Edexcel

IGCSE

Biology

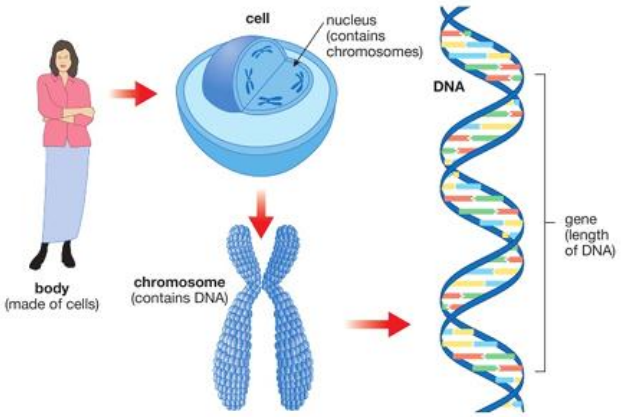
Unit 05

Code (4BI1)

Variation and selection

Chapter 16 – Chromosomes, gens and data

The chemical that is the basis of inheritance in nearly all organisms is **DNA**. DNA is usually found in the nucleus of a cell, in the **chromosomes** (Figure 16.1). A small section of DNA that determines a particular feature is called a **gene**.



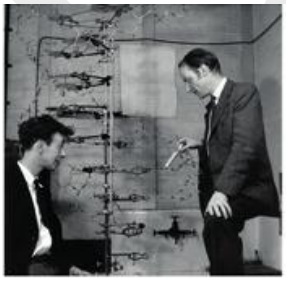
▲ Figure 16.1 Our genetic make-up

THE STRUCTURE OF DNA

Who discovered it?

James Watson and Francis Crick discovered DNA's structure in 1953, earning the Nobel Prize in 1962. However, Rosalind Franklin's research using X-ray diffraction helped them propose DNA's structure, a concept that dates back to earlier times.

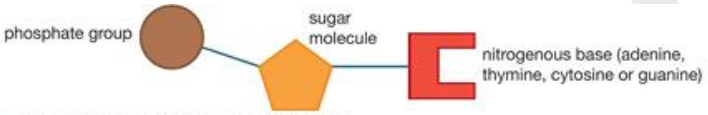
Watson and Crick proposed the double helix structure for DNA using Rosalind Franklin's results. DNA molecules consist of two nucleotides with deoxyribose, phosphate, and base, with four bases: adenine, thymine, cytosine, and guanine.



▲ Figure 16.2 (a) Watson and Crick with their double helix model

▲ Figure 16.2 (b) Rosalind Franklin (1920–1958)

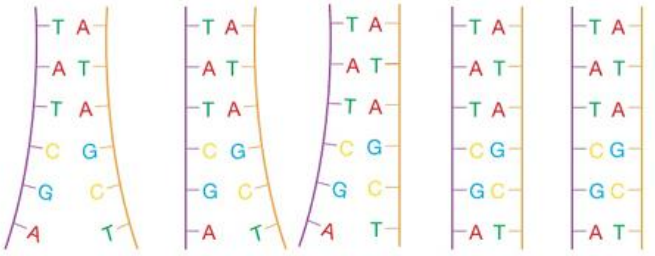
Each nucleotide contains a sugar molecule (deoxyribose), a phosphate group and a nitrogen-containing group called a **base**. There are four bases, adenine (A), thymine (T), cytosine (C) and guanine (G) (Figure 16.3).



▲ Figure 16.3 The structure of a single nucleotide.

DNA replication

When a cell is about to divide (see Mitosis, Chapter 17) it must first make an exact copy of each DNA molecule in the nucleus. This process is called replication. As a result, each cell formed receives exactly the same amount and type of DNA. Figure 16.5 summarises this process.



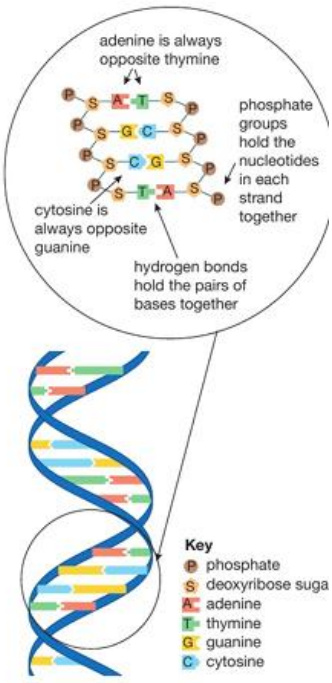
1 The polynucleotide strands of DNA separate.

2 Each strand acts as a template for the formation of a new strand of DNA.

3 DNA polymerase assembles nucleotides into two new strands according to the base-pairing rule.

4 Two identical DNA molecules are formed – each contains a strand from the parent DNA and a new complementary strand.

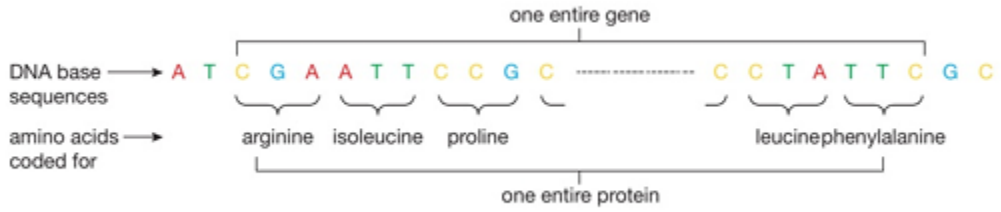
▲ Figure 16.5 How DNA replicates itself.



▲ Figure 16.4 Part of a molecule of DNA.

THE GENETIC CODE

The genetic code consists of two identical DNA molecules, each containing a strand from the parent DNA and a new complementary strand. Only one strand, the template strand, codes for protein manufacture in a cell. Proteins are made of chains of amino acids, with a sequence of three bases in the template strand coding for one amino acid.



▲ Figure 16.6 The triplet code.

THE STAGES OF PROTEIN SYNTHESIS

DNA stays in the nucleus, but protein synthesis takes place in the cytoplasm. This means that for proteins to be made, the genetic code must be copied, and then transferred out of the nucleus to the cytoplasm. This is carried out by a different kind of nucleic acid called **ribonucleic acid (RNA).**

There are three main differences between DNA and RNA:

■DNA is a double helix, RNA is a single strand

■DNA contains the sugar deoxyribose, RNA contains ribose

■RNA contains the base uracil (U) instead of thymine (T).

Two types of RNA take part in protein synthesis:

■**Messenger RNA (mRNA**), which forms a copy of the DNA code

■**Transfer RNA (tRNA**), which carries amino acids to the ribosomes to make the protein.

Protein synthesis takes place in two stages, called **transcription and translation.**

Transcription

Transcription happens in the nucleus. In a chromosome, part of the DNA double helix unwinds and 'unzips', so that the two strands separate, exposing the bases along the template strand (Figure 16.7).

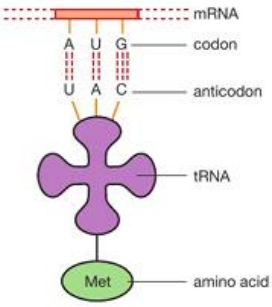
Table 16.1 Base-pairing rules in transcription

Base on DNA	Base on mRNA
G	C
C	G
T	A
A	U

RNA nucleotides form mRNA molecules through bonds between ribose and phosphate groups, creating a sugar-phosphate backbone. After transcription, mRNA leaves DNA and enters the cytoplasm, passing through nuclear membrane pores. The DNA helix zips up again.

Translation

Translation is the process of converting mRNA into a protein at ribosomes. The code consists of sets of three bases called **codons**, each coded for a specific amino acid. The mRNA molecule attaches to a ribosome, and tRNA molecules begin their part with an **anticodon** complementary to the mRNA codon. Each tRNA molecule carries its amino acid to the ribosome.



▲ Figure 16.8 A tRNA molecule with the anticodon UAC, carrying the amino acid methionine.

It happens as follows:

■ The first tRNA to bind at the mRNA does so at the 'start codon', which always has the base sequence AUG. This codes for the amino acid methionine.

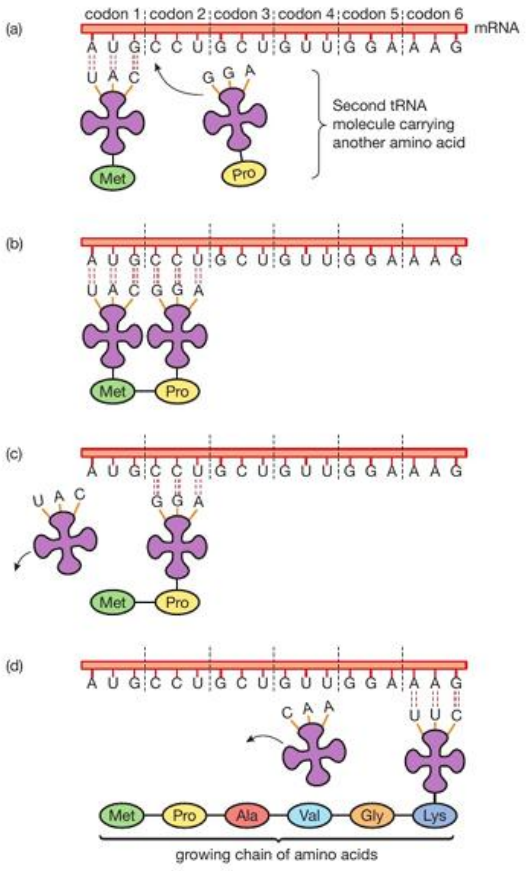
■ Another tRNA brings along a second amino acid. The anticodon of the second tRNA binds to the next codon on the mRNA.

■ A bond forms between the methionine and the second amino acid.

■ The first tRNA molecule is released and goes off to collect another amino acid.

■ More tRNA molecules arrive at the mRNA and add their amino acids to the growing chain, forming a protein.

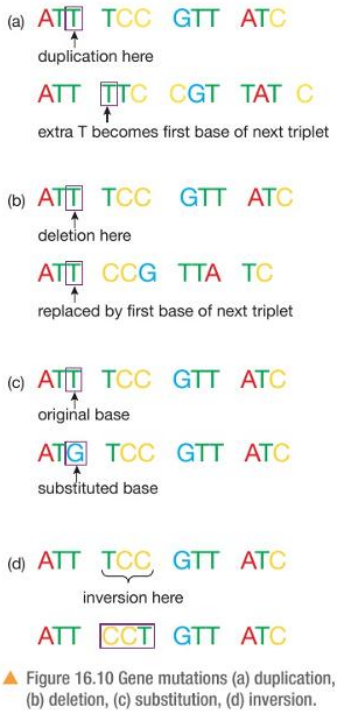
■ At the end of the chain a 'stop codon' tells the translation machinery that the protein is complete, and it is released.



▲ Figure 16.9 Interaction between mRNA and tRNA is the basis of translation

Gene mutations – when DNA makes mistakes

A **mutation** is a change in the DNA of a cell, which can occur in individual genes or whole chromosomes. When DNA is replicating, mistakes are made, leading to a gene mutation that alters the sequence of bases in a gene, causing the gene to code for the wrong amino acid and protein. Gene mutations can occur in various ways, such as duplication, deletion, substitution, or inversions. They can affect body cells, such as the heart, intestines, or skin, and can lead to genetic diseases. Mutations in gametes or cells that divide to form gametes can be passed on to the next generation, but they are lost with the organism when it dies. Some gene mutations can be advantageous to an individual, such as insects becoming resistant to insecticides or bacteria becoming resistant to antibiotics. This is an example of **natural selection.**



▲ Figure 16.10 Gene mutations (a) duplication, (b) deletion, (c) substitution, (d) inversion.

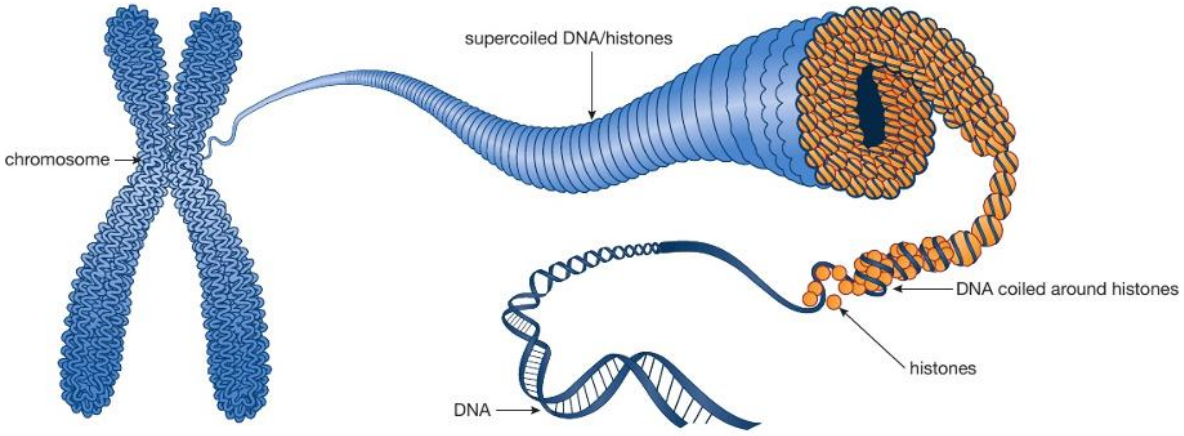
Gene mutations are random events that occur in all organisms. The rate at which they occur can be increased by a number of agents called mutagens. Mutagens include:

■ionising radiation (such as ultraviolet light, X-rays and gamma rays)

■chemicals including mustard gas and nitrous oxide, and many of the chemicals in cigarette smoke and the tar from cigarettes.

THE STRUCTURE OF CHROMOSOMES

Each chromosome contains one double-stranded DNA molecule. The DNA is folded and coiled so that it can be packed into a small space. The DNA is coiled around proteins called histones (Figure 16.11).



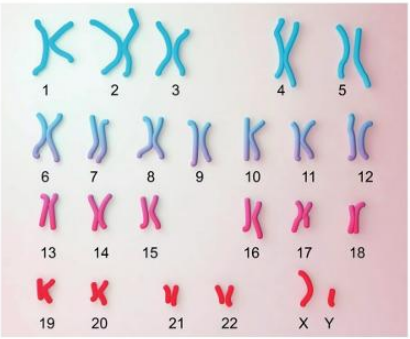
▲ Figure 16.11 The structure of a chromosome

Because a chromosome contains a particular DNA molecule, it will also contain the genes that make up that DNA molecule. Another chromosome will contain a different DNA molecule, and so will contain different genes.

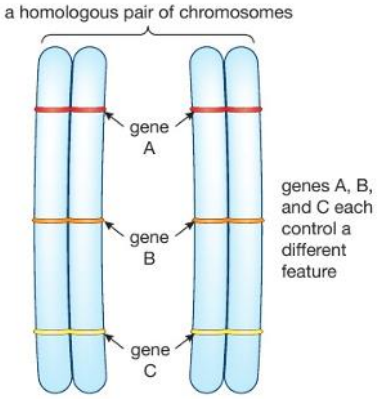
How many chromosomes?

Nearly all human cells contain 46 chromosomes. The photographs in Figure 16.12 show the 46 chromosomes from the body cells of a human male.

Pairs of matching chromosomes are called **homologous pairs**. They carry genes for the same features, and these genes are arranged at the same positions and sequence along the chromosome (Figure 16.13). Cells with chromosomes in pairs like this are **diploid** cells.



◀ Figure 16.12 A man's chromosomes. One of each of the 22 homologous pairs are shown, along with the X and Y sex chromosomes. A woman's chromosomes are the same, except that she has two X chromosomes. A picture of all the chromosomes in a cell is called a karyotype.



▲ Figure 16.13 Both chromosomes in a homologous pair have the same sequence of genes.

Not all human cells have 46 chromosomes. Red blood cells have no nucleus and so have none. Sex cells have only 23 - just half the number of other cells. They are formed by a cell division called **meiosis** (see Chapter 17). Each cell formed has one chromosome from each homologous pair, and one of the sex chromosomes. Cells with only half the normal diploid number of chromosomes, and therefore only half the DNA content of other cells, are **haploid** cells.

When two gametes fuse in **fertilisation**, the two nuclei join to form a single diploid cell (a **zygote**). This cell has, once again, all its chromosomes in homologous pairs and two copies of every gene. It has the normal DNA content.

How many genes?

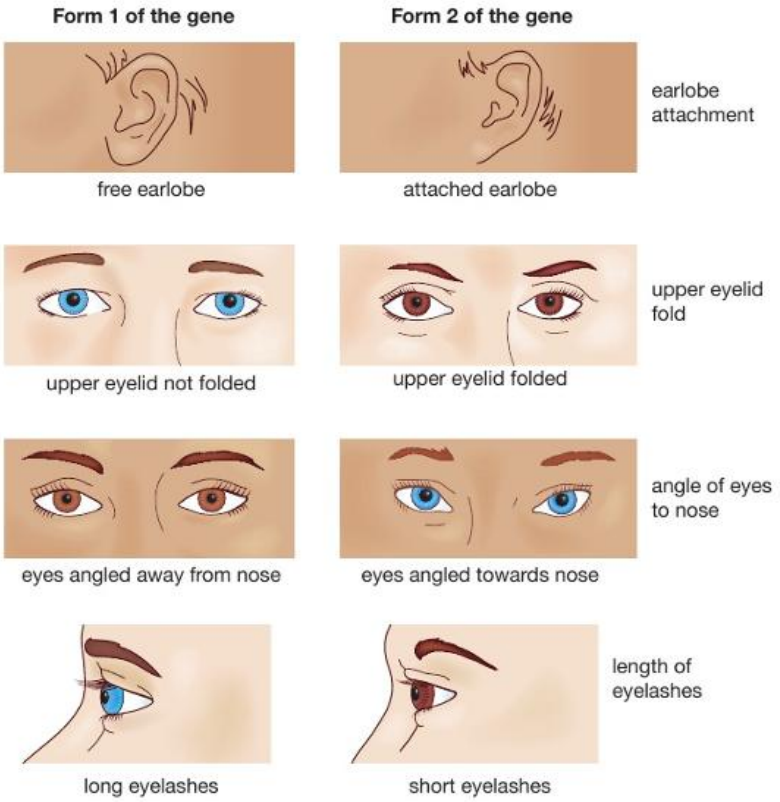
The entire DNA of an organism (the amount present in a diploid cell) is known as its genome. The human genome is made up of about 3.2 billion base pairs. One of the surprise discoveries of modern molecular biology is that only a small fraction of the genome consists of protein-coding genes.

Genes and alleles

Genes are sections of DNA that control the production of proteins in a cell. Each protein contributes towards a particular body feature. Sometimes the feature is visible, such as eye colour or skin pigmentation. Sometimes the feature is not visible, such as the type of haemoglobin in red blood cells or the type of blood group antigen on the red blood cells.

The gene for earlobe attachment has the forms 'attached earlobe' and 'free earlobe'. These different forms of the gene are called **alleles**.

Some genes have more than one form. For example, the genes controlling several facial features have alternative forms, which result in alternative forms of the feature (Figure 16.14).



▲ Figure 16.14 The alternate forms of four facial features

Chapter 17 – Cell division

Only in the sex organs is cell division different. Here, some cells divide to produce gametes (sex cells), which contain only half the original number of chromosomes. This is so that when male and female gametes fuse together (fertilisation) the resulting cell (called a **zygote**) will contain the full set of chromosomes and can then divide and grow into a new individual.

Human body cells are **diploid** - they have 46 chromosomes in 23 homologous pairs. The gametes, with 23 chromosomes (one copy of each homologous chromosome), are **haploid** cells.

There are two kind of cell division: **mitosis and meiosis**. When cells divide by mitosis, two cells are formed. These have the same number and type of chromosomes as the original cell.

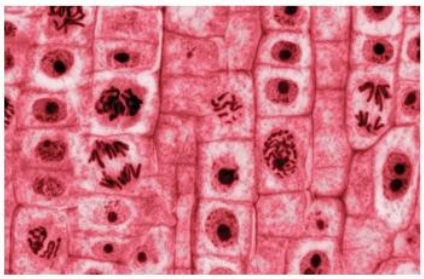
MITOSIS

When a 'parent' cell divides it produces 'daughter' cells. Mitosis produces two daughter cells that are genetically identical to the parent cell - both daughter cells have the same number and type of chromosomes as the parent cell. To achieve this, the dividing cell must do two things.

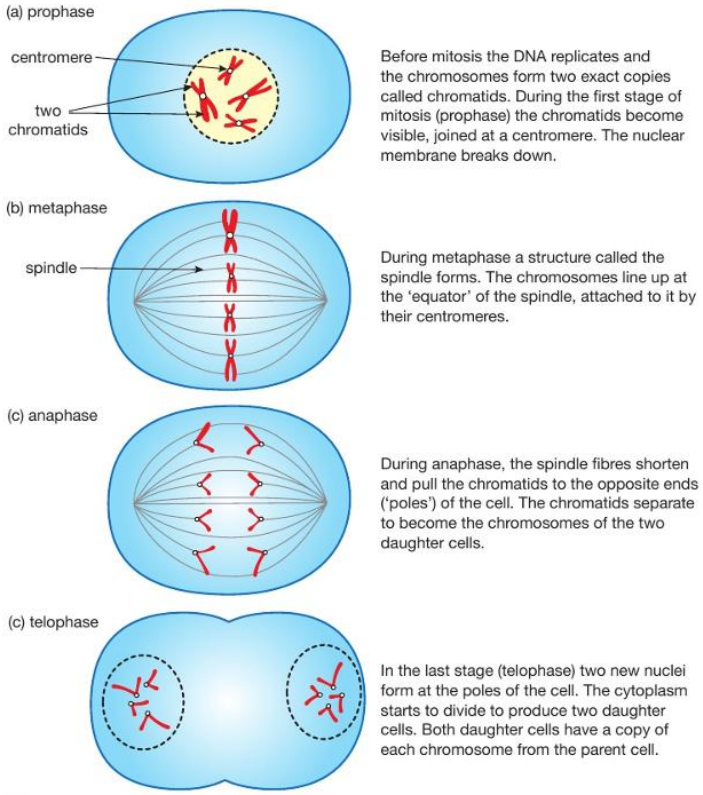
■It must copy each chromosome before it divides. This involves the DNA replicating and more proteins being added to the structure. Each daughter cell will then be able to receive a copy of each chromosome (and each molecule of DNA) when the cell divides.

■It must divide in such a way that each daughter cell receives one copy of every chromosome. If it does not do this, both daughter cells will not contain all the genes.

A number of distinct stages occur when a cell divides by mitosis. These are shown in Figure 17.1. Figure 17.2 is a photograph of some cells from the root tip of an onion. Cells in this region of the root divide by mitosis to allow growth of the root.



▲ Figure 17.2 Cells in the root tip of an onion dividing by mitosis. Can you identify any of the stages shown in Figure 17.1?



▲ Figure 17.1 The stages of mitosis. For simplicity the cell shown contains two homologous pairs of chromosomes (one long pair, one short). (You do not need to remember the names of the stages.)

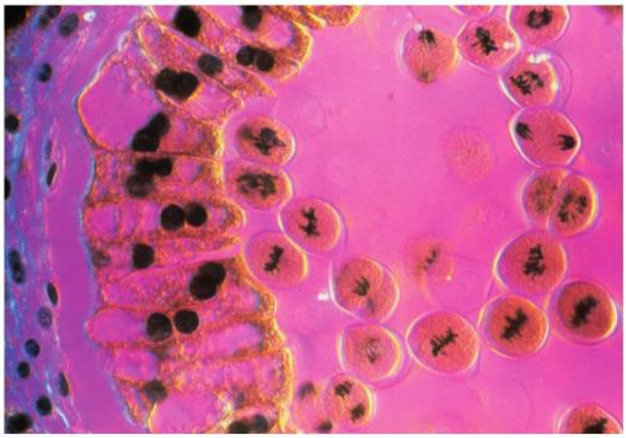
Whenever cells need to be replaced in our bodies, cells divide by mitosis to make them. This happens more frequently in some regions than in others.

- The skin loses thousands of cells every time we touch something. This adds up to millions every day that need replacing. A layer of cells beneath the surface is constantly dividing to produce replacements.

- Cells are scraped off the lining of the gut as food passes along. Again, a layer of cells beneath the gut lining is constantly dividing to produce replacement cells.
- Cells in our spleen destroy worn out red blood cells at the rate of 100 000 000 000 per day! These are replaced by cells in the bone marrow dividing by mitosis. In addition, the bone marrow forms all our new white blood cells and platelets.
- Cancer cells also divide by mitosis. The cells formed are exact copies of the parent cell, including the mutation in the genes that makes the cells divide uncontrollably.

MEIOSIS

Meiosis forms gametes. It is a more complex process than mitosis and takes place in two stages called meiosis I and meiosis II, resulting in four haploid cells. Each daughter cell is genetically different from the other three and from the parent cell.



▲ Figure 17.3 Photomicrograph of an anther showing cells dividing by meiosis.

During meiosis the parent cell must do two things:

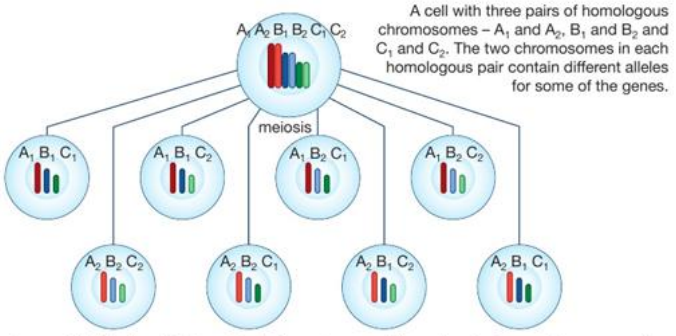
■It must copy each chromosome so that there is enough genetic material to be shared between the four daughter cells

■It must divide twice, in such a way that each daughter cell receives just one chromosome from each homologous pair.

These processes are summarised in Figure 17.4. Figure 17.3 shows cells in the anther of a flower dividing by meiosis.

There are two main events during meiosis:

- during the first division, one chromosome from each homologous pair goes into each daughter cell
- during the second division, the chromosome separates into two parts. One part goes into each daughter cell.



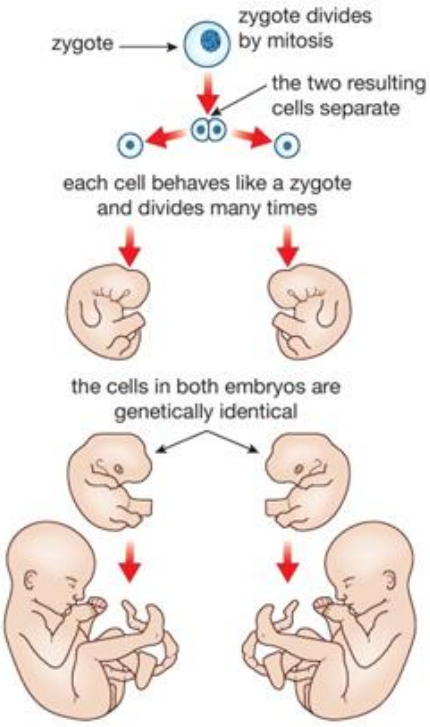
As a result of the two divisions of meiosis, each sex cell formed contains one chromosome from each homologous pair. This gives eight combinations. As A_1 and A_2 contain different alleles (as do B_1 and B_2, and C_1 and C_2) the eight possible sex cells will be genetically different.

▲ Figure 17.5 How meiosis produces variation

The gametes formed by meiosis don't all have the same combinations of alleles - there is genetic variation in the cells. During the two cell divisions of meiosis, the chromosomes of each homologous pair are shared between the two daughter cells independently of each of the other homologous pairs. This allows for much possible genetic variation in the daughter cells (Figure 17.5).

Table 17.1 Comparison of meiosis and mitosis.

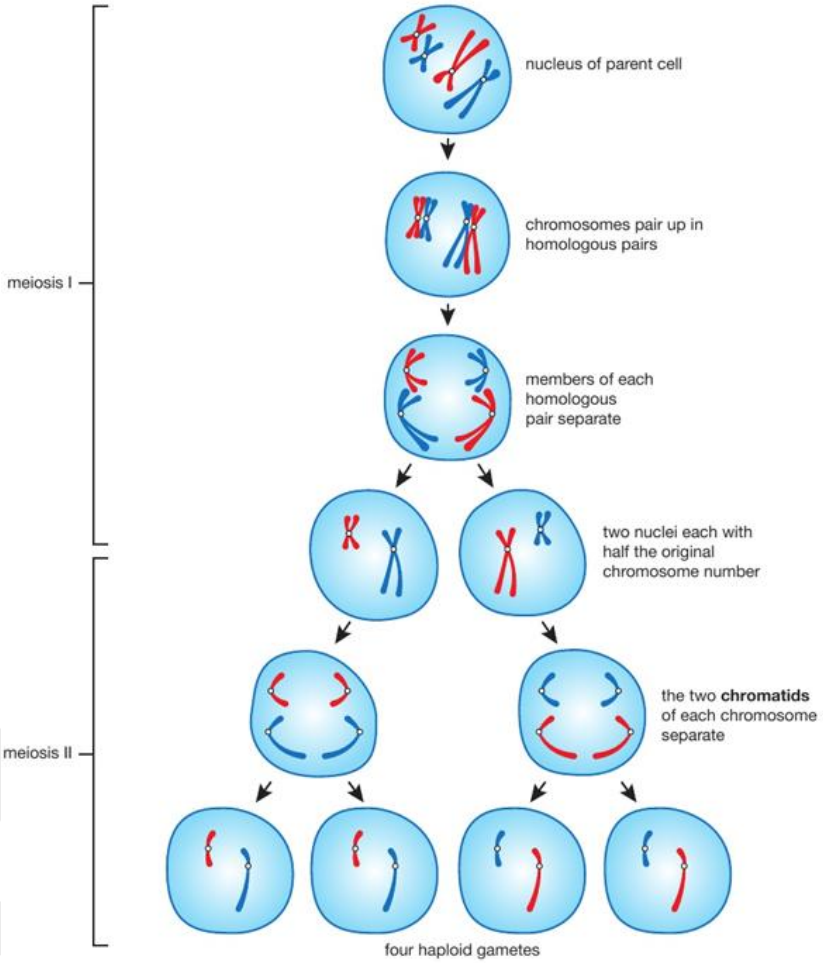
Feature of the process	Mitosis	Meiosis
Chromosomes are copied before division begins	Yes	Yes
Number of cell divisions	One	Two
Number of daughter cells produced	Two	Four
Daughter cells are haploid or diploid	Diploid	Haploid
Genetic variation in the daughter cells	No	Yes



▲ Figure 17.6 How identical twins are formed

Sexual reproduction

Sexual reproduction in multicellular organisms involves fusion of two gametes to form a zygote, resulting in genetic variation due to the large variation in gametes and the random nature of fertilisation. In humans, any sperm from a male could potentially fertilize any ova from a female. The number of possible combinations of chromosomes and genes in a zygote is 72 trillion, making every individual likely to be genetically unique. Identical twins, formed from the same zygote, are the only exceptions.

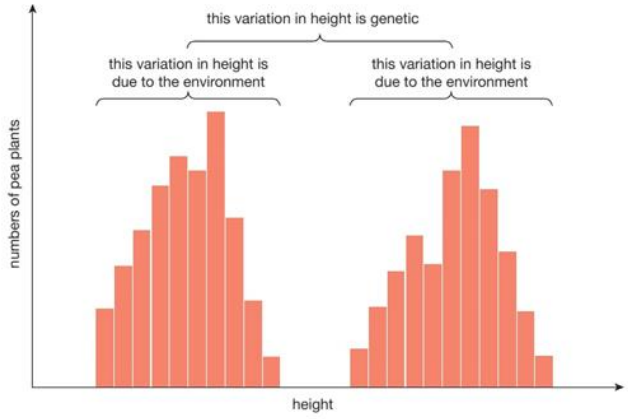


▲ Figure 17.4: The stages of meiosis. For simplicity the parent cell contains only two homologous pairs of chromosomes (one long pair, one short). To help you to see what happens, one member of each pair is coloured red and one blue. The cell membrane is shown, but the nuclear membrane has been omitted. A spindle forms during each division, but these have also been omitted for clarity.

ASEXUAL REPRODUCTION AND CLONING

Plant breeders have long understood that sexual reproduction produces variation, and modern techniques allow for the production of thousands of identical plants from a few cells. Asexual reproduction, on the other hand, involves a part of an organism growing and breaking away from the parent organism, producing offspring genetically identical to the parent and each other.

GENES AND ENVIRONMENT BOTH PRODUCE VARIATION



▲ Figure 17.7 Bar chart showing variation in height of pea plants.

There are two varieties of pea plants that are either tall or short. This difference in height is due to the genes they inherit. There are no 'intermediate height' pea plants. However, all the tall pea plants are not exactly the same height and neither are all the short pea plants exactly the same height. Figure 17.7 illustrates the variation in height of pea plants.

Several environmental factors can influence the height of the plants.

- They may not all receive the same amount of light and so some will not photosynthesise as well as others.
- They may not all receive the same amount of water and mineral ions from the soil - this could affect the manufacture of a range of substances in the plant.
- They may not all receive the same amount of carbon dioxide. Again, some plants will not photosynthesise as well as others.

Chapter 18 – Genes and heritance

GREGOR MENDEL

Gregor Mendel was a monk who lived in a monastery in Brno in what is now the Czech Republic (Figure 18.1). He became interested in the science of heredity, and carried out hundreds of breeding experiments using pea plants. From his research Mendel was able to explain the laws governing inheritance. Mendel found that for every feature or 'character' he investigated:

■a 'heritable unit' (what we now call a gene) is passed from one generation to the next

■the heritable unit (gene) can have alternative forms (we now call these different forms alleles)

■each individual must have two alternative forms (alleles) per feature

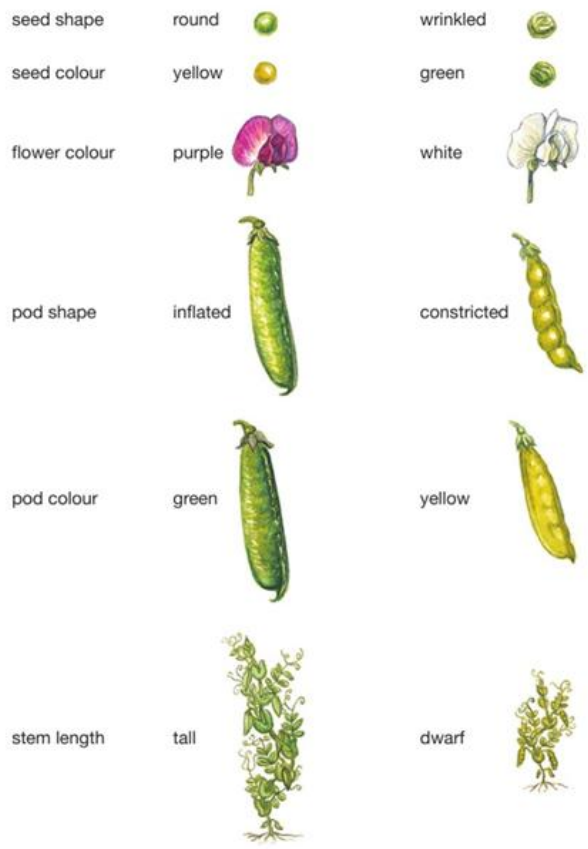
■the gametes only have one of the alternative forms (allele) per feature

■one allele can be dominant over the other.

Mendal's experiments on inheritance

Mendel noticed that many of the features of pea plants had two alternative forms. For example, plants were either tall or very short (called a 'dwarf' variety); they either had purple or white flowers; they produced yellow seeds or green seeds. There were no intermediate forms, no pale purple flowers or green/yellow seeds or intermediate height plants. Figure 18.2 shows some of the contrasting features of pea plants that Mendel used in his breeding experiments.

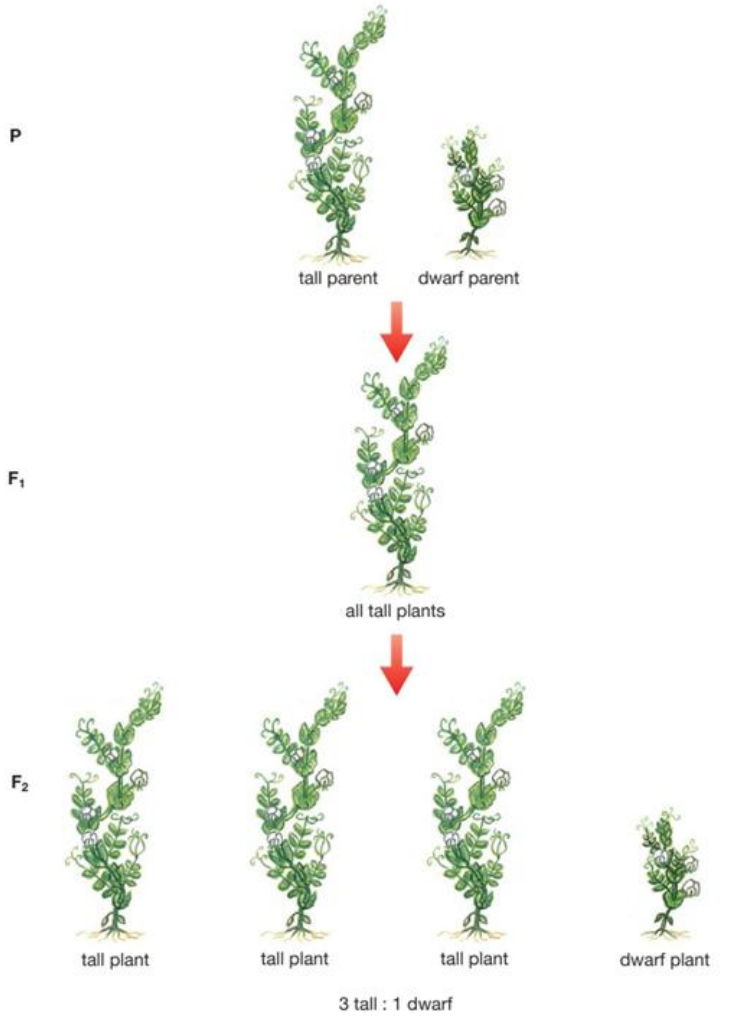
He collected all the seeds formed, grew them and noted the features that each plant developed. These plants were the first generation of offspring, called the **F1 generation**. He did not cross-pollinate these plants, but allowed them to self-fertilise. Again, he collected the seeds, grew them and noted the features that each plant developed. These plants formed the second generation of offspring or **F2 generation**. When Mendel used pure-breeding tall and pure-breeding dwarf plants as his parents, he obtained the results shown in Figure 18.3.



▲ Figure 18.2 Some features of pea plants used by Mendel in his breeding experiments.

Mendel obtained similar results when he carried out breeding experiments using plants with other pairs of contrasting characters (Figure 18.4). He noticed two things in particular.

- All the plants of the F, generation were of one type. This type was not a blend of the two parental features, but one or the other.
- There was always a 3:1 ratio of types in the F2 generation. Three-quarters of the plants in the F2 generation were of the type that appeared in the F, generation. One-quarter showed the other parental feature.

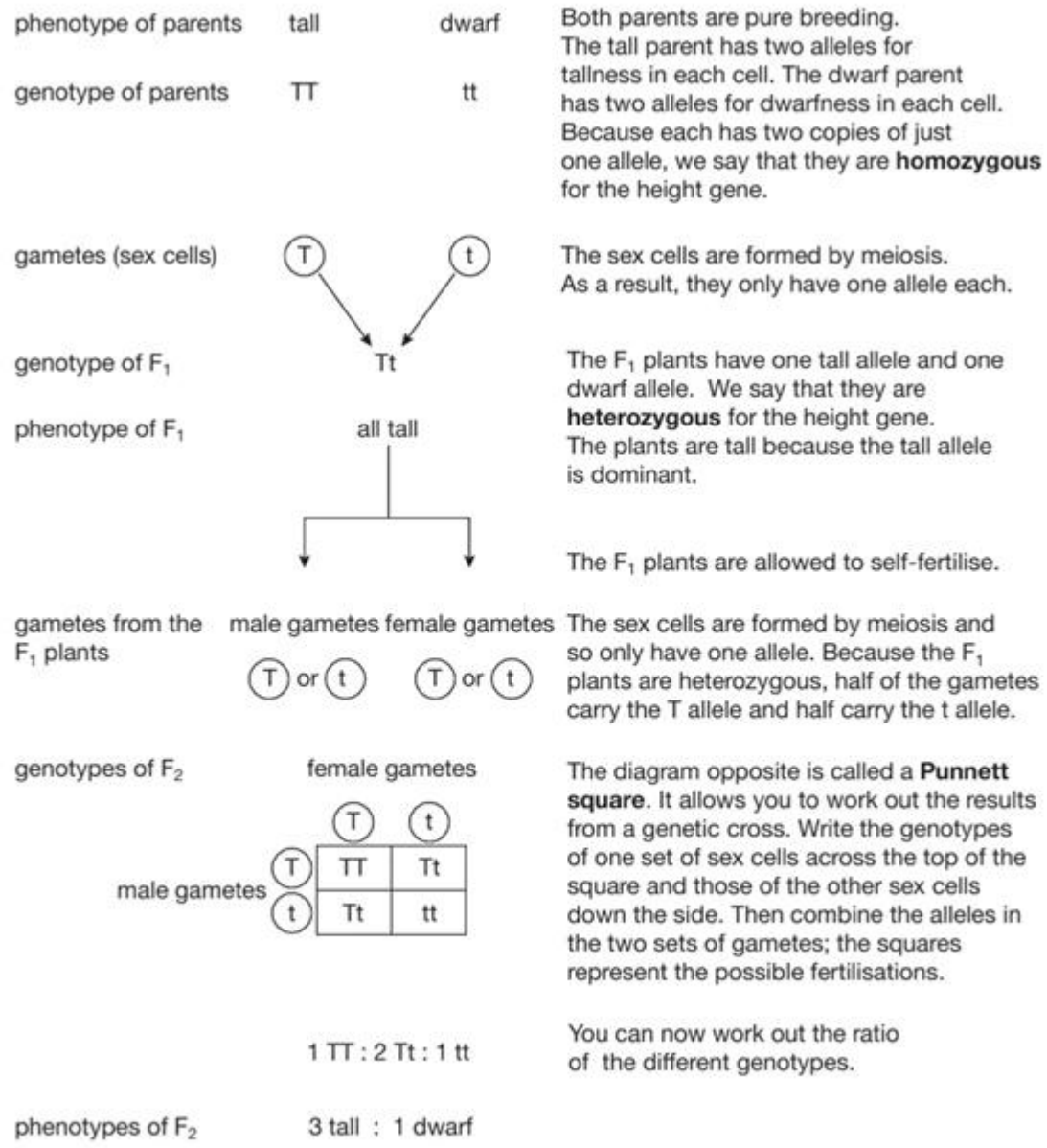


▲ Figure 18.3 A summary of Mendel's results from breeding tall pea plants with dwarf pea plants.

Explaining mendel's result

- Each feature is controlled by a gene, which is found on a chromosome.
- There are two copies of each chromosome and each gene in all body cells, except the gametes.
- The gametes have only one copy of each chromosome and each gene (i.e. one allele).
- There are two alleles of each gene.
- One allele is **dominant** over the other allele, which is **recessive**.
- When two different alleles (one dominant and one recessive) are in the same cell, only the dominant allele is expressed (shown in the appearance of the organism).
- An individual can have two dominant alleles, two recessive alleles or a dominant allele and a recessive allele in each cell.

The term genotype describes the alleles each cell has for a certain feature (e.g. TT). The **phenotype** is the feature that results from the **genotype** (e.g. a tall plant).

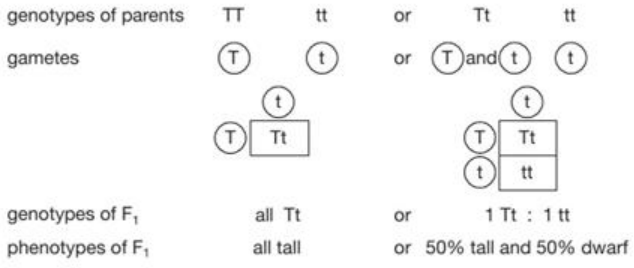


▲ Figure 18.4 Results of crosses using true-breeding tall and dwarf pea plants.

Working out genotypes – the test cross

You cannot tell just by looking at a tall pea plant whether it is **homozygous** (TT) or **heterozygous** (Tt). Both these genotypes would appear equally tall because the tall allele is dominant.

If you don't know the genotypes of the parents, the only way you can find out is by carrying out a breeding experiment called a **test cross**.



▲ Figure 18.5 A test cross

WAYS OF PRESENTING GENETIC INFORMATION

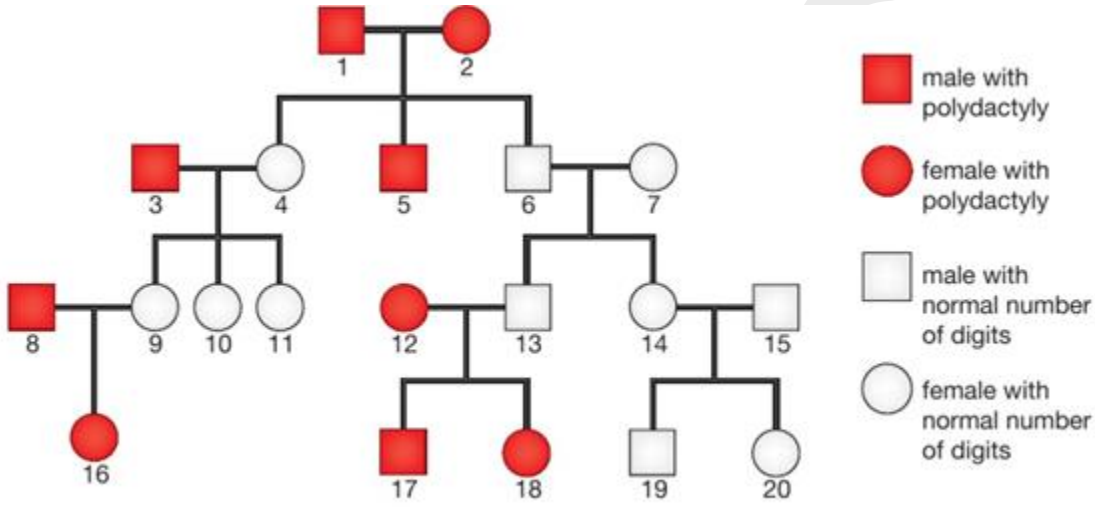
Writing out a genetic cross is a useful way of showing how genes are passed through one or two generations, starting from the parents. To show a family history of a genetic condition requires more than this. We can use a diagram called a pedigree.

If we use the symbol D for the polydactyly allele and d for the normal-number allele, the possible genotypes and phenotypes are:

■DD - person has polydactyly (has two dominant polydactyly alleles)

■Dd-person has polydactyly (has a dominant polydactyly allele and a recessive normal allele)

■dd - person has the normal number of digits (has two recessive, normal- number alleles).



▲ Figure 18.6 A pedigree showing the inheritance of polydactyly in a family.

We can extract a lot of information from a pedigree. In this case:

■there are four generations shown (individuals are arranged in four horizontal lines)

■individuals 4, 5 and 6 are children of individuals 1 and 2 (a family line connects each one directly to 1 and 2)

■individual 4 is the first-born child of 1 and 2 (the first-born child is shown to the left, then second born to the right of this, then the third born and so on)

■individuals 3 and 7 are not children of 1 and 2 (no family line connects them directly to 1 and 2)

■individuals 3 and 4 are father and mother of the same children - as are 1 and 2, 6 and 7, 8 and 9, 12 and 13, 14 and 15 (a horizontal line joins them).

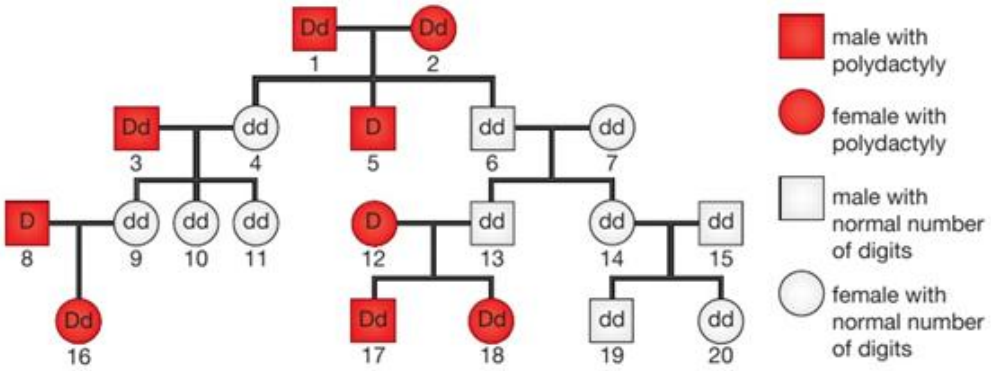
It is usually possible to work out which allele is dominant from a pedigree. You look for a situation where two parents show the same feature and at least one child shows the contrasting feature. In Figure 18.6, individuals 1 and 2 both have polydactyly, but children 4 and 6 do not. There is only one way to explain this:

■the normal alleles in 4 and 6 can only have come from their parents (1 and 2), so 1 and 2 must both carry normal alleles

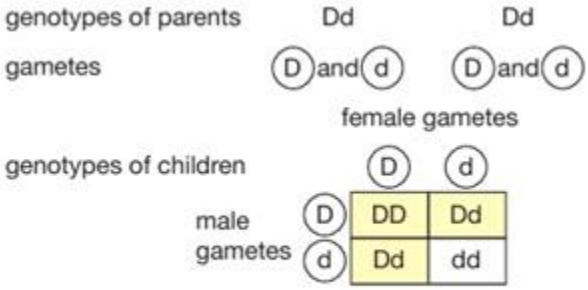
■1 and 2 show polydactyly, so they must have polydactyly alleles as well

■if they have both polydactyly alleles and normal alleles but show polydactyly, the polydactyly allele must be the dominant allele.

We can now add this genetic information to the pedigree. This is shown in Figure 18.7.



▲ Figure 18.7 A pedigree showing the inheritance of polydactyly in a family, with details of genotypes added.



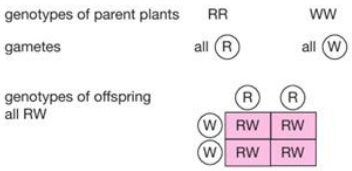
▲ Figure 18.8 Possible outcomes from a genetic cross between two parents, both heterozygous for polydactyly.

CODOMINANCE

So far, all the examples of genetic crosses that we have seen involve complete dominance, where one dominant allele completely hides the effect of a second, or recessive allele. However, there are many genes with alleles that both contribute to the phenotype. If two alleles are expressed in the same phenotype, they are called **codominant**.

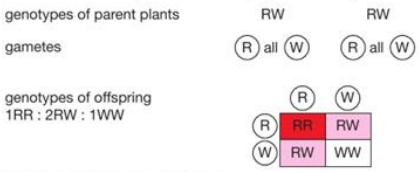
▲ Figure 18.9 Flower colours in snapdragons are caused by a gene showing codominance.

Figure 18.10 shows the cross between the parent plants. Note that the alleles for red and white flowers are given *different* letters, since one is not dominant over the other.



▲ Figure 18.10 Crossing red-flowered snapdragons with white-flowered plants produces a third phenotype, pink.

When pink-flowered plants are crossed together, all three phenotypes reappear, in the ratio 1 red : 2 pink : 1 white (Figure 18.11).

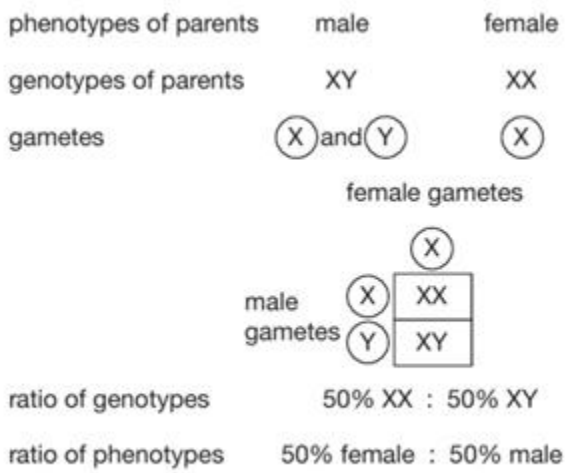


▲ Figure 18.11 Crossing pink-flowered snapdragons

SEX DETERMINATION

Our sex - whether we are male or female - is not under the control of a single gene. It is determined by the X and Y chromosomes - **the sex chromosomes.** As well as the 44 non-sex chromosomes, there are two X chromosomes in all cells of females (except the egg cells) and one X and one Y chromosome in all cells of males (except the sperm). Our sex is effectively determined by the presence or absence of the Y chromosome.

The inheritance of sex follows the pattern shown in Figure 18.12. In any one family, however, this ratio may well not be met. Predicted genetic ratios are usually only met when large numbers are involved. The overall ratio of male and female births in all countries is 1:1.



▲ Figure 18.12 Determination of sex in humans

POLYGENIC INHERITANCE

All of the genetic crosses that you have seen in this chapter have been examples of inheritance involving single genes. The reason for this is that it is easier to draw genetics diagrams and explain what is happening if we start by considering alleles of a single gene. However, many characteristics are controlled by two or more genes working together. This is called **polygenic inheritance.**

Other human characteristics determined by several genes (**polygenes**) are human height and body mass (weight).

▲ Figure 18.13 Skin colour depends on the amount of melanin in the skin. It is a result of polygenic inheritance.

Chapter 19 – Natural selection and evolution

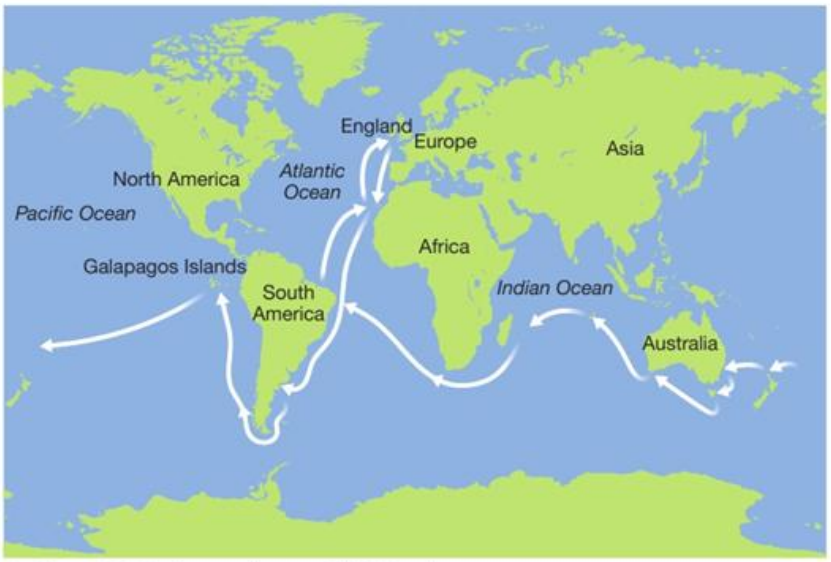
The meaning of **'evolution'** is that species of animals and plants are not fixed in their form, but change over time. It is not a new idea. For thousands of years philosophers have discussed this theory. By the beginning of the nineteenth century there was overwhelming evidence for evolution, and many scientists had accepted that it had taken place. What was missing was an understanding of the mechanism by which evolution could have occurred.

The person who proposed the mechanism for evolution that is widely accepted today was the English biologist Charles Darwin (Figure 19.1). He called the mechanism **natural selection.**

THE WORK OF CHARLES DARWIN

Charles Darwin was the son of a country doctor. He did not do particularly well at school or university and was unable to decide on a profession. His father is supposed to have said: 'you're good for nothing but shooting guns and rat- catching... you'll be a disgrace to yourself and all of your family'. He was wrong - Darwin went on to become one of the most famous scientists of all time!

At the age of 22, Charles Darwin became the unpaid biologist aboard the survey ship HMS Beagle, which left England for a five-year voyage in 1831 (Figure 19.2).



▲ Figure 19.2 The five-year journey of HMS *Beagle*

On his return to England, Darwin began to evaluate his data and wrote several essays, introducing the ideas of natural selection. He arrived at his theory of natural selection from observations made during his voyage on HMS Beagle and from deductions made from those observations. Darwin's observations were that:

■organisms generally produce more offspring than are needed to replace them - a single female salmon can release 5 million eggs per year; a giant puffball fungus produces 40 million spores

■despite this over-reproduction, stable, established populations of organisms generally remain the same size - the seas are not overflowing with salmon, and we are not surrounded by lots of giant puffball fungi!

■members of the same species are not identical - they show variation.

He made two important deductions from these observations.

■From the first two observations he deduced that there is a 'struggle for existence'. Many offspring are produced, yet the population stays the same size. There must be competition for resources and many individuals must die.

■From the third observation he deduced that, if some offspring survive whilst others die, those organisms best suited to their environment would survive to reproduce. Those less suited will die. This gave rise to the phrase 'survival of the fittest'.

SOME EXAMPLES OF HOW NATURAL SELECTION MIGHT HAVE WORKED

The hoverfly

Figure 19.4 shows two insect species, a wasp and a hoverfly. Wasps have a sting and yellow and black stripes, a 'warning colouration' that predators like birds avoid. Hoverflies, on the other hand, do not have a sting but have a similar appearance, mimicking a wasp's sting. This evolution can be explained by natural selection, where mutations led to the development of stripes in hoverflies, allowing them to survive predators and reproduce.

▲ Figure 19.4 Two insects showing 'warning colouration'. (a) A wasp, which has a sting. (b) A harmless hoverfly.

The polar bear

Polar bears have many adaptations that suit them to their habitat. These include:

- a thick layer of white fur, which reduces heat loss and acts as camouflage in the snow
- wide, large paws. These help with walking in the snow, and are used for swimming
- strong, muscular legs - a bear can swim continuously in the cold Arctic waters for days
- nostrils that close when the bear is swimming under water
- a large body mass. Polar bears are the largest bears on Earth. An adult male averages 350 to 550 kilograms, and the record is over 1000 kilograms. This large size results in the animal having a small surface area to volume ratio, which reduces heat loss
- a 10 centimetre thick layer of insulating fat under the skin
- a well developed sense of smell - used to detect the bear's prey
- bumps on the pads of the paws to provide grip on the ice
- short, powerful claws, which also provide grip, and are needed for holding the heavy prey.

CAN WE OBSERVE NATURAL SELECTION IN ACTION?

Most animals and plants reproduce slowly, so it takes a long time for natural selection to have an observable effect. To observe natural selection happening we can study organisms that reproduce quickly, such as bacteria or insects.

Antibiotics resistance in bacteria

Alexander Fleming discovered the first antibiotic in 1929. It is made by the mould **Penicillium** and is called penicillin. Penicillin kills bacteria, and was first used to treat bacterial infections in the 1940s. Since then other natural antibiotics have been discovered, and many more have been chemically synthesised in laboratories. The use of antibiotics has increased dramatically, particularly over the last 20 years. We now almost expect to be given an antibiotic for even the most minor of ailments.

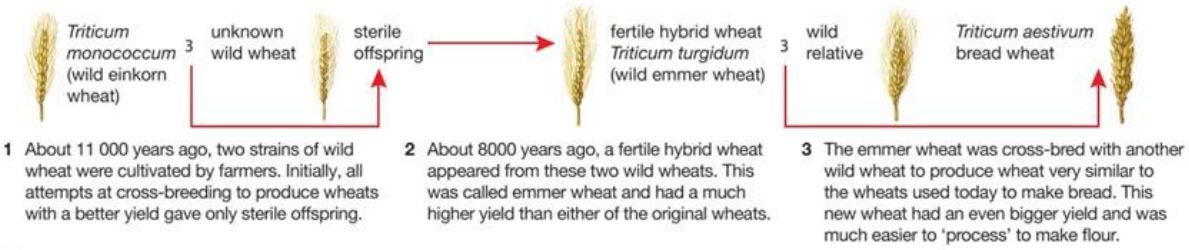
Chapter 20 – Selective breeding

Selective breeding is best described as the breeding of only those individuals with desirable features. It is sometimes called 'artificial selection', as human choice, rather than environmental factors, is providing the selection pressure (compare this with natural selection, described in Chapter 19).

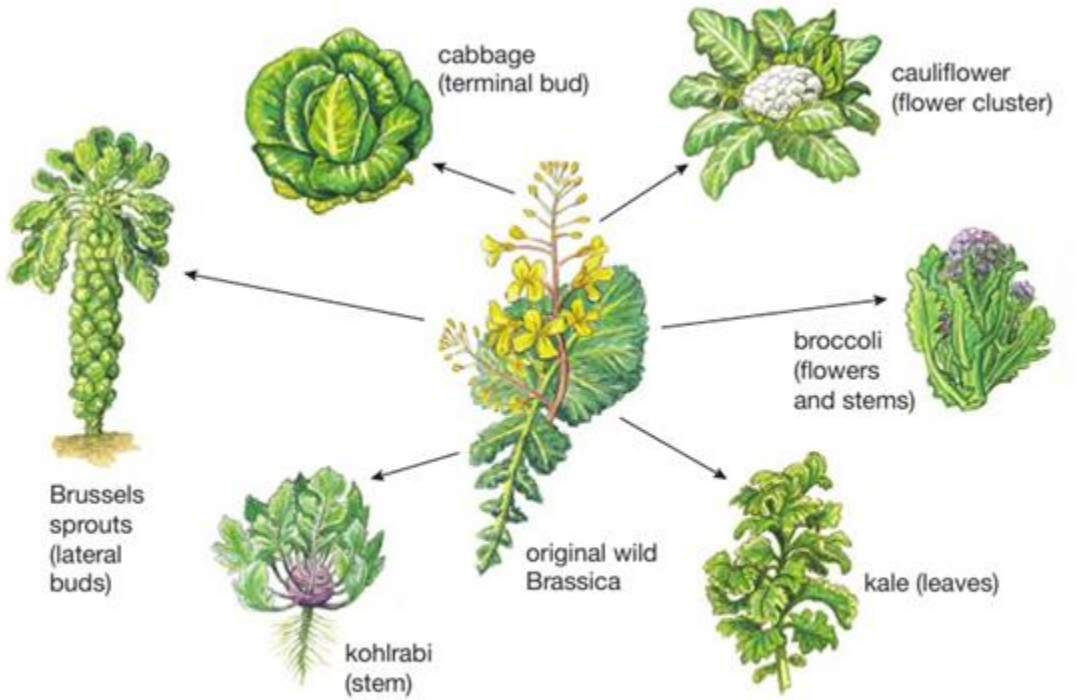
TRADITIONAL SELECTIVE BREEDING

Plants

Traditionally, farmers have bred crop plants of all kinds to obtain increased yields. Probably the earliest example of selective breeding was the cross- breeding of strains of wild wheat. The aim was to produce wheat with a much increased yield of grain and with shorter, stronger stems (Figure 20.1). This wheat was used to make bread.



▲ Figure 20.1 Modern wheat is the result of selective breeding by early farmers.



▲ Figure 20.2 Selectively breeding the original wild brassica plants to enhance certain features has produced several familiar vegetables.

parsnips are also the result of selective breeding programmes. Crop plants are bred to produce strains that:

■give higher yields

■are resistant to certain diseases (the diseases would reduce the yields)

■are resistant to certain insect pest damage (the damage would reduce the yield)

■are hardier (so that they survive in harsher climates or are productive for longer periods of the year)

■have a better balance of nutrients in the crop (for example, plants that contain more of the types of amino acids needed by humans).

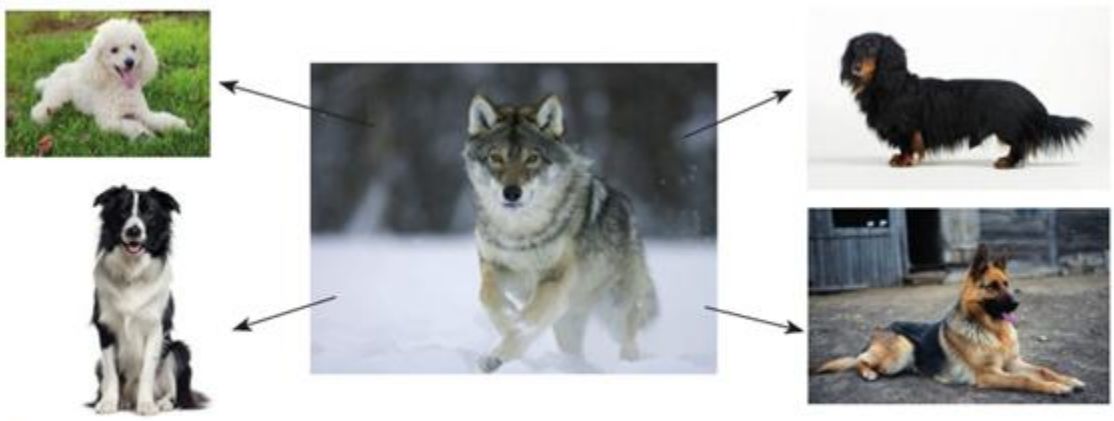
▲ Figure 20.3 Selective breeding can reduce damage by pests. The plants on the right have been bred to be resistant to a fungal pest. Plants on the left are not resistant to the pest.

Animals

Farmers have bred stock animals for similar reasons to the breeding of crops. They have selected for animals that:

- produce more meat, milk or eggs
- produce more fur or better quality fur
- produce more offspring
- show increased resistance to diseases and parasites.

Since about 1950, the technique of **artificial insemination (AI)** has become widely available. Bulls with many desirable features are kept and semen is obtained from them. The semen is diluted, frozen and stored. Farmers can buy quantities of this semen to inseminate their cows. the semen is transferred into the cow's uterus using a syringe. Al makes it possible for the semen from one prize bull to be used to fertilise many thousands of cows.

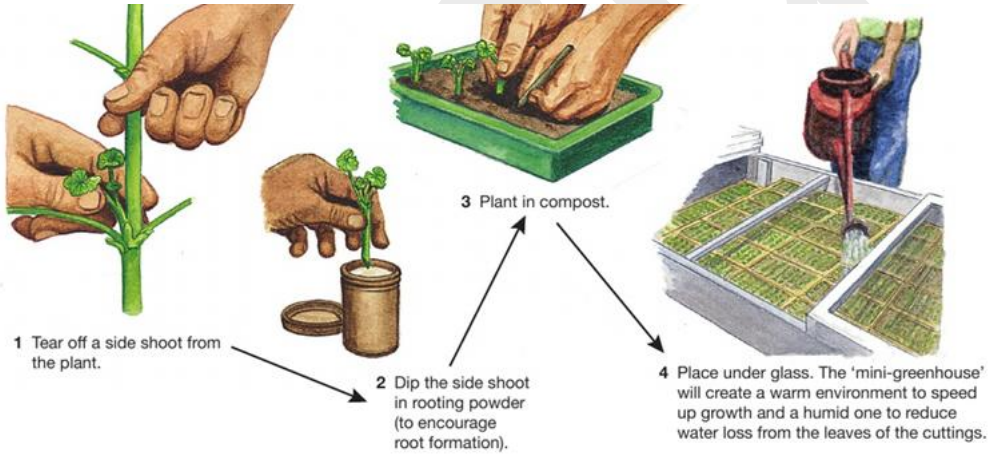


▲ Figure 20.4 The many different breeds of dog all originate from a common ancestor – the wolf.

Modern selective breeding

Cloning parts

The term cloning describes any procedure that produces genetically identical offspring. Taking cuttings of plants and growing them is a traditional cloning technique (Figure 20.5).



▲ Figure 20.5 Taking stem cuttings

All the cuttings contain identical genes as they are all parts of the same parent plant. As they grow, they form new cells by mitosis, copying the genes in the existing cells exactly. The cuttings develop into a group of genetically identical plants - a **clone**. Any differences will be due to the environment. Many garden flowers have traditionally been propagated this way.

Some modern cloning techniques are essentially the same as taking cuttings - removing pieces of a plant and growing them into new individuals. The technology, however, is much more sophisticated. By using the technique of **micropropagation**, thousands of plants can quickly be produced from one original (Table 20.1).

Table 20.1 The main stages in micropropagation

Stages	Illustrations
The tips of the stems and side shoots are removed from the plant to be cloned. These parts are called **explants**. The explants are trimmed to a size of about 0.5–1 mm, and surface-sterilised to kill any microorganisms. They are then placed in a sterile agar medium that contains nutrients and plant hormones to encourage growth (Figure 20.6). More explants can be taken from the new shoots that form on the original ones. This can be repeated until there are enough to supply the demand.	 ▲ Figure 20.6 Explants growing in a culture medium.
The explants with shoots are transferred to another culture medium containing a different balance of plant hormones to induce root formation (Figure 20.7).	 ▲ Figure 20.7 Explants forming roots.
When the explants have grown roots, they are transferred to greenhouses and transplanted into compost (Figure 20.8). They are then gradually acclimatised to normal growing conditions. The atmosphere in the greenhouse is kept very moist to reduce water loss from the young plants. Because of the amount of water vapour in the air, they are often called 'fogging greenhouses'.	 ▲ Figure 20.8 Young plants being grown in compost in a greenhouse.

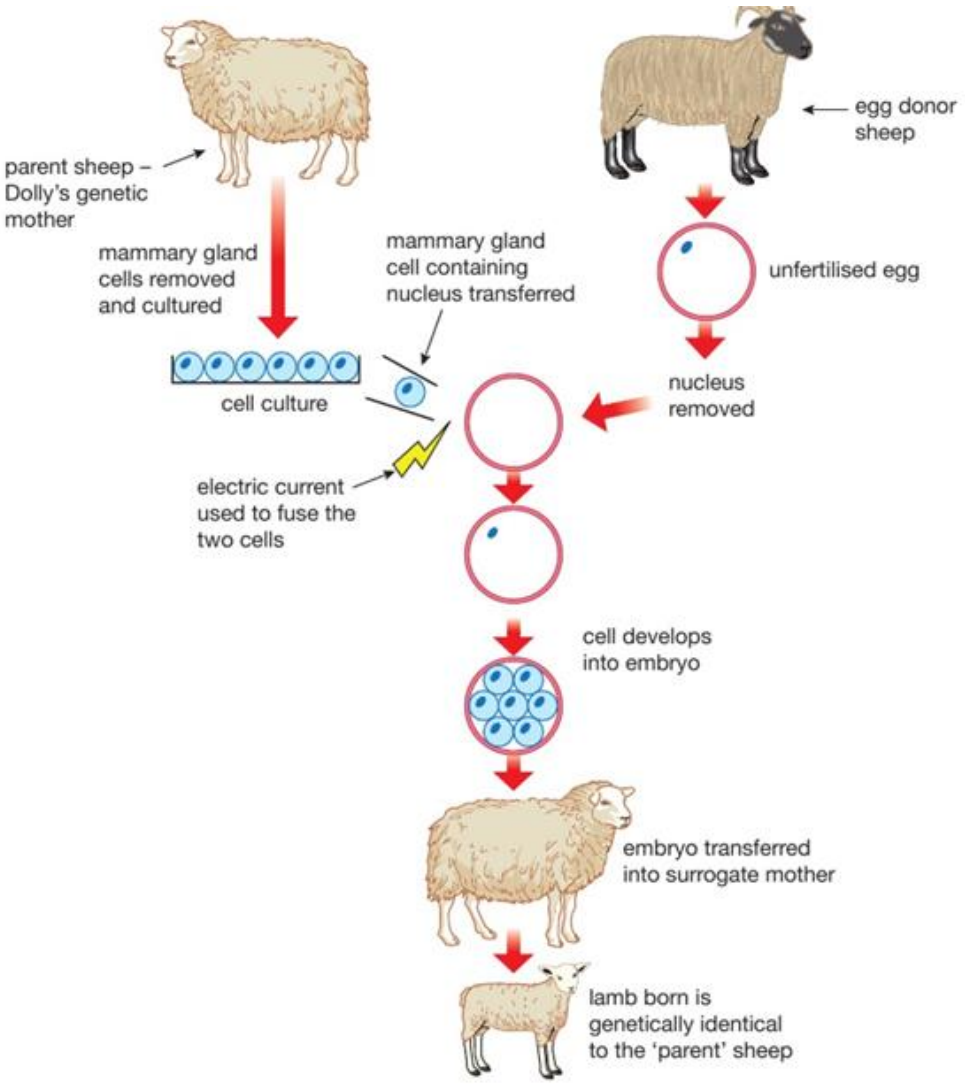
There are many advantages to propagating plants in this way:

- large numbers of genetically identical plants can be produced rapidly
- species that are difficult to grow from seed or from cuttings can be propagated by this method
- plants can be produced at any time of the year
- large numbers of plants can be stored easily (many can be kept in cold storage at the early stages of production and then developed as required)
- genetic modifications can be introduced into thousands of plants quickly, after modifying only a few plants.

CLONING ANIMALS

We have been able to clone plants by taking cuttings for thousands of years. It is now possible to make genetically identical copies of animals. The first, and best-known, example of this is the famous cloned sheep, Dolly.

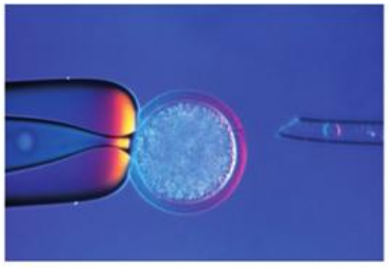
Dolly was cloned from a body cell of an adult sheep (Figure 20.9). Scientists first took an ovum (egg cell) from a donor sheep and removed its nucleus, producing an enucleated cell. They then took cells from the mammary (milk-producing) gland of a second 'parent' sheep (Dolly's genetic mother) and cultured them in a special solution that kept them alive but stopped them growing.



▲ Figure 20.9 How 'Dolly' was produced.

using clone animal to make proteins

Cloning animals, particularly sheep, is valuable for producing important products like alpha-1-antitrypsin, a protein used in treating conditions like emphysema and cystic fibrosis. Polly, the first cloned sheep, was born a year after Dolly.



▲ Figure 20.10 Inserting a mammary gland cell into an egg cell that has had its nucleus removed.

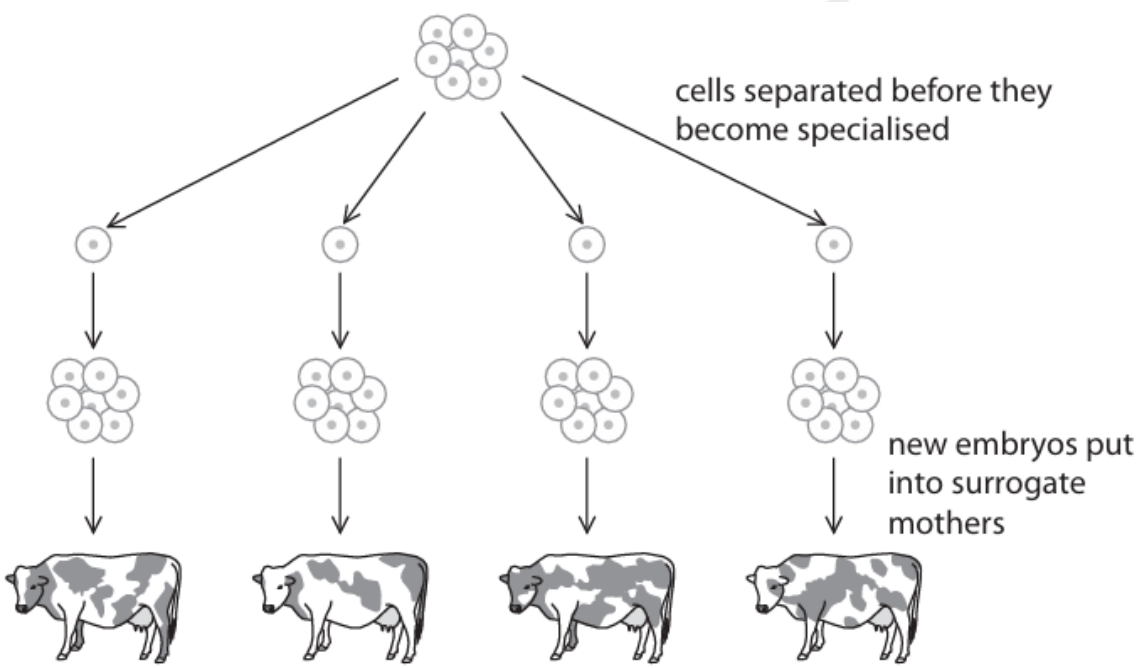
Revision questions

1. Farmers have used selective breeding to produce cows that give high milk yields.

(a) Describe how selective breeding can be used to produce cattle that give high milk yields.

(b) The diagram shows a different way to obtain cows that produce high milk yields. The process is called embryo cloning.

In this process individual cells from an embryo known to have the potential to become a high milk yielding cow are separated before they become specialised. Each separated cell is then allowed to develop into a new embryo. These new embryos are then put into surrogate mothers



(i) Where in the body of the surrogate mothers do the new embryos develop?

(ii) Suggest three advantages of producing cows with desirable characteristics using embryo cloning rather than using selective breeding

(c) Explain what is meant by the term clone.

(d)Name the type of cell division that produces an embryo from an individual cell.

2. (a) Describe the stages that are used to genetically modify a bacterium that is able to manufacture human growth hormone.

(b)BST is a hormone that increases milk yield in cows.

(i) Explain what is meant by the term hormone.

(ii) In some countries BST from genetically modified bacteria has been injected into cows to improve milk production. In other countries selective breeding has been used to improve milk production. Describe how selective breeding could be used to increase milk production

3. (a) Crop plants have been developed by a process called selective breeding. (i) Describe the process of selective breeding.

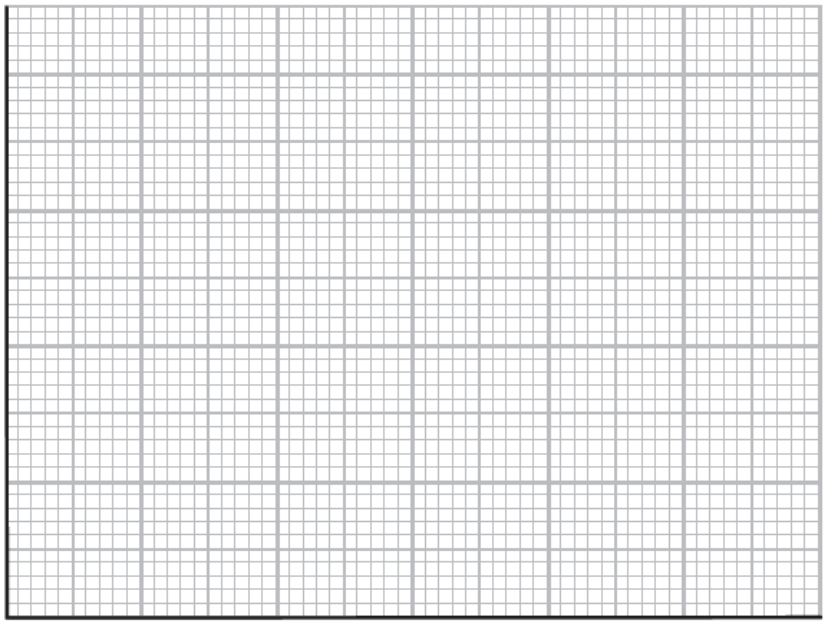
(ii) Give one example of a desired characteristic developed by selective breeding in a named crop plant.

(b)Give two ways in which natural selection differs from selective breeding

4. The table describes four different geographical regions. It also gives the amount of energy converted into plant biomass each year in each region

Region	Description of region	Energy converted into plant biomass in kJ per m^2 per year
A	woodland in the UK	26 000
B	tropical forest in Indonesia	40 000
C	grassland in the UK	15 000
D	farmed land in the UK	30 000

(a) Plot a bar graph on the grid to show the amount of energy converted into plant biomass each year in each region



(b) The amount of energy converted into plant biomass each year depends on the effect that abiotic (non-living) factors have on the rate of photosynthesis. Carbon dioxide is one of these abiotic factors. Name three other abiotic factors likely to affect the rate of photosynthesis.

(c) Regions C and D have the same climate. Plants grown in region D have more energy converted into plant biomass than plants grown in region C. One reason for this is the use of selective breeding to produce high yielding crops.

(i) Suggest two other reasons for more energy being converted into plant biomass in region D

(ii)What is meant by the term selective breeding?

(d)Describe how you could use a quadrat to estimate the plant biomass in one of the regions.

5. Read the passage below. Use the information in the passage and your own knowledge to answer the questions that follow.

Snail Farming

The photograph shows a snail that is farmed for its meat.

Farming snails has many benefits. Economically, there are many people prepared to pay for the luxury of eating snail meat. The meat itself is high in protein. It is also low in fat, so snail meat is healthy to eat. Also, farming snails helps to conserve natural snail populations which are at risk due to being collected in large numbers in many places.

In the wild, snails grow fastest in warm temperatures and a humid atmosphere. Maintaining these conditions on a snail farm creates problems with insect pests and bacterial infections. Natural predators of the insect pests, such as spiders, are encouraged on farms, as is the constant use of fly swatters and sticky fly traps. To prevent bacterial infections, disinfectant is added to the water used to clean the cages.

Snails are herbivores but on a snail farm they are not fed with green vegetables as might be expected. Green vegetables are not assimilated very well by many organisms. The assimilation efficiency (AE) of an organism is the percentage of total food eaten that is absorbed into the blood after digestion, and not lost as faeces. Carnivores tend to have an AE of 80%, while most leaf-eating herbivores have an AE of about 50%. However, snails have symbiotic microorganisms in their gut that release the enzyme, cellulase, to digest cellulose into glucose. This boosts their AE to about 75%. Nevertheless, snails on a farm are fed with high quality food containing a mixture of amino acids, carbohydrates, vitamins and mineral ions.

The production efficiency (PE) of an animal is the proportion of assimilated food that is turned into new biomass rather than being metabolised. Birds and mammals have a very low PE of 1 to 2%, but snails have a much higher PE. This is because the metabolic use of assimilated food, particularly glucose, is much reduced in snails.

Selective breeding is used on a snail farm to produce fast-growing snails that have thin shells and lay lots of eggs. The eggs are put on damp, sterilised soil and incubated. The young snails that hatch are put in plastic trays that are easy to clean.

(a)Explain why snail meat is healthy to eat (line 4).

(b)Suggest a reason why conservationists are pleased that snail farming exists.

(c)Name the organism used in biological control on snail farms

d)The shell of a snail is called an exoskeleton. Use this information to suggest onemineral ion in the diet of farmed snails that would help them to make their shell

(e) (i) Suggest why many organisms cannot assimilate green vegetables very well (lines 14 and 15)

6. Read the passage below. Use the information in the passage and your own knowledge to answer the questions that follow.

Bees

Photographer: Eigene Aufnahme, August 2006

Bees are insects that are important for the pollination of flowers of many plants. Bees are attracted to flowers to collect a sweet substance called nectar. After collecting nectar they return to their nest. Some of the nectar is used to make honey. Humans keep bees in small homes called hives and collect some of the honey. The bees live in a group called a colony inside the hive and they do not mate as individual pairs like most insects.

Each bee colony consists of a single fertile queen bee and her many infertile female offspring called worker bees. The colony also contains her male offspring called drones.

Under normal circumstances the fertile queen bee will fly out of the hive to mate with a number of drones from different hives. The queen takes the risk of mating in this way so that her offspring have extra genetic variation that may help to combat disease. The sperm are stored in the queen's body and released a few at a time as the eggs are laid. Some of the eggs may be fertilised by the sperm and some may not be fertilised. Fertilised eggs develop into worker bees with diploid body cells. Unfertilised eggs develop into drones.

The body cells of the fertile queen bee contain 32 chromosomes. The sperm cells produced by a single drone contain 16 chromosomes which are genetically identical to those of the other drones. If a queen bee mates with only one drone all the worker bees in the hive receive identical alleles from the drone and all the genetic variation comes from the queen. If the queen mates with two or more drones from different hives there will be greater variation in the worker bees.

It has been difficult to improve the characteristics of bees by selective breeding because bees do not mate as individual pairs. However, in the colony there are a small number of virgin queen bees that have not yet mated. These virgin queen bees can be used in selective breeding to form new colonies.

(a)What is meant by the term pollination (line 1)?

(b) Suggest why the bees collect nectar (lines 2 and 3).

(c) Suggest what is meant by the term fertile (line 7).

(d) Suggest how having 'extra genetic variation' may help the bees to combat disease (lines 12 and 13).

(e)How many chromosomes would you expect to find in an unfertilised bee egg?

f) Explain what determines the genetic variation in worker bees.

(g) Suggest two characteristics of a colony that would encourage a beekeeper to use the colony for selective breeding.

7. (a) Describe how the process of micropropagation (tissue culture) can be used to produce plants with desirable characteristics

(b)Plants can also be produced from seeds. Give two advantages of using micropropagation rather than using seeds to produce plants with desirable characteristics.

8. Describe the stages used to produce a cloned mammal.

9.

The diagram shows one side of an organ donor card.

I request that after my death

A. any part of my body may be used for the treatment of others ☐, or

B. my kidneys ☐ corneas ☐ heart ☐ lungs ☐ liver ☐ pancreas ☐ be used for transplantation.

Signature _____ Date _____

Full name _____
(BLOCK CAPITALS)

In the event of my death, if possible contact:

Name _____ Tel. _____

Remember to tell someone close to you that you want to be an organ donor. We'll need their agreement if the time ever comes.

(a) The table lists different human illnesses. Complete the table by giving the donated organ named on the card needed to cure each illness. The first one has been done for you

Illness	Organ needed to cure illness
uremia	kidney
emphysema	
coronary failure	
diabetes	
hepatitis	
poor vision	

(b)Describe the role of the liver in digestion

(c) There is a shortage of people willing to donate their organs. Scientists hope to create cloned organisms to solve this problem.

(i) What is a cloned organism?

(ii) Suggesttwo advantages of using cloned organisms to provide organs rather than relying on people to donate organs.

10. During the cloning of mammals unfertilised eggs are collected from the female. These unfertilised eggs are stored in a special nutrient solution before they are fertilised. Design an investigation to find the best storage temperature for the survival of the unfertilised eggs. Your answer should include experimental details and be written in full sentences.