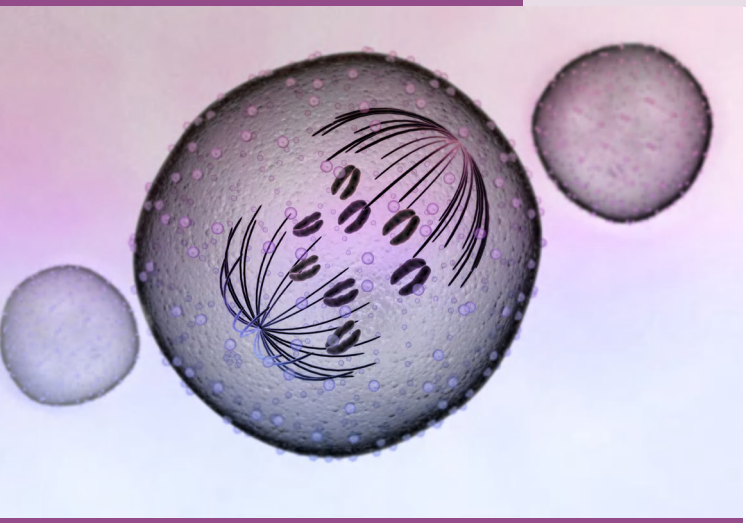
Chapter

2

Cell Division and Cell Cycle



REMEMBER

Before beginning this chapter, you should be able to:

- Recall the different phases of mitosis and meiosis
- Remember the events in a cell cycle

KEY IDEAS

After completing this chapter, you should be able to:

- Understand the significance of cell division
- Describe the stages of mitosis and meiosis
- Explain the characteristic changes in different phases of cell division
- Differentiate mitosis from meiosis

INTRODUCTION

All the living organisms start their life from a single pre-existing cell. A single cell undergoes repeated divisions to form many groups of cells.

The process of formation of new cells by the division of pre-existing cells is known as **cell division**. The cell that undergoes cell division is known as **parent cell** or **mother cell**. The cells that are formed as a result of cell division are known as **daughter cells**. During cell division, each cell splits up to form two identical daughter cells that resemble their parent cell.

SIGNIFICANCE OF CELL DIVISION

Cell division is a necessary process taking place in all the living organisms without any exception. Following are some of the points of significance explaining why cell division is essential:

- Growth of the body
- Replacement of damaged and dead cells
- Reproduction
- Repair of tissues

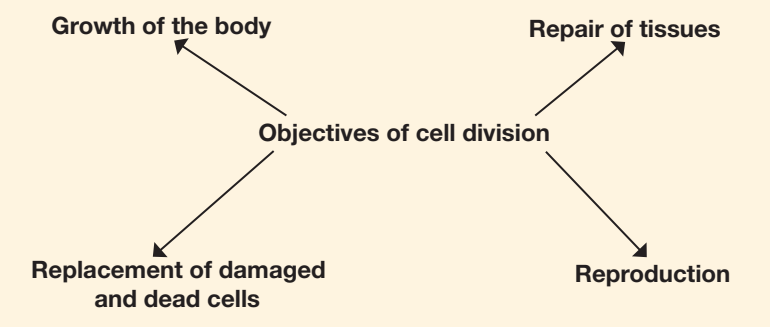


FIG. 2.1 Objectives of cell division

Info Box!

If not corrected in time, mistakes made during mitosis can result in changes in the DNA that can potentially lead to genetic disorders

Growth of the Body

Growth is one of the basic activities that takes place in all living organisms. In unicellular organisms, growth results due to the increase in the size and volume of the cytoplasmic contents of the cell. In multicellular organisms, the cells undergo repeated divisions to form many cells of different sizes and shapes. This is followed by other phenomena such as cell differentiation and organ formation. This ultimately results in the growth of an individual organism.

Maintenance and Repair of Cells

Injuries, cuts, bruises or fractures result in the rupture of cells. The process of healing takes place by the formation of new cells in place of ruptured ones. Cell division results in the formation of new cells that fill the gaps formed at the site of injury.

Replacement of Dead and Damaged Cells

The cells may get damaged due to wear and tear in the course of time. Such damaged cells are replaced by the division of cells. The different types of cells have different life spans. The cells die after a specific period. Such cells are worn out from the body and are replaced by new cells formed by cell division. For example, the life span of RBC in blood is 120 days. These are destroyed in the spleen and are formed in the bone marrow. Cell division takes place constantly to replace the damaged or worn out cells.

Formation of New Individuals by Reproduction

In case of unicellular organisms, the nucleus of the single cell (organism) divides to produce a new individual. In multicellular organisms, both asexual reproduction and sexual reproduction take place. Asexual reproduction take place by the nuclear and cytoplasmic division of the cells in the organism to produce new cells that form the entire organism identical to the parent organism. Sexual reproduction involves the formation of male and female gametes (sperms and ova) by cell division followed by the fusion of the male and female gametes to form a zygote. The life of every organism starts from a zygote. Zygote undergoes repeated cell divisions to develop into an organism.

> **Info Box!**
>
> Our body is undergoing mitosis constantly as all sorts of cells die and are replaced

Modes of Cell Division

Depending on the method in which the division of nucleus takes place, the cell division can be of two types:

1. Direct cell division (Amitosis)
2. Indirect cell division

The direct cell division is the only primitive mode of cell division. This takes place generally in lower organisms like bacteria. This is known as amitosis.

Amitosis is the mode of cell division in which the division takes place within the nucleus. Following changes take place in the cell during amitosis:

- The nucleus elongates along with the nuclear membrane and develops constriction.
- This constriction deepens and divides the nucleus into two daughter nuclei.
- The cytoplasm also divides and surrounds these nuclei thereby forming two daughter cells.

> **Info Box!**
>
> In amitosis two daughter cells are formed without the occurrence of any nuclear event

In this mode of cell division, there is no appearance of chromosomes. This is not a regular mode of cell division in higher organisms. It takes place only in certain specific cases in higher organisms, such as cells in the cartilage of mammals and cells of old tissues. It also occurs in the foetal membranes of humans. Indirect cell division is characterized by the appearance of chromosomes. There are two modes of indirect cell division. They are listed as follows.

1. Mitosis
2. Meiosis

Info Box!

Mitosis has only 1 complete sequence of chromosome division and cytokinesis

Mitosis

The term 'mitosis' was coined by Fleming. This cell division takes place in all the somatic cells in the body of the organism. Somatic cells are the cells that are not involved with the fertilization process of sexual reproduction. A newly formed cell is not capable of cell division immediately. The cell undergoes a series of changes to be capable of cell division. This stage of the cell during which such changes take place and the cell becomes ready for cell division is known as interphase. This interphase which is the non-dividing phase of the cell division is followed by the mitotic phase (M phase) which is the dividing phase. Interphase is the preparatory phase for the cell division. It can be divided into three sub-phases depending upon the events taking place in the cell. They are:

1. First growth phase (G_1 phase)
2. Synthetic phase (S phase)
3. Second growth phase (G_2 phase)

Characteristic Changes in Respective Mitosis Phases

The characteristic changes during various stages of a cell cycle are described below.

G1 phase (Gap Phase I)

G1 phase is characterized by the following changes:

- Increase in the size of the cell and the nucleus
- Synthesis of RNA and proteins
- Increase in the number of cell organelles
- No change in DNA content

Info Box!

Human DNA is 95% identical to the DNA of chimpanzees.

S Phase

S phase is the most significant step in the process of cell division and is characterized by the following changes:

- Synthesis of new DNA in which the DNA content of the cell is doubled. This is called DNA replication.
- DNA replication results in the formation of duplicate set of genes without increase in the chromosome number.

Process of DNA Replication

The process of DNA replication is explained below.

The two strands of the DNA double helix get separated. Two new strands are synthesized for the two separated strands. Each strand of the original DNA molecule serves as a template for the synthesis of a new strand as its counterpart. This newly synthesized strand will be complementary to the original strand. This means the sequence of base pairing in the new strand remains the same as the counterpart of the original DNA which got separated. This means, a duplicate copy of the same DNA is produced during this process. This entire process of synthesis of new DNA from the original DNA is called DNA replication or DNA copying. DNA replication involving complementary base pairing is responsible for the preservation of DNA sequence of the original cell (parent cell).

Example: Sequence of nucleotides of the original DNA

A A G A G G A T A A G A G G C G.....(Sequence of strand 'A'—template)
T T C T C C T A T T C T C C G C ... (Sequence of strand 'B')

Sequence of nucleotides of the newly synthesized strands of DNA

T T C T C C T A T T C T C C G C ... (Sequence of strand 'C' which is complementary to strand 'A' template)
A A G A G G A T A A G A G G C G .... (Sequence of new strand 'D' which is complementary to strand 'B' template)

Sequence of nucleotides in the new sets of DNA formed after replication

A A G A G G A T A A G A G G C G ... (Sequence of strand 'A')
T T C T C C T A T T C T C C G C ... (Sequence of strand 'C'—new)
T T C T C C T A T T C T C C G C ... (Sequence of strand 'B')
A A G A G G A T A A G A G G C G ... (Sequence of strand 'D'—new)

The daughter cells that are produced at the end of cell division possess the same DNA as the parent cell. The number of chromatids in the chromosomes gets doubled. But, the sister chromatids remain attached at the centromere. This means that the chromosomes occur in pairs. As a result, the number of chromosomes remains the same at the end of this phase. The resulting sets of chromosomes with duplication of genes are called homologous chromosomes. At this stage, chromosomes are clearly visible.

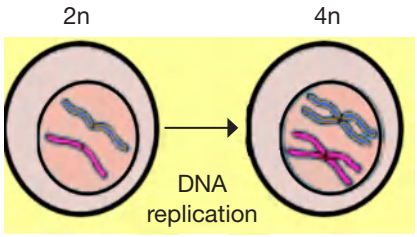


FIG. 2.2 S Phase—DNA replication

The number of chromatids becomes double keeping the number of chromosomes constant. For example, in human cell, there are 46 chromosomes. At the end of S phase, there are 92 chromatids in the cell. This means that 46 sets of homologous chromosomes are present in the cell. Synthesis of histone protein also takes place during this phase. Duplication of centrioles also takes place in animal

Info Box!

It will take 50 years to type the entire human genome if someone types at a speed of 60 wpm (words per minute) and works 8 hours a day

cell. In the plant cell, centrosome is absent. Hence, microtubules play the role of centrioles. After the DNA replication, the original cell is considered to be almost ready to undergo mitotic cell division.

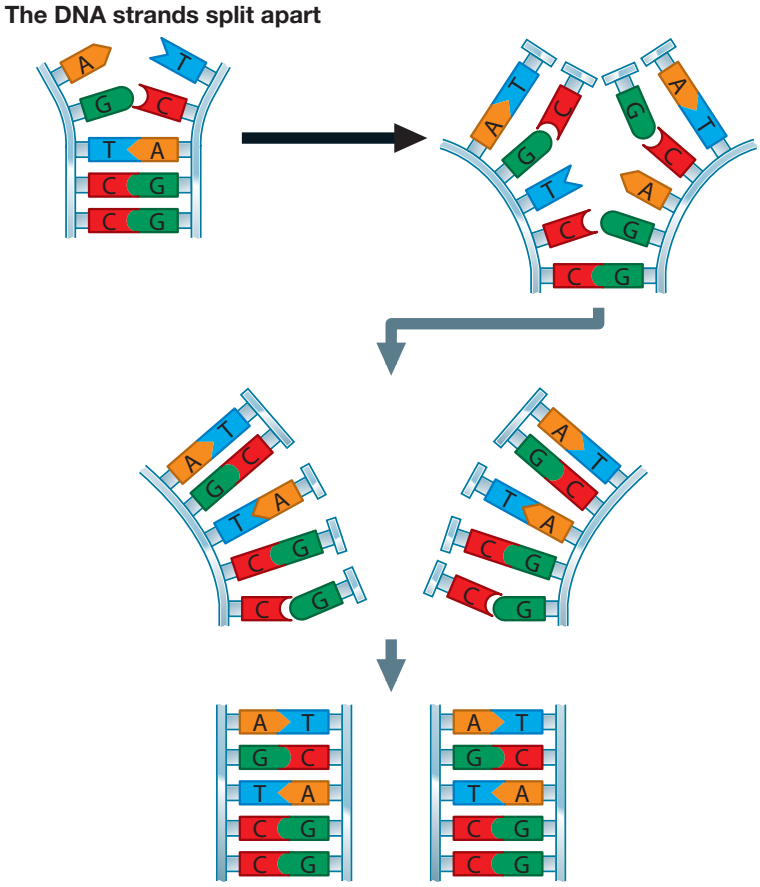


FIG. 2.3 Diagram showing cell DNA replication

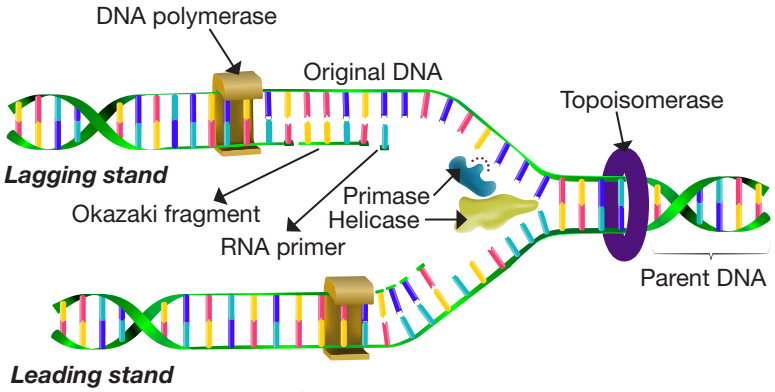


FIG. 2.4 Overview of DNA replication and enzymes involved

G2 Phase

G2 phase is characterized by the following changes:

- Continuation of synthesis of RNA and proteins
- Multiplication in the number of cell organelles
- Growth of cytoplasmic content of the cell
- Formation of spindle fibres

With G2 phase, the interphase concludes. At the end of the interphase (G2 phase), the cell is totally ready for entering the phase of actual cell division that is M phase. M phase of cell division is referred to as actual Mitotic Cell division or Mitosis.

M-Phase

The M phase or the actually dividing phase (Mitosis) of the cell cycle takes place in two steps:

1. Karyokinesis (division of nucleus)
2. Cytokinesis (division of cytoplasm)

Info Box!

Several critical steps in mitosis are controlled by phosphorylation or dephosphorylation of proteins.

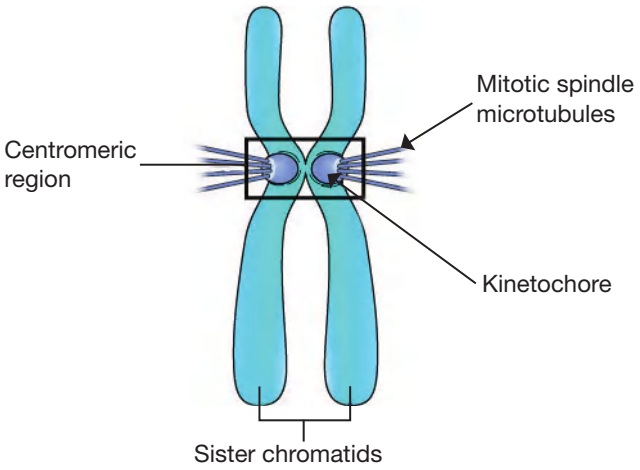


FIG. 2.5 Sister chromatids each showing a kinetochore and centromere

Division of nucleus is the most significant step in the cell division as it involves the distribution of genetic material to the daughter cells. The genetic material is distributed in the form of chromosomes. Karyokinesis in mitosis takes place in four successive steps usually referred to as phases of mitosis. They are listed as follows.

1. Prophase 2. Metaphase 3. Anaphase 4. Telophase

Karyokinesis is followed by cytokinesis in which the cytoplasm of the parent cell divides eventually producing two daughter cells. These four phases of karyokinesis are explained in the following section.

Prophase

- This phase is marked by the initiation of the condensation of chromatin material in the nucleus.
- The chromatin network becomes untangled and begins to condense and become thick chromosomes which are prominent and visible.
- In an animal cell, the centriole that has already undergone duplication during the S phase now begins to move towards the opposite poles of the cell.
- In a plant cell, the mitotic spindle is formed with the help of microtubules.
- In animal cells, each daughter centriole is surrounded by radiating rays called aster rays. Spindle fibres appear between the daughter centrioles. There is no astral formation in a plant cell.
- Towards the end of prophase, the nuclear membrane disappears.
- The nucleolus, Golgi complex and endoplasmic reticulum (ER) also disappear.

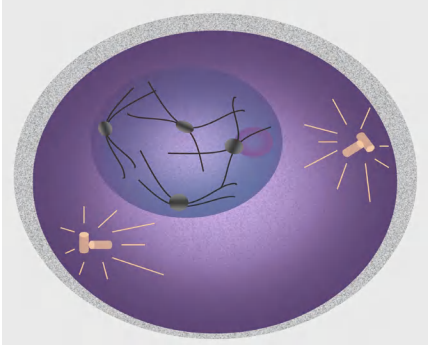


FIG. 2.6 Prophase

Metaphase

The complete breakdown of the nuclear membrane is the beginning of metaphase. The chromosomes are spread throughout the cytoplasm of the cell. A small disc-like protein structure called kinetochore is formed at the surface of the centromeres. This structure allows the chromatids to be attached to a spindle fibre on a chromosome. Each chromosome gets attached to the spindle fibre by the kinetochore of the centromere. The chromosomes arrange themselves at the equator plane.

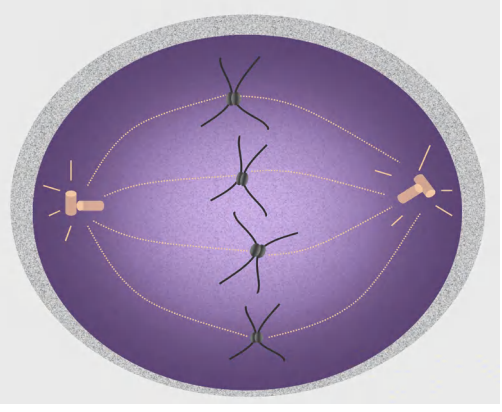


FIG. 2.7 Metaphase

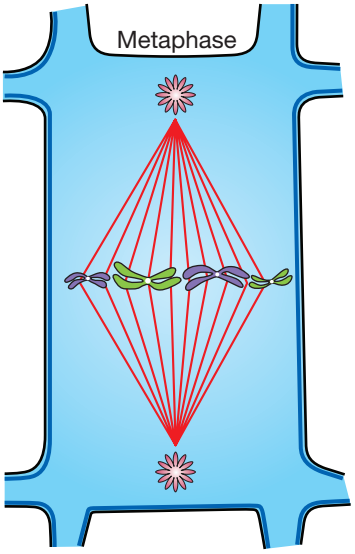


FIG. 2.8 Metaphase of mitosis in a plant cell

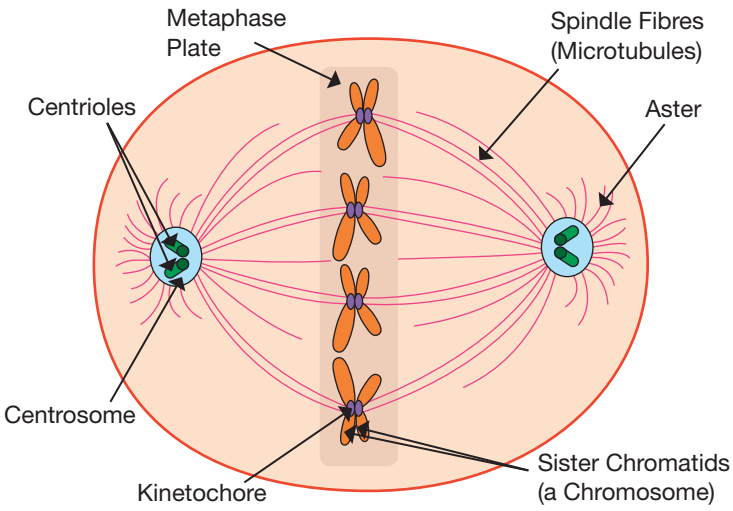


FIG. 2.9 Metaphase in animal cells

Anaphase

This is the shortest phase. Each chromosome that is arranged at the equator plane gets split. Each daughter chromatid begins to migrate towards the two opposite poles. As each chromatid moves away from the equator plane, the centromere of each is pushed towards the poles. These daughter chromatids are finally referred to as chromosomes of the future daughter nuclei.

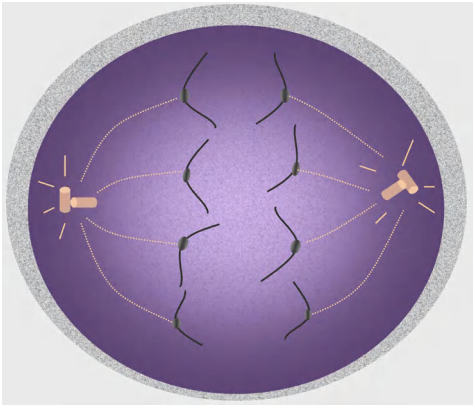


FIG. 2.10 Anaphase

Telophase

This is the beginning of the final stage of mitosis. The daughter chromosomes reach their respective poles. Once they reach their poles, the chromosomes start unwinding

and form the chromatin network. The nuclear membrane and nucleolus reappear and surround the respective daughter chromosomes. Reformation of cell organelles such as Golgi complex and ER in the cell takes place. Disappearance of spindle fibres and astral rays. The centrioles duplicate and get surrounded by centrosphere thus producing a centrosome near each daughter nucleus. The nucleus reappears, and the two daughter nuclei begin to increase in size.

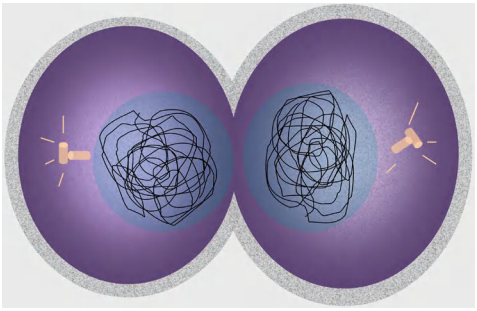


FIG. 2.11 Telophase

Cytokinesis

Karyokinesis takes place more or less in the same way in both an animal cell and a plant cell. But the process of cytokinesis differs to a large extent from an animal cell to plant cell.

Cytokinesis in an Animal Cell

During cytokinesis, the cytoplasm undergoes division by a process called cleavage. This happens with the appearance of a furrow in the plasma membrane. The furrow gradually deepens and finally joins in the middle thus dividing the cell into two parts. The cell membrane starts constricting from the sides and continues inward until the mother cell is divided into two daughter cells. This type of cytokinesis is said to be centripetal as the process starts at the periphery and proceeds towards the centre.

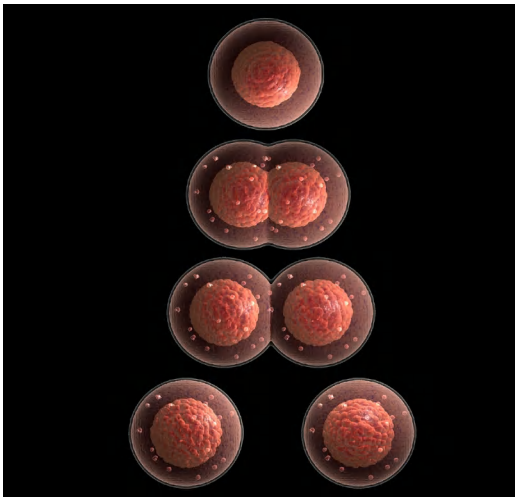


FIG. 2.12 Cytokinesis in an animal cell

Cytokinesis in a Plant Cell

Plant cells undergo cytokinesis differently because the cell is bound by a rigid cell wall in addition to the plasma membrane. During telophase, a cell plate is formed across the cell, that is, a new cell wall is formed between the two membranes of the cell. During telophase, membrane-enclosed vesicles derived from the Golgi apparatus migrate to the centre of the cell to form a cell plate. Eventually, the growing cell plate fuses with the existing plasma membrane, producing two daughter cells, each with its own plasma membrane. This kind of cytoplasmic division is said to be centrifugal as it starts at the centre and moves towards the periphery. A new cell wall is formed between the two membranes of the cell plate. At the time of cytoplasmic division, the organelles get distributed within the two daughter cells.

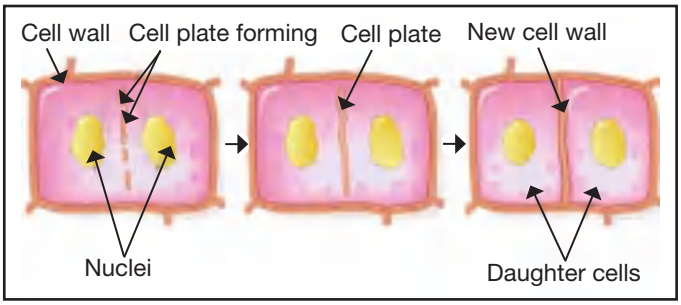


FIG 2.13 Cytokinesis in a plant cell

Significance of Mitosis

A few points of significance of mitosis are discussed below:

- Mitosis results in equal distribution of genetic material from parent cell to the daughter cells.
- At the end of this cell division, the chromosome number is maintained same as the parent cell.
- This results in growth and development of the organisms.
- This cell division also maintains the size of the body of the organism.
- It helps in the regeneration of cells during healing of injuries.
- It helps in the replacement of old and dead cells.
- In plants, mitosis helps in the production of new plants through vegetative propagation, tissue culture, etc.
- It also helps in the production of new organisms by the technique of cloning where the parental characters are retained as it is in the new organisms.

Info Box!

Siblings from same parent have different genetic make up

Meiosis

The term meiosis was coined by J.B. Farmers and J.E.S. Moore. Meiosis is the type of cell division that occurs in the reproductive cells or germ cells. This is the type of cell division that is involved in the formation of male and female gametes in the higher organisms. The interphase stage involving DNA replication takes place to prepare the cell for the cell division in the same way as in the case of mitotic cell division. Just like mitosis, karyokinesis is followed by cytokinesis in meiosis. However, meiosis differs from mitosis in that it involves two successive nuclear divisions during karyokinesis. The first nuclear division is known as meiosis-I and the second one is known as meiosis-II.

Meiosis-I

Meiosis-I takes place in four phases just like mitosis. The four phases of meiosis-I are:

1. Prophase-I
2. Metaphase-I
3. Anaphase-I
4. Telophase-I

But, the events taking place during these phases are quite different from those taking place in the respective phases of mitosis. Meiosis-I may be followed by cytokinesis or may directly lead to meiosis-II. At the end of meiosis-I, two haploid daughter cells are formed from one diploid mother cell. Meiosis-II is similar to mitosis cell division. It results in the formation of two haploid daughter cells from each haploid daughter cell formed at the end of meiosis-I. Among all the four phases, Prophase-I of meiosis is the most prolonged and complicated phase and can further be divided into five subphases:

1. Leptotene
2. Zygotene
3. Pachytene
4. Diplotene
5. Diakinesis

Metaphase-I

- Spindle fibres are formed from centromere or microtubules.
- Bivalents are arranged in such a way that they form an equatorial plate

Anaphase-I

- The chromosomes of bivalents get separated and move towards the opposite poles. This process is known as disjunction.
- These separated chromosomes are called dyads. Each dyad comprises two chromatids joined at the centromere.
- This results in the formation of two groups of chromosomes, each with half the number of chromosomes present in the original cell. This means haploid condition is attained.

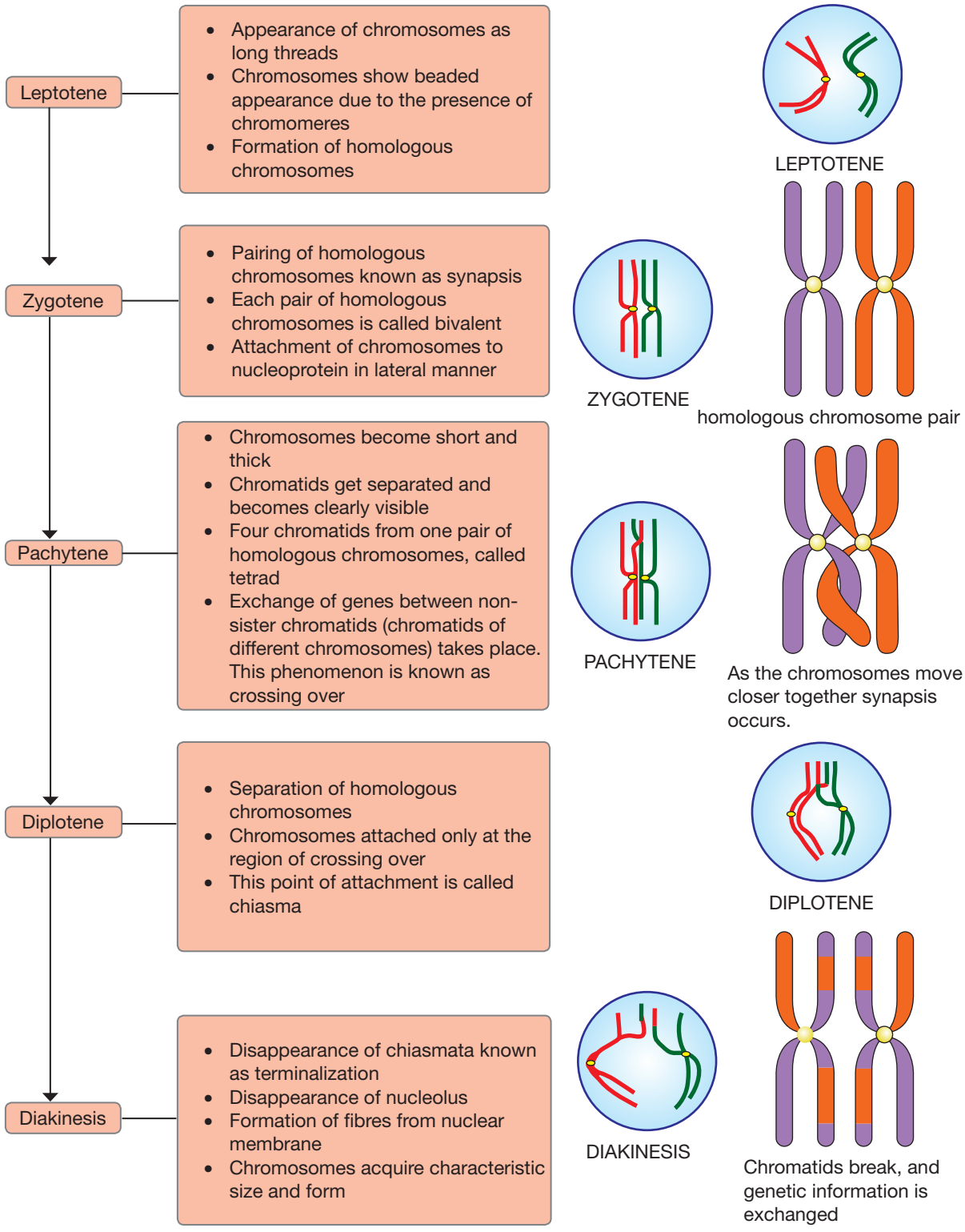


FIG. 2.14 Sub-phases of prophase-I (meiosis-I)

Info Box!

Mutation is the process of changing a DNA sequence permanently and it can occur during meiosis

Telophase-I

- Disappearance of spindle fibres
- Reappearance of nucleolus, nuclear envelope and nucleoplasm.
- Elongation of chromosomes without the formation of network

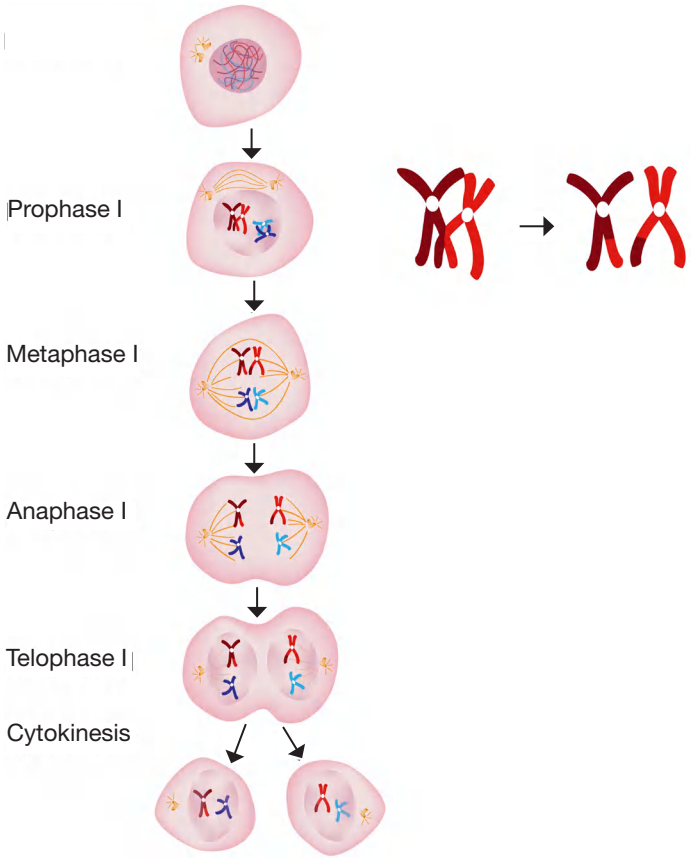


FIG. 2.15 Sub-phases of meiosis-I

Meiosis-II

Meiosis-II is similar to normal mitotic division in which the chromosome number is retained. However, meiosis-II is not preceded by interphase. Just like mitosis, meiosis-II takes place in four phases. They are: prophase-II; metaphase-II; anaphase-II and telophase-II. The two stages of karyokinesis are followed by cytokinesis. This completes the entire meiotic division. The two haploid daughter cells formed at the end of meiosis-I undergo meiosis-II separately resulting in the formation of four haploid daughter cells. This means that two daughter cells are formed from each daughter cell of meiosis-I. Meiotic cell division eventually results in the formation of four haploid daughter cells from a diploid mother cell in contrast to mitotic cell division which results in the formation

of two diploid daughter cells from a diploid mother cell. On the whole, as a result of meiotic cell division of one diploid germ cell, four haploid daughter cells are formed. These haploid daughter cells are called gametes. In the case of male organisms, the male gametes (sperms) are produced by meiotic cell division of the germ cells. In the case of female organisms, the female gametes (eggs or ova) are produced by meiotic cell division of the germ cells.

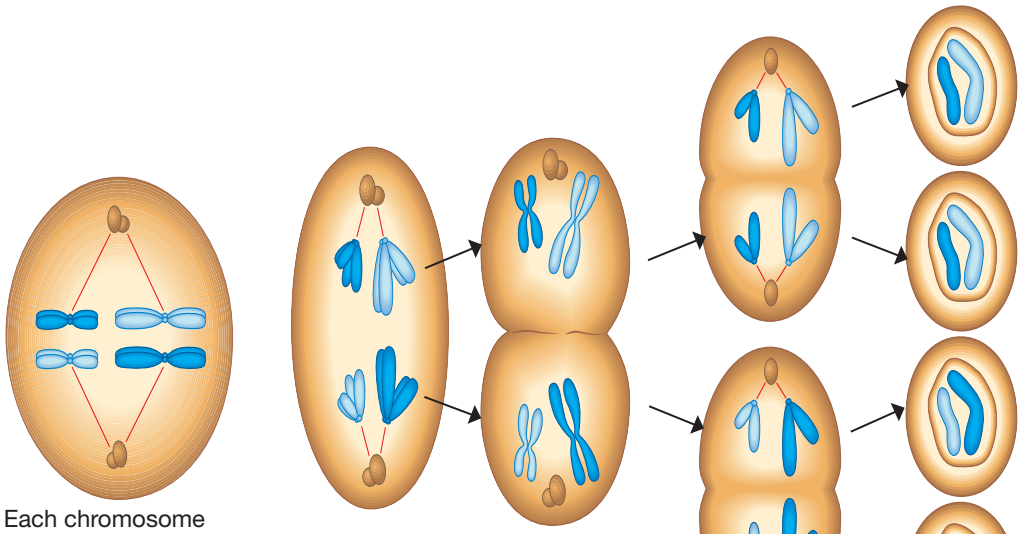


FIG. 2.16 Sub-phases of Meiosis-II

CELL CYCLE

The haploid male gamete fuses with the haploid female gamete to form a diploid zygote during the process of fertilization. Thus, the chromosome number is retained for the organism. The diploid zygote undergoes repeated mitotic divisions and subsequent processes resulting in the development and growth of the organism. Every mitotic division of a cell results in the formation of two new daughter cells. As the daughter cells are not ready for further cell division, they go through the interphase in which DNA replication and other events take place. Thus, the cells undergo cyclic sequence of events in the body of the organism. This is known as cell cycle.

Info Box!

Different phases of mitosis can be identified and distinguished through microscopic examination

The series of events taking place in a cell involving duplication of DNA followed by the formation of two daughter cells which again follow the same series of events is known as cell cycle.

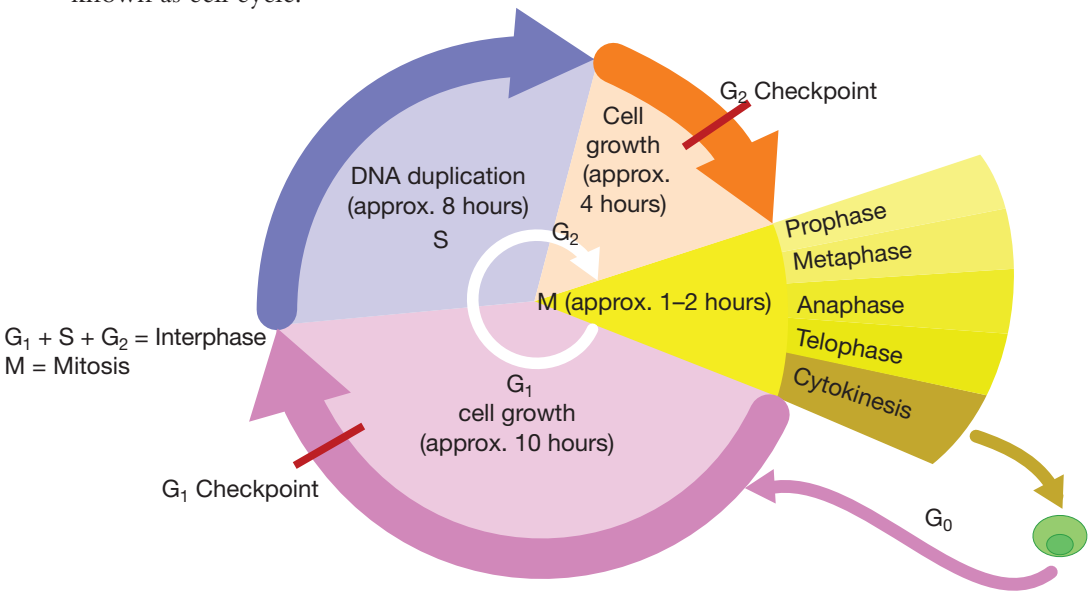


FIG. 2.17 Cell cycle

The cell cycle can be basically divided into two phases:

1. Non-dividing interphase
2. Dividing mitotic phase

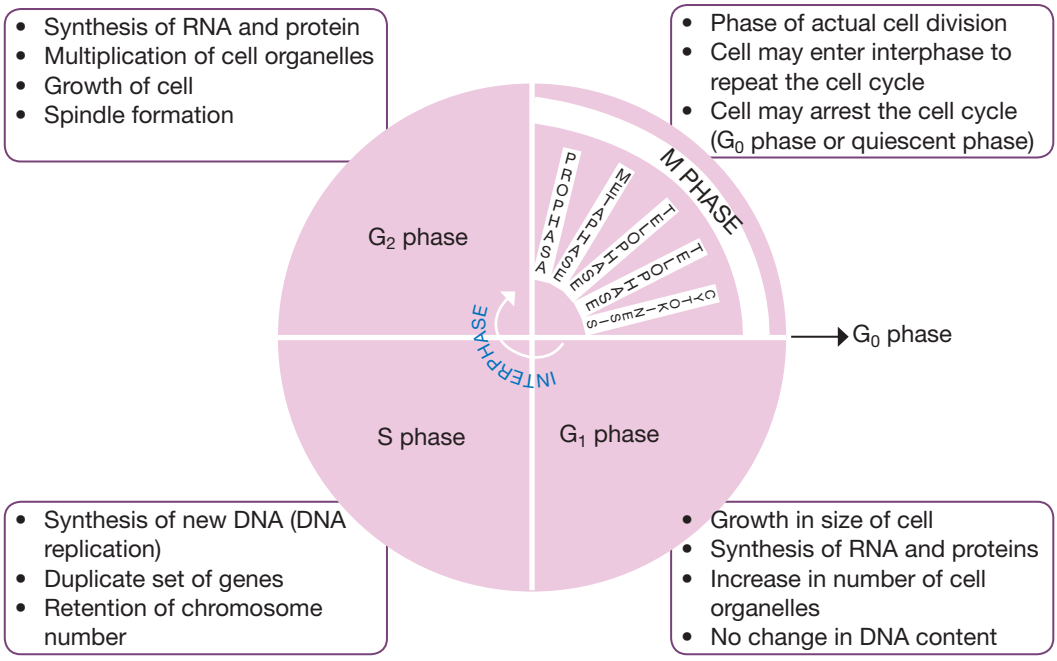


FIG. 2.18 Cell cycle—Schematic representation

Interphase pertains to the changes taking place in newly formed cell. This is basically a preparatory phase for the cell during which the cell undergoes certain changes required for undergoing cell division by itself. Interphase (I phase) is the longest phase as it lasts for around or more than 90% of the time. This phase can further be divided into three sub-phases depending on the events taking place inside the cell. The three sub-phases include first growth phase (G_1 phase), second growth phase (G_2 phase) and synthetic phase. This is followed by mitotic phase (M phase) which is the actual dividing phase and lasts for a short span of time. After M phase, a cell again enters the interphase and repeats the cycle of cell division. During this transition from interphase to M-phase, some of the cells may take a different course. This is called G_0 phase or quiescent phase. The cell may stop further cell division due to lack of nutrients and may remain inactive or die. The period of inactivity may differ from cell to cell. The cell may stop the cell division but remain metabolically active by undergoing a process of cell differentiation where it becomes specialized to perform specific tasks. This above process results in the formation of tissues. The cells of these tissues may undergo cell division only at the time of injury for the purpose of healing.

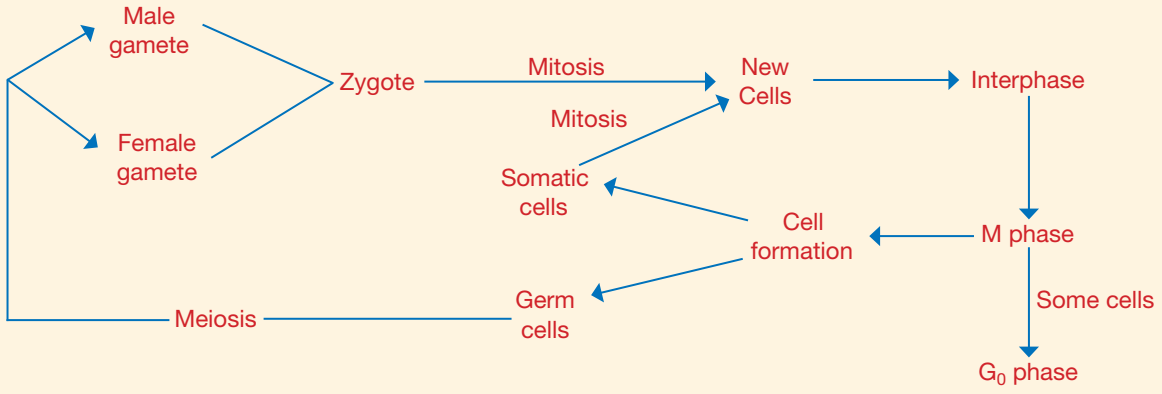


FIG. 2.19 Typical life cycle of cells of a higher organism involving cell cycle

QUICK RECAP

1. Is duration of cell cycle same for all cells? Explain by giving suitable examples.

The duration of cell cycle varies drastically from one cell to another. For example, in yeast cells, cell cycle takes only 90 min. In humans, the average duration of cell cycle is around 24 h. But, the fastest dividing cells such as skin cells have a cell cycle duration of 9–10 h.

QUICK RECAP

2. Mention the differences between mitosis and meiosis.

Mitosis	Meiosis
Occurs mainly in somatic cells	Occurs in germ cells or reproductive cells
Two daughter cells are formed which may be haploid or diploid	Four daughter cells are formed which are always haploid
This divisions occur both in asexually and sexually reproducing organisms	Occurs only in sexually reproducing organisms
DNA replication takes place only once for every cell division during interphase	DNA replication takes place only once for two cell divisions that are meiosis I and II
Daughter nuclei formed are exactly similar to that of parent cell	Daughter nuclei are formed by genetic recombinations caused due to crossing over. Hence, they are not similar to parent
Prophase is very short and simple	Prophase is elaborate and made up of sub-stages
Synapsis of homologous chromosomes and crossing over does not occur	Synapsis and crossing over take place
Synaptonemal complex is not formed.	Synaptonemal complex is formed
Chromosomal number remains constant.	Chromosomal number is reduced to half
Helps in growth and repair of tissues.	Helps in formation of gametes

3. Distinguish between the mitotic cell division in plant cell and that in animal cell.

Mitosis in plant cell	Mitosis in animal cell
Usually takes place in growing regions such as root tip, shoot tip and lateral regions of stems and roots	It takes place in almost all the regions of the body, except brain.
Before the cell division, cell does not undergo change in shape	The cell becomes spherical prior to cell division
Centrioles and asters are not formed	Centrioles and asters are formed
Cytokinesis takes place by the formation of cell plate	Cytokinesis takes place by cleavage

4. How are gametes produced in haploid organisms?

Lower plants are generally haploid. In those cases, the zygote is diploid. It undergoes meiosis producing four haploid gametes which develop into spores. All the four spores undergo mitotic divisions forming the individual organisms that are haploid.

In some organisms, the haploid gametes are produced from haploid germ cells by mitotic cell division.

POINTS TO REMEMBER

- The process of formation of new cells by the division of pre-existing cells is known as cell division.
- Depending on the method in which the division of nucleus takes place, the cell division can be of two types direct cell division and indirect cell division.
- Amitosis is the mode of cell division in which the division takes place within the nucleus.
- Mitosis takes place in all the somatic cells in the body of the organism.
- Mitosis can be divided into three sub-phases: First growth phase (G_1 phase), Synthetic phase (S phase) and Second growth phase (G_2 phase).
- Mitosis results in growth and development of the organisms.
- Meiosis is the type of cell division which is responsible for production of male and female gametes in higher organisms.
- Meiosis-I is divided into 4 sub-phases: Prophase-I, Metaphase-I, Anaphase-I and Telophase-I.
- Prophase-I of meiosis-I is the most prolonged and complicated phase and can further be divided into five subphases: Leptotene, Zygotene, Pachytene, Diplotene and Diakinesis.
- Meiosis-II is similar to normal mitotic division in which the chromosome number is retained.
- The series of events taking place in a cell involving duplication of DNA followed by the formation of two daughter cells which again follow the same series of events is known as cell cycle.

TEST YOUR CONCEPTS

PRACTICE QUESTIONS

Directions for questions from 1 to 14: Fill in the blanks in each question.

1. The phase that occupies maximum part of cell cycle is _____.
2. Splitting of centromeres is observed in _____ stage of mitosis cell division.
3. The cells that undergo meiosis are known as _____.
4. In animal cells, meiotic cell division occurs during _____ formation.
5. The pair of synapsed homologous chromosomes is known as _____.
6. Mitosis takes place in somatic cells and _____ takes place in _____ cells.
7. The X-shaped structures formed in diplotene stage are known as _____.
8. Diploid cells are formed at the end of _____
9. At the end of meiosis-I, two _____ cells are formed.
10. The process in which cytoplasm undergoes division in cytokinesis in an animal cell is called _____.
11. Daughter chromosomes reach their poles in the _____ stage of the cell division.
12. Spindle fibres disappear in _____ phase of meiosis-I
13. _____ is the most appropriate stage to count the number of chromosomes.
14. Meiotic division of a diploid germ cell results in the formation of daughter _____ cells.

Directions for questions from 15 to 31: For each of the following questions, for choices have been provided. Select the correct alternatives.

15. Crossing over takes place in which stage of meiosis?
    (a) Diplotene
    (b) Leptotene
    (c) Pachytene
    (d) Zygotene
16. In which phase of a cell cycle does the DNA replication take place?
    (a) Prophase (b) S phase
    (c) G1 phase (d) G2 phase
17. Which of the following stages is associated with quiescent stage?
    (a) Cell undergoes division
    (b) Cell stops division
    (c) Formation of homologous chromosomes
    (d) DNA content of cell increases
18. In which phase of meiosis-I does the process of disjunction take place?
    (a) Prophase (b) Metaphase
    (c) Anaphase (d) Telophase
19. Identify the first activity that takes place in the metaphase of a cell division
    (a) Spread of chromosomes throughout the cytoplasm
    (b) Formation of kinetochore
    (c) Complete breakdown of nuclear membrane
    (d) All the above activities take place simultaneously
20. Which of the following occurs in anaphase stage of cell division?
    (a) Formation of dyads
    (b) Formation of spindle fibres
    (c) Disappearance of spindle fibres
    (d) Reappearance of nucleolus

21. Which of the following is true at the end of the mitotic cell division process regarding chromosome number?

(a) Chromosome number in a daughter cell is less than that in the parent cell.

(b) Chromosome number in a daughter cell is less than or equal to that in the parent cell.

(c) Chromosome number in a daughter cell is equal to that in the parent cell.

(d) Chromosome number in a daughter cell is greater than or equal to that in the parent cell.

22. Identify the number of chromosomes in human germ cell.

(a) 23

(b) 46

(c) 92

(d) 23 in males and 46 in females

23. Which stage of mitosis cell division bears V-shaped chromosomes?

(a) Prophase (b) Anaphase

(c) Metaphase (d) Telophase

24. Identify the cell which does not undergo meiosis.

(a) Bacterial cell (b) Plant cell

(c) Animal cell (d) Fungal cell

25. Identify the location in which exchange of genetic material occurs in the process of cross-ing over.

(a) Chromatids and non-homologous chromosomes.

(b) Sister chromatids of the homologous chromosomes.

(c) Non-sister chromatids of the homologous chromosomes.

(d) Between chromosomes.

26. In which of the following aspects, meiosis-II differs from mitotic cell division?

(a) Meiosis-II involves crossing over

(b) Meiosis-II is not followed by cytokinesis

(c) Meiosis-II gives rise to four daughter cells from one parent cell.

(d) Meiosis-II is not preceded by interphase.

27. How many daughter cells are formed after meiotic cell division from five mother cells?

(a) 40 (b) 10

(c) 30 (d) 20

28. Identify (i) and (ii) in the following chart?

Parent cell → 2 Daughter cells → 4 Daughter cells
(i) (ii)

(a) (i) = 2n; (ii) = n

(b) (i) = n; (ii) = n

(c) (i) = n; (ii) = 2n

(d) (i) = 2n; (ii) = 2n

29. Which of the following are wrong statements/?

(i) Bivalents are tetrads

(ii) A bivalent means four chromatids and two centromeres

(iii) One bivalent consists of two homologous chromosomes

(iv) Bivalents are formed in zygotene

(a) (i) (ii) (iii) and (iv)

(b) (ii) only

(c) (iii) and (iv)

(d) (iv) only

30. Identify the correct sequence of cell cycle.

(a) G2 → M → G1 → S.

(b) S → G2 → M → G1.

(c) G1 → S → G2 → M.

(d) M → G1 → S → G2.

PRACTICE QUESTIONS

31. Which is the most appropriate stage to count the number of chromosomes?

(a) Prophase

(b) Interphase

(c) Metaphase

(d) Telophase

Directions for questions from 32: Match the entries of Column 1 with those of Column 2.

32.

Column 1	Column 2
A. Crossing over	(i) Diakinesis
B. Pairing of homologous chromosomes	(ii) Diplotene
C. Formation of fibres from nuclear membrane	(iii) Pachytene
D. Chiasmata formation	(iv) Zygotene

MASTERING THE CONCEPTS

Knowledge and Understanding

1. Mention the stages included in a cell cycle.

2. Give technical terms for the following.

(a) Division which brings about vegetative propagation.

(b) The stage in which bivalents are formed.

(c) The process during which meiosis occurs in human beings.

(d) Points at which two sister chromatids are held together.

(e) The process of division of cytoplasm.

(f) Proteins and RNA synthesis takes place in this stage.

3. What are the changes occurring during anaphase of mitotic cell division?

4. Write short notes on the following.

(a) Synapsis

(b) Bivalent

(c) Chiasmata

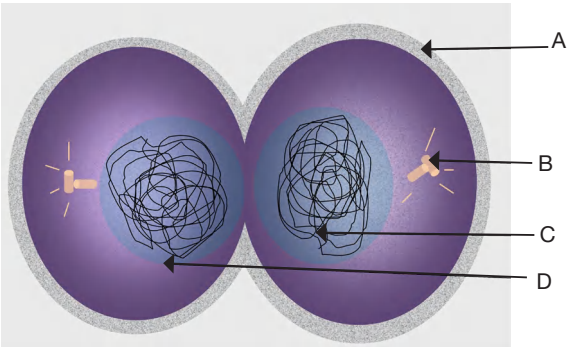
5. How are spindle fibres formed during cell division? What is their importance?

6. All the somatic cells in the body of an individual have exactly identical DNA. Why?

7. Mitosis helps in cellular regeneration. Give reason.

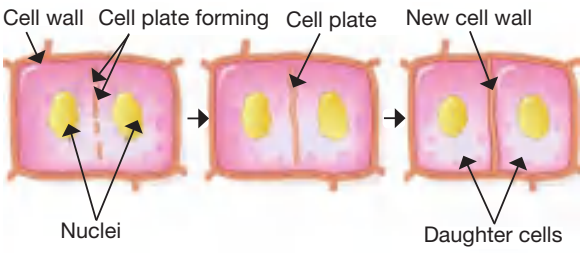
8. Why is mitosis known as equatorial division while meiosis is known as reduction division?

9. Mention the phase of mitosis that is shown in the below figure and label the parts A, B, C and D. Mention the changes taking place in the given phase.



PRACTICE QUESTIONS

10. Observe the figure and answer the questions that follow.



(a) Name whether this type of cell division takes place in plants or animals and why?

(b) Name and explain the phase of cell division that is shown.

11. Identify the odd one out and justify.

(a) G1 phase, Anaphase, G2 phase, S phase.

(b) Lepotene, Diakinesis, Zygotene, Cytokinesis

Application and Analysis

12. Interphase was once considered as resting phase during the cell cycle though it covers almost 95% of time during the entire cell cycle. Comment on the statement.

13. Give importance of mitosis in embryo development.

14. Haploid cells also undergo mitotic cell division. Give reason.

15. Quiescent stage is the inactive stage. Justify.

16. Brain damage caused due to disease or trauma is permanent. Give reason.

17. Is the DNA sequence of the gametes same as the DNA of the germ cell? Give reason in support of your answer.

18. Which kind of cell division leads to cancer? Explain.

19. After the removal of cancerous tumor by surgical procedure, the organ is treated with chemotherapy or radiotherapy. Explain the reason with reference to the concept of cell cycle.

Assertions and Reasons

Direction for Questions from 20 to 30: Choose the correct option.

(a) Both A and R are true and R is the correct explanation for A.

(b) Both A and R are true, but R is not the correct explanation for A.

(c) A is true and R is false.

(d) A is false and R is true.

20. **Assertion (A):** Inactive stage in the cell cycle is quiescent stage.
Reason (R): All the cells pass through quiescent stage.

21. **Assertion (A):** All the cell organelles are seen until the end of prophase.
Reason (R): Chromatids separate but remain in the centre of the cell in anaphase.

22. **Assertion (A):** Haploid cells are formed by meiosis cell division.
Reason (R): Gametes are haploid cells.

23. **Assertion (A):** Recombination and crossing over take place in meiosis I.
Reason (R): In the process of meiosis two stages of DNA replication take place.

24. **Assertion (A):** Crossing over takes place between two homologous chromosomes.

PRACTICE QUESTIONS

Reason (R): Crossing over is the exchange of chromosomal fragments between homologous chromosomes.

25. **Assertion (A):** Gametes formed from the same individual have exactly identical DNA.
Reason (R): Homologous chromosomes are formed by DNA replication.

26. **Assertion (A):** The cell division in a plant cell is called an astral division.
Reason (R): Cytokinesis in plant cell takes place by the formation of cell plate.

27. **Assertion (A):** All the cells in an individual possess same DNA.
Reason (R): DNA replication involves complementary base pairing.

28. **Assertion(A):** Mitotic cell division is referred to as homotypic division.
Reason (R): Mitotic cell division retains the number of chromosomes.

29. **Assertion (A):** Karyokinesis is the significant stage in cell division.
Reason (R): Crossing over takes place during karyokinesis.

30. **Assertion (A):** Chromosome number is maintained constant at the end of S phase.
Reason(R): S phase does not involve crossing over phenomenon.

ASSESSMENT TESTS

Direction for Questions from 1 to 10: Fill in the blanks in each question.

1. _____ is the basic structural, functional and hereditary unit of all living organisms.
2. _____ is also referred to as ribosome factory.
3. DNA is a part of _____ in nucleus.
4. Adenine and Guanine are called _____ bases.
5. The membrane by which vacuoles are bound is _____.
6. Thymine and Cytosine are called _____ bases.
7. The kind of structure of a DNA is _____.
8. The number of sets of chromosomes in a cell is _____.
9. The pair of chromosomes that are similar in structure is called _____ chromosomes.
10. The life span of a RBC in blood is approximately _____.

Direction for Questions from 11 to 20: For each of the following questions four choices have been provided. Select the correct alternatives.

11. Asexual reproduction takes place by the division of:
    (a) nucleus only
    (b) cytoplasm only
    (c) both nucleus and cytoplasm
    (d) none of these

12. In which of the following does direct cell division take place?
    (a) Horse (b) Bacteria
    (c) *Hydra* (d) Monkey

13. Pairing of homologous chromosomes is known as _____.
    (a) synapsis
    (b) terminalization
    (c) fertilization
    (d) gametization

14. Which of the cell organelles do not contribute to the greenery of a plant?
    (A) Leucoplasts
    (B) Chromoplasts
    (C) Chloroplasts
    (a) Only A
    (b) Both A and B
    (c) Both B and C
    (d) Both A and C

PRACTICE QUESTIONS

15. Choose among the given correct pairing of nitrogen bases in a DNA.

(A) Adenine with Guanine
(B) Adenine with Thymine
(C) Adenine with Cytosine
(D) Thymine with Guanine
(E) Guanine with Cytosine
(F) Thymine with Cytosine

(a) A, and D
(b) A, and C
(c) Both B and E
(d) Both B and D

16. A cell that comprises two kinds of chromosomes is called _____.

(a) Diploid (b) Haploid
(c) Polyploid (d) Biploid

17. Chromatids of the same chromosome are called _____chromatids.

(a) Synchronous (b) Sister
(c) Secondary (d) Primary

18. Identify the actual dividing phase of mitotic cell division.

(a) S phase (b) G1 phase
(c) G2 phase (d) M phase

19. Division of centromere and chromatids takes place between which stages of mitotic cell division?

(a) Prophase and metaphase.
(b) Metaphase and anaphase.
(c) Anaphase and telophase.
(d) Telophase and prophase.

20. The order of phases in mitosis is

(a) Metaphase, Prophase, Anaphase and Telophase
(b) Prophase, Metaphase, Telophase, Anaphase
(c) Prophase, Metaphase, Anaphase, Telophase
(d) Anaphase, Prophase, Metaphase, Telophase

Direction for Questions from 21 and 22: Check if the given statement is correct or not, if found incorrect rewrite the correct statement.

21. The number of chromosomes depends on the size of the organism.

22. Autosomes in human cells determine the sex of the human.

Direction for Questions from 23 to 25: Find the odd term out giving reasons.

23. Mitochondria; Endoplasmic reticulum; Chromoplast; Ribosomes

24. Endoplasmic reticulum; Chloroplast; Chromoplast; Leucoplast

25. Chromatin fibre; Ribosome; Mitochondria; Vacuoles

Direction for Questions from 26 to 28: Write the missing correlated terms.

26. RNA → Single helix: DNA → _____

27. Diploid : 2n :: _____ :: Haploid

28. Karyokinesis: Nuclear division :: Cytokinesis : _____

Direction for Questions from 29 to 30: Answer the following questions.

29. What is cell differentiation?

30. What is a nucleosome?

PRACTICE QUESTIONS

TEST YOUR CONCEPTS

1. Interphase
2. The anaphase
3. Meiocytes
4. Gamete
5. Bivalents
6. Meiosis, The germ
7. Chiasmata
8. Mitosis
9. Haploid daughter
10. Cleavage
11. Telophase
12. The telophase
13. Metaphase
14. Haploid
15. (c)
16. (b)
17. (b)
18. (c)
19. (c)
20. (a)
21. (c)
22. (b)
23. (b)
24. (a)
25. (c)
26. (d)
27. (d)
28. (b)
29. (b)
30. (c)
31. (c)
32. A → (iii), B → (iv), C → (i), D → (ii)

MASTERING THE CONCEPTS

Knowledge and Understanding

1. The stages of a cell cycle include:

   (1) Meiotic phase M phase in which cell division takes place. Interphase is called resting phase in which the cell prepares for division by growth and DNA replication.

   The interphase is divided into three phases.
   (a) G1 phase—cells become metabolically active and grow
   (b) S phase—DNA synthesizes and replication takes place
   (c) G2 phase—Proteins are synthesized, and cell is ready to divide by growing continuously

   Interphase is followed by M phase.

2. Technical terms
   (a) Mitosis
   (b) Zygotene
   (c) Gamete formation
   (d) Chiasmata
   (e) Cytokinesis
   (f) G2 phase of interphase

3. Anaphase is the third stage of mitotic cell division. The chromosomes arranged on the equatorial plate split into two chromatids and move apart. The centromeres of the chromosomes and divide, and chromatids move to the opposite poles of the cell.

HINTS AND EXPLANATION

4. (a) Synapsis—Pairing of homologous chromosomes. It takes place during leptotene-stage meiosis—I.

(b) Bivalent—Pair of homologous chromosomes in zygotene stage of meiosis—I.

(c) Chiasmata—The point of attachment of chromosomes after crossing over which appears in diplotene stage of meiosis—I.

5. Microtubules are seen in the cytoplasm of cell during cell division. These give rise to fine thread-like structures called spindle fibres.

Spindle fibres move chromatids or chromosomes apart and help them in reaching the poles of the cell.

6. DNA sequence is preserved during mitotic division because of complementary base pairing. Therefore, all the somatic cells have the same DNA sequence.

7. Any somatic tissue or cells can undergo the process of mitosis.

Injured tissue heals by the process of mitosis.

This cell division helps in formation of new cells at the injured part.

Bones form new cells at the fractured region.

Liver cells have the highest power of regeneration that takes place by only cell division that is mitosis.

8. Mitosis is known as the equatorial division in which a single parent cell division gives rise to two daughter cells.

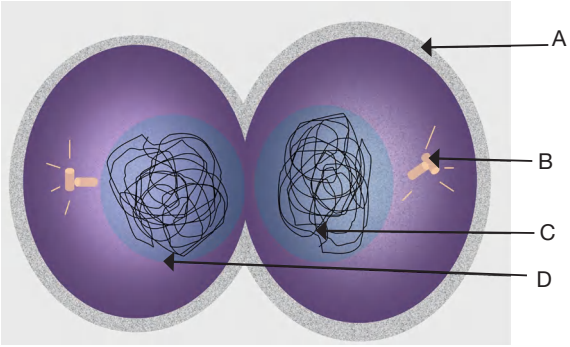
The genetic material is distributed equally in which the chromosomal number remains constant.

In meiosis, the chromosomal number is reduced to half.

The cells formed are haploid cells. Hence, the division is considered as reduction division.

9. The phase of mitosis shown in the figure is telophase

A → Cell membrane, B → Centriole, C → Chromatids, D → Nuclear membrane



10. (a) The type of cell division shown occurs in plants because the cell is bound by a rigid cell wall in addition to the plasma membrane.

(b) The phase of cell division shown is cytokinesis.

Plant cells undergo cytokinesis differently because the cell is bound by a rigid cell wall in addition to the plasma membrane.

During telophase, a cell plate is formed across the cell, in other words, a new cell wall is formed between the two membranes of the cell.

During telophase, membrane-enclosed vesicles derived from the Golgi apparatus migrate to the centre of the cell to form a cell plate.

Eventually, the growing cell plate fuses with the existing plasma membrane, producing two daughter cells, each with its own plasma membrane.

This kind of cytoplasmic division is said to be centrifugal as it starts at the centre and moves towards the periphery.

A new cell wall is formed between the two membranes of the cell plate.

11. (a) Anaphase is a subphase in M phase. All others are subphases in interphase.

(b) Cytokinesis is cytoplasmic division while others are phases in karyokinesis.

HINTS AND EXPLANATION

Application and Analysis

12. Interphase was once considered a resting phase. This is because the cell does not undergo actual cell division during this phase. It was assumed that the cell remains in rather inactive phase. But, it is not so. During this phase, the cell is metabolically active as the most significant process of DNA replication resulting in the pairing up of homologous chromosomes takes place during this phase. As a result, this cannot be considered as resting phase in true sense.

13. Mitosis is important in embryonic development as single cell zygote develops into embryo. This embryo undergoes mitotic cell division and gives rise to many cells. These cells form tissues, undergoes differentiation to form organs and organ systems for the normal functioning of an individual. Perfect development of embryo is not possible without mitotic cell division.

14. Haploid cells also undergo mitotic cell division as they retain the number of chromosomes. They do not undergo meiotic cell division because the haploid cells possess only one set of chromosomes.

15. There are certain cells in the animal body that do not divide and enter into an inactive stage. This stage is known as quiescent stage G0 of cell cycle.
Cells of this stage are metabolically active, but do not divide until the requirement of an organism.
They divide occasionally when needed to be replaced. For example, heart cells.

16. Brain damage results in the death or damage of brain cells or nerve cells. Nerve cells once formed during the embryonic development last for the entire lifetime. They cannot undergo cell division. They remain in an inactive stage forever. In case they are damaged, they cannot be replaced. This results in permanent disability.

17. DNA sequence of germ cell of an individual is the combination of DNA of his father and mother. Gametes are formed by the meiotic cell division of the germ cell. During the cell division, the exchange of genetic material takes place between the non-sister chromatids of homologous chromosomes. As a result, there is slight variation in the DNA sequence of the gametes from the parent germ cell.

18. Normally, cells undergo cell division which is controlled by enzymes. They go through cell cycles repeatedly and at some stage, like 40--60 cycles, they become inactive and eventually die. This phenomenon is called apoptosis. But, due to some reason, when the controlling mechanism fails, the cell cycles take place rapidly and in an uncontrolled manner and the phenomenon of apoptosis fails. As a result, the cells divide abnormally producing a lump of tissues in the respective organ. This is called tumor. If the cells do not have the ability to invade other organs, it is called benign tumor. If the cells have the ability to invade other organs, it is called malignant or cancerous tumor.

19. Once the cancerous tumor is removed by surgery, the few cells that are left over get abundant supply of nutrients in the system. As a result, they undergo cell divisions much more rapidly thereby spreading the cancerous tissue further. Therefore, these few cells are destroyed or killed by exposing them to high frequency radiation or by giving medicines which can arrest the cell divisions or kill the cells.

Assertions and Reasons

20. All the cells do not undergo quiescent stage. Assertion is true and reason is false.

Hence, the correct option is (c).

21. Some of the cell organelles disappear at the end of prophase. Chromatids after separation remain at the centre in anaphase. Only during telophase, they move to the periphery.

Hence, the correct option is (d).

22. Haploid cells are formed by meiotic cell division. This is a reduction division in which the chromosomal number is reduced to half. Gametes are haploid cells. Both assertion and reason are true, but reason does not support assertion.

Hence, the correct option is (b).

23. Recombination and crossing over takes place in meiosis I in which exchange of genetic material takes place.
DNA replication in meiosis takes place only once before prophase I. After telophase I, the cycle is continuous which starts with prophase II. Assertion is true and reason is false.

Hence, the correct option is (c).

24. Crossing over is the exchange of genetic material between two homologous chromosomes. This takes place in pachytene stage of prophase I in meiotic cell division. Assertion is true and supported by reason.

Hence, the correct option is (a).

25. Gametes are formed by the meiotic cell division of the germ cell in an individual. The crossing over takes place during the course of cell division. In this, there is exchange of genetic material between the non-sister chromatids. Due to this, the gametes do not have exactly identical DNA, though DNA replication preserves the nucleotide sequence in the homologous chromosomes.

Hence, the correct option is (c).

26. The cell division in a plant cell does not involve the formation of aster as the plant cell lacks centriole or centrosome.
It is not because of cell plate formation during cytokinesis. Both assertion and reason are true but reason does not support assertion.

Hence, the correct option is (b).

27. Due to the complementary base pairing during DNA replication in cell division, the daughter cells formed as a result of cell division possess the same DNA as the parent cell. Hence, DNA sequence in an individual is preserved.

Hence, the correct option is (b).

28. The daughter cells formed during mitotic cell division have the same number of chromosomes as the parent cell. Hence it is known as homotypic division.

Hence, the correct option is (a).

29. Karyokinesis involves the nuclear division. It involves the distribution of chromosomes that contain the genetic material. Therefore, this is the most significant stage during cell division. This pertains to both mitosis and meiosis. Crossing over takes place during karyokinesis in only meiosis. Both assertion and reason are true but reason does not support assertion.

Hence, the correct option is (b).

30. DNA replication is the main event which takes place during S phase. The genetic material gets doubled. The number of chromatids becomes doubled. Since the sister chromatids remain attached at the centromere, the number of chromosomes remains the same.
S phase is a part of interphase which is preparatory phase for the cell. It is not the actual dividing phase of the cell. Crossing over phenomenon is related to the dividing phase of only meosis. Reason does not support assertion.

Hence, the correct option is (b).

HINTS AND EXPLANATION

ASSESSMENT TESTS

1. Cell
2. Nucleolus
3. Chromatin
4. Purine
5. Tonoplast
6. Pyrimidine
7. Double helix
8. Ploidy
9. Homologous
10. 120 days
11. (c)
12. (b)
13. (a)
14. (c)
15. (c)
16. (a)
17. (b)
18. (d)
19. (b)
20. (c)
21. Each species of organisms is characterized by a specific number of chromosomes and is not involved with the size of the organism.
22. Autosomes are not sex-related chromosomes, and hence cannot influence the sex of an individual. Allosomes are the sex chromosomes that influence the sex of an individual.
23. Chromoplast is the odd one as this is the cell organelle which is present only in a plant cell, whereas the other three are present either in a plant cell or an animal cell.
24. Endoplasmic reticulum is the odd one as this is the cell organelle which is present either in plant or animal cell whereas the other three are the organelles that are present only in plant cells.
25. Chromatin fibre is the odd one as this is a component which is present in the nucleus of a cell whereas the other three are the organelles of the cells.
26. RNA → Single helix: DNA → Double helix
27. Diploid : 2n :: n :: Haploid
28. karyokinesis : Nuclear division :: Cytokinesis : Cytoplasmic division
29. Cell differentiation is a process through which a cell changes from one type to another, to perform special functions during its development. This generally takes place during the development of multicellular organisms, as a multicellular organism changes from a simple zygote to a complex system of tissues and cell types.
30. The double helix of DNA bound by eight molecules of histone protein is known as nucleosome.
    Nucleosomes are the basic units of chromatin fibre.

HINTS AND EXPLANATION