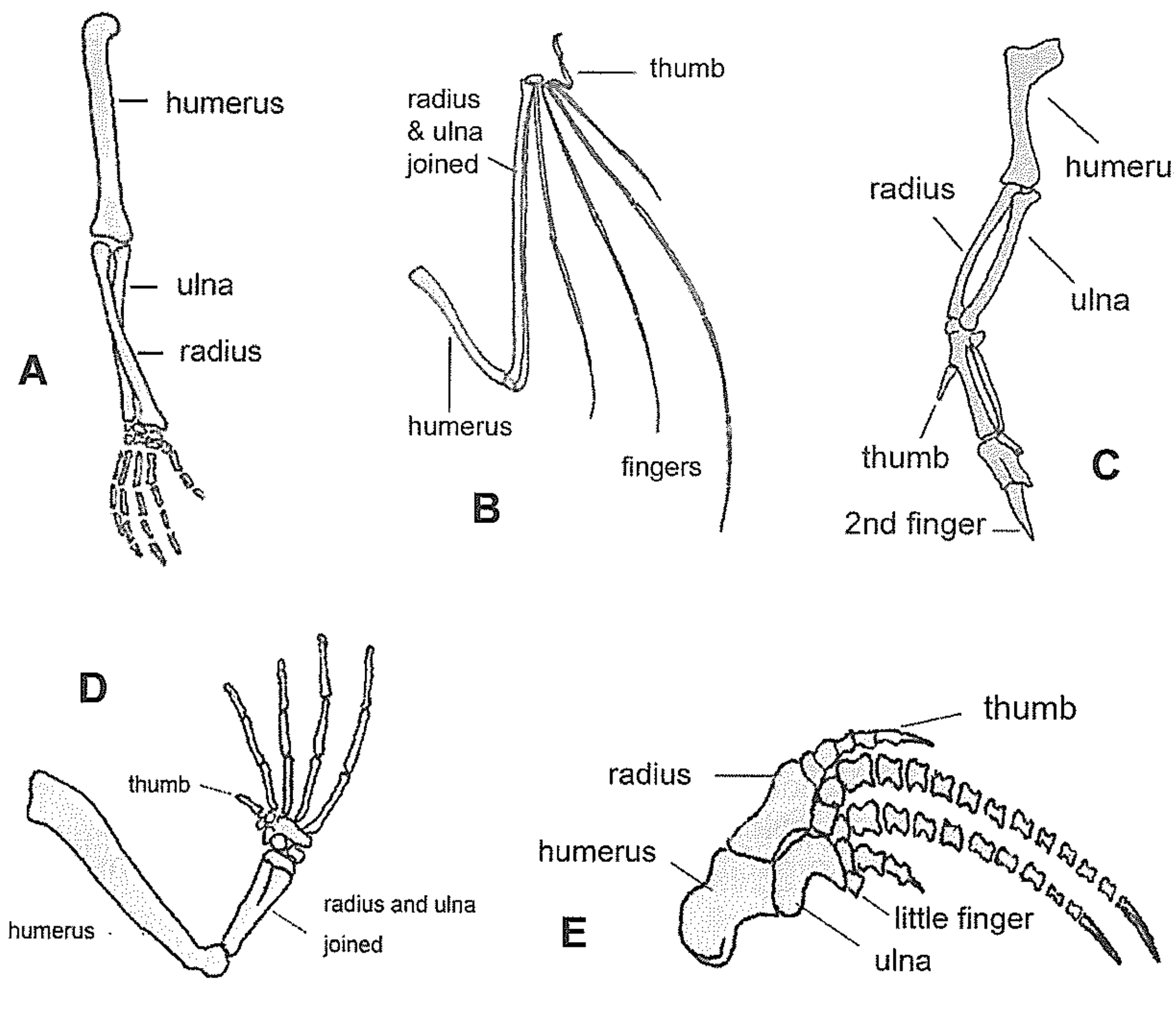
Crocodile embryo **Bird embryo**

The vertebrae in the tails of humans and great apes fail to become bony and disappear except for a few fused bones on the end of the spine. Very rarely, things don't go according to plan and a human baby will be born with two or three vertebrae projecting in a small tail. The tail is easily removed by surgery.

Old patterns, different shapes

A human hand for gripping, a mole's hand for digging, the leg of a horse, the flipper of a porpoise and the wing of a bat—all have the same bones arranged in the same order. Common basic plans can be seen everywhere in nature. The mouthparts of insects all show variations on the same plan. The parts of flowers are also arranged on a common plan.

Such variations on a plan supported Darwin's idea that the different versions of each plan had evolved from the same ancient ancestor.



A. Human arm. **B.** Bat's wing. **C.** Bird's wing. **D.** Frog's leg. **E.** Dolphin's flipper.

What Darwin did not know

The science of genetics scarcely existed in Darwin's time. He died without knowing anything about the laws of inheritance. The greatest weakness of his theory of natural selection was that he could not explain how variations occurred, or how they were inherited. In fact, while Darwin was finishing his book *The Origin of Species*, an Austrian monk, called Gregor Mendel (1822 - 1884), was beginning his experiments on heredity in garden peas, but Darwin was not aware of it.

Although nothing was known about genes at that time, Mendel showed that the characteristics of pea plants must be produced by some sort of inherited particles. He reasoned that the particles remained separate and were passed on in certain ratios during sexual reproduction. Nobody realised the importance of Mendel's work until 1900. After that, the laws of heredity became known as 'Mendelism'.

The early theories of Mendelism and Darwinism grew together to become what is now the foundation of modern biology

Facts and theories

Science deals with evidence and degrees of certainty, not absolute truth. When scientists try to explain something, they start with the explanation that seems best at the time. They call this early explanation a hypothesis. If the hypothesis cannot explain new discoveries, then it may have to be changed or dropped altogether in favour of a different hypothesis. When a hypothesis has continued to explain all new discoveries for a long time, then scientists become content to call it a theory.

So, the word 'theory' has more than one meaning. In everyday language it is used to mean a guess or an untested idea (it's my theory that Joe is scared of Bill). In science, a theory is a hypothesis backed by so much scientific evidence that nobody has been able to find a better explanation. Darwin's theory of evolution by natural selection has been improved over the years to take in new findings, especially from genetics. It now forms one of the foundations of science along with other great theories such as quantum theory and Einstein's theory of relativity.

Today, we cannot learn biology without understanding evolution. It would be like trying to learn astronomy with no mention of gravity. Many things would be described but not much would be explained. This is not to say that scientists no longer argue about evolution. There are great debates about such issues as the importance of small versus large mutations, or the importance of random changes that are not the result of natural selection, or rates of evolution at different times. But this all amounts to fine-tuning of evolutionary theory, not a questioning of the theory itself.

As a final point, bear in mind that the general theory of relativity explains how gravitation works. If Einstein's theory is ever shown to be false, it will not mean the end of gravity. We shall not all start floating off the planet! It will mean that we need a new scientific theory to explain the evidence for gravitation. So it is with evolution.

Section 13 Revision

Circle the best answer:

1. Charles Darwin could not explain heredity because
   a. he knew nothing about genetics
   b. he thought the earth was not old enough
   c. he had not seen enough fossils

2. Charles Darwin's most important book was called
   a. *The Origin of Species*
   b. *Origin of the Species*
   c. *The Origin of the species*

3. In Darwin's understanding, breeders of fancy pigeons
   a. had created new genes
   b. had been careful in selecting birds for breeding
   c. had crossed many different species of pigeon

4. Charles Darwin was aware that
   a. human hands came from bats' wings
   b. flowers and insect mouthparts have the same pattern
   c. a single pattern in nature can be selected for different purposes

5. Vertebrate embryos appear very similar at first because
   a. later developments have been built upon earlier patterns
   b. the species is not fixed until later
   c. They don't have different genes to begin with

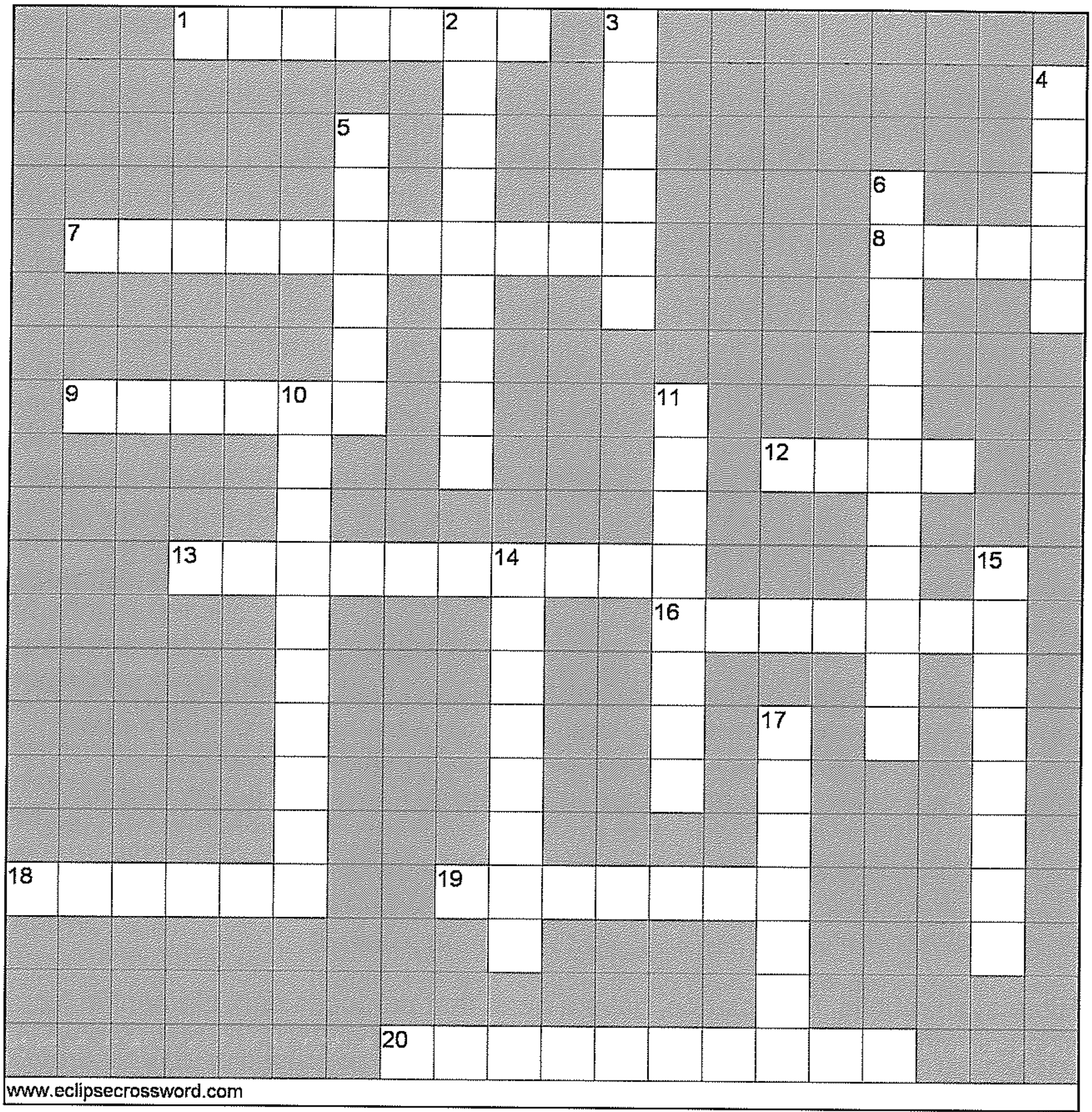
6. Gregor Mendel's detailed records proved to be important because
   a. they made it easier to grow garden peas
   b. they showed the structure of genes
   c. They showed something about how heredity works

7. In science, a hypothesis is
   a. a new discovery
   b. another name for theory
   c. an explanation that might not last long

8. Try to answer the next question in a few words of your own:

In the book referred to in Question 2, Darwin was trying to explain how gun dogs got their particular behaviour. He wrote: "*methodical selection and the inherited effects of compulsory training...would soon complete the work.*" Darwin was partly mistaken. Can you say what he got wrong?

Finally, have a go at the second crossword.



Clues across

1. Coloured and sensitive to light (7)
7. Not much from a cell membrane, but enough to send signals (11)
8. On the evolutionary scale, impossible to imagine (4)
9. The gas that changed the world, thanks to green tissue (6)
12. Provided all the genes of a dog (4)
13. It left our path about six million years ago (10)
16. When different species cross-breed, the young are often in this state (7)
18. Moving on land with no bones? This stuff can make it possible (6)
19. Bacteria manage without one (7)
20. In science, a possible explanation, but not yet a theory (10)

Clues Down

2. The simplest of 'backbones' (9)
3. Earlier features show for a time in this (6)
4. Information in very small sections of a very big molecule (5)
5. His name will always be linked to evolution (6)
6. Natural selection is favouring the most common (11)
10. This has already been the fate of most species on earth (10)
11. The further back you go, the more things share the same (8)
14. This sea creature has eyeballs full of sea water (8)
15. Different species don't share one (4,4)
17. Solid evidence of the past (7)