CHAPTER 3

CELL DIVISION

(Hours: 1L + 4T)

CHAPTER 3: CELL DIVISION

3.1 The Cell Cycle
3.2 Mitosis
3.3 Meiosis

UPS 1	PSPM 1
3 MCQ	7 marks

LEARNING OUTCOMES

3.1 The Cell Cycle

a) Show the stages of cell cycle (C2 - LECTURE)

b) Explain the stages in cell cycle : Interphase & Mitotic phase (C3- TUTOR)

c) Describe the loss of cell cycle control in cancer cell at G_1 and M checkpoint (C2 - TUTOR)

The stages of cell cycle

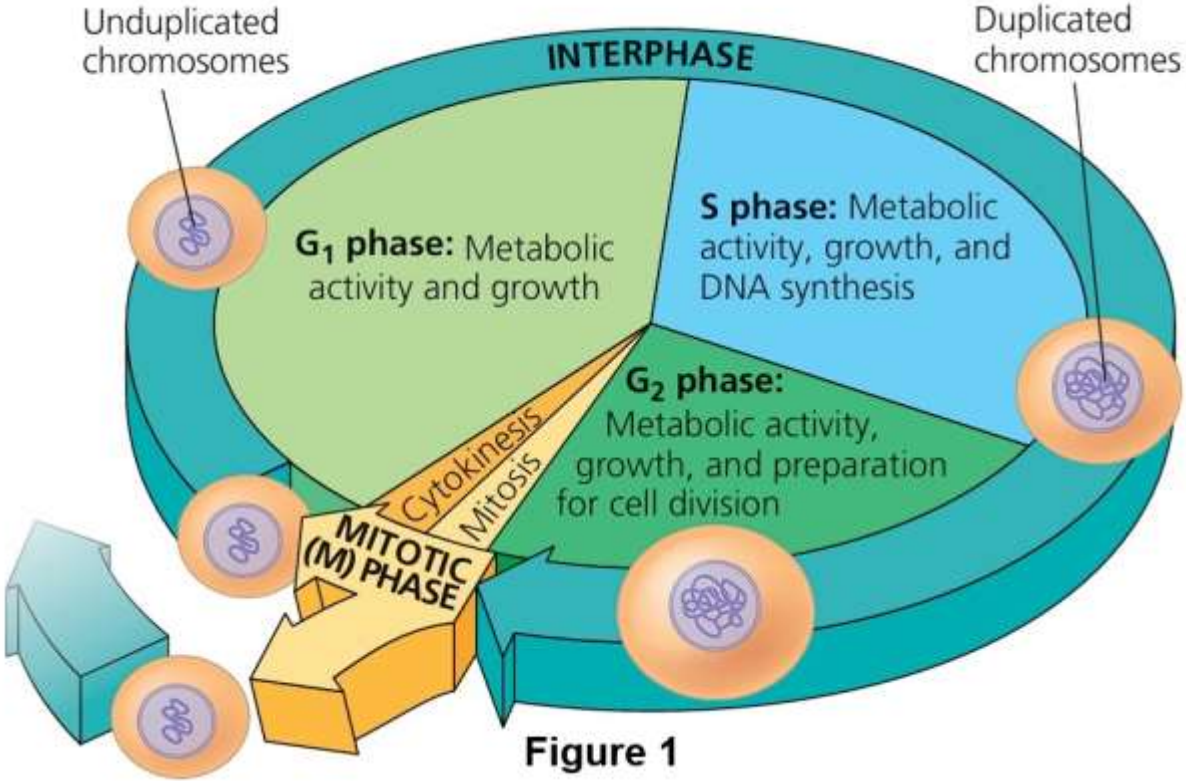


Figure 1

The stages of cell cycle

- **An ordered sequences of events in the life of a cell, from its origin in the division of a parent cell until its own division into two.**

- The eukaryotic cell cycle involve two phases :
  1. **Interphase** :
     - G_1 phase (first gap)
     - S phase (synthesis)
     - G_2 phase (second gap)
  2. **M phase**: Mitosis and Cytokinesis

The stages of cell cycle

INTERPHASE

G_1 phase (First Gap Phase)

- Synthesis of lipid, carbohydrate, proteins and enzyme needed for DNA replication.
- Organelles synthesized (number of organelles increases)
- Volume of cytoplasm increase
- Cell increase in size

The stages of cell cycle

INTERPHASE

S phase (Synthesis Phase)

- DNA replication occurs.
- Forming two identical sister chromatids which attached to centromere.
- Histones protein are synthesized.

Learning Outcomes :
3.1 b) Explain the stages in cell cycle: Interphase and Mitotic phase (TUTOR)

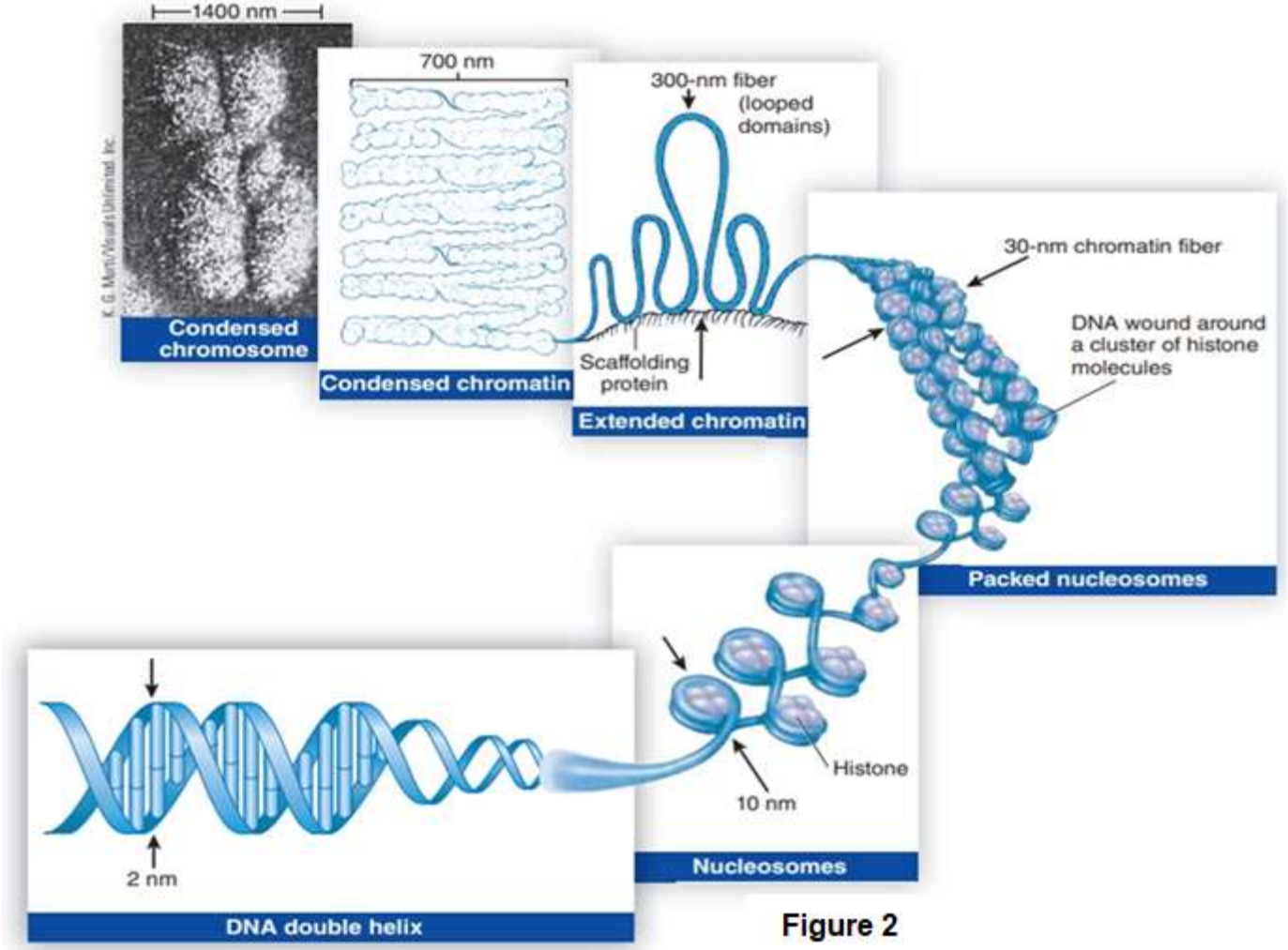


Figure 2

Learning Outcomes :

3.2 a) Explain the four stages of mitosis and the behaviour of the chromosome for each stage (TUTOR)

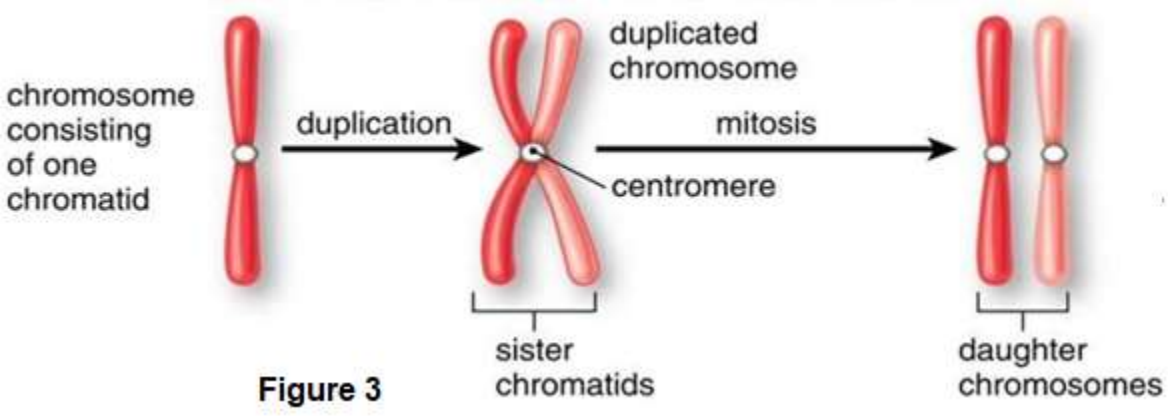
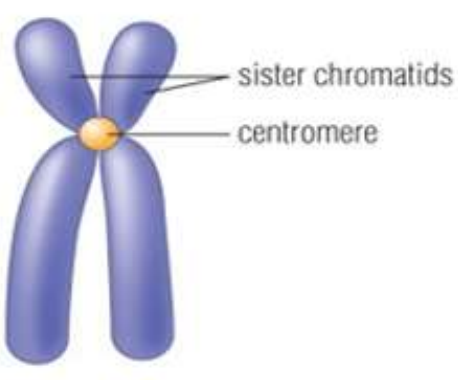


Figure 3



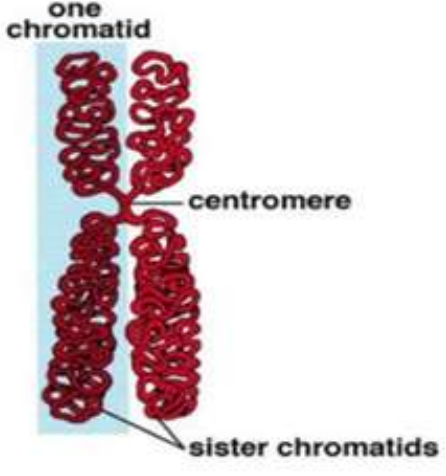


Figure 4

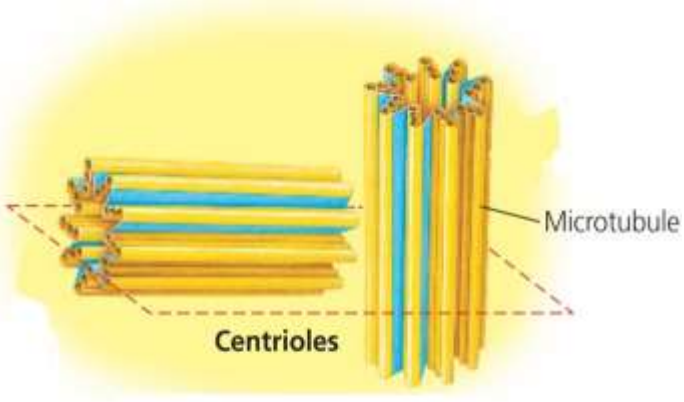
The stages of cell cycle

INTERPHASE

G_2 phase (Second gap phase)

- Cell continue to grow.
- Further synthesis of organelles.
- Mitochondria are highly replicated and energy stores increases.
- Formation of microtubules for development of spindle fibers.
- Centrosome duplicated.
- Increase in size of nucleus.

Learning Outcomes :
3.2 a) Explain the four stages of mitosis and the behaviour of the chromosome for each stage (TUTOR)



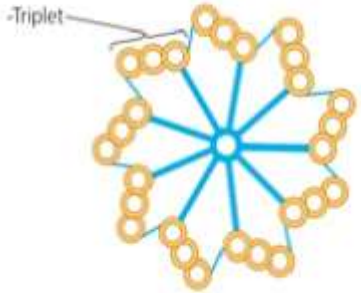


Figure 5

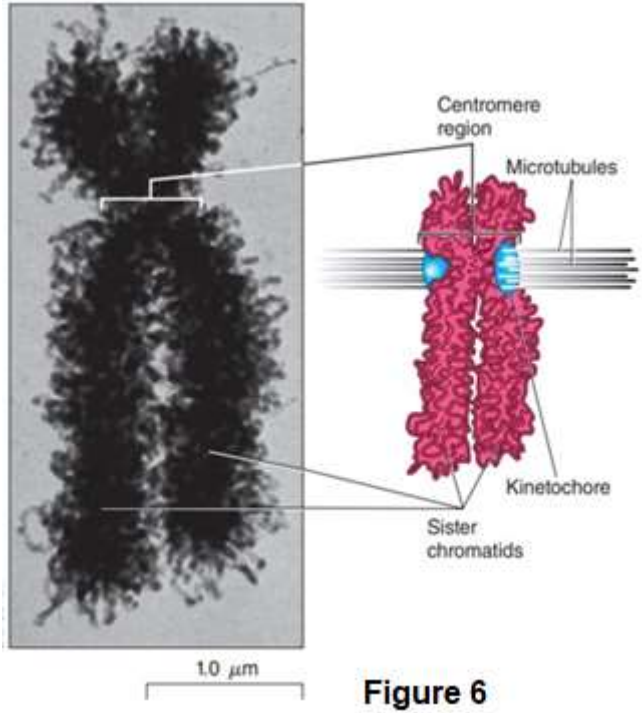


Figure 6

Solomon, 11th Ed. Page 213

The stages of cell cycle

G_0 phase

- Non dividing state occupied by cell that have left the cell cycle.
- During G_1 phase, if energy to continue the cycle is insufficient, it will enter G_0 phase.
- Sometimes reversibly.

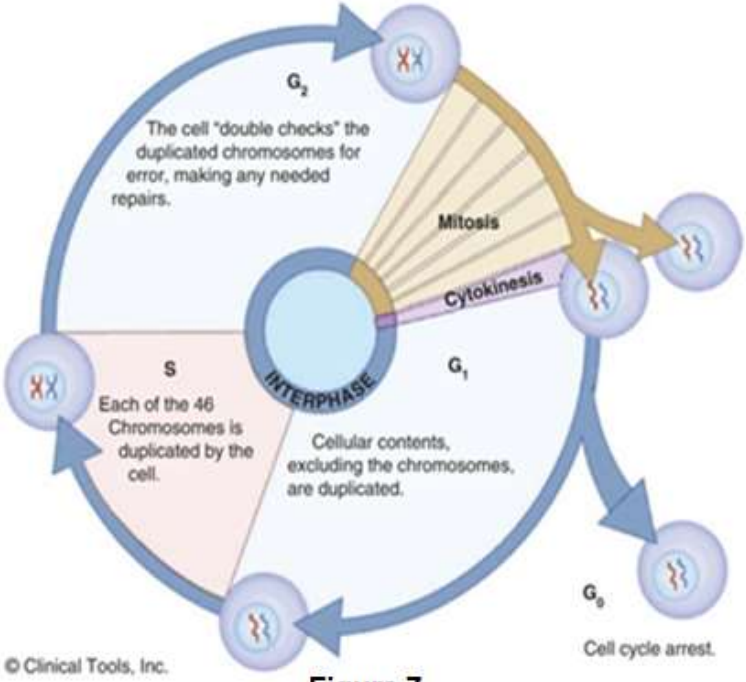


Figure 7

The stages of cell cycle

MITOTIC (M) PHASE

Mitosis

- Mitosis refers to division of nucleus (karyokinesis)
- It consists of four stages:
  i. Prophase
  ii. Metaphase
  iii. Anaphase
  iv. Telophase

Cytokinesis

- Cytokinesis refers to division of cytoplasm.
- It occur during telophase.

Learning Outcomes :
3.1 c) Describe the loss of cell cycle control in cancer cell at G_1 and M checkpoints (TUTOR)

Cell cycle control system

Regulatory molecules in the eukaryotic cells that trigger and coordinate event in the cell cycle.

3 specific checkpoints that cell cycle stops until a go-ahead signal is received.

Checkpoint	Check for
G_1	Adequate cell size, sufficient nutrient and no DNA damage.
G_2	Completion of DNA replication and that the replicated DNA is not damaged.
M	All the chromosomes are attached to the spindle microtubules.

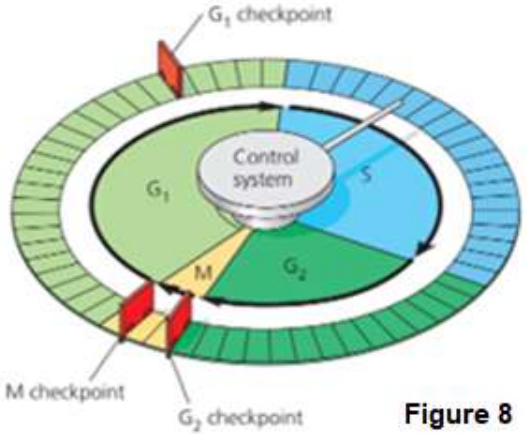


Figure 8

Cell cycle regulators

Two types of regulatory molecules:

1) **Cyclins**
   A protein that is cyclically fluctuating concentration in the cell and **control the cell cycle**.

2) **Cdks (Cyclin-dependent kinases)**
   Protein kinase (enzyme) that is activated by cyclin.

Cyclin-cdk complexes that acts as go-ahead signal at cell cycle checkpoint

Go-ahead Signal at G_1 Checkpoints

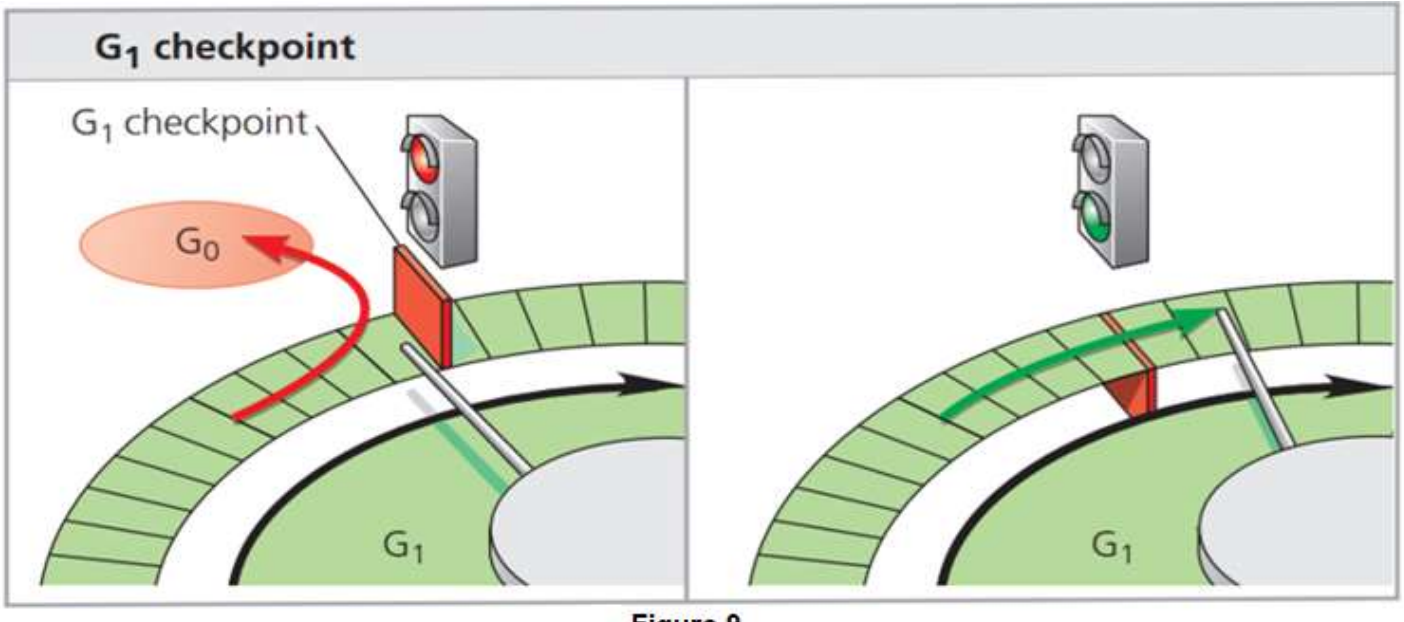


Figure 9

If it **does not receive a go-ahead signal** at that point, it may **switch into a nondividing state (G_0 phase)**.

If a cell **receives a go-ahead signal** at the G_1 checkpoint, it will usually **complete the G_1, S, G_2, and M phases and divide**.

Go-ahead Signal at M Checkpoints

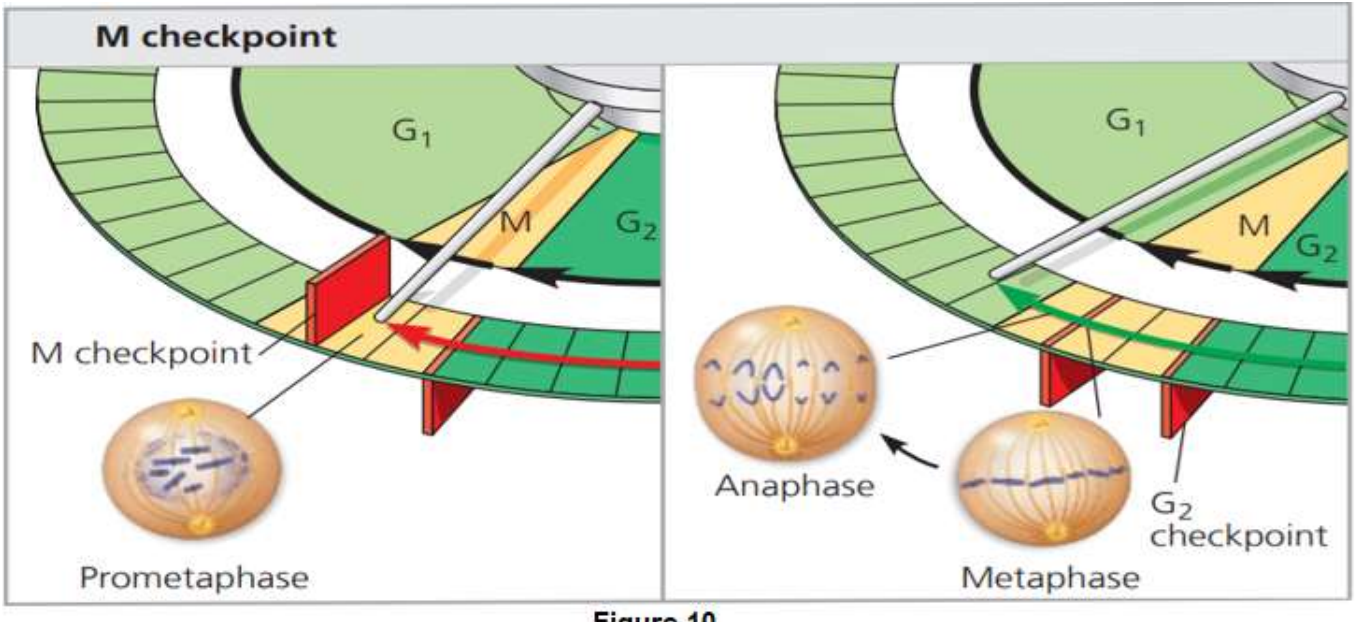


Figure 10

A cell in mitosis **receives a stop signal** when **<u>any of the chromosomes</u> are not attached to spindle fibers**

When **<u>all</u> chromosomes are attached to spindle fibers** from both poles, a **go-ahead signal** allows the cell to **proceed into anaphase**.

The loss of cell cycle control in cancer cells

- **Cancer** is a **result of a disruption in the normal** cell cycle**.** Cancer cells divide unchecked forming **tumors.**
- Occur if a cell is **abnormal** in some way **and does not pass the "inspection" at a checkpoint** within the cell cycle.
- Cells which proceed through the cell cycle in an unregulated manner are considered **cancers.**
- **Cancer cells do not follow the normal signals** that regulate the cell cycle and shut down the cell division process.
- They continue to **divide** even when they are very densely packed or growth factor are depleted.

Learning Outcomes :
3.1 c) Describe the loss of cell cycle control in cancer cell at G_1 and M checkpoints (TUTOR)

- When a single cell in a tissue undergoes **loss of cell cycle,** the body's immune system normally **recognizes** the **damage cell and destroys it.**

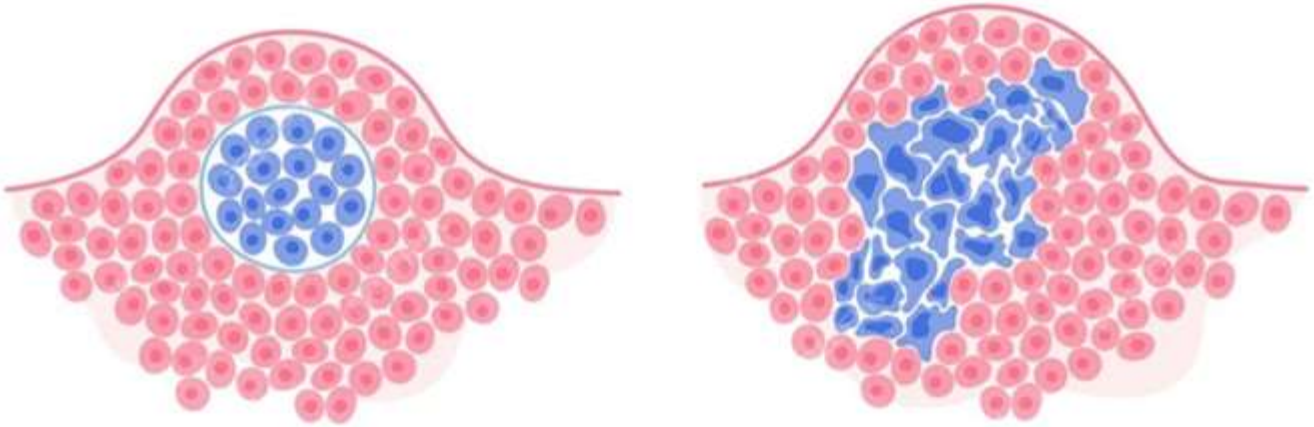
- But if the cell evades **destruction,** it will **continue** to **proliferate** and **form a tumor.**

Cancer cells

- **2 types of tumor:**
  - **i. Benign tumor.**
    - Abnormal cells remain at the original site.
  - **ii. Malignant tumor.**
    - Abnormal cells that able to spread to new tissues and impair the functions of one or more organs.
    - An individual with malignant tumor is said to have cancer.

Learning Outcomes :
3.1 c) Describe the loss of cell cycle control in cancer cell at G_1 and M checkpoints (TUTOR)

Cancer cells



i) Benign tumor.

ii) Malignant tumor.

Figure 11

LEARNING OUTCOMES

3.2 Mitosis

a) Explain the four stages of mitosis and the behavior of the chromosome for each stage (C3 - **TUTOR**)

b) Explain the cytokinesis process in animal and plant cell (C3- **TUTOR**)

Mitosis

Definition:

- **A process of nuclear division in eukaryotic cells.**
- followed **by cytokinesis.**
- **To produce two daughter cells**, each contain the **identical number of chromosomes to the parent cell.**

- Mitosis occurs in **somatic cells.**

Tip LKC : Example of somatic cells :- Muscle cell, skin cell, liver cell etc.

Prophase

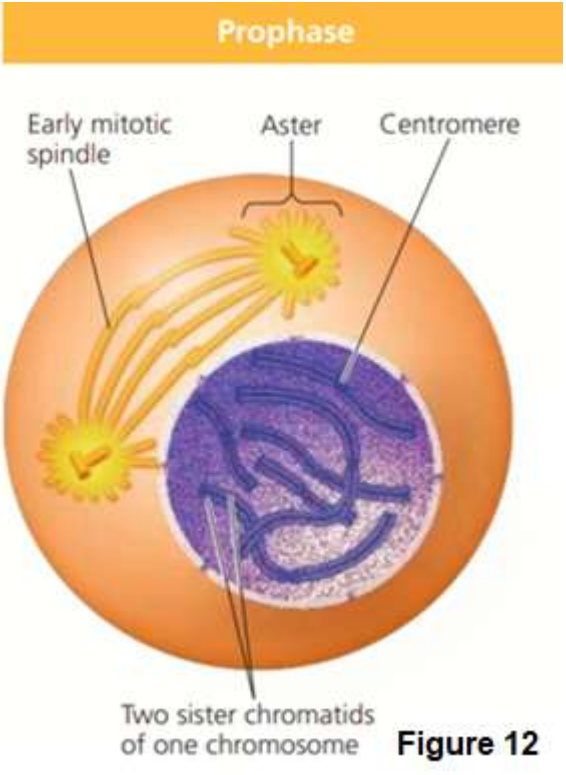


Figure 12

- **Chromatin shorten <u>and</u> thicken (condense) and become visible chromosome.**
- **Each chromosome consists of two sister chromatids attached together at the centromere.**

Prophase

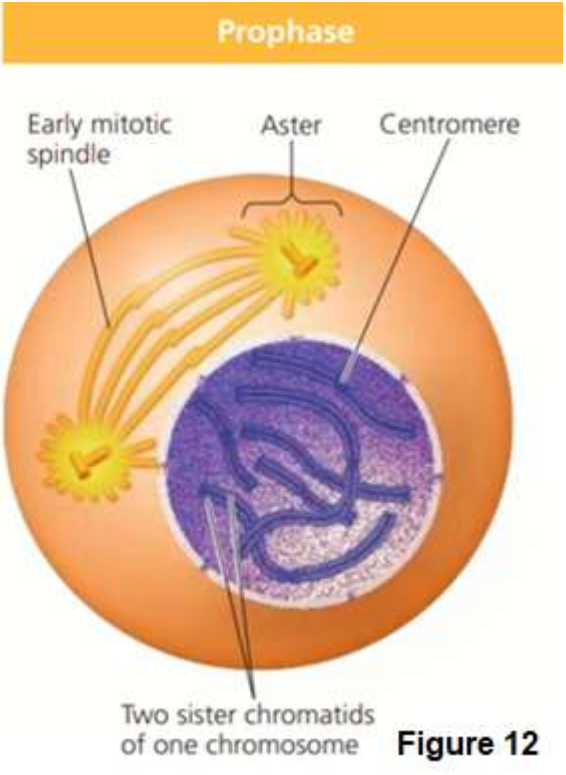


Figure 12

- Centrosomes move away from each other.
- Microtubules (aster) extend from centrosomes.
- Spindle fibers begin to form.
- Nucleolus disappear.
- At late prophase, nuclear envelope disintegrates.

Metaphase

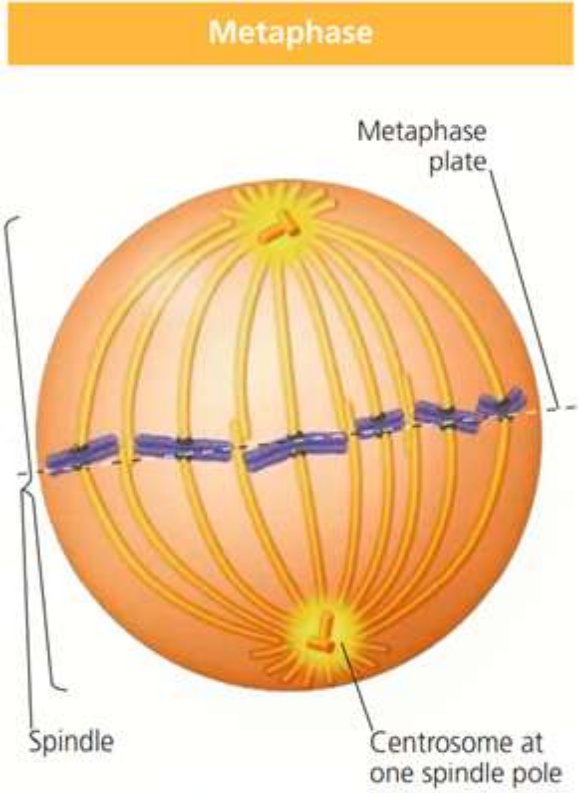


Figure 13

- **Chromosomes are aligned at metaphase plate.**
- **Microtubules of spindle fiber from each pole attach to the centromere of the same chromosome.**
- Centrosomes are at opposite poles of the cell.

Anaphase

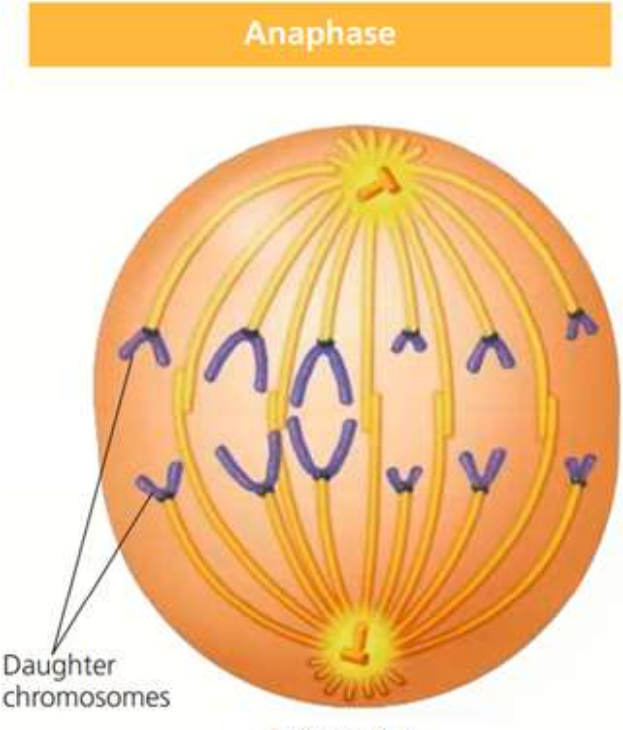


Figure 14

- **Centromere split.**
- **Sister chromatids separate and move to the opposite poles due to the shorten of spindle fibers.**
- **The separated chromatids now called as chromosomes.**
- **By the end of anaphase, both poles have equivalent number of chromosomes.**

Tip LKC : separate and move (/)
move and separate (X)

Telophase

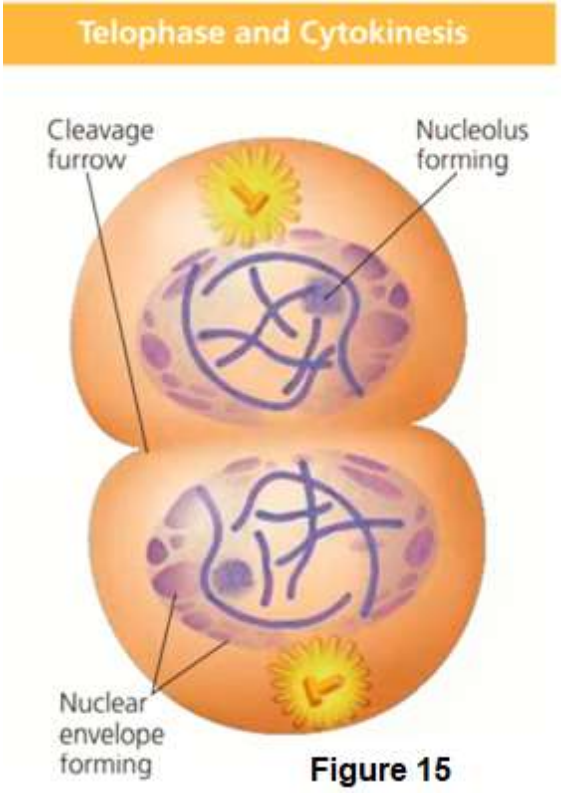


Figure 15

- Chromosomes arrive at the opposite poles of the cell
- The chromosomes uncoil and lengthen or decondense to form chromatin.
- Each pole consists of a complete set of chromosomes enveloped in a new nucleus.

Telophase

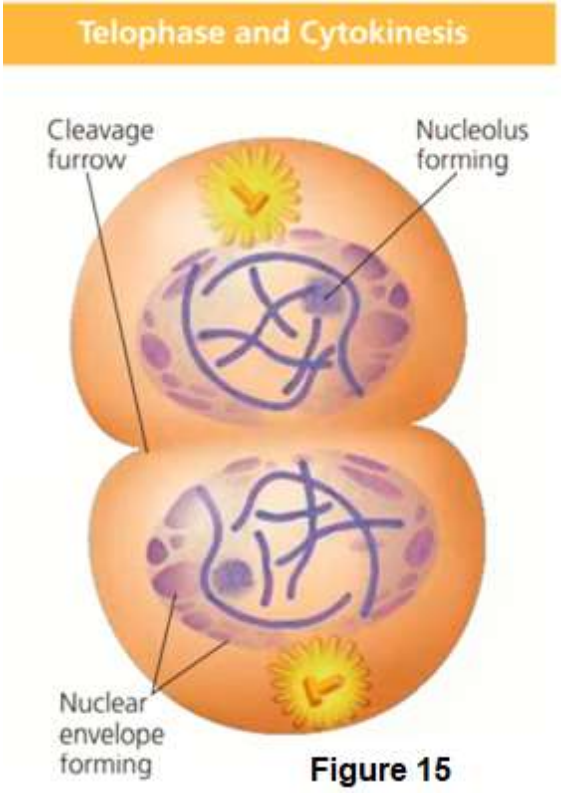


Figure 15

- Nuclear envelope reform and nucleolus reappear.
- The spindle fibers disintegrate
- Two daughter nuclei formed in the cell.

Cytokinesis

Definition:

The division of cytoplasm to form two separate daughter cells. Occurs during telophase in nuclear division.

Cytokinesis in animal cell

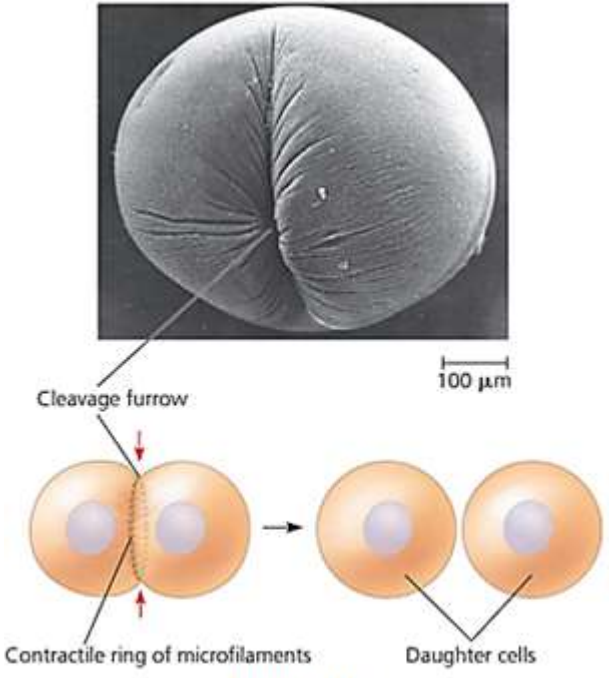


Figure 16

- Cytokinesis occurs by forming **cleavage furrow, a shallow groove** in the cell surface near the old metaphase plate.
- **A contractile ring forms** on the cytoplasmic side of the furrow.
- The cell membrane is pinches toward center of cell begin from outer inward by the contraction of microfilament.

Cytokinesis in animal cell

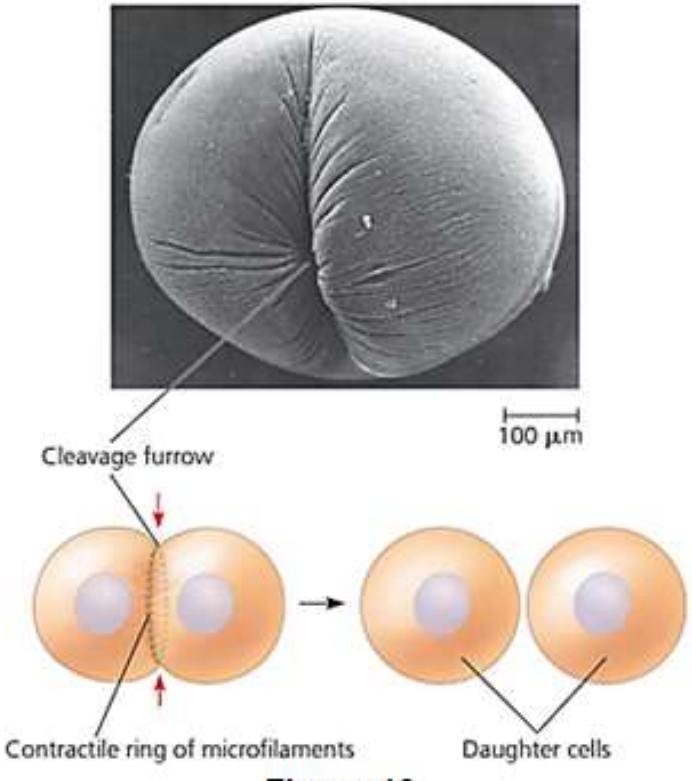
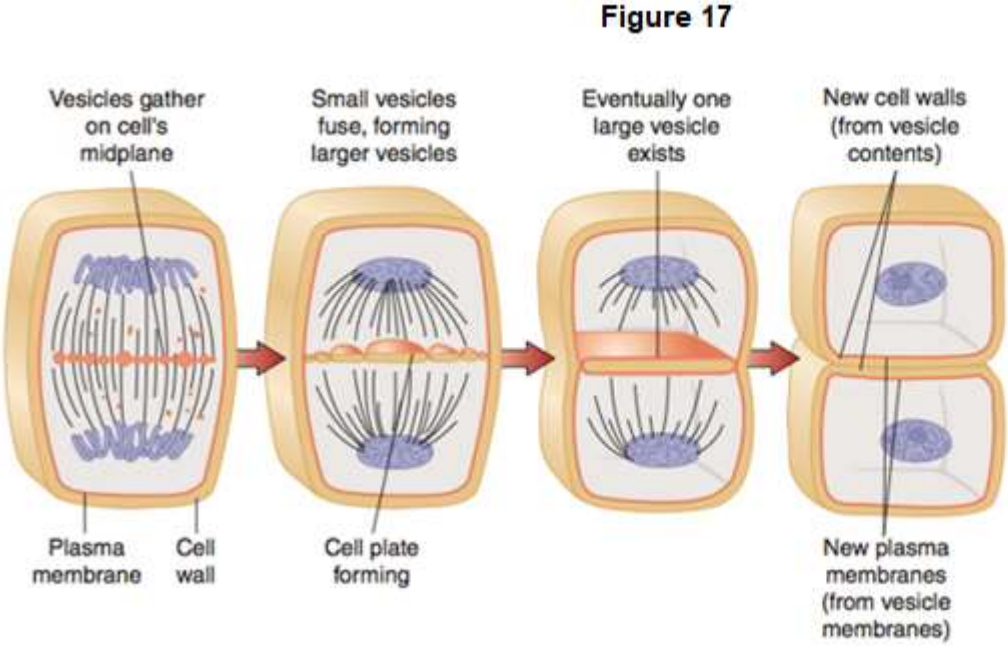
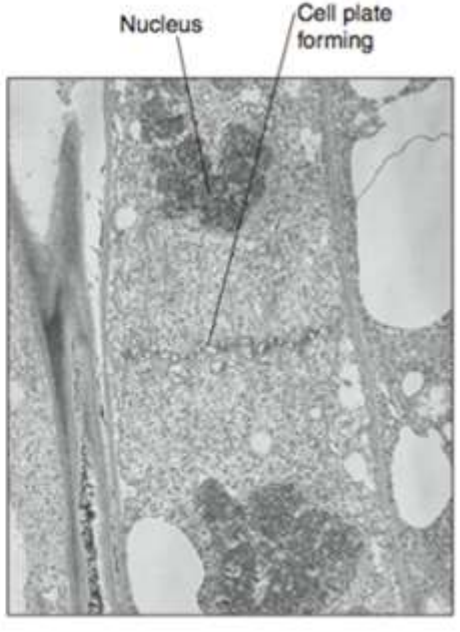


Figure 16

- The cleavage furrow deepens until the parent cell is pinches into two.
- The diameter of the ring reduces.
- The cells are completely **separated**
- Two daughter cells are formed.

Cytokinesis in plant cell





Cytokinesis in plant cell

- Involved **formation of cell plate** during late telophase.

- **Vesicles containing cell wall materials** derived from the Golgi apparatus move along microtubules to the middle of the cell, producing a **cell plate.**

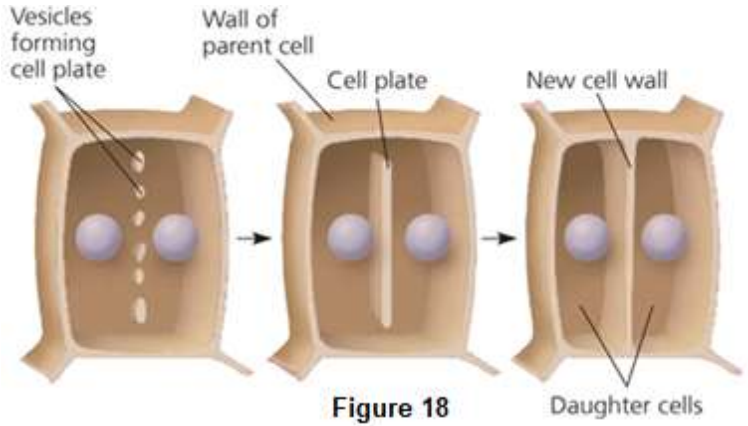


Figure 18

- **Vesicles enlarged and fuse** to form a cell plate.
- Cell plate expands **outward and fuses** with existing membranes.

Cytokinesis in plant cell

- Two daughter cells result, each with its own plasma membrane.
- Meanwhile, a new cell wall formed between the daughter cells.

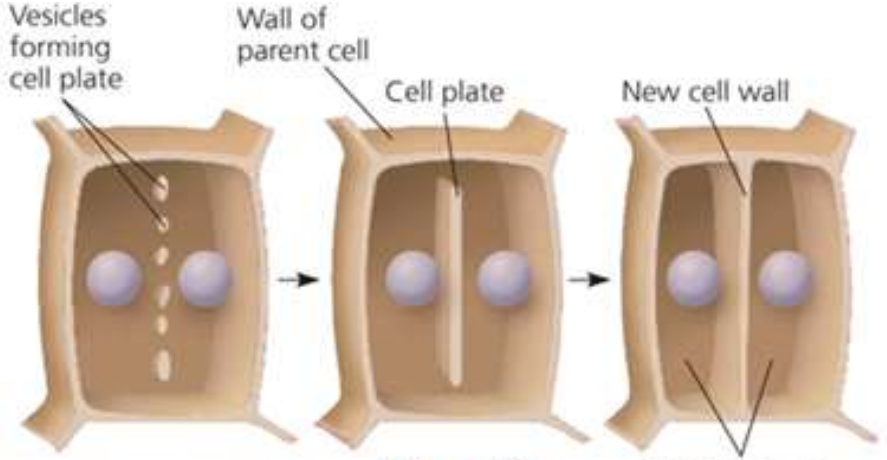


Figure 18

Differences of cytokinesis in animal and plant cell

Differences	
Animal cell	**Plant cell**
Cleavage furrow is formed during cytokinesis.	Cell plate is formed during cytokinesis.
Cytokinesis begins from the outer inwards	Cytokinesis begins from the center outwards
Contractile ring is formed from microfilament during telophase	Cell plate is formed from vesicles during telophase

LEARNING OUTCOMES

3.3 Meiosis

a) Define chromatid, homologous chromosome, synapsis, bivalent, tetrad, chiasmata, crossing over and centromere (C1- LECTURE)

b) State the stages of Meiosis I and Meiosis II (C1- LECTURE)

c) Explain the behaviour of the chromosomes at each stage including leptotene, zygotene, pachytene, diplotene and diakinesis in Prophase I (C3 - TUTOR)

Chromatid and sister chromatid

- A **chromatid** is **one** of two **identical halves** of a **duplicated chromosome.**
- Two copies of a **duplicated chromosome** attached to each other by proteins at the **centromere** is called **sister chromatid.**

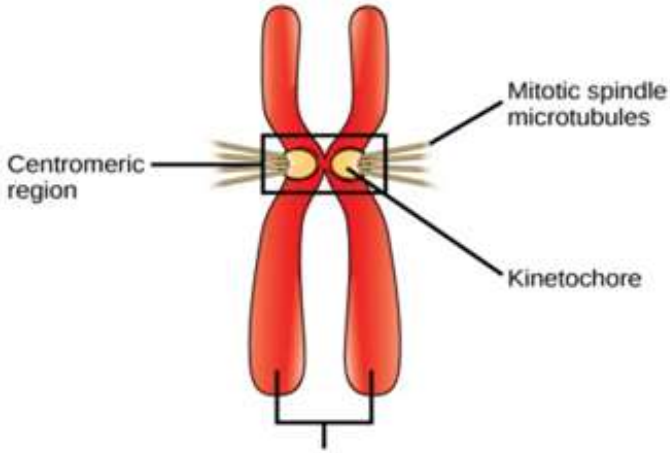
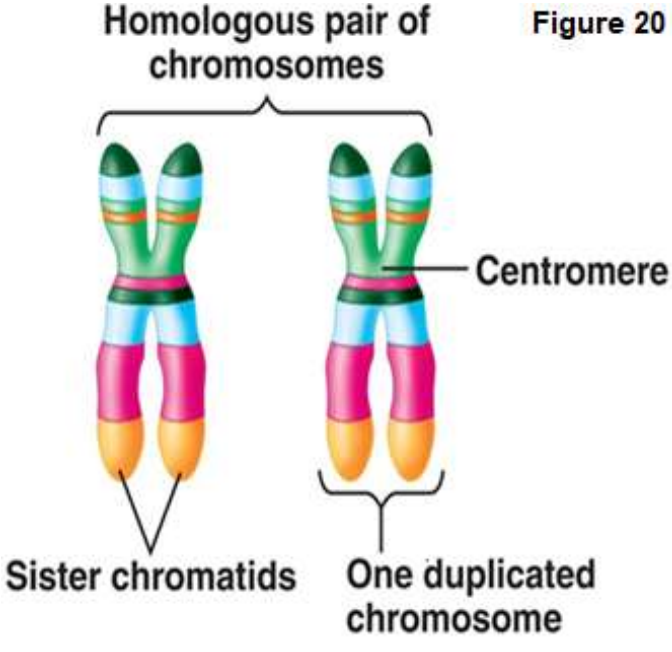


Figure 19

- **While joined**, two sister chromatids make up **one chromosome**.
  **Chromatids are eventually separated during mitosis or meiosis II.*

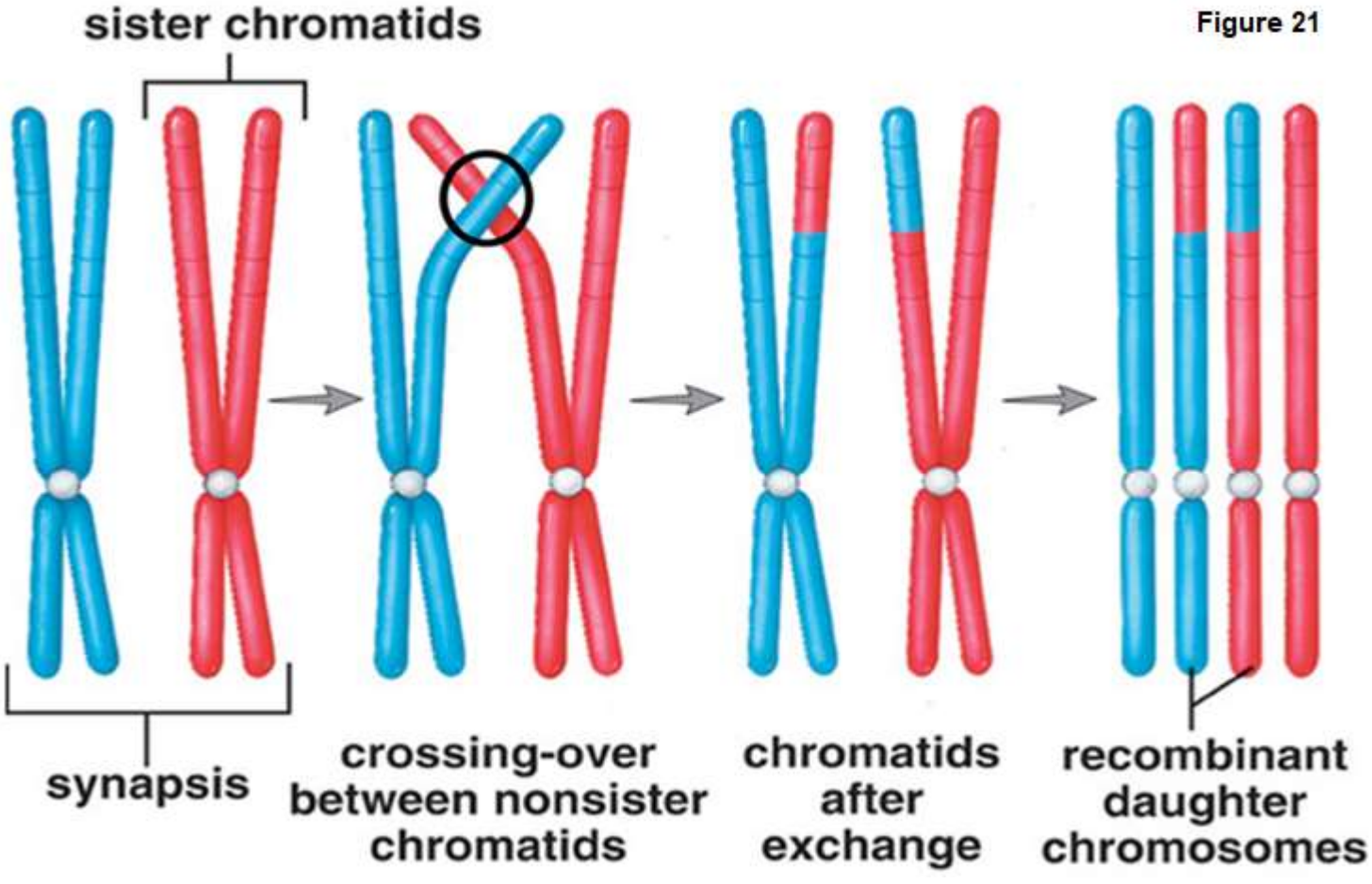
Homologous chromosome

- A **pair of chromosomes** that is **identical in size** or **length**, **genetic information** and **centromere position**.
- **One homologous** chromosome is inherited from the **father**, the **other from the mother**.



Learning Outcomes :

3.3 a) Define chromatid, homologous chromosome, synapsis, bivalent, tetrad, chiasmata, crossing over and centromere (LECTURE)



Synapsis and bivalent

Synapsis

- A **process** of **pairing duplicated homologous chromosome.**

Bivalent

- A **pair of homologous** chromosomes **which undergo synapsis.**

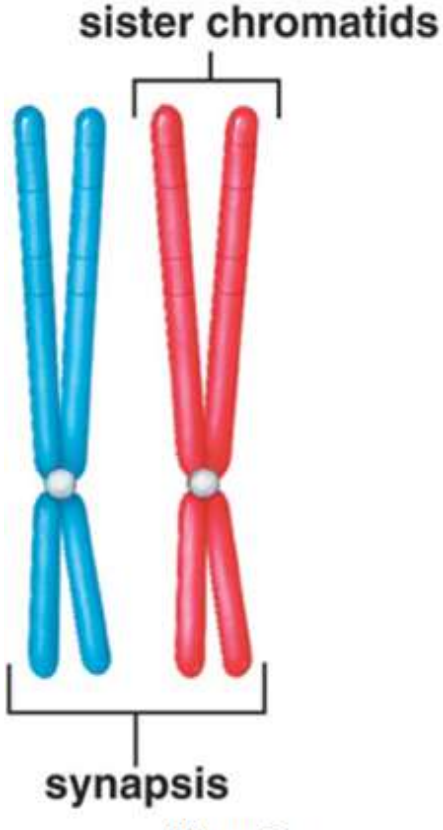


Figure 22

Tetrad and chiasma

Tetrad

- **The chromosome complex formed by the synapsis that consisting <u>four chromatids</u> during prophase I.**

Chiasma

- **The region of crossing over at which two nonsister chromatids are joined.**



crossing-over between nonsister chromatids

Figure 23

Crossing over

Crossing over

- The **exchange of genetic material** between **nonsister chromatids of homologous chromosome** during prophase I of meiosis.

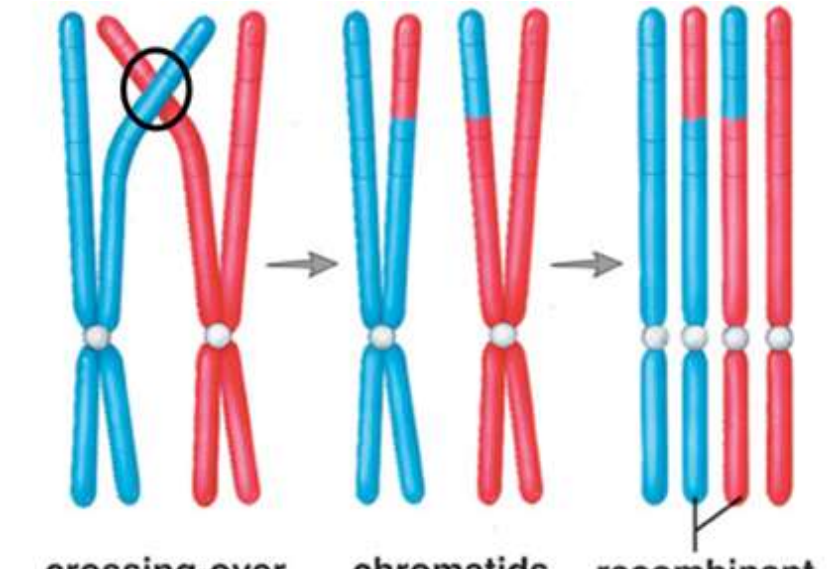


Figure 24

Centromere

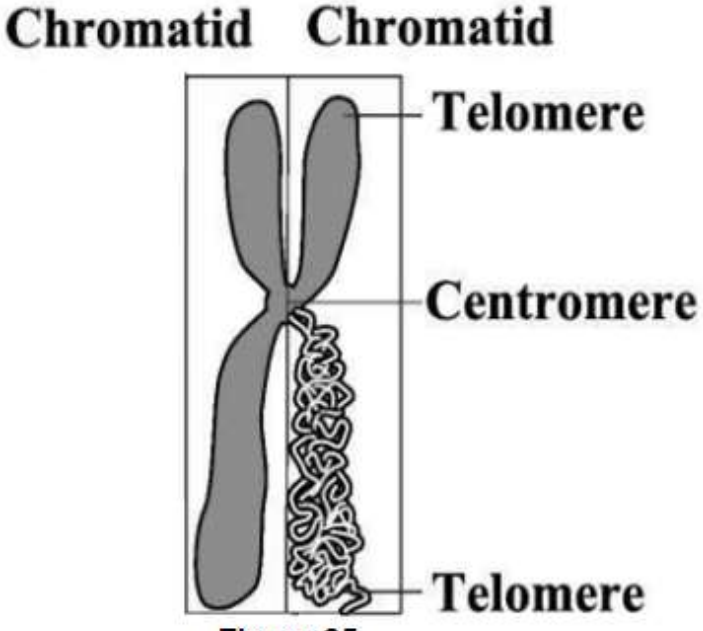


Figure 25

- Constricted region which two sister chromatids attached to each other.
- Each site of centromere has a protein called kinetochore where spindle fiber attach to it.

Meiosis

Definition:

- Is a process by which a cell nucleus divides **twice** to produce **four daughter cells** with **recombined genetic material**.
- Each cell contains **half number of chromosomes** of parent cell.
- The **genetic material** is **not identical** from one cell to another.

Meiosis

Occurs in the reproductive organs, that is in:

- In plant: Ovules / pollen sac / megasporangium / microsporangium - the production of spores

- In animal: Ovary and testis - the formation of gametes (sperm and ovum) through gametogenesis

Stages in meiosis

The stages in meiosis I and II are:

Meiosis I	Meiosis II
Prophase I	Prophase II
Metaphase I	Metaphase II
Anaphase I	Anaphase II
Telophase I	Telophase II

Stages in meiosis

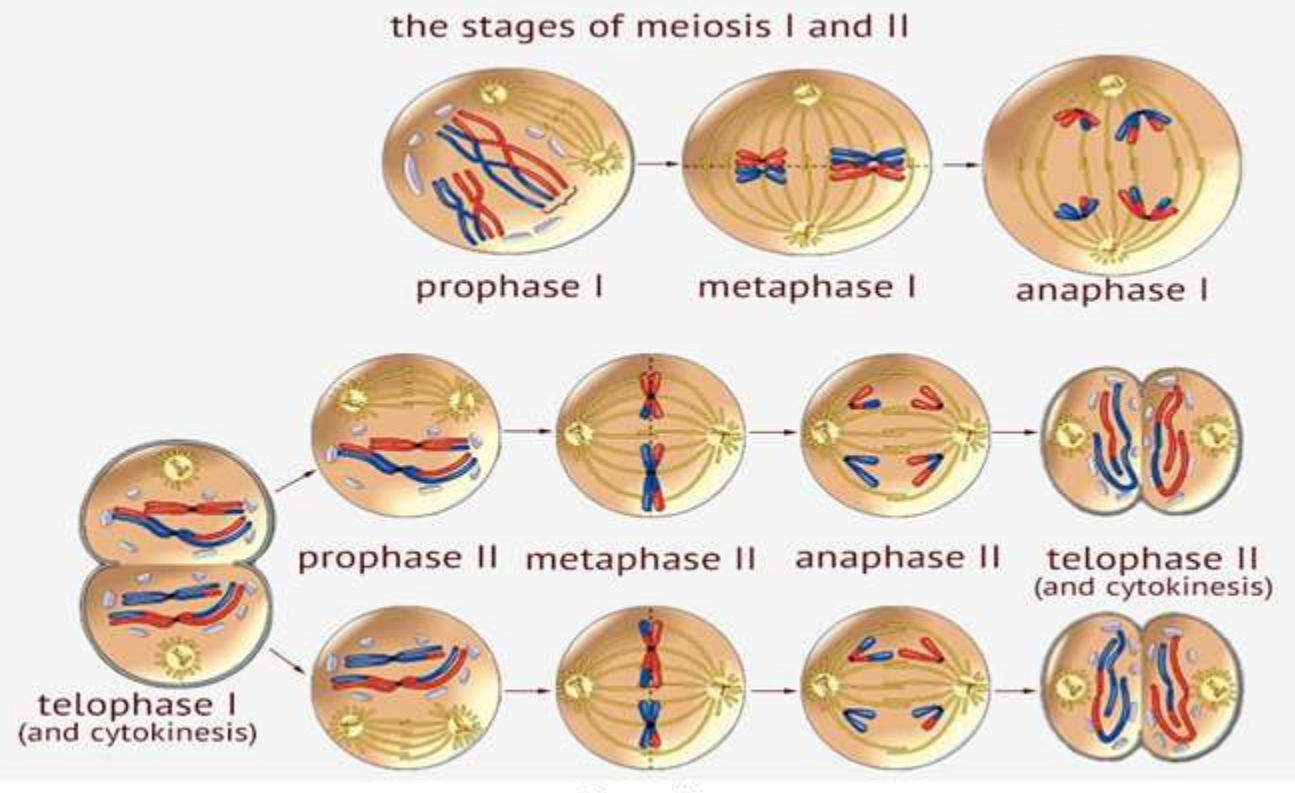


Figure 26

Learning Outcomes :
3.3 c) Explain the behaviour of the chromosomes at each stage including leptotene, zygotene, pachytene, diplotene and diakinesis in Prophase I (TUTOR)

Prophase I

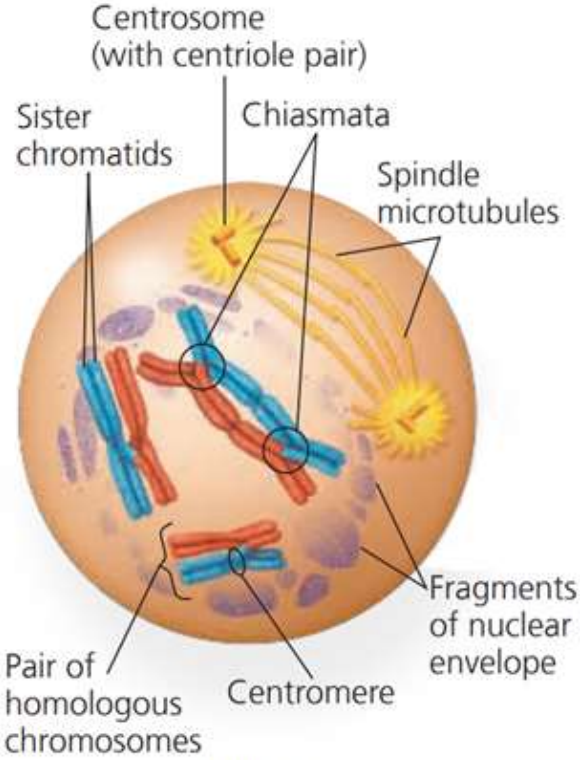


Figure 27

- **Chromosomes condense.**
- **Homologous chromosomes undergoes synapsis forms bivalent/tetrad.**
- **Crossing over occur at chiasmata between nonsister chromatid**

Prophase I

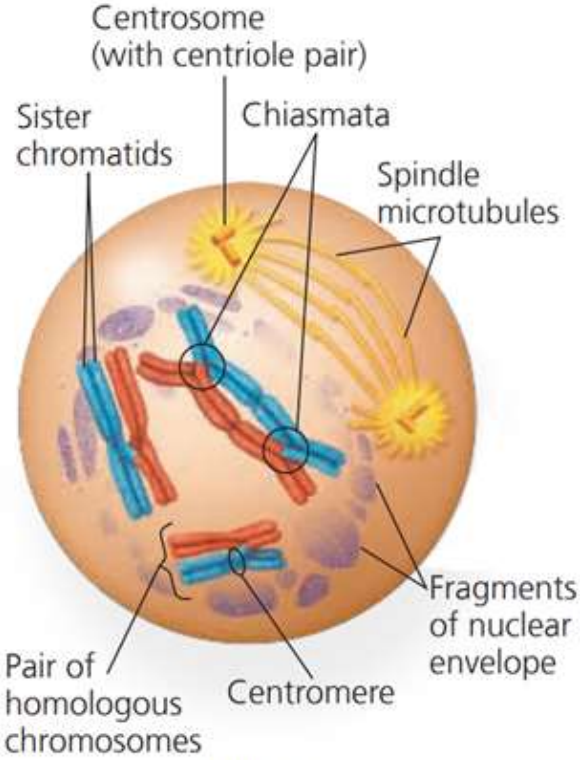


Figure 27

- Centrosome move to opposite poles of the cell
- The nucleolus disappear and nuclear envelope disintegrate.
- Spindle fibers begin to form.

*The **longest** phase.

Learning Outcomes :
3.3 a) Define chromatid, homologous chromosome, synapsis, bivalent, tetrad, chiasmata, crossing over and centromere (LECTURE)

Homologous chromosome

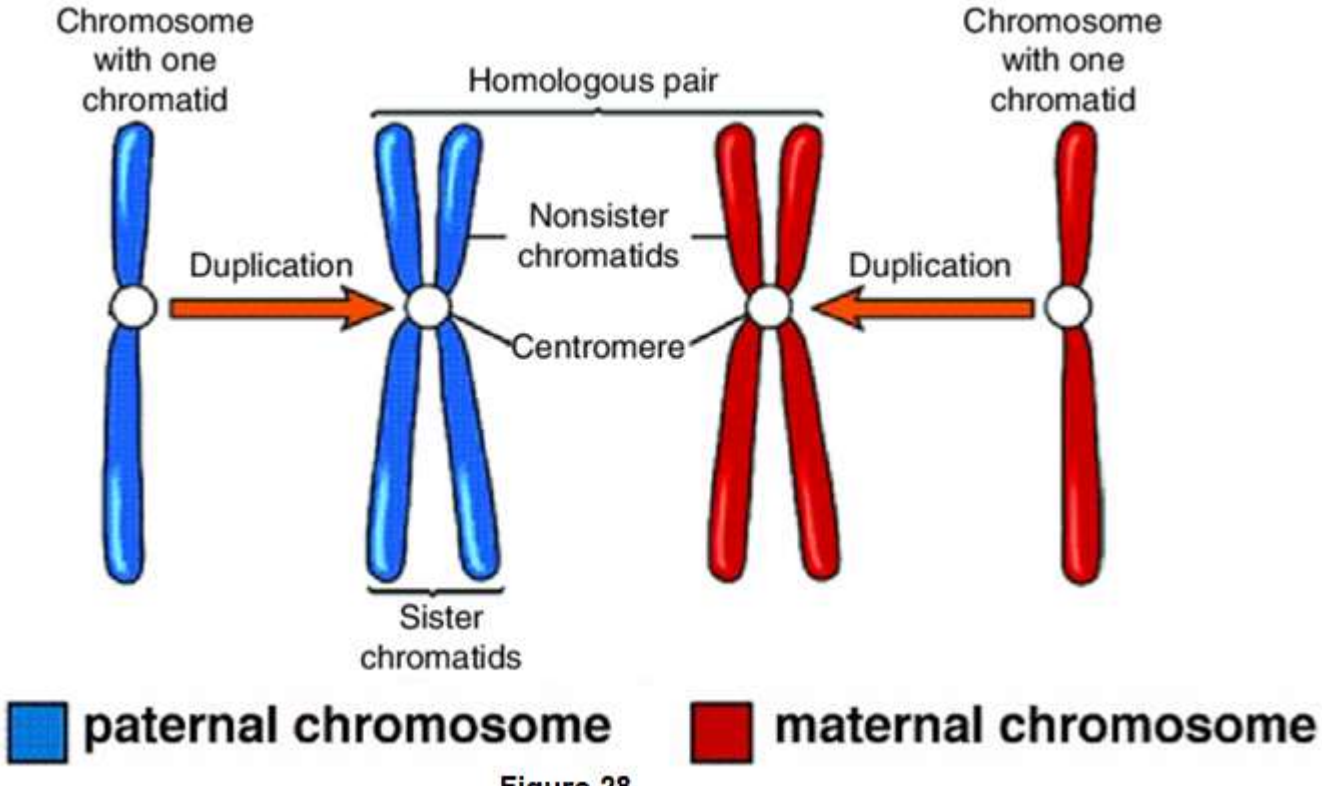


Figure 28

Learning Outcomes :
3.3 a) Define chromatid, homologous chromosome, synapsis, bivalent, tetrad, chiasmata, crossing over and centromere (LECTURE)

Bivalent, Tetrad and chiasma

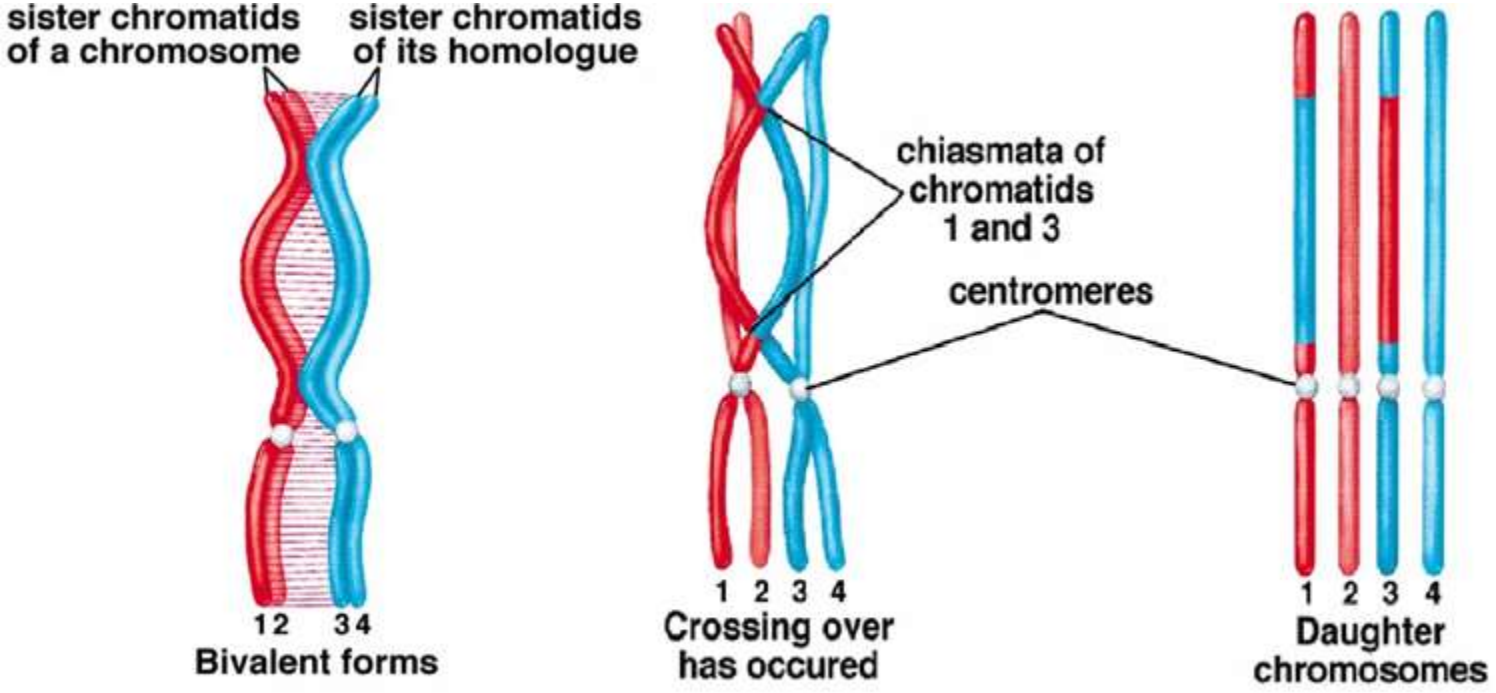


Figure 29

Prophase I

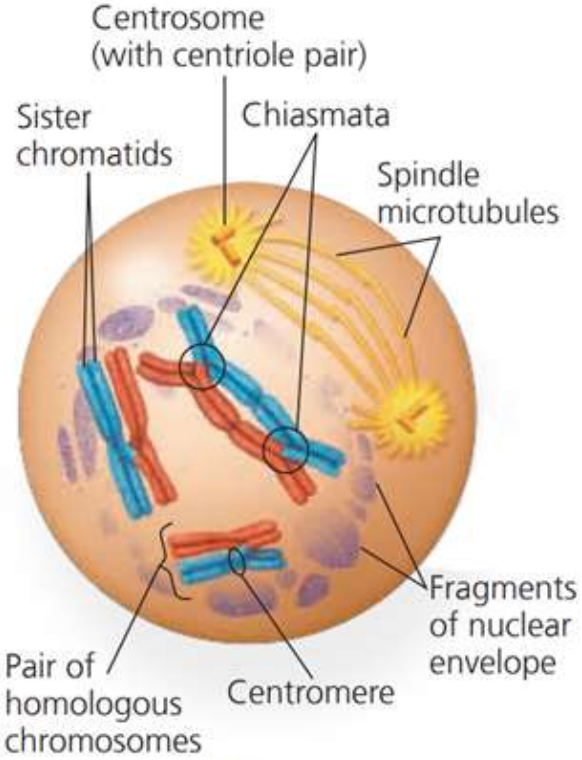


Figure 27

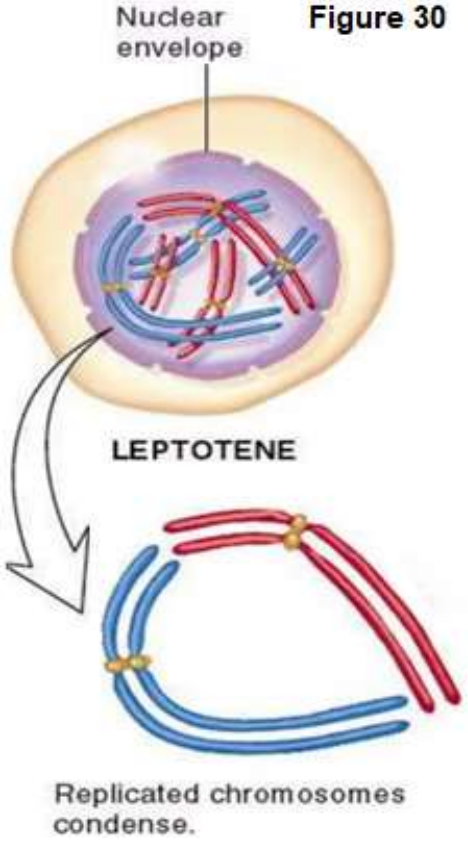
Prophase I

- The ***longest*** *phase*
- Divided into five stages:
  1. Leptotene
  2. Zygotene
  3. Pachytene
  4. Diplotene
  5. Diakinesis

* *Each stage shows its own chromosome behavior (**in bold words**)*

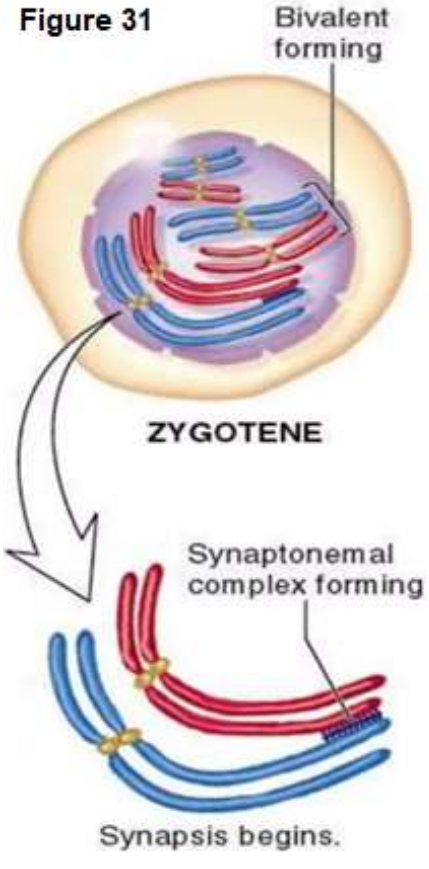
Prophase I : Leptotene

- Chromosomes in the form of fine, long fine threads begin to **condense** and become visible but have not associated in pairs yet.



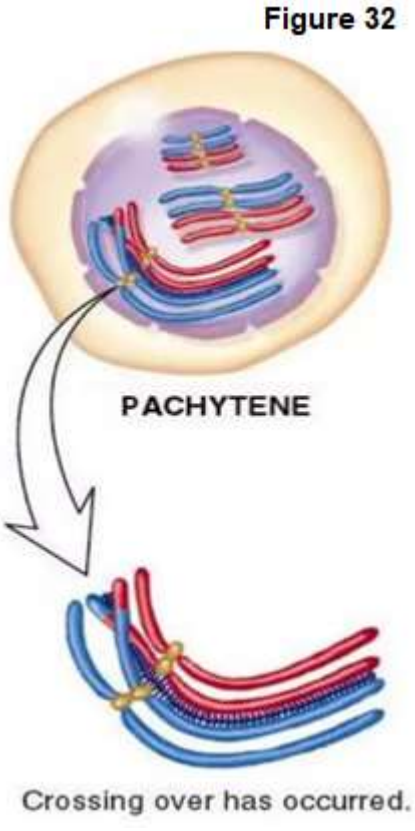
Prophase I : Zygotene

- **Synapsis** occurs.
- Homologous chromosome come together as pairs called **bivalent or tetrad.**
- A special group of proteins form a zipper-like structure called the **synaptonemal complex** which holds the chromosomes together.



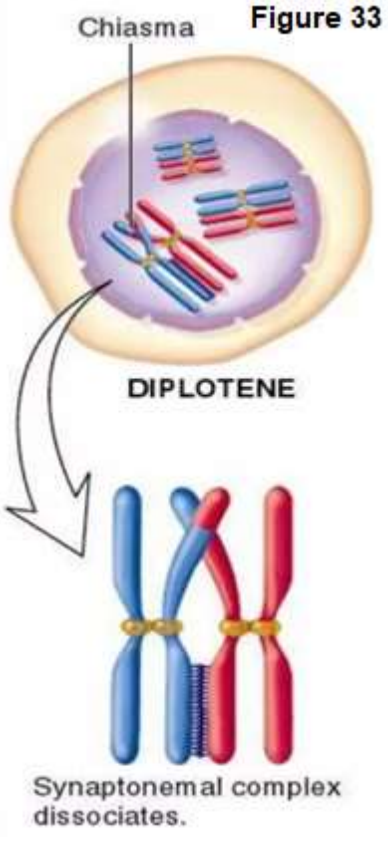
Prophase I : Pachytene

- Begins when synapsis is complete.
- **Crossing over** occurs between nonsister chromatids of homologous chromosomes exchange their genetic material



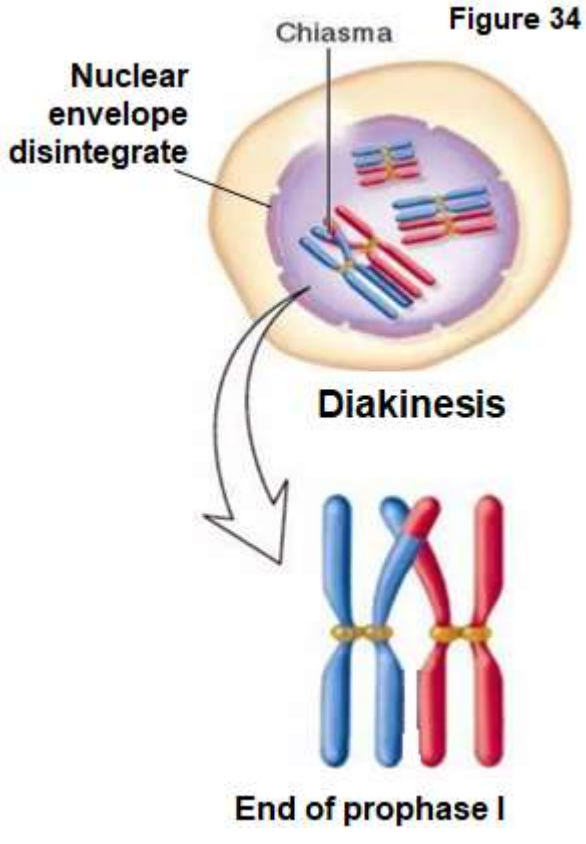
Prophase I : Diplotene

- **Separation** of homologous chromosome that are paired in the bivalents then begins.
- Due to dissemble of synaptonemal complex.
- A tetrad of four chromatids become visible.
- Homologous chromosomes still attach at chiasma.



Prophase I : Diakinesis

- The chromosome fully condense as the two bivalents move further away from each other.
- Chiasma appear as open crosses.
- Nucleoli disappear & nuclear envelope disintegrate.



Learning Outcomes :

3.3 c) Explain the behaviour of the chromosomes at each stage including leptotene, zygotene, pachytene, diplotene and diakinesis in Prophase I (TUTOR)

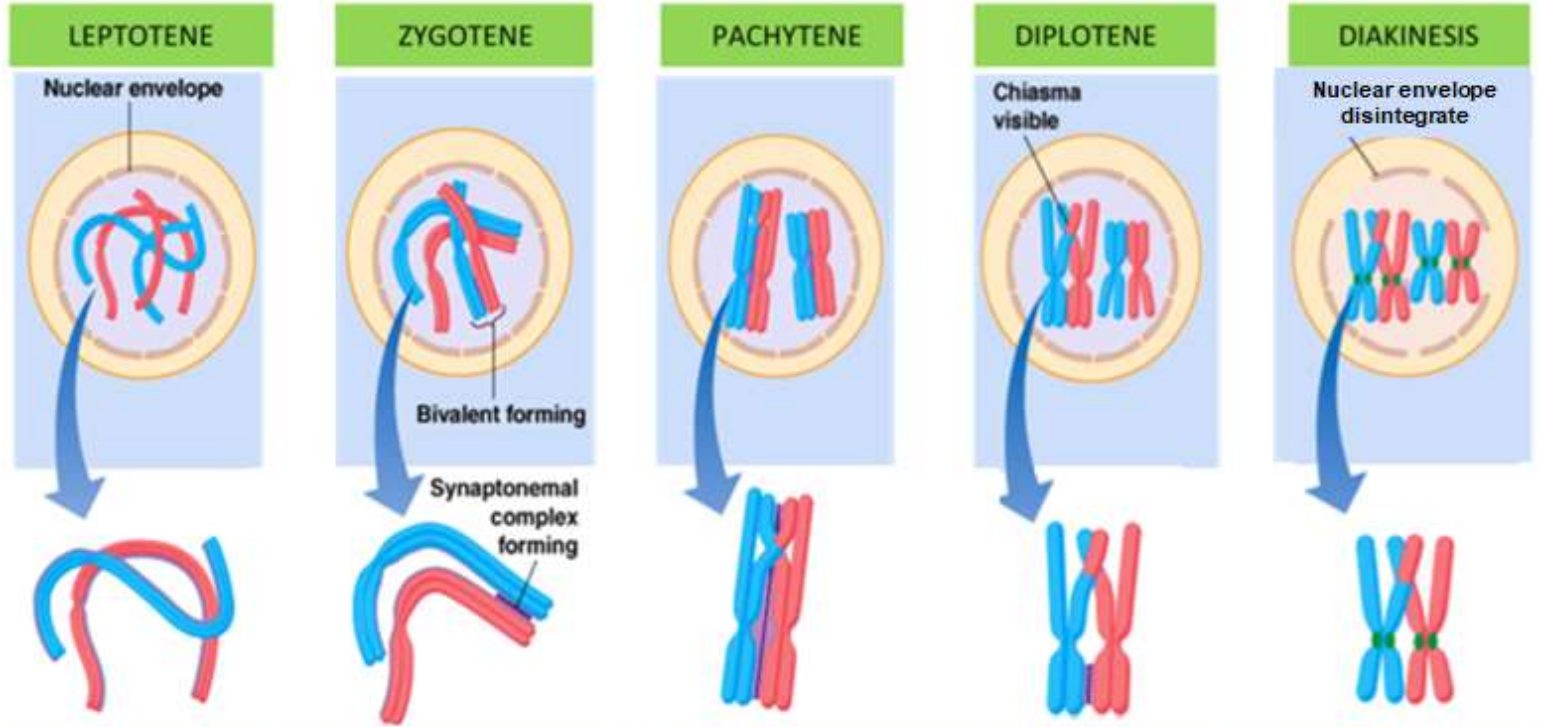


Figure 35

Metaphase I

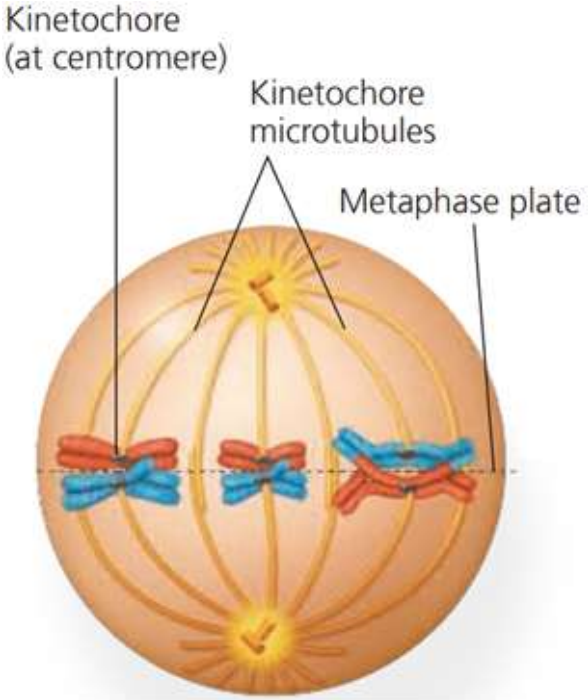


Figure 36

- **Pairs of homologous chromosomes aligned at the metaphase plate.**
- **Each pair has lined up independently of other pairs (independent assortment).**
- **Homologous chromosome remain attach to one another at chiasmata.**

Metaphase I

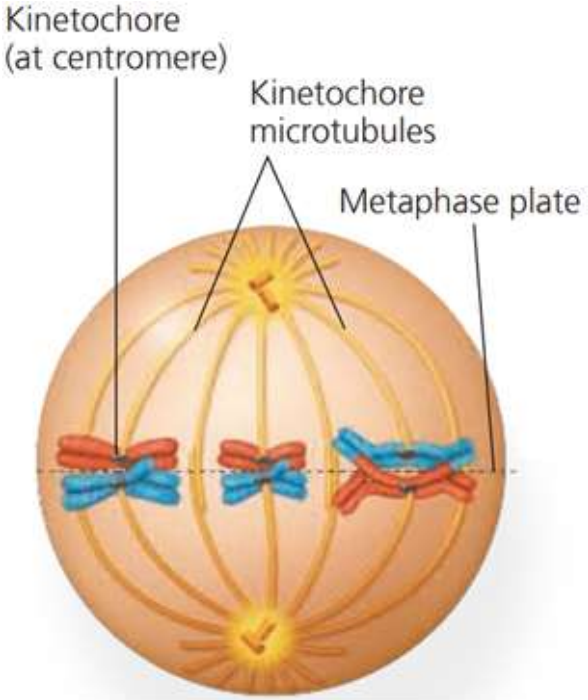


Figure 36

- **Microtubule of spindle fiber from one pole to kinetochore of one chromosome.**
- **One chromosome of each homologous chromosome face different pole.**
- Centrosomes are at opposite poles of the cell.
- Spindle fibers attached at their centromeres.

Anaphase I

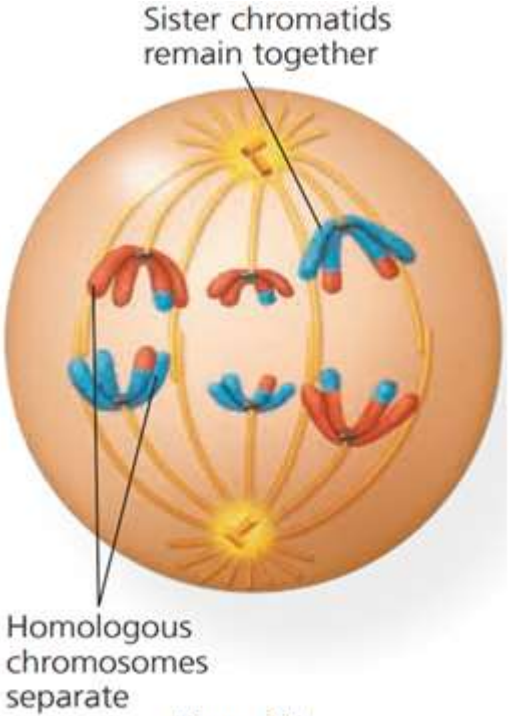


Figure 37

Homologous chromosomes separated and move towards opposite poles of the cell.

Each of the chromosomes still consist of two sister chromatids remain attached at the centromere.

Anaphase I

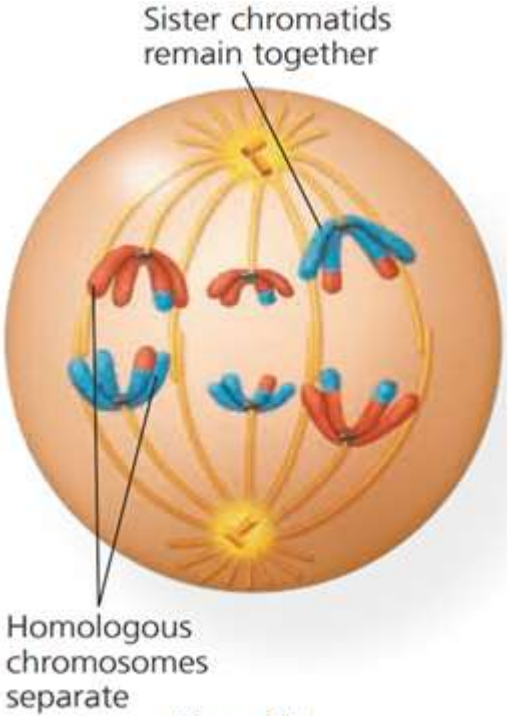


Figure 37

- Movement separated homologous chromosomes leads by centromeres.
- Centromeres of chromosomes are not separated

Telophase I

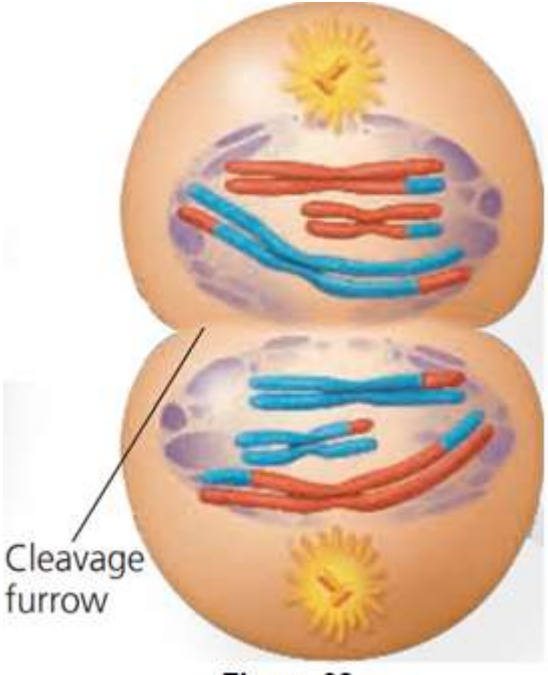


Figure 38

- **Chromosomes arrive at opposite poles.**
- **Each pole has a haploid (n) number of chromosome.**
- **Chromosomes uncoiled and lengthen or decondense forming chromatins.**

Telophase I

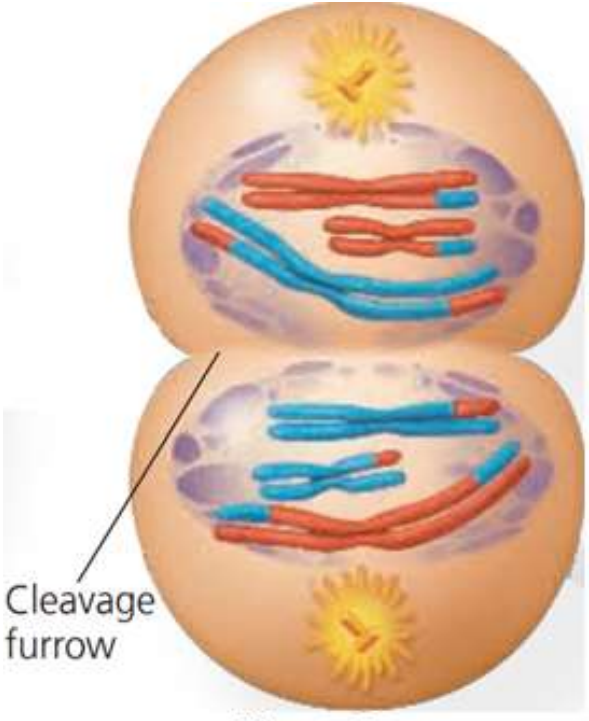


Figure 38

- The spindle fibers disintegrate.
- The nuclear envelope reforms and nucleoli reappear.
- Cytokinesis begins at late telophase I by forming cleavage furrow (animals) or cell plate formation (plants).

Prophase II



Figure 39

- Chromatin shorten and thicken (condense) and visible chromosome.
- Each chromosome consists of two sister chromatids attached together at the centromere.

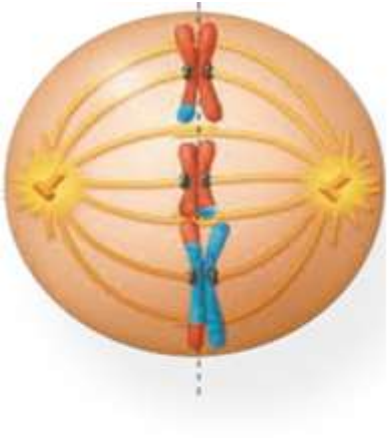
Prophase II



Figure 39

- Centrosomes move away from each other.
- Microtubules (aster) extend from centrosomes
- Spindle fibers begin to form.
- Nucleolus disappear.
- At late prophase II, nuclear envelope disintegrates.

Metaphase II



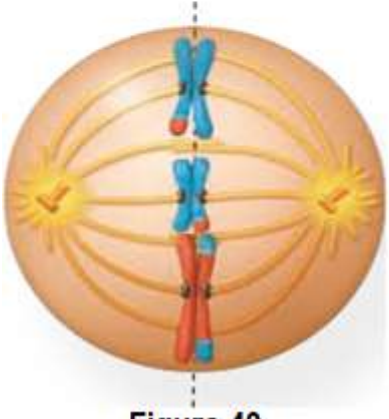


Figure 40

- **Chromosomes are aligned at metaphase plate.**
- **Microtubules of spindle fiber from each pole attach to the centromere of the same chromosome.**
- Centrosomes are at opposite poles of the cell.
- No chiasmata on chromosome.

Anaphase II

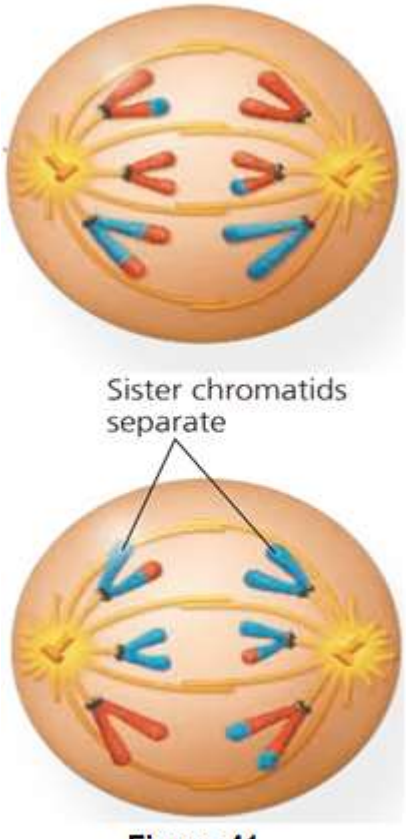


Figure 41

- **Centromere split.**
- **Sister chromatids separate and move to the opposite poles due to the shorten of spindle fibers.**
- **The separated chromatids now called as chromosomes.**

Learning Outcomes :
3.3 c) Explain the behaviour of the chromosomes at each stage including leptotene, zygotene, pachytene, diplotene and diakinesis in Prophase I (TUTOR)

Telophase II

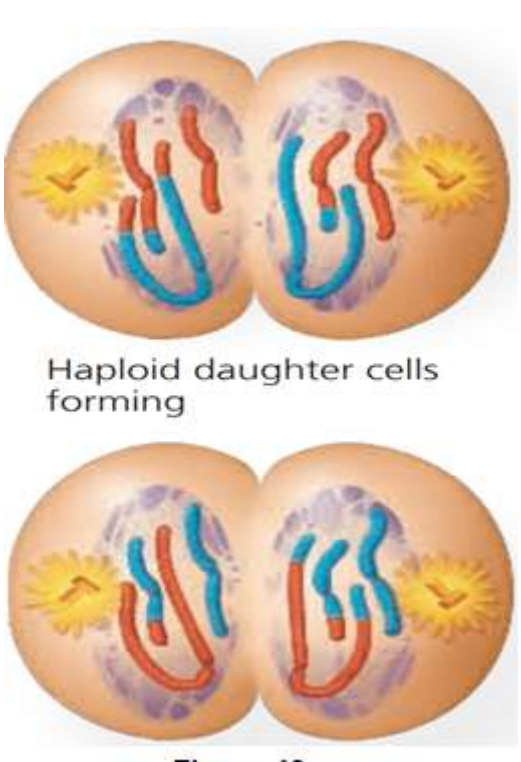


Figure 42

- Chromosomes arrive at the opposite poles of the cell
- Chromosomes uncoil and lengthen or decondense to form chromatin.
- At the end, produce 4 haploid daughter cells (gamete cells) which genetically distinct from one another.

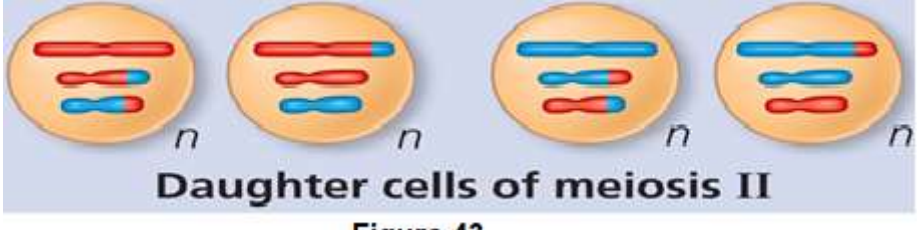


Figure 43

Telophase II

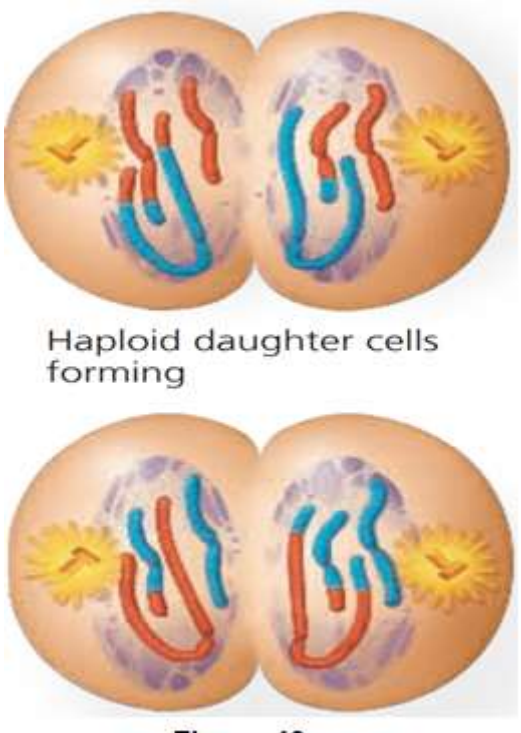


Figure 42

- Spindle fibers disappear.
- Nuclear envelope reform and nucleoli reappear.
- Cytokinesis occurs.

Stages of meiosis I

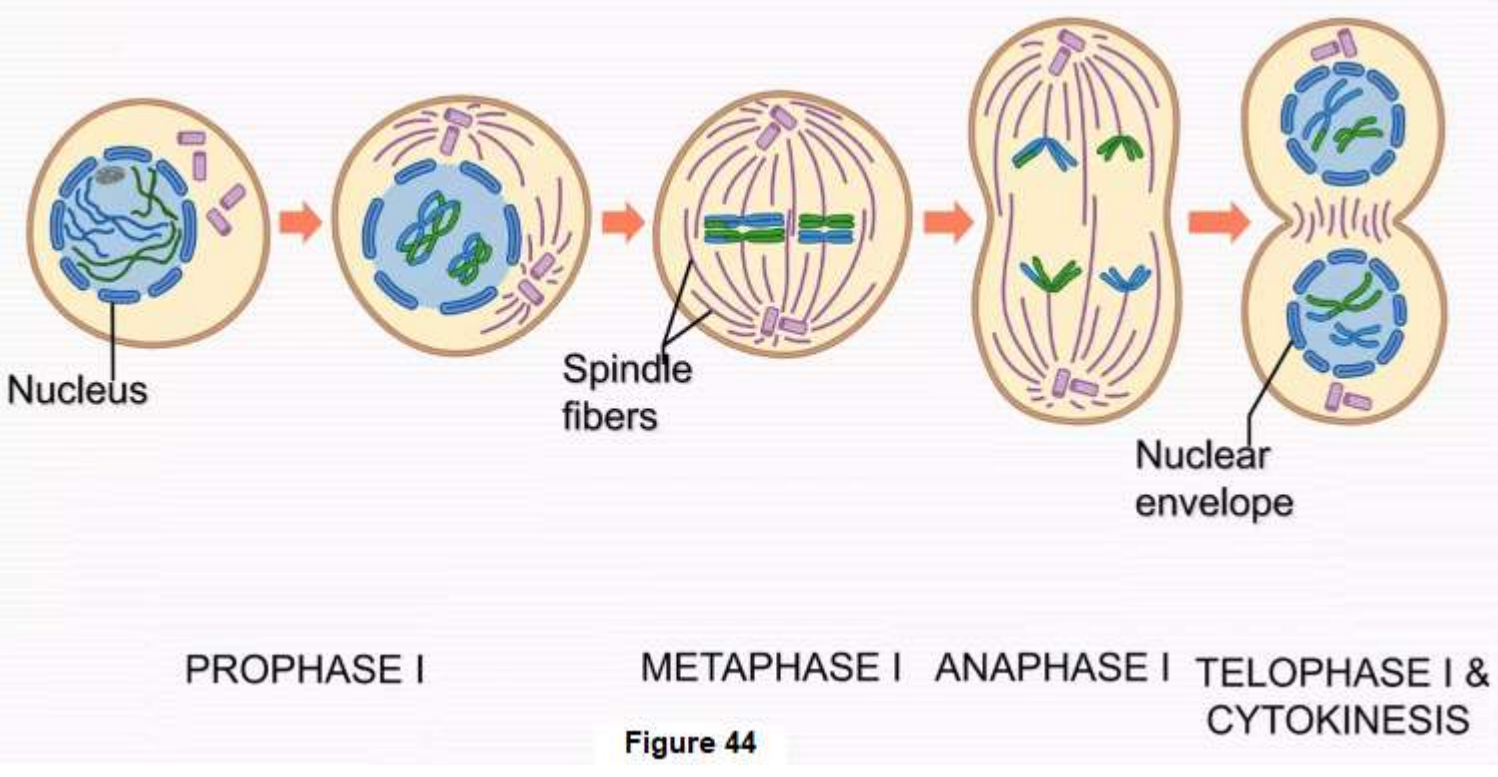


Figure 44

Stages of meiosis II

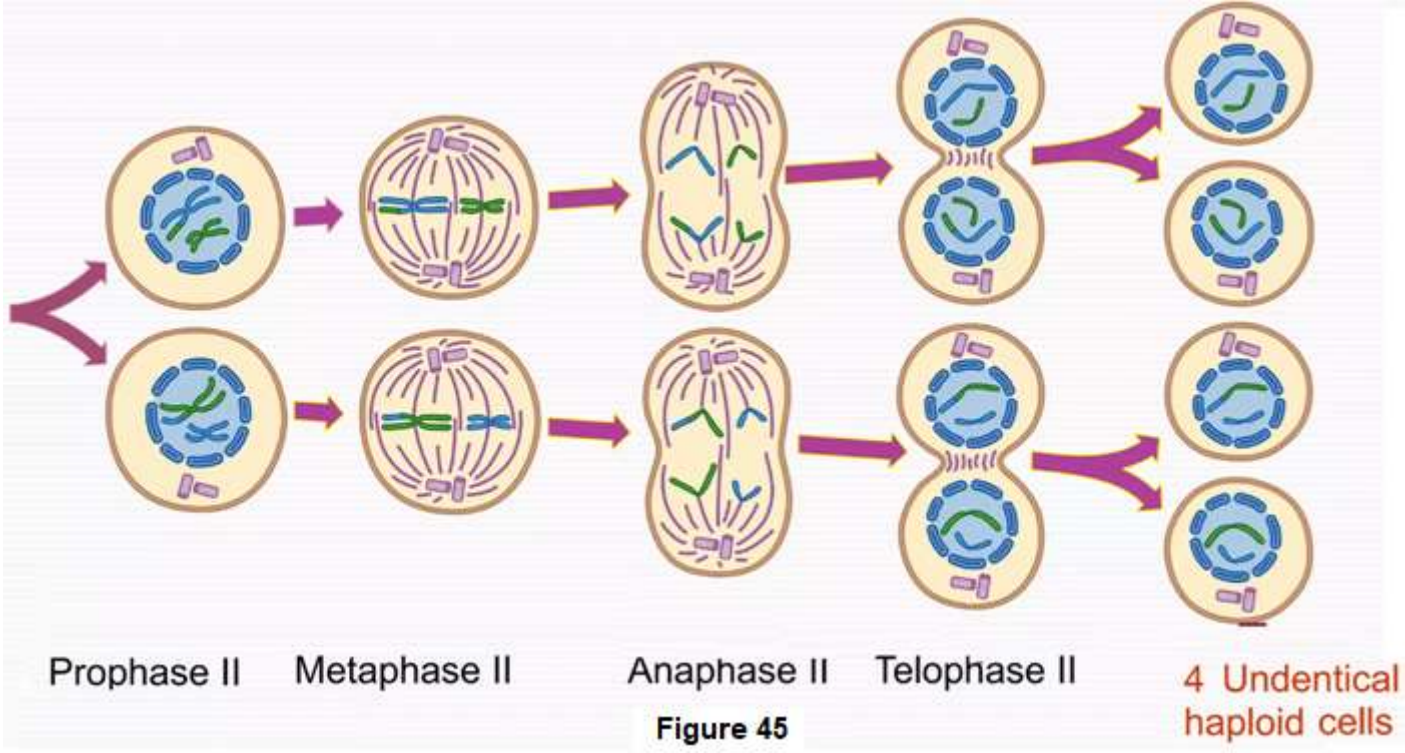


Figure 45

Significance of meiosis

1. **To produces haploid gametes.**
   - Meiosis produces sperm and ovum for sexual reproduction.
   - Halving the chromosome number to ensures that when gametes fuse to form a zygote with normal chromosome number is maintained over generations.
2. **To increase genetic variation by**:
   - Independent assortment of homologous chromosomes during metaphase I
   - Crossing over between nonsister chromatids during prophase I

Comparison between mitosis and meiosis

Similarities
1. Both occur in eukaryotic cells.
2. Both involve four basic stages (prophase, metaphase, anaphase and telophase) for division.

Comparison between mitosis and meiosis

Differences	
Mitosis	**Meiosis**
Occurs in somatic cells.	Occurs in germ cells (animal) or megasporocyte/ microsporocyte (plant)
Produce 2 daughter cells from single parent cell	Produce 4 daughter cells (gametes) from single parent cell
Daughter cells are genetically identical to parent cell	Daughter cells are genetically different from parent cell
Daughter cells have same chromosome number as parent cell [daughter cells are diploid (2n)]	Daughter cells have half number of chromosome from parent cell [daughter cells are haploid (n)]

Comparison between mitosis and meiosis

Differences	
Mitosis	**Meiosis**
Involve 1 cell division	Involve 2 cell division (Meiosis I & II)
No crossing over / No chiasma form	Crossing over occurs between nonsister chromatids during prophase I / Chiasmata remain between homologous chromosome.
No synapsis occurs during prophase.	Synapsis of homologous chromosome occurs during prophase I
Cytokinesis occurs once.	Cytokinesis occurs twice.

Comparison between mitosis and meiosis

Mitosis	Meiosis
During metaphase: Alignment of chromosomes at metaphase plate	• During metaphase I: alignment of homologous chromosomes at metaphase plate. • During metaphase II: alignment of chromosomes / sister chromatids at metaphase plate
During anaphase: Separation of sister chromatids	• During anaphase I: separation of homologous chromosomes • During anaphase II: separation of sister chromatids

Tip LKC : Identical to parent cell (X)
Genetically identical to parent cell (/)

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- Figure 4 – https://www.slideserve.com/tyler/chapter-terms#google_vignette
- Figure 5 – Campbell (12th ed, Page 114 & 116) E-book
- Figure 6 – Solomon (11th Ed. Page 213)
- Figure 7 - https://scihub.se/https:/link.springer.com /chapter/10.1007/978-3-319-76457-3_1
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- Figure 18 – http://www.zo.utexas.edu/faculty/sjasper /bio301l/respiration.html
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