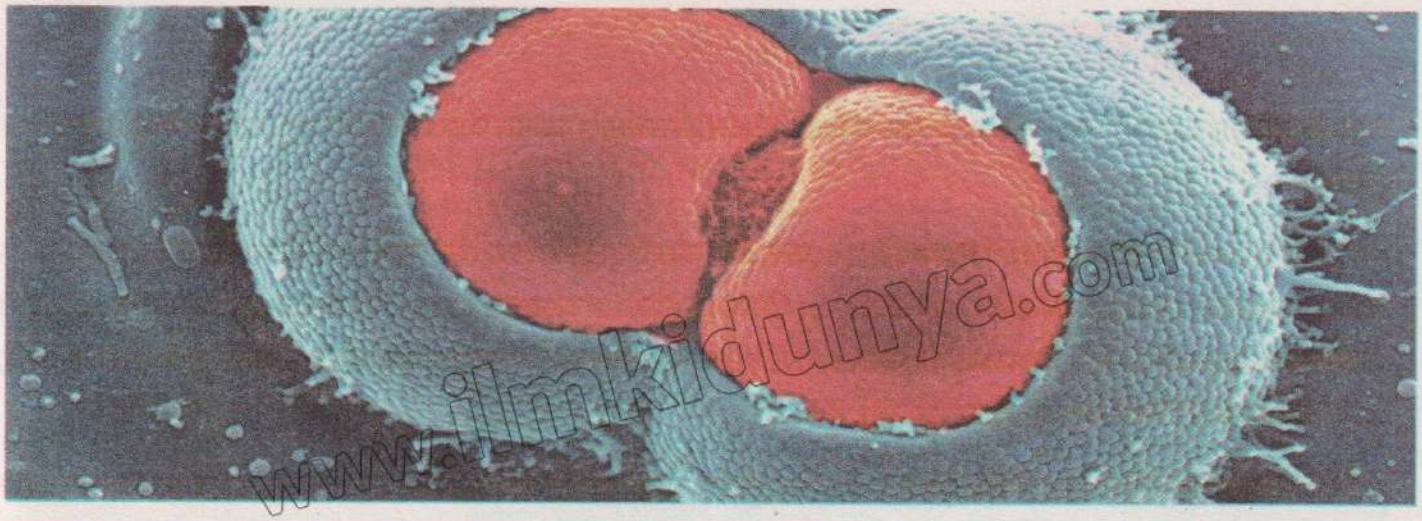

Chapter 4

CELL CYCLE

After studying this chapter, students will be able to:

- Describe cell cycle.
- Explain mitosis and stages of mitosis (by use of sketch and diagrams).
- Explain meiosis and stages of meiosis (by use of sketch and diagrams).
- Compare the processes of mitosis and meiosis.
- Outline the significance of mitosis and meiosis.

The cell follows a regular series of events called the "cell cycle" during its life. This series includes stages of growth, preparation, and cell division. The process of cell division may happen in two way i.e., mitosis (cells make identical copies of themselves) or meiosis (cells produce special cells with half the genetic material, needed for reproduction). Mitosis is essential for growth and repair in the body, while meiosis is vital for creating reproductive cells like eggs and sperm. Together, these processes keep living organisms growing, healing, and passing on traits to the next generation. In this chapter, we will explore the events of the cell cycle and cell divisions i.e., mitosis and meiosis.

4.1- Cell Cycle

It is the series of events that take place in a eukaryotic cell from its formation to its division into two daughter cells. The cell cycle can be divided in two main phases i.e. interphase and the mitosis phase.

Interphase

This phase lasts for about 90% of the total time of cell cycle. During interphase, the cell performs the life functions according to its specialty and

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prepares itself for next division. Interphase consists of the following three phases:

G1 Phase (First Gap Phase): It starts from the end of the Mitosis phase. It is also called the growth phase. During this phase cell makes proteins and organelles and so grows in size. Cell also makes enzymes that are required in S phase for the replication of DNA.

S Phase (Synthesis Phase): During this phase, the DNA of each chromosome is replicated (copied). It results in the duplication of chromosomes (each chromosome consists of two sister chromatids). The total number of chromosomes in cell remains the same.

G2 Phase (Second Gap Phase): In this phase, the cell continues to grow and produces proteins necessary for cell division. The cell checks for any DNA damage that may have occurred during replication and makes necessary repairs. It also begins to reorganize its contents in preparation for mitosis.

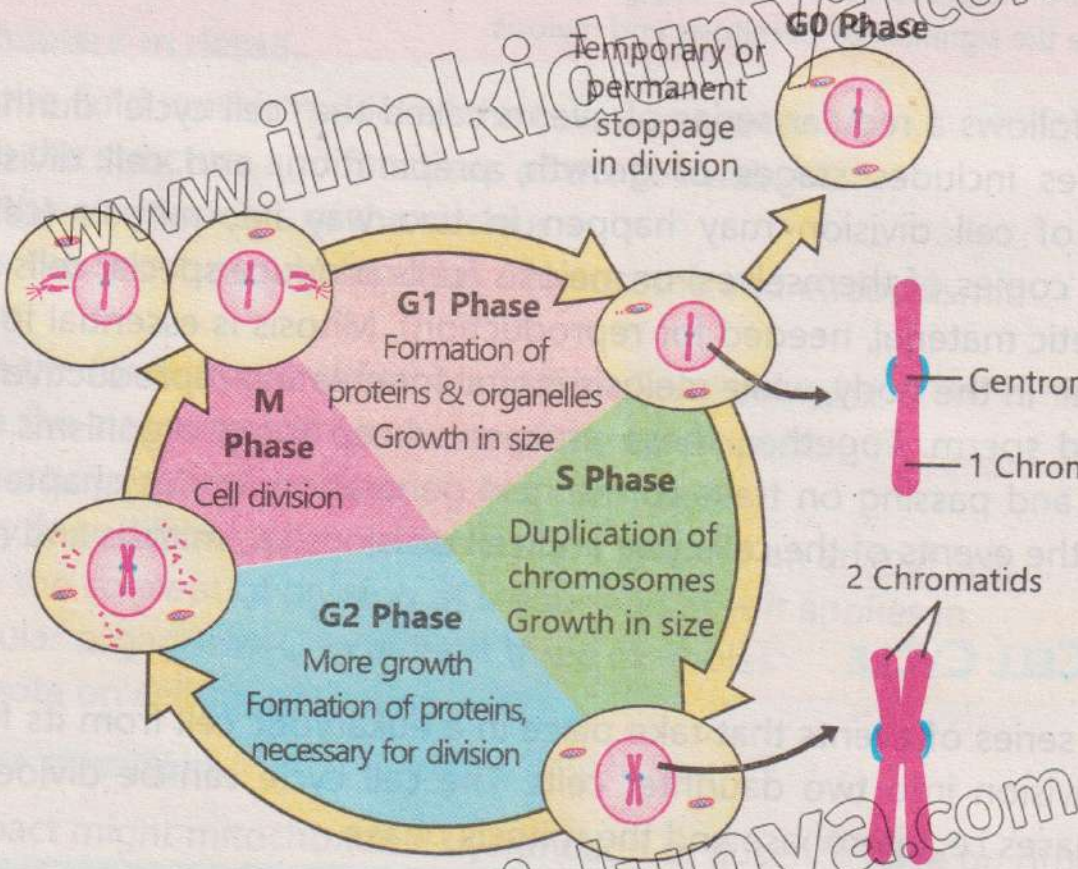

FIGURE 4.1: Eukaryotic Cell cycle

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After interphase, the cell enters the division phase and divides into the two daughter cells. The events of cell cycle are controlled by special genes. All phases occur in a sequence.

G0 Phase:

Many cells stop dividing and start performing their specific functions. This phase is called G0 phase. Many cells (e.g. neurons) remain in G0 for indefinite periods. Some cell (e.g. cells of liver and kidney) remain in G0 phase temporarily. Other cells (e.g. epithelial cells) do not enter G0 and continue to divide throughout life.

Table: Main Phases in Eukaryotic Cell Cyle

Phase	Description
Interphase	The cell prepares for division and goes through growth in size and DNA replication.
Gap 1 (G1) Phase	The cell grows in size and carries out normal functions. It prepares for DNA replication.
Synthesis (S) Phase	The cell replicates its DNA, making an exact copy of its genetic material.
Gap 2 (G2) Phase	The cell grows further. Cell ensures that all preparations are complete for division.
Gap 0 (G0) Phase	The cell exits the cycle and stops dividing, often to carry out specialized functions (not all cells enter this phase).
M Phase	The cell divides its genetic material equally into two new, identical cells.

4.2- Mitosis

Mitosis is the type of cell division in which a cell divides into two daughter cells, each with the **same number of chromosomes** as were present in the parent cell. Mitosis occurs in the somatic cells of eukaryotes. Prokaryotes also divide to make identical cells. But the events of their division are different from mitosis. That is why we call it **binary fission.**

Phases of Mitosis

The German biologist, Walther Flemming discovered the events of mitosis in 1880s. There are two major phases of mitosis i.e. karyokinesis and cytokinesis.

A. Karyokinesis: Karyokinesis means the division of the nucleus. it is further divided into four phases.

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i. Prophase

During prophase, the thread-like **chromatin** material condenses and makes thick visible **chromosomes**. Each chromosome consists of two sister chromatids attached with a single centromere. The nuclear envelope and nucleolus break down during prophase.

The centrosome of cell duplicates into two. The two centrosomes migrate to opposite side of the nucleus. When they are migrating, they make a network of microtubules called **spindle fibres** (complete set is called **mitotic spindle**). In plant cells, there is no centrosome. Their mitotic spindle is formed by the aggregation of spindle fibres present in cytoplasm.

ii. Metaphase

During this phase, some spindle fibres bind with chromosomes. They attach at the point of centromere where special kinetochore proteins are present.

Two spindle fibres from both sides bind with one chromosome. The chromosomes attached with spindle fibres arrange themselves along the equator of the cell. In this way a plate is formed called **metaphase plate.**

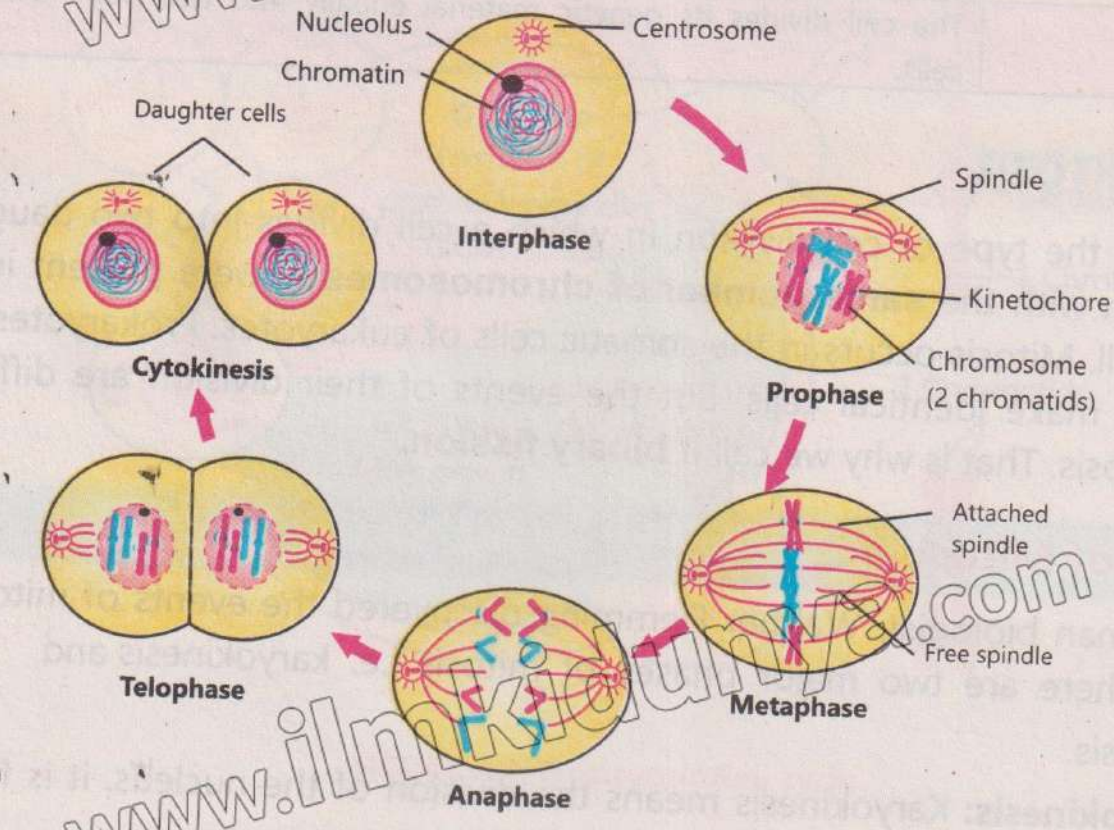

FIGURE 4.2: Phases of mitosis

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iii. Anaphase

The spindle fibres attached with chromosomes pull toward the poles. Due to this pulling, the chromosome's sister chromatids separate. In this way, there are two similar sets of chromatids, which move towards the poles of the cell.

iv. Telophase

In this phase, new nuclear envelope forms around each set of separated chromosomes and nucleolus reforms. Both sets of chromosomes unfold back into chromatin.

B. Cytokinesis: It is the division of cytoplasm. In animal cells, a furrow develops in the cell membrane at the equator. At this furrow, the cytoplasm has a **ring of microfilaments.** The ring contracts and the furrow moves inward. In this way parent cell is pinched into two.

In plant cells, Golgi apparatus makes vesicles. These vesicles move to the middle and fuse to form a plate called **phragmoplast.** The plate grows outward and its membranes fuse with the cell membrane. The result is two daughter cells.

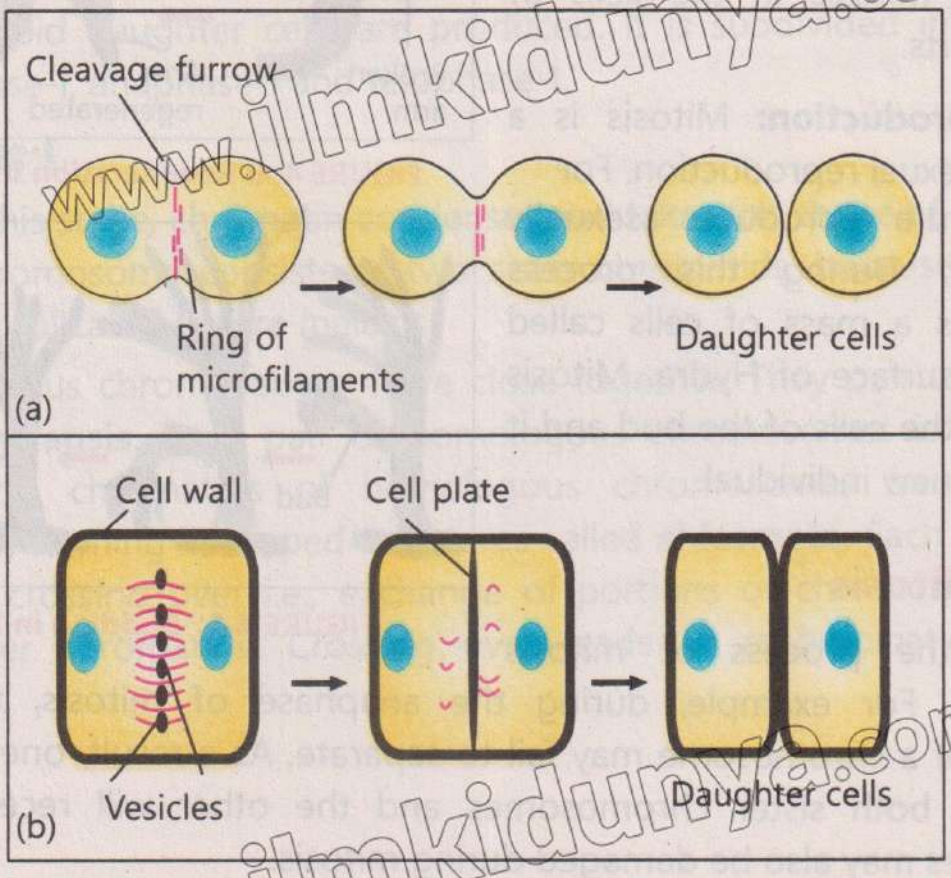

FIGURE 4.5: Cytokinesis; (a) in animal cell, (b) in plant cell

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Significance of Mitosis

Growth: Growth in organisms means an increase in size. It occurs due to increase in the number of cells. Mitosis plays a crucial role in growth by producing new cells that are identical to the original cells.

Your body consists of about 200 trillion cells. All these cells were formed from a single cell (zygote) at the start of your life. Millions of cell divisions occurred while your body was reaching its present form. In each of these divisions the genetic material was equally distributed between the daughter cells. It happened through mitosis.

Cell Replacement: Many cells are constantly dying in our bodies. For example, the red blood cells and the cells of the walls of intestine and skin etc. These are replaced by new ones which are exact copies of the older cells. The new cells are formed by mitosis.

Regeneration: Some animals can regenerate parts of the body. For this purpose, they form new cells by carrying out mitosis in the cells of remaining parts.

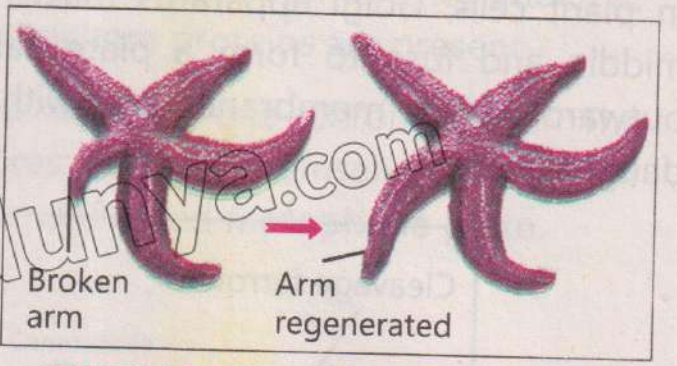

FIGURE 4.4: Regeneration in sea star

Asexual reproduction: Mitosis is a means for asexual reproduction. For example, Hydra reproduces asexually by budding. During this process mitosis forms a mass of cells called bud on the surface of Hydra. Mitosis continues in the cells of the bud and it grows into a new individual.

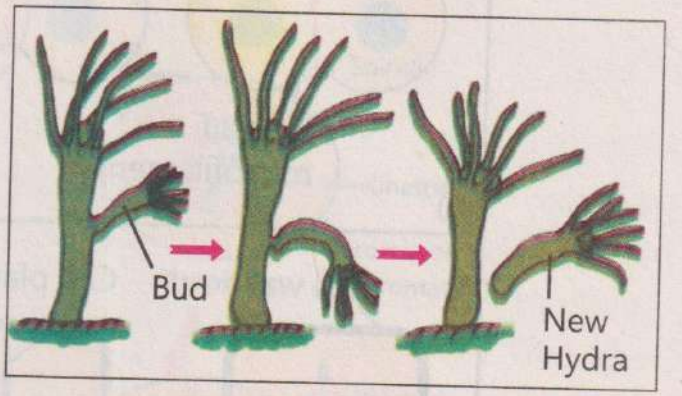

FIGURE 4.5: Budding in Hydra

Errors in Mitosis

Sometimes the process of mitosis goes wrong. For example, during the anaphase of mitosis, the sister chromatids of a chromosome may fail to separate. As a result, one daughter cell receives both sister chromosomes and the other will receive none. Chromosomes may also be damaged during mitosis.

If the genes that regulate mitosis are mutated (changed), the cells continue to divide. Due to this uncontrolled division, masses of cells are formed. These

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masses are called **tumors**. If the tumors remain in their original location, they are called **benign**. If they migrate and invade other tissues, they are called **malignant** tumors (cancer). It is called **metastasis**(spreading of disease).

4.3- Meiosis

It is the type of cell division in which each daughter cell receives half the number of chromosomes as compared to the parent cell. In meiosis, a diploid parent cell divides to produce four haploid daughter cells. **Diploid** means the cells in which chromosomes are in pairs (homologous pairs) while **haploid** means the cells with half number of chromosomes i.e., cells with no pairs of chromosomes.

Phases of Meiosis

Meiosis was discovered in 1876 by a German biologist Oscar Hertwig. Meiosis consists of two divisions i.e., Meiosis-I and Meiosis-II.

Meiosis-I

In meiosis-I, the homologous chromosomes in a diploid cell separate and so two haploid daughter cells are produced. It is subdivided into prophase-I, metaphase-I, anaphase-I and telophase-I.

Prophase-I

During this stage, chromatin condenses and takes the shape of chromosomes. Each chromosome consists of two sister chromatids, because the DNA has already replicated before meiosis.

Homologous chromosomes move close together. They pair up in a process called **synapsis**. Each pair of homologous chromosomes is called **tetrad**. Non-sister chromatids of homologous chromosomes become "zipped" together, forming X-shaped structures called **chiasmata**. Each chiasma is the site for crossing over i.e., exchange of portions of chromosomes between non-sister chromatids. Crossing over leads to recombination of genetic material.

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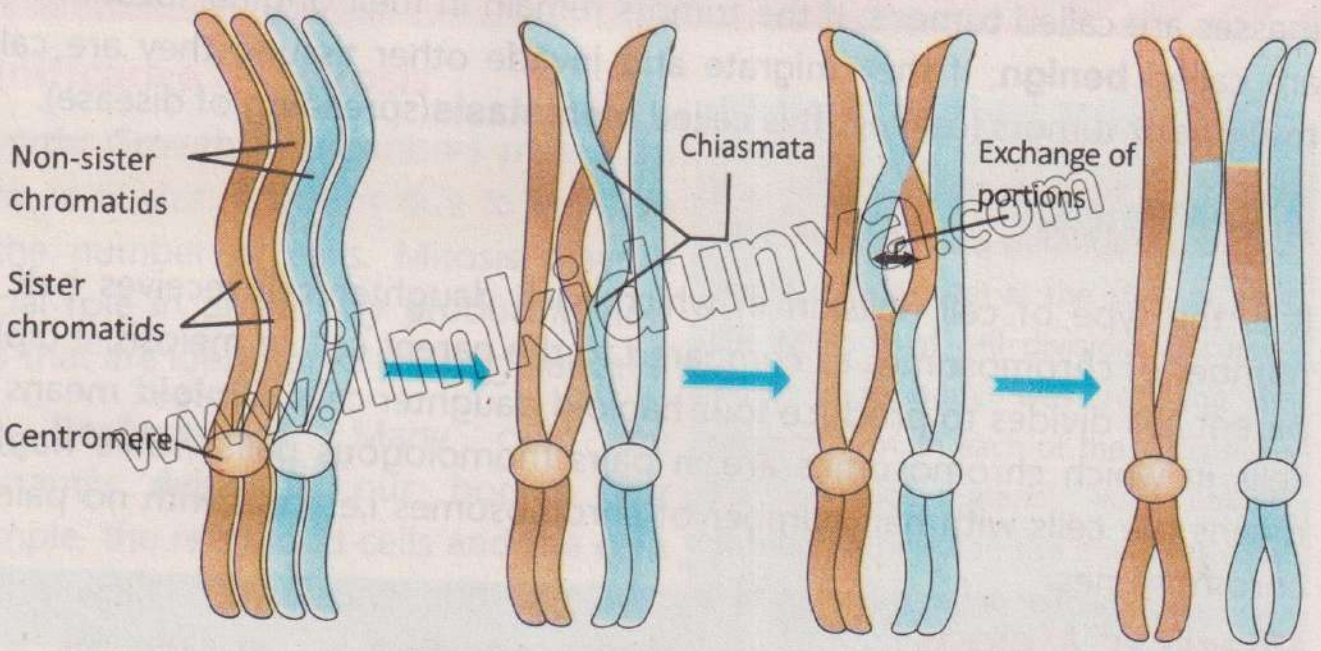

FIGURE 4.6: Crossing over

Other events of prophase-I are similar to prophase of mitosis. The nucleoli disappear and nuclear envelope breaks. Centrioles migrate to opposite poles and make spindle fibres to which chromosomes attach.

Metaphase-I

The tetrads attached with spindle fibres align along the equator. In this way, they form metaphase plate. In the metaphase plate of meiosis-I, two spindle fibres from both poles attach with one pair of homologous chromosomes.

Anaphase-I

Each spindle fibre attached with a single chromosome pulls towards the pole. In this way, the paired chromosomes are separated. One chromosome of each pair is pulled toward one pole and the other towards opposite pole. So, two haploid sets of chromosomes are formed. Each chromosome still contains two sister chromatids.

Telophase-I

Spindles disappear and a new nuclear envelope is made around each haploid set. Nucleolus also reforms during Telophase-I. The chromosomes uncoil into chromatin. Cytokinesis occurs and two daughter cells are made.

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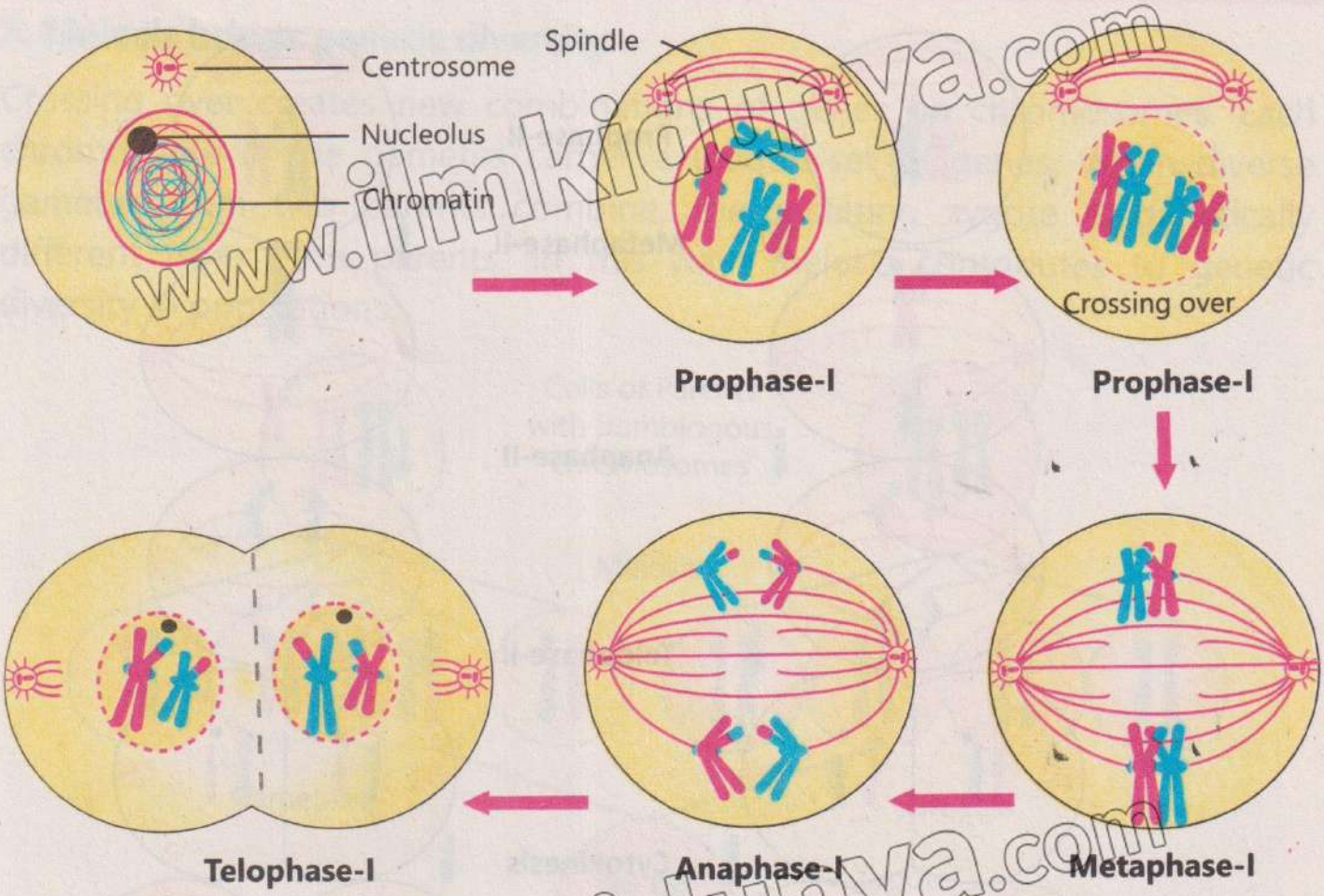

FIGURE 4.7: Phases of meiosis-I

Meiosis-II

Meiosis-II closely resembles mitosis and consists of four phases: prophase-II, metaphase-II, anaphase-II, and telophase-II.

In prophase-II, the nucleoli and nuclear envelope disappear, and the chromatin condenses. Centrioles move to the poles, forming spindle fibres. During metaphase-II, spindle fibres attach to the kinetochores of chromosomes, aligning them at the cell's equator. In anaphase-II, spindle fibres pull sister chromatids apart toward opposite poles. Finally, in telophase-II, chromosomes uncoil back into chromatin, nuclear envelopes and nucleolus reform, and cytokinesis occurs. This results in the formation of four daughter cells, each with half number of chromosomes.

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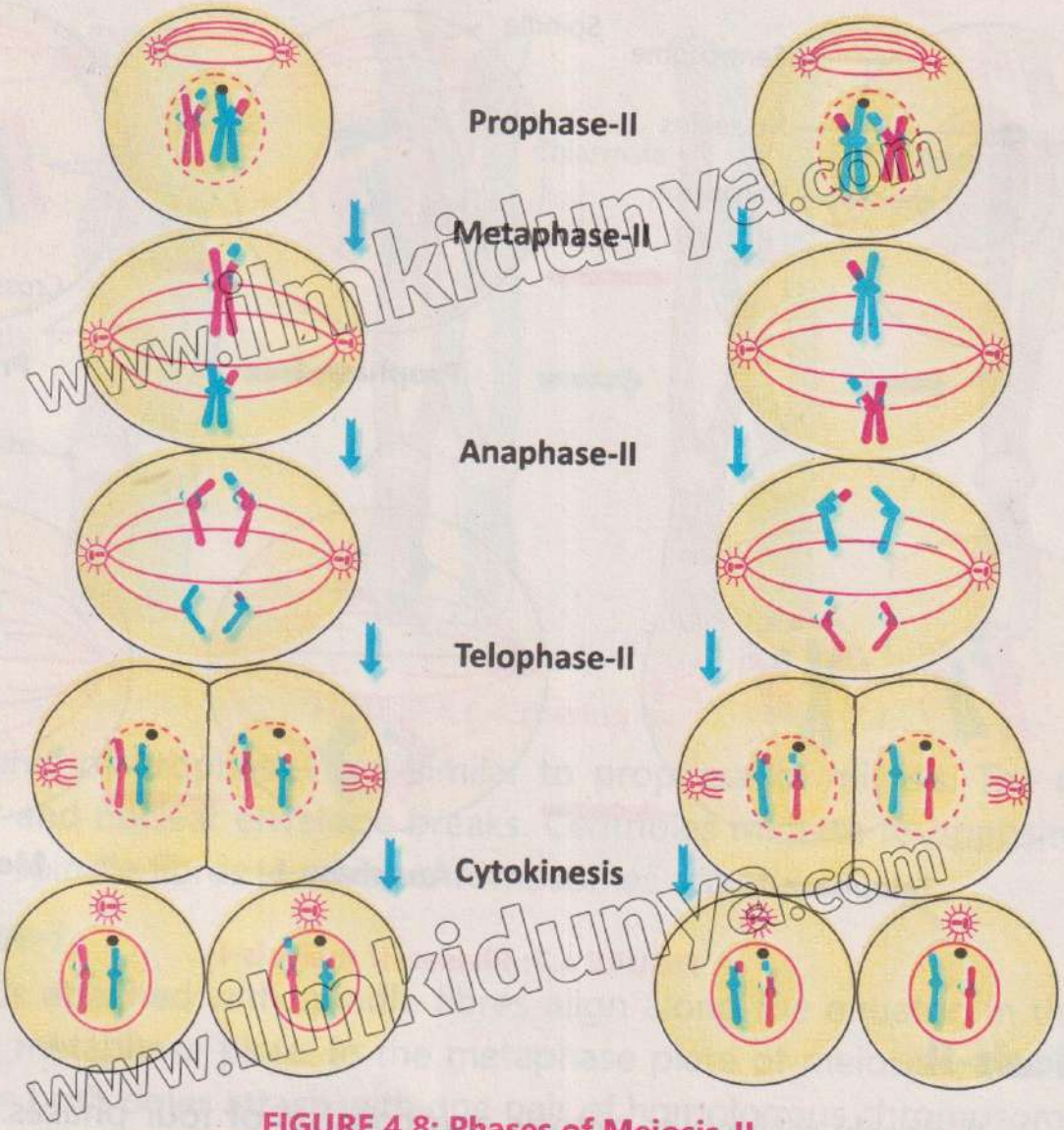

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FIGURE 4.8: Phases of Meiosis-II

Significance of Meiosis

1. Meiosis maintains the number of chromosomes

In animals, special cells in reproductive organs undergo meiosis. The daughter cells, called **gametes**, have half the number of chromosomes (with no pairs). During sexual reproduction, male and female gametes join to make the first cell (zygote) of new generation. The original number of chromosomes is restored in zygote. It undergoes mitosis many times and develops into the new animal.

In flowering plants, specialized cells in flowers undergo meiosis. The daughter cells, called **spores** have half number of chromosomes. These spores grow into new generation inside the flowers. This generation produces gametes by mitosis. The gametes join to make zygote with full set of chromosomes. The zygote undergoes mitosis and develops into new plant.

2. Meiosis brings genetic diversity

Crossing over creates new combinations of genes on chromosomes. Each chromosome in the gametes carries a unique set of genes. When diverse gametes from two parents combine, the resulting zygote is genetically different from both parents. In this way, meiosis contributes to genetic diversity in populations.

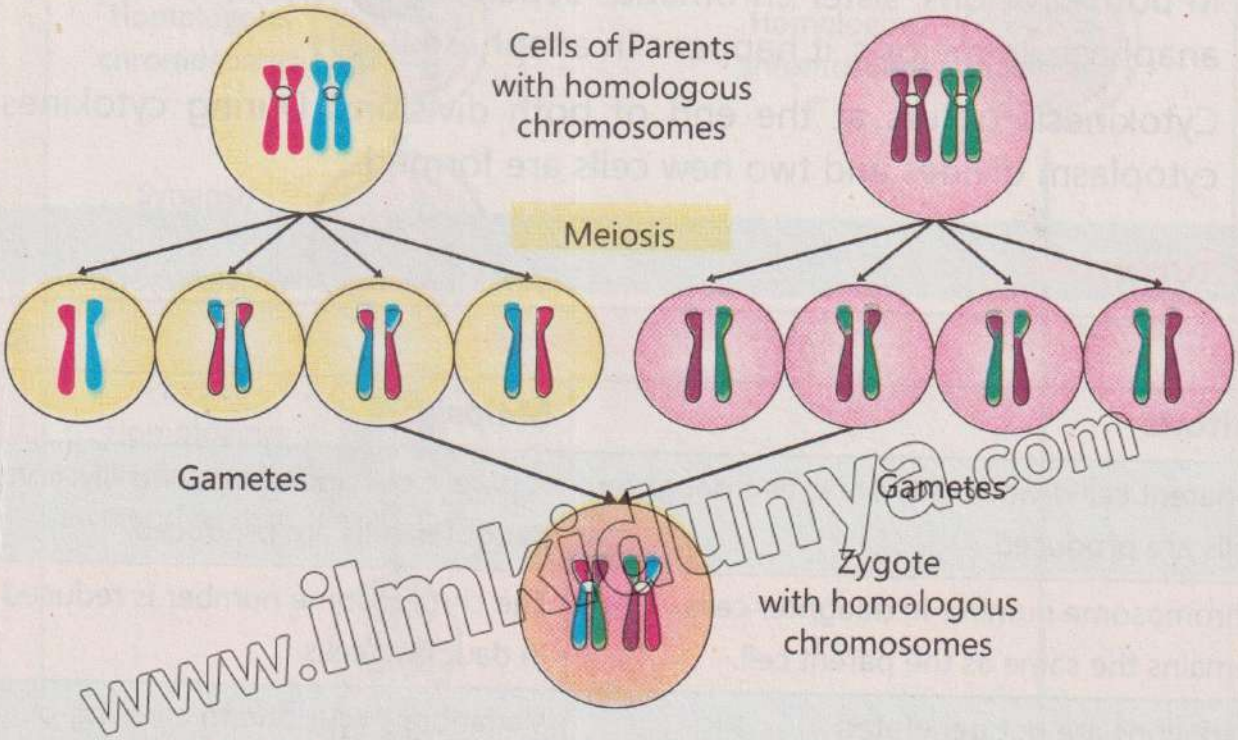

FIGURE: 4.9: Meiosis creates cells with new combinations of genes

Errors in Meiosis

During meiosis-I, chromosomes separate while during meiosis-II sister chromatids separate. It is called **disjunction**. Sometimes **non-disjunction** occurs. Due to it, the daughter cells (gametes) receive more or less than the normal number of chromosomes. If such gametes fuse, the zygote receives abnormal number of chromosomes. If such zygote develops, the resulting offspring suffers from severe medical problems.

4.4- Comparison between Meiosis and Mitosis

Similarities

1. DNA replication occurs during interphase (S phase) before both divisions.
2. Both divisions begin with a parent cell that has chromosomes in pairs.

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3. In both divisions, chromatin condenses and chromosomes become visible during prophase.
4. Both mitosis and meiosis involve the formation of a spindle apparatus.
5. Both involve prophase, metaphase, anaphase, and telophase. However, meiosis has two rounds i.e., meiosis-I and meiosis-II.
6. In both divisions, sister chromatids separate. In mitosis, it happens during anaphase. In meiosis, it happens in anaphase II.
7. Cytokinesis occurs at the end of both divisions. During cytokinesis, the cytoplasm divides and two new cells are formed.

Differences

Table: Difference between mitosis and meiosis

Mitosis	Meiosis
A parent cell divides only once; two daughter cells are produced.	A parent cell undergoes two divisions; four daughter cells are produced.
Chromosome number in daughter cells remains the same as the parent cell.	The chromosome number is reduced by half in daughter cells.
Variations are not generated	Variations occur due to crossing-over
Occurs in somatic cells.	Occurs in germ line cells.
Homologous chromosomes do not form pairs.	Homologous chromosomes form pair.
No crossing over occurs during prophase.	Crossing over occurs during prophase.
Single chromosome aligns to form a metaphase plate.	Homologous pairs align to form a metaphase plate.
During anaphase, chromosomes break and individual chromatids are pulled towards poles.	During anaphase-I, individual chromosomes are pulled towards poles.
Occurs for growth, development, and maintenance of multicellular organisms.	Occurs for producing gametes in animals and spores in plants for sexual reproduction.

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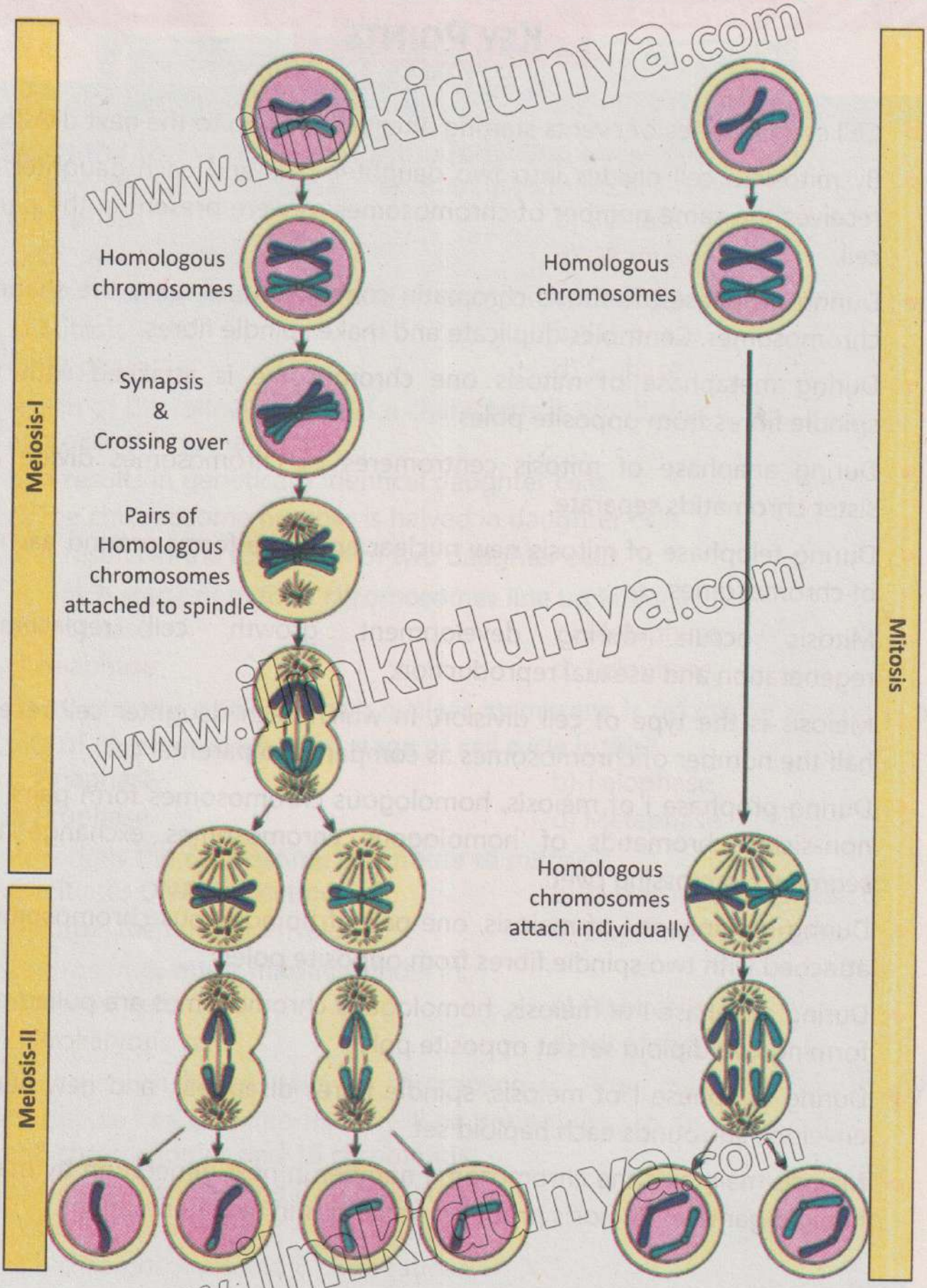

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FIGURE 4.10: Comparison between meiosis and mitosis

KEY POINTS

- Cell cycle is series of events starting after cell division to the next division.
- By mitosis a cell divides into two daughter cells and each daughter cell receives the same number of chromosomes as were present in the parent cell.
- During prophase of mitosis chromatin condenses and takes the shape of chromosomes. Centrioles duplicate and make spindle fibres.
- During metaphase of mitosis one chromosome is attached with two spindle fibres from opposite poles.
- During anaphase of mitosis centromeres of chromosomes divide and sister chromatids separate.
- During telophase of mitosis new nuclear envelope forms around each set of chromosomes.
- Mitosis occurs during development, growth, cell replacement, regeneration and asexual reproduction.
- Meiosis is the type of cell division, in which each daughter cell receives half the number of chromosomes as compared to parental cell.
- During prophase I of meiosis, homologous chromosomes form pairs. The non-sister chromatids of homologous chromosomes exchange their segments in crossing over.
- During metaphase I of meiosis, one pair of homologous chromosomes is attached with two spindle fibres from opposite poles.
- During anaphase I of meiosis, homologous chromosomes are pulled apart forming two diploid sets at opposite poles.
- During telophase I of meiosis, spindle fibres disappear, and new nuclear envelope surrounds each haploid set.
- Meiosis maintains the chromosome number in next generation by making haploid gametes. Meiosis produces variations in next generations.

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EXERCISE

A. Select the correct answers for the following questions.

1. In which phase of cell cycle, maximum growth occurs in cell?
   a) M phase
   b) S phase
   c) G1 phase
   d) G2 phase
2. In which phase of cell cycle, the chromosomes duplicate?
   a) Mitosis
   b) G1 phase
   c) G2 phase
   d) S phase
3. Which of the following is NOT a characteristic of mitosis?
   a) It occurs in somatic cells.
   b) It results in genetically identical daughter cells.
   c) The chromosome number is halved in daughter cells.
   d) It results in the formation of two daughter cells.
4. At which stage of mitosis chromosomes line up in the centre?
   a) Prophase
   b) Metaphase
   c) Anaphase
   d) Telophase
5. If you observe a cell in which nuclear membrane is reforming around two sets of chromosomes, what stage of cell cycle is this?
   a) Anaphase
   b) Telophase
   c) Prophase
   d) Metaphase
6. How does the centrosome contribute to mitosis?
   a) Initiates DNA replication
   b) Makes mitotic spindle
   c) Forms the nuclear envelope
   d) Duplicates organelles
7. Centrosomes make mitotic spindle in;
   a) Animal cells
   b) Plant cells
   c) Prokaryotic cells
   d) All of these
8. An organism has 4 pairs of chromosomes. After meiosis-I, how many chromosomes and chromatids will be present in each daughter cell?
   a) 8 chromosomes and 16 chromatids
   b) 4 chromosomes and 8 chromatids
   c) 4 chromosomes and 4 chromatids
   d) 8 chromosomes and 8 chromatids
9. Which event is unique to meiosis but not mitosis?
   a) DNA replication
   b) Chromosome alignment
   c) Crossing over
   d) Nuclear division

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10. Why is meiosis-II necessary after meiosis-I?
    a) To replicate chromosomes
    b) To reduce chromosome number
    c) To separate sister chromatids
    d) To ensure genetic recombination

B. Write short answers.

1. Enlist the events that occur during the G1 phase of interphase?
2. What is the main purpose of the S phase in the cell cycle?
3. During which phase of mitosis sister chromatids separate?
4. How does crossing over contribute to genetic variation in meiosis?
5. What is the role of spindle fibres in mitosis?
6. How is cytokinesis in animal cell different from plant cell?
7. What is the difference between prophase of mitosis and prophase-I of meiosis-I?
8. How does meiosis differ from mitosis in terms of chromosome number?
9. What are the key events of anaphase in mitosis?
10. What is the function of the centrosome during cell division?
11. What are sister chromatids, and when do they separate in meiosis?
12. How is mitosis related to the process of regeneration?

C. Write answers in detail.

1. Describe the events that occur during the phases of mitosis.
2. Describe cytokinesis in animal and plant cells.
3. Describe the significance of mitosis.
4. Describe the events that occur during the phases of meiosis-I.
5. Describe the significance of meiosis.

D. Inquisitive questions.

1. What role might mistakes in the cell cycle checkpoints play in the emergence of cancer?
2. Why do skin cells divide continuously throughout an organism's existence, but nerve and muscle cells permanently exit the cell cycle?

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