Bio Factsheet

September 2000 Number 76

# The Eukaryotic cell cycle and Mitosis

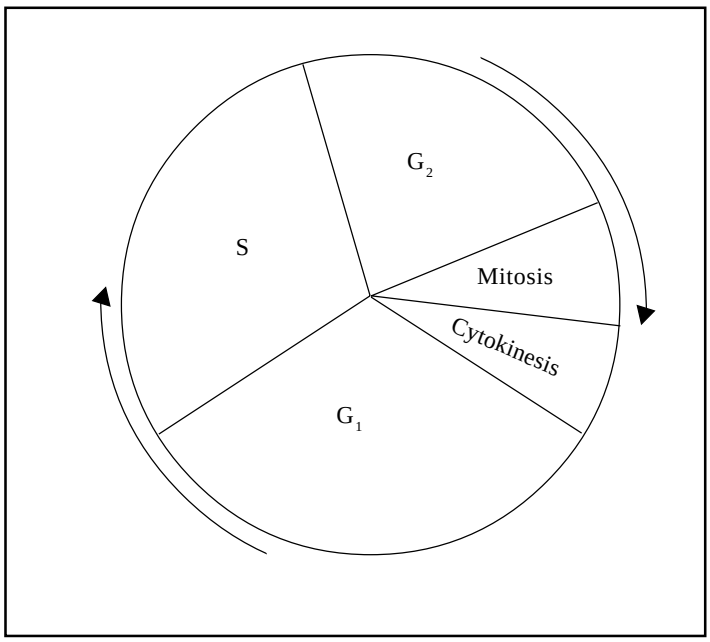
**This Factsheet covers the relevant AS syllabus content of the major examining boards. By studying this factsheet the candidate will gain a knowledge and understanding of:**

- **the different phases of the eukaryotic cell cycle (a eukaryotic cell has membrane bound organelles)**
- **the importances of mitosis**
- **the process of mitosis**

## The eukaryotic cell cycle

This is illustrated by Fig 1.

**Fig 1. The eukaryotic cell cycle**



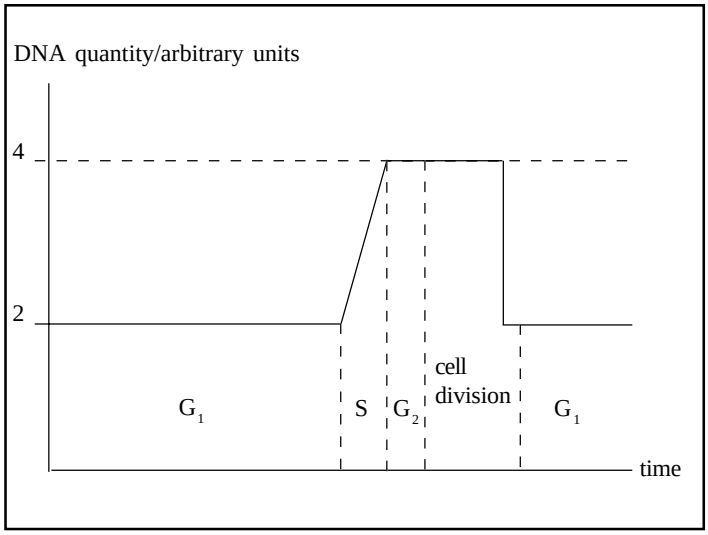

Cell division consists of two phases, **mitosis** and **cytokinesis**. Mitosis, is the division of the nucleus. Cytokinesis is the division of the cytoplasm which usually, but not always, occurs immediately after nuclear division. Only a small time period of the cell cycle consists of the cell division stages. The other phases, known as **$G_1$**, **S** and **$G_2$** take up the majority of the time.

The total time of the cell cycle varies from around 30 minutes in growing yeast cells, 18 to 24 hours in animal sperm-producing cells, 10 to 30 hours in plant meristematic cells to several weeks in slowly regenerating tissues.

For example in a cell with a 24 hour cycle the times of the phases would be around $G_1$ 10 hours, S 9 hours, $G_2$ 4 hours and mitosis with cytokinesis 1 hour.

Fully differentiated cells generally remain arrested in the $G_1$ stage and will not normally divide again. Some cells remain arrested in the $G_2$ stage, for example, human cardiac muscle cells. The synthesis of DNA occurs in the S phase when the quantity of DNA in the cell is doubled. This is shown in Fig 2.

**Fig 2. Quantity of DNA in the cell during different phases**




The $G_1$, S and $G_2$ phases are termed **interphase**. Interphase is the stage of the cell cycle between cell divisions. It is not a resting stage, since in an actively dividing and growing cell new DNA and proteins are being synthesised and in a non-dividing mature cell, the $G_1$ or $G_2$ cell is performing all its metabolic cell functions and specific jobs.

## The importances of mitosis

Cell division by mitosis is important during growth of eukaryotic organisms and is the way in which eukaryotes increase their cell numbers, either in a population of a single celled organism, such as Amoeba or yeast, or within the body of a multicellular organism. Growth may be **allometric** meaning that different parts of the organism grow at different rates. This can be due to mitosis occuring at different rates in different organs. Mitosis is also important during repair of damaged tissue.

Mitosis produces two 'daughter' or offspring nuclei from the original parent nucleus. The chromosome number of each of the offspring nuclei is the same as the parent nucleus and the **genome** (nature and arrangement of the genes) is kept exactly the same. Thus mitosis maintains the same chromosome number and genotype throughout growth, life and repair. Mitosis ensures that every body cell throughout life, with the exception of gametes, has a genome identical to that of the original zygote.

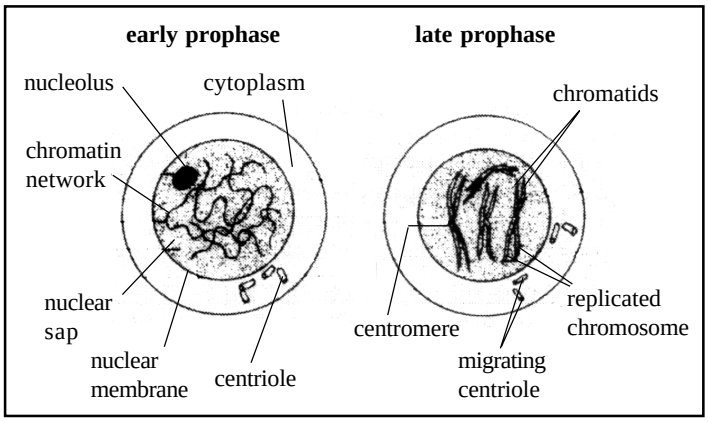
Mitosis of a diploid cell will produce two diploid cells and mitosis of a haploid cell will produce two haploid cells. For example, when the haploid leafy gametophyte stage of a moss or the haploid gametophyte prothallus of a fern produce haploid gametes they do so by mitosis.

## The process of mitosis

For easy reference the process of mitosis is divided into four phases.These are prophase, metaphase, anaphase and telophase. Cytokinesis occurs at the end of telophase.

**Prophase**: The events of prophase are shown in Fig 3.

**Fig 3. Appearance of the cell in prophase**




***Remember*** *– the replication of the DNA to give copy DNA occurs in the S phase, several hours before the onset of mitosis. A common error made by candidates is to say that it occurs in prophase.*

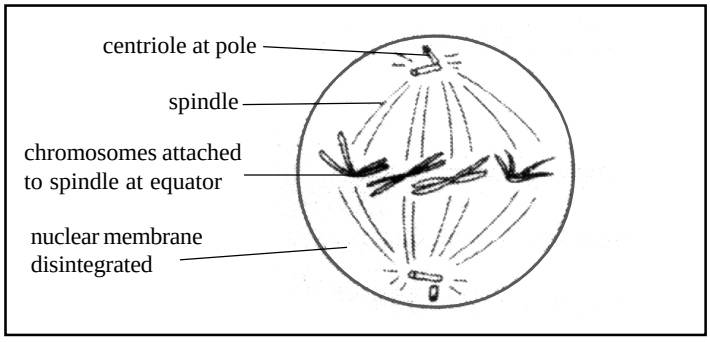
**Prophase** can be considered as a stage that prepares the nucleus for the separation of two complete sets of chromosomes into the daughter nuclei. During prophase the initially indistinct chromosomes **condense** into visible threads which become progressively shorter and thicker. They can also be more readily stained with dyes as the already replicated DNA deposits on them. In early prophase the chromosomes appear as intertwined, long, thin threads. By late prophase they appear as short rodlike structures. This shortening is probably due to the coiling of the chromosomes.The chromosomes then replicate, each appearing as two strands or chromatids joined by the centromere (central body).

During prophase the nucleoli disappear and in animal cells the two centrioles move towards opposite poles of the nucleus. Centrioles are absent in plant cells.

At the end of prophase the double chromosomes start to move towards the middle (equator) of the nucleus and the nuclear membrane fragments and disappears. The centrioles reach the poles of the nucleus and give rise to a system of microtubules forming the spindle which forms a 'basket' around the nucleus. A spindle is also formed in plant cells, although centrioles are absent.

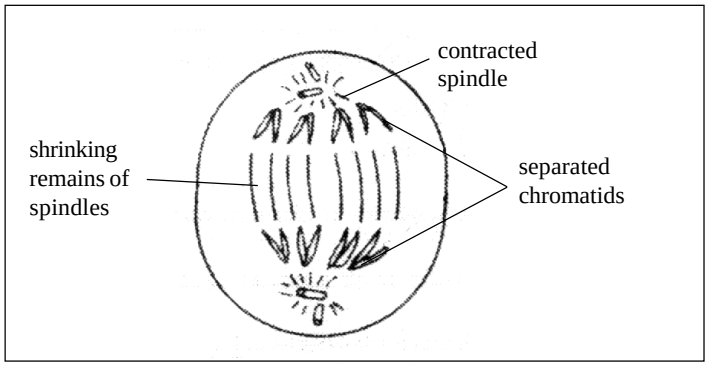
**Metaphase**: This is a brief phase when the replicated chromosomes are arranged in the equatorial plane of the spindle with their centromeres attached to the microtubule ends. In side view they appear as a line across the middle of the spindle. (Fig 4.)

**Fig 4. Appearance of the cell in metaphase**




**Anaphase**: Fig 5 shows the appearance of a cell in mid anaphase.

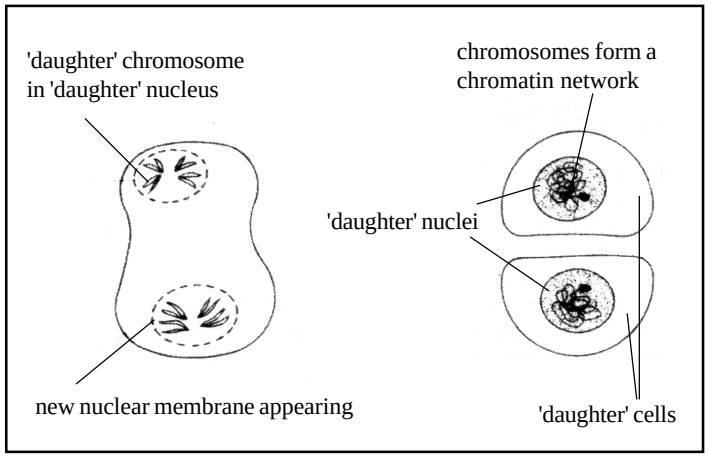
**Fig 5 Appearance of a cell in mid anaphase.**




The double stranded chromosomes complete their replication at the centromeres and so each one becomes two single stranded chromosomes. These start to move away from one another, drawn towards the poles by the contracting spindles, to which their centromeres are attached. By late anaphase the cell contains two equal groups of chromosomes each near the respective pole of the spindle.

**Telophase**: Fig 6 shows the appearance of a cell in telophase.

**Fig 6. Appearance of cell in telophase**




Once the two sets of chromosomes have reached their respective poles they become enclosed in new nuclear membranes which are derived from the endoplasmic reticulum. Meanwhile the spindles disappear and the centriole of each nucleus replicates. The chromosomes become longer and thinner and return to their interphase form and the nucleoli reappear. Cytokinesis usually starts once the two 'daughter' nuclei are established.

**Cytokinesis**: In animals a **cleavage furrow** develops and runs round the cell in line with the original equator of the spindle. Once 'daughter' nuclei have formed the cleavage furrow deepens and eventually cuts the cell in two. In plants a **phragmoplast** or **cell plate** is formed between the two 'daughter' nuclei. This cell plate is assembled from membraneous vesicles from the Golgi body and endoplasmic reticulum. The vesicles give rise to the middle lamella of calcium and magnesium pectates on which cellulose is deposited, forming new a cell wall. The two new genetically identical cells then pass into the $G_1$ phase of the cell cycle.

***Exam Hint*** *- Candidates must be able to recognise phases of mitosis from diagrams or photographs and be able to draw the nucleus shown at a different phase in the process. Candidates should ensure that the number and shape of the chromosomes in their drawing relates to the chromosomes in the pictures provided.*

**Practice Questions**

1. 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. 1

   (ii) the nuclear membrane reforms and cytokinesis follows. 1

   (iii) the chromosomes align on the equator of the spindle. 1

   (iv) the chromosomes become stainable and the spindle starts to form. 1

   (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. 1

   (ii) immediately after telophase? 1

   Total 6

2. (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 = ..... . 12

   (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. 2

   Total 14

3. 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. 4

   (b) (i) Draw accurately the appearance of the same nucleus at the metaphase stage of mitosis. 3

   (ii) On your drawing label a centromere and a centrosome(aster). 2

   Total 9

4. (a) The statements in the list below the table describe some of the stages of mitosis. Complete the table by writing in the correct statement with the appropriate stage.

| Stage | Description |
|---|---|
| Prophase | |
| Metaphase | |
| Anaphase | |
| Telophase | |
| Interphase | |
| Cytokinesis | |

nuclear membranes reappear
DNA replicates
division of the cytoplasm occurs
chromosomes become shorter and thicker
chromosomes attach to spindle ends at equator
daughter chromosomes move to the poles 6

   (b) How does cytokinesis in plants differ from cytokinesis in animals? 2

   Total 8

**Answers**

semi colons indicate marking points

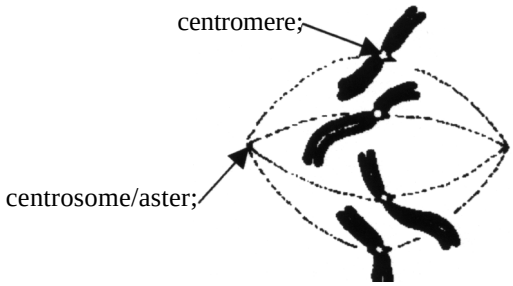
1. (a) (i) anaphase; (ii) telophase; (iii) metaphase; (iv) prophase; 4
   (b) (i) 20 units; (ii) 10 units; 2

2. (a) meristems; buds/intercalary meristems; allometric; S; $G_2$; prophase; chromatids; centromere; 40/20 pairs; 20/10 pairs; diploid; 20; 12

   (b) can secrete/release colchicine into surrounding soil; where it can inhibit mitosis/root growth of nearby plants/inhibit seed germination; thus reducing competition from other plants; ref to Autumn Crocus being an 'aggressive' plant; 2

3. (a) spindles formed from centrosomes/centrioles; (daughter/replicated) chromosomes migrating to the poles; pulled by contracting spindles; which are attached to the centromeres; one set of chromosomes goes to one pole and other set to the other pole; max 4

   (b) (i) and (ii)
   Drawing:
   4 chromosomes not yet replicated;
   attached to spindles by their centromeres;
   same chromatid length/centromere positions as in anaphase drawing; 5




4. (a)

| Stage | Description |
|---|---|
| Prophase | chromosomes become shorter and thicker; |
| Metaphase | chromosomes attach to spindle ends at equator; |
| Anaphase | daughter chromosomes move to the poles ; |
| Telophase | nuclear membranes reappear; |
| Interphase | DNA replicates ; |
| Cytokinesis | division of the cytoplasm occurs; |

   (b) (in animals) cytoplasm divides by constriction (between daughter nuclei);
   (in plants) a phragmoplast/cell plate/new cell wall is synthesised (between the daughter nuclei); 2

***Acknowledgements;***
*This Factsheet was researched and written by Martin Griffin*
***Curriculum Press, Unit 305B, The Big Peg,***
***120 Vyse Street, Birmingham. B18 6NF***

***ISSN 1351-5136***