Cambridge

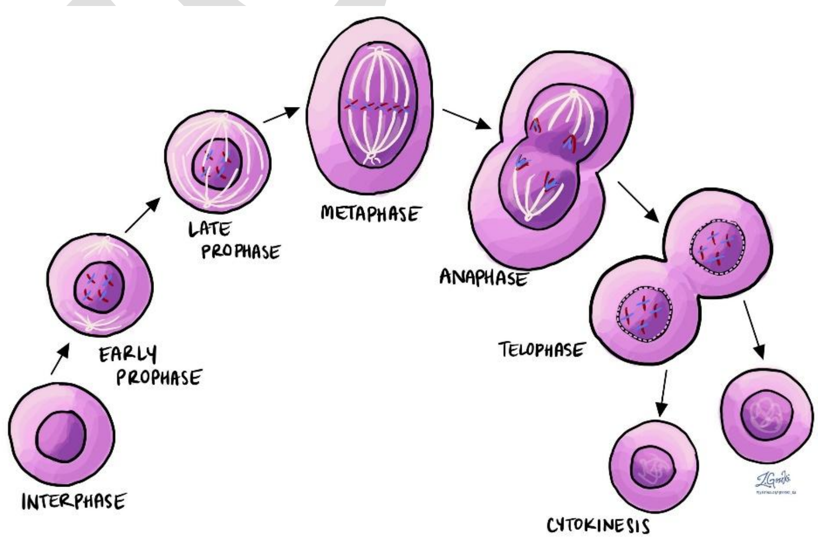
AS level

Biology

CODE: (9700)

Chapter 05

The mitotic cell cycle



Chromosomes

Just before a eukaryotic cell divides, several thread- like structures called chromosomes gradually become visible in the nucleus. They are easily seen, because they stain intensely with stains. They were originally termed chromosomes because 'chromo' means coloured and 'somes' means bodies.

Figure 5.2 Photograph of a set of chromosomes in a human male, just before cell division. Each chromosome is composed of two chromatids held at the centromere. Note the different sizes of the chromosomes and the different positions of the centromeres.

The structure of chromosomes

The chromosome, a crucial component of DNA, is a double structure consisting of two identical **chromatids**, which are joined together during nuclear division.

This is because during the period between nuclear divisions, which is known as **interphase**, each DNA molecule in a nucleus makes an identical copy of itself.

Each chromatid contains one of these DNA copies, and the two chromatids are held together by a narrow region called the **centromere**, forming a chromosome.

Each chromatid contains one DNA molecule.

DNA, the genetic material stored in sister chromatids, is crucial for precise nuclear division. The total length of DNA in an adult human cell is 1.8 meters, which must be packed into a 6 cm diameter nucleus. To prevent tangles, a precise scaffolding of protein molecules is used, called chromatin. Chromosomes are made of chromatin, which is primarily basic histone proteins that interact easily with acidic DNA. Controlled coiling of DNA is the solution to this packing problem. Supercoils, which can be looped or folded, are still not fully understood.

The extent of coiling varies during the cell cycle, the period between one cell division and the next. The chromosomes seen just before nuclear division represent the most tightly coiled (condensed) form of DNA.

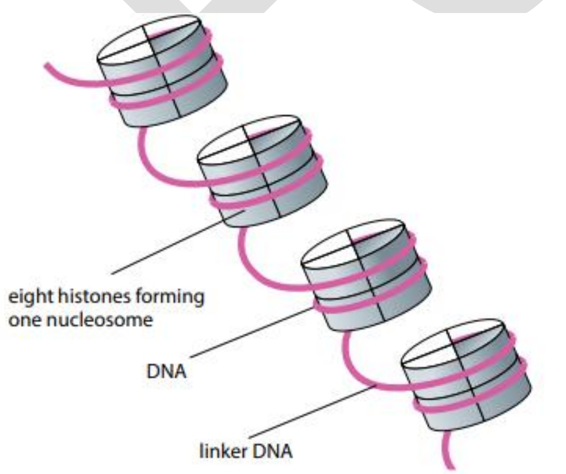


Figure 5.4 How nucleosomes are involved in DNA coiling. Note that you do not need to learn about nucleosomes.

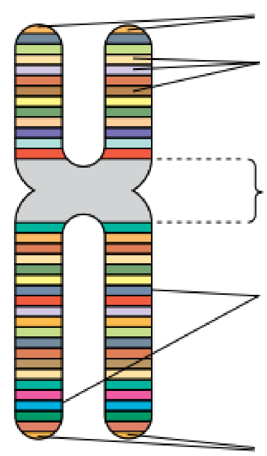


Figure 5.3 Simplified diagram of the structure of a chromosome.

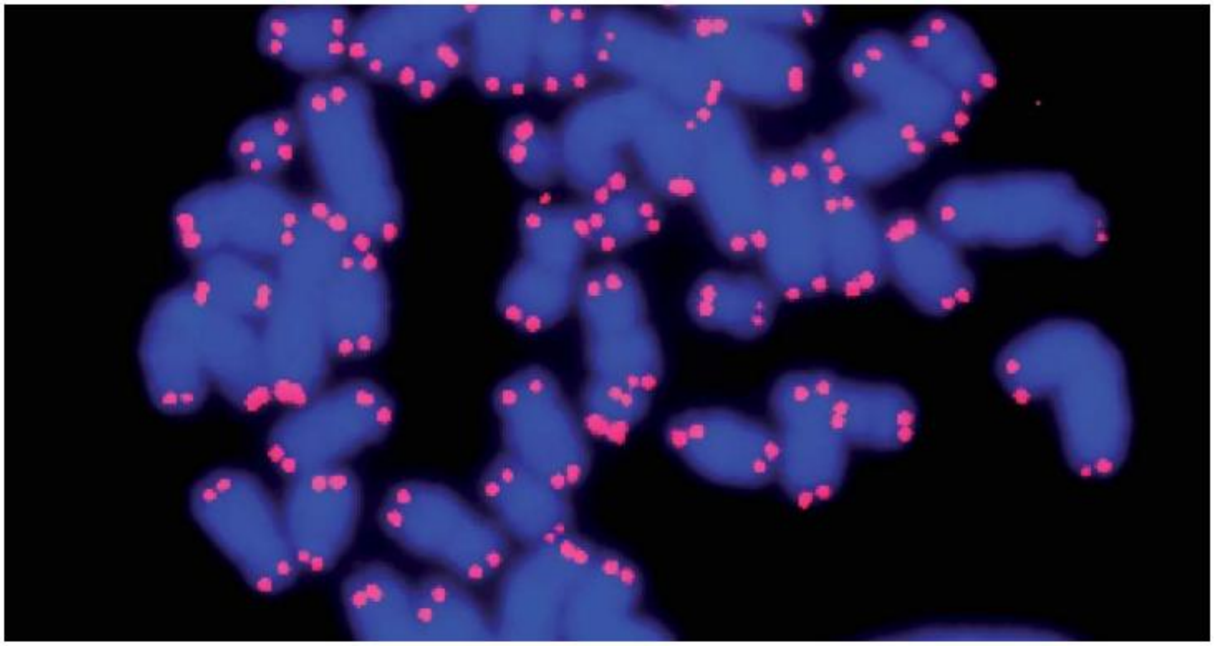


Figure 5.5 Fluorescent staining of human chromosome telomeres as seen with a light microscope. Chromosomes appear blue and telomeres appear pink. (×4000)

Mitosis

Mitosis is nuclear division that produces two genetically identical daughter nuclei, each containing the same number of chromosomes as the parent nucleus. Mitosis is part of a precisely controlled process called the **cell cycle**.

The cell cycle

The cell cycle is the regular sequence of events that takes place between one cell division and the next. It has three phases, namely interphase, nuclear division and cell division. These are shown in Figure 5.6.

S phase – S stands for synthesis (of DNA). This is a relatively short phase. The gap after cell division and before S phase is called the **G1 phase** (G for gap). The gap after S phase and before cell division is called the **G2 phase.**

Nuclear division follows interphase. This may be referred to as the **M phase** (M for mitosis). Growth stops temporarily during mitosis.

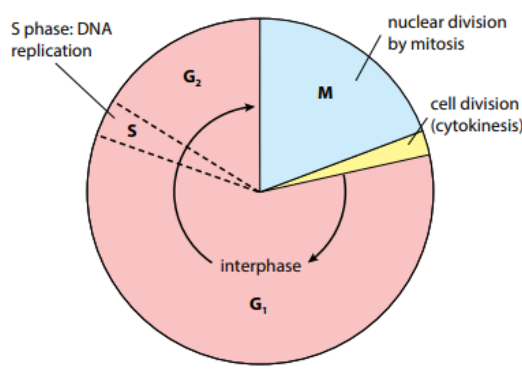


Figure 5.6 The mitotic cell cycle. DNA replication takes place during interphase, the period between cell division and the next nuclear division: **S** = synthesis (of DNA); **G** = gap; **M** = mitosis.

In animal cells, cell division involves constriction of the cytoplasm between the two new nuclei, a process called **cytokinesis**.

In plant cells, it involves the formation of a new cell wall between the two new nuclei.

Mitosis

The process of mitosis is best described by annotated diagrams as shown in Figure 5.7. Although the process is continuous, it is usual to divide it into four main stages for convenience, like four snapshots from a film. The four stages are called **prophase, metaphase, anaphase and telophase.**

However, plant cells do not contain centrosomes, and, after nuclear division, a new cell wall must form between the daughter nuclei. It is **chromosome** behaviour, though, that is of particular interest.

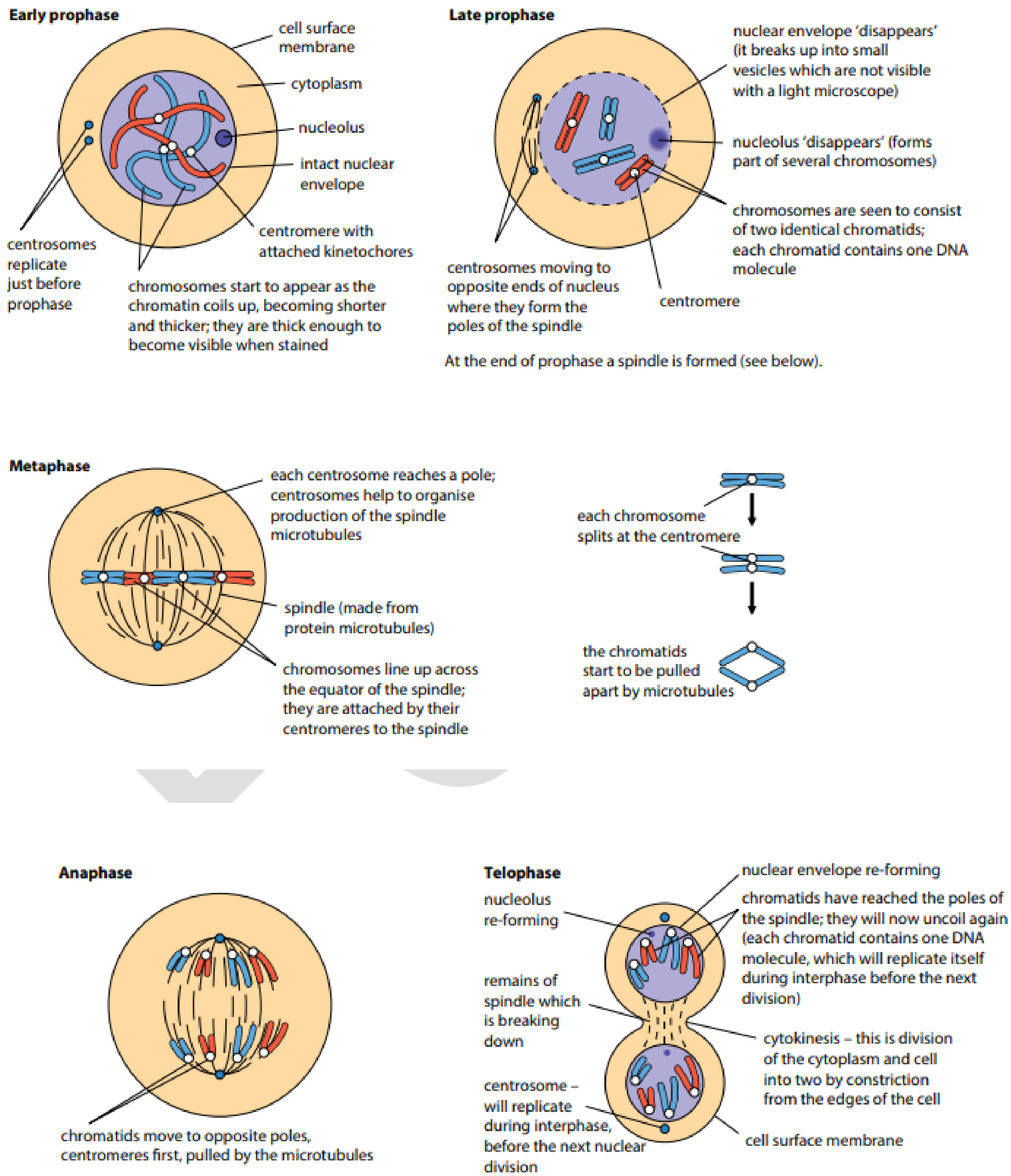


Figure 5.7 Mitosis and cytokinesis in an animal cell.

Centromeres, centrosomes and centrioles

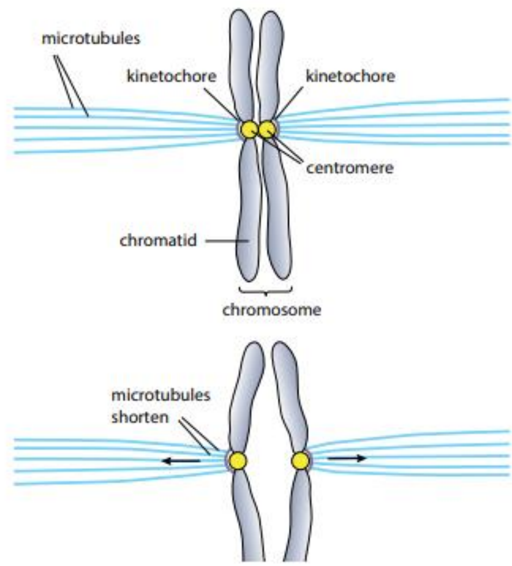


Figure 5.10 Role of the centromere, kinetochores and microtubules during mitosis.

The centromere is needed for the separation of chromatids during mitosis. It is visible as a constriction (Figures 5.2 and 5.3) and is the site of attachment of spindle microtubules. Each metaphase chromosome has two **kinetochores** at its centromere, one on each chromatid.

Protein molecules bind to DNA in the centromere and microtubules, creating spindle fibres that extend from kinetochores to spindle poles during mitosis. Construction of kinetochores begins before nuclear division and is lost after. Centrosomes, located at the poles of the spindle, are organelles that act as microtubule organizing centers. Plant mitosis occurs without centrosomes.

Biological significance of mitosis

Growth - The two daughter cells, genetically identical, enable multicellular organism growth from unicellular zygotes, allowing growth to occur over the entire body or specific regions.

Replacement of cells and repair of tissues - Mitosis and cell division enable cell replacement, with rapid regeneration in the human body, particularly in skin and gut lining, and in some animals, like starfish, regenerating entire parts.

Asexual reproduction - Mitosis is the process of asexual reproduction, where a single organism produces new individuals of a species, with offspring genetically identical to the parents. This can take various forms, such as cell division in unicellular organisms or budding in multicellular organisms. This ability to generate whole organisms from cells is crucial in biotechnology and genetic engineering.

Figure 5.11 **a** Asexual reproduction by budding in *Hydra* (×60). *Hydra* lives in fresh water, catching its prey with the aid of its tentacles. The bud growing from its side is genetically identical to the parent and will eventually break free and live independently. **b** Asexual reproduction in *Kalanchoe pinnata*. The plant produces genetically identical new individuals along the edges of its leaves.

Immune response. The cloning of B- and T-lymphocytes during the immune response is dependent on mitosis.

Stem cells

The extent of the power of a stem cell to produce different cell types is variable and is referred to as its **potency**. Stem cells that can produce any type of cell are described as **totipotent**. After that, some cells become specialised to form the placenta, while others lose this ability but can form all the cells that will lead to the development of the embryo and later the adult. These **embryonic stem cells** are described as **pluripotent.**

The significance of telomeres

Telomeres are structures on chromosome ends that seal DNA with repeated base sequences. They ensure that the ends of the molecule are included in replication, preventing the copying enzyme from running to the end. If part of the DNA is not copied, it loses information, leading to cell death.

Adult stem cells lose their ability to divide, becoming **multipotent** and producing only a few types of cells, despite their importance for growth and repair. They lose some of the potency of embryonic stem cells.

Stem cell therapy is the introduction of new adult stem cells into damaged tissue to treat disease or injury.

Cancer

Cancer is a prevalent disease in developed countries, accounting for one in four deaths. Lung cancer caused 1 in 16 deaths in the UK in 2009. There are over 200 different forms, and cancers are a result of uncontrolled mitosis. Cancerous cells divide repeatedly, forming tumors with abnormal shape changes.

The term for a mutated gene that causes cancer is an **oncogene**, after the Greek word 'onkos', meaning bulk or mass.

Most mutated cells are either affected in some way that results in their early death or are destroyed by the body's immune system.

Any agent that causes cancer is called a **carcinogen** and is described as **carcinogenic**.

Malignant tumours are those that spread through the body, invade other tissues, and destroy them, causing cancer, while benign tumours, like warts, do not spread from their origin.

Malignant tumours interfere with the normal functioning of the area where they have started to grow.

Cells can break off and spread through the blood and lymphatic system to other parts of the body to form **secondary growths**. The spread of cancers in this way is called **metastasis.**

It is the most dangerous characteristic of cancer, since it can be very hard to find secondary cancers and remove them. The steps involved in the development of cancer are shown in Figure 5.15.

a

b

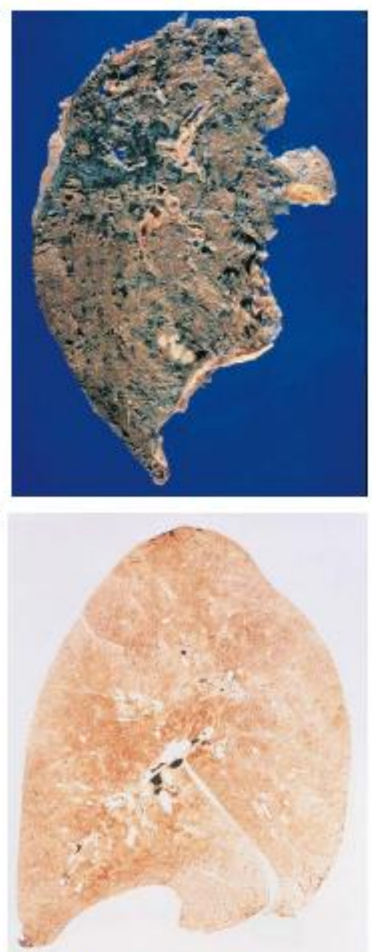


Figure 5.13 **a** Lung of a patient who died of lung cancer, showing rounded deposits of tumour (bottom, white area). Black tarry deposits throughout the lung show the patient was a heavy smoker. **b** Section of a healthy human lung. No black tar deposits are visible.

a

b

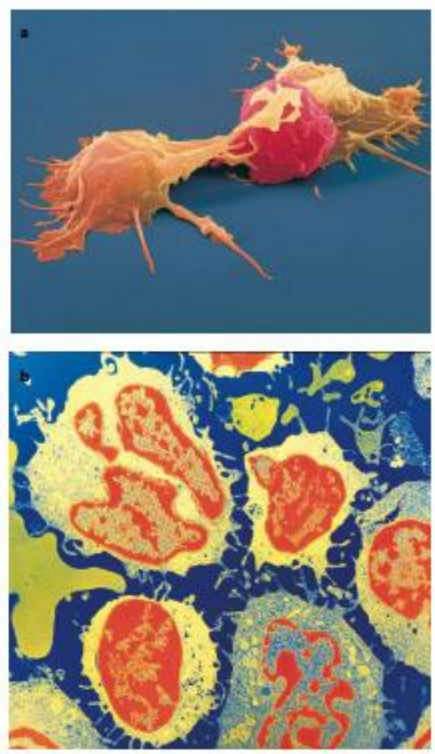


Figure 5.14 **a** False-colour scanning electron micrograph of a cancer cell (red) and white blood cells (orange and yellow). White blood cells gather at cancerous sites as an immune response. They are beginning to flow around the cancer cell, which they will kill using toxic chemicals (×4500). **b** False-colour transmission electron micrograph of abnormal white blood cells isolated from the blood of a person with hairy-cell leukaemia. The white blood cells are covered with characteristic hair-like cytoplasmic projections. Leukaemia is a disease in which the bone marrow and other blood-forming organs produce too many of certain types of white blood cells. These immature or abnormal cells suppress the normal production of white and red blood cells, and increase the patient's susceptibility to infection (×6400).

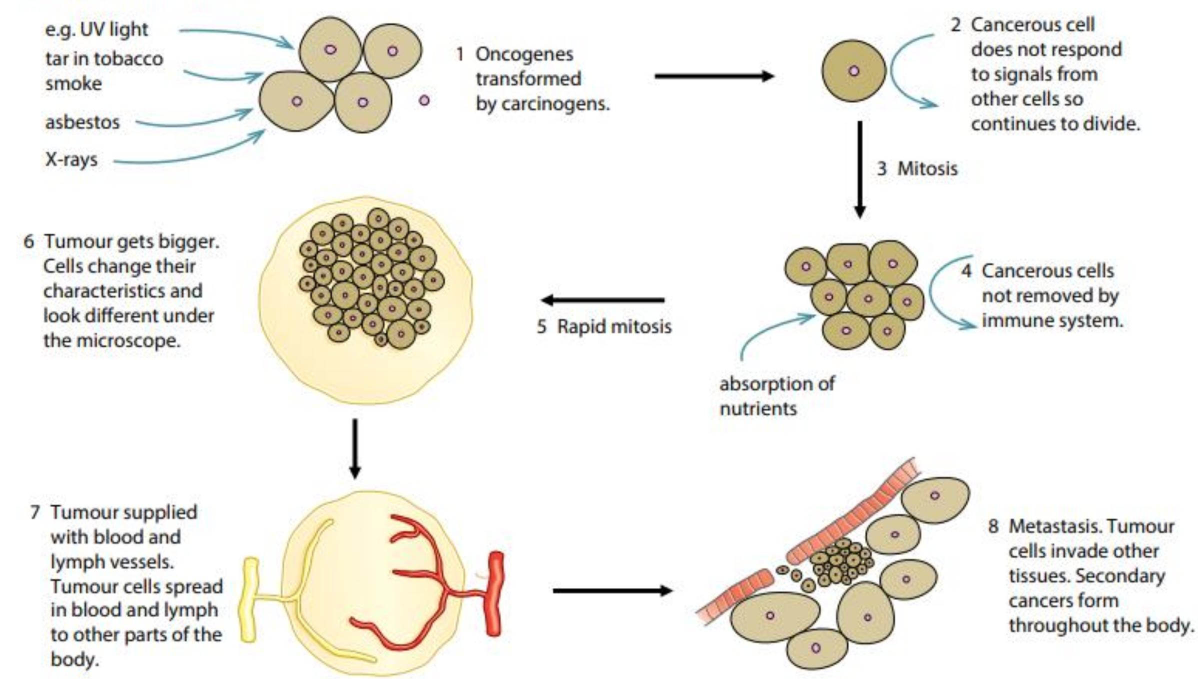
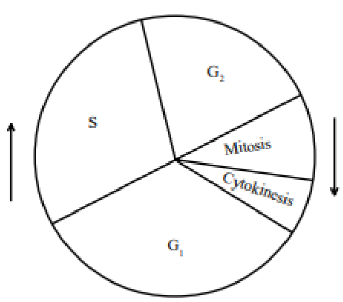
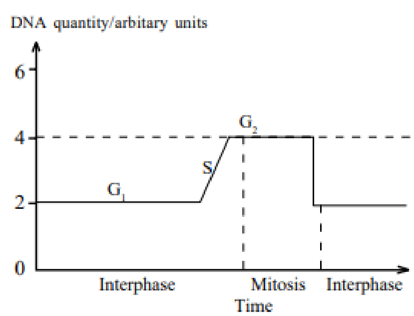


Figure 5.15 Stages in the development of cancer.

Revision questions

(1) Diagram A below shows the different phases during the cell cycle of a eukaryotic cell. Diagram B shows the amount of DNA present during the different phases. G1 and G2 represent the gap phases during which cell growth may occur. S is an intermediate phase.





(a) Descibe how the quantity of DNA in cells is increased during phase S.

(b) What will be the quantity of DNA in arbitary units at the end of mitotic cell division?

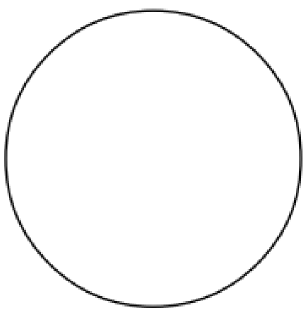
(c) How is the quantity of DNA returned to this level?

(d) What would be the quantity of DNA in arbitary units at the end of a meiotic division.

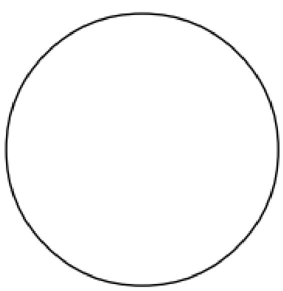
(2) The diagram below shows the chromosomes of a white blood cell from a mammal (not human).

(a) In the circles below draw the chromosome content for the same species of mammal of:

(i) an epithelial cell.



(ii) an egg cell.



(b) What sex of the mammal did the above chromosomes come from? Explain your answer.

(3) (a) There are 18 chromosomes in the somatic (body) cells of a cabbage. How many chromosomes would be present in each of the following?

(i) male nucleus in the pollen grain.

(ii) a cell in anaphase of mitosis.

(iii) a cell in anaphase I of meiosis.

(iv) a cell in anaphase II of meiosis.

(v) a nucleus in telophase II of meiosis.

(b) The diploid chromosome number of the radish is also 18 chromosomes.

(i) How many chromosomes would there be in a diploid nucleus of the hybrid offspring produced by crossing a cabbage with a radish? Show your working

(ii) Suggest why such a hybrid would be infertile

(4) (a) What type of cell division occurs in the following tissues?

(i) the apical meristem of a flowering plant.

(ii) red bone marrow of a mammal

(iii) a pollen sac in the anther of a flowering plant

(iv) the embryo sac in the ovule of a flowering plant.

(v) the inner layer of a seminiferous tubule in a mammalian testis.

(b) Mitosis is usually involved in producing diploid cells from diploid cells. However there are examples in nature where it produces haploid cells from haploid cells. Give two such examples

(5) Although mitosis is a continuous process, for ease of reference it is conventionally divided into the following stages: interphase, prophase, metaphase, anaphase and telophase.

(a) Name the stages of mitosis during which,

(i) the chromatids separate and move to the poles.

(ii) the nuclear membrane reforms and cytokinesis follows

(iii) the chromosomes align on the equator of the spindle.

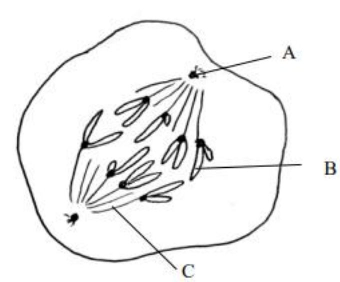
(iv) the chromosomes become stainable, and the spindle starts to form

(b) If the amount of DNA present in the cell at metaphase is 20 units, how much DNA will be present in each nucleus:

(i) at the start of prophase.

(ii) immediately after telophase

(6) The diagram below shows the nucleus of a cell during mitosis



(a) Identify structures A, B and C:

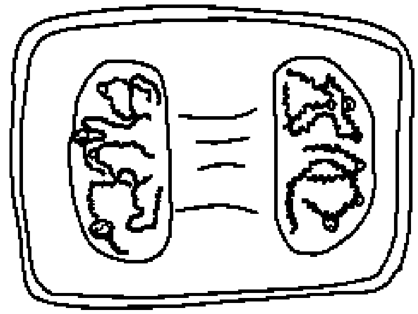
(b) Name the stage in which each of the following processes takes place.

(i) condensation of chromosomes.

(ii) movement of daughter chromosomes to the poles.

(c) The substance colchicine can be used specifically to inhibit the formation of spindle fibres and so stop mitosis at a particular stage. At which stage would colchicine stop mitosis?

(d) Name two precise locations where mitosis occurs in plants.



(7) (a) Outline the sequence of changes undergone by chromosomes, during mitosis.

(b) The diagram shows a plant cell at a particular stage of mitosis

(i) Identify the stage of mitosis shown.

(ii) Briefly describe the events of the next stage of cell division.

(8) (a) Outline the function of each of the following in the process of mitosis:

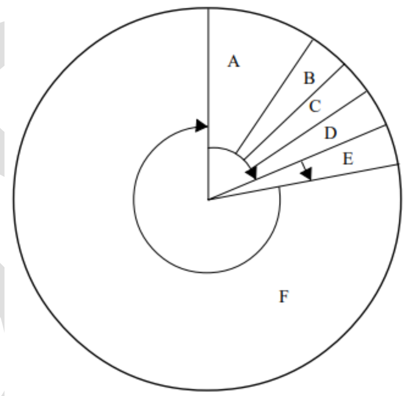
(i) centromere

(ii) spindle.

(b) Outline the significance of meiosis in the process of gamete formation

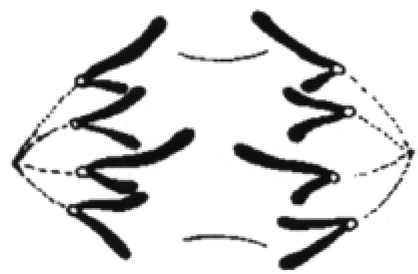
(9) (a) Explain why it is inappropriate to call interphase a 'resting stage'?

(b) The diagram below represents the cell cycle.



Identify the stages A, C, E and F

(9) The drawing below shows a dividing animal cell nucleus at the anaphase stage of mitosis.



(a) Briefly describe what you can see happening in this stage of mitosis

(b) (i) In the space below draw accurately the appearance of the same nucleus at the metaphase stage of mitosis.

(ii) On your drawing label a centromere and a centrosome (aster)

(10) a) Read through the following passage about mitosis and then complete it by writing the most appropriate word or words in the spaces.
In flowering plants, the process of mitosis is restricted to the apical .... and to... In growing mammals' mitosis can occur throughout the body. However, not all regions of the young mammal grow at the same rate, and this is called .... growth. In the cell cycle, replication of DNA occurs in the .... phase, after which there is a lag or gap phase, called the .... phase, before actual mitosis starts. The chromosomes also replicate before the onset of mitosis, but this replication is not visible until the middle of the................................. stage. At this stage, each chromosome consists of two .... held together by a .... In the kangaroo, there are 10 pairs of chromosomes. Thus, in mitosis an anaphase cell will contain .... chromosomes with migrating .... to each pole. The daughter cells therefore have the .... number of 2n = ...

(b) The drug colchicine is used in chromosome studies since it inhibits mitosis at metaphase when the chromosomes are most clearly visible. It does this by inhibiting spindle formation or by breaking down the spindle. Colchicine is produced by the roots of the Autumn Crocus (Colchicum autumnale). Suggest an advantage to Autumn Crocus plants of producing colchicine.