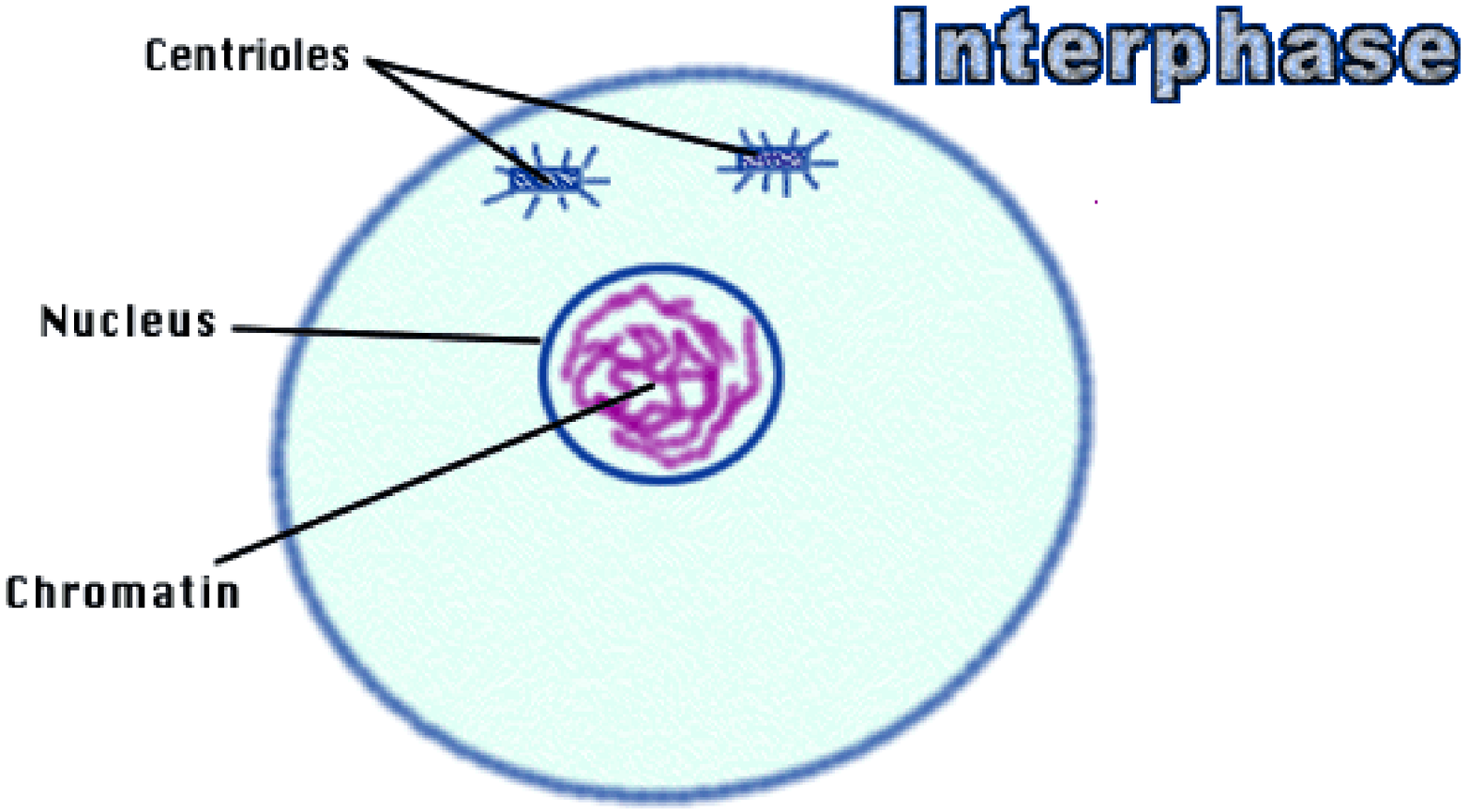
CHAPTER

5 Cell Cycle



Animation 05: Mitosis
Source & Credit: Buffonescience.wikispaces

The most basic characteristic of life is reproduction. Reproduction occurs at different levels of organization. Parts of cell such as chromosomes produce new chromosomes, cells produce new cells and individuals produce offspring like themselves. If we recall from chapter 1, we should remember Rudolf Virchow. He proposed an important biological principle i.e. all cells come from cells. This principle tells us that the continuation of life, including all aspects of reproduction, is based on the reproduction of cells. We commonly refer cellular reproduction as cell division and it is a part of the whole life of a cell i.e. cell cycle.

5.1 Cell Cycle

Cell cycle is the series of events from the time a cell is produced until it completes mitosis and produces new cells. Cell cycle consists of two major phases i.e. interphase and mitotic phase (M phase). Mitotic phase is a relatively short period of cell cycle. It alternates with the much longer interphase, where cell prepares itself for division.
Interphase is the time when a cell's metabolic activity is very high, as it performs its various functions. It is divided into three phases, G1 (first gap), S (synthesis), and G2 (second gap).

G1 phase: After its production, a cell starts its cell cycle in G1 phase. During this phase, cell increases its supply of proteins, increases the number of its organelles (such as mitochondria, ribosomes), and grows in size. This phase is also marked by the synthesis of various enzymes that are required in next phase i.e. S phase for the duplication of chromosomes.

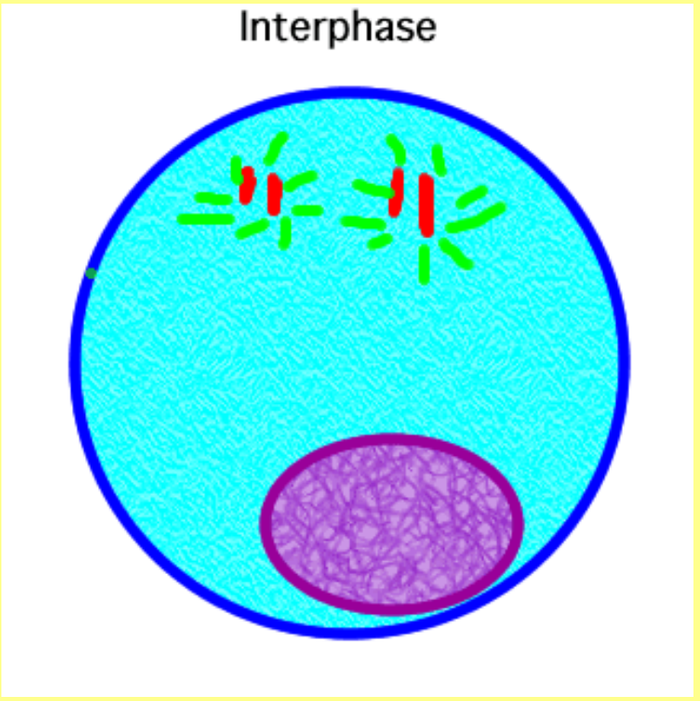
Typically,interphase lasts for at least 90% of the total time required for the cell cycle.

S phase: In this phase, cell duplicates its chromosomes. As a result, each chromosome consists of two sister chromatids.

G2 phase: In the G2 phase, cell prepares proteins that are essential for mitosis, mainly for the production of spindle fibres.

After the G2 phase of interphase, cell enters the division phase i.e. M phase. It is characterized by mitosis, in which cell divides into the two daughter cells.

Cells that have temporarily or permanently stopped dividing are said to have entered a state of quiescence, called G0 phase.



Animation 5.1: Cell cycle
Source & Credit: amersol

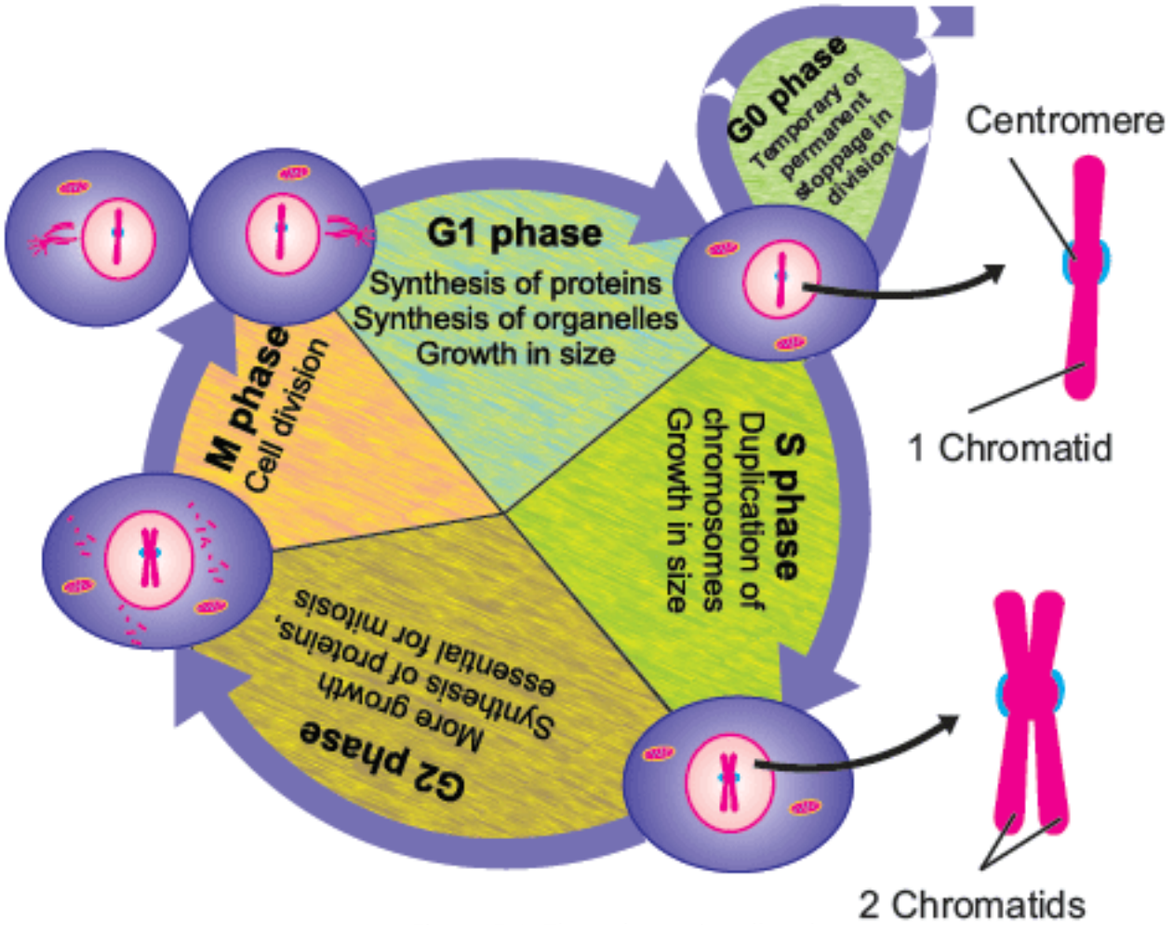


Figure 5.1: The eukaryotic cell cycle

Inhibition of protein synthesis during G2 phase prevents cell from undergoing mitosis.

G0 phase: In multicellular eukaryotes, cells enter G0 phase from G1 and stop dividing. Some cells remain in G0 for indefinite period e.g. neurons. Some cells enter G0 phase semipermanently e.g. some cells of liver and kidney. Many cells do not enter G0 and continue to divide throughout an organism's life, e.g. epithelial cells.

The events of cell cycle are ordered and directional i.e each event occurs in a sequential fashion and it is impossible to "reverse" the cycle.

5.2 Mitosis

In 1880s, a German biologist **Walther Flemming** observed that in a dividing cell, nucleus passes through a series of changes which he called 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 parent cell.

Mitosis occurs only in eukaryotic cells. In multicellular organisms, the somatic cells undergo mitosis. Prokaryotic cells undergo a process similar to mitosis called binary fission. They do not undergo proper mitosis. Why?

5.2.1 Phases Of Mitosis

The process of mitosis is complex and highly regulated. There are two major phases i.e. the division of nucleus known as karyokinesis; and the division of cytoplasm known as cytokinesis.

A. Karyokinesis: The division of nucleus is further divided into four phases i.e. prophase, metaphase, anaphase and telophase.

Somatic cells are those which form the body of organisms while germ line cells are those which give rise to gametes. Somatic cells undergo mitosis while germ line cells undergo meiosis.

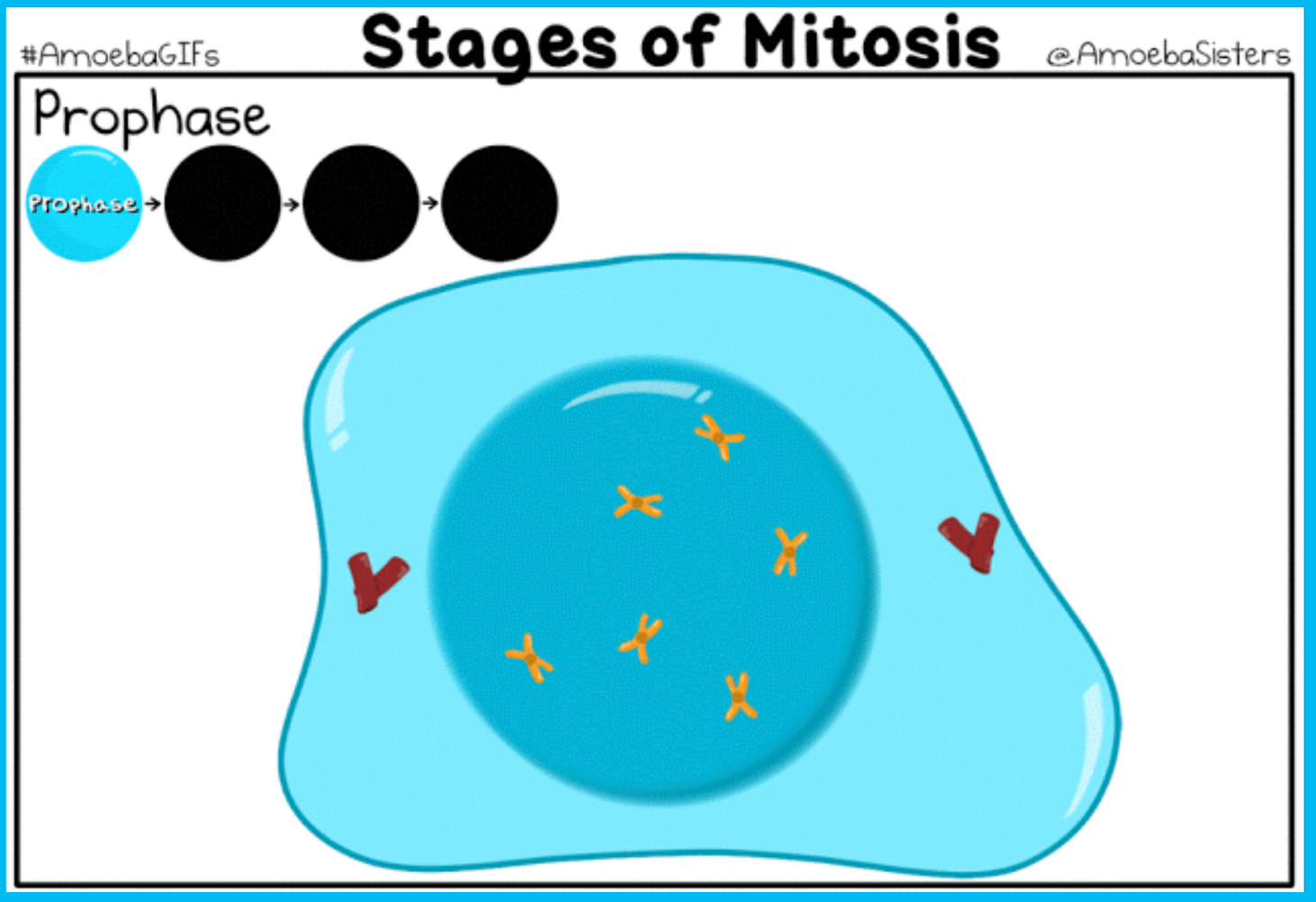
i. Prophase

Normally, the genetic material in nucleus is in a loose thread-like form called chromatin. At the onset of prophase, chromatin condenses into highly ordered structures called chromosomes. Since the genetic material has already been duplicated earlier in S phase, each chromosome is made of two sister chromatids, bound together at the same centromere. Each chromosome also has kinetochore at centromere. Kinetochore is a complex protein structure that is the point where spindle fibers attach.

Prokaryotes do not have proper nucleus and do not form spindles during division. That is why their division is not called mitosis.

There are two centrioles (collectively called a centrosome) close to nucleus (recall from chapter 4: Figure 4.19). Each centriole duplicates and thus two daughter centrosomes are formed. Both centrosomes migrate to the opposite poles of cell. Here, they give rise to microtubules by joining tubulin proteins present in cytoplasm. The microtubules thus formed are called **spindle fibres.** Complete set of spindle fibres is known as **mitotic spindle.** By this time, nucleolus and nuclear envelope have degraded, and spindle fibres have invaded the central space.

In highly vacuolated plant cells, nucleus has to migrate to the centre of cell before prophase. The cells of plants lack centrioles. So, spindle fibres are formed by the aggregation of tubulin proteins on the surface of nuclear envelope during prophase.



Animation 5.2: Stages of Mitosis
Source and Credit: Ameoba sisters

ii. Metaphase

When spindle fibres have grown to sufficient length, some spindle fibres, known as kinetochore fibres, attach with the kinetochores of chromosomes. Two kinetochore fibres from opposite poles attach with each chromosome. Chromosomes arrange themselves along the equator of cell forming a **metaphase plate**. A number of other fibres (non-kinetochore) from the opposite centrosomes attach with each other.

iii. Anaphase

When a kinetochore spindle fibre connects with the kinetochore of chromosome, it starts to pull toward the originating centrosomes. The pulling force divides the chromosome's sister chromatids and they separate. These sister chromatids are now sister chromosomes, and they are pulled apart toward the respective centrosomes. The other spindle fibres (non-kinetochore) also elongate. At the end of anaphase, cell has succeeded in separating identical copies of chromosomes into two groups at the opposite poles.

iv. Telophase

Telophase is a reversal of prophase. A new nuclear envelope forms around each set of separated chromosomes. Both sets of chromosomes, now surrounded by new nuclear envelopes, unfold back into chromatin. Nuclear division is completed, but cell division has yet one more step to complete. (Figure 5.2)

B. Cytokinesis:

Cytokinesis is the division of cytoplasm. In **animal cells**, cytokinesis occurs by a process known as cleavage. A cleavage furrow develops where the metaphase plate used to be. The furrow deepens and eventually pinches the parent cell into two daughter cells.

Cytokinesis in **plant cells** occurs differently. Vesicles derived from the Golgi apparatus move to the middle of cell and fuse to form a membrane-bounded disc called cell plate or **phragmoplast**. The plate grows outward and more vesicles fuse with it. Finally, membranes of cell plate fuse with plasma membrane and its contents join the parental cell wall. The result is two daughter cells, each bounded by its own plasma membrane and cell wall (Figure 5.3)

?

Nucleus is visible only in interphase while chromosomes are only visible in cell division stage. Why is that?

Nuclear membrane breaks during cell division so there is no distinct nucleus. In interphase nuclear material is in the form of fine chromatin which condenses during prophase to get the shape of Chromosomes.

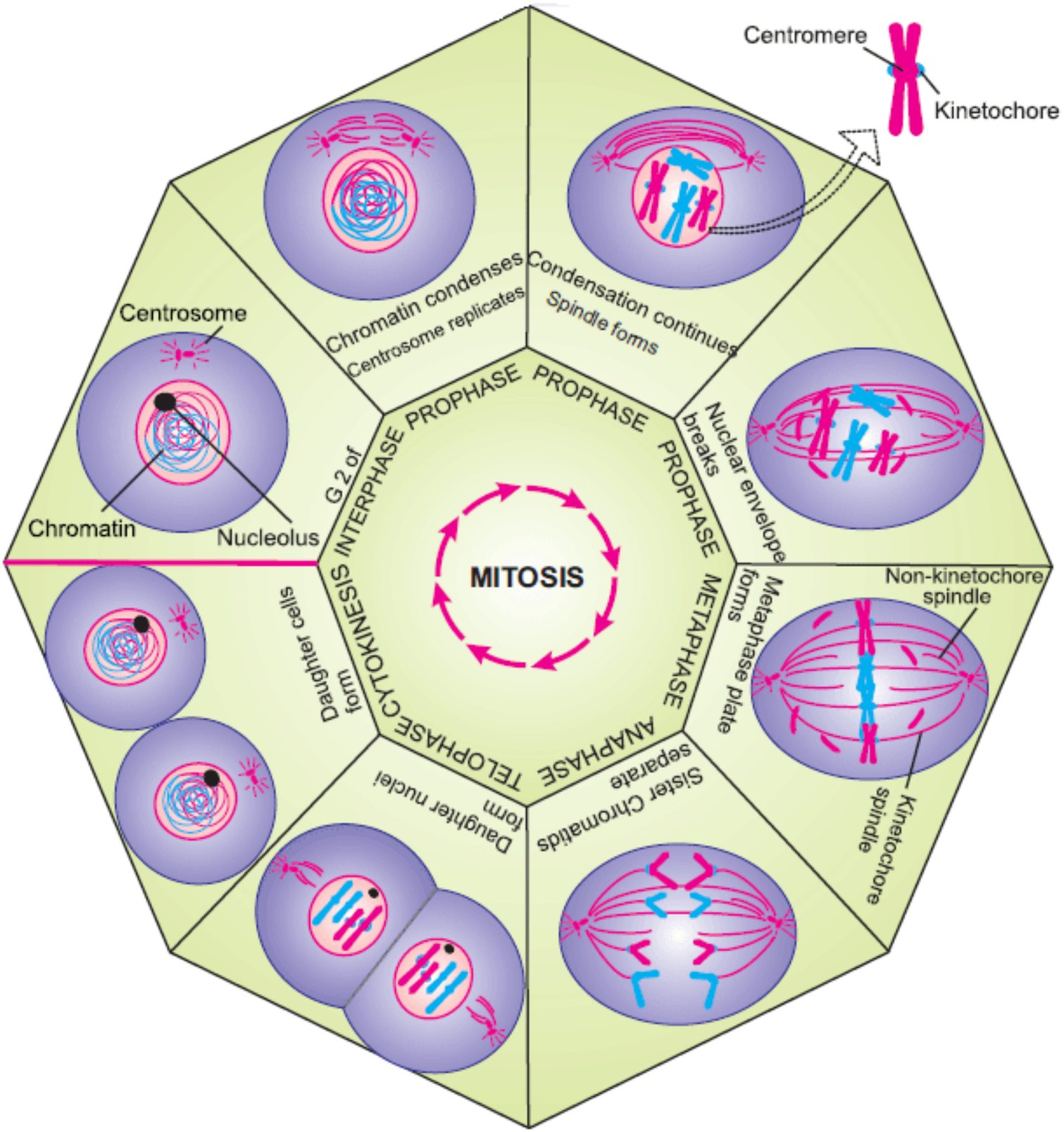


Figure 5.2: Stages in mitosis

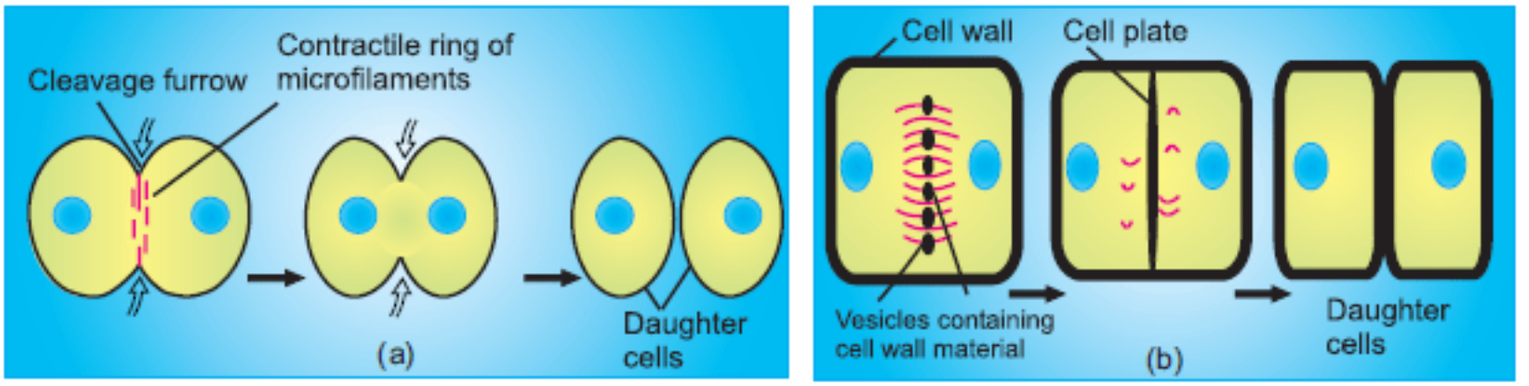


Figure 5.3: Cytokinesis; (a) in animal cell, (b) in plant cell

5.2.2 Significance Of Mitosis

Importance of mitosis is the maintenance of chromosomal set i.e. each daughter cell receives chromosomes that are a like in composition and equal in number to the chromosomes of parent cell.

Following are the occasions in the lives of organisms where mitosis happens.

Development and growth:

The number of cells within an organism increase by mitosis. This is the basis of the development of a multicellular body from a single cell i.e. zygote and also the basis of the growth of multicellular body.

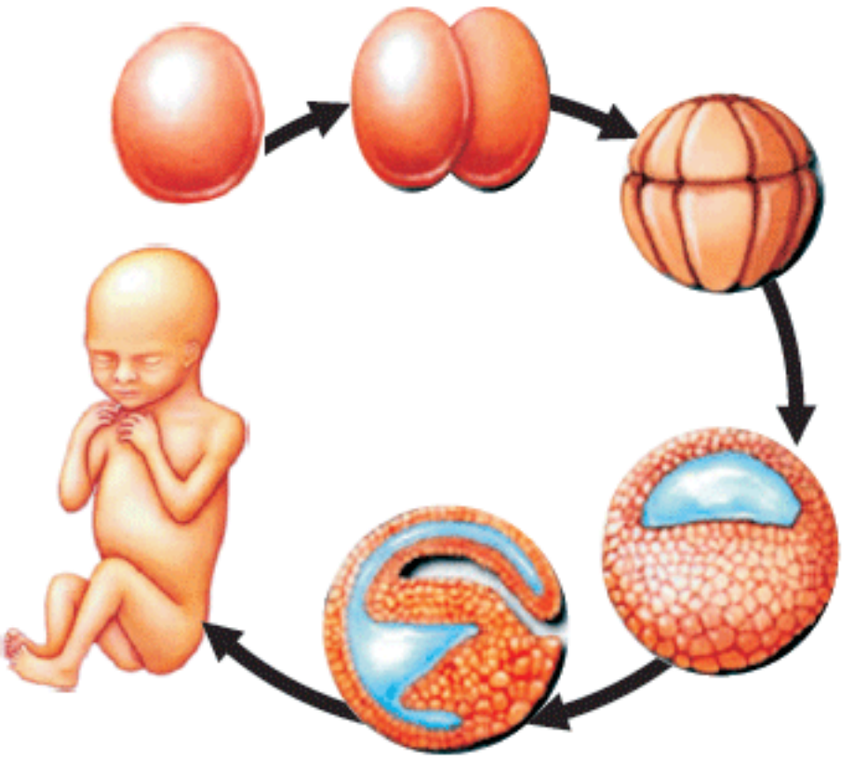


Figure 5.4: Development of a single cell (zygote) into a multicellular body

Cell replacement:

In some parts of body, e.g. skin and digestive tract, cells are constantly sloughed off and replaced by new ones. New cells are formed by mitosis and so are exact copies of the cells being replaced. Similarly, red blood cells have short life span (about 4 months) and new red blood cells are formed by mitosis.

Regeneration:

Some organisms can regenerate parts of their bodies. The production of new cells is achieved by mitosis. For example; sea star regenerates its lost arm through mitosis.

Figure 5.5: Regeneration in sea star

Asexual reproduction:

Some organisms produce genetically similar offspring through asexual reproduction. Mitosis is a mean of asexual reproduction. For example; hydra reproduces asexually by budding. The cells at the surface of hydra undergo mitosis and form a mass called bud. Mitosis continues in the cells of bud and it grows into a new individual. The same division happens during asexual reproduction (vegetative propagation) in plants.

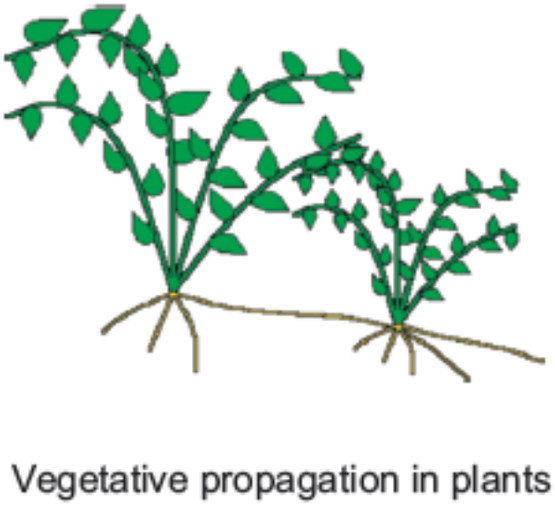


Figure 5.6: Asexual reproduction

Errors In Mitosis

Errors in the control of mitosis may cause cancer. All cells have genes that control the timing and number of mitosis. Sometimes mutations occur in such genes and cells continue to divide. It results in growths of abnormal cells called tumors. As long as these **tumors** remain in their original location, they are called **benign** tumours. But if they invade other tissues, they are called **malignant** (cancerous) tumors and their cells are called cancer cells. Such tumors can send cancer cells to other parts in body where new tumors may form. This phenomenon is called **metastasis** (spreading of disease).

Practical Work:

Preparation of root tip squashes and study of the stages of mitosis

The number of cells within an organism increases by mitosis and this is the basis of growth in multicellular organisms.

Problem:

While observing the cells from the tip of an onion root, can we identify cell in different stages of mitosis. (You may use your textbook to help you identify the stages of mitosis.)

Apparatus required:

Microscope, slides , fresh grown onion root tip, 5-10ml distilled water, 5ml 6M HCl, 1 ml Feulgen reagent in a vial, dropper pipette, beaker, and a pencil with eraser or small cork to squash the slide, toothpicks

Background information:

- Growth in organisms is carefully controlled by regulating the cell cycle.
- In plants, the roots continue to grow.
- The tips of roots are good for studying the cell cycle because at any given time, we can find cells that are undergoing mitosis.
- Slicing the onion root captures many cells in different phases of the cell cycle.
-

Procedure:

1. Take an onion and place it in a cup of water so that only the root portion is under water. (To do this, push toothpicks into the side of the onion which extend outward and hold it on the rim of the cup. New roots should grow within two days.)

2. Preheat about 10 ml of Hydrochloric acid in a small beaker to 60ºC using a waterbath.
3. Using scissors remove the last 2 mm from several growing root tips. Place them in the preheated acid and return to the waterbath for 4-5 minutes.
4. Gently transfer each root tip to a clean microscope slide containing water drop.
5. Gently blot dry with a piece of soft tissue. It is important to remove as much water as possible.
6. Using a dissection needle, thoroughly chop up the root tip and spread over an area equivalent to the size of a 01 rupee coin. (Alternatively you can place another microscope slide at right angles to the original slide to form a cross, and squash the tip between the two slides.)
7. Place a coverslip over the broken tissue trying not to get air bubbles under it.
8. Press down firmly onto the coverslip with a small cork or pencil eraser to spread the cells in a very thin layer
9. For staining, remove the coverslip and add one drop of the stain to the macerated root tip and immediately cover with a coverslip.
10. Place the slide on the compound microscope.
11. Locate growth zone, which is just above the root cap at the very end of the tip.
12. Focus in on low power, and then switch to medium or high power.
13. Find textbook diagrams of the four stages of mitosis and use them to help you to identify the stages on the microscope slide.

Observation:

Each slide shows a number of cells in different stages and the darkly stained areas can be easily distinguished.

Evaluation:

i. Copy this table onto a paper. You can enter data in this table as you go along, or at the end of the activity.

	Prophase	Metaphase	Anaphase	Telophase	Total
Number of Cells					

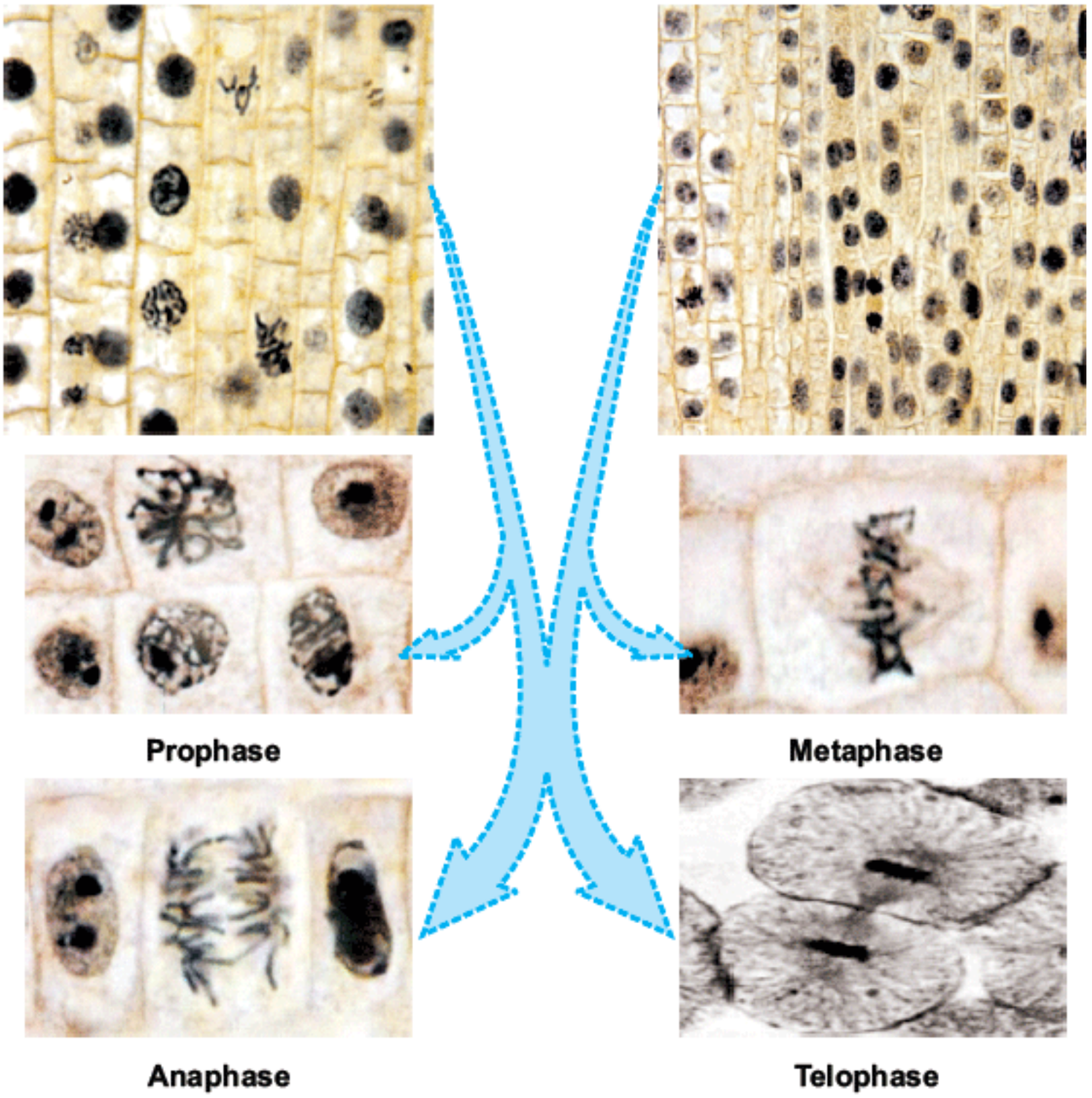


Figure 5.7: Cells in different stages of cell cycle

5.3 Meiosis

Meiosis is the process by which one diploid (2n) eukaryotic cell divides to generate four haploid (1n) daughter cells. Diploid means the cells in which chromosomes are in pairs (homologous pairs) while haploid means the cells with half the number of chromosomes i.e. chromosomes are not in the form of pairs.

The word meiosis comes from Greek word 'meioun', meaning "to make smaller," since it results in a reduction in chromosome number.

5.3.1 Phases Of Meiosis

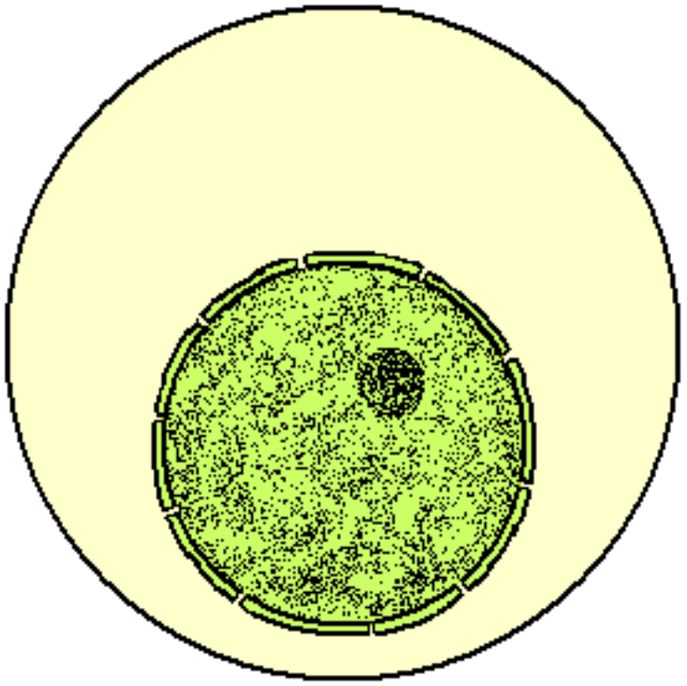
Meiosis was discovered and described for the first time in 1876, by a German biologist **Oscar Hertwig**. The preparatory steps of meiosis are identical to the interphase of mitosis. Interphase is divided into the same three phases i.e. G1, S phase, and G2. Interphase is followed by meiosis I and meiosis II.

Meiosis I

In meiosis I, the homologous chromosomes in a diploid cell separate and so two haploid daughter cells are produced. It is the step in meiosis that generates genetic variations. Meiosis I occurs in two main steps i.e. karyokinesis and cytokinesis. The karyokinesis of Meiosis I is subdivided into prophase I, metaphase I, anaphase I, and telophase I.

Prophase I

Prophase I is the longest phase in meiosis. During this stage, chromatin condenses into chromosomes. The homologous chromosomes line up with each other and form pairs by a process called **synapsis**. Each pair of homologous chromosomes is called bivalent. Each **bivalent** has four chromatids, so it may also be called a **tetrad**. The two non-sister chromatids of homologous chromosomes join each other at certain points along their length. These points of attachment are called **chiasmata.** In the next stage, the non-sister chromatids of homologous chromosomes exchange their segments and the phenomenon is known as **crossing over** (Figure 5.8).



Animation 5.3: Meiosis
Source & Credit: geocities

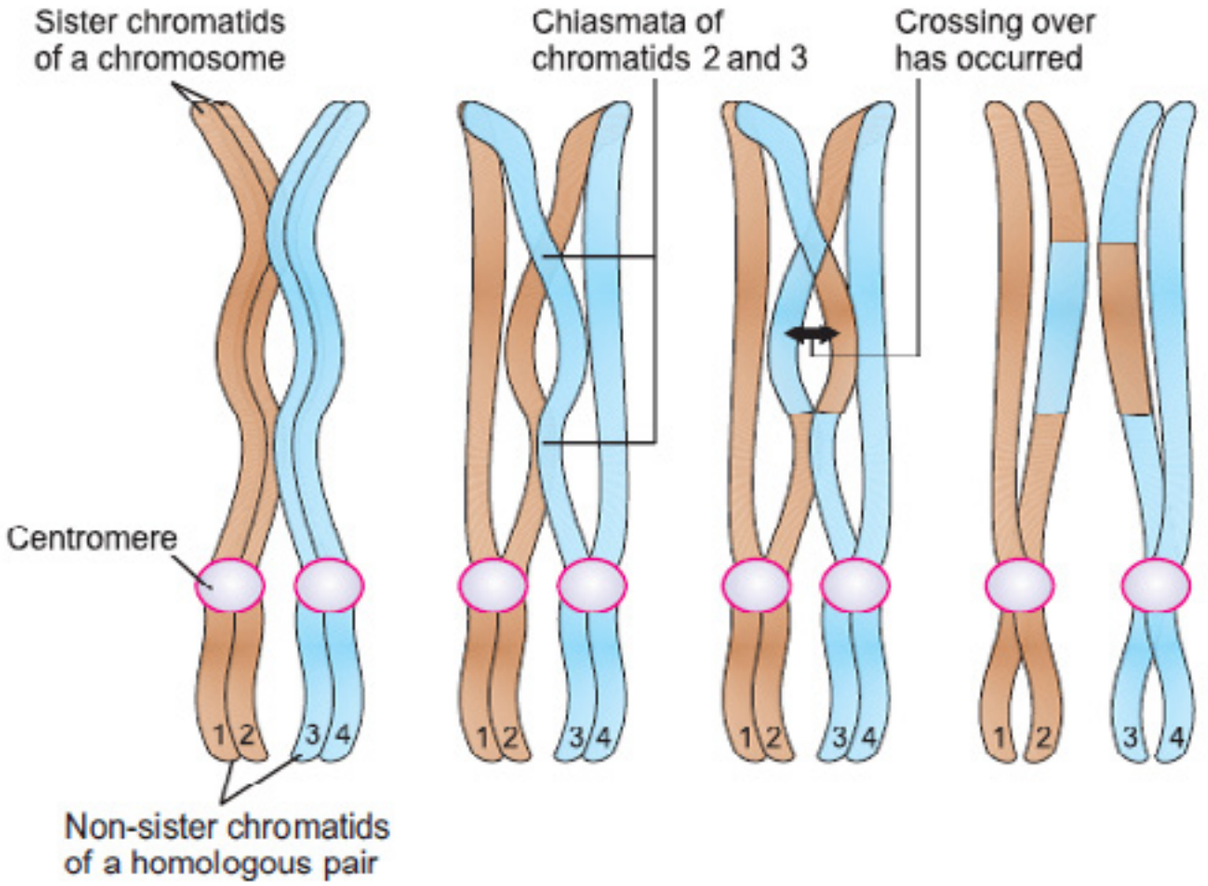


Figure 5.8: Crossing over

The exchange of segments results in the recombination of genetic information. After crossing over, each pair of homologous chromosomes remain as a bivalent.
Chromosomes condense further, the nucleoli disappear, and the nuclear envelope disintegrates. Centrioles, which were duplicated during interphase, migrate to the two poles and form spindle fibres. The kinetochore spindle fibres attach with the kinetochores of chromosomes. While the non-kinetochore spindle fibres from both sides interact with each other. Two kinetochore spindle fibres (from the opposite poles) attach with a pair of chromosomes. In mitosis, we have seen that two kinetochore spindle fibres attach with one chromosome.

Metaphase I

The pairs of homologous chromosomes align along equatorial plane forming the metaphase plate.

In 1911, the American geneticist Thomas Hunt Morgan observed the phenomenon of crossing over in fruit fly Drosophila melanogaster.

Anaphase I

Kinetochore spindle fibres shorten. It results in pulling apart the chromosomes of each pair. Since one chromosome is pulled toward one pole, two haploid sets are formed. Each chromosome still contains a pair of sister chromatids.

Telophase I

Chromosomes arrive at the poles. Each pole now has half the number of chromosomes but each chromosome still consists of two chromatids. Spindle network disappears, and nuclear envelope is formed around each haploid set. Chromosomes uncoil back into chromatin.

Cytokinesis (the pinching of the cell membrane in animal cells or the formation of the cell wall in plant cells) occurs and the creation of two haploid daughter cells is completed (Figure 5.9).

After meiosis I both haploid daughter cells enter a period of rest known as **interkinesis** or **interphase II.** The interphase II is different from the interphase of mitosis and meiosis I. There is no S-phase and so there is no duplication of chromosomes during this stage.

? During crossing over, genetic material is exchanged between sister/non-sister chromatids of homologous /non-homologous chromosomes.

Non-sister chromatids of homologous chromosomes.

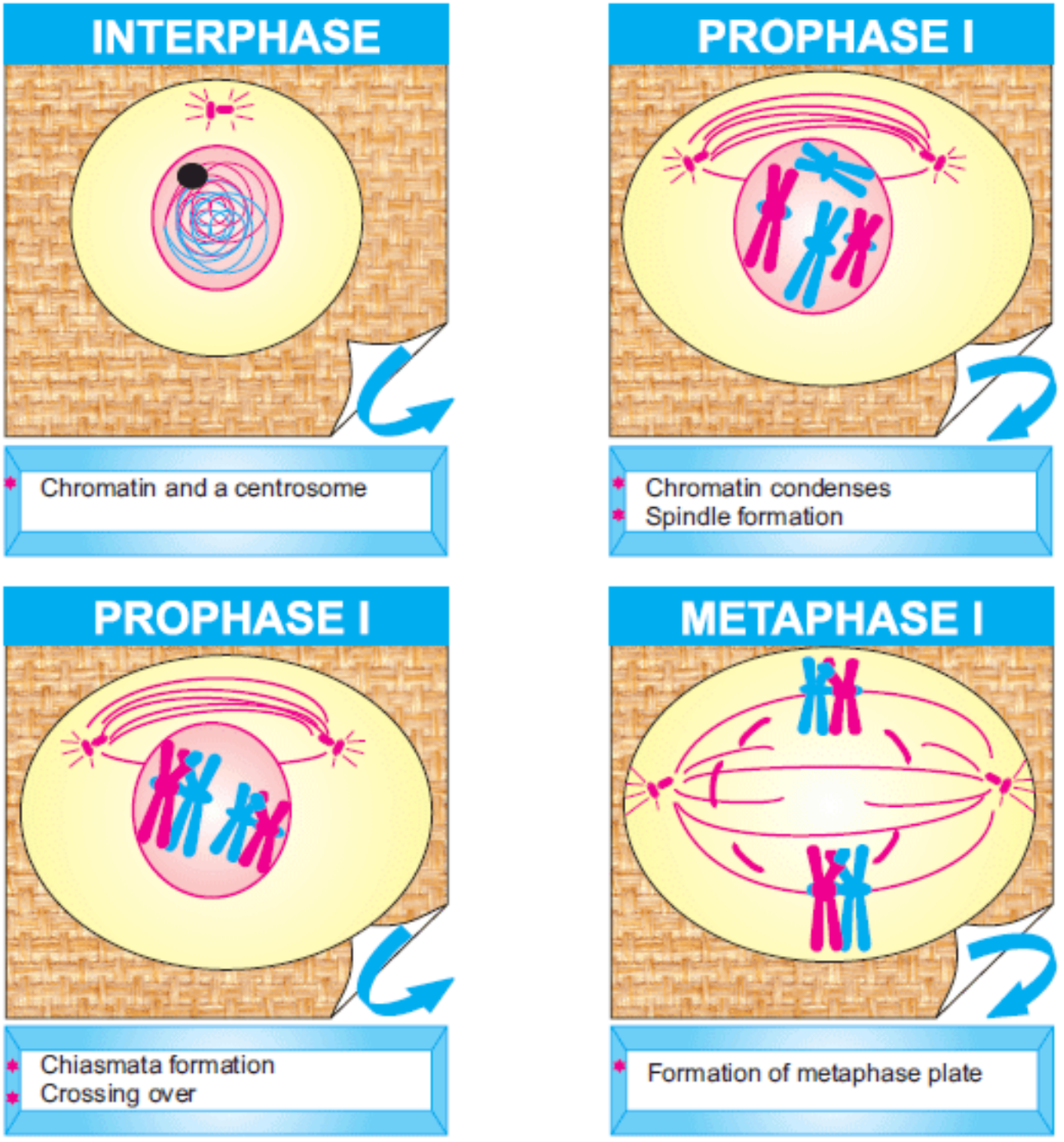


Figure 5.9: Stages in Meiosis-I (a)

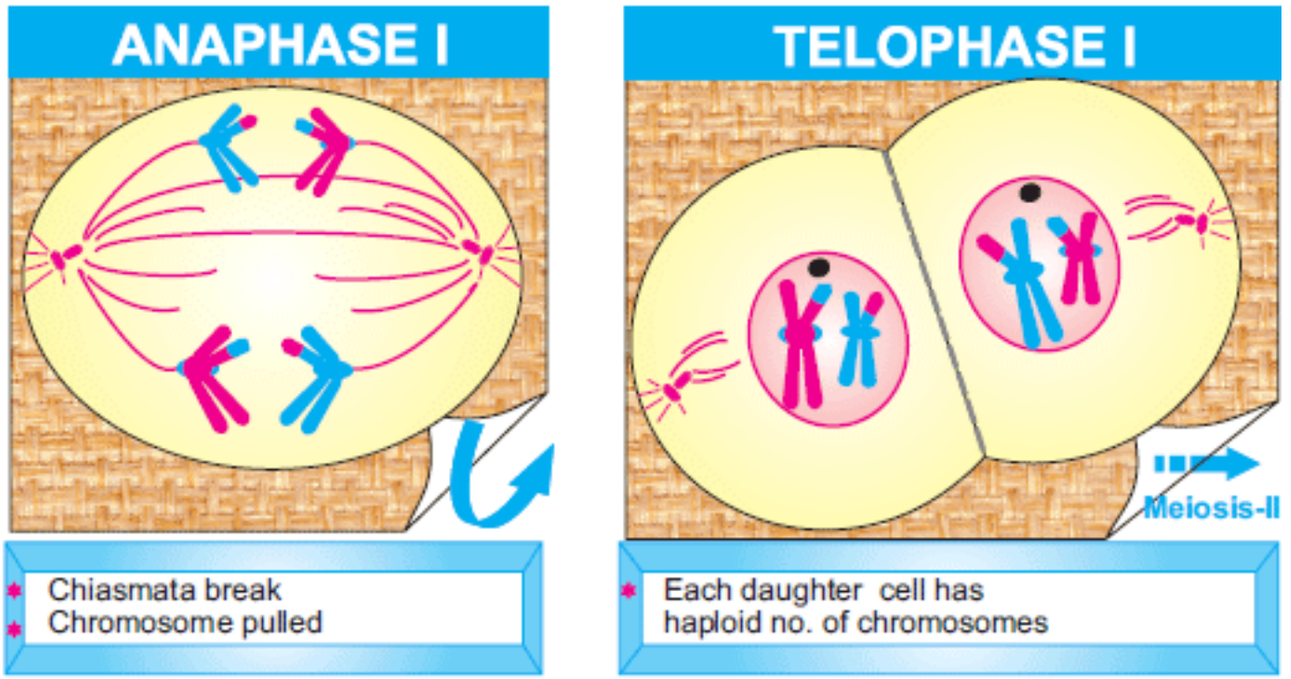


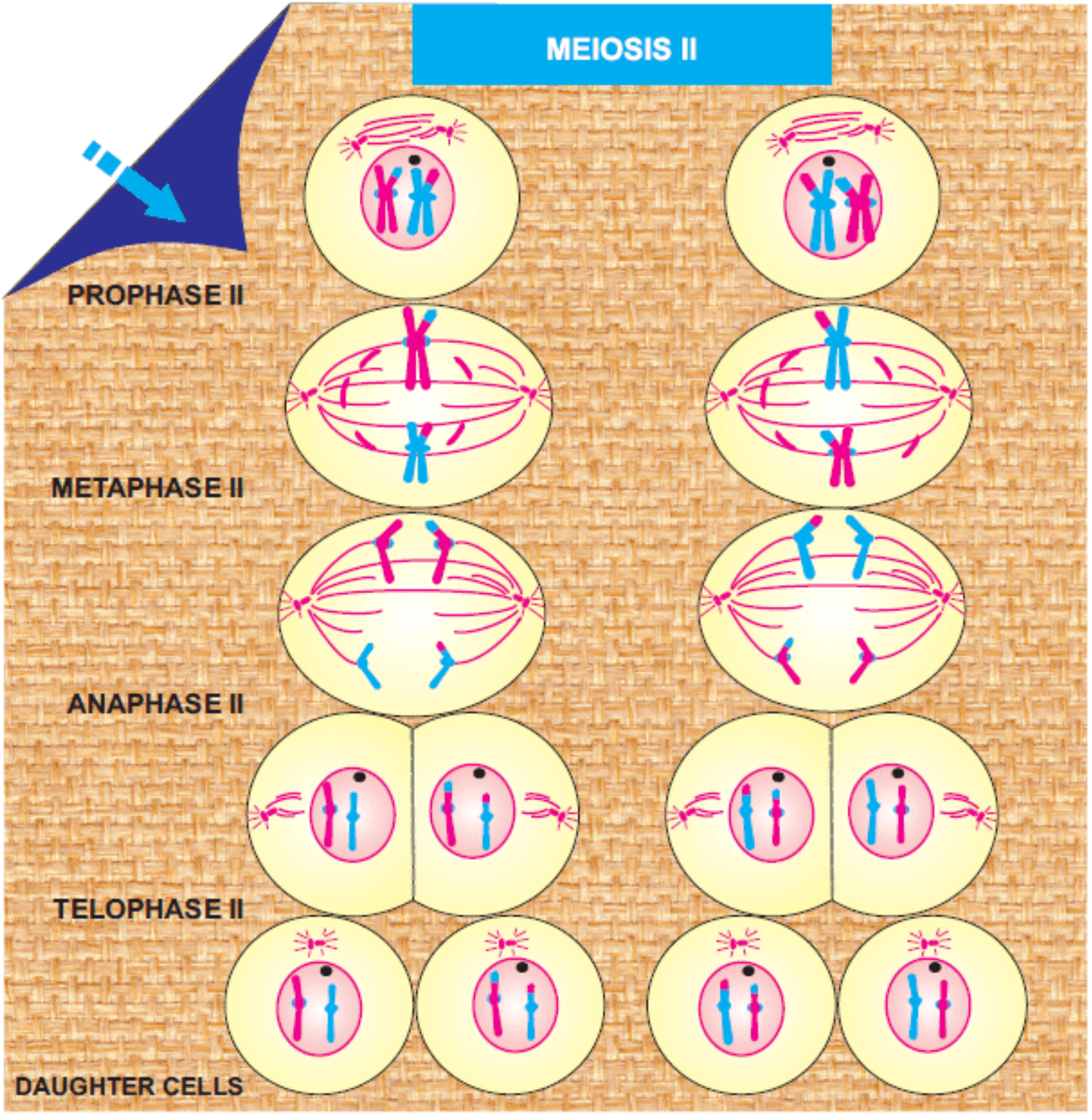
Figure 5.9: Stages in Meiosis-I (b)

Meiosis II

It is the second part of meiosis and is similar to mitosis. It is subdivided into prophase II, metaphase II, anaphase II, and telophase II.

Prophase II takes much less time compared to prophase I. In this prophase, nucleoli and nuclear envelope disappear and chromatin condenses. Centrioles move to the polar regions and make spindle fibres. In metaphase II, chromosomes attach with kinetochore spindle fibers and align at the equator of cell.

This is followed by anaphase II, where centromeres are cleaved and sister chromatids are pulled apart. The sister chromatids are now called sister chromosomes, and they are pulled toward opposing poles. Telophase II is marked with uncoiling of chromosomes into chromatin. Nuclear envelopes reform; cleavage or cell wall formation eventually produces a total of 4 daughter cells, each with a haploid set of chromosomes (Fig. 5.10).



Each daughter cell has haploid number of chromosomes

Figure 5.10: Stages in Meiosis-II

5.3.2 Significance Of Meiosis

The significance of meiosis for reproduction and inheritance was described in 1890 by German biologist August Weismann. He pointed out that meiosis was necessary not only to maintain the number of chromosomes in the next generation but also to produce variations in next generation.

Maintenance of the chromosome number in next generation

Meiosis is essential for sexual reproduction. In humans, diploid gamete-mother cells or germ line cells undergo meiosis to produce haploid gametes. Male and female gametes unite to form diploid zygote, which undergoes repeated mitosis and develops into a new diploid human. Many haploid fungi and protozoans produce haploid gametes through mitosis. Plants' life cycle shows alternation of generations. The cells of diploid sporophyte generation undergo meiosis to produce haploid spores, which grow into haploid gametophyte generations. Gametophyte generation produces haploid gametes through mitosis. The gametes combine to produce diploid zygote. Zygote undergoes repeated mitosis to become diploid sporophyte.

Production of variations in next generations

The chromosome pairs of each parent undergo crossing over during meiosis. So daughter cells i.e. gametes have genetic variations. When gametes fuse and form zygote, its genetic make up is different from both parents. Thus meiosis allows a species to bring variations in the next generations. Beneficial variations help organisms to adapt to the changes in environment.

Errors in meiosis

During anaphase I, chromosomes separate and go to opposite poles while during anaphase II sister chromosomes separate. It is called **disjunction**. Sometimes the separation is not normal and it is called **non-disjunction**. This results in the production of gametes which have either more or less than the normal number of chromosomes. If such abnormal gamete fuses with a normal gamete, it results abnormal chromosome number in next generation, for example 47 or 45 chromosomes in humans.

5.3.3 Comparison Between Mitosis And Meiosis

Meiosis II is similar to mitosis while meiosis I makes the actual difference between these two cell divisions. The following chart describes the main differences between mitosis and meiosis I.

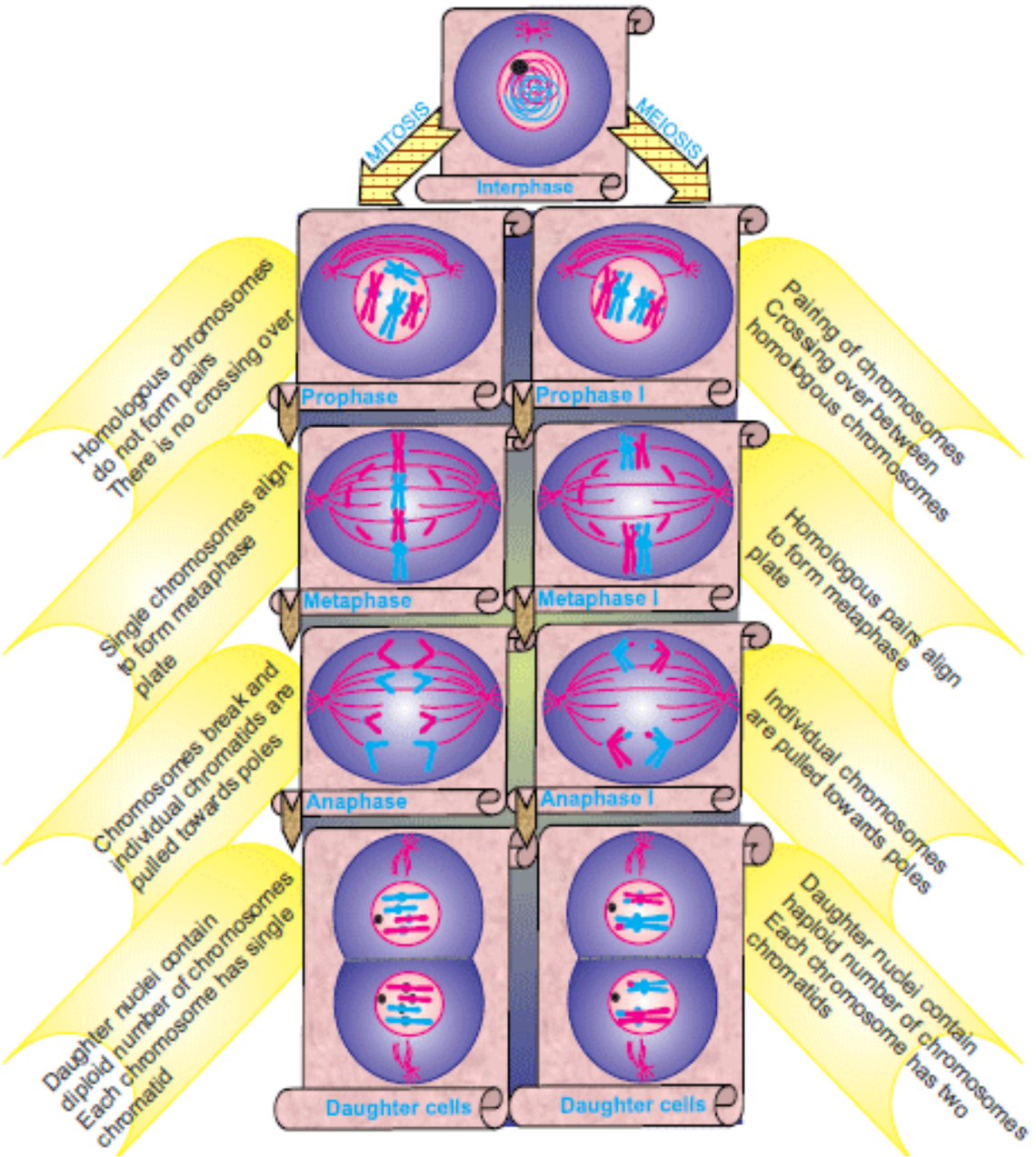


Figure 5.11: Mitosis and Meiosis; a comparison

Practical Work:

Observation of various stages of mitosis and meiosis by slides, models and charts.

Mitosis and meiosis are sequential events in which a parent cell divides.

Problem:

Can we recognize the stage of mitosis or meiosis by finding some hints in the slide or diagram?

Background information:

- We should have a comprehensive knowledge of the events that occur in each stage of mitosis and meiosis.

Procedure:

1. Observe the given material (slide, model or chart). Slide must be observed under microscope.
2. Draw illustration on your notebook and try to label different components.
3. Point out important features of your illustration and recall the events that occur during mitosis and meiosis.
4. Indicate the stage of cell division which you think may be.

Evaluation:

1. If you found that the given specimen was taken from an animal tissue and the cells were undergoing meiosis, what would be the daughter cells?
2. What is the main feature of prophase-I of meiosis, which differentiates it from the prophase of mitosis?
3. Chromosomes are only visible during cell division and not visible during interphase. Why?

5.4 Apoptosis And Necrosis

Apoptosis and necrosis are two phenomena of cell death.

Apoptosis

Apoptosis is one of the main types of programmed cell death. During apoptosis, cell shrinks and becomes rounded due to the breakdown of cytoskeleton by enzymes. Its chromatin undergoes condensation and nuclear envelope breaks. In this way, nucleus spreads in the form of several discrete chromatin bodies. Cell membrane makes irregular buds known as **blebs**. Blebs break off from the cell and are now called **apoptotic bodies**, which are then phagocytosed by other cells.

In an adult human,50 to 70 billion cells die each day by apoptosis.

Apoptosis can occur when a cell is damaged or undergoes stress conditions. Apoptosis removes the damaged cell, preventing it from getting further nutrients, or to prevent the spread of infections. Apoptosis also gives advantages during development. For example during the formation of fingers, the cells between them undergo apoptosis and the digits separate.

Necrosis

Necrosis is the accidental death of cells and living tissues. Necrosis is less sequential than apoptosis. There are many causes of necrosis including injury, infection, cancer etc. Necrosis may occur when a cell is given hypoxic (with less oxygen) environments.

During necrosis, there is a release of special enzymes from lysosomes. Lysosomal enzymes break cellular components and may also be released outside cell to break surrounding cells. Cells that die by necrosis may also release harmful chemicals that damage other cells.

Spider bites also cause necrosis in some areas.

Necrosis may be due to lack of proper care to a wound site.

UNDERSTANDING THE CONCEPTS

1. What is cell cycle and what are its main phases?
2. The S-phase of interphase is important and a cell can never divide without it. Justify.
3. How would you state the events of prophase of mitosis?
4. Make a list of the events of mitosis.
5. How is mitosis significant?
6. Describe the events that occur during the phases of meiosis-I.
7. Describe the significance of meiosis.
8. Contrast mitosis and meiosis, emphasizing the events that lead to different outcomes.
9. Describe necrosis and apoptosis.

Short Questions

1. A nerve cell does not divide after its formation. In which phase of cell cycle it is?
2. How is cytokinesis different in plant cells as compared to animal cell?
3. What type of cell division occurs when our wounds are healed?
4. Plants do not make their gametes by meiosis. How is that?

TERMS TO KNOW

Anaphase	Chromosomes	Non-sister chromatids
Apoptosis	Interphase	Phragmoplast
Benign	Karyokinesis	Prophase
Budding	Kinetochore	S phase
Cell cycle	M phase	Sister chromatids
Chiasmata	Malignant	Spindle
Crossing over	Metaphase	Synapsis
G 0 phase	Metaphase plate	Telophase
G 1 phase	Mitosis	
G 2 phase	Necrosis	
Homologous	Necrosis	

Activities

1. Observe various stages of mitosis and meiosis through slides, models and charts.

Science, Technology And Society

1. Describe the inability of some mature cells (nerve cells) to divide and the uncontrolled division of certain cells (tumors).

ON-LINE LEARNING

1. www.columbia.edu
2. www.agen.ufl.edu/.../lect/lect_15/lect_15.htm
3. http://sps.k12.ar.us/massengale/biology%20I%20page.htm
4. www.cell-research.com