5 The mitotic cell cycle

When body cells reach a certain size they divide into two. Nuclear division occurs first, followed by division of the cytoplasm. The mitotic cell cycle of eukaryotes involves DNA replication followed by nuclear division. This ensures the genetic uniformity of all daughter cells.

5.1 Replication and division of nuclei and cells

During the mitotic cell cycle, DNA is replicated and passed to daughter cells.

Stem cells in bone marrow and the skin continually divide by mitosis to provide a continuous supply of cells that differentiate into blood and skin cells.

By the end of this section you should be able to:

a) describe the structure of a chromosome, limited to DNA, histone proteins, chromatids, centromere and telomeres
b) explain the importance of mitosis in the production of genetically identical cells, growth, cell replacement, repair of tissues and asexual reproduction
c) outline the cell cycle, including interphase (growth and DNA replication), mitosis and cytokinesis
d) outline the significance of telomeres in permitting continued replication and preventing the loss of genes
e) outline the significance of mitosis in cell replacement and tissue repair by stem cells and state that uncontrolled cell division can result in the formation of a tumour

The division of cells

New cells arise by division of existing cells. In this process, the first step is for the nucleus to divide. The cytoplasm then divides around the daughter nuclei.

Unicellular organisms grow quickly under favourable conditions. They then divide in two. This cycle of growth and division is repeated rapidly, at least whilst conditions remain supportive.

In **multicellular organisms** the life cycle of individual cells is more complex. Here, life begins as a single cell which grows and divides, forming many cells. These eventually make up the adult organism. Certain of these cells retain the ability to grow and divide throughout life. They are able to replace old or damaged cells. However, the majority of the cells of multicellular organisms become specialised. Most are then unable to divide further.

The importance and role of the nucleus

The structure of the nucleus was introduced in Topic 1 (page 16). The nucleus is the organising centre of a cell, and has a double function. Firstly, it controls all the activities of the cell throughout life. Secondly, it is the location within the cell of the hereditary material, which is passed from

generation to generation during reproduction. Both of the functions depend on 'information'. The information in the nucleus is contained within structures called **chromosomes**. These uniquely:

- control cell activities
- are copied from cell to cell when cells divide
- are passed into new individuals when sex cells fuse together in sexual reproduction.

So, the nucleus contains the chromosomes of the cell, and the chromosomes contain the coded instructions for the organisation and activities of cells and for the whole organism. It is on the structure of the chromosomes that we focus first.

Introducing the chromosomes

At the time a nucleus divides the chromosomes become compact, much-coiled structures. Only in this **condensed** state do the chromosomes become clearly visible in cells, provided they have been treated with certain dyes, At all other times, the chromosomes are very long, thin, uncoiled threads. In this condition they give the stained nucleus a granular appearance. The granules are called **chromatin**.

The information the nucleus holds on its chromosomes exists as a nucleic acid called **deoxyribonucleic acid** (**DNA**). DNA is a huge molecule made up of two paired strands in the form of a double helix (Figure 6.3, page 113). A single, enormously long DNA molecule runs the full length of each chromosome.

Look up the structure of DNA now.

The chromosomes are effectively a linear series of genes. A particular gene always occurs on the same chromosome in the same position. We can define 'gene' in different ways. For example, a gene is:

- a specific region of a chromosome that is capable of determining the development of a specific characteristic of an organism
- a specific length of the DNA double helix, hundreds or (more typically) thousands of base pairs long, which codes for a protein
- a unit of inheritance.

Meanwhile, there are four features of the chromosomes that are helpful to note at the outset:

- **The shape of a chromosome is characteristic**. Chromosomes are long, thin structures of a particular, fixed length. Somewhere along the length of the chromosome occurs a short, constricted region called the **centromere**. A centromere may occur anywhere along the chromosome, but it is always in the same position on any given chromosome. The position of the centromere, as well as the length of a chromosome is how they are identified in photomicrographs.
- **The number of chromosomes per species is fixed**. The number of chromosomes in the cells of different species varies, but in any one species the number of chromosomes per cell is normally constant. For example, the mouse has 40 chromosomes per cell, the onion has 16, humans have 46, and the sunflower 34. These are the chromosome numbers for the species. Please note that these are all even numbers.
- **Chromosomes occur in pairs**. The chromosomes of a cell occur in pairs, called homologous pairs (meaning 'similar in structure'). One of each pair came originally from each parent. So, for example, the human has 46 chromosomes, 23 coming originally from each parent in the process of sexual reproduction. This is why chromosomes occur in homologous pairs.
- **Chromosomes are copied**. Between nuclear divisions, whilst the chromosomes are uncoiled and cannot be seen, each chromosome is copied. This copying process occurs in the cell before nuclear division occurs. The two identical structures formed are called **chromatids**. The chromatids remain attached by their centromeres until they are divided during nuclear division. Then the **centromeres** and the chromatids separate. After this separation, the chromatids are recognised as chromosomes again. Of course, when chromosomes copy themselves the critical event is the copying of the DNA double helix that runs the length of the chromosome. This is known as **replication** of the DNA. You will discover how this replication process is brought about in Topic 6.

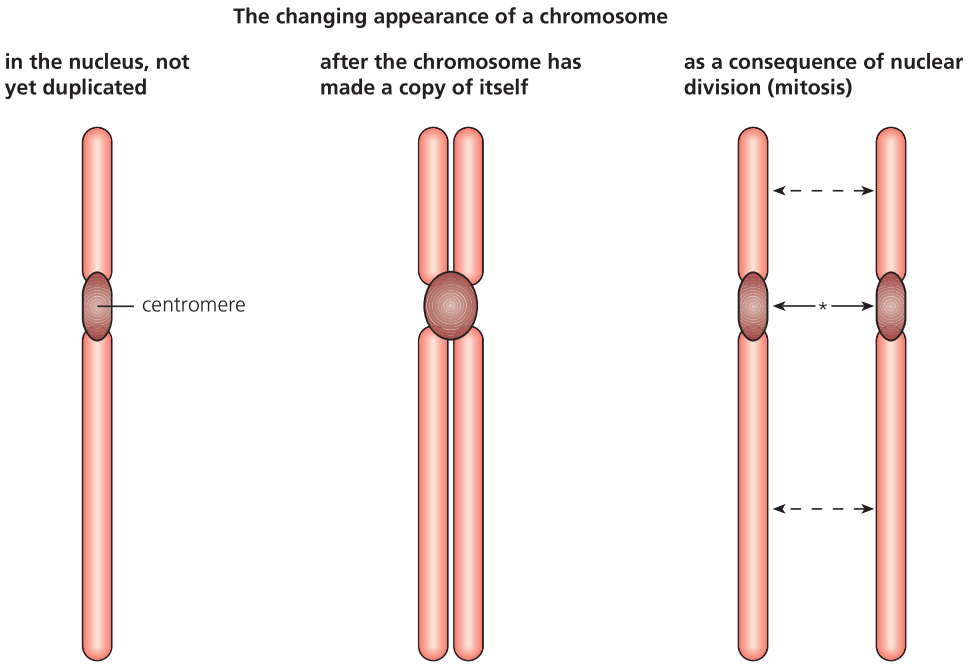


Figure 5.1 One chromosome as two chromatids

Question

1 Explain why chromosomes occur in homologous pairs in cells.

The structure of chromosomes

We have already noted that each chromosome consists of a macromolecule of DNA in the form of a double helix. This runs the full length of the chromosome. However, it is supported by protein. About 50 per cent of a chromosome is built of protein, in fact. Some of these proteins are enzymes that are involved in copying and repair reactions of DNA. However, the bulk of chromosome protein has a support and packaging role for DNA.

Why is packaging necessary?

Well, take the case of human DNA. In each nucleus, the total length of the DNA of the chromosomes is over 2 metres. We know this is shared out between 46 chromosomes.

Chromosomes are of different lengths, but we can estimate that within a typical chromosome of 5 µm length, there is a DNA molecule approximately 5 cm long. This means that about 50 000 µm of DNA is packed into 5 µm of chromosome.

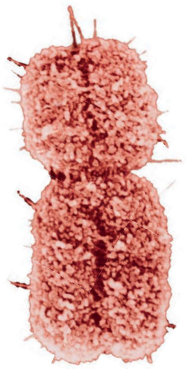
This phenomenal packaging problem is achieved by the much-coiled DNA double helix being looped around protein beads consisting of a packaging protein called **histone**. This is a basic (positively charged) protein containing a high concentration of amino acid residues with additional base groups ($-NH_2$), such as lysine and arginine. Eight histone molecules combine to make a single bead. Around each bead, the acidic (negatively charged) DNA double helix is wrapped in a double loop.

At times of nuclear division the whole beaded thread is itself coiled up, forming the chromatin fibre. The chromatin fibre is again coiled, and the coils are looped around a 'scaffold' protein fibre, made of a **non-histone protein**. This whole structure is folded (supercoiled) into the much-condensed chromosome, shown in Figure 5.2. This arrangement enables the safe storage of these phenomenal lengths of DNA that are packed in the nuclei. However, it also allows access to selected lengths of the DNA (particular genes) during transcription – a process you will encounter in Topic 6.

drawing of the chromosome showing the packaging of DNA

Here the structure is progressively unpacked to show how a huge molecule of DNA is held and supported, by:
1) double-coiling around histone proteins (bead structures = nucleosomes) and then
2) looped along the length of the chromatid, attached to a protein scaffold.

electron micrograph of chromosome during mitosis (metaphase) – showing two chromatids held together at the centromere (×40 000)



(typically a DNA molecule of about 5 cm in length is packed into each chromatid of approximately 5 µm in length)

Also present are enzymes involved in the transcription and replication of the DNA.

Figure 5.2 The packaging of DNA in the chromosome – the role of histone protein

Question

2 Deduce the significance of the positively charged histone protein and the negatively charged DNA.

This is the arrangement in the nuclei of eukaryotes. We can conclude that the single circular chromosome of prokaryotes does not present the same packaging problem, for in these organisms the DNA is described as 'naked'. It occurs without the support of any protein.

The nature and significance of telomeres

Each time the DNA of the chromosomes is copied (replicated), prior to mitosis and cell division, the ends of the DNA molecules cannot be copied. As a result, a few terminal nucleotide sequences are lost. With repeated replications comes progressive shortening on the DNA of each chromosome. If the ends were not protected in some way, chromosomes would lose genes or parts of genes. In fact the ends are protected by special, non-coding nucleotide sequences called telomeres. Typically, a telomere consists of a six-nucleotide sequence such as 'TTAGGG', repeated up to a thousand times. It is parts of this non-coding sequence that are lost at each replication of the DNA, without any harm to the genes the chromosome carries.

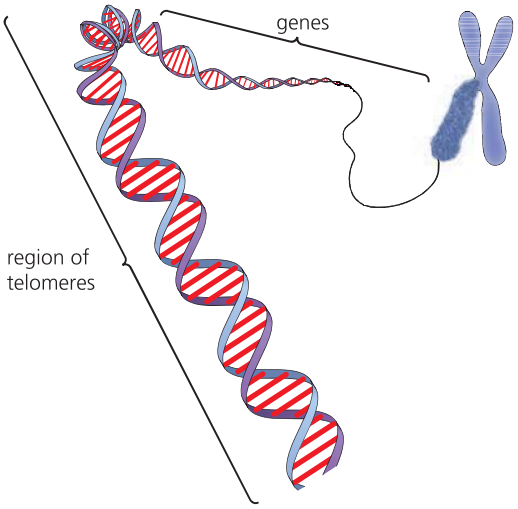


Figure 5.3 The position of telomeres

The chromosomes in nuclear division

Divisions of the nucleus are very precise processes, ensuring the correct distribution of chromosomes between the daughter cells. There are two types of nuclear division, known as mitosis and meiosis.

In **mitosis**, the daughter cells produced have the same number of chromosomes as the parent cell, typically two of each type and this is known as the **diploid (2*n*)** state. Mitosis is the nuclear division that occurs when cells grow or when cells need to be replaced and when an organism reproduces asexually.

In **meiosis**, the daughter cells contain half the number of chromosomes of the parent cell. That is, one chromosome of each type is present in the nuclei formed and this is known as the **haploid (*n*)** state. Meiosis is the nuclear division that occurs when sexual reproduction occurs, typically during the formation of the sex cells (called **gametes**) (see pages 345–8).

Whichever division takes place, it is normally followed by division of the cytoplasm to form separate cells. This process is called **cytokinesis**.

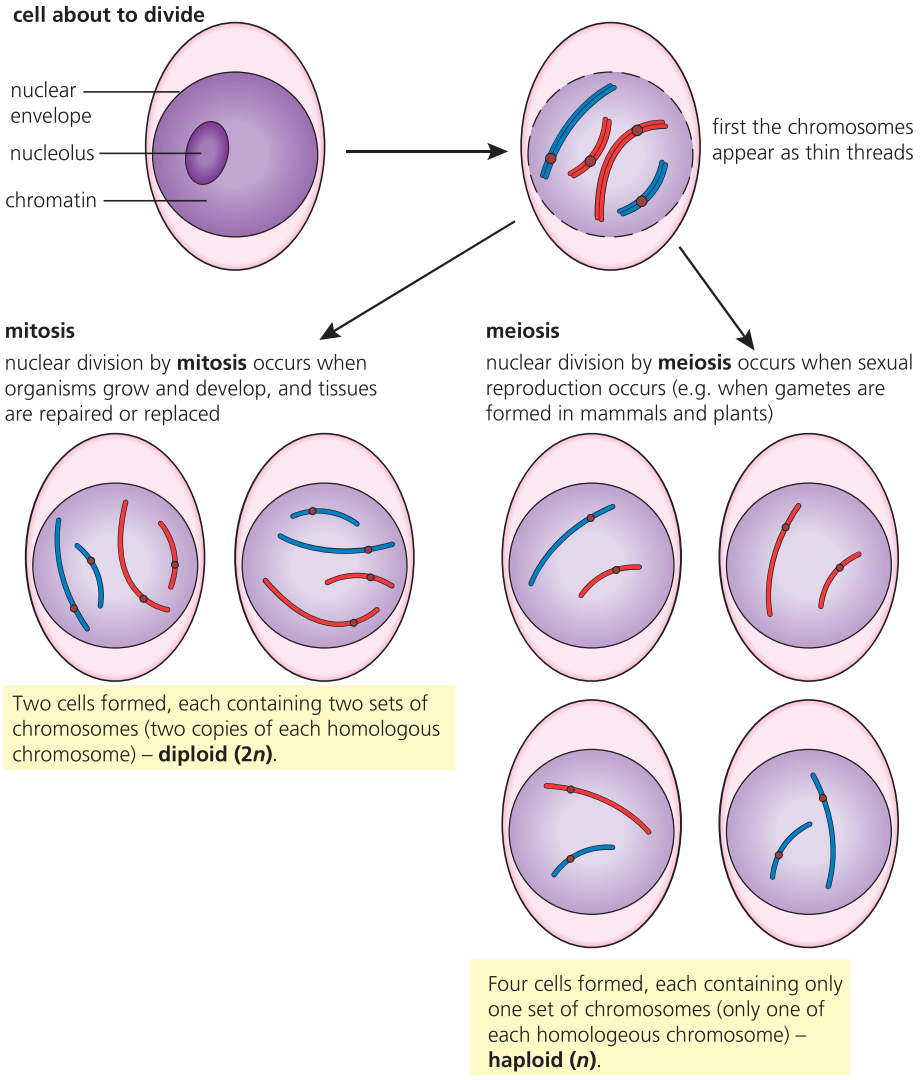


Figure 5.4 Mitosis and meiosis: the significant differences

Question

3 **a** What is a haploid cell?

b Where in the human body would you find cells undergoing:

i meiosis

ii mitosis?

Mitosis and the cell cycle

The cell cycle is the sequence of events that occur between one division and the next (Figure 5.5). It consists of three main stages: **interphase**, **nuclear division** and finally **cell division** (also called **cytokinesis**). The length of the cycle depends partly upon conditions external to the cell, such as temperature, supply of nutrients and oxygen. Its length also depends upon the type of cell. In cells at the growing point of a young stem or of a developing human embryo, the cycle is completed in less than 24 hours. The epithelium cells that line the gut typically divide every 10 hours. Liver cells divide every year or so. Nerve cells never divide again, after they have differentiated. Here the nucleus remains at interphase. In specialised cells the genes, other than those needed for the specific function, are 'switched off', so they cannot divide.

Interphase

Interphase is always the longest part of the cell cycle but it is of extremely variable length. At first glance the nucleus appears to be 'resting' but this is not the case at all. The chromosomes, previously visible as thread-like structures, have become dispersed. Now they are actively involved

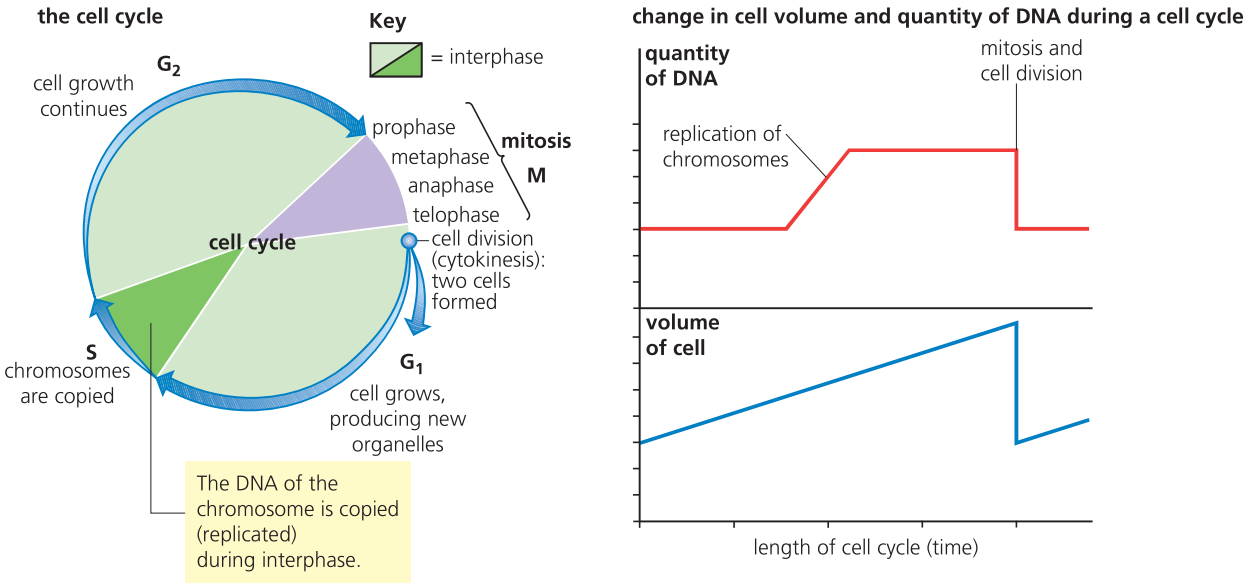


Figure 5.5 The stages of the cell cycle

in protein synthesis – at least for most of interphase. From the chromosomes, copies of the information of particular genes or groups of genes are taken in the form of ribonucleic acid (RNA), ('messenger RNA', page 123), for use in the cytoplasm. In the cytoplasm, ribosomes assemble proteins from amino acids, combining them in sequences dictated by the information from the gene. We return to this process later in this topic.

Look at Figure 5.5. The sequence of the events of interphase is illustrated there. The changes that occur are summarised in Table 5.1.

Table 5.1 The events of interphase

G_1: the 'first gap' phase	The cell grows by producing proteins and cell organelles, including mitochondria and endoplasmic reticulum.
S: synthesis	Growth of the cell continues as replication of DNA occurs (see Topic 6). Protein molecules called histones are synthesised and attach to the DNA. Each chromosome becomes two chromatids.
G_2: the 'second gap' phase	Cell growth continues by protein and cell organelle synthesis. Mitochondria and chloroplasts divide. The spindle begins to form.
Nuclear division, mitosis (M), follows.	

The significance of mitosis

Each daughter cell produced by mitosis has a full set of chromosomes, identical to those of the parent cell. No variation in genetic information arises by mitosis.

In the **growth and development of an embryo** it is essential that all cells carry the same genetic information (the same chromosomes) as the existing cells of the organism. Similarly, when **repair of damaged or worn out cells** occurs, the new cells must be exact copies of the cells being replaced. Mitosis ensures this. Otherwise, in growth, development and repair activities, different parts of the body of an organism might start working to conflicting blueprints. The results would be chaos!

In **asexual reproduction**, of which various forms exist, the offspring produced are identical to the parent since they are produced as a result of mitotic cell division. As a consequence, the offspring have all the advantages of the parents in mastering the same habitat – and any disadvantages, too. The offspring produced by asexual reproduction are often described as clones.

Question

4 What are the essential differences between mitosis and meiosis?

Cancer – diseases of uncontrolled cell division

Cancer is the result of the ill-regulated proliferation of cells, typically resulting in the formation of a solid tumour. There are many different forms of cancer, affecting different tissues of the body – cancer is not thought of as a single disease. Cancers are usually fatal if untreated. Today, many cancers are treatable, and in these cases, survival rates are improving markedly.

Today, in developed countries, one in three people suffer from cancer at some point in their life and approximately one in four will die from it. In these regions the commonest cancers are of the lung in males and of the breast in females. However, in many parts of the world, cancer rates are different – often they are significantly lower. You can see the range of common cancers and their incidences worldwide at: **http://globocan.iarc.fr/**

So, cancer arises when the cell cycle operates without its normal controls. In a healthy cell the cell cycle is regulated by a molecular control system, itself controlled by specific genes. However, cells may start to divide by mitosis, repeatedly, without control or regulation. Now the rate of cell multiplication is very much faster than the rate of cell death, and an irregular mass of cells, a tumour, is formed (Figure 5.6).

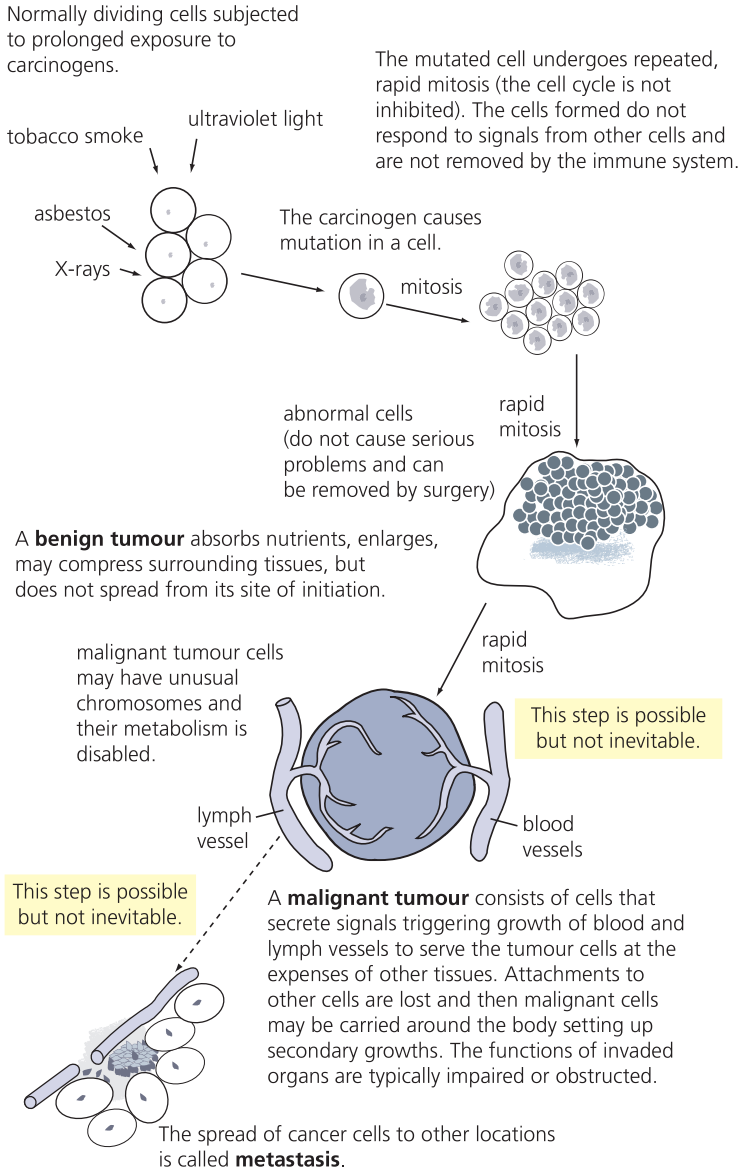


Figure 5.6 Steps in the development of a malignant tumour

Cancers start when changes occur in the genes that regulate the cell cycle. This is where carcinogens may enter the story. A carcinogen is any agent that may cause cancer. Some highly significant carcinogens are identified in Table 5.2.

So, carcinogens are highly likely to cause damage to the DNA molecules of chromosomes. The result is a mutation – a change in the amount or chemical structure of DNA of a chromosome. Mutations of different types build up in the DNA of body cells over time. A single mutation is unlikely to be responsible for triggering cancer. With time, mutations may accumulate in the body and then trigger a disease. This explains why the majority of cancers arise in older people. Also, mutation may occur in the cells of different body tissues, and hence cancer is not one single disease.

Whatever the cause, two types of genes play a part in initiating a cancer, if they mutate:

- **Proto-oncogenes**. These are genes that code for the proteins that play a part in the control of the cell cycle. When a proto-oncogene mutates, an oncogene results. In this state, the gene permanently switches on cell division, causing cells in the tissue concerned to become 'immortal', if their nutrient supply is maintained.
- **Tumour-suppressing genes**. These are normal genes that either slow down cell division, repair mistakes in DNA when they arise, or instruct the cell to die (by programmed cell death). These genes, too, are vulnerable to carcinogens. For example, a mutation may inactivate the gene that codes for a protein known as p53. When protein p53 is present, copying of faulty DNA is stopped. Then, other enzymes are able to repair the DNA and correct the fault, or programmed cell death is switched on in the faulty cell, so cancer is avoided. Abnormalities in the p53 gene have been found in more than 50 per cent of human cancers.

Table 5.2 Common carcinogens known to increase mutation rates and the likelihood of cancer

Ionising radiation	Ionising radiation includes X-rays and radiation (gamma rays, α particles, β particles) from various radioactive sources. These may trigger the formation of damaging ions inside the nucleus – leading to the break-up of the DNA.
Non-ionising radiation	Non-ionising radiations such a UV light. This is less penetrating than ionising radiation, but if it is absorbed by the nitrogenous bases of DNA, may modify it – causing adjacent bases on the DNA strand to bind to each other, instead of binding to their partner on the opposite strand (page 108).
Chemicals	Several chemicals that are carcinogens are present in tobacco smoke (page 171). Also, prolonged exposure to asbestos fibres may trigger cancer in the linings of the thorax cavity (pleural membranes, Figure 9.XX, page 000) – the harm usually becomes apparent only many years later.

Question

5 Describe three environmental conditions that may cause normal cells to become cancerous cells.

5.2 Chromosome behaviour in mitosis

The events that occur during mitosis can be followed by using a light microscope.

By the end of this section you should be able to:

a) describe, with the aid of photomicrographs and diagrams, the behaviour of chromosomes in plant and animal cells during the mitotic cell cycle and the associated behaviour of the nuclear envelope, cell surface membrane and the spindle

b) observe and draw the mitotic stages visible in temporary root tip squash preparations and in prepared slides of root tips of species such as those of *Vicia faba* and *Allium cepa*

Mitosis, the steps

In mitosis, the chromosomes, present as the chromatids formed during interphase, are separated and accurately and precisely distributed to two daughter nuclei. Here, mitosis is presented and explained as a process in four phases but this is for convenience of description only. Mitosis is one continuous process with no breaks between the phases.

Follow the phases of mitosis in Figure 5.8.

In **prophase** the chromosomes become visible as long thin threads. During interphase the DNA had been extended to allow for activity of the genes and for replication. Now, in nuclear division, the DNA must become tightly packed for the chromosomes to move about and to separate. They increasingly shorten and thicken by a process of supercoiling. Only at the end of prophase is it possible to see that the chromosomes consist of two chromatids held together at the centromere. At the same time, the nucleolus gradually disappears and the nuclear envelope breaks down. In animals, the **centrosome** divides and the two centrioles replicate (make copies) to form two centrosomes.

In **metaphase** the two centrosomes move to opposite ends of the cell. Microtubules of the cytoplasm start to form into a spindle, radiating out from the centrioles (page 19). Each pair of chromatids is attached to a microtubule of the spindle and is arranged at the equator of the spindle. (Note: in plant cells, a spindle of exactly the same structure is formed but without the presence of the centrosomes).

In **anaphase** the centromeres separate, the spindle fibres shorten and the chromatids are pulled by their centromeres to opposite poles. Once separated, the chromatids are referred to as chromosomes.

In **telophase** a nuclear envelope reforms around both groups of chromosomes at opposite ends of the cell. The chromosomes 'decondense' by uncoiling, becoming chromatin again. The nucleolus reforms in each nucleus. Interphase follows division of the cytoplasm.

Question

6 As the contents of a nucleus in the human body prepares to undergo mitosis, how many chromatids does it contain?

Cytokinesis

Cytokinesis is the division of the cytoplasm that follows telophase. During cytokinesis, cell organelles such as mitochondria and chloroplasts become evenly distributed between the cells. In animal cells, the cytoplasm separates by in-tucking of the cell surface membrane at the equator of the spindle, 'pinching' the cytoplasm in half (Figure 5.8).

In plant cells, the Golgi apparatus forms vesicles of new cell wall materials which collect along the line of the equator of the spindle, known as the cell plate. Here the vesicles merge, forming the new cell surface membranes and the cell walls between the two cells (Figure 5.7).

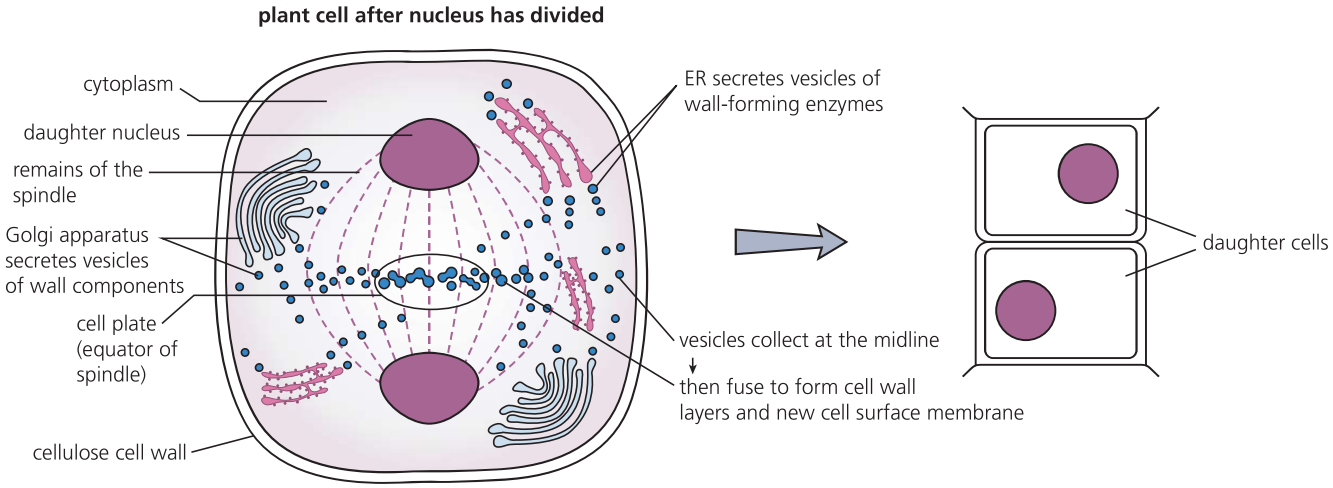


Figure 5.7 Cytokinesis in a plant cell

Mitosis – a summary

Daughter cells produced by mitosis have a set of chromosomes identical to each other and to the parent cell from which they were formed because:

- an **exact copy** of each chromosome is made by accurate copying during interphase, when two chromatids are formed
- **chromatids remain attached** by their centromeres during metaphase of mitosis, when each becomes attached to a spindle fibre at the equator of the spindle
- centromeres then separate during anaphase and the chromatids of each pair are pulled apart to **opposite poles** of the spindle. Thus, one copy of each chromosome moves to the poles of the spindle
- the chromosomes at the poles **form the new nuclei** – two to a cell at this point
- two cells are then formed by separation of the cytoplasm at the mid-point of the cell, **each with an exact copy of the original nucleus**.

Question

7 Using slides they had prepared to observe chromosomes during mitosis in a plant root tip (Figure 5.9), five students observed and recorded the number of nuclei at each stage in mitosis in 100 cells.

Stage of mitosis	Number of nuclei counted				
	Student 1	Student 2	Student 3	Student 4	Student 5
Prophase	64	70	75	68	73
Metaphase	13	10	7	11	9
Anaphase	5	5	2	8	5
Telophase	18	15	16	13	13

a Calculate the mean percentage of dividing cells at each stage of mitosis. Present your results as a pie chart.

b Assuming that mitosis takes about 60 minutes to complete in this species of plant, deduce what these results imply about the lengths of the four steps?

For simplicity, the drawings show mitosis in a cell with a single pair of homologous chromosomes.

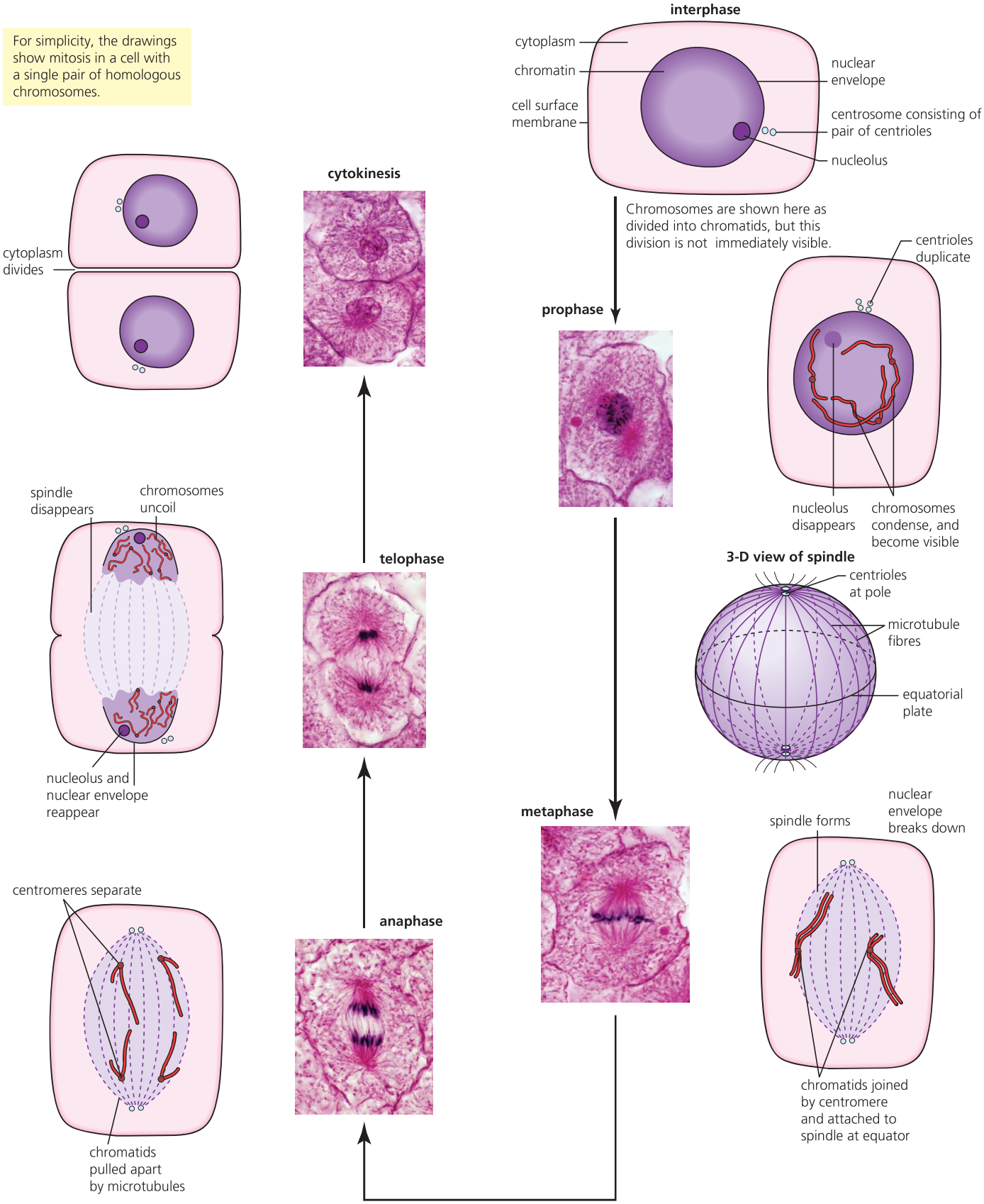


Figure 5.8 Mitosis in an animal cell

Observing chromosomes during mitosis

Actively dividing cells, such as those at the growing points of the root tips of plants, include many cells undergoing mitosis. This tissue can be isolated, stained with an ethano-orcein (aceto-orcein) stain, squashed and then examined under the high power of the microscope. Nuclei at interphase appear red–purple with almost colourless cytoplasm. The chromosomes in cells undergoing mitosis will be visible, too, rather as they appear in the electron micrographs in Figure 5.8. The procedure is summarised in the flow diagram in Figure 5.9.

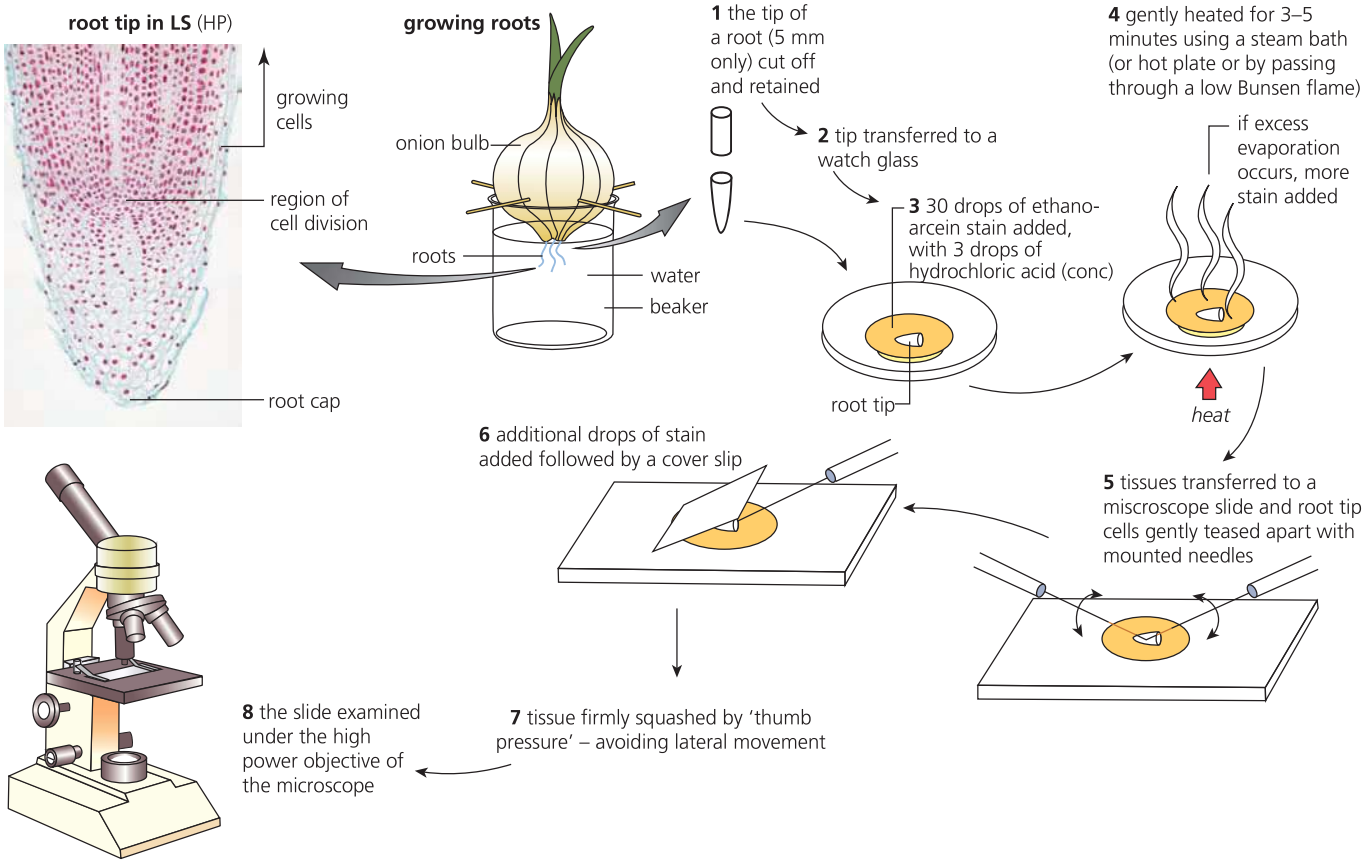


Figure 5.9 Preparing an onion root tip squash with ethano-orcein stain

Drawing the stages of mitosis, using temporary mounts

The temporary mounts you have produced from root tip squashes are likely to contain one or more cells at each stage of mitosis, when carefully examined.

Follow the instructions on biological drawing, on page 8, in producing an image of each stage. These should show, drawn to scale:

- the cell surface membrane
- the presence or absence of the nuclear envelope, the spindle fibres and the equator of the spindle, according to the stage of mitosis observed
- the position, number and shapes of the chromatids or chromosomes
- evidence of early stages in cytokinesis.

Note that, as you are observing plant cells, the centrioles seen in the photomicrographs in Figure 5.8 will be absent.

Summary

- The **nucleus** controls the activities of the cell throughout life. It is the location of the hereditary material which is passed from generation to generation in reproduction. The division of the nucleus is the first step in **cell division**.
- **Chromosomes** occur in the nucleus but are only visible, when stained, at times of nuclear division. The number of chromosomes per nucleus in each species is fixed. Chromosomes occur in pairs and have a characteristic shape.
- **Mitosis** is the replicative nuclear division in which, after cell division, the nucleus present in each of two daughter cells formed has exactly the same number of chromosomes as the parent cell, typically two of each type. It is in the **diploid (2*n*)** state. Mitosis is associated with cell divisions of growth and asexual reproduction.
- **Nucleic acids** are long, thread-like **macromolecules** with a uniform and unvarying 'backbone' of alternating sugar and phosphate molecules. Attached to each sugar molecule is a nitrogenous base which projects sideways. Since the bases vary, they represent a unique sequence that carries the **coded information** held by the nucleic acid.
- **DNA** exists as two strands arranged as a **double helix**. It occurs in the chromosomes in a highly coiled state, supported by a **protein framework.** Within a chromosome, specific lengths of the DNA code for particular polypeptides and are called **genes**.
- **Replication of the DNA** of the chromosomes occurs in the **interphase** of the **cell cycle** when the chromosomes are less coiled, well before nuclear division occurs.
- Each time the DNA of the chromosomes is copied (replicated) prior to mitosis and cell division, a part of the end of the DNA molecules of chromosomes is lost. Ultimately, chromosomes would lose genes or parts of genes by this process, if they were not protected by the presence of **telomeres**. Telomeres are long, seemingly disposable non-coding sequences of nucleotide bases at the ends of the DNA molecules of chromosomes that fulfil this important function.
- **Mutations** are unpredictable changes in the genetic make-up of a cell involving the sequence of particular bases at one location (gene mutation).
- **Cancers** are initiated when cells start to divide repeatedly, by mitosis, without control or regulation. An irregular mass of cells is formed, called a **tumour**. There are many forms of the disease, affecting different tissues of the body. Often cancers are the result of numerous chance mutations triggered by agents known as **carcinogens**. These include ionising radiation, tobacco smoke.

Examination style questions

1 **a)** When does mitosis occur in the life cycle of an animal from its development from a fertilised egg cell until the point when it forms gametes? [2]

b) What do you understand by the 'cell cycle'? [2]

c) By means of fully annotated diagrams explain the difference between the phases of the cycle and the events that characterise each phase. [12]

d) What changes occur during the phases of the cell cycle to

i) the volume of a cell

ii) the quantity of DNA during the phases of the cell cycle? [4]

[Total: 20]

2 **a)** Explain how uncontrolled cell division can result in the formation of a tumour.

b) What do you understand by non-malignant and malignant tumours?

c) Outline the range of factors that can increase the chances of cancerous growths.

3 Muntjac are small deer found throughout Asia. Cells at the base of the epidermis in the skin continually divide by mitosis. Fig. 3.1 shows the chromosomes from a skin cell of a female Indian muntjac deer at metaphase of mitosis.

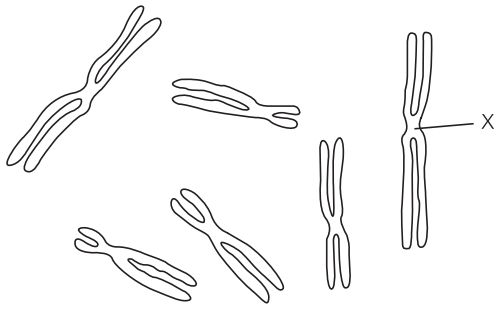


Fig. 3.1

a) **i)** State the diploid chromosome number of the female Indian muntjac deer. [1]

ii) Name **X** and state its role in mitosis. [2]

iii) On a copy of Fig. 3.1, **shade in** a pair of homologous chromosomes. [1]

iv) Draw one of the chromosomes shown in Fig. 3.1 as it would appear during **anaphase** of mitosis. [2]

b) Outline what happens to **a chromosome** between the end of anaphase and the start of the next mitosis. [3]

c) During the formation of eggs in the ovary of the female Indian muntjac deer, the chromosome number changes.

State what happens to the chromosome number and explain why this change is necessary. [2]

[Total: 11]

(Cambridge International AS and A Level Biology 9700, Paper 02 Q3 June 2007)