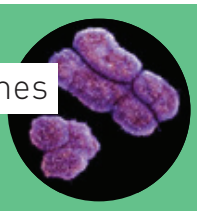
GENETICS

1



What if?

What you need:

coin (or plastic counter with 'Heads' written on one side and 'Tails' on the other)

What to do:

1 Toss the coin (or counter) five times and record the results in a table.

2 Predict how many heads or tails will land for the next five tosses.

What if?

» What if heads represented the chance of having a daughter and tails represented the chance of having a son? (Would this change the outcome?)

» What if heads represented the chance of having red hair and tails represented the chance of having black hair?

» What if you had a coin with two heads (for red hair)?

//SCIENCE AS A HUMAN ENDEAVOUR//

1.1 Scientists review the research of other scientists

Scientific understanding is constantly being reviewed, challenged and refined. Sometimes scientists collaborate and sometimes scientific teams 'compete' to make discoveries first. The scientific understanding of genes and DNA is no exception. Gregor Mendel is now known as the 'father of genetics'. He made his discoveries by studying peas. James Watson and Francis Crick used other people's research to develop the double helix model of DNA. Rosalind Franklin was mistaken for a laboratory assistant by a fellow researcher and her research on DNA was shown to competing scientists without her permission.

Figure 1.1 Gregor Johann Mendel, 1822–1884, is known as the father of genetics.

Gregor Mendel

Gregor Mendel was an Austrian monk and scientist who lived in Brno, which is in the modern Czech Republic (Figure 1.1). He was the first person to make accurate conclusions about how genes work. Mendel taught maths, but he loved experimenting with peas – and he did many experiments in his garden. In the mid-1800s, Mendel accurately concluded that genes exist in pairs (one from each parent) and that they can separate and form pairs again in the next generation. Mendel did not use the word 'gene'. Rather, he used the word 'factor' and said that a factor is something in the cell that controls a characteristic.

Before this, it was thought children inherited a group of characteristics 'mixed together' from both their parents, resulting in a mixing pot of looks, in the same way that red paint and yellow paint produces orange paint. Therefore, you can never separate the pure red or yellow forms again.

Mendel's research on pea plants led him to develop two important principles that form the basics of genetics today: the principle of segregation and the principle of independent assortment.

The importance of Mendel's work was not recognised until several decades after his death.

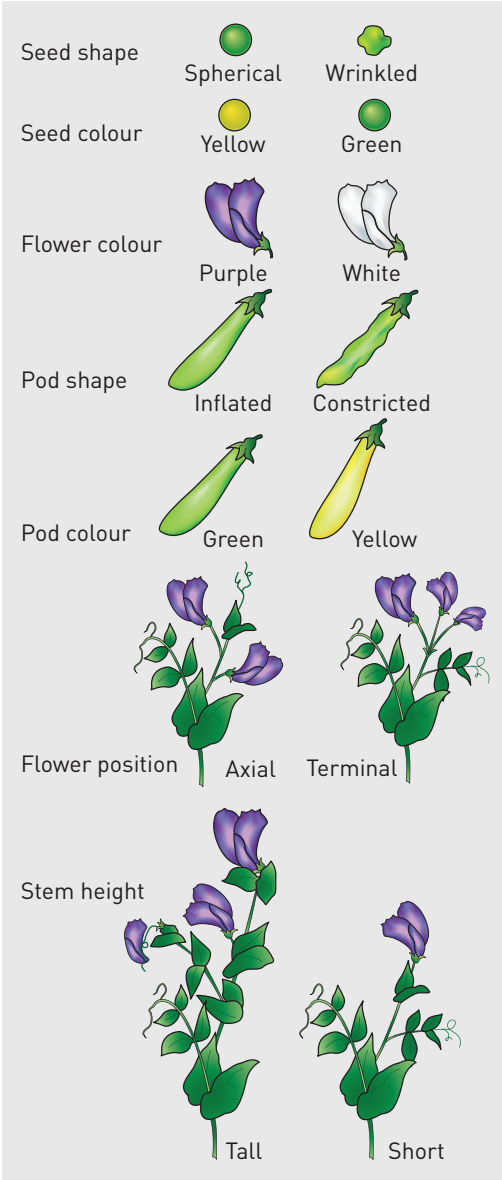


Figure 1.2 The seven traits, or characteristics, of pea plants studied by Mendel.

It wasn't until his experiments were repeated in 1900 that he received credit for his discoveries. All our current knowledge and understanding of genetics began and developed from Mendel's work. Mendel is considered the 'father of genetics'.

EXPERIMENT 1.1: EXTRACTING DNA
GO TO PAGE 180

Principle of segregation

Traits or characteristics of living things exist in pairs of factors. These factors must become separated or segregated before they can be passed on to offspring. Every organism inherits one set of factors from their mother and one set from their father.

Principle of independent assortment

The inheritance of one set of factors from one parent is independent from the inheritance of other factors. So, just because you inherit one factor (for example, blue eyes) from your mother, that does not mean you inherit all other factors from her (for example, her blonde hair and small nose). Factors are inherited independently from each other.

Watson and Crick's double helix discovery

Almost 70 years after Mendel's death, James Watson, a young chemist from the United States, went to the University of Cambridge, in the United Kingdom. There he met Francis Crick, an English physicist (Figure 1.3). They worked as a team to unravel the secret of the structure of **DNA (deoxyribonucleic acid)**, which they identified as a double helix (two-stranded spiral) in 1953. However, they performed no experiments themselves; their talent lay in interpreting the experimental results of others. Many scientists contributed to Watson and Crick's research on DNA, including Linus Pauling, Erwin Chargaff and Rosalind Franklin.

Rosalind Franklin

Rosalind Franklin had wanted to study science since the age of 15. With the reluctant acceptance of her father, Franklin eventually earned her doctorate in physical chemistry at the University of Cambridge in 1945 (Figure 1.4).

In 1951, she began work in John Randall's laboratory at King's College in London. When Franklin started work in Randall's laboratory, Maurice Wilkins (another scientist working on DNA) was away. When Randall gave Franklin responsibility for her part of the DNA project, no one had worked on it for months. When Wilkins returned, he misunderstood her role, treating her as though she were a technical assistant. Both scientists were actually peers. His mistake was not surprising given the situation for women at the university at the time. Only males were allowed in the university dining rooms, and after hours Franklin's colleagues went to men-only pubs.

Between 1951 and 1953, Franklin came very close to solving the DNA structure. She was beaten to publication by Crick and Watson in part because of the friction between Wilkins and herself. At one point, Wilkins showed Watson one of Franklin's crystallographic images of DNA (Figure 1.5). When Watson saw the picture, the solution became clear to him, and the results were published in the journal *Nature* almost immediately. Franklin's work appeared as a supporting article in the same issue of the journal.

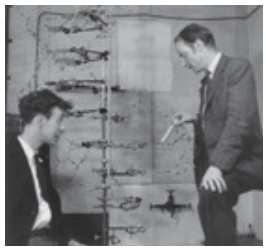


Figure 1.3 James Watson and Francis Crick with their DNA model. They interpreted other scientists' research.

Figure 1.4 Rosalind Franklin, 1920–1958. Her contribution to solving the structure of DNA was not acknowledged at the time.

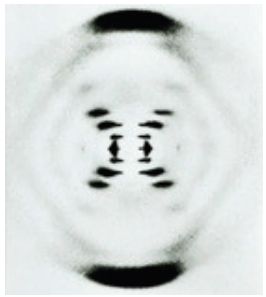


Figure 1.5 X-ray crystallography image of DNA taken by Rosalind Franklin.

Extend your understanding 1.1

1 According to Mendel, how many factors for a characteristic are present in the cells of each organism? Where do these factors come from?
2 Why did Mendel have such an influence on genetics?
3 Search the Internet to research the work of either Linus Pauling or Erwin Chargaff and explain their contribution to Watson and Crick's work.
4 Rosalind Franklin died from cancer at the age of 37. Watson and Crick received a Nobel Prize in 1962 for their work on the structure of DNA. The Nobel Prize cannot be awarded posthumously (after death). If Franklin had been alive, should she have been awarded the Nobel Prize with Watson and Crick? Provide arguments to support your answer.
5 Wilkins showed Franklin's results to Watson and Crick without her knowledge. If she had been given a choice, should she have shared her results with other scientists? Should all scientists share their results with each other? Provide reasons why or why not.

1.2 DNA consists of a sugar–phosphate backbone and four complementary nitrogen bases

Genes are made of a chemical called deoxyribonucleic acid (DNA). DNA is the genetic material that is passed from one generation to another. It is found in the nucleus of almost every cell in your body. The DNA molecule consists of two long, thin strands of complementary nucleotides that are held together by hydrogen bonds. The double-helix shape of DNA is often compared to a twisted ladder.

Your DNA blueprint

DNA is like a blueprint for every structure and function in an organism. It contains a code unique to the individual that can be passed to offspring, generation after generation, with little or no change. Each cell (except red blood cells) within a single organism contains DNA molecules with the same general structure. Each species has its own unique DNA that defines the species. However, individuals within a species have fine variations in the structure of their DNA and therefore in the code that it carries. An understanding of the structure of DNA enables us to explain the similarities and differences that exist between and within species.

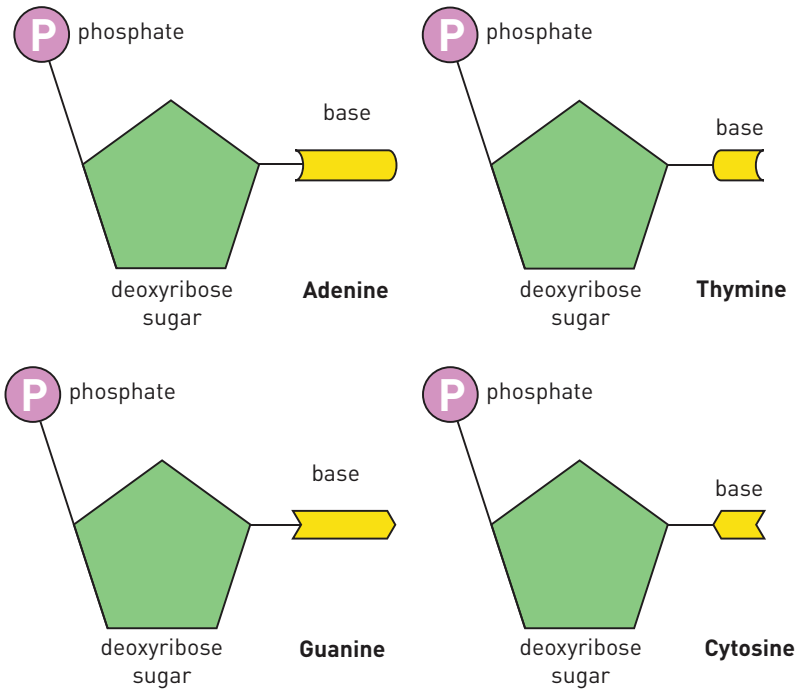


Figure 1.6 Nucleotides: the building blocks or subunits of DNA.

Structure of a nucleotide

Each DNA strand is like a necklace of beads. The individual 'beads' are called **nucleotides**. These are the subunits or building blocks of DNA (Figure 1.6).

A nucleotide is a complex molecule composed of three smaller molecules:

- a nitrogen base (sometimes just called a 'base')
- a sugar molecule (deoxyribose)
- a phosphate molecule.

In DNA there are four different types of nitrogen bases: **adenine** (A), **guanine** (G), **cytosine** (C) and **thymine** (T).

Structure of a polynucleotide chain

When nucleotides join together, they form a long polynucleotide chain called a nucleic acid. DNA is a nucleic acid.

Nucleotides are joined together by their sugar and phosphate groups. The sugar of one nucleotide is joined to the phosphate of the next nucleotide. This forms a sugar–phosphate backbone like the sides in a ladder (Figure 1.7).

Double helix

Two polynucleotide chains, or strands, are attached together by **hydrogen bonds** (relatively weak bonds) between the nitrogen bases. A large base (adenine or guanine) is always bonded to a small base (thymine or cytosine) because this gives the correct amount of space between the strands.

The four different types of nitrogen bases link in a specific way: adenine (A) always pairs with thymine (T) and cytosine (C) always pairs with guanine (G). These base pairs are called **complementary bases** or complementary base pairs. The two polynucleotides then wind into a double helix – the twisted ladder (Figure 1.8).

DNA molecules have two vital properties.

- DNA can make copies of itself: If two strands unwind, each strand can be used to make a new DNA molecule.
- DNA can carry information: The order of bases along a strand is a code for making proteins.

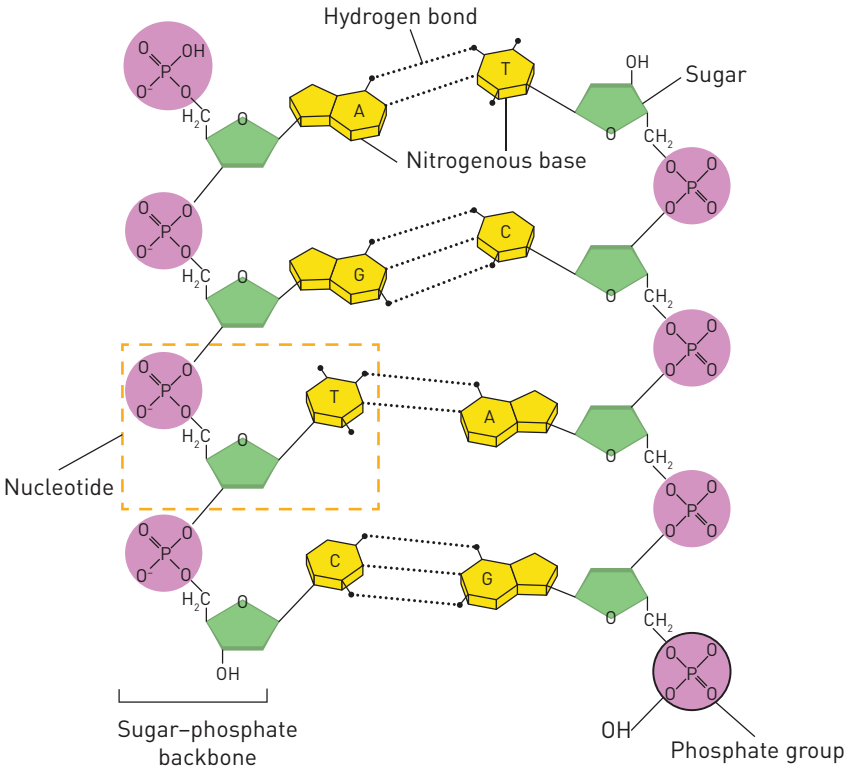


Figure 1.7 Nucleic acids like DNA are made of a chain of nucleotides joined together through a sugar–phosphate backbone.

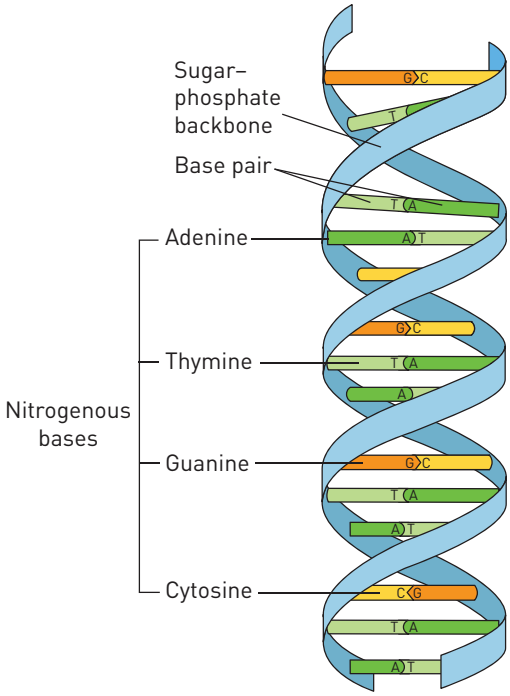


Figure 1.8 The DNA double helix. If you picture the DNA molecule as a twisted ladder, the sides are sugar and phosphate molecules and the rungs are pairs of nitrogen bases.

Check your learning 1.2

Remember and understand

1 What is a nucleotide?

2 Explain how nucleotides join together to form polynucleotides.

Apply and analyse

3 Explain how two polynucleotides can twist helically around each other to form a double helix of DNA.

4 What part of the DNA molecule varies? What part remains constant?

5 How does the order of the bases on one polynucleotide chain determine the order of the bases on the other chain?

6 What is the complementary DNA sequence of GTTAGCCAGT?

1.3 Chromosomes are DNA molecules carrying genetic information in the form of genes

Each cell in your body (except red blood cells) contains 46 chromosomes. These chromosomes are made up of DNA molecules tightly wound around proteins. Along the DNA strand are the sections called genes. When a protein needs to be made, the DNA in the gene unwinds to make a complementary copy of **ribonucleic acid (RNA)**. The RNA can leave the nucleus to make a protein in the cell's cytoplasm.

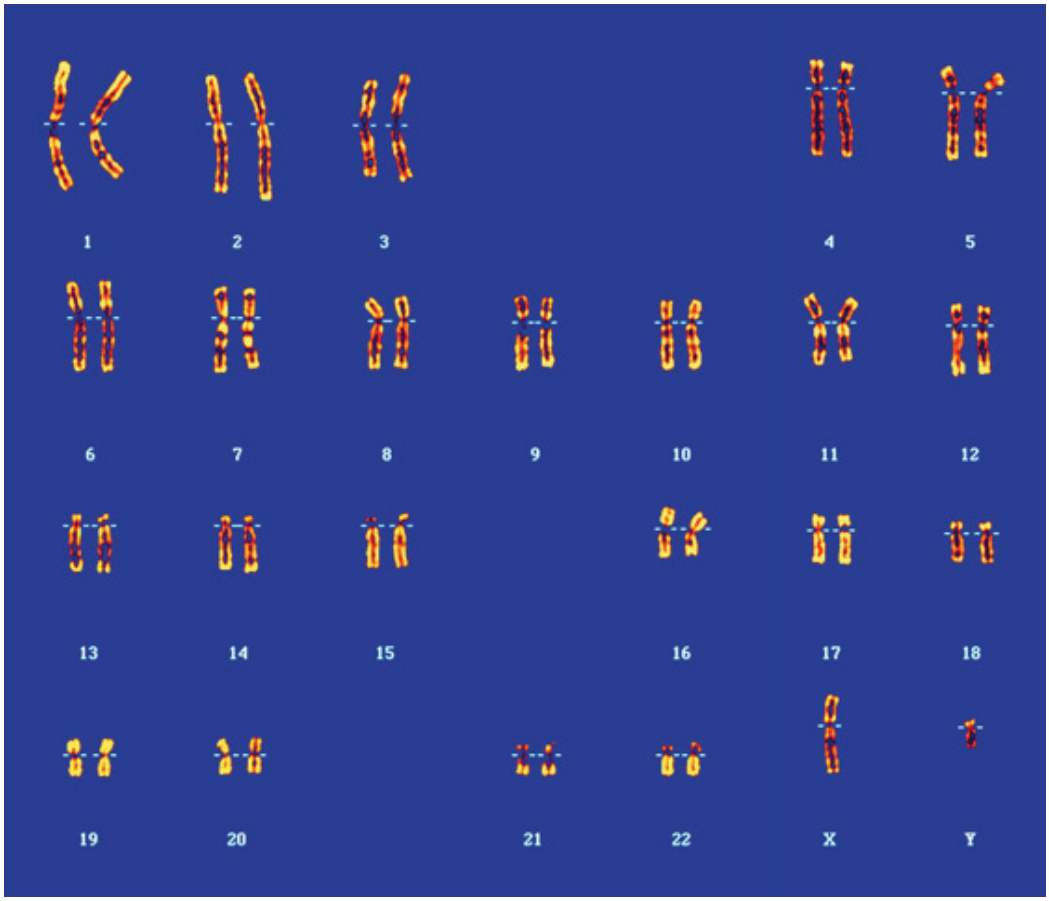


Figure 1.9 Pairs of chromosomes are often referred to by numbers according to their size – the largest pair is number 1. The last two chromosomes determine the sex of an individual. Human females have two X chromosomes and males have one X and one Y chromosome. This karyotype is from a male (XY).

SKILLS LAB 1.3: MAKING PROTEIN
GO TO PAGE 182

Relationship between DNA, chromosomes and genes

Inside the nucleus of a cell are the chromosomes. There are 46 chromosomes in a human nucleus: 23 of them come from the mother and 23 come from the father. Along the length of each chromosome, in specific positions, are the genes.

Chromosomes can be organised into pairs according to length and banding patterns. Pairs of matching chromosomes are called homologous. A picture of all the homologous chromosomes in a cell, arranged from largest to smallest, is called a **karyotype** (Figure 1.9).

How we relate chromosomes to DNA

DNA is found inside a cell's nucleus, looking a little like a pile of wool. By the time a cell is ready to divide, the DNA has copied itself and the chromosomes can clearly be seen under a microscope.

A simple equation to understand the relationship between DNA and chromosomes is:

A single chromosome = a molecule of DNA (a DNA helix)

Chromosomes may be single or bivalent. The **bivalent chromosome** is the 'X' that you are familiar with. The two strands of a bivalent chromosome are identical to each other. Bivalent chromosomes are formed during DNA replication so that two identical copies are produced. Each strand of a bivalent chromosome is called a **chromatid**. The two chromatids are joined at the centromere (Figure 1.11).

If the DNA in a single chromosome were unwound, it would be 5 cm long. With 46 chromosomes in the average human cell, this means all the unravelled DNA in a single cell would be approximately 2 m long! The DNA fits inside the cell because the DNA molecules are tightly wound around small proteins called histones. These histones stack tightly together and only unwind when the instructions they carry are needed by the cell.

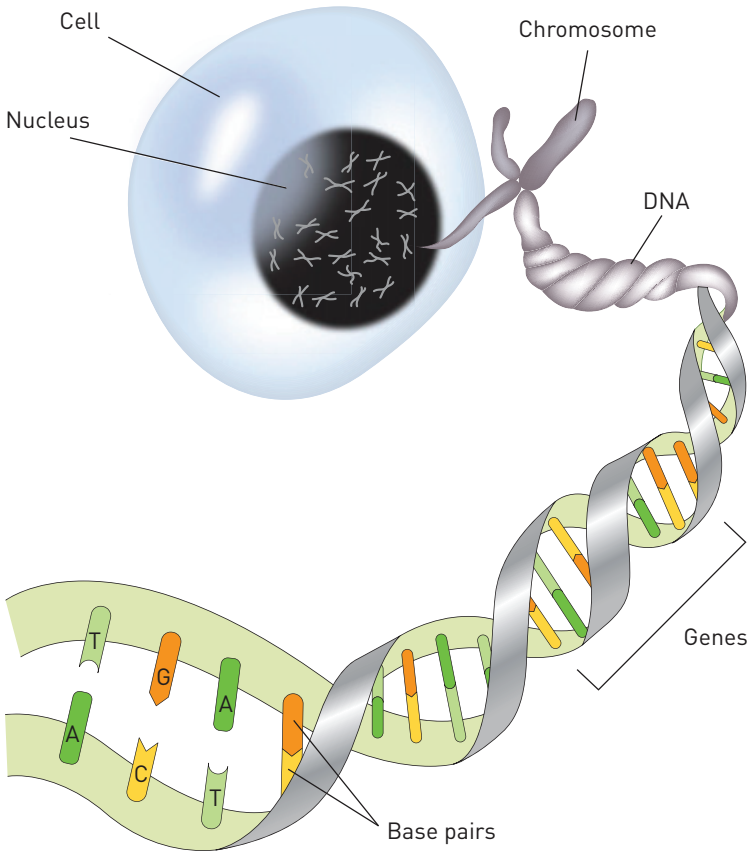


Figure 1.10 The relationship between DNA and chromosomes.

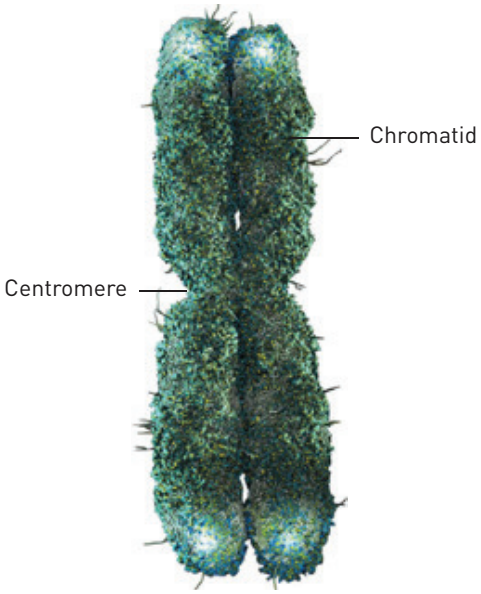


Figure 1.11 A bivalent chromosome is made up of two sister chromatids joined at the centromere.

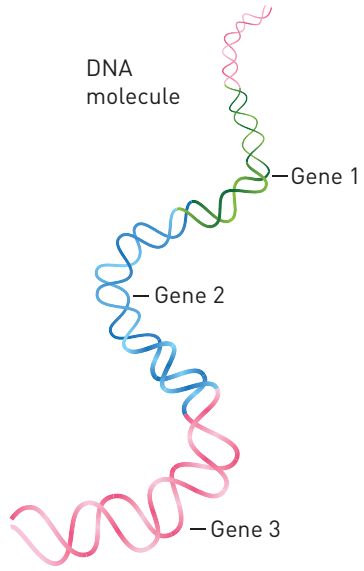


Figure 1.12 The relationship between DNA and genes.

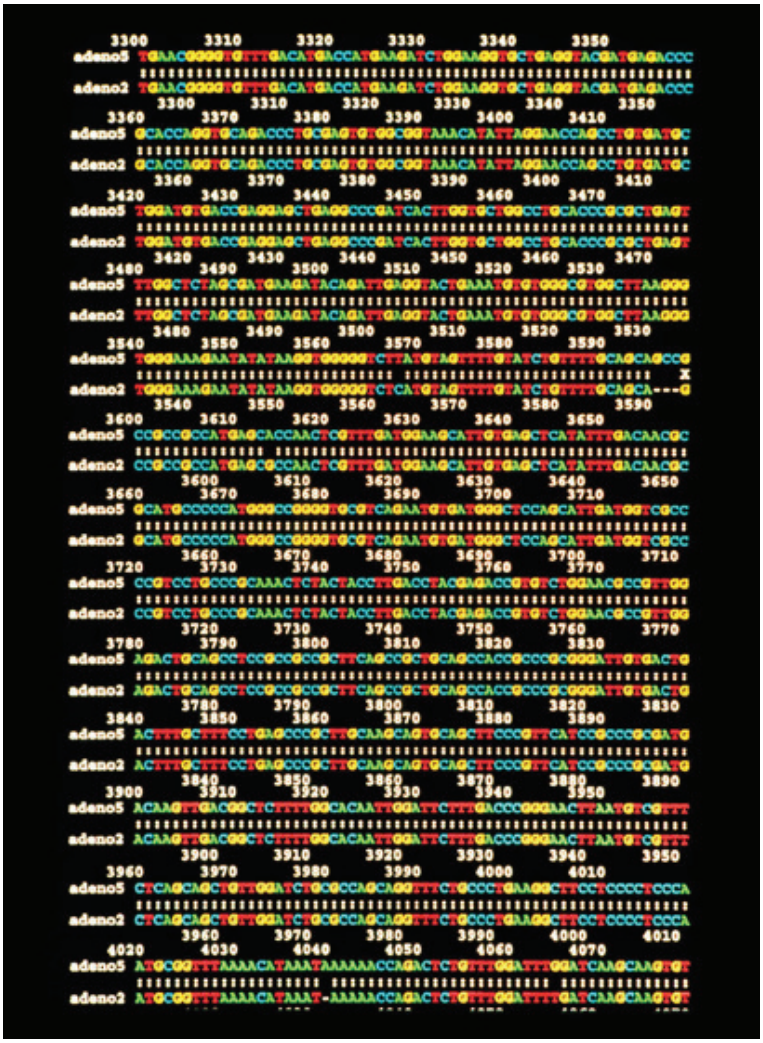


Figure 1.13 The sequence of bases on DNA is the coding system for life. The sequence of bases here comes from the DNA in adenovirus types 5 and 2. These viruses cause a range of illnesses including colds, sore throats and diarrhoea.

How we relate genes to DNA

DNA in chromosomes consists of sections that are genes (Figure 1.12). The order of nitrogen bases in each gene contains information for one characteristic or trait. For example, a gene may have information for making the pigment melanin, which gives our skin colour. Another gene may have the information for making keratin for hair and nails. So a chromosome, which contains many genes, is like a recipe book with a lot of recipes.

Genetic code

One major feature of DNA is its ability to replicate; the other is that it carries a genetic coding system for making proteins. The order of nitrogen bases on the DNA strands is the **genetic code** for an organism.

The genetic code specifies the structure of proteins (Figure 1.14). Some proteins (such as collagen) provide support for cells in the body. Other proteins are enzymes that help us digest food and speed up the chemical reactions of our metabolism.

How genes make protein

To synthesis protein, first the DNA double helix unwinds and one strand acts as a pattern or template to form a molecule of RNA (Figure 1.15).

RNA

RNA (ribonucleic acid) contains a ribose sugar, unlike DNA, which has a deoxygenated ribose sugar. The nitrogen bases of RNA are adenine, cytosine, guanine and **uracil**. RNA plays a key role in protein synthesis. RNA acts like a photocopy of the original DNA blueprint. This process of making an RNA copy from a DNA strand is called **transcription**.

Unlike DNA, RNA can leave the nucleus and attach to a ribosome in the cytoplasm. The RNA now 'tells' the ribosome the order in which to connect the amino acids that will make up a protein. The nitrogen bases on the RNA are read in groups of three, called codons. Each codon corresponds to a single amino acid. Eventually all the amino acids line up like beads on a necklace and form the finished protein. This process of forming a protein from RNA is called **translation**.

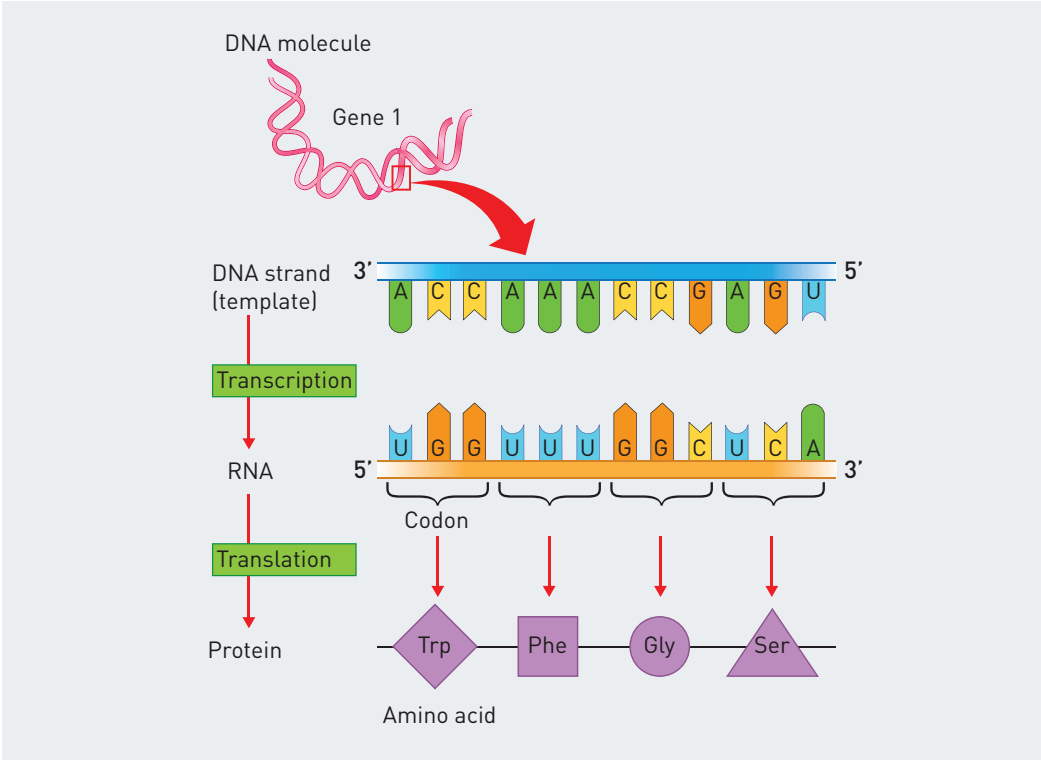


Figure 1.14 Protein synthesis.

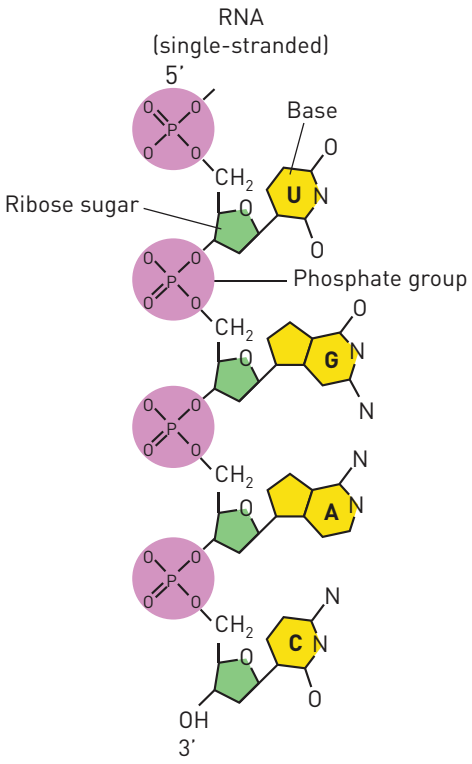


Figure 1.15 The structure of RNA.

Check your learning 1.3

Remember and understand

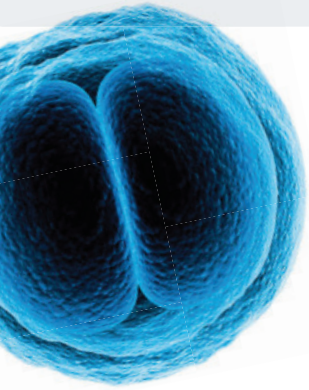
1. How many chromosomes are in each of your cells?
2. What is karyotyping?
3. What role does RNA play in the conversion of DNA information into protein?
4. How is a protein like a string of beads?

Apply and analyse

5. If part of a base sequence on one polynucleotide strand of DNA reads ACTGGCATTCAG, what is the base sequence of the corresponding part of the other polynucleotide strand? What is the base sequence of the RNA for which this strand acts as a template?
6. What is the difference between transcription and translation?
7. What would be the RNA sequence for the template DNA sequence GTTAGCCAGT? (Remember to pair uracil with adenine.)

1.4 Mitosis forms new somatic cells

Most of the cells in your body are somatic cells (all except sperm and egg cells). Somatic cells are **diploid**, which means they carry two sets of genetic material – one from the mother and one from the father. **Mitosis** is the division of the genetic material to produce two identical nuclei. The cell then divides in two in a process called **cytokinesis**. Together, these processes produce two new, genetically identical daughter cells.



Mitosis is cell division that does not change the number of chromosomes

Every organism needs to grow and repair damage throughout its lifetime. This means cells need to reproduce. Somatic cells are all the cells in the body except for the egg and sperm cells (which are called gametes). When somatic cells reproduce, they undergo a process called mitosis.

Mitosis is a type of cell division where one parent cell divides to form two genetically identical daughter cells. In humans, this means the parent cells have 46 chromosomes and the daughter cells each have 46 chromosomes.

Mitosis is essential for an organism to grow or repair damage. In humans, intestine cells replace themselves every 4 days, skin cells every 3 weeks and bones every 7–10 years. This means the body is constantly undergoing mitosis and cytokinesis.

Most of the time, cells that are not dividing are in the phase called interphase (Figure 1.16), in which they do everyday processes such as making proteins. Cells will only start mitosis when new cells are needed.

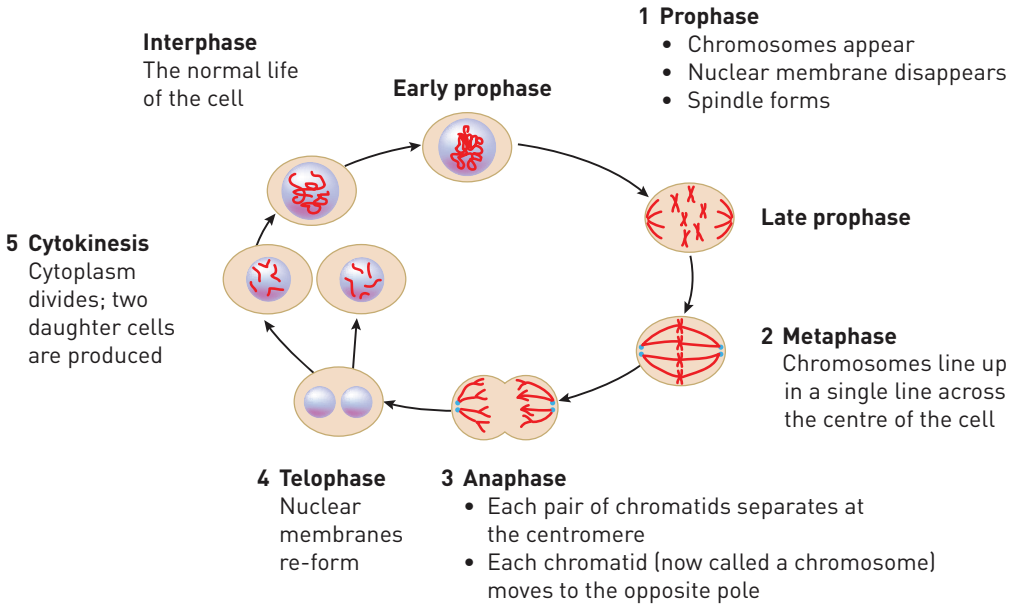


Figure 1.16 Interphase and the phases of mitosis.

SKILLS LAB 1.4: CELL DIVISION IN ACTION
GO TO PAGE 183

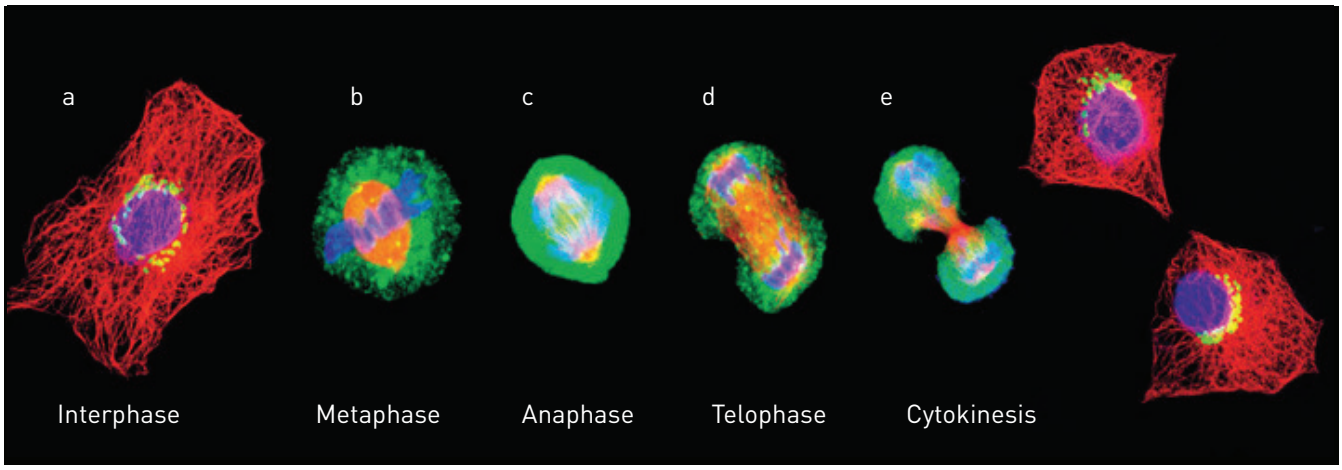


Figure 1.17 These mitotic cells have been stained with a fluorescent stain to show the separation of DNA. (a) The cell is at the end of interphase – the DNA has been replicated. During prophase, the nuclear membrane breaks down and the red spindle fibres bind to the centromere. (b) The (blue) chromosomes line up along the middle of the cell during metaphase. (c) Anaphase occurs when the spindles contract, separating the two chromatids at the centromere and pulling them to the end of the cell. (d) During telophase, the nuclear membrane re-forms around the two sets of DNA. (e) Cytokinesis occurs when the cell membrane divides in two.

Cancer: mitosis out of control

The rate of mitosis in a cell needs to be carefully controlled. Cells do not survive indefinitely in an organism. The death of a cell is carefully programmed into a cell's DNA. All cells are constantly checking to make sure that everything is running normally. If any errors occur, then the cell will undergo programmed cell death, called **apoptosis**. This checking of errors is especially important during mitosis. Before the cell enters prophase or telophase, the DNA is carefully checked to make sure there are two complete sets of unaltered chromosomes.

Sometimes the DNA of a cell can become damaged. This may be due to radiation, viruses or chemicals called mutagens. If this damage is not detected, then the cell may start undergoing continual cycles of mitosis without apoptosis. This is one of the key characteristics of cancer cells.

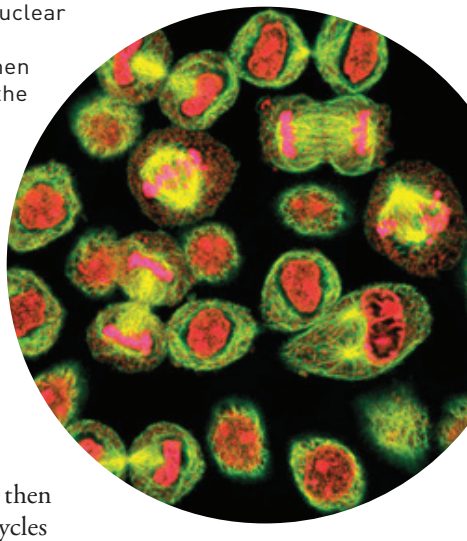


Figure 1.18 Stages of mitosis

Check your learning 1.4

Remember and understand

1 What is the difference between mitosis and cytokinesis?
2 Why do cells undergo mitosis?
3 In which phase do most cells spend most of their time?
4 Describe what happens in each phase of mitosis.

Apply and analyse

5 A cell that is about to undergo mitosis must double its amount of DNA. Suggest why this needs to occur.

Evaluate and create

6 Identify each of the stages of mitosis that are happening in Figure 1.18.
7 Write a story of a chromosome as it undergoes mitotic division. Describe how it replicates, remains attached at the centromere until anaphase, and the final goodbye during cytokinesis.

1.5 Meiosis forms gamete cells

A gamete is a sex cell (egg and sperm) that has half the genetic material of the parent cell. Gametes are **haploid**. **Meiosis** is the process of cell division that produces haploid gametes. Two haploid gametes combine to produce the first diploid cell of a new organism.

Meiosis is cell division in which the number of chromosomes is halved

Half of the genetic material in each of your cells comes from your mother, and the other half comes from your father. Have you ever wondered how the genetic material in one of your parent's cells divided in half?

A gamete is a sex cell. In animals, the male gamete is a sperm and the female gamete is an ovum. In flowering plants, the male gamete is contained in a pollen grain and the female gamete is located in the flower's ovary. The male and female gametes of a species join to form the first cell of the offspring.

Gametes differ from all other body cells because they contain half the number of chromosomes of somatic cells – they are haploid. Most somatic cells in your body contain 46 chromosomes arranged in pairs (two sets of 23 chromosomes, or 2*n*). They are diploid. Gametes (egg and sperm) in humans have 23 chromosomes (*n*) (Figure 1.20). When the egg and sperm combine at fertilisation, a diploid somatic cell is produced – one set of 23 chromosomes comes from the mother and one set of 23 chromosomes comes from the father. In this way, all children are similar, but not identical, to their parents.

Meiosis is a special type of cell division in which the number of chromosomes is halved. Meiosis occurs only when gametes are being made. It is sometimes called reduction division and occurs in two stages, known as meiosis I and meiosis II (Figure 1.22).

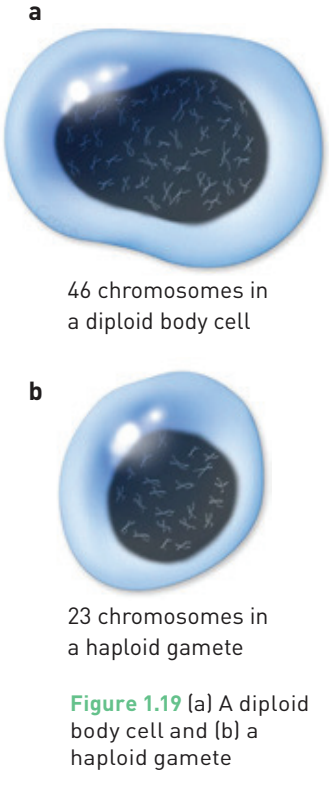


Figure 1.19 (a) A diploid body cell and (b) a haploid gamete

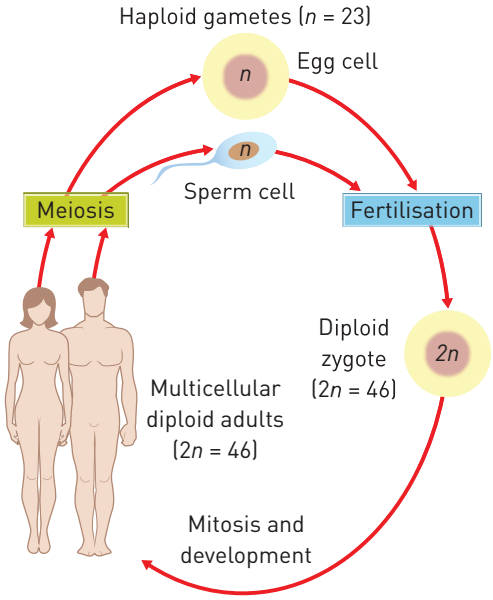


Figure 1.20 The human life cycle, involving mitosis and meiosis.

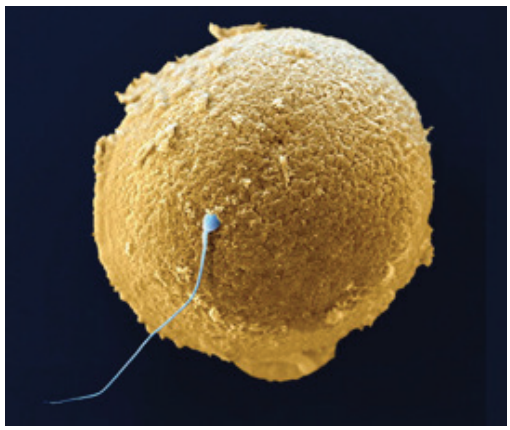


Figure 1.21 When a haploid sperm cell (*n*) fertilises a haploid egg cell (*n*), a diploid somatic cell (2*n*) is formed.

CHALLENGE 1.5: MODELLING MEIOSIS
GO TO PAGE 183

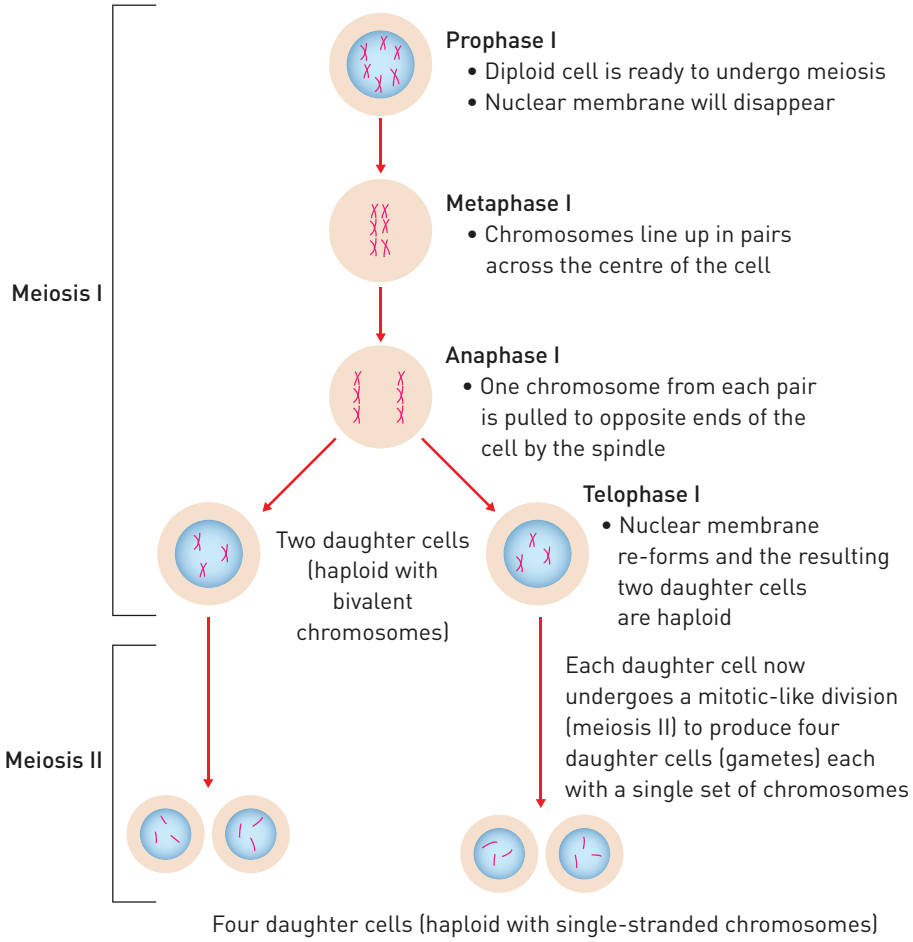


Figure 1.22 Meiosis consists of two rounds of each phase: prophase, metaphase, anaphase and telophase. If a gamete is fertilised, the chromosomes of the zygote will become diploid again so that the zygote can grow (by mitosis) into an embryo.

Check your learning 1.5

Remember and understand

1 What is the difference between a haploid cell and a diploid cell? Give an example of each.

2 Prepare a table showing the similarities and differences between mitosis and meiosis.

Apply and analyse

3 We all started from a single cell, a zygote, which then grew into an embryo. What type of cell division is involved in the growth of a zygote into an embryo? Explain your answer.

4 Are the offspring of sexually reproducing organisms identical to their parents?

5 Interphase is the 'normal' life stage of the cell – the stage between one mitotic division and the next. Interphase also occurs before meiotic divisions. What important process involving DNA occurs during interphase and why does it occur?

6 Why is it essential that the number of chromosomes is halved during meiosis?

7 The chromosomes in Figure 1.23 are separating at the centromere. What phase of meiosis is the cell undergoing?

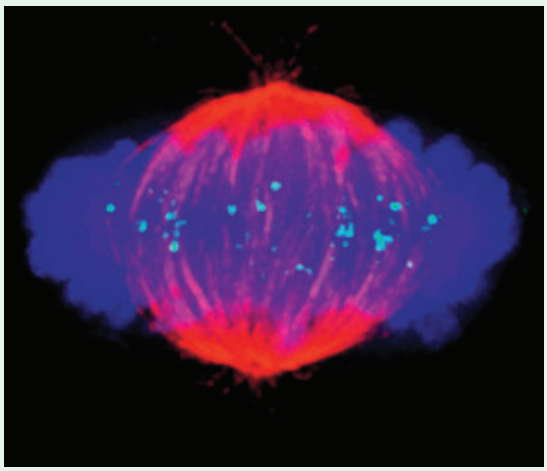


Figure 1.23

1.6 Alleles can produce dominant or recessive traits

Genes can have different versions (alleles) on the same location of a chromosome. The unique combination of alleles for a gene inherited from parents is called the **genotype** of the organism. **Homozygous** individuals have two identical alleles. **Heterozygous** individuals have two different alleles. Only a single allele for a trait needs to be present for a dominant trait to appear in the **phenotype**. Recessive traits need two copies of the allele before it can be expressed in the phenotype. A person who is heterozygous for a recessive trait is said to be a carrier for the trait. Phenotypes can be influenced by the environment.

Alleles

Have you ever wondered why some people look so much like their mother or father? Each cell in your body contains two sets of chromosomes – one from your mother and one from your father. If your mother has blue eyes, then you may inherit the gene for blue eyes from her. If your father has brown eyes, then you may inherit the gene for brown eyes from him. Both genes are for eye colour. Each version of the same gene (for eye colour) at the same position (or loci) of a chromosome is called an **allele**.

If a person has two identical alleles for a trait or characteristic, they are said to be homozygous for that trait. If a person has two different alleles for the same trait (for example, a blue eye allele and a brown eye allele), they are heterozygous for the trait.

If someone is heterozygous for eye colour, then the colour of their eyes is determined by which version is dominant. **Dominant traits** only need one copy of the allele to be visible in the appearance of the individual. Dominant traits are usually represented by capital letters. For example, brown eyes is a dominant trait and is often given the symbol 'B'.

Other traits are called **recessive traits**. These traits can only be seen if there are two copies of the allele present. The alleles for recessive traits are represented by lower-case letters. For example, blue eyes is a recessive trait and is often given the symbol 'b'.

Therefore, a person with blue eyes must have two alleles for blue eyes (bb). In contrast, a person with brown eyes could be homozygous (BB) or heterozygous (Bb) for the trait. A brown-eyed individual who is heterozygous for the trait is sometimes called a **carrier** for the blue eye trait. They have the allele for blue eyes, but the trait cannot be seen in their appearance.

The combination of allelic symbols that a person has for a trait (i.e. BB, Bb or bb) is called their genotype.

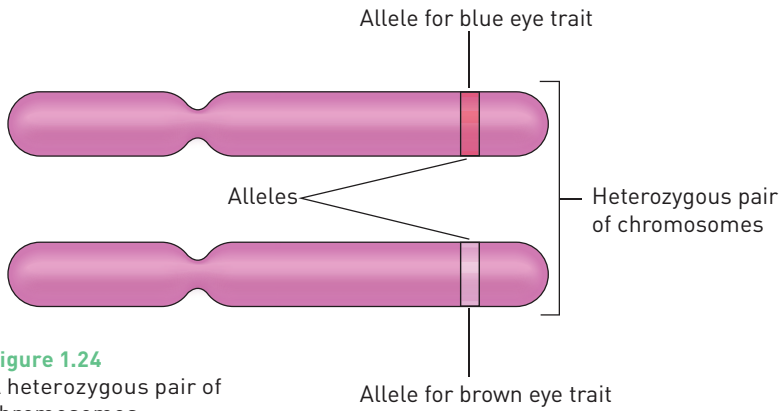


Figure 1.24
A heterozygous pair of chromosomes

EXPERIMENT 1.6: ZAZZLE GENETICS
GO TO PAGE 184

Figure 1.25 Genetically identical hydrangeas produce different coloured flowers depending on the environment.

Nature versus nurture

For over a century, scientists have puzzled over whether the genetic material you inherit (nature) or the environment in which you are raised (nurture) is more important in determining your characteristics. For example, genetically identical hydrangeas (Figure 1.25) that produce pink flowers in alkaline soil and blue flowers in acidic soil suggest that nurture is more important. However, the growth of the stem, flowers and leaves is a result of the genes in the plant.

Phenotype is the physical expression of a trait or characteristic that results from the genetic make-up of the organism and is influenced by the environment. An example is how tall you will grow. You inherit a series of genes from your parents that will determine your growth potential, but if you don't get enough food when you are growing, then you will not reach your full height.

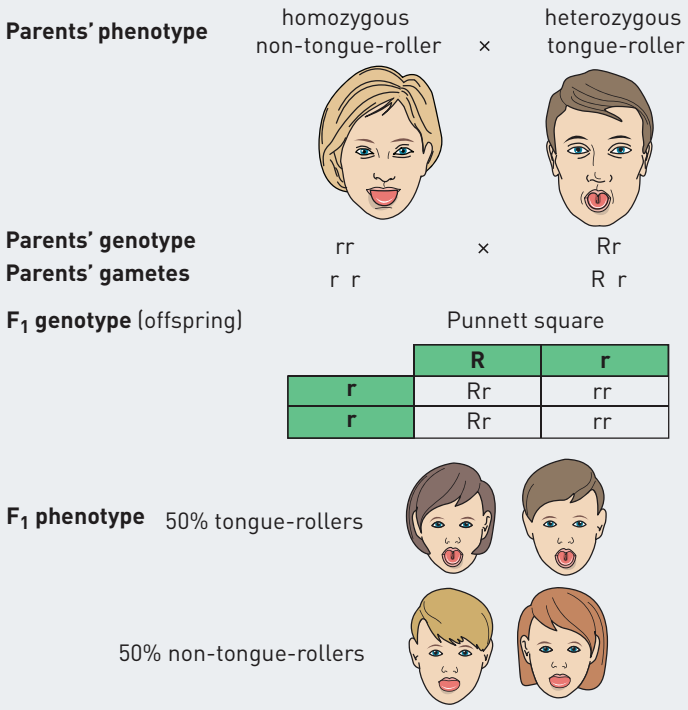


Figure 1.26 The ability to roll your tongue is inherited.

Monohybrid cross

Some traits, such as the ability to roll your tongue, are controlled by only one gene. This single gene has two alleles: one for rolling your tongue (the dominant trait, R) and one for non-tongue rolling (the recessive trait, r). We can examine how this single trait is passed on by using a **Punnett square** (Figure 1.26). In a Punnett square, the parents' genes are listed across the top and down the side. The remaining boxes are filled by combining the letters of each parent.

Check your learning 1.6

Remember and understand

1 Dimples (D) is dominant to no dimples. Write the genotypes for individuals who:
   a are homozygous for dimples
   b are heterozygous for dimples
   c have no dimples.
2 What is a carrier?

Apply and analyse

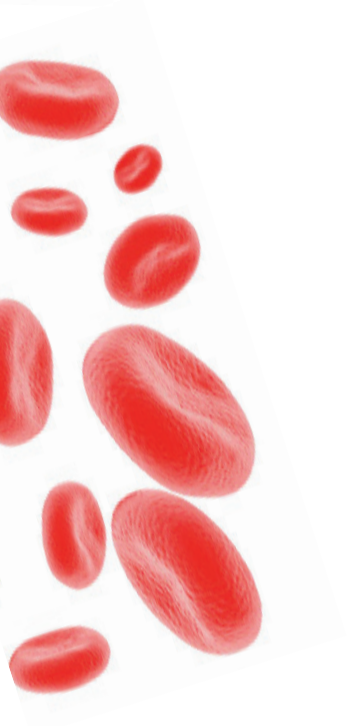
3 If the children of a right-handed man and a left-handed woman are all left-handed, does this mean that left-handedness is dominant? Provide evidence to support your view.
4 The trait for blue eyes is recessive to the trait for brown eyes. What are the chances of two blue-eyed parents having a brown-eyed child? What are the chances of two brown-eyed parents having a blue-eyed child?
5 Wavy hair in humans is dominant to straight hair. A wavy-haired man and a straight-haired woman have two children. The first child has wavy hair and the second child has straight hair. State the genotype of all four individuals and use suitable symbols to show your working.

Evaluate and create

6 A student wants to check if her grey cat is heterozygous or homozygous for coat colour. Assuming breeding was ethical and time efficient, what cross should she carry out? What results would she obtain if the cat is:
   a homozygous?
   b heterozygous?

1.7 Alleles for blood group traits co-dominate

Some traits do not dominate other traits. Red blood cells can display special molecule markers on their surface. These markers can be 'A' sugars or 'B' sugars. People with blood group A or blood group B display the sugar markers 'A' or 'B' respectively. Individuals with blood group O do not have either marker on their red blood cells. People with blood group AB display both markers on the surface of their red blood cells. This is an example of both traits being expressed equally. They are **co-dominant**.



Blood types

Some genotypes are more complex and involve more alleles. This is the case when determining your blood group. When stating your blood group, two components are usually referred to – a letter grouping (ABO) and whether you are Rhesus positive or negative. Rhesus markers are present on the surface of the red blood cells of 80% of people. These people are called Rhesus positive. If the Rhesus marker is not present on the red blood cells, the person is said to be Rhesus negative. People belong to one of four other main blood groupings. Table 1.1 shows the proportion of Australians who fall into each of four groups.

Table 1.1 Blood groupings in Australia

BLOOD GROUP (PHENOTYPE)	FREQUENCY IN AUSTRALIAN POPULATION (%)	FREQUENCY IN AUSTRALIAN POPULATION OF RHESUS POSITIVE (%)	FREQUENCY IN AUSTRALIAN POPULATION OF RHESUS NEGATIVE (%)
O	49	40	9
A	38	31	7
B	10	8	2
AB	3	2	1

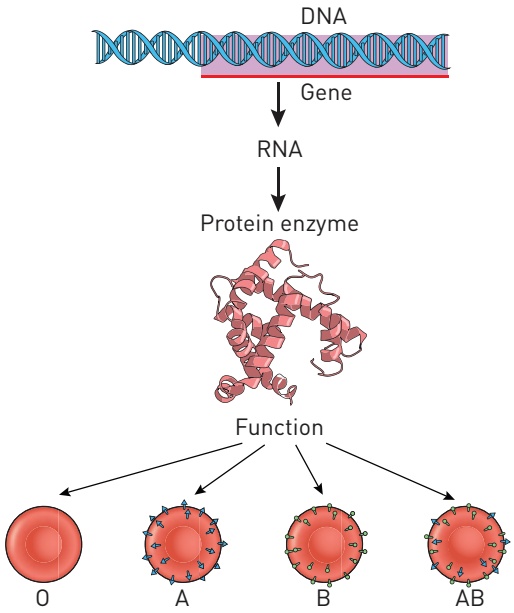


Figure 1.27 Genes for blood type produce an enzyme that makes a sugar (A or B) on the surface of a red blood cell.

People who have blood group A have red blood cells that display a special sugar marker A on the surface of their red blood cells. People who are blood group B display sugar marker B on their red blood cells. Group AB people display both markers A and B and people in blood group O have neither marker. The gene for each of these traits produces an enzyme (a protein) that makes the specific red blood cell sugar marker (Figure 1.27).

It is important to know your blood group because mixing different types of blood can cause clots to form that block blood vessels. A person who is transfused with the wrong type of blood can die.

EXPERIMENT 1.7: BLOOD TYPING EXPERIMENT
GO TO PAGE 185

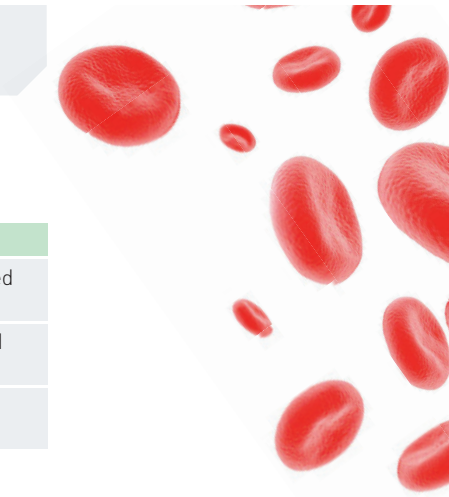


Table 1.2 Blood group alleles

TRAIT	ALLELE SYMBOL	FUNCTION
Dominant trait	I^A	Produces an enzyme that forms an A sugar on red blood cells.
Dominant trait	I^B	Produces an enzyme that forms a B sugar on red blood cells.
Recessive trait	i	Results in a non-functioning enzyme. No specific sugar on the surface of red blood cells.

ABO blood grouping is determined by a different gene from Rhesus grouping, so the inheritance of each component must be investigated separately. Three alleles determine the ABO blood group (Table 1.2). Depending on which of these three alleles you inherit from your parents, your blood group may be different from that of your parents or your siblings.

The I^A and I^B alleles are described as co-dominant. In other words, they are expressed equally together, rather than one being dominant over the other. However, either of these alleles is completely dominant over the recessive trait (i).

Consider a couple – Greg, who is blood group A, and Ellie, who is blood group B. Both Greg's mother and Ellie's mother were blood group O. What are the possibilities for their child in terms of their blood group? To answer this question, we first need to consider the phenotype and then the genotype of each parent (Figure 1.28).

We know that Greg's blood group is A. This means there are two possibilities for his genotype: I^AI^A or I^Ai. We know that Greg's mother was blood group O, which means that Greg could have only inherited the alleles for the recessive trait(i) from his mother and so he must be heterozygous (I^Ai). By applying the same process to Ellie, you can determine that she is I^Bi.

In the process of meiosis, Greg can pass on only one of his two chromosomes and, hence, either the I^A or i allele. Likewise, Ellie can only pass on the I^B or i allele. The chance of either allele being inherited is equal (i.e. 50% or ½). This information can be used to construct a Punnett square, as shown in Figure 1.28.

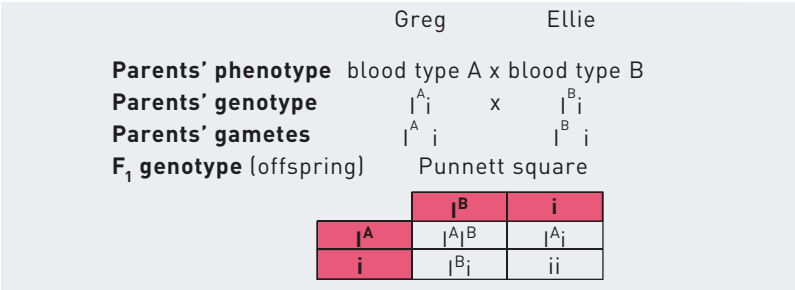


Figure 1.28 Determining blood types of offspring.

Thus, the four possibilities for Greg and Ellie's child with respect to ABO blood groups are:

Genotypic ratio: ¼ I^AI^B : ¼ I^Ai : ¼ I^Bi : ¼ ii

Phenotypic ratio: ¼ AB: ¼ A: ¼ B: ¼ O

Check your learning 1.7

Remember and understand

1. Why is it important to know your blood group?
2. From Table 1.1, in Australia what blood group is the:
   a. most common?
   b. least common?
3. Complete the following table to record the possible genotypes that combine to produce each blood group phenotype and the sugars displayed.

BLOOD GROUP (PHENOTYPE)	POSSIBLE GENOTYPES	SUGARS DISPLAYED ON A RED BLOOD CELL
O		
A		
B		
AB		

Apply and analyse

4. Consider two parents who are both blood group O. What blood groups could their children have?
5. Vinda is homozygous for blood group A. Julie is heterozygous for blood group B. Use a Punnett square to determine the possible genotype(s) and blood group(s) for a child of Vinda and Julie.
6. If Vinda and Julie have a second child, will the blood group of the first child affect that of the second? Explain your reasoning.

1.8 Alleles on the sex chromosomes produce sex-linked traits

Sex chromosomes are chromosomes that determine the sex of an organism. Human females have two X chromosomes and human males have an X and a Y chromosome. **Sex chromosomes** contain genes that are inherited in a unique way. Fathers pass their X chromosome to all their daughters and their Y chromosome to all their sons. Mothers will pass one X chromosome to each of their children. **Autosomes** are non-sex chromosomes.

Sex chromosomes

Humans have 22 pairs of chromosomes that are not sex chromosomes, called autosomes. The 23rd pair of chromosomes are the sex chromosomes. The genotype for the sex chromosomes in a female is XX and the genotype for a male is XY. These chromosomes contain the genes with information for sexual traits.

The X chromosome is larger than the Y chromosome (Figure 1.29). In addition to carrying genes for sexual characteristics, it contains information for non-sexual characteristics, such as blood clotting and red–green colour vision. Traits (and the genes that determine them) that are carried on a sex chromosome are said to be sex linked. Males show deficiencies in these genes more commonly than females because they only have one X chromosome.

In general, when investigating the pattern of inheritance for a particular trait (characteristic), it is useful to consider each trait as one of the following four types:

- autosomal dominant
- autosomal recessive
- X-linked dominant
- X-linked recessive.

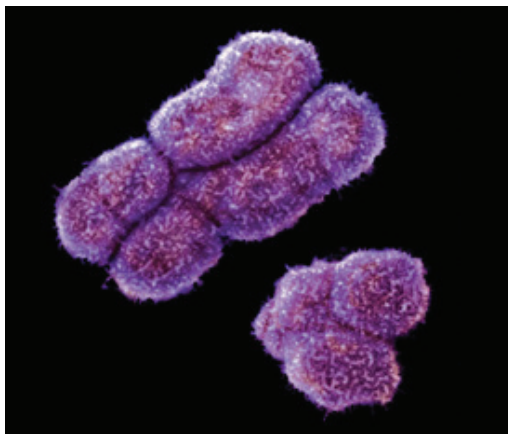


Figure 1.29 The X chromosome (left) is much larger than the Y chromosome (right) and carries more genetic information.

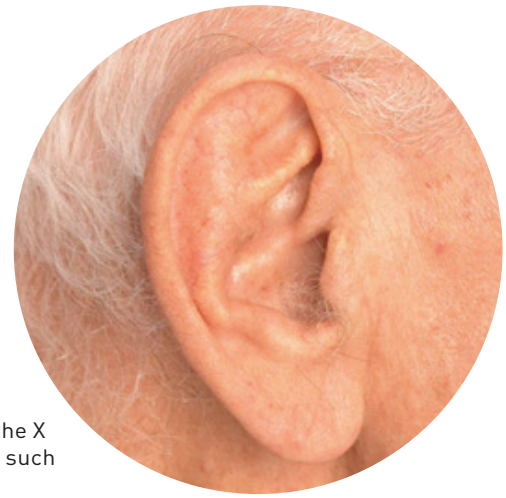


Figure 1.30 Most sex-linked genes are situated on the X chromosome. There are only a few Y-linked genes, such as hairy ears. So only males have hairy ears.

EXPERIMENT 1.8: COLOUR-BLINDNESS INHERITANCE
GO TO PAGE 186

Figure 1.31 A male gets his X chromosome from his mother and his Y chromosome from his father. A female gets one of her X chromosomes from her mother and the other from her father.

Table 1.3 The four patterns of inheritance

	DOMINANT	RECESSIVE
Autosomal	• Males and females are affected equally over a large sample size. • Affected offspring have at least one affected parent (i.e. does not skip a generation).	• Males and females are affected equally over a large sample size. • Affected offspring may have unaffected parents (i.e. parents may be carriers).
X-linked	• Generally, more females than males are affected. • Affected offspring have at least one affected parent (i.e. does not skip a generation). • An affected father will pass the trait to all daughters, but not to any sons. • An affected mother has a 50% chance of passing the trait to any son or daughter.	• Generally, more males than females are affected; females are carriers. • Affected offspring may have unaffected parents (men cannot be carriers, but women may be). • A carrier mother has a 50% chance of passing the trait on to each son. • Daughters of an affected father will all be carriers.

Sex-linked conditions

Two conditions that are caused by defective sex-linked genes are red–green colour blindness and haemophilia.

Red–green colour blindness is an X-linked recessive trait. This means the red–green colour-blindness allele is found on the X chromosome and the trait only appears if no 'normal' alleles for this gene are present. The colour receptors in the retina of the eye are controlled by a gene on the X chromosome. When the gene is defective, the colour receptors do not function properly and the person cannot distinguish red from green (Figure 1.32). Approximately 8% of males and less than 1% of females have red–green colour blindness. It is very rare for a female to have two defective genes, but not so rare for them to be 'carriers' (heterozygous) of the defective gene.

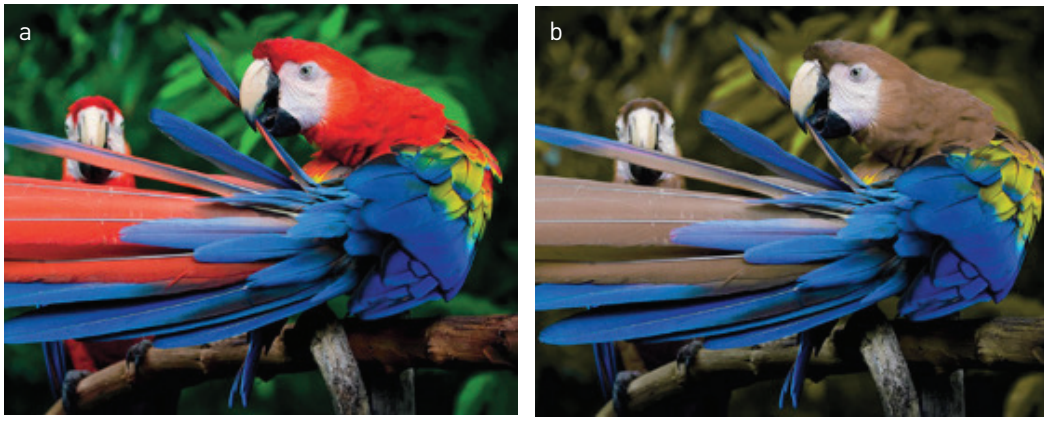


Figure 1.32 A person with colour blindness will have a very different view of the world. (a) A person with normal vision can see all the colours of these parrots. (b) A person with colour blindness would not be able to see the red and green feathers.

Figure 1.33 Queen Victoria's granddaughter Alexandra, her husband Nicholas II (the last Tsar of Russia) and their son Alexei, who suffered from haemophilia.

Haemophilia is a disease that prevents the blood from clotting. This occurs when the X-linked gene that controls one of the clotting factors is defective. Even a small injury to a person with haemophilia can result in prolonged bleeding. It is possible to treat this disease today because the clotting factors can be produced from donated blood or made in the laboratory. These clotting factors are given by injection.

In the past, there was no treatment for haemophilia. Queen Victoria, Queen of the United Kingdom, appears to have had a spontaneous mutation in the gene on the X chromosome for making a blood clotting factor. She passed this defective gene on to some members of her family. When her male descendants inherited the X chromosome with the 'defective' allele, they often died prematurely.

Queen Victoria's granddaughter Alexandra was a carrier of the haemophilia gene. She married the last Tsar of Russia, Nicholas II, with whom she had four unaffected daughters and a son, Alexei, with haemophilia (Figure 1.33). Alexei's disease caused great stress to the family. Alexandra even consulted the monk Rasputin to pray over him, but there was no reliable treatment for haemophilia in the early 20th century.

Communicating sex-linkage

When writing genotypes for sex-linked crosses, it is important to show the allele as being attached to either the X or the Y chromosome because the gender of the offspring is important in determining phenotype.

For example, in colour blindness, using X for normal and X^c for colour blindness, the genotype for a colour-blind female is X^cX^c, the genotype of a carrier female is XX^c and the genotype for a colour-blind male is X^cY. For haemophilia, we can use X^H and X^h to represent the normal allele and the allele for haemophilia, respectively (see Figure 1.34).

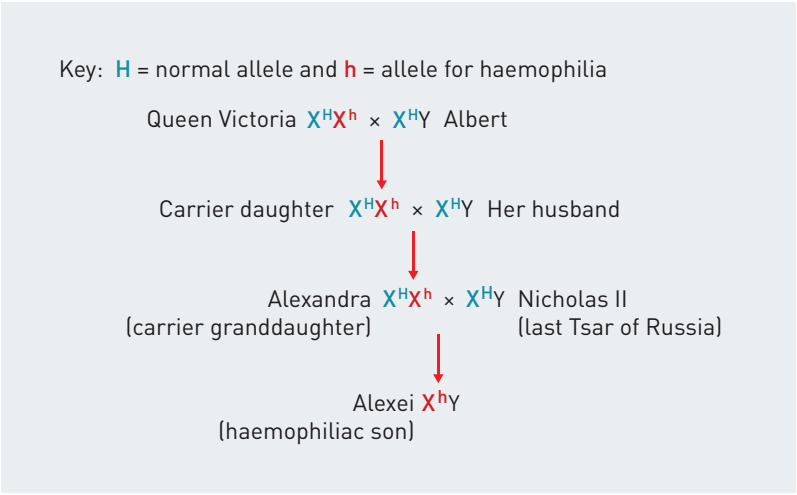


Figure 1.34 Genotypes in the family tree of Queen Victoria leading to Alexei.

Check your learning 1.8

For the following questions, assume that the sex-linked gene is X-linked and recessive.

Remember and understand

1 Why does a defect in a sex-linked gene affect males more than females?

Apply and analyse

2 A man and a woman, both of whom had normal sight, had three children, two boys and a girl. One of the boys had normal sight and the other was red–green colour blind. The girl had normal sight. Write the genotypes for this family.

3 The girl from the family in question 2 married a normal-sighted man and had a son who was colour blind. Write the genotypes for this family.

4 The colour-blind son from the family in question 3 married a normal-sighted woman and had a son with normal sight and a colour-blind daughter. Write their genotypes.

5 What is the probability that the four girls in the family of the last Russian Tsar were carriers of the allele for haemophilia?

6 Who will be affected by a Y-linked gene? Explain your answer.

7 If a man has a mutated gene on his Y chromosome, which grandparent did he inherit it from?

Evaluate and create

8 Tortoiseshell cats have fur coats that are a combination of orange and black. The gene for hair colour is found on the X chromosome.

a Explain why all tortoiseshell cats are female. Use diagrams to explain your answer.

b What colour would the offspring of a tortoiseshell and a black cat be?

Figure 1.35 Tortoiseshell cat

1.9 Inheritance of traits can be shown on pedigrees

Pedigrees are a diagrammatic way to show the inheritance pattern of a trait. Symbols are used to represent different individuals in a family. Circles represent females and squares represent males. Symbols that are shaded represent individuals who express the trait. Generations are indicated by Roman numerals and individuals are numbered from left to right. Recessive traits may skip a generation. Once a dominant trait disappears from a family line, it will not reappear.

Pedigree construction and analysis

Although each of your parents contributed to your genotype, the genotypes of other family members (e.g. grandparents, aunts and uncles) can all be important in explaining who you are. Inheritance of characteristics is often traced through families using family tree diagrams or pedigrees. There are specific symbols used in constructing pedigrees (you can see these in Figure 1.36).

- Males are represented by squares and females by circles.
- A marriage is shown by a horizontal line; a vertical line leads to the offspring.
- The characteristic being studied is shown by shading.
- Generation numbers are represented by Roman numerals and individuals are represented by Arabic numerals.

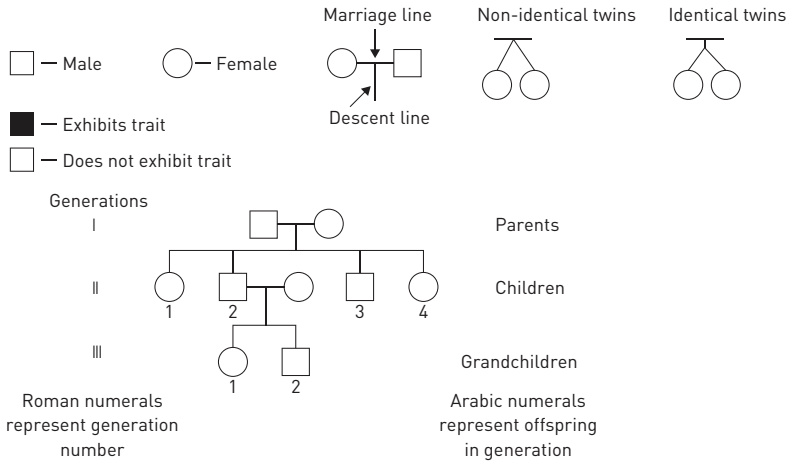


Figure 1.36 Some symbols used in family tree diagrams.

When analysing a pedigree to determine whether a trait is dominant or recessive, the following rules apply.

- If neither parent has a characteristic and some of their offspring have it, then the characteristic is recessive (i.e. both parents are carrying the allele for the recessive trait but it is not shown in their phenotype).
- If both parents have a characteristic and some of their children have it, then the characteristic is dominant (i.e. both parents are heterozygous).
- If both parents have a characteristic and none of their children has it, then the characteristic is dominant (because, if both parents have a characteristic and it is recessive, then all of their children will have that characteristic).

Hence, for the pedigree in Figure 1.37, red hair is recessive because individual II2 and his partner do not have red hair but some of their children have it. They are both carrying the allele for red hair, but not expressing it. They both contribute their allele for red hair to some of their offspring.

In the pedigree shown in Figure 1.38, tongue rolling is dominant. This is because individual II1 and her partner can roll their tongues and some of their offspring can and some cannot. The parents are both heterozygous for tongue rolling.

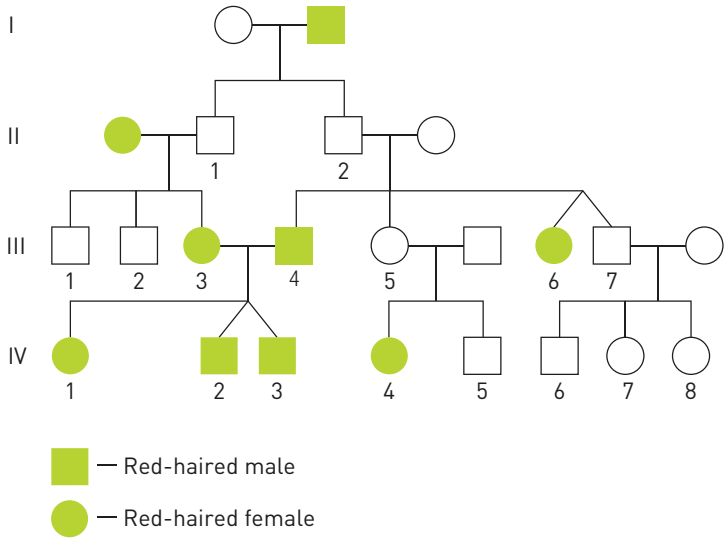


Figure 1.37 A pedigree for red hair.

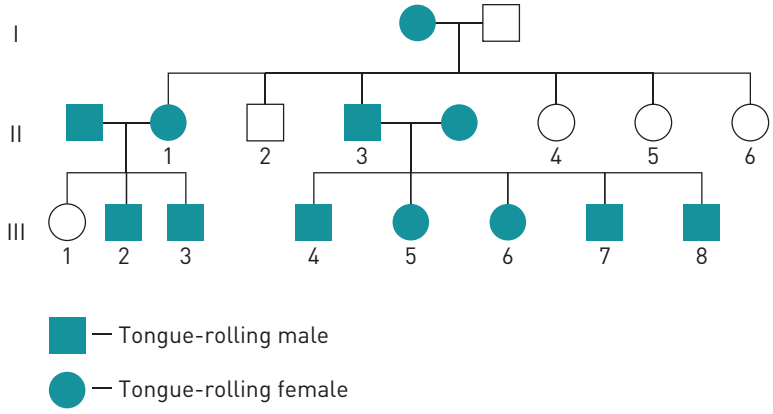


Figure 1.38 A pedigree for tongue rolling.

Analysing pedigrees

Pedigrees can be analysed to determine whether an individual will inherit a disease. There are a series of questions you should ask when determining the inheritance pattern from a pedigree.

1. Are more males or females affected by the trait?
   If YES, go to 2. If NO, go to 3.
2. Do all daughters of affected males have the trait?
   YES – Sex-linked dominant. NO, go to 4.
3. Do all affected children have an affected parent?
   YES – Autosomal dominant. NO, go to 5.
4. Has a carrier mother passed it on to half/some of her sons?
   YES – Sex-linked recessive
5. Do affected children have unaffected parents?
   YES – Autosomal recessive

Figure 1.39
Achondroplasia is the most common form of dwarfism.

Dwarfism

Achondroplasia is the most common form of dwarfism and is inherited as an autosomal dominant trait (although spontaneous mutations can also arise with no prior family history) (Figure 1.39). The gene is located on chromosome 4 and it controls the production of a growth factor receptor. Therefore, individuals with an affected allele will have dwarf stature. Most people with achondroplasia have normal intelligence and lead independent and productive lives, although they have medical problems.

Because the trait is dominant, people affected by achondroplasia have at least one affected parent. If one parent is affected, there is a 50% chance of the children being affected (Figure 1.40).

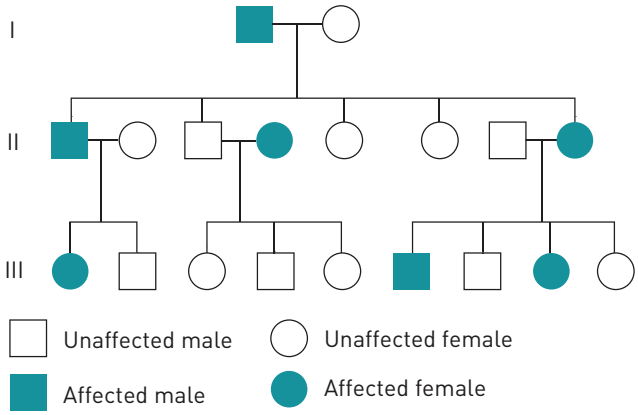


Figure 1.40 The pedigree chart of a family affected by achondroplasia. Some of the children could be unaffected.

Check your learning 1.9

Apply and analyse

1 Some people have ear lobes that hang free and some people's are attached. Natalie has attached ear lobes but both Natalie's parents and her brother, Daniel, have free-hanging ear lobes as shown in the pedigree (Figure 1.41).

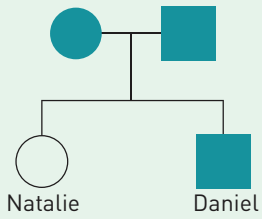


Figure 1.41

a Is the characteristic of free-hanging ear lobes a dominant trait or a recessive trait? Explain your choice.

b Use suitable symbols to represent the alleles for the ear lobe gene, then write the genotypes of:

i Natalie

ii Natalie's parents.

c What are the possible genotypes for Daniel?

2 A particular X-linked disease causes weakening of the muscles and loss of coordination. This often leads to death in childhood. A pedigree for this disease is shown in Figure 1.42.

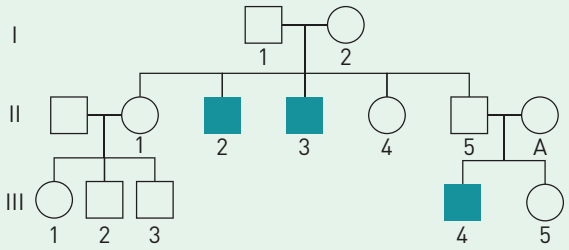


Figure 1.42

a Use this pedigree and suitable symbols to show the genotype of individuals I1, I2 and II5. What must be the genotype of individual 4?

b What is a carrier? Identify one carrier in the pedigree shown in Figure 1.42.

3 Look at Figure 1.43.

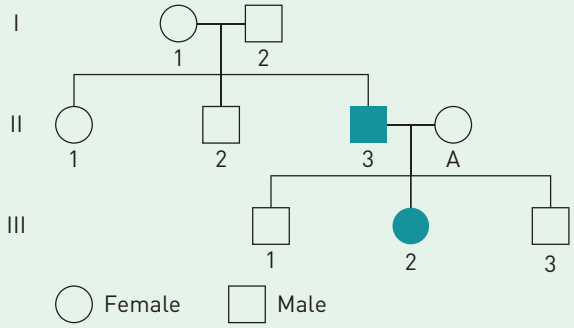


Figure 1.43

a In this family pedigree, is the characteristic indicated by shading dominant or recessive? Explain.

b If R represents the allele for the dominant trait and r represents the allele for the recessive trait, write the genotypes for I1, I2 and person A.

c If A and her partner had another child, what is the chance of the child having the characteristic indicated by shading? Show your working.

4 The pedigrees in Figure 1.44 show the inheritance of two genetic disorders (vision and limb defects) in the same family.

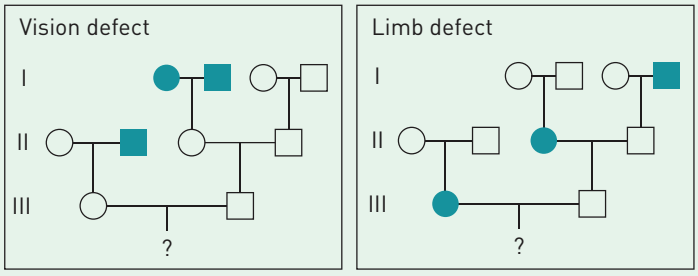


Figure 1.44

a Is the allele responsible for the vision defect dominant or recessive? Explain your choice.

b Is the allele responsible for the limb defect dominant or recessive? Explain your choice.

1.10 Mutations are changes in the DNA sequence

Mutagens such as chemicals, UV light and cigarette smoke can cause permanent changes in the sequence of nucleotides that make up DNA. These changes are called **genetic mutations**. They can involve substituting one nucleotide for another, or deleting or adding a nucleotide. Chromosomal mutations result from the centromere failing to separate (non-disjunction) during meiosis. The resulting daughter cells have too many or too few chromosomes. This causes a variety of changes in the organism, called a syndrome.

Mutations and mutagens

A mutation is a heritable change in the structure or amount of the genetic material (DNA). Therefore, a mutation is a permanent change in the DNA and it may be in one gene or in a number of genes (part or all of a chromosome). 'Heritable' refers to the change being 'inherited'.

If the change is in a single gene, then it is called a monogenic or genetic mutation; if it affects most of a chromosome, it is called a chromosomal mutation.

Because DNA replication (and other similar genetic events) is a copying process involving huge numbers of base pairs, mistakes occasionally happen – these are natural mutations. The base sequence (order of nucleotide nitrogen bases) in DNA is critical – a tiny change in the sequence changes the order of amino acids in the protein being made, which, in turn, may affect how the protein functions. Although the aim of genetic copying is to preserve that order, occasional errors can occur. On many occasions, these changes can be corrected by the cell or they do not cause a change in an important part of the protein that is produced by the gene.

It was a single mutation many thousands of years ago that prevented the production of brown pigment in eyes. As a result, blue eyes developed in humans. The mutation gave humans a new allele. However, some mutations are deadly, and our body works hard to correct them.

Natural mutations occur at a continuous low rate. However, environmental factors called **mutagens** can increase the frequency of mutations. Mutagens include chemicals, radiation and ultraviolet (UV) light (Figure 1.45).

Radiation

- Ionises biochemical compounds in cells, forming free radicals
- The free radicals cause damage to DNA and proteins (e.g. breakages in chromosomes)

Chemicals

- Some chemicals insert into DNA instead of bases (i.e. they substitute for bases)
- Other chemicals insert between bases, causing problems when the DNA replicates

UV light

- Causes thymines that are close together on a DNA polynucleotide chain to bind together, forming 'thymine dimers'. This causes problems during DNA replication

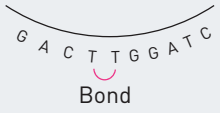


Figure 1.45 The effect of mutagens.

SKILLS LAB 1.10: IDENTIFYING MUTATIONS
GO TO PAGE 187

Genetic mutations

There are two types of genetic mutation:

- point or substitution mutations
- frameshift mutations.

A point mutation occurs when one base substitutes for another. As the genetic code is read in groups of three (called triplets), this may or may not have an effect on the final protein. This is best shown using the sentence:

THE CAT ATE THE RAT AND RAN FAR

If there was a point mutation in this sentence, it might read:

THE CAR ATE THE RAT AND RAN FAR

In this case, the sixth letter, T, was substituted by R. In DNA it might be a G substituted for A. This small change will be passed on to the RNA, but may not affect the order of amino acids in a protein.

Sickle cell anaemia is an example of a point substitution that does affect the final protein. The gene that makes part of the haemoglobin molecule, which carries oxygen around the body, has substituted an adenine (A) for a thymine (T). So the code in the DNA sequence reads CAC instead of CTC. As a result, the codon on the RNA reads GUG instead of GAG. This makes the matching amino acid valine rather than glutamic acid. This means a slightly deformed haemoglobin is produced, which doesn't carry oxygen as effectively (Figure 1.46).

However, a deletion or an addition can have a large impact on how the genetic code is read.

A deletion of the sixth letter (T) in the sentence would result in the triplet code becoming:

THE CAA TET HER ATA NDR ANF AR

An addition of an extra R would result in the triplet code becoming:

THE CAR TAT ETH ERA TAN DRA NFA R

These are called **frameshift** mutations because the group of three reading frame has been shifted along the DNA strand.

Frameshift mutations have more damaging effects than point mutations because they change the entire reading frame of the DNA and RNA, producing quite a different protein. If the RNA sequence reads UAC after the mutation, then this is a 'stop codon' and the protein synthesis will stop at that location, resulting in a shorter molecule that is unable to be useful.

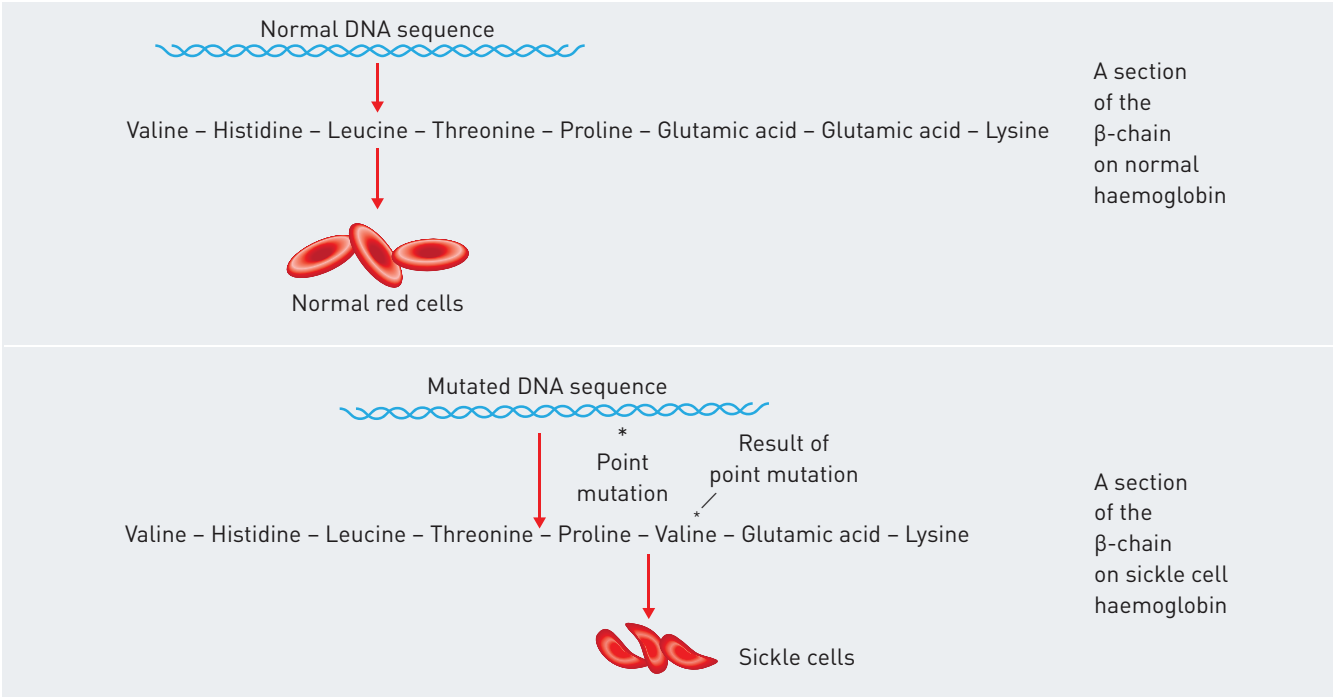


Figure 1.46 Haemoglobin and sickle cell anaemia – an example of the effects of a point mutation.

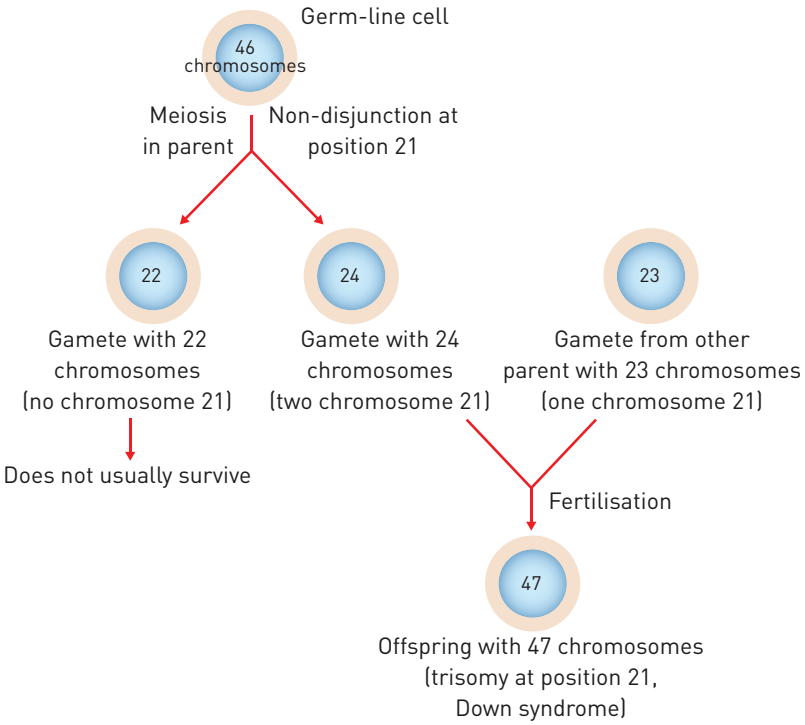


Figure 1.47 Changes in chromosome numbers due to non-disjunction.

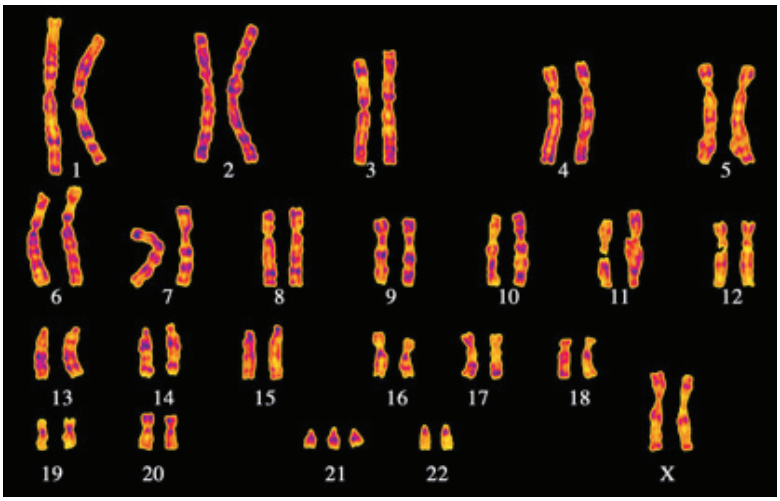


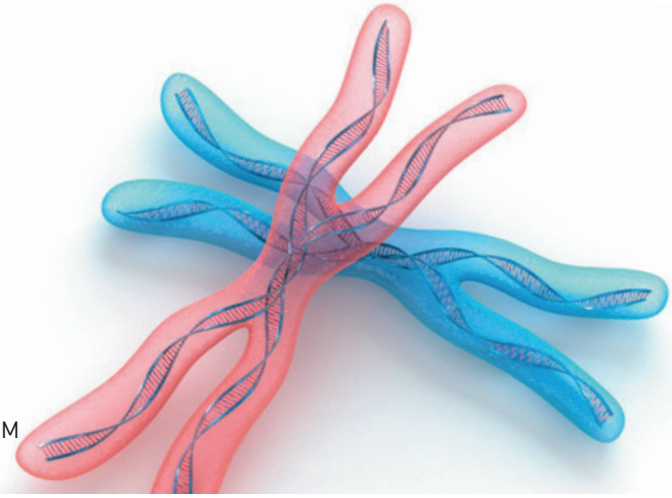
Figure 1.48 Individuals with Down syndrome have three copies of chromosome 21.

Mutations involving chromosome number

This type of mutation is usually the result of **non-disjunction** – the failure of a chromosome pair to separate at the centromere in meiosis. In such cases, one of the daughter cells (gametes) will have too many chromosomes and the other will have too few chromosomes (Figure 1.47). If an abnormal gamete is fertilised, the offspring will have either too many or too few chromosomes.

Down syndrome is the result of non-disjunction in chromosome pair 21 during the formation of the gametes in one parent. A person with Down syndrome has three copies (trisomy) of chromosome 21 (Figure 1.48).

Figure 1.49 This girl has Down syndrome, which is a result of non-disjunction of chromosome 21.



Non-disjunction in sex chromosomes

Non-disjunction can also occur with the sex chromosomes X and Y. This can result in a variety of syndromes.

Females with Turner syndrome have only one X chromosome (Figure 1.50). Turner syndrome can manifest in many different ways and it is not always apparent from the person's physical appearance. Symptoms can include a shorter than average height, infertility, extra webbing on the neck, swollen hands and feet, diabetes and many other difficulties. Turner syndrome does not normally affect intellectual ability.

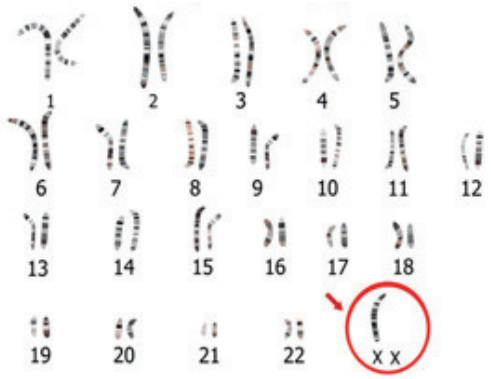


Figure 1.50 Turner syndrome is a result of non-disjunction of the X chromosome.

Males with Klinefelter syndrome have an extra X chromosome, giving them a total of 47 chromosomes (Figure 1.51). This can affect their fertility, muscle development and intellectual abilities. Many of these individuals will be undiagnosed. Approximately 1 in 660 males are affected.

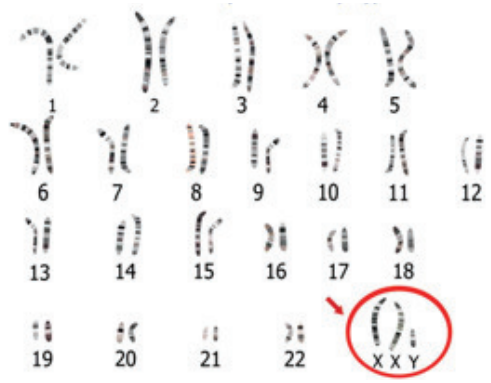


Figure 1.51 Males with Klinefelter syndrome have an extra X chromosome.

Cri du chat syndrome

This series of symptoms is caused by missing portions of chromosome 5 (Figure 1.52). Both males and females can be affected. Symptoms include having a high-pitched cry (similar to that of a cat) as a baby. People with Cri du chat syndrome are slow to grow, and often have a small head and intellectual difficulties. Their fingers or toes can sometimes be fused together.

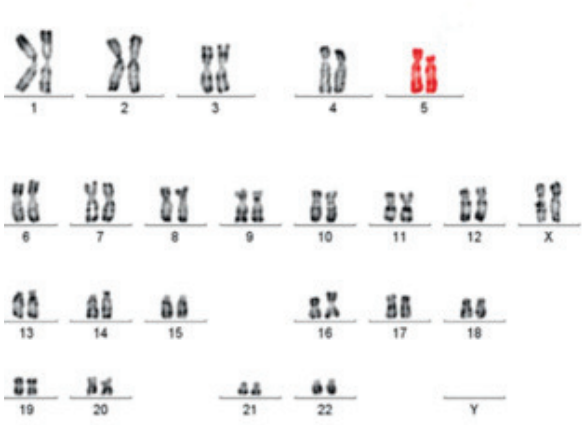


Figure 1.52 Cri du chat syndrome occurs when part of chromosome 5 is missing.

Check your learning 1.10

Remember and understand

1. Define 'mutation'.
2. What is a mutagen? Give some examples of mutagens and how they act to cause mutations.
3. What is a trisomy? Give an example of a trisomy in humans.
4. What is a frameshift mutation?

Evaluate and create

5. Can mutations ever be advantageous? Provide evidence to support your answer.
6. Draw a series of diagrams that show non-disjunction occurring in meiosis.
7. How would you test if a male had Klinefelter syndrome?

//SCIENCE AS A HUMAN ENDEAVOUR//

1.11 Genes can be tested

*Unique probes (short sections of complementary nucleotides) can be used to bind to the specific alleles of individuals at risk of genetic diseases. These probes can be used to identify if an individual has inherited the alleles for a disease or if they are at increased risk of developing a disease such as breast cancer, cardiovascular disease or Alzheimer's disease. While this has advantages in the treatment of the disease, there are many social and ethical issues that must be considered.

Genetic screening and testing

Genetic testing is carried out on people who are known to be at risk of a particular genetic disease or condition. This is usually evident from an individual's family history. The genetic material of a person at risk is obtained through a blood sample. DNA from the white blood cells (red blood cells do not have a nucleus) is isolated and replicated. Special probes act like a stain that sticks to specific genes in the chromosomes, identifying the particular allele that is present in people at risk of the trait.

Genetic screening refers to testing that is readily available to a cross-section of people within the community regardless of a previous family history of genetic disease.

Figure 1.53 A blood sample is being collected from a newborn infant to screen for phenylketonuria – a disease that affects the way the body breaks down proteins.

Genetic screening and testing services currently available in Australia include:

- **maternal serum screening (MSS)** – offered to all pregnant women for the detection of Down syndrome and neural tube defects
- **newborn screening** – the screening of all newborn babies for genetic diseases, including phenylketonuria (PKU), hypothyroidism and cystic fibrosis
- **early detection and predictive testing for adults** – the screening of adults to detect existing disease, a predisposition to disease or carriers with a reproductive genetic risk.

Genetic screening can increase the early diagnosis of and subsequent intervention in genetic diseases. Potentially, this will minimise the frequency of such diseases in subsequent generations; however, it sometimes involves some very difficult decisions. For example, parents who are carriers of genetic mutations must decide whether to have children, who may suffer from the disease. Genetic screening also raises the following questions. What are the risks of the tests and are they prepared to take them? Who should be screened, and for what? What is the impact of false positives? What options are available if it's not good news?

Genetic counsellors can help clarify the situation, but they cannot make the decision for the people involved.

The collection, storage and potential uses of genetic information raise many ethical questions, including who should access the information and the possible misuse of such information.

Sex, Down Syndrome Tests Popular

The Weekend West November 7–8, 2015, p.17

by Cathy O' Leary, Medical Editor

A growing number of pregnant women in WA are having a simple blood test that can pick up signs of Down syndrome and the baby's sex as early as 10 weeks.

Doctors say demand has gone 'crazy' in WA for non-invasive prenatal testing (NIPT), which costs more than $400 but is more accurate than the blood test used in traditional prenatal screening. Women found to be at low risk of Down syndrome by the test could avoid having invasive procedures such as amniocentesis, which increases the risk of miscarriage.

Instead of testing cells from the foetus or the placenta, NIPT picks up traces of foetal DNA circulating in the mother's blood. Because there is an option to screen for sex-linked chromosomes, it can also show the gender of the foetus.

Some ethics experts are worried that detecting the gender early on could make it easier for couples who want a child of a particular sex to terminate the pregnancy.

Prenatal screening is usually aimed at women at higher risk of Down syndrome, such as those aged over 35, but even low-risk women are having the newer test, despite it not having any Medicare or private health insurance rebate. It cost $1400 when it became available in Australia three years ago but it is now as low as $420. While it is not a diagnostic test, it is 99 per cent accurate and has a very low false positive rate. A WA survey of high-risk pregnant women presented at the Royal Australian and New Zealand College of Radiologists scientific meeting in Adelaide yesterday showed most preferred it.

Obstetric radiologist Emmeline Lee, from Western Ultrasound for Women, said there had been a huge uptake in WA. 'The market has gone crazy,' she said. 'Even though we were cautious about offering it only to high-risk women, we're seeing low-risk women wanting it as an extra layer of security.'

Professor Peter O'Leary from Curtin University's Faculty of Health Sciences, said there was a push to have test publicly funded but he believed it should be limited to 20 per cent of women at higher risk.

What is NIPT?

- Non-invasive prenatal testing is a new way to screen for genetic abnormalities.
- Unlike invasive tests such as amnioncentesis and chorionic villus sampling (CVS) that collect cells from the foetus or the placenta, NIPT uses traces of foetal DNA in the mother's blood.
- It can be done from 10 weeks and is 99 per cent accurate at detecting Down syndrome.
- Costs between $420 and $900.
- Samples have to be sent to the eastern states, with results usually within a week.
- A 12-week ultrasound should still be done to check for structural abnormalities.
- It is not a diagnostic test, so women who test positive need to have it confirmed by amniocentesis or CVS.

Extend your understanding 1.11

1 Research one of the diseases mentioned in the text. What are the symptoms of the disorder? How can the disorder be treated? What is the life expectancy of a person suffering from the disorder?

2 List two advantages and disadvantages of prenatal testing.

3 Prepare a debate on the topic 'Public funding for pre-natal testing should only be made available to high-risk pregnant women'.

//SCIENCE AS A HUMAN ENDEAVOUR//

1.12 Genes can be manipulated

*

The ability to insert genes from one organism into another relies on the universal nature of DNA. This means that the DNA in every organism is made out of the same four nucleotides (A, T, C and G). The DNA is transcribed into RNA. Each codon (group of three nucleotides) in the RNA must code for the same amino acid. A **genetically modified organism** is an organism that has its DNA changed in some way. A **transgenic organism** is an organism with DNA from a different species inserted into its genome.

Genetically modified organisms

One of the most controversial developments in modern food production is the proliferation of genetically modified organisms, or GMOs. Genetically modified (GM) plants have been modified in the laboratory to enhance certain desired traits, such as increased resistance to herbicides or improved nutritional content. Traditionally, the enhancement of desired traits has been achieved through selectively breeding or mating two organisms that have the trait. Genetic engineering can create plants with the exact desired trait very rapidly and with great accuracy. For example, geneticists can isolate a gene for drought tolerance and insert that gene into a different plant. The new GM plant will display a tolerance to drought. Not only can genes from one plant be transferred into another plant, but genes from non-plant organisms can also be used. Transgenic organisms are those that contain a foreign gene inserted from another organism, usually a different species.

Agriculture has been significantly affected by the introduction of transgenic animals and genetically modified crops and foods (GM foods), including plants that are resistant to herbicides and pesticides. There are also 'pharm' plants and animals that produce pharmaceutical proteins required by humans.

Crops that have been engineered to resist disease mean that farmers use lower amounts of pesticides and herbicides when growing these crops. This reduces production costs. Reducing the amount of pesticides and herbicides also reduces environmental pollution.

Examples of plants that have been genetically engineered in this way include those shown in Figures 1.54–1.56. Figure 1.57 shows the process of introducing a gene from a daffodil into corn.

Figure 1.54 Transgenic variety of cotton that is pest resistant. Genes (specifying a protein toxic to many serious insect pests) from the bacterium *Bacillus thuringiensis* have been introduced into the chromosomes of this plant. The protein is called Bt (*Bacillus thuringiensis*) toxin and the plants are Bt plants. The toxin only becomes active in the alkaline environment of the insect gut, whereas in vertebrate animals it is destroyed by the acid in the stomach.

Figure 1.55 Transgenic papaya plants in Hawaii are resistant to the ring spot virus. Genetically engineering papaya has saved the industry. The technology has also been exported to other countries where ring spot virus is damaging papaya plants.

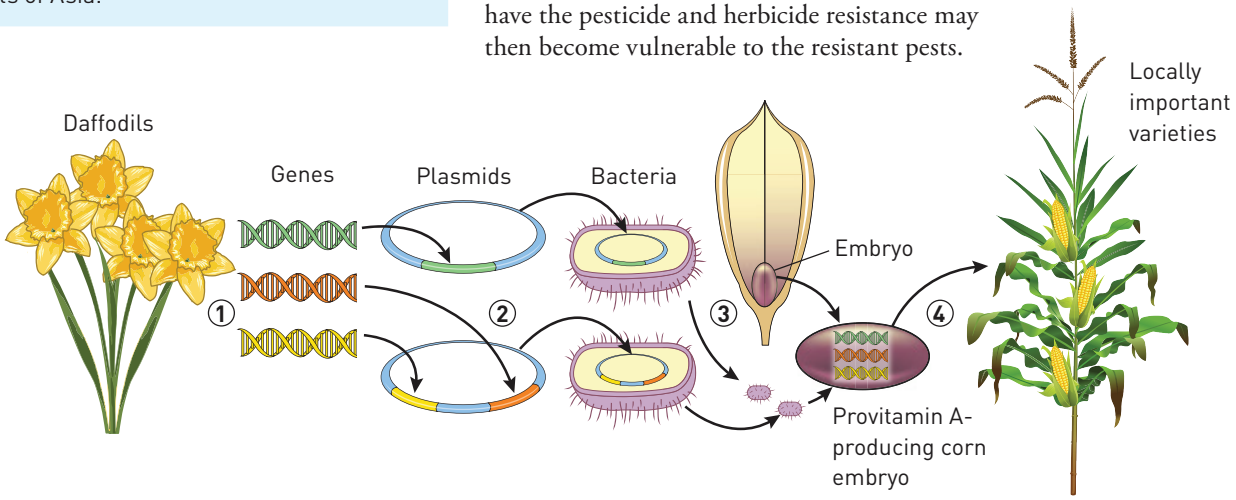
Figure 1.56 Golden rice has had genes inserted from daffodils. These genes control the production of a chemical that is converted into vitamin A, making this rice much richer in vitamin A than non-transgenic rice. Without adequate amounts of vitamin A, people's eyesight can be severely impaired, even leading to blindness. Many people in South-East Asia, the great rice-consuming area of the world, are blind or have severe sight problems because of vitamin A deficiency. Therefore, this high-nutrition rice is most valuable in parts of Asia.

GMO issues

GM crops pose a threat to biodiversity because they replace a number of natural varieties of plants with one variety: the genetically engineered plant. The significant increase in GM plants has only occurred in the past decade or so.

The organic food movement is completely against the principle of GM foods, and public debate into the benefits and dangers of such foods is likely to continue well into the future. Some people believe that GM foods pose health risks, although there is no clear evidence for or against this.

A criticism of GM foods is the potential for accidental gene transfer to other species. GM plants may also contaminate non-GM plants of the same species; for example, when wind blows the pollen from one farm to another nearby. Another problem is that increased pesticide and herbicide resistance may develop in insects and other pests. The GM plants that have the pesticide and herbicide resistance may then become vulnerable to the resistant pests.



1 The gene that produces vitamin A is isolated from a daffodil.

2 This gene is added into a plasmid, a small loop of DNA that acts as a vector transporting the gene into a bacterial cell.

3 The bacterial cells containing the plasmid are added to the embryonic corn plant.

4 The transgenic corn plant grows. The introduced genes produce high levels of vitamin A.

Figure 1.57 Scientists can grow transgenic corn that produces high levels of vitamin A.

Extend your understanding 1.12

1 Give an example of an organism that has been genetically engineered for use in agriculture. How has it been useful?
2 Briefly describe a method that is used to insert 'new' genes into plant cells.
3 What are some reasons for genetically engineering plants?
4 As a consumer, do you think that food containing GMOs should be labelled?
5 What factors would influence your decision to purchase or not to purchase food containing GMOs?

//SCIENCE AS A HUMAN ENDEAVOUR//

1.13 Genetic engineering is used in medicine

Genetic engineering is the process of changing the genetic code of an organism. **Gene cloning** uses this process to produce multiple copies of a particular gene. This can be done to mass produce proteins such as insulin. **Gene therapy** involves the insertion of a healthy version of a gene into the chromosomes of an individual with a defective gene. Current Australian laws prevent any changes to the germ-line cells of an individual.

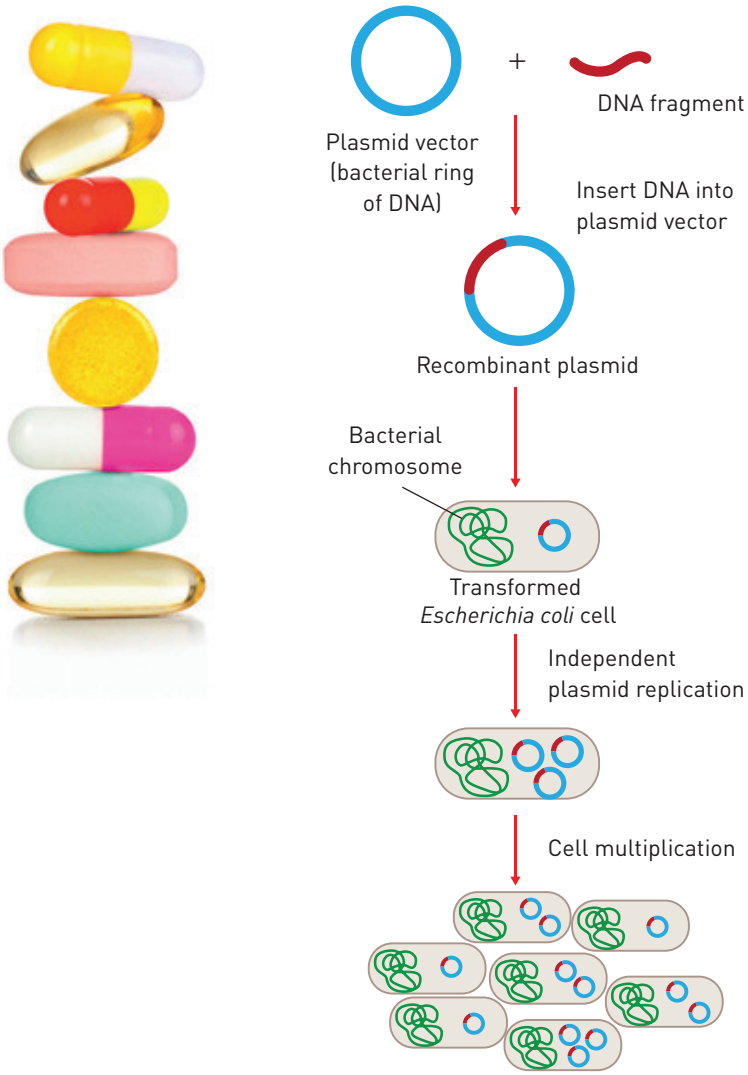


Figure 1.58 Gene cloning

Gene cloning

Another application of genetic engineering is gene cloning: to insert a gene, for example a human gene, into bacteria so that the bacteria now produce a human protein that can be purified and used to treat a human disease (Figure 1.58). This method avoids the rejection issues faced by using similar products from animals, such as pigs or sheep. An example is the production of human insulin by bacteria. People with diabetes need to inject insulin to help control their blood sugar levels.

Gene therapy

Gene therapy involves inserting a healthy gene into the chromosomes of an individual with a defective gene. Gene therapy that involves the body cells (somatic cells) can be therapeutic only. This means that the new gene cannot be passed on to the next generation. At present, gene therapy targeting germ-line cells (cells destined to become gametes) is not legal in Australia.

Gene therapy has been quite successful in the treatment of cystic fibrosis (CF). Patients with CF have a deficiency in a gene that controls the production of a protein that regulates the movement of chloride ions across cell membranes. A major symptom of CF is the accumulation of a thick mucus that can damage lung tissue. This reduces the life span of patients significantly. Medical scientists have been able to clone the healthy gene in bacteria. The purified gene is then attached to a carrier molecule called a vector. The vector in this case is a harmless virus and it is added via a spray through the nose of patients. The virus enters many of the lung cells and inserts into the DNA in the nucleus. When the lung cells divide, the new cells contain the healthy gene (Figure 1.59).

Apart from the success with CF and the great potential of gene therapy, there has been limited progress since the first clinical trials in 1990. Several people died as a consequence of the technique. The ethics of treating patients with a technique that involves significant risks to life have to be considered carefully.

Stem cells and ethics

Stem cells are undifferentiated cells that can differentiate (mature) into many different types of specialised cells, such as muscle, nerve, liver and blood cells. There are two types of stem cells. Pluripotent embryonic stem cells (obtained from embryos) can develop into most cell types in the body, whereas multipotent adult stem cells can only develop into certain cell types in the body.

There are many ethical issues associated with the use of embryonic stem cells. The establishment of a stem cell line involves the artificial creation of an embryo solely for the purpose of collecting stem cells. This process results in the destruction of the embryo. At present, such procedures are illegal in Australia. The only embryos that are used for research are those classed as 'excess embryos', having been originally created for use in *in vitro* fertilisation (IVF). However, some people consider the use of these excess embryos to be unethical. They regard the embryos as potential life and their use in research as depriving life to these embryos.

Most recently, scientists have been able to reverse the differentiation process and turn multipotent adult stems cells back into pluripotent stem cells. These cells are called induced pluripotent cells. In the future, induced pluripotent stem cells may be used to treat a variety of diseases, including cancer, multiple sclerosis (MS), Parkinson's disease, motor neurone disease and spinal cord injuries.

Some potential parents also want to choose certain embryos over others. For example, they may want a male or a female child. They may want a child with blue eyes and fair hair. They may choose a healthy embryo over one with, say, cystic fibrosis. This situation has ethical implications. What will parents do with embryos that don't have the desired characteristics?

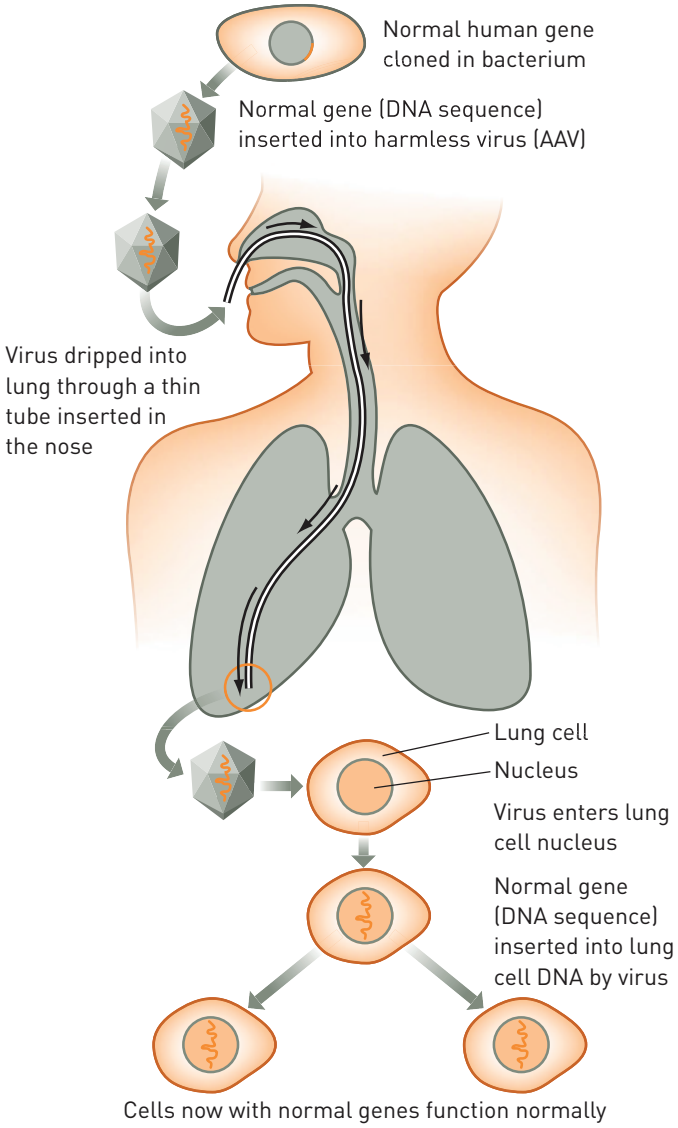


Figure 1.59 Gene therapy.

Extend your understanding 1.13

1 What is the aim of gene cloning?
2 Describe the process used to produce human insulin by gene cloning.
3 Why do scientists choose bacteria to clone human genes?
4 Give an example of a successful gene therapy treatment for a disease.
5 Why is the use of induced pluripotent cells more acceptable to some people than embryonic stem cells?

* REVIEW

1

Remember and understand

1 Name the four nitrogen bases found in DNA.

2 Use the terms 'gametes' and 'fertilisation' to explain how DNA is transferred from one generation to the next.

3 Relate a chromosome to a molecule of DNA and explain how the replication of DNA is important for both mitosis and meiosis.

4 Describe three differences between the structure or function of DNA and RNA.

5 Use words and/or diagrams to explain the differences between:

- a nitrogen base and codon
- b diploid and haploid.

6 What is a monohybrid cross?

7 What were Mendel's conclusions from his work on breeding peas?

8 What is the difference between the following pairs of terms?

- a Autosome and sex chromosome
- b Gene and allele
- c Heterozygous and homozygous

9 Explain what is meant by the following formula:

Phenotype = genotype + environment

10 Define:

- a GMO
- b transgenic organism.

11 Explain the process of:

- a gene cloning
- b gene therapy.

Apply and analyse

12 If the protein-coding region of a gene contains 600 nitrogenous bases, how many amino acids would be incorporated into the resulting protein?

13 Which of the following is not a function of mitosis?

- A Replenishing the epithelial cells of the small intestine that are shed daily
- B Forming new red blood cells to replace those that are worn out
- C Forming cells for sexual reproduction
- D Repairing cuts and abrasions of the skin

14 What sort of information can be determined from the pedigree shown in Figure 1.60? List as many points as possible.

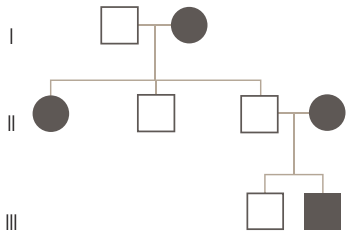


Figure 1.60

15 Can large-scale genetic screening programs reduce the prevalence of genetic diseases? Explain your answer.

16 Gene therapy has been proposed as a treatment for a young boy suffering from Duchenne muscular dystrophy, a degenerative disorder of the muscles. Describe three factors that should be considered by the boy's health team prior to treatment.

Evaluate and create

17 Does a chromosome or a gene provide the most information about the make-up of an individual? Explain the reasons why.

18 A newborn baby shows distinct facial abnormalities. A karyotype (Figure 1.61) was prepared to determine whether there were any chromosomal abnormalities.

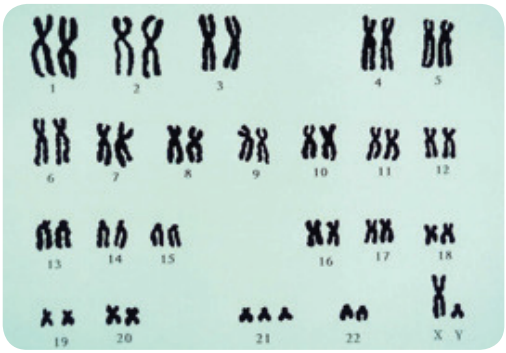


Figure 1.61

- a What is the total number of chromosomes shown?
- b Is the child male or female? How do you know?
- c As the geneticist, what would you advise the parents about the health of their baby?

19 If both parents have achondroplasia, what are the chances of their children being unaffected?

20 Phenylketonuria is an autosomal recessive genetic disorder. It results in the lack of production of an enzyme that is needed to metabolise the amino acid phenylalanine to the amino acid tyrosine. A diet low in phenylalanine and high in tyrosine is prescribed to people with phenylketonuria to avoid problems with brain development. Every child born in Australia is now screened for phenylketonuria within weeks of birth. What is the benefit of such genetic screening?

21 Create a teaching resource that could be used to teach a Year 7 student about the process of cell division.

22 Select a genetic disease and create a pamphlet for display in the reception area of a doctor's surgery. The pamphlet should outline information about the cause of the disease (gene or chromosomal abnormality), pattern(s) of inheritance, the frequency of the disease in the population, diagnosis, symptoms and treatment.

23 Produce a brochure that promotes the benefits of purchasing organic and non-GM foods. Alternatively, produce a brochure promoting the benefits of GM foods.

Ethical understanding

24 The debate around embryonic stem cells is heated. What are the reasons for and against using embryonic stem cells? How have governments intervened in this area? Based on your findings, do you think that using embryonic stem cells could provide benefits to humans?

Research

25 Choose one of the following topics for a research project. Some questions have been included to help you begin your research. Present your report in a format of your own choosing.

> **Breast cancer**

To what extent does a family history affect an individual's chances of developing breast cancer? How is breast cancer detected and treated?

> **A shrinking Y chromosome**

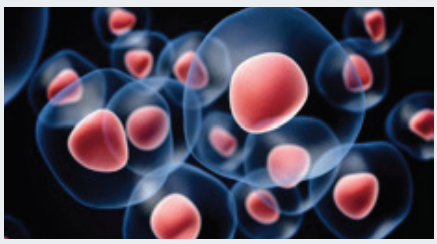
The Y chromosome has been losing genes over the course of time so that it is now only a fraction of the size of the X chromosome. How has this happened? Will it disappear altogether? What is the future of the Y chromosome? What effect will this have on humans?

> **Cloning**

What other sorts of animals have been cloned since Dolly the sheep in 1997? What are some of the arguments for and against cloning?

> **Stem cell survival technique**

Australian scientists have found a way to keep muscle stem cells alive so they can regenerate damaged tissue around them. Why is this technique a breakthrough? What does the technique involve? What are the immediate uses of this technique?



KEY WORDS

1

adenine
a nitrogen base of DNA or RNA; complementary to thymine in DNA and uracil in RNA

allele
a version of a gene. Each person inherits one allele from each parent

autosome
a chromosome that does not determine the sex of an organism

carrier
a person who has the allele for a recessive trait that does not show in their phenotype

complementary base
a nucleotide base that pairs with its partner nucleotide on the alternative DNA strand. Adenine pairs with thymine, cytosine pairs with guanine

cytosine
a nitrogen base of DNA or RNA; complementary to guanine

deoxyribonucleic acid (DNA)
a molecule that contains all the instructions for every job performed by the cell; this information can be passed from one generation to the next

diploid
a nucleus that contains two complete sets of chromosomes

dominant trait
a characteristic that needs only one copy of an allele to appear in the physical appearance of an organism

frameshift
the process of moving the reading frame of codons through the addition or deletion of a nucleotide; results in a deformed protein

genetic code
the sequence of nucleotides found in DNA that is inherited from parents

genetic mutation
a permanent change in the sequence of nucleotides in DNA

genotype
the combination of alleles for a particular trait

guanine
a nitrogen base of DNA or RNA; complementary to cytosine

haploid
a nucleus that contains one complete set of chromosomes; usually found in a gamete

heterozygous
having two different alleles for a particular trait; a carrier for the recessive trait

homozygous
having two identical alleles for a particular trait

karyotype
the arrangement of a complete set of chromosomes in pairs of decreasing size

meiosis
the process that results in the formation of gametes with half the genetic material of the parent cell

mitosis
process of cell division to provide growth or repair

mutagen
a chemical or physical agent that causes a change in genetic material such as DNA

non-disjunction
the failure of one or more chromosomes to separate and move to the end of the cell during meiosis; it can result in an abnormal number of chromosomes in the daughter cells

nucleotide
a subunit of a DNA molecule

phenotype
the physical characteristics that result from an interaction between the genotype and the environment

Punnett square
a diagram that is used to predict the outcome of breeding organisms

recessive trait
a characteristic that results from the inheritance of two identical alleles

ribonucleic acid (RNA)
a complementary copy of DNA that is able to carry the genetic message from the nucleus to the cytoplasm

sex chromosome
a chromosome that determines the sex of an organism

stem cell
a cell that can produce a number of different types of cells. Adult stem cells can produce a limited number of cell types (e.g. skin stem cells), whereas embryonic stem cells can produce multiple types of cells

thymine
a nitrogen base of DNA; complementary to adenine

transcription
the formation of complementary RNA from DNA

translation
the formation of a protein from RNA; occurs on a ribosome