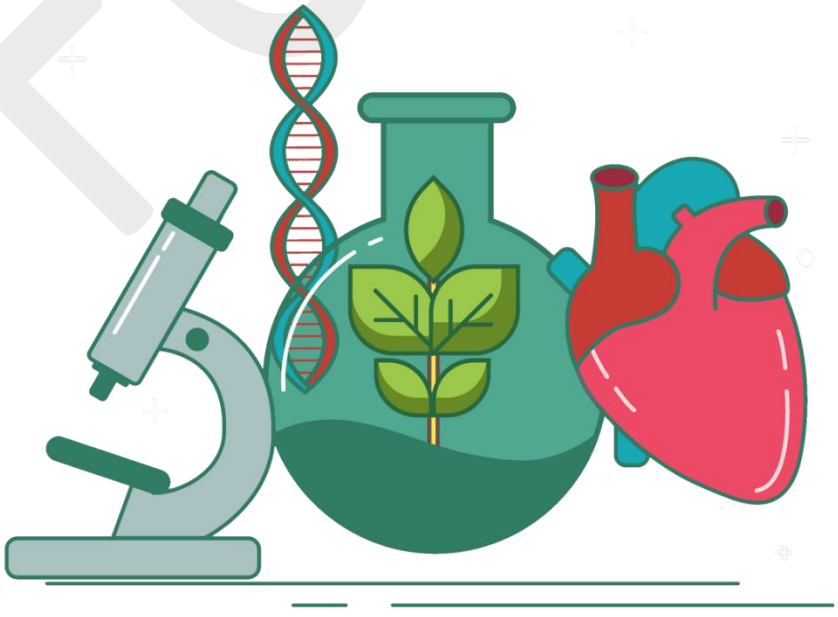
# Cambridge OL

# Biology

CODE: (5090)

## Chapter 17 and chapter 18

## Inheritance AND biotechnology and genetic modification



# Chapter 17 – Inheritance

**Key definitions**
**Variation** is the differences between individuals of the same species.

## Variation

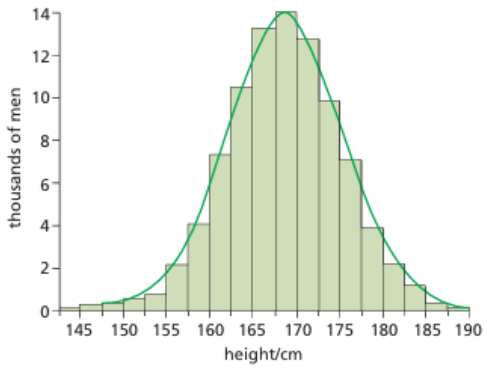
The term variation refers to observable differences within a species. All domestic cats belong to the same species, i.e. they can all interbreed, but there are many variations of size, coat colour, eye colour, fur length, etc. Some variations are inherited, and these are controlled by genes. They are **genetic** variations. **Phenotypic** variations may be produced by genes but can also be caused by the environment, or a combination of both genes and the environment.

▲ **Figure 17.1** Acquired characteristics. These apples have all been picked from different parts of the same tree. All the apples have similar genotypes, so the differences in size must have been caused by environmental effects

They are caused by environmental effects. In the same way, a fair-skinned person may be able to change the colour of his or her skin by exposing it to the Sun and getting a tan. The tan is an acquired characteristic. You cannot inherit a suntan. Black skin, on the other hand, is an **inherited** characteristic.

## Continuous variation

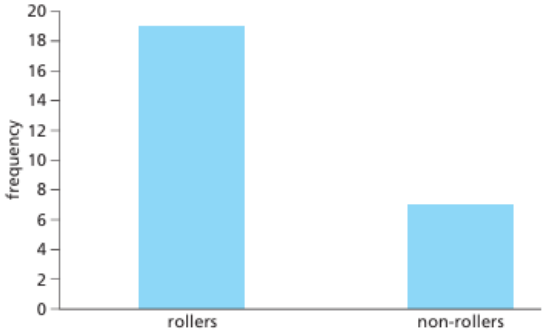
**Continuous variation** is influenced by a combination of both genetic and environmental factors. An example of continuous variation is height. There are no distinct categories of height; people are not either tall or short. There are all possible intermediates between very short and very tall (Figure 17.2).




▲ **Figure 17.2** Continuous variation. Heights of 90000 army recruits. The apparent steps in the distribution are the result of randomly chosen categories, differing in height by 1 cm. But heights do not differ by exactly 1 cm. If measurements could be made accurately to the nearest millimetre there would be a smooth curve like the one shown in colour

Continuously variable characteristics are usually controlled by several pairs of alleles (see later in this chapter). There might be five pairs of alleles for height – (**Hh), (Tt), (Ll**), (**Ee) and (Gg**) – each dominant allele adding 4 cm to your height. If you inherited all ten dominant genes (**HH, TT, etc**.) you could be 40 cm taller than a person who inherited all ten **recessive** genes **(hh, tt,** etc.). Scientists do not know the actual number of genes that control height, intelligence and even the colour of hair and skin.

A plant may have the genes for large fruits but not get enough water, mineral ions or sunlight to produce large fruits. Continuous variations in human populations, like height, physique and intelligence, are always the result of contributions from both the **genotype** and the environment.



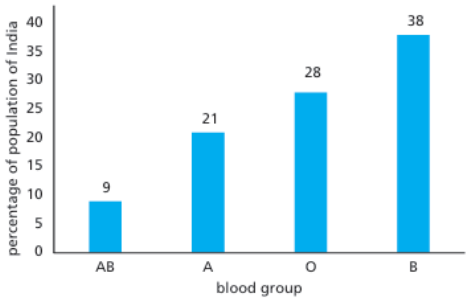

▲ **Figure 17.3** Discontinuous variation. Tongue rollers and non-rollers in a class

## Discontinuous variation

In discontinuous variation, the variations take the form of distinct, alternative phenotypes with no intermediates (Figures 17.3 and 17.4). Pea seeds may be wrinkled or smooth and their colour can be yellow or green.

Note: This is an oversimplification and there may be some environmental factors involved as well. Some children gradually develop the ability to roll their tongue as they get older.

Discontinuous variation is controlled by a single pair of alleles or a few genes, like human blood groups. Discontinuous characteristics, like eye color and hair color, are difficult to classify as completely continuous or discontinuous. For example, brown eyes have a dominant gene, while red hair has a continuous range from blond to black.

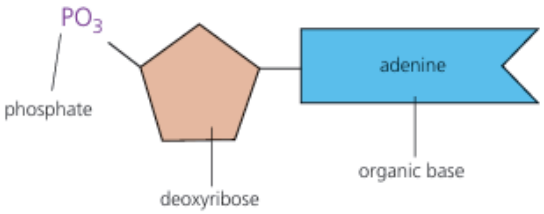



▲ **Figure 17.4** Discontinuous variation. Frequencies of ABO blood groups in India. The figures could not be adjusted to fit a smooth curve because there are no intermediates. **Note:** The figures do not add up to 100% because there are other less common blood groups as well

## DNA

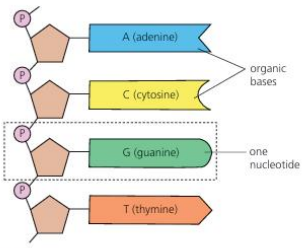
**Key definitions**
A **gene** is a length of DNA that codes for a protein.

A DNA molecule is made up of long chains of **nucleotides** (Figure 17.5), formed into two strands. In DNA the sugar is deoxyribose, and the organic base is either adenine (A), thymine (T), cytosine (C) or guanine (G).

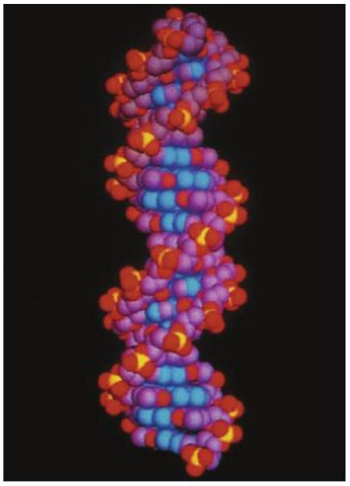



▲ **Figure 17.5** A nucleotide (adenosine monophosphate)

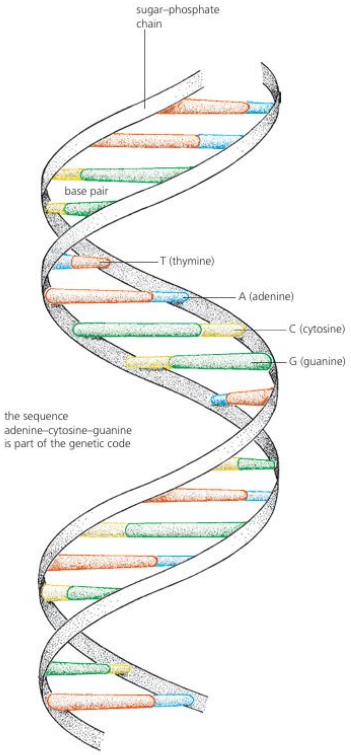
The DNA in a chromosome is made of two strands (chains of nucleotides) held together by chemical bonds between the bases. The size of the molecules makes sure that A always pairs with T and C pairs with G. The double strand is twisted to make a helix (like a twisted rope ladder with the base pairs being the rungs) (Figures 17.7 and 17.8).




▲ **Figure 17.6** Part of a DNA molecule with four nucleotides



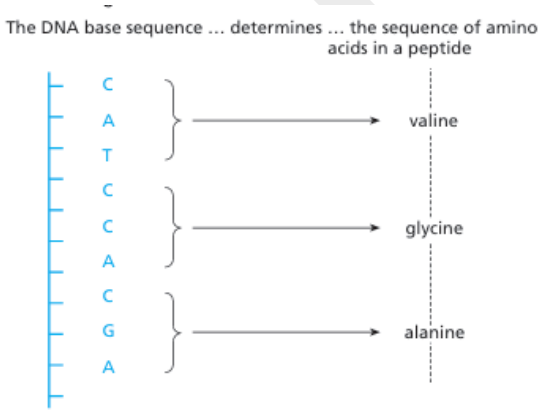
▲ **Figure 17.7** Model of the structure of DNA




▲ **Figure 17.8** This schematic shows part of a DNA molecule

## The genetic code

DNA is a string of nucleotides containing a sequence of bases, which forms a code for cell function. Proteins are made from amino acids linked together, and the type and sequence of these amino acids determine the shape of the protein. A gene is a sequence of triplets of the four bases, which codes for a complete protein..




▲ **Figure 17.12** The genetic code (triplet code)

# Inheritance

**Key definitions**

**Inheritance** is the transmission of genetic information from generation to generation.

An **allele** is an alternative form of a gene.

**Genotype** is the genetic make-up of an organism in terms of the alleles present.

**Phenotype** is the observable features of an organism.

**Homozygous** means having two identical alleles of a particular gene.

**Heterozygous** means having two different alleles of a particular gene.

**Dominant** describes an allele that is expressed if it is present in the genotype.

**Recessive** describes an allele that is only expressed when there is no dominant allele of the gene present in the genotype.

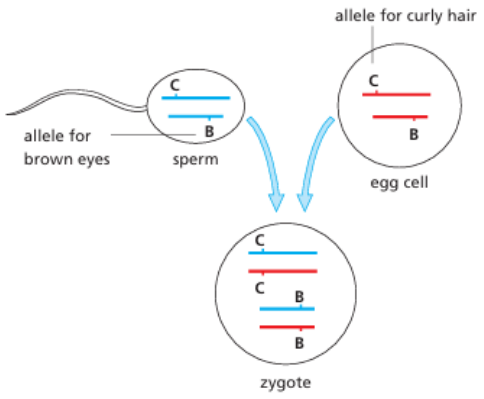
## Patterns of inheritance

The allele in a mother's body cells that causes her to have brown eyes may be present on one of the chromosomes in each egg cell she produces.

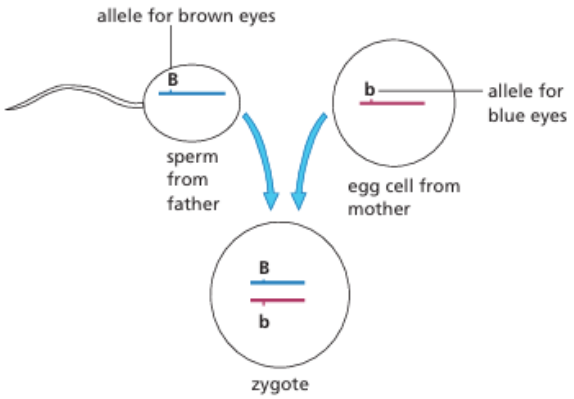
Figure 17.14 shows this happening, although it is very simplified – it does not show all the other chromosomes with thousands of genes for producing the enzymes making different types of cell and all the other processes that control the development of the organism.

## Single-factor inheritance

The inheritance of thousands of characteristics controlled by genes is impossible. To study a single gene controlling one characteristic, we use eye color as an example. If a child receives an allele for blue eyes from both parents, they will have brown eyes, but the allele for brown eyes is dominant. Eye color is a useful model for explaining inheritance, but it is not entirely reliable due to variations in blue eyes and brown pigment.




▲ **Figure 17.14** Fertilisation brings the chromosomes back to the diploid number and combines the alleles from the mother and father




▲ **Figure 17.15** Combination of alleles in the zygote (only one chromosome is shown). The zygote has both alleles for eye colour; the child will have brown eyes

This example illustrates the following important points:

» There is a pair of alleles for each characteristic, one allele from each parent.

» Although the allele pairs control the same characteristic (e.g. eye colour) they may have different effects. One tries to produce blue eyes, the other tries to produce brown eyes.

» Often one allele is dominant over the other.

» The alleles of each pair are on corresponding chromosomes and occupy corresponding positions. For example, in Figure 17.14 the alleles for eye colour are shown in the corresponding position on the two short chromosomes. The alleles for hair curliness are in corresponding positions on the two long chromosomes. In diagrams and explanations of heredity

– alleles are represented by letters
– alleles controlling the same characteristic are given the same letter
– the dominant allele is given the capital letter.

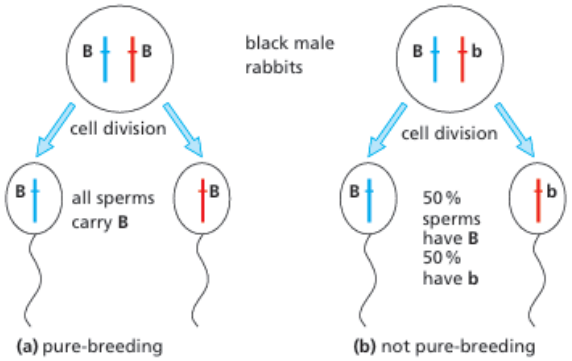
## Breeding true

A white rabbit must have both the recessive alleles **b** and **b**. If it had **B** and **b**, the dominant allele for black (**B**) would dominate the allele for white (**b**) and produce a black rabbit. A black rabbit, on the other hand, could be either **BB** or **Bb** and, by just looking at the rabbit, you could not tell the difference. When a male black rabbit **BB** produces sperm, each one of the pair of chromosomes carrying the **B** alleles will end up in different sperm cells. Since the alleles are the same, all the sperm will have the **B** allele for black fur (Figure 17.16(a)).

A black rabbit **BB** is called a **pure-breeding** black and is said to be homozygous for black coat colour (*homo-* means *the same*). If this rabbit mates with another black (**BB**) rabbit, all the babies will be black because all will receive a dominant allele for black fur. When all the offspring have the same characteristic as the parents, this is called pure breeding for this characteristic.

When a **Bb** black rabbit produces gametes by meiosis, the chromosomes with the **B** allele and the chromosomes with the **b** allele will end up in different gametes. So, 50% of the sperm cells will carry **B** alleles and 50% will carry **b** alleles (Figure 17.16(b)). Similarly, in the female, 50% of the eggs will have a **B** allele and 50% will have a **b** allele. If a **b** sperm fertilises a **b** egg cell, the offspring, with two **b** alleles (**bb**), will be white. The black **Bb** rabbits are not pure breeding because they may produce some white babies as well as black ones. The **Bb** rabbits are called heterozygous (*hetero-* means *different*).

The black **BB** rabbits are homozygous dominant.
The white **bb** rabbits are homozygous recessive.




▲ **Figure 17.16** Breeding pure

## Genotype and phenotype

The two kinds of black rabbit **BB** and **Bb** have the same phenotype. This is because their coat colours look the same. However, because they have different allele pairs for coat colour, they have different genotypes, i.e. different combinations of alleles. One genotype is **BB** and the other is **Bb**.

Two brothers might both be brown-eyed phenotypes, but one brother's genotype could

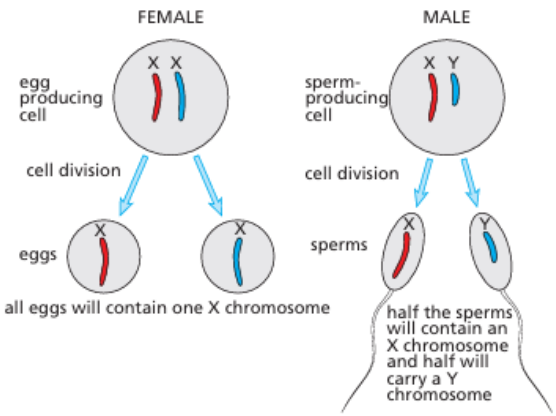
### Alleles

The genes that occupy corresponding positions on homologous chromosomes and control the same characteristic are called alleles. The word allele comes from allelomorph, which means alternative form.

There are often more than two alleles of a gene. The human ABO blood groups are controlled by three alleles, though only two of these can be present in one **genotype**

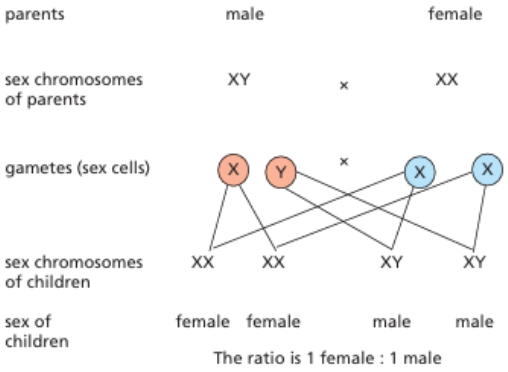
## The inheritance of sex

The pair of chromosomes called the sex chromosomes controls whether you are a male or female. In females, the two sex chromosomes, called the X chromosomes, are the same size as each other.
Males have two sex chromosomes, one representing female sex chromosomes and the other smaller, XY. A process in the female's ovary creates gametes with half the normal number of chromosomes. Each egg cell receives one of the X chromosomes. In males, 50% of sperms receive an X chromosome and 50% a Y chromosome. The chances of fertilizing an egg cell are equal, resulting in roughly equal births.




▲ **Figure 17.18** Determination of sex. **Note:** Only the X and Y chromosomes are shown

Figure 17.19 shows how sex is inherited.

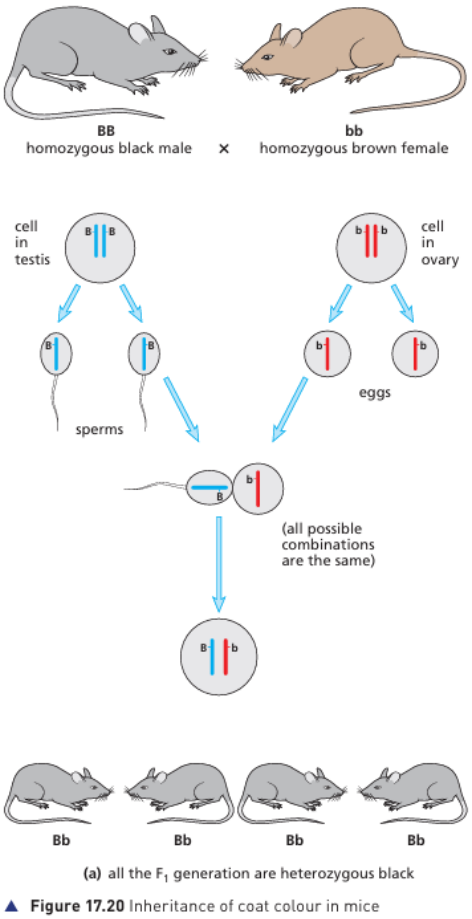



▲ **Figure 17.19** Determination of sex

## The three to one ratio

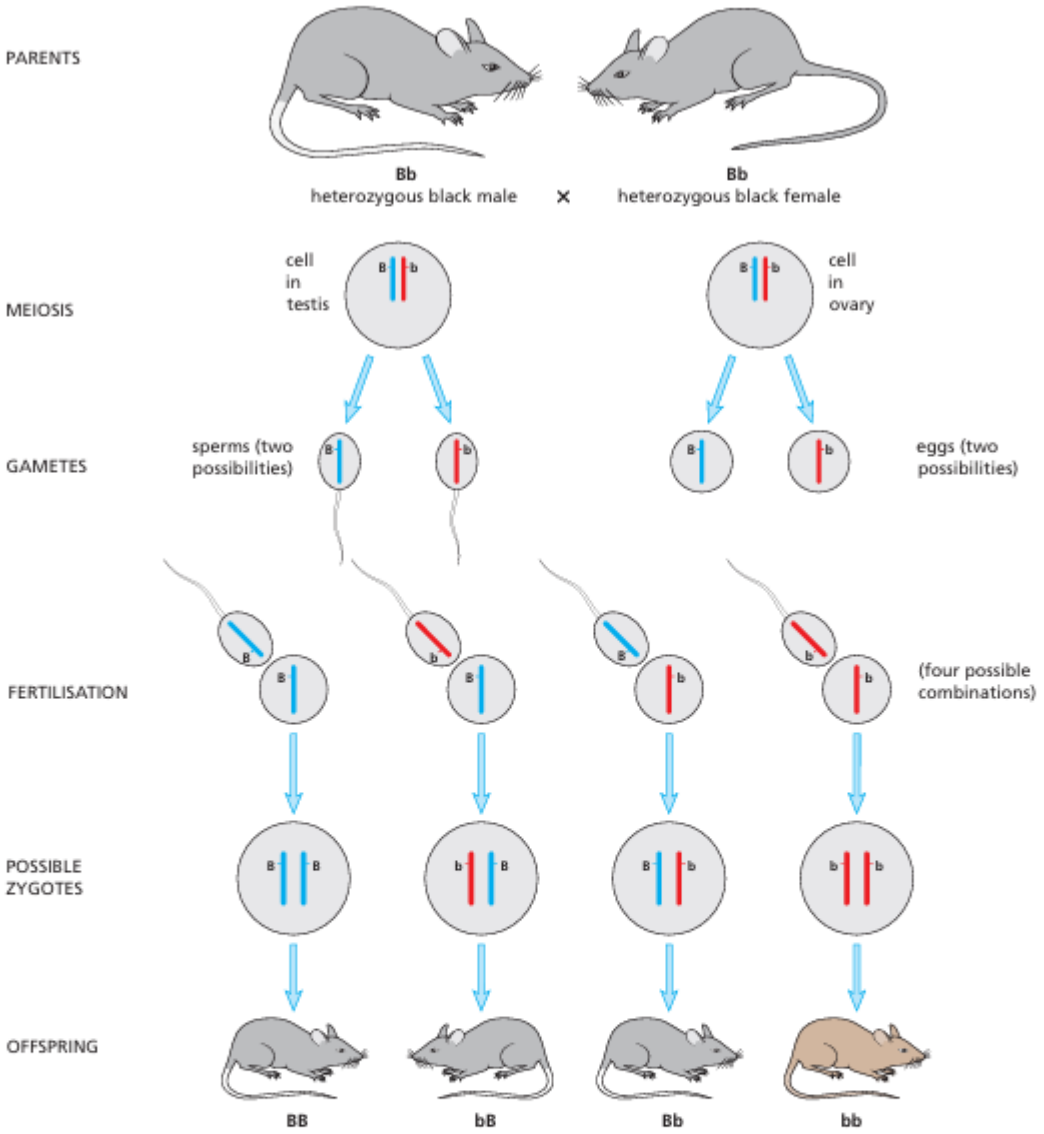
The result of a mating between a true-breeding (homozygous) black mouse (BB) and a true-breeding (homozygous) brown mouse (bb) is shown in Figure 17.20(a). The example is simplified because it only shows one pair of the 20 pairs of mouse chromosomes and only one pair of alleles on the chromosomes.

The F1 generation of black mice is characterized by their dominant black fur allele from the father and recessive b allele from the mother. When these heterozygous offspring are mated, the F2 generation is produced. Sperm and egg cells can only contain one of the coat color alleles, resulting in two types of sperm cells and egg cells.




(a) all the $F_1$ generation are heterozygous black

▲ **Figure 17.20** Inheritance of coat colour in mice




(b) the probable ratio of coat colours in the $F_2$ generation is 3 black : 1 brown

▲ **Figure 17.20** Inheritance of coat colour in mice (continued)

- A **b** sperm fertilises a **B** egg cell. Result: **bB** zygote.
- A **b** sperm fertilises a **b** egg cell. Result: **bb** zygote.
- A **B** sperm fertilises a **B** egg cell. Result: **BB** zygote.
- A **B** sperm fertilises a **b** egg cell. Result: **Bb** zygote.

There is no difference between **bB** and **Bb**, so there are three possible genotypes in the offspring – **BB**, **Bb** and **bb.** There are only two phenotypes – black (**BB** or **Bb**) and brown (**bb**). So, according to the laws of chance, we would expect three black baby mice and one brown. Mice usually have more than four offspring and what we really expect is that the ratio (proportion) of black to brown will be close to 3:1.

If the mouse had 13 babies, you might expect nine black and four brown, or eight black and five brown.

When working out the results of a genetic cross it is useful to display the outcomes in a **Punnett square** (Figure 17.21). This is a box divided into four compartments. The two boxes along the top are labelled with the genotypes

of the gametes of one parent. The genotypes are circled to show they are gametes. The parent's genotype is written above the gametes.

In this example, two heterozygous tall organisms (**Tt)** are the parents. The genotypes of the offspring are **TT, Tt, tT** and **tt**. We know that the allele T is dominant because the parents are tall, although they carry both tall and dwarf alleles. So, the phenotype

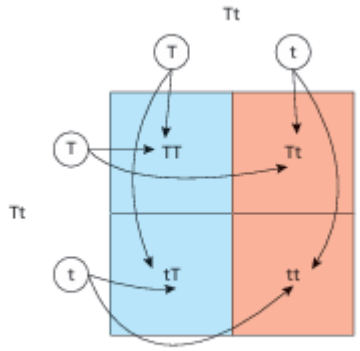



**Figure 17.21** Using a Punnett square to predict the outcomes of a genetic cross

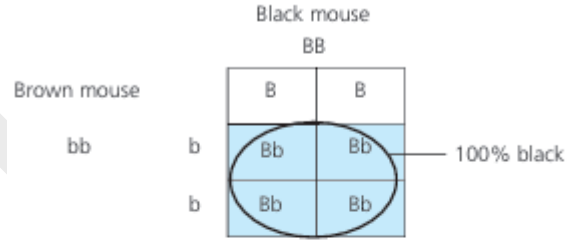
### 1:1 phenotypic ratio

A black mouse could have either the **BB** or the **Bb** genotype. One way to find out the genotype is to cross the black mouse with a known homozygous recessive mouse, **bb**. The **bb** mouse will produce gametes with only the recessive **b** allele. A black homozygote, **BB**, will produce only **B** gametes.

So, if the black mouse is **BB**, all the offspring from the cross will be black heterozygotes, **Bb**.

Half the gametes from a black **Bb** mouse would carry the **B** allele and half would have the **b** allele. So, if the black mouse is **Bb**, half of the offspring from the cross will, on average, be brown homozygotes, **bb**, and half will be black heterozygotes, **Bb**.

BB x bb



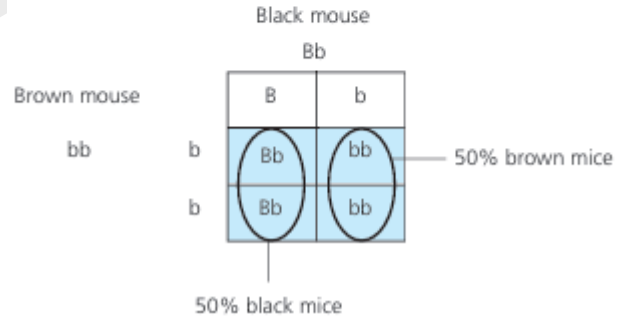

## Codominance

**Key definitions**

**Codominance** is a situation in which both alleles in heterozygous organisms contribute to the phenotype.

Allelomorphic pairs have codominant alleles, meaning both genes produce their effects in an individual. In the human ABO blood system, alleles for groups A and B are codominant, causing red blood cells to carry both antigens. However, alleles for group O are completely dominant.

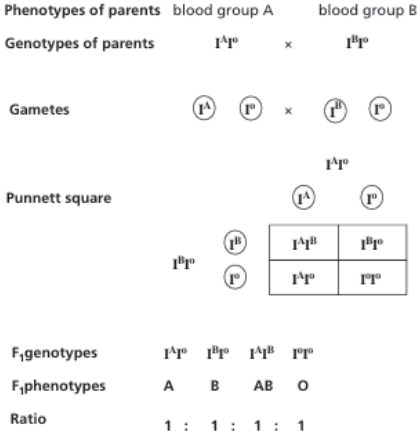
Bb x bb




### Inheritance of blood group O

Blood group O can be inherited even though neither parent shows this phenotype.

Two parents have the groups A and B. The father is $I^AI^o$ and the mother is $I^BI^o$ (Figure 17.23).




▲ **Figure 17.23** Inheritance of blood group O

▼ **Table 17.1** The ABO blood groups

| Genotype | Blood group (phenotype) |
|---|---|
| $I^AI^A$ or $I^Ai^o$ | A |
| $I^BI^B$ or $I^Bi^o$ | B |
| $I^AI^B$ | AB |
| $i^oi^o$ | O |

Some plants show codominance with petal colour. For example, with the gene for flower colour in the geranium, the alleles are $C^R$ (red) and $C^W$ (white). The capital letter 'C' has been chosen to represent colour. Pure-breeding (homozygous) flowers may be red ($C^RC^R$) or white ($C^WC^W$). If these are cross-pollinated, all the first filial ($F_1$) generation will be heterozygous ($C^RC^W$) and they are pink because both alleles have an effect on the phenotype.

Self-pollinating the pink ($F_1$) plants results in an unusual ratio in the next ($F_2$) generation of 1 red : 2 pink : 1 white.

**Key definitions**

**Gene mutation** is a random change in the base sequence of DNA.

**Mutation** is genetic change.

A **chromosome mutation** is a change in the chromosome number or structure.

## Mutations

Mutations are spontaneous genetic changes that create new alleles. They can occur in genes or chromosomes, causing errors in gene copying or damage during mitosis or meiosis. Mutations can also affect the protein coded for by the gene, such as haemoglobin in Sickle-cell anemia. Most mutations are harmful to the organism, as they can cause faulty enzymes and disrupt complex cell reactions. Only about 3% of human DNA is made up of genes, with the rest consisting of non-coding nucleotides. Mutations in gametes or somatic cells can have a significant impact on the organism, contributing to its success.

## Mutations in bacteria

Mutations in bacteria often produce resistance to drugs. Bacterial cells reproduce very rapidly, perhaps as often as once every 20 minutes. As a result, a mutation, even if it occurs very rarely, is likely to appear in a large population of bacteria. If a population of bacteria containing one or two drug resistant mutants is exposed to that drug, the non resistant bacteria will be killed but the drug-resistant mutants will survive (see Figure 17.29).

## Causes of increases in the rate of mutation

Substances, such as some chemicals and also ionising radiation can change DNA. Exposure to them increases the rate of mutation. Some of the substances in tobacco smoke, like tar, are mutagens, which can cause cancer. Ionising radiation from X-rays and radioactive compounds, and ultraviolet radiation from sunlight, can increase the mutation rate. It is uncertain whether there is a minimum dose of radiation below which there is only a tiny risk

## Sources of genetic variation in populations

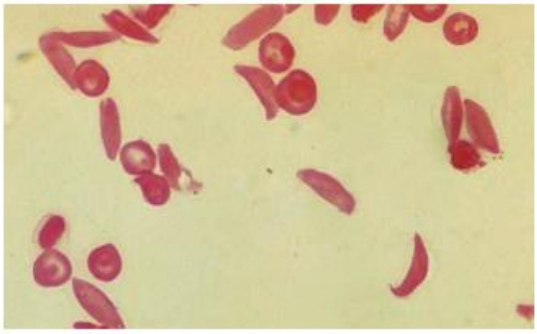
Genetic variation may be the result of mutations. In addition, meiosis, random mating and new combinations of genes in the zygote through random fertilisation are all sources of genetic variation in populations.

## New combinations of genes

If a grey cat with long fur is mated with a black cat with short fur, the kittens will all be black with short fur. If these offspring are mated together, eventually the litters of kittens may include four varieties: black short, black–long, grey–short and grey–long. Two of these are different from either of the parents.

### Sickle-cell anaemia

A person with sickle-cell disease has inherited both recessive alleles (HbSHbS) for defective haemoglobin. The distortion and destruction of the red blood cells, which occurs in low oxygen concentrations, leads to bouts of severe anaemia (Figure 17.25). In many African countries, sufferers have a reduced chance of reaching reproductive age and having a family. There is thus a selection pressure, which tends to remove the homozygous recessives from the population.

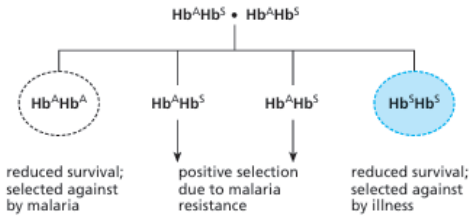


▲ **Figure 17.25** Sickle-cell anaemia (× 800). At low oxygen concentration the red blood cells become distorted

With **sickle-cell anaemia**, the defective haemoglobin molecule differs from normal haemoglobin by only one amino acid (represented by a sequence of three bases), i.e. valine replaces glutamic acid. This could be the result of faulty replication at meiosis.

### Down's syndrome

Down's syndrome is a form of mental and physical disability, which results from a chromosome mutation. During the process of meiosis which produces an egg cell, one of the chromosomes (chromosome 21) fails to separate from its homologous partner, a process known as non disjunction.




▲ **Figure 17.26** Selection in sickle-cell disease

## Selection

### Natural selection

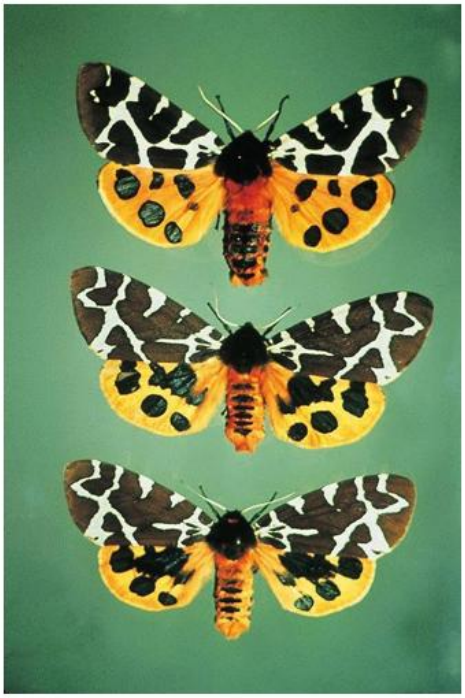
The theory of evolution by natural selection states that:

» Individuals within a population of a species are all slightly different from each other (Figure 17.27). These differences are called variations.

» If the climate or **food supply** changes, individuals with some of these variations may be more able to survive than others. For example, a variety of animal that could eat the leaves of shrubs as well as grass would be more likely to survive a drought than one that only fed on grass.

» If one variety lives longer than others, it is also likely to leave behind more offspring. A mouse that lives for 12 months may have ten litters of five babies (50 in total). A mouse that lives for 6 months may have only five litters of five babies (25 in total).

» If some of the offspring inherit alleles responsible for the variation that helped the parent survive better, they will also live longer and have more offspring.



▲ **Figure 17.27** Variation. The garden tiger moths in this picture are all from the same family. There is a lot of variation in the pattern on the wings

» In time, this particular variety will outnumber and finally replace the original variety.

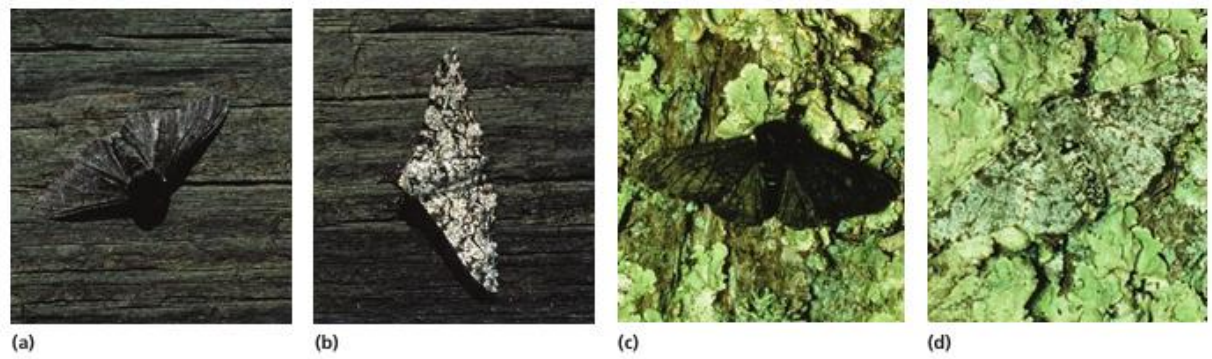
## Competition and selection

There will be competition between members of the rabbit population for food, burrows and mates. If food is limited, space is short and the number of potential mates limited, then only the healthiest, most active, most fertile and well-adapted rabbits will survive and breed.

For natural selection to be effective, the variations must be heritable. Variations that are not heritable are of no value in natural selection. Training may give athletes more efficient muscles, but this characteristic will not be passed on to their children.

## The peppered moth

The selection pressure, in this case, was presumed to be mainly **predation** by birds. The adaptive variation that produced the selective advantage was the dark colour. Although this is an attractive and likely hypothesis of how natural selection could occur, some of the evidence does not support the hypothesis or has been challenged. For example, the moths settle most often on the underside of branches rather than visibly on tree trunks, as in Figure 17.28. Also, in several unpolluted areas the dark form is quite common,

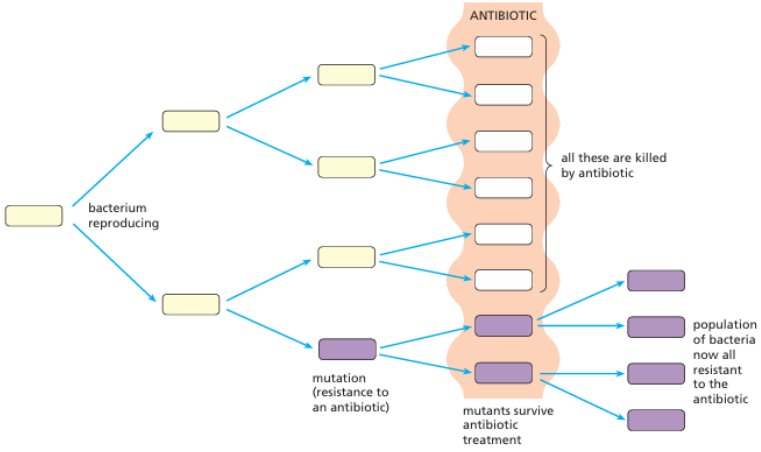



▲ **Figure 17.28** Selection for varieties of the peppered moth

## Adaptation

Slow changes in the environment result in adaptations in a population to cope with the changes. These adaptations are the result of natural selection, by which populations become more suited to their environment over many generations. When they reproduce, all their offspring will have the drug resistance, so the antibiotic will become less effective (Figure 17.29).

MRSA (methicillin-resistant Staphylococcus aureus) is one type of bacteria that has developed resistance to several widely used antibiotics. These types of bacteria are sometimes called superbugs because they are so difficult to treat. Staphylococcus aureus is very common and lives harmlessly on the skin, nose and throat, sometimes causing mild infections.




▲ **Figure 17.29** Mutation in bacteria can lead to drug resistance

## Development of strains of antibiotic-resistant bacteria

If a population of bacteria containing one or two drug-resistant mutants is subjected to that particular drug, the non-resistant bacteria will be killed but the drug-resistant mutants survive (Figure 17.29).

## Artificial selection (selective breeding)

The process of selective breeding involves humans choosing individuals with desirable features. These individuals are then cross-bred to produce the next generation. Offspring with the most desirable features are chosen to continue the breeding programme and the process is repeated over several generations. Human communities use this form of selection when they breed plants and animals for specific characteristics. The range of varieties of cat that you see today have been produced by selecting individuals with pointed ears, fur colour or length, or even no tail, etc.

▲ **Figure 17.30** Selective breeding. The Siamese cat, produced by selective breeding over many years

The process is repeated until the desired or fashionable ear shape is established in a pure-breeding population (Figure 17.30).

Selective breeding in farm stock can be slow and expensive because the animals often have small numbers of offspring and breed only once a year. Another disadvantage of selective breeding is that the whole set of genes is transferred. As well as the desirable genes, there may be genes that, in a homozygous condition, would be harmful. It is known that **artificial selection** repeated over several generations tends to reduce the fitness of the new variety.

▲ **Figure 17.31** Selective breeding in tomatoes. Different breeding programmes have selected genes for fruit size, colour and shape. Similar processes have resulted in most of our cultivated plants and domesticated animals

## Comparing natural and artificial selection

Natural selection occurs in groups of living organisms by the best adapted organisms passing on genes to the next generation, without human interference. Those with genes that provide an advantage to cope with changes in environmental conditions,

Artificial selection is used by humans to produce varieties of animals and plants that have an increased economic importance.


▲ **Figure 17.32** The genetics of bread wheat. A primitive wheat (a) was crossed with a wild grass (b) to produce a better-yielding hybrid wheat (c). The hybrid wheat (c) was crossed with another wild grass (d) to produce one of the varieties of wheat (e), which is used for making flour and bread

# Chapter 18 – Biotechnology and genetic modification

## Biotechnology

**Biotechnology** is the application of biological organisms, systems or processes to manufacturing and service industries. **Genetic modification** involves the transfer of genes from one organism to (usually) an unrelated species.

## Use of bacteria in biotechnology and genetic modification

Bacteria are useful in biotechnology and genetic modification because they can be grown and manipulated without raising ethical concerns. They have a genetic code that is the same as all other organisms, so scientists can transfer genes from other animals or plants into bacterial DNA. They are especially useful because they multiply so fast (up to three times an hour).

Antibiotics, like penicillin, are produced by mould fungi or bacteria. The production of industrial chemicals like citric acid or lactic acid needs bacteria or fungi to bring about essential chemical changes. Sewage disposal depends on bacteria in the filter beds to form the basis of the **food chain** that purifies the effluent.

## Fermentation

Fermentation includes a wide range of reactions under the influence of enzymes or microorganisms such as yeast. In Chapter 10, the anaerobic respiration of glucose to ethanol was described. This is a form of fermentation. Microorganisms involved in fermentation are using the chemical reaction to release energy, which they need for their living processes.

## Ethanol

Ethanol (alcohol) can be produced from fermented sugar or spare grain by yeast. This could replace, or at least supplement, petrol. Brazil, Zimbabwe and the USA produce ethanol as a renewable source of energy for cars. Since 2013, 94% of new cars in Brazil use a mixture of petrol and ethanol. As well as being a renewable resource, ethanol produces less pollution than petrol.

## Bread

Yeast is the microorganism used in bread-making, but the only fermentation product needed is carbon dioxide. The carbon dioxide makes bubbles in the bread dough. These bubbles make the bread light in texture. Flour, water, salt, oil and yeast are mixed to make a dough. Yeast has no enzymes for digesting the starch in flour, but adding water activates the amylases already present in flour. The amylases digest some of the starch to sugar. With highly refined white flour, adding sugar to the dough helps the process. The yeast then ferments the sugar to ethanol and carbon dioxide.

▲ **Figure 18.1** A new palm oil plantation, replacing a rain forest

▲ **Figure 18.2** Carbon dioxide produced by the yeast has caused the dough to rise

### Fruit juice production

Pectinases are enzymes used to separate the juices from fruit like apples. The enzymes can be extracted from fungi (e.g. Aspergillus niger). They work by breaking down pectin, the jelly-like substance that sticks plant cell walls to each other. The enzymes can also be used to make fruit juice more transparent. During the breakdown process several different polysaccharides are released, which make the juice cloudy. Pectinases break these down to make the juice clearer

### Biological washing powders

Most commercial enzyme production involves protein digesting enzymes (proteases) and lipid-digesting enzymes (lipases) for use in the food and textile industries. When combined in washing powders they remove stains in clothes caused by proteins (e.g. blood or egg) and lipids (e.g. grease and oil). Protein and lipid molecules tend to be large and insoluble. When they have been digested the products are small, soluble molecules, which can pass out of the cloth.

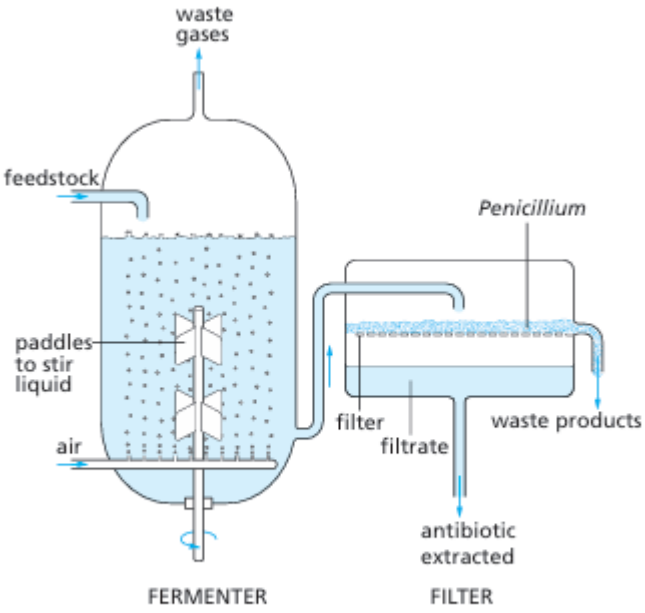
## Fermenters

### Lactose-free milk

Lactose is a type of disaccharide sugar found in milk and dairy products. Some people have problems with lactose intolerance. This is a digestive problem where the body does not produce enough of the enzyme lactase. As a result, the lactose stays in the gut, where it is fermented by bacteria. This causes symptoms like flatulence (wind), diarrhoea and stomach pains.

### Antibiotics

When microorganisms are grown in **fermenters** to produce antibiotics, it is not their fermentation products that are wanted but complex organic compounds, called antibiotics, that they synthesise (Figures 18.4 and 18.5).




▲ **Figure 18.4** Principles of antibiotic production using a fermenter

▲ **Figure 18.5** A laboratory fermenter for antibiotic production, which will eventually be scaled up to 10 000-litre fermentation vessels

## Commercial production of insulin

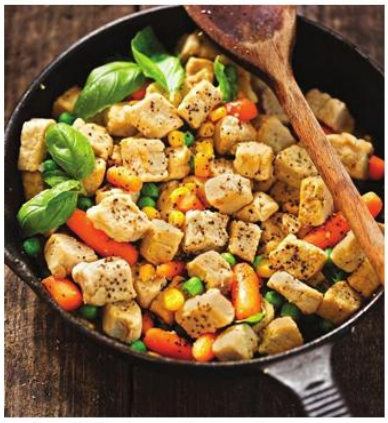
Insulin can be produced in large quantities using fermenters. The DNA in bacteria is genetically modified to carry the human insulin gene (insulin is a protein). Bacteria respire aerobically, so air is pumped into the fermenter. Other conditions such as nutrient levels, temperature, pH and moisture are maintained at optimum levels so that the bacteria grow and reproduce rapidly

## Penicillin

Antibiotics are produced in giant fermenting tanks, up to 100 000 litres in capacity. The tanks are filled with a nutrient solution. For penicillin production, the carbohydrate source is sugar, mainly lactose or corn steep liquor, which is a by-product of the manufacture of cornflour and maize starch. It contains amino acids as well as sugars. Mineral salts are added and the pH is adjusted to between 5 and 6. The temperature is maintained at about 26 °C, air is blown through the liquid and it is stirred. The main features of industrial fermentation are shown in Figure 18.3.

## Mycoprotein

Mycoprotein is a protein-rich meat substitute extracted from fungi. The filamentous fungus, Fusarium venenatum, is found in soil. Mycoprotein is becoming more popular because it contains no cholesterol and is lower in saturated fats than protein in meat products. It is suitable as part of a vegan diet (which contains no animal products), partly because of its high protein content.



## Conditions that need to be controlled in a fermenter

These have been described in the section on the commercial production of penicillin, above. Table 18.1 summarises these.

**Table 18.1** Conditions that need to be controlled in a fermenter in the manufacture of an antibiotic

| condition | details |
|---|---|
| temperature | maintained at around 26 °C. Heat is generated during fermentation, so the mixture needs to be cooled |
| pH | slightly acidic – 5 to 6 |
| oxygen | sterilised air is blown into the mixture through air pipes and the mixture is stirred to aerate it |
| nutrient supply | depends on what is being manufactured, but for penicillin the feedstock is molasses or corn-steep liquor |
| waste products | depends on what is being manufactured, but for penicillin they are the waste nutrient fluid with bacterial residue. These are quite hazardous because of the presence of traces of antibiotic. Gases given off may include carbon dioxide. |

## Genetic modification

As stated in the definition, genetic modification involves changing the genetic material of an organism by removing, changing or inserting material. It is achieved by transferring one or more genes from one organism to another organism, which is usually a totally unrelated species

**Key definitions**

**Genetic modification** is changing the genetic material of an organism by removing, changing or inserting individual genes.

## Use of bacteria in genetic modification

To understand the principles of genetic modification you need to know something about bacteria (Figure 1.9). Bacteria are microscopic single-celled organisms with cytoplasm, cell membranes and cell walls, but without a proper nucleus.

The human DNA in the plasmids continues to produce the same protein as it did in the human cells. In the example mentioned, this would be the protein, insulin (Chapter 14). The bacteria are cultured in special vessels called fermenters (Figure 18.4) and the insulin that they produce can be extracted from the culture medium and purified for use in treating diabetes (Chapter 14).

## Variations in genetic modification

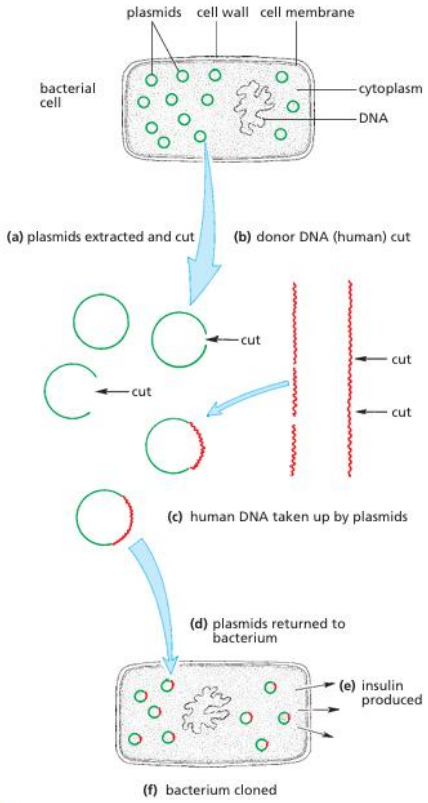
The plasmids are said to be the vectors that carry the human DNA into the bacteria and the technique is sometimes called gene-splicing. Using plasmids is only one type of genetic modification. The vector may be a virus rather than a plasmid; the DNA may be inserted directly, without a vector; the donor DNA may be synthesised from nucleotides rather than extracted from cells; yeast may be used instead of bacteria. The outcome, however, is the same. DNA from one species is inserted into a different species and made to produce its normal proteins

## Applications of genetic modification

The following section gives only a few examples of genetic modification, a rapidly advancing process. Some products, like insulin, are in full-scale production. A few genetically modified (GM) crops e.g. maize and soya bean) are being grown on a large scale in the USA.

## Production of human insulin

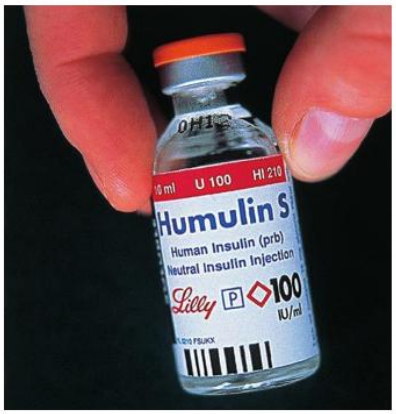
As stated in the previous section, human proteins like insulin can be produced by genetically modified bacteria, and it has been in use since 1982. The human insulin gene is inserted into bacteria, which then secrete human insulin. The human insulin produced in this way (Figure 18.7)




▲ **Figure 18.7** The principles of genetic modification

## GM crops

Genetic modification has huge potential benefits in agriculture but, apart from a relatively small range of crop plants, most developments are in the experimental or trial stages. In the USA, 94% of the soya bean crop and 92% of the maize harvest consist of genetically modified plants, which are resistant to **herbicides** and insect pests.




▲ **Figure 18.8** Human insulin prepared from genetically modified bacteria. Though free from foreign proteins, it does not suit all patients

## Herbicide resistance

Some of the most effective herbicides are those, like glyphosate, which kill any green plant but become harmless as soon as they reach the soil. These herbicides cannot be used on crops because they kill the crop plants as well as the weeds. A gene for an enzyme that breaks down glyphosate is introduced into a plant cell culture (Chapter 16). Most American GM maize has a herbicide-resistant gene. This should lead to a reduced use of herbicides

## Providing additional vitamins

Traditionally, vitamins and minerals have been added to food to boost their nutritional value or given in tablet form to help people avoid deficiency diseases. The development of GM technology is now allowing scientists to study other ways of helping populations to achieve a balanced diet.

▲ **Figure 18.10** The maize stem borer can cause considerable losses by killing young plants

# Advantages and disadvantages of genetic modification

## Crops

Although GM crops show increased yields, one of the objections is that only the farmers and the chemical companies in the industrialised world have benefited. So far, genetic modification has done little to improve yields or quality of crops in the newly industrialising world, except perhaps in China. However, there are many trials in progress, which have hopes of doing just that.

If the gene, or genes, for **nitrogen fixation** (Chapter 19) from bacteria or leguminous plants could be introduced to cereal crops, yields could be increased without the need to add fertilisers. Similarly, genes for drought resistance would make dry areas available for growing crops.

One of the possible harmful effects of planting GM crops is that their modified genes might get into wild plants. If a gene for herbicide resistance found its way, via pollination, into a weed plant, this plant might become resistant to herbicides and so become a super weed. The purpose of field trials is to assess the likelihood of this happening. Until it is certain that this is a tiny risk, licences to grow GM crops will not be issued.

## GM food

This is food prepared from GM crops. Most genetic modifications are aimed at increasing yields rather than changing the quality of food. However, it is possible to improve the protein, mineral or vitamin content of food (Figure 18.10) and the shelf life of some products.

▲ **Figure 18.11** Samples of golden rice and non-GM rice

Another concern is that GM food could contain pesticide residues or substances that cause allergies (allergens). However, all GM products are rigorously tested for toxins and allergens over many years, far more so than any products from conventional cross breeding.

There were also concerns about a reduction in **biodiversity** as a result of the introduction of GM species. Subsistence farmers could also be tied to large agricultural suppliers who may then manipulate seed prices.

## Bacteria

Bacteria are particularly useful in genetic modification because they have a rapid reproduction rate and there is a lack of ethical concerns over their manipulation and growth. Also, the genetic code in bacteria is shared with all other organisms.

## Revision questions

1. (i) State the genotypes of cats 1, 4, and 5 in Fig. 3.1.

(ii) Coat colour in cats is an example of discontinuous variation.
Explain why coat colour is an example of discontinuous variation.

**(a)** Sex in cats is determined in the same way as in humans.

Complete the diagram below to show how sex is determined in cats.

male cat × female cat

| | | female cat (XX) | |
|---|---|---|---|
| | gametes | X | X |
| male cat (.....) | ..... | | |
| | ..... | | |

offspring ratio..... [3]

**(b)** A scientist investigated the inheritance of fur colour in cats.

The gene for coat colour is located on the X chromosome. The gene has two alleles:

- **B** black
- **b** orange.

The X chromosome with the allele for black is represented by $X^B$.
The X chromosome with the allele for orange is $X^b$.

A female cat can be a mixture of these colours, described as calico.

Fig. 3.1 shows the inheritance of this condition in a family of cats.

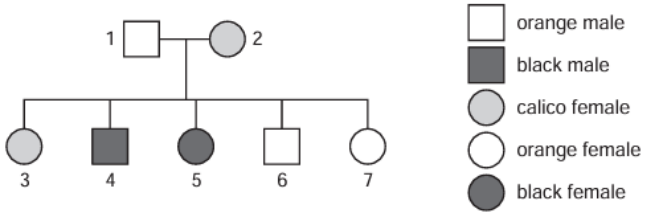



**Fig. 3.1**

2. Fig. 5.1 shows the nematode, Caenorhabditis elegans

(a) (i) State the genus of this nematode.

(ii) State two structural features of nematodes.

(b) Nematodes feed on dead and decaying material. Explain why this gives nematodes an important role in ecosystems.

**Fig. 5.1**

**(c)** Fig. 5.2 shows the life cycle of *C. elegans*. The diploid number of this species is 12.

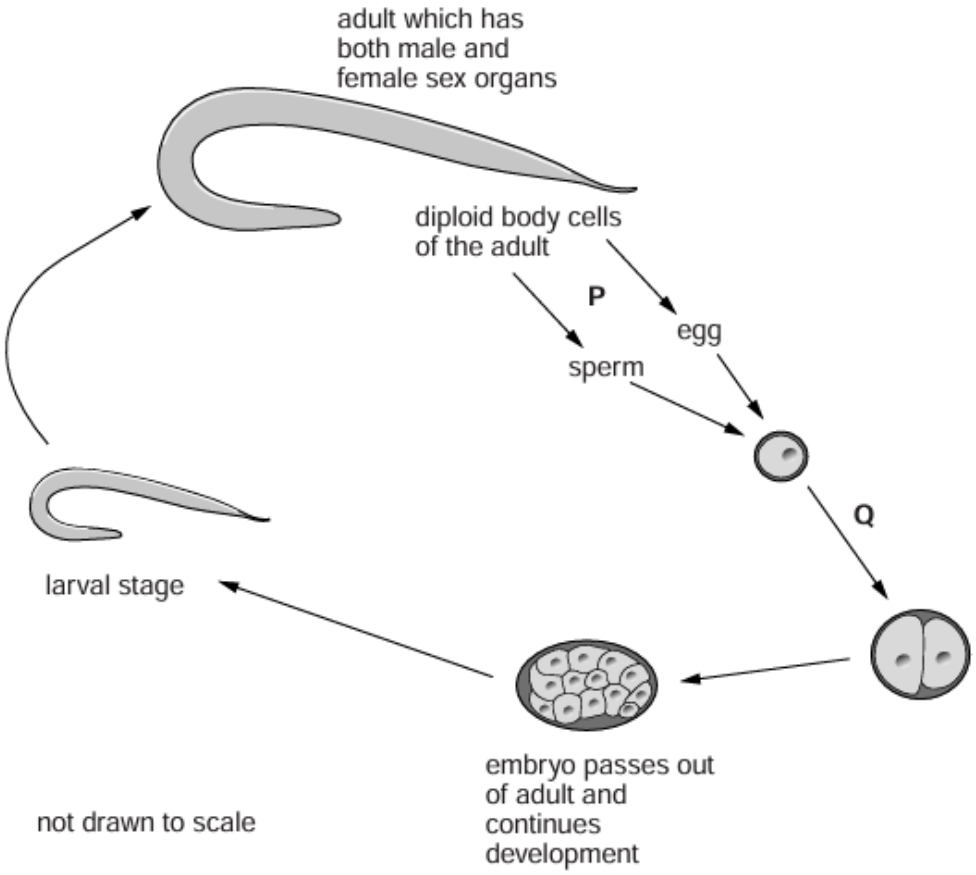



**Fig. 5.2**

**(i)** Suggest why there is very little genetic variation in the offspring of the adult nematode shown in Fig. 5.2.

(ii) State the haploid number of C. elegans.

iii) Explain why meiosis occurs at P and mitosis occurs at Q.

(d) C. elegans was one of the first organisms to have its genome sequenced. An organism's genome is the sum of all its genetic material. Gene sequencing identifies all the component parts of the DNA that makes up the genome. State where DNA is located in a cell

3. In tulip plants, the petals can have markings called flecks. There are two alleles for flecks in tulip plants: with flecks F; and without flecks f.

(a) Explain the meaning of the term dominant allele.

b) A tulip grower crosses two tulip plants. He finds that 76 of the offspring have petals with flecks and 23 of the offspring have petals without flecks.

**(i)** Complete the genetic diagram to explain this result.

*parental genotypes* ..... X .....

*parental phenotypes* ..... X .....

*gametes* (....) (....) X (....) (....)

*offspring genotypes* ..... .....

*offspring phenotypes* petals with flecks present petals without flecks

(ii) The tulip grower wants to produce a pure-breeding variety of tulips with petals without flecks. State the genotypes of the parent plants he should use to produce tulip plants without flecks. Explain your answer

*parental genotypes* ..... X .....

4.

**(a)** Sickle cell anaemia is an inherited disease. The gene for haemoglobin exists in two forms, $Hb^N$ and $Hb^S$. People who are $Hb^SHb^S$ have the disease and experience symptoms including fatigue and extreme pain in their joints. People who are $Hb^NHb^S$ are carriers of the disease and may have mild symptoms, if any at all.

**(i)** Table 2.1 shows four genetic terms.

Complete Table 2.1 by stating a specific example, used in the paragraph above, of each genetic term.

**Table 2.1**

| genetic term | example used in the passage |
|---|---|
| an allele | |
| a heterozygous genotype | |
| a homozygous genotype | |
| phenotype | |

(ii) Sickle cell anaemia is not found throughout the whole world. Most cases of the disease occur in sub-Saharan Africa and in parts of Asia.

The distribution is similar to that for the infectious disease malaria. Explain why the distribution of sickle cell anaemia and malaria are similar.

(b) Down's syndrome is an example of a characteristic that shows discontinuous variation. State the cause of Down's syndrome.

(c) Explain how discontinuous variation differs from continuous variation, in its expression and cause.

5. (a) Sickle cell anaemia is a genetic disorder that is found among people in certain parts of the world. A sample of blood was taken from a person with sickle cell anaemia and examined with an electron microscope.

Fig. 4.1 shows some of the red blood cells in the sample.

Explain the problems that may occur as these cells circulate in the blood system.

**Fig. 4.1**

**(b)** The gene for haemoglobin exists in two alternative forms:

$H^A$ codes for the normal form of haemoglobin;
$H^S$ codes for the abnormal form of haemoglobin.

**(i)** State the name for the alternative forms of a gene.

..... [1]

**(ii)** A child has sickle cell anaemia. The parents do not have this disorder.

Complete the genetic diagram to show how the child inherited the disorder.

**Use the symbols $H^A$ and $H^S$ in your answer.**

| | | | |
|---|---|---|---|
| *parental phenotypes* | normal | × | normal |
| *parental genotypes* | $H^AH^S$ | × | $H^AH^S$ |
| *gametes* | ◯ ◯ | + | ◯ ◯ |

*child's genotype* .....

*child's phenotype* sickle cell anaemia

[2]

Iii) The parents are about to have another child.
What is the probability that this child will have sickle cell anaemia?

6. a) The production of human gametes involves the type of nuclear division known as meiosis. State two reasons why meiosis is suitable for gamete production.

(b) The sex of a human fetus is determined by the sex chromosomes, X and Y. Fig. 5.1 shows the determination of sex in four different examples. Examples 3 and 4 show sex determination in twins.

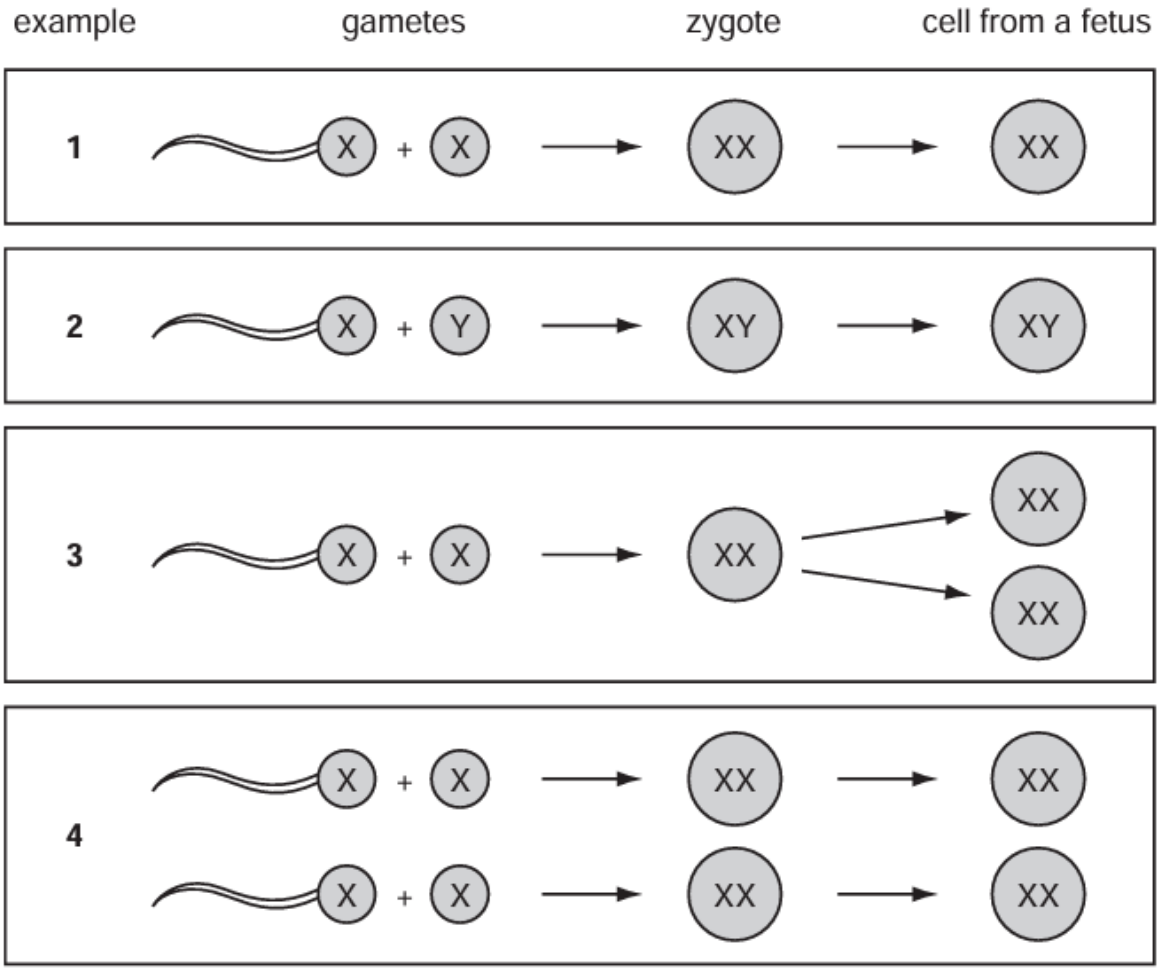



**Fig. 5.1**

(i) Use 5.1 to explain how the sex of a fetus is determined.

(ii) Examples 3 and 4 show two ways in which twins are formed. The twins in example 3 are identical. Use Fig. 5.1 to explain why.

(c) During the development of a fetus, different genes are expressed at different times. Explain what is meant by the term development

7. The flowers of pea plants, Pisum sativum, are produced for sexual reproduction. The flowers are naturally self-pollinating, but they can be cross-pollinated by insects.

(a) Explain the difference between self-pollination and cross-pollination.

(b) Explain the disadvantages for plants, such as P. sativum, of reproducing sexually.

Pea seeds develop inside pea pods after fertilisation. They contain starch. A gene controls the production of an enzyme involved in the synthesis of starch grains.

The allele, **R**, codes for an enzyme that produces normal starch grains.
This results in seeds that are round.

The allele, **r**, does not code for the enzyme. The starch grains are not formed normally. This results in seeds that are wrinkled.

Fig. 6.1 shows round and wrinkled pea seeds.

round pea seed wrinkled pea seed

**Fig. 6.1**

Pure bred plants are homozygous for the gene concerned. A plant breeder had some pure bred pea plants that had grown from round seeds and some pure bred plants that had grown from wrinkled seeds.

**(c)** State the genotypes of the pure bred plants that had grown from round and from wrinkled seeds.

8. (a Explain the meaning of the term transpiration.

(b) Root hair cells provide a large surface area for the absorption of water from the soil. Explain, using the term water potential, how water is absorbed from the soil into root hair cells.

**Fig. 3.1**

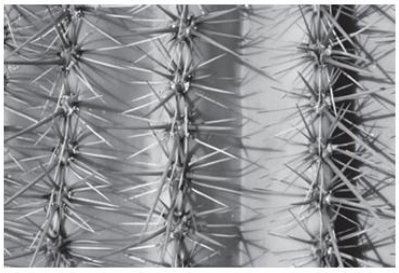


**Fig. 3.2**

Some plants are adapted for life in dry habitats where it can be very hot during the day and very cold at night. Fig. 3.1 shows some saguaro cacti from the Sonoran desert in Arizona and Mexico. Fig. 3.2 shows the surface of the stem of a saguaro cactus.

(c) Explain how two features, visible in Fig. 3.1 or Fig. 3.2, are adaptations to the conditions in the Sonoran desert

(d) The stomata of some desert plants, such as the saguaro cactus, open at night and close during the day. Explain how this allows the cacti to survive in the desert, but limits their growth rate

9. The field mustard plant, Brassica rapa, is cross-pollinated by insects.
(a) Describe the advantages of cross-pollination to plants.

Fig. 6.1 shows the events that follow pollination in B. rapa.

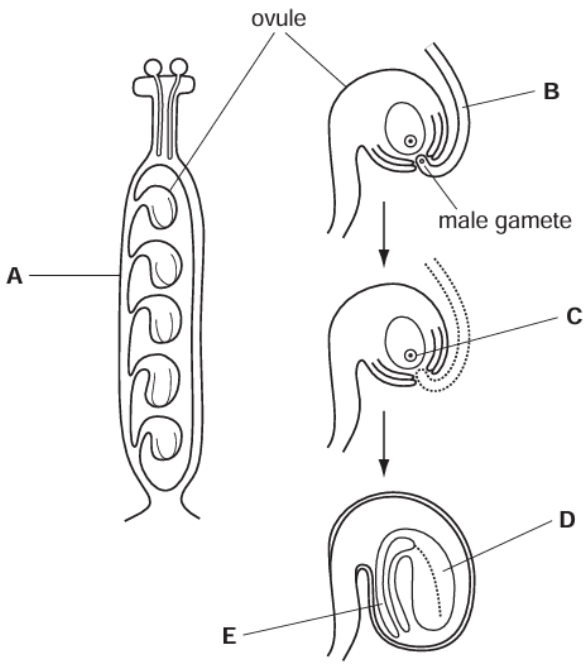



Fig. 6.1

(b) Name
(i) structures A to E.
ii) the type of nuclear division that occurs to produce the new cells as the seed grows.

(c) Explain why the genotypes of the seeds are not all the same

When ripe, the seed pod breaks open and the seeds are scattered. Some of the seeds germinate and grow into adult plants, but many do not.

(d) Explain why many seeds released by B. rapa do not germinate and grow into adult plants.

10. Transpiration and translocation are processes responsible for transporting materials around a plant.
(i) Complete the table by stating the materials moved by these processes, their sources and their sinks.

| process | materials moved | source of materials in the plant | sink for materials in the plant |
|---|---|---|---|
| transpiration | 1 .....<br>2 ..... | ..... | ..... |
| translocation | 1 .....<br>2 ..... | ..... | ..... |

ii) State two reasons why the source and sink for translocation in a plant may change at different stages in the growth of a plant.