Cell division

13.1 Introduction

Mitosis is a kind of nuclear cell division that produces two daughter cells that are identical to each other. Each daughter cell has the same number of chromosomes and organelles and performs the same functions as the mother cell. The daughter cell chromosomes are exact copies of those of the mother cell. Just as you would expect, the daughter cells must have the same genetic characteristics as the mother cell. The importance of mitosis as a kind of cell division is to maintain the cell chromosome number for purpose of growth and repair of an organism. In some organisms, mitosis is used to produce new offspring through the process of asexual reproduction as in prokaryotes. This is a kind of reproduction that does not involve union of male and female gametes.

This unit will discuss the different parts of a cell cycle that is undergoing cell division. The different phases of mitosis will be emphasized to you. It is important that you pay particular attention to the behavior and organization of chromosomes during the different phases of mitosis. It is necessary to note that cell division is under strict chemical control. The significance of mitosis for growth and repair is also discussed to show the need for it in an organism.

13.2 Objectives

By the end of this module, you should be able to:

1. describe the behavior and activity of chromosomes during each phase of interphase.
2. describe the behavior and activity of chromosomes during each phase of mitosis.
3. discuss mitosis in relation to binary fission.
4. discuss the chemical basis for cell cycle control.
5. explain the consequences of loss of cell cycle control
6. state the main roles of mitosis in an organism

13.3 Contents

A cell is capable of reproducing itself. From one cell would arise two identical daughter cells and so on until there were several cells of one type. This is possible through the process of cell division. It is the process organism use for growth and reproduction. Cell division involves the study of the behaviour of chromosomes during different stages of the process. It also involves the division of the whole cell including the cytoplasm and its contents. The cell cycle is a series of events between two cell divisions.

Two main types of cell division are distinguished. These are mitosis and meiosis. Mitosis is primarily responsible for growth and repair of tissue by duplication of cells, while keeping the chromosome number the same. It is the process used by organisms to increase their volume and mass and to replace broken tissue. Meiosis, on the other hand, is responsible for the reduction of the chromosome number in its daughter cells from the diploid (2n) condition to a haploid (n) condition. This cell division helps organisms to restore their diploid condition when the egg cells unite during sexual reproduction in a cell.

Mitosis occurs in any cell of a vegetative part of an organism whose cells are diploid while meiosis is restricted to the reproductive parts of an organism where reproductive cells such as pollen grains and ovules are produced for plants or sperm and ova for animals.

The main stages of cell division are prophase, metaphase, anaphase and telophase. The prefixes 'pro-', 'meta-', 'ana-' and 'telo-' mean 'before', 'between', 'towards' and 'end' respectively. Although cell division is discussed in stages, the process is a protracted and continuous one. It is broken down into sections for convenience only.

For convenience geneticists suggest that a chromosome should be considered to consist of one DNA double helix as it is not yet clear how it is arranged. Therefore, the simplest model would be one in which each chromosome contains one very long molecule of DNA which may be considerably folded or coiled.

13.3.1 Haploid and diploid conditions of a cell

Consider the case of an onion cell as an example.

1. An onion vegetative cell that is diploid (2n) has 16 chromosomes (Fig. 126).
2. Eight of the chromosomes were a contribution by the female (maternal) gamete (n).
3. The second eight chromosomes came from the paternal gamete (n).
4. After fertilization in the zygote, matching maternal and paternal chromosomes pair up.
5. Such pairs of chromosomes resemble in size and form and function the same way.
6. They are called a **homologous pair** of chromosomes (Fig. 126).
7. Each member of the pair of chromosomes is called a **homologue**.
8. Each homologue is capable of independent duplication during cell division.

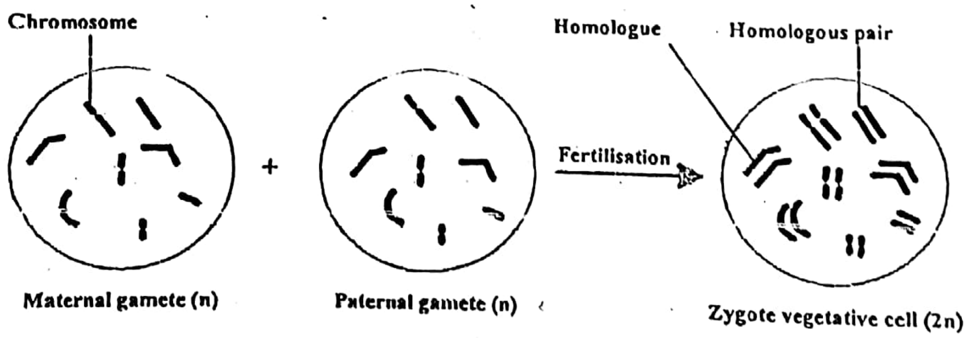


Fig. 126 A female gamete (n) fusing with a male gamete (n) to form a diploid zygote vegetative cell (2n). Maternal and paternal chromosomes pair up according to size, type and function at the time of zygote formation.

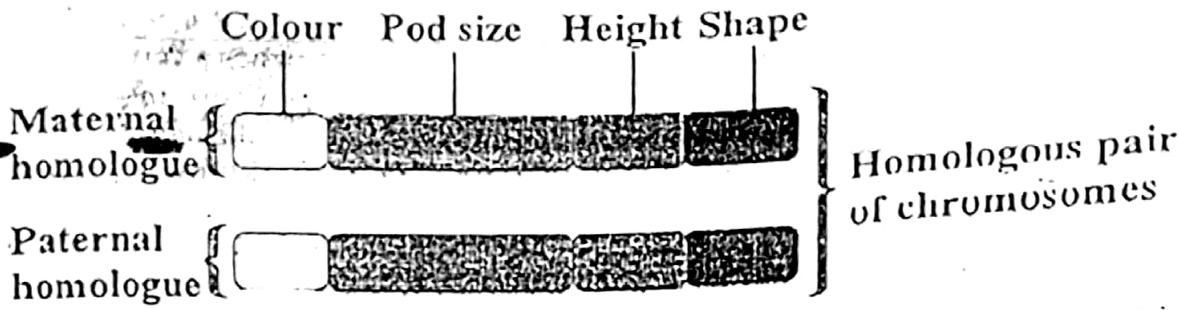


Fig. 127 Homologous pair of chromosomes showing a homologue from each parent cell with similar gene loci in identical positions on the homologues.

13.3.2 The cell cycle

The events that take place in a dividing cell from the beginning to the end is called a cell cycle. This series of events normally lead to the division of a cell resulting in two duplicate copies of the original one. The cycle of events is broadly divided into two domains called **interphase and mitosis**. Interphase is subdivided into three distinct phases called Gap 1 (G1) phase, Synthesis phase (S) and Gap 2 (G2) phase. Mitosis takes place in two phases called **karyokinesis and cytokinesis**. The kinases are the class of enzymes that are involved in triggering events in the cell cycle (Fig. 128).

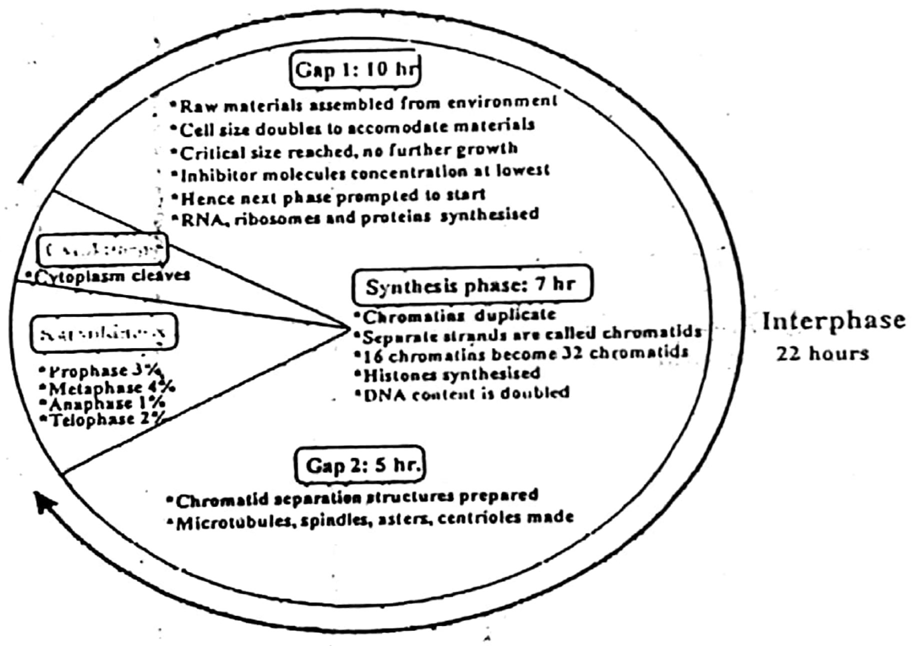


Fig. 128 A schematic representation of events in a cell cycle, showing activities of the various stages of interphase and mitosis in cell division.

Interphase

There are a lot of biochemical reactions going on in the cell at this stage, although the cell might appear to be relatively inactive.

G_1 Phase

The first stage is called the G1 phase. It lasts about ten hours. For the duration of this period, the cell undergoes intense biochemical activity as it takes in raw materials from the environment, for synthesis of new structural molecules and molecules for specific functional purposes. The cell size doubles as the contents of the cell are also doubled. For example, the quantity of enzymes is doubled, while some cellular structures are synthesised for the first time. This is a period of intense biochemical activity. The cell reaches a certain critical size of metabolic state, when it ceases to grow, due to the release of inhibitor molecules from G1, which prevent the succeeding phases to proceed. As soon as the concentrations of the inhibitor molecules in the cell reach a critical low level concentration, the succeeding phase is initiated. At this stage, the chromosomes are too thin to take any stain. They are, therefore, invisible even with the aid of an electron microscope. At this stage, the chromosomes are referred to as chromatin material. A cell would now be preparing to begin the process of DNA replication.

__S phase__

During this period the chromatin material duplicates its DNA along the length. Therefore, more DNA molecules are synthesized through the process of replication. The duplicating strands spiral independently and lie apart beside one another, connected to each other through a centromere. The separated strands are called chromatids. For example, the onion cell, which has sixteen chromosomes, now has thirty-two chromatids. The cell is also involved in the production of cellular histones. Therefore, the replication of chromosomes begins with the production of sister chromatids. The complex is considered to be one chromosome since there is only one centromere. This phase lasts approximately seven hours.

Note that cells that fail to replicate all their chromosomes fail to enter mitosis. This checkpoint involves the recognition of un-replicated DNA and inhibition of MPF activation. Little is known about the proteins that mediate this checkpoint control.

__G_2 phase__

The Sphase resulted in the duplication of each chromosome. Since there is only one centromere on the sister chromatids, the complex is still referred to as one chromosome. Subsequently the cells enter the G_2 phase. The biochemical activities of the cell take approximately five hours to complete. At this stage, the cell prepares for structures that will assist chromosomes to separate from one another during the process of mitosis. Examples of some structures that would be synthesised are microtubules, spindles, asters and centrioles.

Not that cells whose DNA is damaged by irradiation with ultraviolet (UV) light, gamma-rays or by chemical modification become arrested in G1 and G2 until the damage is repaired. Arrest in G1 prevents copying of damaged bases, and so prevents mutations in the genome.

Mitosis

Summary

Mitosis is divided into four stages namely; prophase, metaphase, anaphase and telophase. Mitosis results in the production of two new diploid daughter cells, each of which is identical to the diploid parent cell. During mitosis, cell growth stops because most of the energy in a cell is directed at the dividing cell.

1. Prophase

Chromosomes condense into structures that become visible under the light microscope, with the help of giemsa stain. The duplicated chromatin completes condensation into chromosomes. Each chromosome is made up of two chromatids connected through a centromere. At the site of the centromere is located a protein called a kinetochore to which microtubules will subsequently attach (Fig. 129).

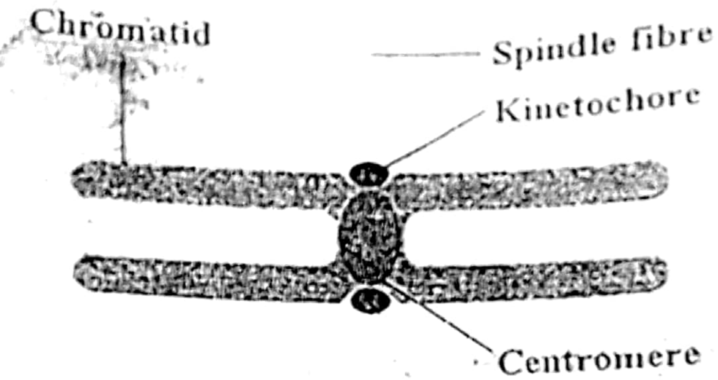
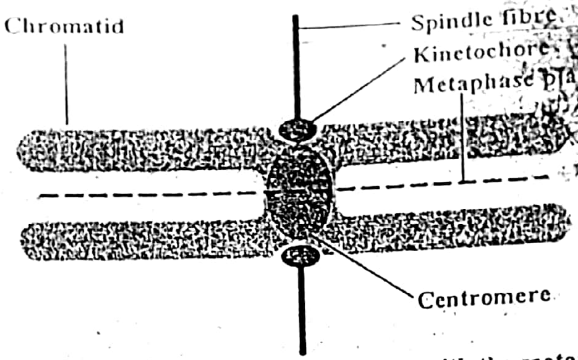
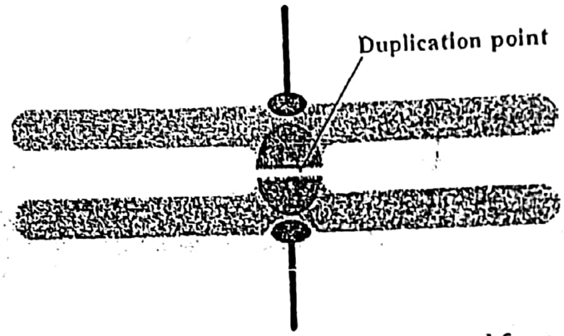


Fig. 129 A chromosome showing sister chromatids held together through a centromere with spindle fibres attached to the kinetochore.

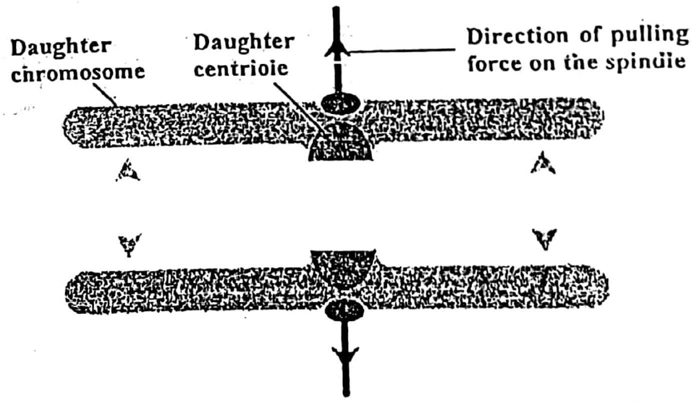
The centrosome is a microtubule organising center in multicellular organisms. During prophase, the two centrosomes replicate separately from mitosis. Centrosomes move to opposite ends of a cell when present and spin spindle microstubules that help to move chromosomes during their separation. The nuclear envelope breaks down to allow the microtubules to reach the kinetochores on the chromosomes. The nucleolus also disappears from the nucleoplasm. These events mark the end of prophase, which takes approximately 3% of the cell cycle's duration (Fig. 130).



At metaphase, a doublet chromosome is aligned with the metaphase plate.



At anaphase, the centromere divides through its center and frees each chromatid.



At the start of telophase, sister chromatids drift apart from each other, due to a pulling force exerted on them by the spindle fibres. Note that each chromatid has a entromere. Therefore each chromatid is considered to be a chromosome.

Fig. 131 Behaviour of chromosomes at metaphase, anaphase and telophase during cell division.

5. Telophase

Daughter chromosomes are drawn to opposite poles of the cell. Subsequently, the two daughter nuclei are completely formed in a cell whose cytoplasm is still undergoing division. This whole process is accompanied by the reverse process of prophase. The nuclear membrane reforms around the daughter nuclei. The nucleolus reappears and the chromosomes uncoil and get dispersed within the nucleus. Telophase accounts for approximately 2% of the cell cycle's duration.

6. Cytokinesis

Cytokinesis refers to division of the cytoplasm. The cell surface develops a dividing depression at the metacentric centre. In animals, the division furrow appears at the cell surface. It occurs at the same time that the nuclear envelope is reforming, yet they are separate processes. The cytoplasm together with its contents divides into two nearly equal parts. This is achieved by a protein fibre ring called actin found around the centre of a cell. When this 'ring' contracts the cell is squeesed into two separate daughter cells.

In plant cells, vesicles released by the Golgi apparatus move to the middle of the cell along a microtubule scaffold called **phragmoplast.** The vesicles carrying cell wall materials gather at the metacentric centre of the cell and get arranged into a disk-shaped structure called a cell plate. The cell plate grows outward radially and gradually develops into a proper cell wall, separating two daughter cells.

Two daughter cells are produced that are complete duplicate copies of the genetic and cytoplasmic material of their parent cell. Soon after their formation, the daughter cells are smaller in size, but progressively grow until they attain the normal size and metabolic functions of the parent cell (Fig. 132).

However, if cytokinesis failed, a cell with two nuclei in one cytoplasm would result. A multinucleate cell is abnormal and would not function properly. Nonetheless, there are cells that are multinucleate and continue to function normally. Examples of such cells are the muscle cells in animals.

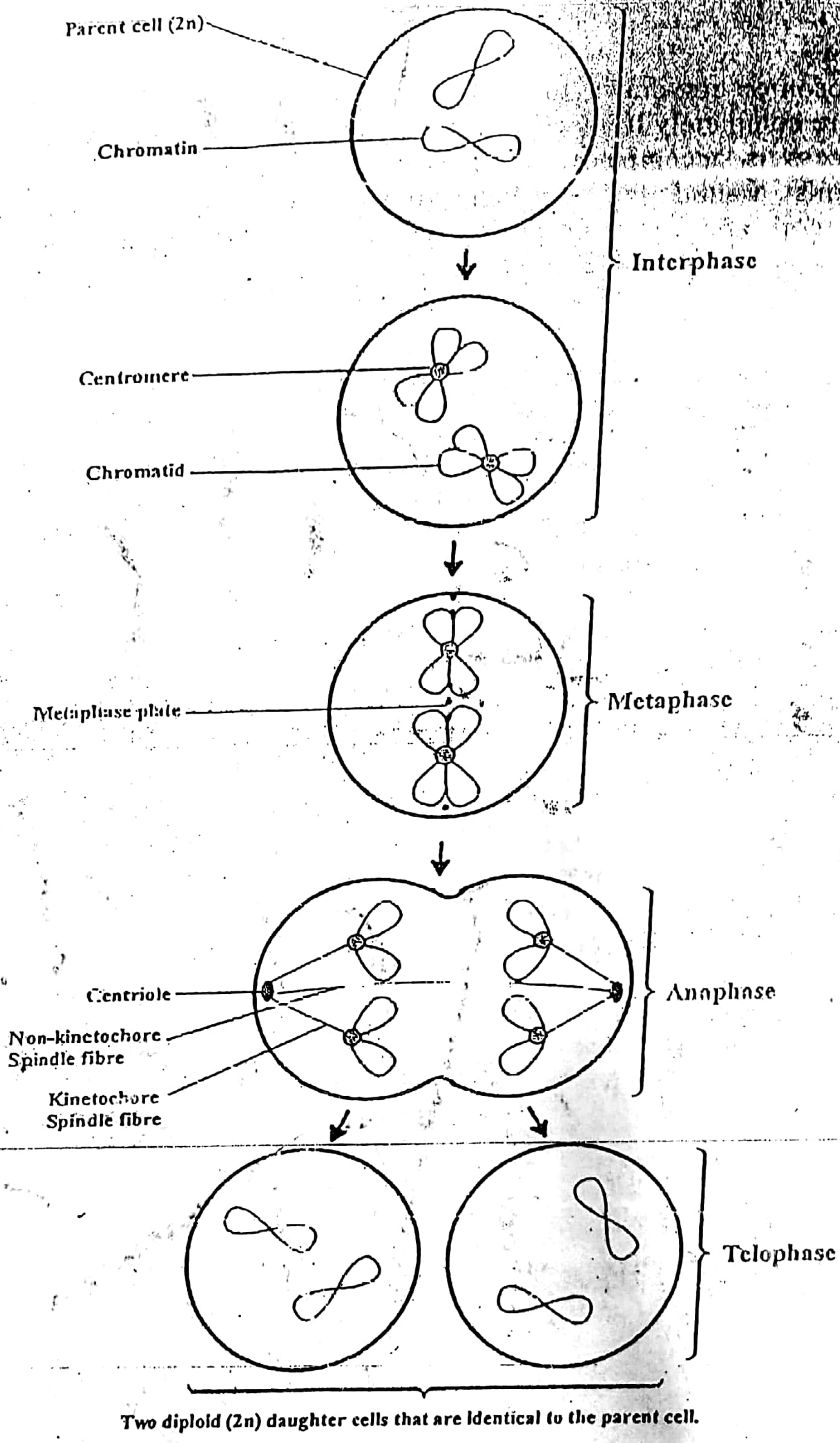


Fig. 132 Major phases in the process of mitosis.