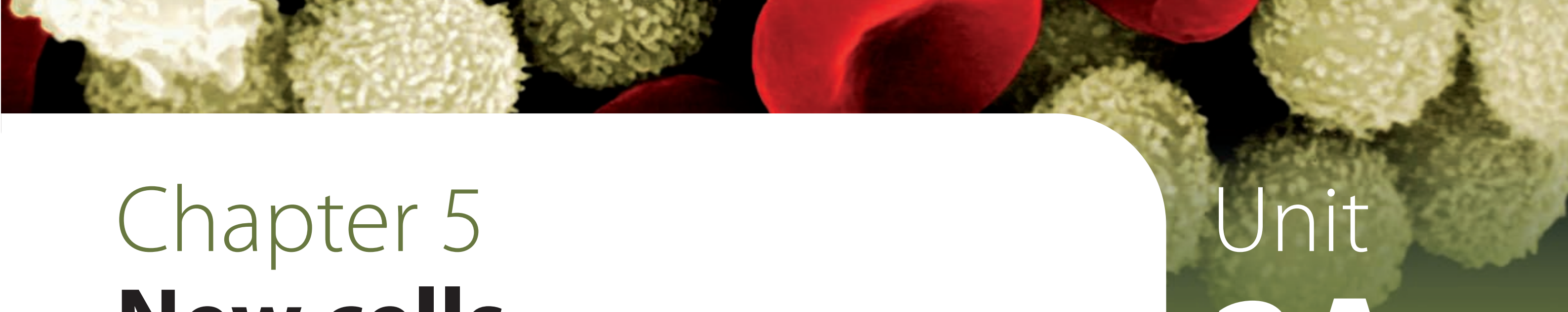


Unit

2A

Chapter 5
New cells

Unit content

Cells, metabolism and regulation
Cellular structures provide for cell division (mitosis and meiosis).

Mitosis:

- function and significance of chromosome number in mitosis

Variation and evolution
New genetic combinations are made as a result of meiosis and fertilisation, giving rise to unexpected variations.

Meiosis:

- function and significance of chromosome changes in meiosis
- compare mitosis and meiosis.

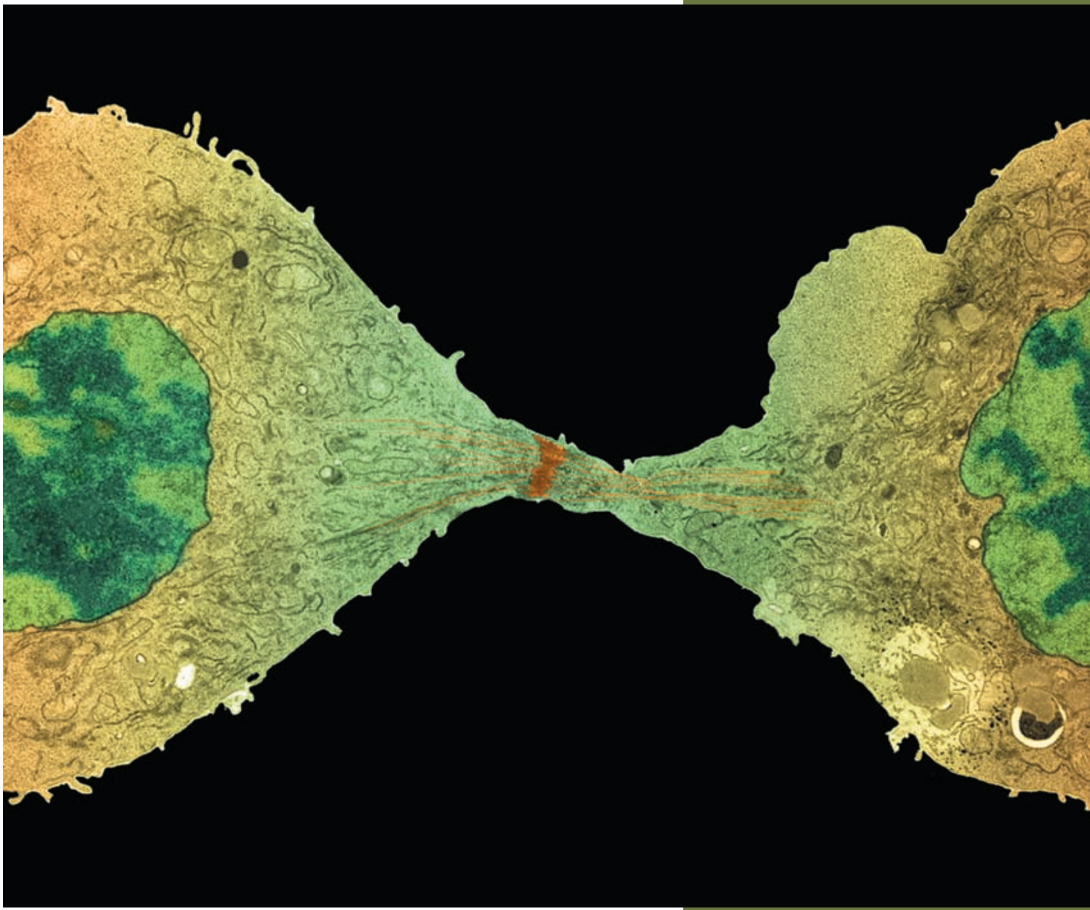


Figure 5.1 New cells are formed when a cell divides in two

New cells are produced from existing cells. In this chapter we examine the process by which cells are produced for growth, maintenance and repair of the body—**mitosis**. We also look at the process by which cells are produced for sexual reproduction—**meiosis**.

Mitosis

Cells reproduce so that organs can grow larger, but even in a mature person cells are constantly reproducing. Cells that are damaged, worn out or diseased must be replaced. Some human cells have a very short life span. Those lining the intestines live for less than two days; on the other hand, many nerve cells in the brain last for the lifetime of the person. Generally, the more wear and tear on a cell, the shorter the life span. Table 5.1 shows the life span of a number of different types of human cells.

Table 5.1 Average life span of human cells

Cell type	Average life span (days)
Intestinal lining	1.3
Stomach lining	2.9
Tongue surface	3.5
Cervix (neck of the uterus)	5.7
Cornea of the eye	7
Epidermis of the abdomen	7
Epidermis of the cheek	10
Alveolus (air sac in the lung)	21
White blood cell	depending on type and activity, from hours to years
Red blood cell	120
Kidney	170
Bladder lining	330
Liver	450
Nerve cell in brain	29 200+ (80+ years)

The phases of mitosis

Deoxyribrose nucleic acid or DNA (see Fig. 4.3 on pages 44–45) is a molecule that occurs in the nucleus of all cells. The DNA in the nucleus determines the types of protein that the cell can make. Since proteins are the structural materials of a cell, the DNA determines the structure of a cell, and since the body is made up of cells, the DNA therefore determines the structure of the whole body. DNA not only determines the structure of each cell, and of the body, but also the way each cell functions and the way in which the body functions. Enzymes are proteins so the DNA determines which enzymes a cell will make. In this way the DNA determines the chemical reactions that go on inside and outside the body cells. Thus, it is vital that when a cell reproduces each new cell gets *exactly* the same DNA as the parent cell. In other words, each new cell must contain the same genetic information as the parent cell. This is achieved by division of the nucleus known as **mitosis**. Mitosis ensures that each body cell receives exactly the same hereditary material (DNA) as that possessed by its parent cell.

For convenience, biologists describe mitosis in four stages (Table 5.2): prophase, metaphase, anaphase and telophase. However, the process is continuous; it does not occur in steps.

Table 5.2 A summary of cell division

Stage	Events occurring
Interphase	DNA molecules duplicate.
Prophase	Nucleoli disappear; nuclear membrane breaks down; centrioles migrate to opposite poles; chromosomes appear as pairs of chromatids; spindle forms.
Metaphase	Chromosomes line up on the spindle at the equator of the cell.
Anaphase	Centromeres divide; chromosomes move to opposite ends of the spindle.
Telophase	Spindle disappears; nuclear membranes and nucleoli form; centrioles divide; chromosomes uncoil and disappear; during this phase cytokinesis occurs.
Cytokinesis	Cytoplasm of the cell divides into two, each with a nucleus.

Interphase

Interphase is the period between nuclear divisions. During interphase the DNA molecules in the nucleus form exact copies of themselves. Thus, in the period between one cell division and the next, the quantity of DNA in the nucleus doubles.

Prophase

Prophase is the first phase of mitosis. Two pairs of centrioles become visible early in prophase. They move to opposite ends (or **poles**) of the cell and microtubules begin to radiate from them (Fig. 5.2). At the same time the nucleolus disappears and the nuclear membrane begins to break down. The chromatin threads of DNA become tightly coiled and can be seen as **chromosomes**. Each chromosome consists of two **chromatids**, which are joined at a point called the **centromere** (Fig. 5.3 on page 57). The two chromatids that make up a chromosome are identical, tightly coiled DNA molecules. Coiling the long delicate DNA molecules makes it easier to distribute the DNA to the daughter cells.

By the end of prophase the centrioles have reached opposite poles of the cell and some of the microtubules radiating from them join to form a framework of fibres called a **spindle**. The nuclear membrane has now completely disappeared, and the chromatid pairs migrate towards the centre (**equator**) of the cell (Fig. 5.2).

There are many websites that show animations of mitosis, including:
- http://www.cellsalive.com/mitosis.htm
- http://www.johnkyrk.com/mitosis.html

Metaphase

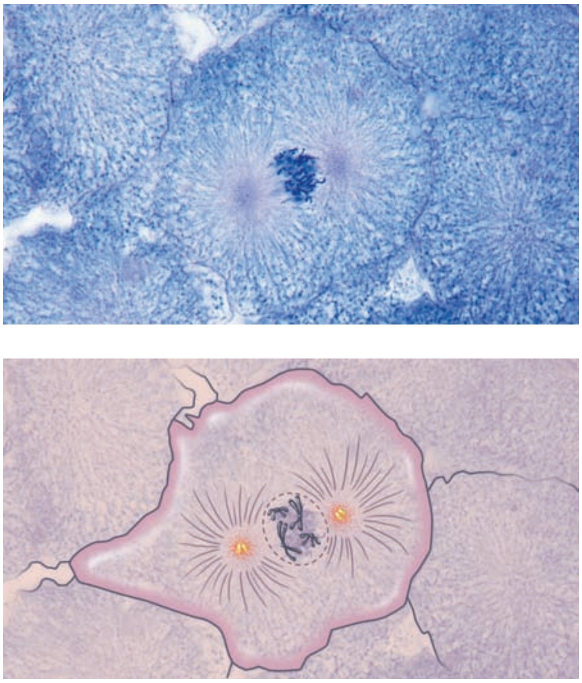
During **metaphase**, the chromatid pairs line up on the equator of the spindle (Fig. 5.2). The centromere of each pair is attached to a spindle fibre.

Anaphase

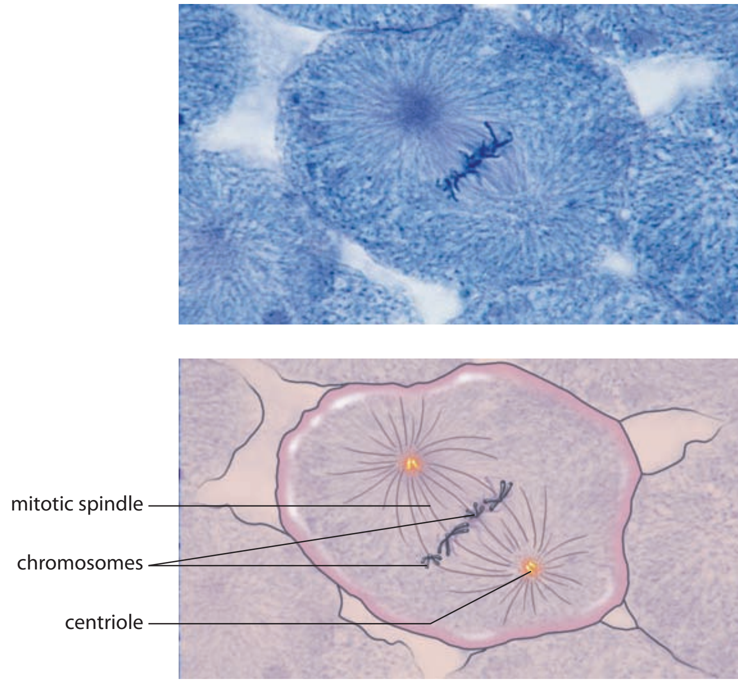
In **anaphase**, each pair of chromatids separates at the centromere. As the chromatids have become independent of each other, they are now called chromosomes. The new chromosomes are then pulled apart towards opposite poles of the cell. The centromeres are still attached to the spindle fibres, and it seems that the spindle fibres pull the chromosomes apart in some way (Fig. 5.2).

Telophase

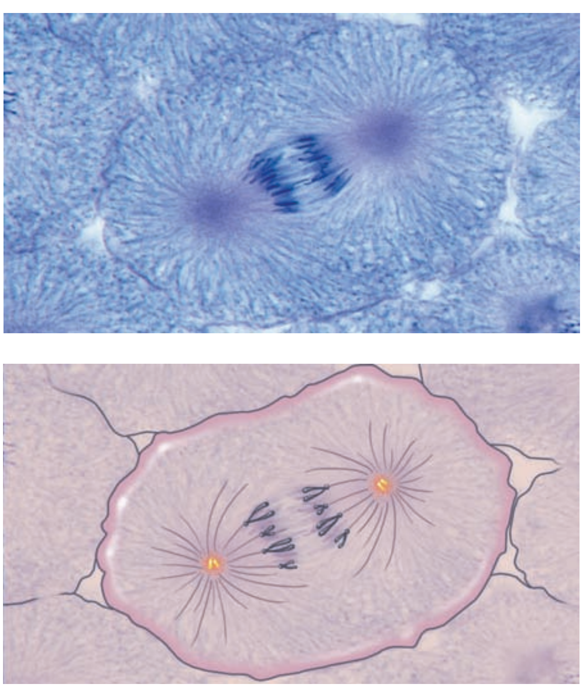
In **telophase**, the two sets of chromosomes form tight groups at each pole of the cell. A nuclear membrane forms around each group, and a nucleolus appears in each



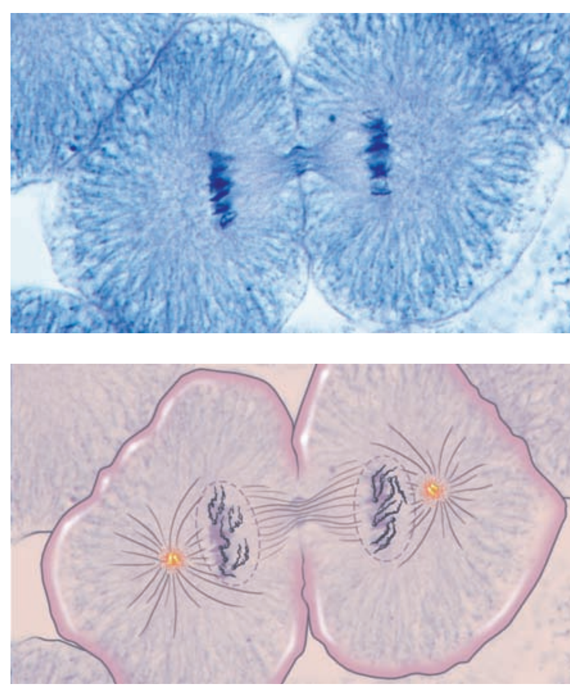
Prophase
Chromatin coils to become chromosomes.
Nucleolus and nuclear membrane break down.
Spindle fibres grow from centrioles.
Centrioles migrate to opposite poles of cell.



Metaphase
Chromosomes lie along midline of cell.
Some spindle fibres attach to centromeres.



Anaphase
Centromeres divide in two.
Spindle fibres pull the new chromosomes to opposite poles of cell.
Each pole (future daughter cell) now has an identical set of genes.



Telophase
Chromosomes gather at each pole of cell.
Chromatin uncoils.
New nuclear membrane appears at each pole.
New nucleolus appears in each nucleus.
Mitotic spindle disappears.
(Above photo also shows cytokinesis.)

Figure 5.2 The phases of mitosis. The drawings below each photograph show a cell with only four chromosomes. Human cells have 46 chromosomes new nucleus. The spindle fibres disappear, and the chromosomes gradually uncoil to become chromatin threads once more.

Cytokinesis

Telophase is the last phase of nuclear division but while the events of telophase are occurring, the cytoplasm usually begins to divide. Division of the cytoplasm is called **cytokinesis**. A furrow develops in the cytoplasm between the two nuclei. The furrow gradually deepens until it cuts the cytoplasm into two parts, each with its own nucleus (Fig. 5.2). (Note: Although the term 'mitosis' is commonly used to refer to cell division, it technically refers just to the division of the nucleus.)

Mitosis and cytoplasmic division have thus resulted in the formation of two **daughter cells**, which are now in interphase. Because each chromosome was duplicated, and because the duplicates have separated into daughter cells, *each daughter cell has exactly the same number and type of chromosomes as the parent cell*. The genetic information is therefore passed on completely, and without change, from parent cell to daughter cells.

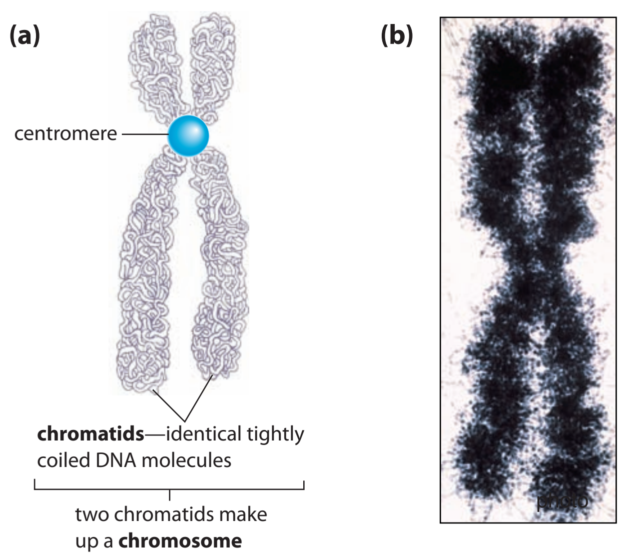


Figure 5.3 **(a)** During prophase, chromosomes become visible as pairs of chromatids. **(b)** Scanning electron micrograph of a chromosome

Meiosis

The cells that make up the human body contain 46 chromosomes, and all cells that arise by the process of mitosis contain 46 chromosomes as well. If human **gametes**, the sperm and egg, were produced by mitosis they also would contain 46 chromosomes because mitosis maintains a constant chromosome number. At fertilisation, the fusion of the sperm and egg results in a doubling of the chromosome number. Thus, the new individual would have 92 chromosomes. Such a person would produce sperm and eggs containing 92 chromosomes, and any resultant offspring would have 184 chromosomes. If mitosis were responsible for the production of the gametes, the chromosome number would double with each succeeding generation. In just 10 generations (from about the time Europeans first settled in Australia) the chromosome number would increase from 46 in the cells of the individuals of the first generation to 23 552 in the cells of the members of the tenth generation. Obviously, this is not what happens. There is another form of cell division, meiosis, which results in the production of gametes with half the usual number of chromosomes.

Meiosis is the type of cell division that is necessary for the formation of the gametes that combine in sexual reproduction. It takes place in the sex organs of sexually reproducing organisms—those that produce the gametes. The process of gamete development, which includes meiosis, is called **gametogenesis**. There are two types of gametogenesis: the formation of spermatozoa in the testis is called **spermatogenesis**, whereas the formation of ova in the ovary is called **oogenesis**.

Meiosis results in the production of four cells, each with *half* the number of chromosomes that were present in the original cell (Fig. 5.4). Meiosis is sometimes referred to as reduction division because the number of chromosomes in the daughter cells is reduced to half the usual chromosome number.

The process of meiosis involves two nuclear divisions, but the chromosomes duplicate only once. The first division of meiosis is somewhat similar to mitosis. At the beginning of both types of cell division the number of chromosomes is the same. In meiosis, however, chromosomes pair off during the prophase stage. The members of each pair of chromosomes are identical in size and shape, and are called **homologous chromosomes** (Fig. 5.5). Each member of a pair of homologous chromosomes carries genetic information that influences the same characteristics. When a cell has two of each type of chromosome it is said to have the **diploid** chromosome number.

Diploid cells are designated $2n$, where n stands for the number of different types of chromosomes. The diploid number for humans is 46. In gametes, only *one* of each type of chromosome is present, and these cells are described as **haploid**. Haploid cells have half the usual number of chromosomes and are designated n. The haploid number for humans is therefore 23.

A number of websites have animations of meiosis, including:
- http://www.johnkyrk.com/meiosis.html
- http://www.cellsalive.com/meiosis.htm

Figure 5.4 illustrates the stages of meiosis using a cell with the diploid number of eight. This is for convenience, as the diagram would be very complicated if all 46 chromosomes were shown. The first division of meiosis involves the reduction of the chromosome number and includes similar stages to those discussed for mitosis earlier in this chapter.

The first meiotic division: a reduction in the chromosome number

During the **prophase** of the first division of meiosis, the chromosomes become visible as long threads. Each has already duplicated and consists of a pair of chromatids. These chromosomes gradually move, so that the members of a pair of homologous chromosomes come to lie alongside each other throughout their entire length (see Fig. 5.4). The chromosomes then shrink and thicken as the DNA becomes more tightly coiled. As each chromosome consists of two chromatids, each chromosome pair appears as *four* strands, frequently all twisted together.

While the chromosomes are shortening and thickening, a spindle forms, stretching between the poles of the cell. The paired chromosomes move towards the spindle fibres until, at **metaphase**, they are arranged on the spindle fibres across the centre, or equator, of the cell (see Fig. 5.4). At **anaphase**, the pairs of homologous chromosomes move apart, with *one* member of each *pair* (consisting of two chromatids) moving to one pole of the cell while the other member of the pair moves to the opposite pole. During this stage the centromeres do not divide and the pairs of chromatids remain intact. Instead, the members of each *pair* of homologous chromosomes separate, resulting in 23 chromosomes moving to each pole of the cell. Thus, in the first division of meiosis, the number of chromosomes assembling at each pole of the cell is half the number present in the original cell. This is a major difference from the events occurring in mitosis. In mitosis, the centromeres divide so that each chromatid becomes a chromosome. Forty-six chromosomes then migrate to each pole of the cell.

During **telophase**, the cytoplasm may divide into two parts.

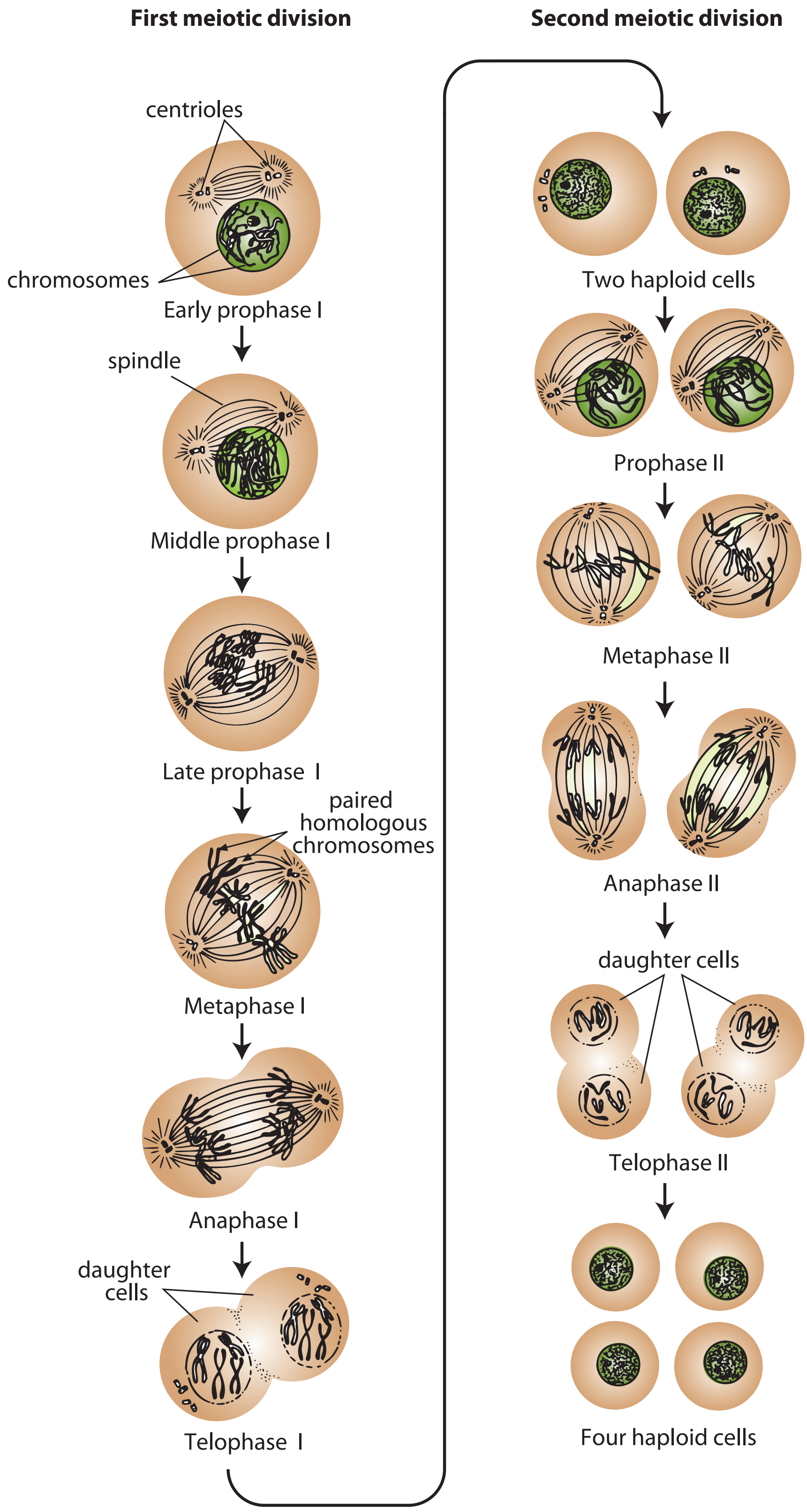


Figure 5.4 The phases of meiosis. The original cell is shown with four pairs of chromosomes. Human cells begin meiosis with 23 pairs

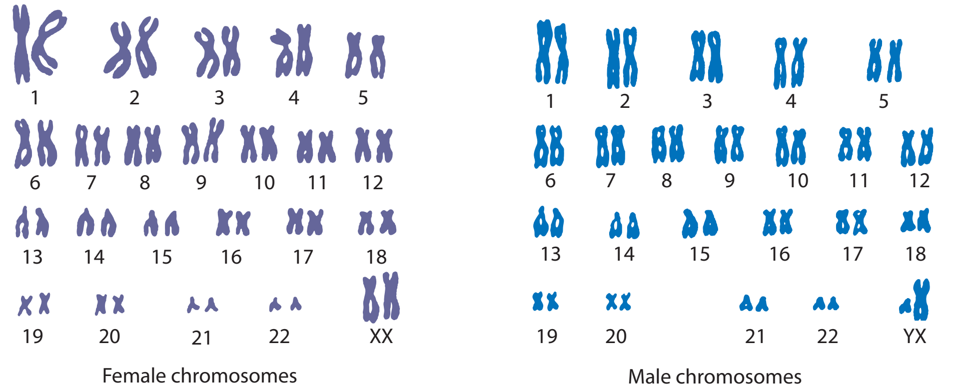


Figure 5.5 Human chromosomes—as chromosomes become visible only during cell division, each appears as a double strand ready for separation into daughter cells; the strands are joined at one point, so that each double strand is referred to as a single chromosome

The second division: the separation of chromatids

At the beginning of the second division the two cells are haploid, each containing half the number of parental chromosomes. Each daughter cell with its 23 chromosomes undergoes the same sequence of events, in which the chromatids separate and migrate to either end of the cell. This results in four haploid cells being formed (see Fig. 5.4).

During the **second prophase**, a new spindle forms at each end of the original spindle and usually at right angles to the original. The chromosomes in each cell gradually move towards the equator, so that at **metaphase** they are arranged on the new spindle. The centromeres then divide, so that each chromatid is now a separate chromosome. These new chromosomes migrate to opposite poles of the cell (**anaphase**). Nuclear membranes begin to form and the cytoplasm starts to divide (**telophase**). By the end of the second division four new cells have been formed, each with half the number of chromosomes of the original cell.

Table 5.3 summarises the differences between the two types of cell division—mitosis and meiosis.

Table 5.3 A comparison of mitosis and meiosis

Mitosis	Meiosis
One duplication of chromosomes and one nuclear division	One duplication of chromosomes and two nuclear divisions
Produces two diploid cells	Produces four haploid cells
Homologous chromosomes do not pair	Homologous chromosomes pair off
Chromatids separate so that each new cell gets a complete set of daughter chromosomes	At first meiotic division members of homologous pairs separate so that new cells get a haploid set of chromosomes. At second division chromatids separate giving four haploid cells
Chromosomes do not change their genetic make-up	Genetic make-up of chromosomes can be changed through crossing over
Produces new cells for growth and repair	Produces haploid gametes for sexual reproduction

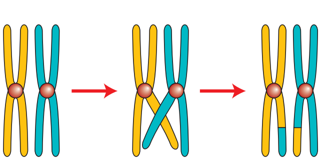


Figure 5.6 Crossing over

An important feature of meiosis occurs during the prophase of the first meiotic division. When the homologous chromosomes are paired the chromatids may break and exchange segments. This is called **crossing over** (see Fig. 5.6). Crossing over creates new combinations of genes so that the chromosomes passed on to the offspring are not the same as those inherited from the parents. Crossing over is discussed in more detail in Chapter 17.

Working scientifically

Activity 5.1 Modelling mitosis and cytokinesis

Simulate the sequence of events that occurs in mitosis and division of the cytoplasm.

You could draw a cell in pencil on a large sheet of paper, or you could draw on a laminated board or benchtop with a whiteboard marker. Items such as strings of beads could be used for chromosomes/chromatids. Use different lengths to represent different chromosomes. The centromeres holding the chromatids together could be paperclips or elastic bands. (Have only three chromosomes in your cell so that the process does not become too complicated.)

Work through the phases of mitosis. As changes occur in the cell, lines on your paper or board can be erased and replaced.

Activity 5.2 Modelling meiosis

You will need

For each pair: A large sheet of paper or laminated board or benchtop to write on; 8 pipe cleaners (4 each of two different colours); wire ties; pencil or whiteboard marker; eraser

What to do

1. Draw a large outline on your paper to represent one cell from an organism produced by sexual reproduction.
2. Inside the cell draw a smaller circle representing the nucleus.
3. Your cell is to have a chromosome number of 4 ($2n = 4$). Since the cell has resulted from sexual reproduction, two of the chromosomes will have come from the female parent and two from the male.
4. The pipe cleaners will be your chromosomes. To model the chromosomes have two pipe cleaners of one colour to represent those from one parent and two of another colour for chromosomes from the other parent.
5. Make the chromosomes that are the same colour different lengths so that you can distinguish them.
6. Place a wire tie around each chromosome to represent the centromere.
7. Place the four chromosomes in the nucleus of your cell. Your cell should now look like Figure 5.7.

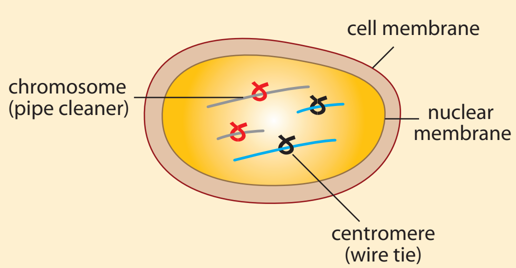


Figure 5.7 The model cell

8. At some time before meiosis begins the chromosomes form duplicates of themselves. When the chromosomes become visible at the start of meiosis they are already duplicated. Duplicate your chromosomes by adding an extra pipe cleaner to each. The duplicates are joined at the centromere (the wire tie). Your cell will now look like Figure 5.8.

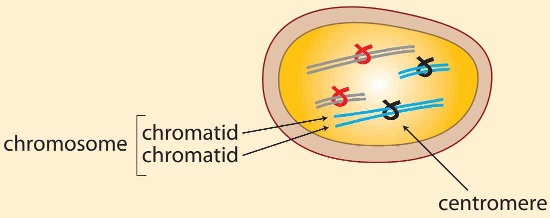


Figure 5.8 The model cell with duplicated chromosomes

9. When meiosis begins the nuclear membrane breaks down. Erase the line in your cell that represents the nucleus.
10. The chromosomes now pair off. Arrange your 'chromosomes' in pairs. The members of each pair will be of equal length but of a different colour.
11. A spindle now forms stretching from one end of the cell to the other. Draw the spindle in your cell.
12. The pairs of chromosomes arrange themselves on the equator of the spindle attached to the spindle fibres by their centromeres. Arrange your chromosomes.
13. The pairs of chromosomes now separate, with one member of each pair going to each end of the cell. Separate your chromosomes.
14. Complete the first division of meiosis by erasing the spindle and drawing nuclear membranes around each of your groups of chromosomes. Now divide your cell into two.
15. For the second meiotic division the nuclear membranes break down and a new spindle forms in each cell at right angles to the first. Erase the nuclear membranes and draw the spindles.
16. The chromosomes arrange themselves on the equator of each spindle. Arrange the chromosomes.
17. The centromeres divide and the chromatids have now become chromosomes. Separate your chromatids (which are now daughter chromosomes).
18. The daughter chromosomes separate to opposite ends of each cell.
19. Nuclear membranes form around each group of chromosomes. Draw the nuclear membranes.
20. The cytoplasm of each cell divides into two. Draw in the new cell membranes.
21. You should now have four gametes each with the haploid number of chromosomes. Redraw your original cell and place four chromosomes in the nucleus. Model the process of meiosis again but do so without looking at any of the instructions given above.

Studying your results

1. What is meant by a *model* in science?
2. With respect to the colours of the chromosomes, how many different types of gametes did your model produce? How many colour combinations are possible?
3. Suppose the chromosome number of your cell was six. How many combinations of chromosomes would now be possible?

4. Humans have a chromosome number of 46. What can you say about the number of possible chromosome combinations in human eggs and sperm?
5. Why is it that children of the same parents do not inherit identical chromosomes (except for identical twins)?

REVIEW QUESTIONS

1. What is the function of the DNA in the nucleus of a cell?
2. Explain the difference between a chromatid and a chromosome.
3. What are homologous chromosomes?
4. Draw up a table (similar to Table 5.2) to summarise, in your own words, the events of mitosis. Include in your table a column with a drawing showing the changes taking place at each stage.
5. Name three places where mitosis would be occurring in the body of a healthy adult human. Explain why cell reproduction is necessary in these places.
6. How does mitosis ensure that each daughter cell has exactly the same genetic information as the parent cell?
7. **(a)** Using a series of diagrams to illustrate your answer, describe the events that take place during the process of meiosis.
   (b) Why is meiosis essential in sexually reproducing organisms?
   (c) Distinguish between haploid and diploid cells.
8. Explain how crossing over can change the combination of genes on a chromosome.

APPLY YOUR KNOWLEDGE

1. Explain the function and significance of the chromosome changes that occur in:
   (a) mitosis
   (b) meiosis
2. What do you think would happen if the spindle fibres did not form in a cell that was undergoing mitosis?
3. Explain the major differences between the processes of mitosis and meiosis. Relate the differences to the type of cells produced by each process.
4. How many chromosomes are present in a cell in a human ovary during each of the following stages of meiosis?
   (a) prophase of the first meiotic division
   (b) at the end of telophase of the first division
   (c) prophase of the second meiotic division
   (d) at the end of telophase of the second division