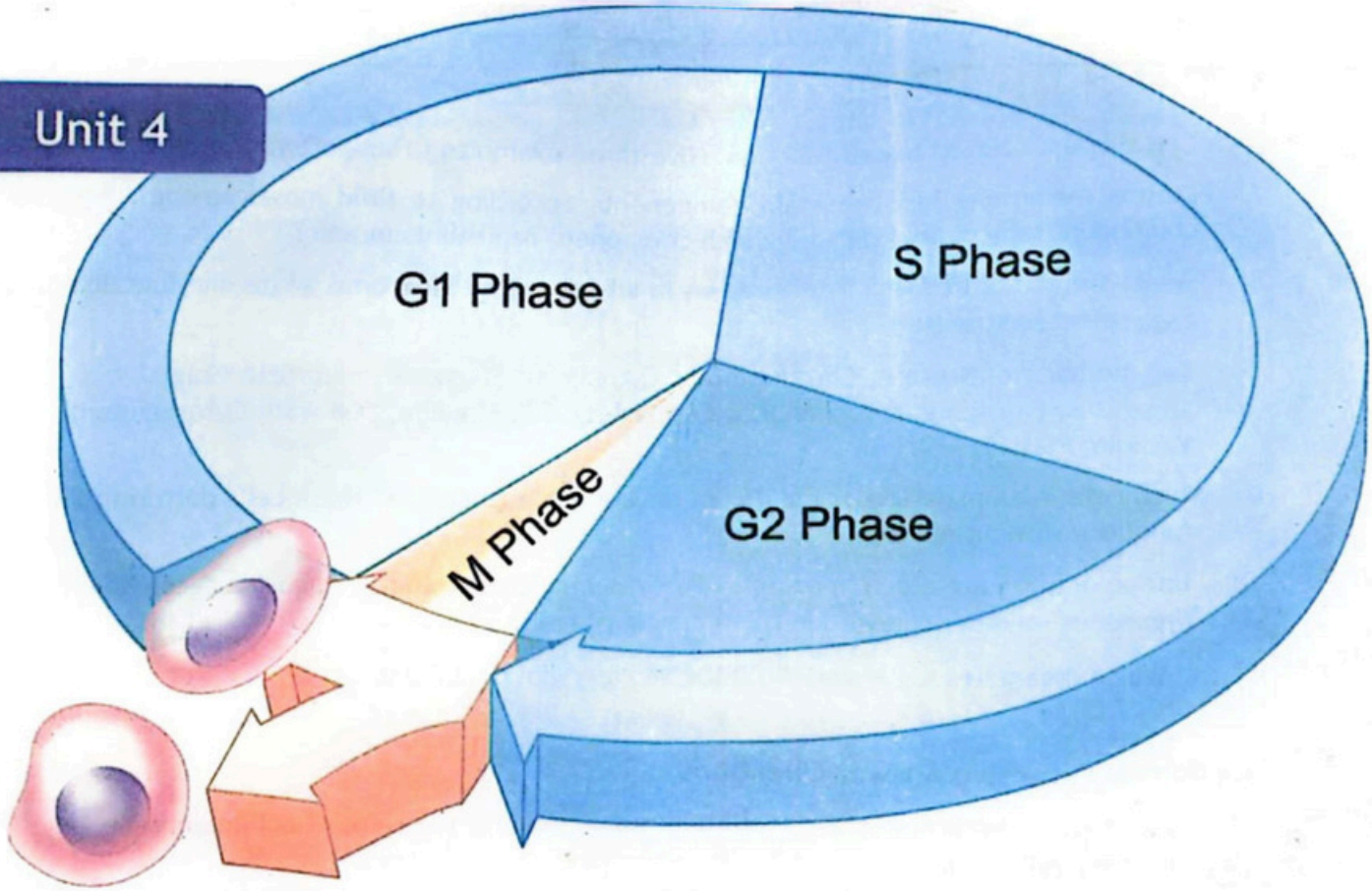
Unit 4



Cell Cycle

SLOs: After completing this lesson, the student will be able to:

1. Describe cell cycle
2. Explain mitosis meiosis and stages of mitosis and meiosis, by use of sketch and diagrams
3. Compare the process of mitosis and meiosis.
4. Outline the significance of mitosis and meiosis.

According to the cell theory, new cells originate by division in the pre-existing cell. The cell which divides is called parent cell and the new cell formed as a result of division are called daughter cell. The process of cell division is needed of development, growth, healing and for sexual and asexual reproduction. Cell not only increase in number but also manage to transfer genetic characteristics to the next generations. During cell cycle, cells grow in size, form new molecules and organelles, replicate their chromosomes and divide by equally distributing genetic material in the daughter cell.

4.1 CELL CYCLE

The cell cycle is the sequence of events which involves growth of newly formed cell, replicates its genome and divides into two daughter cell ultimately. It consists of two main phases; interphase and mitotic phase.

Interphase is the period in cell cycle between two consecutive divisions. It is divided into G_1 (Gap 1), S (Synthesis), and G_2 (Gap 2).

G_1 phase: It starts with the production of new cell. Cell grows in size, increases the number of its organelles, forms needed proteins and other substances. During this phase cell prepares itself for the next phase of cell cycle (S phase). It forms enzymes and nucleotides of DNA required for replication process.

S phase: It is the synthesis phase of DNA. The cell replicates its entire genetic material to form its two copies. That is why each chromosome has two chromatids during cell division, one for each of the daughter cell. These chromatids are attached with one centromere and are called sister chromatids.

G_2 phase: During this phase cell prepares for mitotic phase. Cell forms proteins especially those required for the formation of spindle fibres. Also cell accumulates energy to complete the division process. More mitochondria are formed.

G_o phase: During G_1, cell may exit the cell cycle and enter in G_o phase. In G_o cell stops to divide. Some cells e.g., neurons, once mature never divide again. They remain in G_o forever. Cell of liver, kidneys etc. enter G_o temporarily. When needed they re-enter the cell cycle and start to divide again. Many epithelial cells divide continuously. They never enter in G_o phase.

Mitotic phase (M phase): During this phase cell divides into daughter cell.

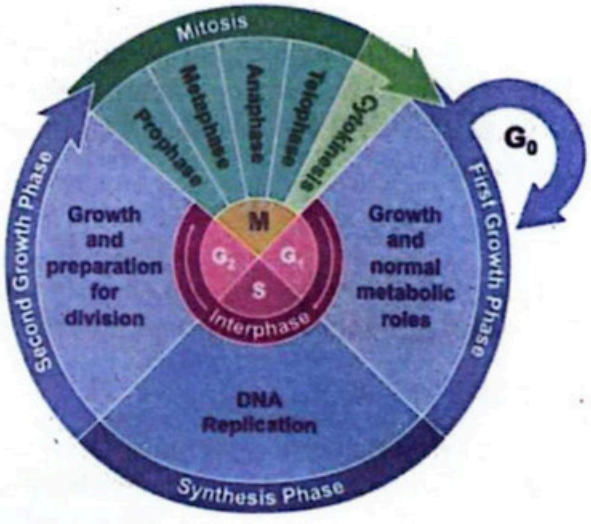


Fig 4.1: Cell cycle

Cancer is a disease of cell cycle. Unlike normal cells of the body, cancer cells do not have a proper functioning cell cycle control system and therefore divide excessively. This excessive growth can result in an abnormal mass of cells called tumour. Not all tumours are cancerous however, a benign tumour is an abnormal mass of essential normal cells. They always remain

at their original site in the body. A malignant tumour is cancerous. It is capable of spreading into neighbouring tissues and often to other distant parts of the body. The spread of cancer cells beyond their original site is called metastasis.

4.2 SPINDLE APPARATUS

Cytoskeleton of the eukaryotic cell forms spindle apparatus during the cell division. Major component of the cytoskeleton are microtubules. The spindle apparatus separates chromatid or chromosomes during cell division and move them to opposite poles. In this way hereditary material of the parent cell is equally distributed into daughter cell.

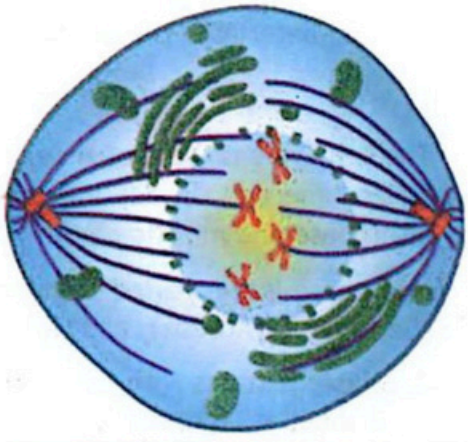


Fig 4.2: Spindle apparatus

A pair of centrioles is situated near the nucleus of animal cell. They duplicate and another pair is formed. Both pairs migrate to opposite poles. They also give rise to spindle fibres. Spindle apparatus is formed around the nucleus, but as soon as nuclear envelop disintegrates, spindle fibres penetrate in to the region of nucleus. They later on attach to the centromere of chromosome and pull them to their poles.

There are no centrioles in plant cell, the spindle apparatus of plant cell is formed without centrioles.

4.3 MITOSIS

The cell division in which parent cell produces two daughter cell with the same number of chromosomes as in the parent cell. Mitosis is a continuous and very fast process which takes less than an hour, but to study easily it is divided into **karyokinesis** and **cytokinesis**.

Karyokinesis

It is division of the nucleus, which form two nuclei in a dividing cell. It is further divided into; **prophase, metaphase, anaphase** and **telophase.**

Prophase

During interphase hereditary material is found in the form of very thin threads called chromatin. If a cell is going to divide, all of its chromatin fibres duplicate during S phase of interphase.

Prophase is the longest phase of cell division. At the start of prophase chromatin fibres coil up and condense into chromosomes. Due to duplication all chromosome consists of two chromatids. The chromatids of each chromosome are attached to each other at centromere.

Nucleolus disappears as its DNA is packed into chromosomes. At the end of prophase nuclear membrane splits into vesicles which disperse in the cytoplasm.

Spindle apparatus is formed.

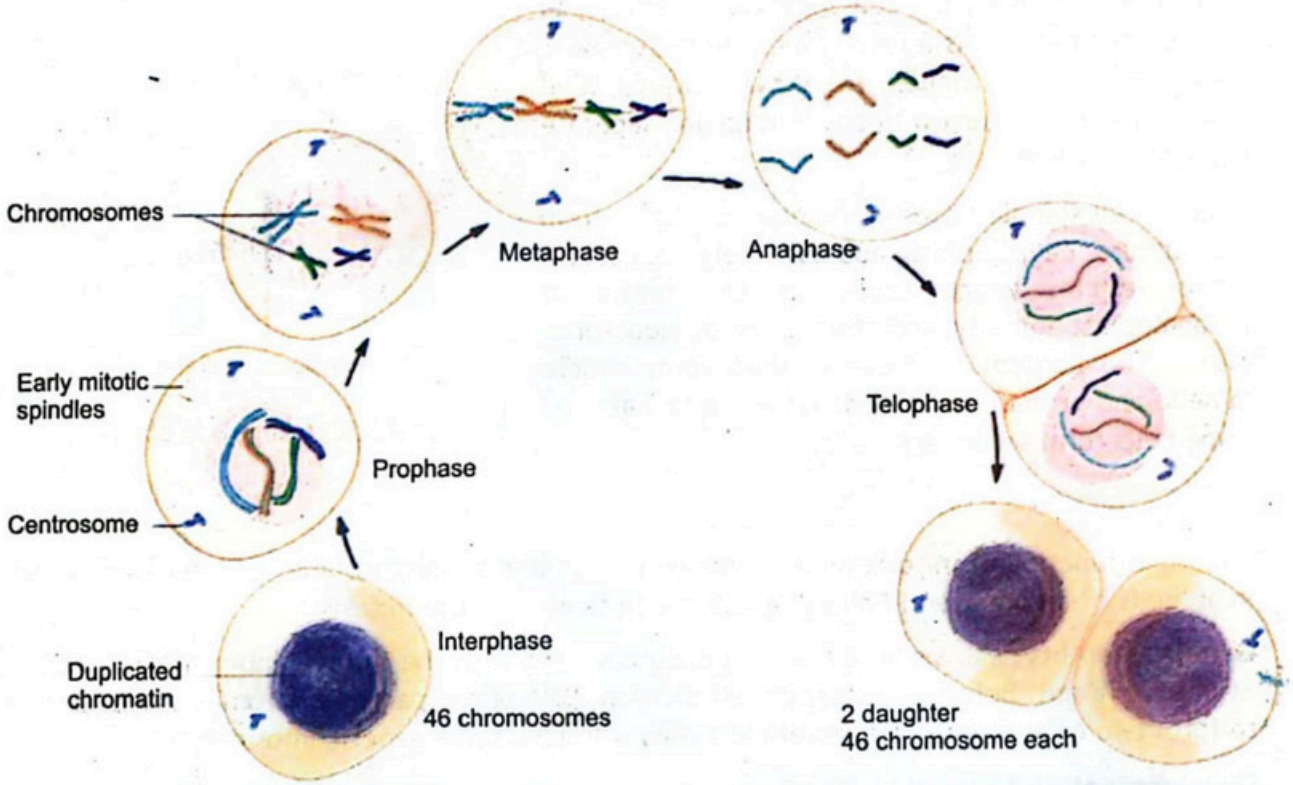


Fig 4.3: Mitosis

Metaphase

Chromosomes are aligned at the equator of spindles. Two spindle fibres, one from each pole, are attached at the centromere of chromosomes.

Anaphase

Spindle fibres pull the centromeres which split and chromatids are separated from each other. Individual chromatids are pulled until they reach their respective poles.

Telophase

Chromatids reach at their poles. They uncoil and lengthen to form chromatin fibres again. The spindle apparatus disintegrates. Nuclear membrane is formed around chromatin at each pole. Nucleoli reappear in both nuclei.

Cytokinesis

It is division of the cytoplasm which results in the formation of two daughter cells. It starts while telophase is in progress. The pattern of cytokinesis is different in animal and plant cell.

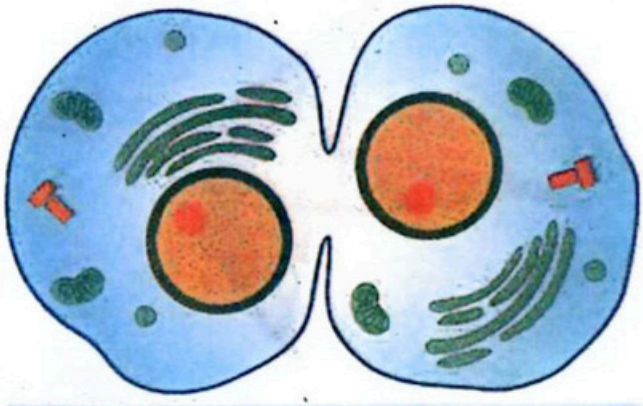


Fig 4.4: Cytokinesis in animal cell

Cell membrane in animal cell begins to invaginate in the equator region. As a result, a cleavage furrow is formed which continues to grow inward. Cell membranes in the furrow finally join up and separate the two daughter cells.

In plant cell spindle fibres in the equator region form a structure called **phragmoplast**. Golgi apparatus forms vesicles which appear in the centre of phragmoplast initially and then grow at equatorial plane. The content in these vesicles form middle lamella and primary walls of daughter cells. Later on some cells form secondary walls.

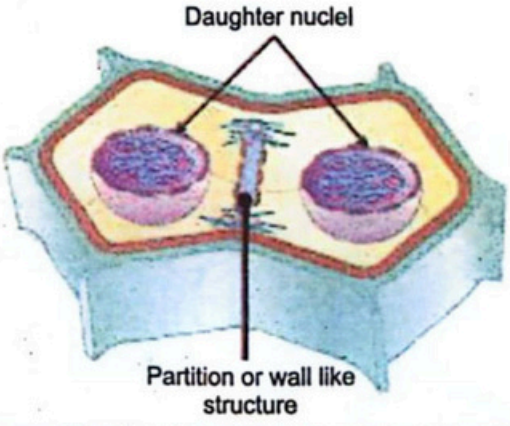


Fig 4.5: Cytokinesis in plant cell

4.3.1 Significance of Mitosis

The main function of mitosis is to maintain the number of chromosomes and genetic material in all cells of an organism. Following is the significance of the mitosis.

Genetic stability: Mitosis produces two daughter cells with the same number of chromosomes as in parent cell. Before the start of cell division, DNA of the parental chromosomes replicates to form two exact copies. Daughter cells thus will have same genetic information.

Development and growth: Life of sexually reproducing multicellular organisms start from a single cell, the zygote. The continuous cell division process leads to the development of adult form. The organisms also grow in size by increasing cell number. Thus the development and growth of multicellular organisms depends on mitosis.

Cell replacement and wound healing: The replacement of worn out cells involves mitosis. The epithelial cells of skin, digestive tract and respiratory tract die off regularly. They are replaced by identical cells produced by mitosis. Damage repair and wound healing depends on the process of mitosis.

Regeneration: Some animals have ability to form whole part of the body if it is removed accidentally. This is called regeneration. For example; sea star can regenerate arm, earthworms can regenerate head, and salamander can regenerate its limb. The production of new cells to form missing parts involves mitosis.

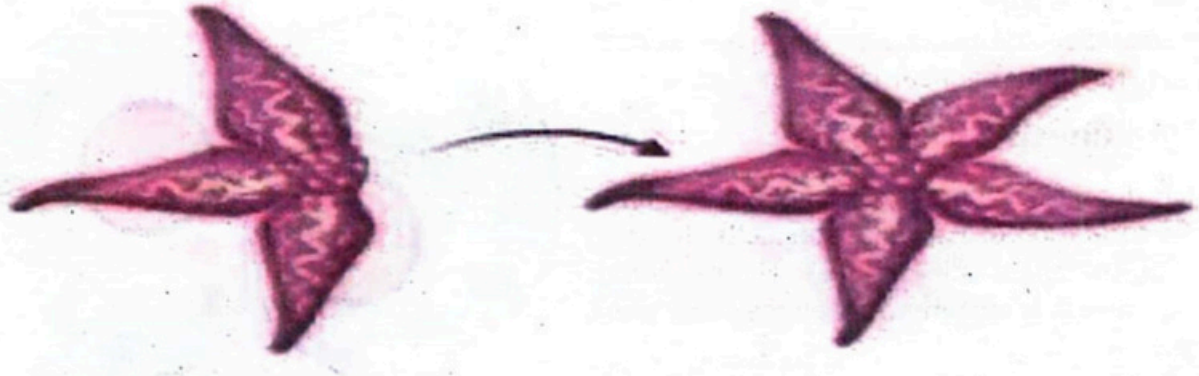


Fig 4.6: Regeneration of arm in Sea star

Asexual reproduction: Mitosis is the basis of asexual reproduction. This reproduction involves only one parent. All asexually produced offspring are genetically identical to their parent organism. The vegetative propagation is very common in plants. It involves new generations from root, stem or leaf of parent plant. Potato, onion, garlic, ginger, grasses etc. reproduce asexually. Many animal species like sponges, planaria and hydra undergo asexual reproduction.

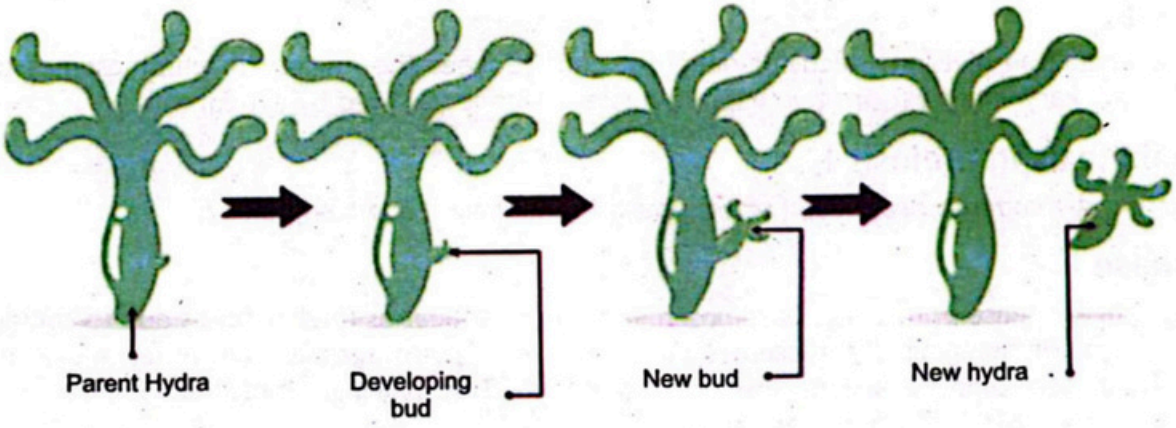


Fig 4.7: Budding in Hydra

Cloning and tissue culture: Mitosis has made it possible for scientists to produce a very large number of identical copies of the living organisms in artificial environment. This process is called cloning or tissue culture if small mass of tissue cells is used.

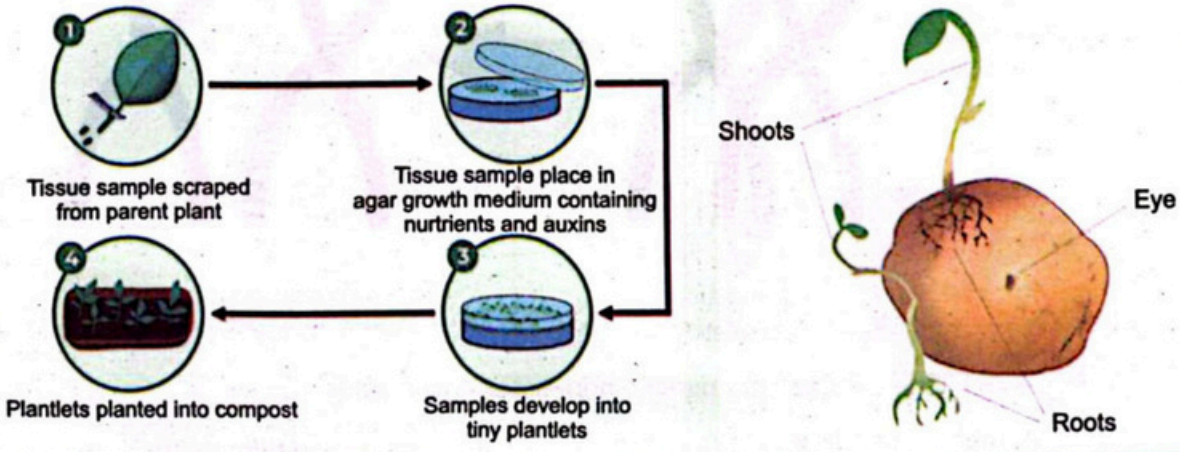


Fig 4.8: Cloning by (a) Tissue culture (b) Vegetative propagation in potato

4.5 MEIOSIS

It is a type of cell division which give rise to four daughter cells each having half the number of chromosome of the parent cell. It takes place only in cells involved in sexual reproduction. Such parent cells are usually **diploid** which by this reduction division produce **haploid** daughter cells. Cells which have two sets of chromosomes are called diploid (2n) and cells with half the number of chromosomes are called haploid (n). Chromosomes in a diploid cell are in homologous pairs. Haploid cells carry one member of each homologous pair.

Meiosis is a continuous process but for convenience is divided into **interphase I, meiosis I, interphase II** and **meiosis II.**

Interphase I

Before the onset of division process, cell forms a copy of its genome by replication process. That is why chromosomes appear with two chromatids during division process.

Meiosis I

It is the reduction division which for daughter cells reduces the number of chromosomes to half. Firstly, karyokinesis forms two haploid nuclei which is followed by cytokinesis.

Karyokinesis in meiosis I

It is further divided into **prophase I, metaphase I, anaphase I** and **telophase I.**

Prophase I

It is the longest phase of meiosis. Chromosomes begin to appear as thicker fibres due to coiling of chromatin. Homologous chromosomes line up point to point against each other and form pairs. Their centromeres are in the same position. This pairing process of homologous chromosomes is called **synapsis**. Each pair is called bivalent.

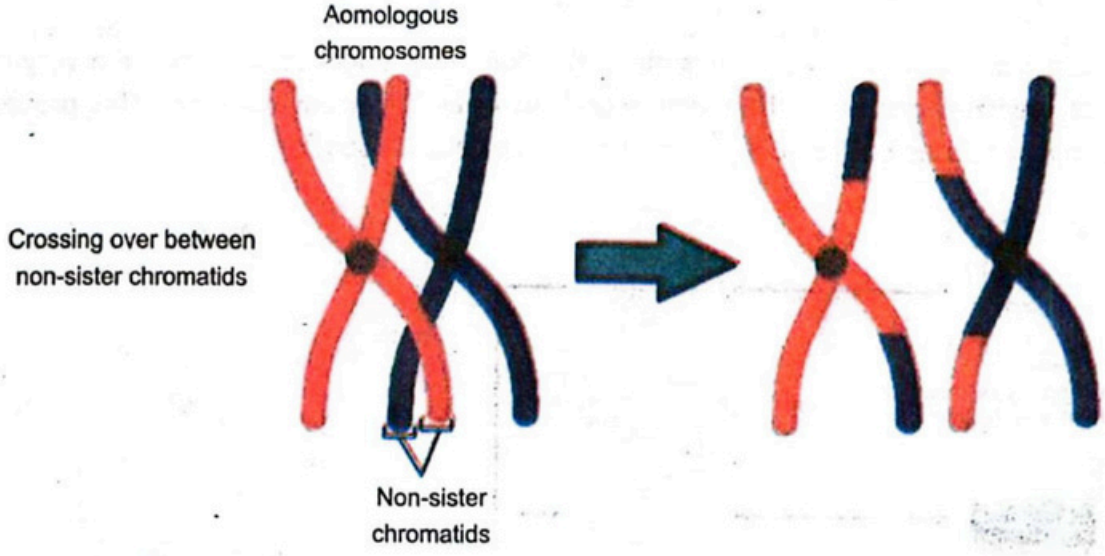


Fig 4.9: Crossing over in non-sister chromatids

The non-sister chromatids of homologous chromosomes join each other at some points along their length. Such points are called **chiasmata**. Each chiasma is a site for the exchange some genetic material between chromatids. The exchange of segments of non-sister chromatids during prophase I is called **crossing over.**

Sister chromatids are two exactly similar copies attached by a centromere while The chromatids of two homologous chromosomes are non-sister chromatids.

To the end of prophase I, chromosomes are fully condensed and paired chromosomes repel each other. However, they are still attached at chiasmata.

Nucleoli and nuclear envelop disappear. Spindle apparatus is formed.

Metaphase I

Bivalents are arranged at the equatorial plate. Spindle fibres are attached to the centromere of chromosome. One member of a homologous pair receives a spindle fibre from one pole and other member from the opposite pole.

Anaphase I

Spindle fibres pull on the homologous chromosomes. Separated chromosomes of each pair move to the opposite poles. Each pole receives haploid set of chromosomes.

Telophase I

Once at their pole, chromosomes uncoil into chromatin. A nuclear envelop is formed at each pole around the haploid set.

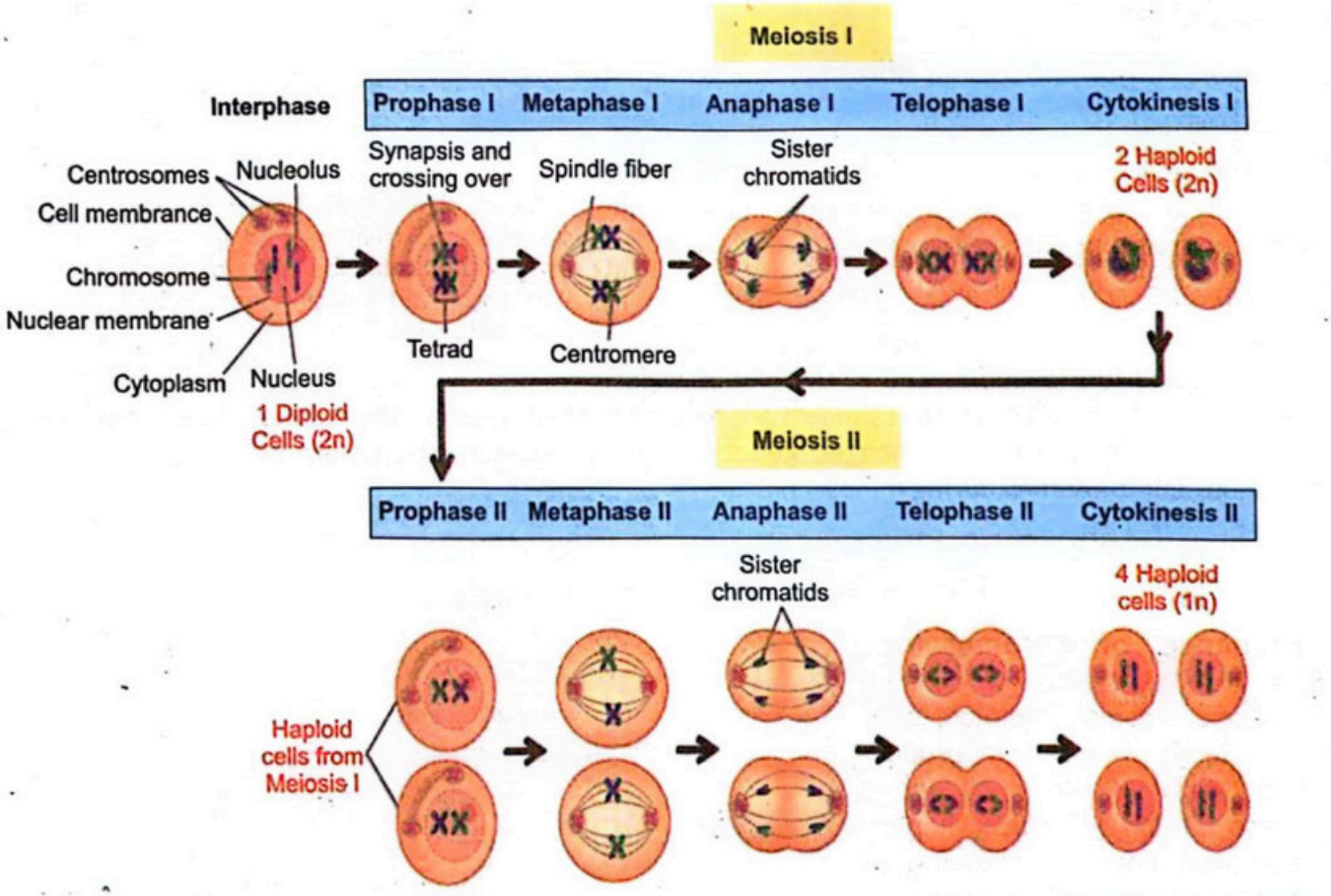


Fig 4.10: Meiosis

Cytokinesis

Cytokinesis occurs by cleavage in animal cell of by forming cell wall in plant cell. Although each daughter cell is haploid with half the number of chromosomes, their chromosomes are composed of two chromatids. Due to crossing over, these chromatids are not genetically identical. They must be separated in second meiosis.

Two haploid daughter cells thus formed enter in interphase II.

Interphase II

This phase varies in length but there is no further DNA replication during this phase.

Meiosis II

It is similar to mitosis and is divided into **prophase II, metaphase II, anaphase II** and **telophase II.**

Prophase II

Chromatin coils again so chromosomes appear as thick fibres. Spindle apparatus is organized. Nucleoli disappear and nuclear envelop disintegrates.

Metaphase II

Chromosomes line up separately around the equator of the spindles. Spindle fibres are attached to the centromere of chromosome. Like mitosis here each chromosome is attached by a fibre from both poles.

Anaphase II

Centromeres divide and spindle fibres pull the chromatids to the opposite poles.

Telophase II

Chromatids reach at their poles and uncoil. The spindle apparatus disappears. Nuclear envelops are formed around chromatin at each pole.

Cytokinesis

Cleavage furrow is animal cells and cell wall formation in plant cells gives four daughter cell at the end of meiosis process. All cells formed by meiosis process are haploid as they have half the number of parental chromosomes. Also they have changed genetic makeup because of crossing over between homologous chromosomes during meiosis I.

> Germ cell are diploid which undergo meiosis to from haploid gametes. All other diploid cells of body undergo mitosis and are called somatic cells.

4.4.1 Significance of meiosis

Maintenance of chromosomes in sexual reproduction

Maintenance of chromosomes: During the life cycle of sexually reproducing organisms, diploid germ cells undergo meiosis to produce haploid daughter cell which act as gametes. Fusion of such haploid gametes thus maintains chromosome number specific for each species.

Human have 46 chromosomes in their somatic cells. The haploid gametes (eggs and sperms) formed by meiosis have 23 chromosomes. In fertilization process a 23 chromosome sperm fuses with an egg also having 23 chromosomes. The original chromosome number of 46 is restored in the zygote.

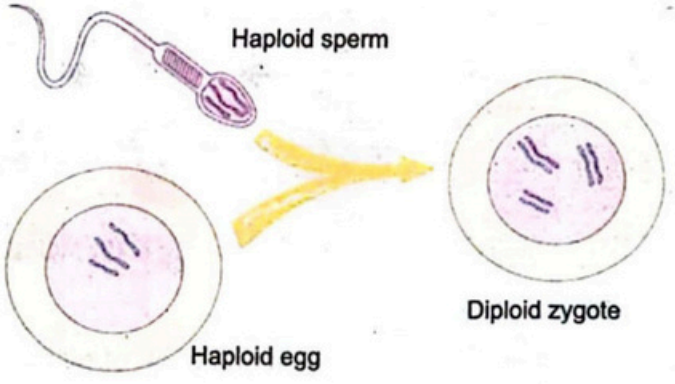


Fig 4.11: Fertilization of sperm and egg cell to form zygote

In plants meiosis takes place during spore formation.

Genetic variations

Variations are the differences among the members of same species. They are necessary for the survival of species in always changing environment. It is because of meiosis that new combinations of genes appear in gametes and then in zygote. Crossing over and independently formed combinations of chromosomes in gametes are two important events of meiosis. Both crossing over and chromosomal combination provide basis of variations.

Fig 4.12: Variation in Butterfly patterns

Table 5.7 Comparison of mitosis and meiosis

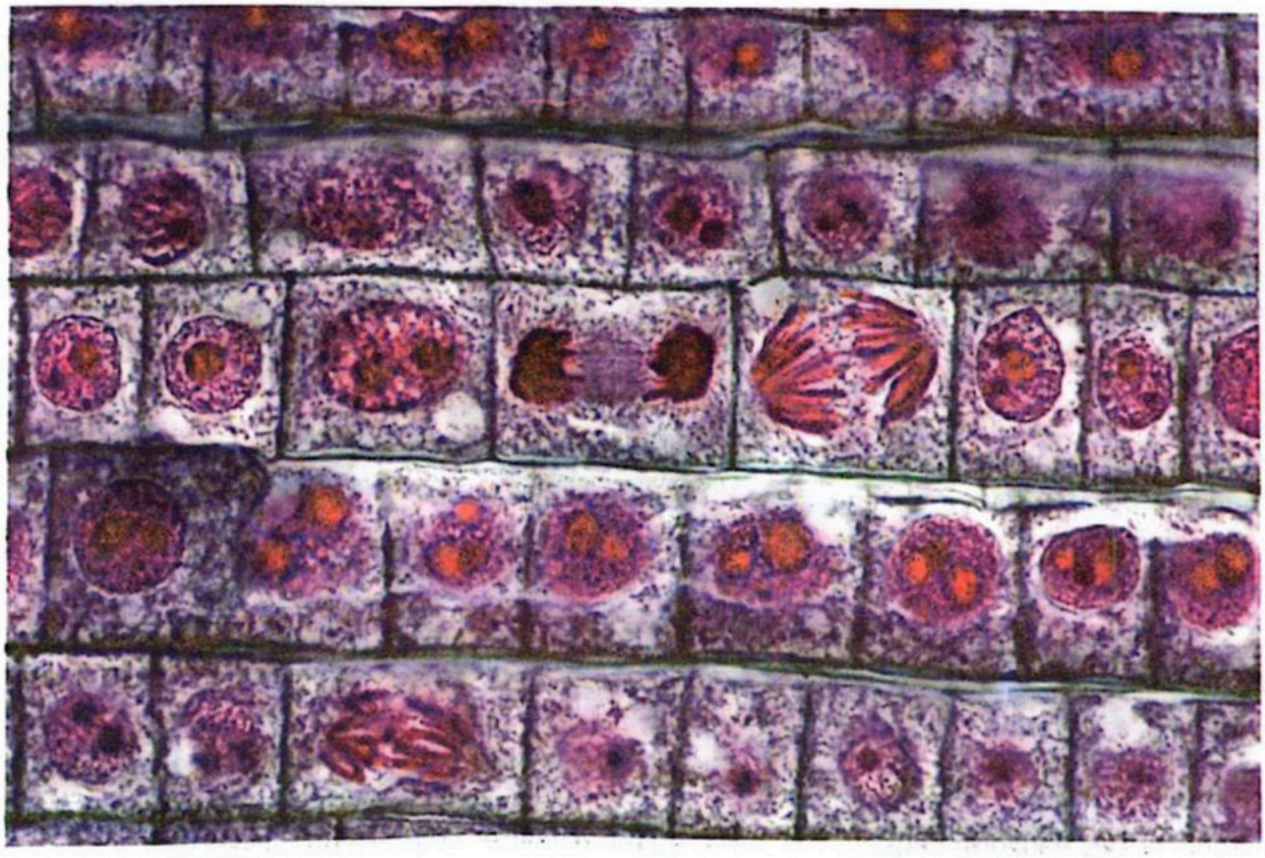
Mitosis	Meiosis
It occurs in somatic cells	It occurs in germ line cells
Cell divides only once	Cell divides twice
It produces two daughter cells	Four daughter cells are produced
Daughter cells produced are diploid	All daughter cells are haploid
Daughter cells become part of somatic body	Daughter cells form gametes
All chromosomes remain independent of each other	Homologous chromosomes pair with each other
No chiasmata formation	Chiasmata are formed
There is no crossing over during mitosis process	Crossing over takes place during meiosis I
Daughter cells are genetically alike.	Daughter cells are genetically different from each other and parent cell
In most cases daughter cells can divide again.	Gametes produced by meiosis cannot divide any more.

STEAM ACTIVITY 4.1

Study of Mitosis in onion root tip

Materials Required

Compound microscope, Acetocarmine stain, Water, Burner, N/10 Hydrochloric acid, Filter paper, Coverslip, Aceto alcohol (Glacial acetic acid and Ethanol in the ratio 1:3), Glass Slide, Onion root peel, Forceps, Blade, Watch glass, Dropper, Needle, Vial.



Procedure

1. Place an onion on a tile
2. With the help of a sharp blade, carefully snip the dry roots of the onion
3. Place the bulbs in a beaker containing water to grow the root tips
4. It may take around 4 to 6 days for the new roots to grow and appear
5. Trim around 3 cm of the newly grown roots and place them in a watch glass
6. With the help of forceps, shift it to a vial holding freshly prepared aceto-alcohol i.e., a mixture of glacial acetic acid and ethanol in the ratio 1:3
7. Allow the root tips to remain in the vial for one complete day
8. With the help of forceps, pick one root and set in on a new glass slide
9. With the help of a dropper, allow one drop of N/10 HCl to come in contact with the tip of the root. Additionally, add around 2 to 3 drops of the acetocarmine stain
10. Heat it lightly on the burner in such a way that the stain does not dry up
11. Excessive stain can be carefully treated using filter paper
12. The more stained part of the root tip can be trimmed with the help of a blade.
13. Discard the lesser stained part while retaining the more stained section
14. Add a droplet of water to it.
15. With the help of a needle, a coverslip can be mounted on it

16. Gently tap the coverslip with an unsharpened end of a needle in order for the meristematic tissue of the root tip present under the coverslip to be squashed properly and to be straightened out as a fine cell layer
17. The onion root tip cells' slide is now prepared and ready to be examined for different stages of mitosis
18. Observe and study mitosis by placing the slide under the compound microscope. Focus as desired to obtain a distinct and clear image

Observations and Conclusion

1. The slide containing the stained root tip cells is placed on the stage of the compound microscope, changes taking place are noted and sketched.
2. The different phases of mitosis, such as prophase, metaphase, anaphase and telophase can be observed.

SUMMARY

1. The cell cycle is the period from beginning of one division to the beginning of the next division.
2. Interphase can be divided into the first gap phase (G_1), the chromosomal synthesis (S), and the second gap phase (G_2).
3. During G_1 phase the cell grows and prepares itself for the S phase. DNA and the chromosomes are replicated during the S phase. During G2 phase, protein synthesis increases for cell division.
4. Spindle apparatus separates chromatid or chromosomes during cell division.
5. During mitosis, identical chromosomes are distributed to each daughter cell. Chormosomal number remains after mitosis.
6. Mitosis is divided into two ph
7. Karyokinesis divides nucleus in four phases i.e., Prophase, Metaphase, Anaphase and Telophase.
8. Cytokinesis divides cytoplasm to form two individual cells.
9. Mitosis is important for genetic stability, development, growth, cell replacement, wound healing, regenration, asexual reproduction, tissue culture and cloning.
10. A diploid cell undergoing meiosis completes two successive cell divisions (Meiosis I and Meiosis II) to give rise to four haploid cells which later form gametes.
11. During meiotic prophase I, the members of a homologous pair of chromosomes undergo synapses and crossing over, during which segments of DNA strands are exchanged between homologous (non-sister) chromatids.
12. During meiosis II the two chromatids of each chromosome separate and one is distributed to each daughter cell. Each former chromatid is now referred to as chromosomes.
13. In sexual reproduction, two haploid gametes fuse to form a single diploid zygote.
14. Meiosis is important for mainrenance of chromosomal number in sexual reproduction and genetic variations.

EXERCISE

Section I: Multiple Choice Questions

Select the correct answer:

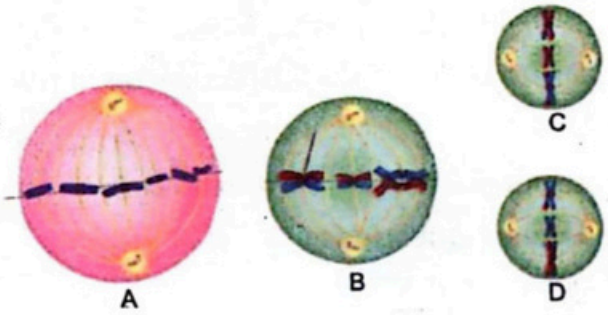
1. A bivalent consists of:
   A) Two chromatids and one centromere
   B) Four chromatids and two centromeres
   C) Four chromatids and four centromeres
   D) Two chromatids and two centromeres
2. During cell division spindle fibres attach a chromosome at:
   A) Centromere B) Telomere
   C) upper arm of chromosome D) lower arm of chromosome
3. Some student of SSC observed a thin cross section from root tip of onion plant under the microscope. They found dividing cells at different stages of their life cycle. One of the students found a cell at late prophase and counted 28 chromosomes in it. The number of chromosomes in daughter cells should be:
   A) 14 B) 28 C) 56 D) 07
4. Crossing over results in genetic recombination. It occurs between:
   A) Two chromatids of the same chromosome.
   B) Two chromatids of any two non-homologous chromosomes
   C) Two chromatids of opposite gametes
   D) Two chromatids of homologous chromosomes
5. The spindle apparatus of plants differs from that of animals in not having:
   A) microtubules B) equator of spindle
   C) centrioles D) centromere
6. Substance and energy required for the replication of DNA is accumulated in the cell during:
   A) G_1 B) G_2 C) S phase D) M phase
7. All of the following events takes place both in mitosis and meiosis except:
   A) Condensation of chromatin to form chromosomes
   B) Formation of spindle apparatus
   C) Nuclear envelop and nucleolus disappear
   D) Chromosomes pair for crossing over
8. The cell shown in this diagram is passing through:

   A) Prophase I of meiosis B) prophase of mitosis
   C) telophase of meiosis I D) anaphase of meiosis II

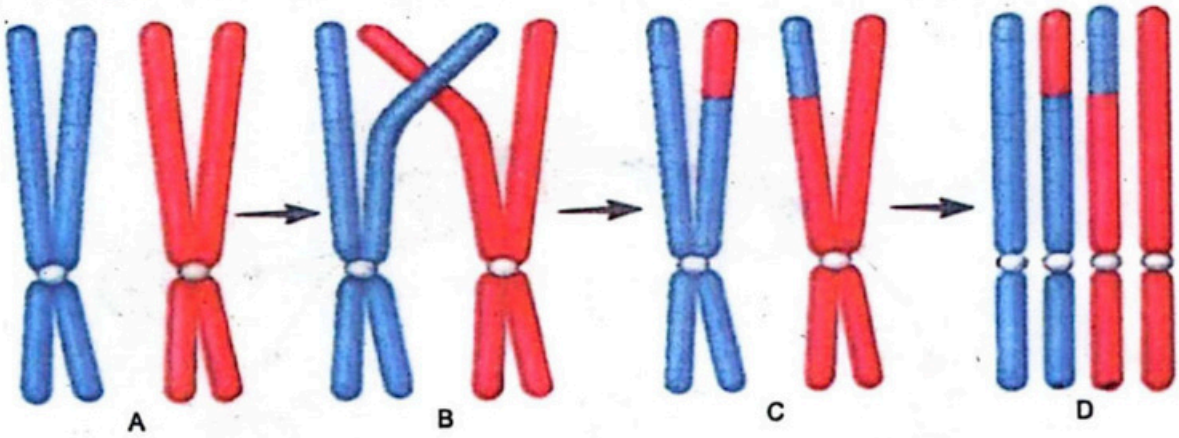
9. The longest phase of meiosis is:
   A) Interphase I
   B) Prophase I
   C) interphase II
   D) prophase II

10. What causes the number of chromosomes to reduce to half when a cell divides by meiosis?
   A) replication of DNA during interphase I
   B) separation of homologous chromosomes during meiosis I
   C) separation of sister chromatids of all the chromosomes during meiosis I.
   D) crossing over during meiosis I

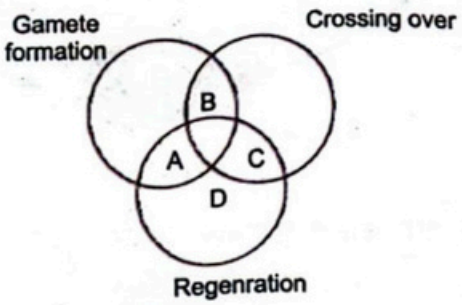
11. Which of the following cell is at Metaphase I stage?



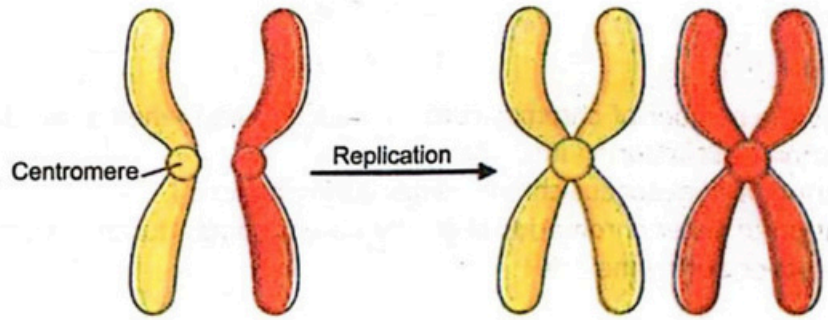
12. This diagram is showing different stages of crossing over. Which stage contains chiasma?



13. Which processes involve meiosis?



14. diagram shows replication of chromosomes.



What is the total number of chromosomes in this diagram?

A. 2 B. 3 C. 4 D. 6

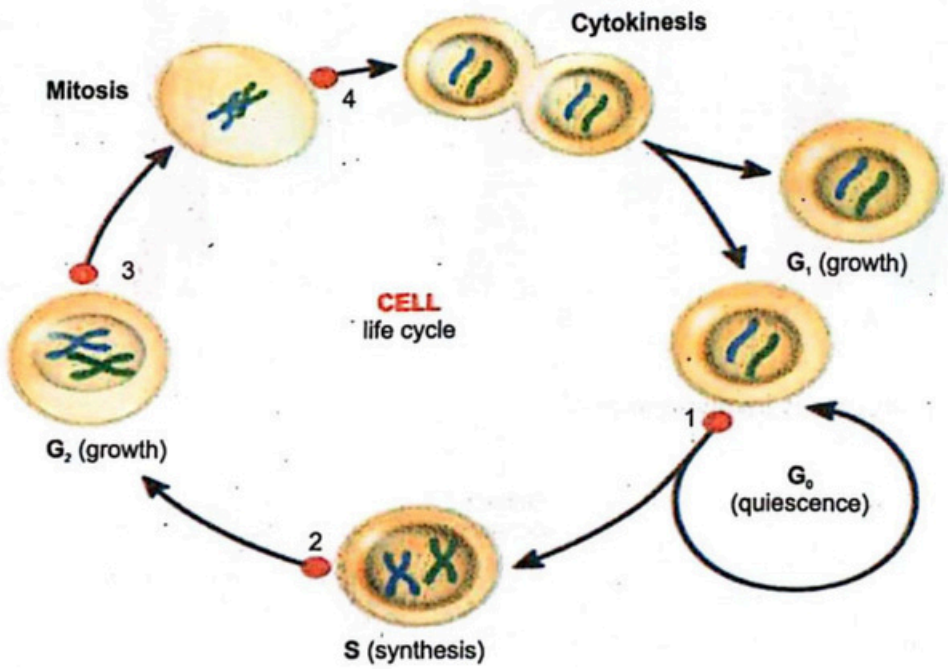
15. Chromosomal number of Fruit fly is 8. The gametes of fruit fly contain:

A. 2 chromosomes B. 4 chromosomes

C. 8 chromosomes D. 16 chromosomes

Section II: Short Answer Questions

1. Explain spindle apparatus in detail
2. What is the significance of crossing over?
3. Enlist the events taking place during G_1 phase.
4. Cell cycle below shows the formation of two daughter cells, cell A and cell B. Cell A continues in the cell cycle while cell B exits in G_o.

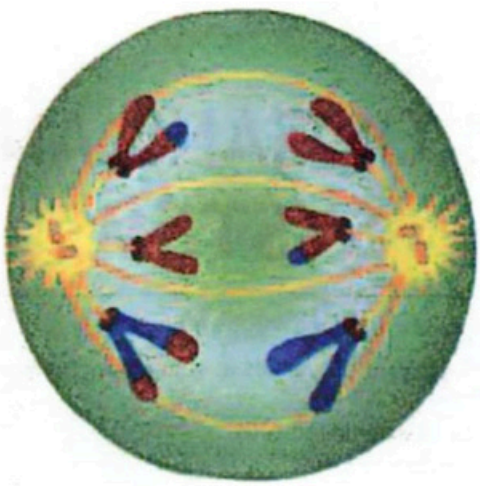


What will be the difference in materials they synthesize after the production of cell A and cell B?

5. Why do epithelial cells of skin divide continuously?
6. Give differences between meiosis I and meiosis II.
7. In rapidly dividing cells which phase of cell cycle is reduced? Explain.
8. What is the difference between cytokinesis of a plant cell and an animal cell?
9. Both skin cells and cancerous cells divide rapidly. Why cancerous cells are harmful but skin cells are not?
10. How haploid organisms produce gametes?
11. Downs syndrome is due to extra copy of chromosome number 21. That is why Down syndrome people have 47 chromosomes. Why their chromosome number is high?

Section III: Extensive Answer Questions

1. If a cell completes meiosis I but meiosis II fails to occur, what type of anomalies will appear in the two daughter cell thus formed?
2. A cell is shown in this diagram. Answer following questions after observing it.



   a. Give at least one finding on the basis of which you can identify it animal or plant cell.
   b. Identify the stage of cell division the given cell is passing through?
   c. Enlist the reasons of your identification.
3. Meiosis II is identical to mitosis, explain.