

# Cytology

- ❑ **Introduction**
- ❑ Cell Biology deals with the study of cells. It is also known as Cellular Biology or Cytology.
- ❑ **Important Events/Discoveries in Cell Biology**

# Nucleus

- ❑ Nucleus is the largest membrane-bound cell organelle which is known as the 'master cell organelle'.
- ❑ It is the first organelle to be discovered
- ❑ It is mainly concerned with the gene expression as well as replication of DNA.
- ❑ Nucleus was discovered by Robert Brown (1831) in the orchid root cells.

# Nucleus cont'd

- A typical nucleus consists of following components:
  - Nuclear envelop
  - Nucleoplasm
  - Nucleolus
  - Chromatin fibres

# Nuclear Envelope

- ❑ Nucleus is surrounded by an envelope called nuclear envelope which isolates it from the cytoplasm.
- ❑ It is a double-membrane structure called outer and inner nuclear membranes.
- ❑ These membranes are lipoprotein membranes.

# Nuclear Envelope cont`d

- ❑ The outer membrane may contain ribosomes and is continuous with the endoplasmic reticulum
- ❑ The outer membrane bears small pores called nuclear pores.
- ❑ Each nuclear pore is surrounded by a ring-like structure called annulus.
- ❑ The pores and annuli together constitute the pore complex.

# Nuclear Envelope cont'd

- Through nuclear pores, exchange of material occurs between the cytoplasm and nucleus.
- The inner surface of the inner membrane bears mesh work of fibrous protein called nuclear lamina.
- Nuclear lamina connects inner nuclear membrane with chromatin.

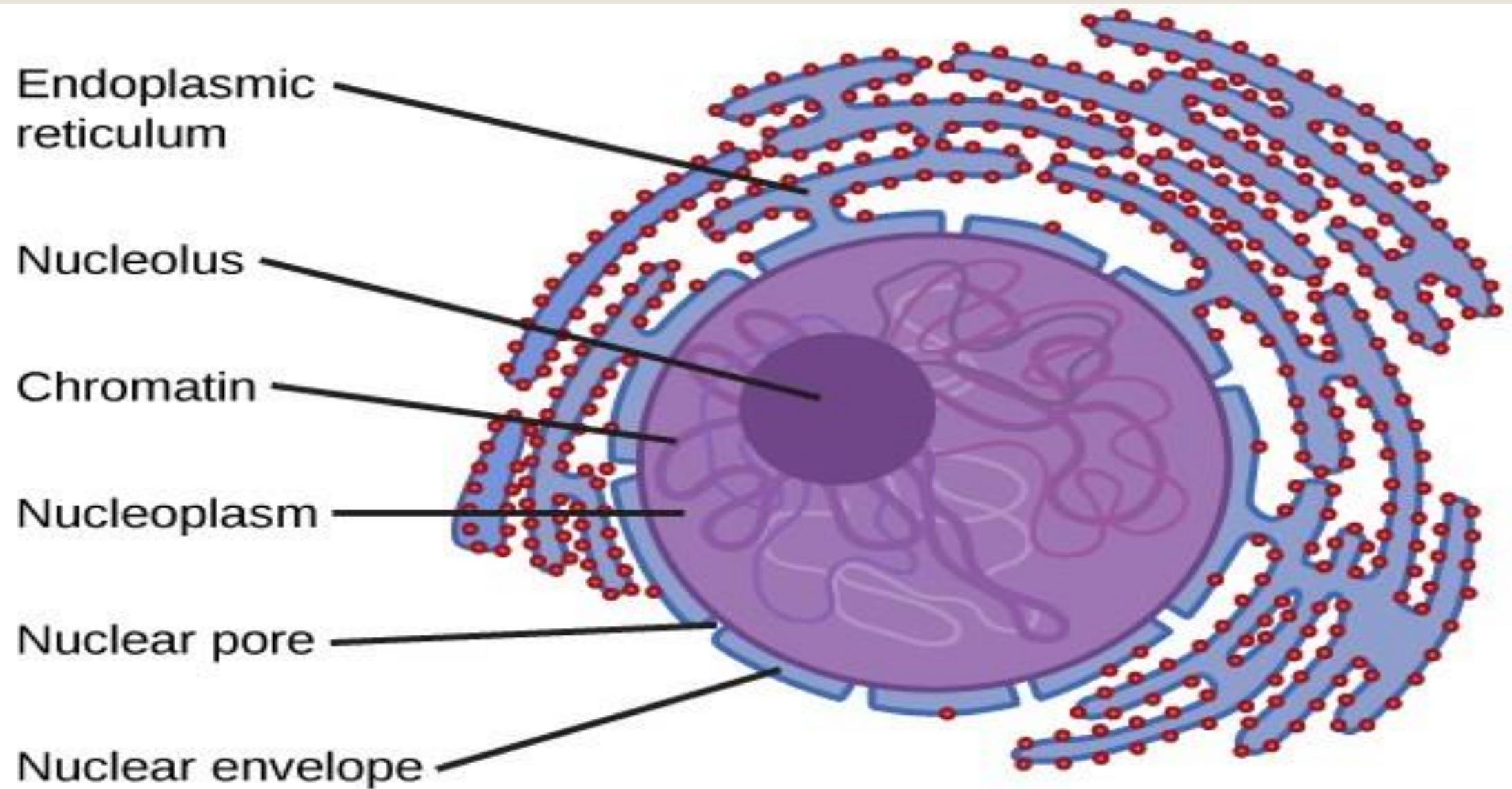
## Nuclear Envelope cont'd

- Nuclear laminas regulate assembly and disassembly of nuclear membrane during cell division.
- Nuclear laminas are made up of three principal proteins, viz., laminas A, B and C.
- Nuclear membranes are impermeable to most molecules.
- Nuclear membranes disappear during late prophase and reappear during telophase

# Nucleoplasm

- ❑ Nucleus contains a jelly-like fluid called nucleoplasm.
- ❑ Nucleoplasm contains various enzymes involved in metabolic pathways as well as replication of DNA and transcription of RNA.
- ❑ Some proteins present in the nucleoplasm are involved in the regulation of chromatin structure and function

# Structure of the Nucleus



# Nucleolus

- ❑ It is a large spherical structure present in the nucleoplasm.
- ❑ It was discovered by Fontana (1728) and the term 'nucleolus' was coined by Bowman (1840).
- ❑ Nucleolus contains 80 per cent proteins and 20 percent mixture of DNA and RNA.

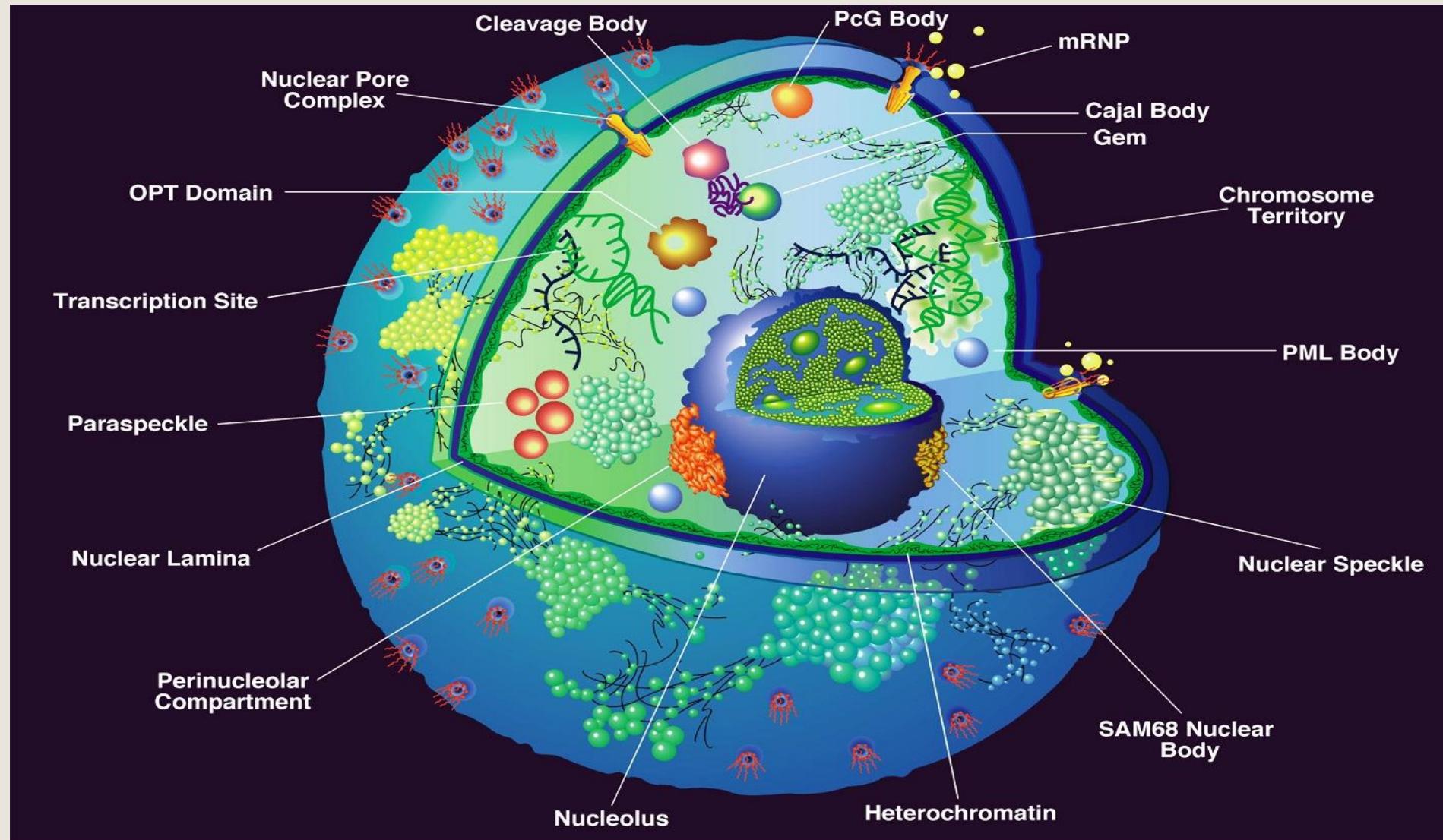
## Nucleolus cont`d

- Nucleolus is formed by a special region of the chromosome called 'Nucleolar Organiser Region' (NOR).
- In eukaryotes, nucleolus is the site of synthesis of ribosomes and its assembly.
- A cell may contain up to four nucleoli, but within each species the number of nucleolus is fixed.
- Nucleolus is renewed at each cycle

# Chromatin Fibres

- ❑ The thread-like filamentous structure present in the nucleoplasm is termed as chromatin fibres.
- ❑ Chromatin fibres are complex of DNA and proteins.
- ❑ Chromatin fibres are observed at interphase stage.

# The structure of a living cell



# Chromatin Fibres

- ❑ During cell division, these chromatin fibres become short and thick thread-like structures called chromosomes.
- ❑ Chromatin materials are of two types, viz., euchromatin and heterochromatin.

## Euchromatin

- \* It stains lightly.
- It is granular.
- It occurs in the diffused region.
- It is genetically active.
- It shows normal crossing over.
- It replicates during early S-phase.
- It is found in the acetylated form.
- It does not exhibit heteropycnosis.
- It is less affected by temperature, sex, age, etc.

## Heterochromatin

- It stains deeply
- It is fibrous.
- It occurs in the condensed region.
- It is relatively inert genetically.
- The frequency of crossing over is less.
- It replicates during late S-phase.
- It is found in the non-acetylated form.
- It exhibits heteropycnosis.
- It is more affected by temperature, sex, age, etc.

# Heterochromatin

- ❑ There are of two types:

## 1. Constitutive Heterochromatin

- ❑ It is found in all cells and all stages of life cycle.
- ❑ DNA of this type of chromatin is permanently inactive.
- ❑ Constitutive DNA is highly repetitive.
- ❑ It remains in condensed state throughout the cell cycle

# Constitutive Heterochromatin cont'd

- ❑ It is never transcribed.
- ❑ Most of the chromatin occurring around centromere, in the telomeres, in C bands of chromosomes is constitutive heterochromatin

# **Types of heterochromatin**

## **2. Facultative Heterochromatin**

- ❑ It develops during the development of the organisms.
- ❑ It has no permanent condensation.
- ❑ It follows periodic dispersal and in dispersal state it is actively transcribed.

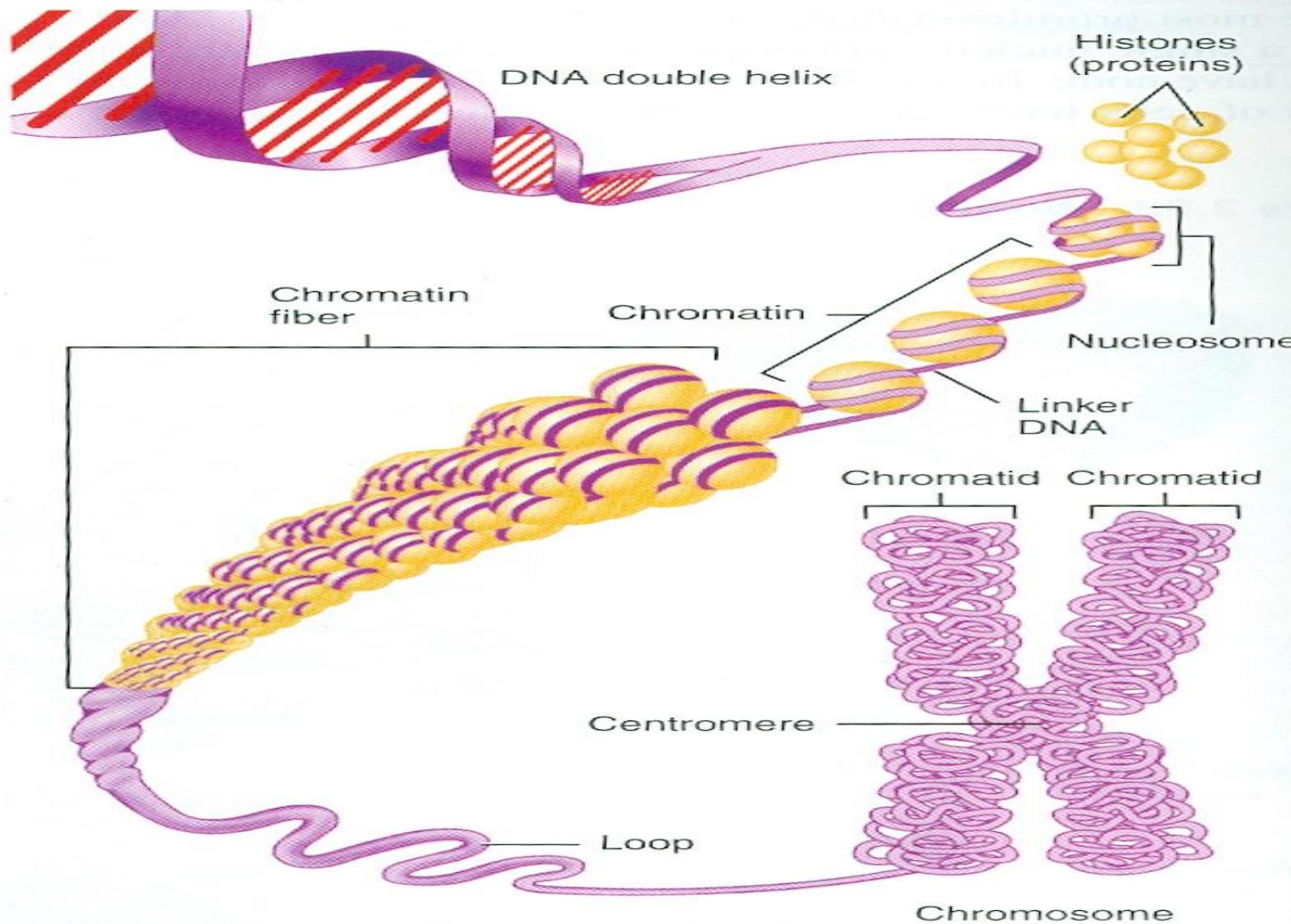
# Facultative Heterochromatin

- ❑ It may have extra chromosomal inheritance.
- ❑ It results from the inactivation of one of the two X chromosomes in females

# Chromosome

- ❑ Chromosomes are nuclear components having the power of self-duplication.
- ❑ They carry all information for a cell to grow, thrive and reproduce.
- ❑ They are popularly known as 'hereditary vehicles' as they carry genetic information from generation to generation.
- ❑ A chromosome is not visible in the nucleus when a cell is not dividing.

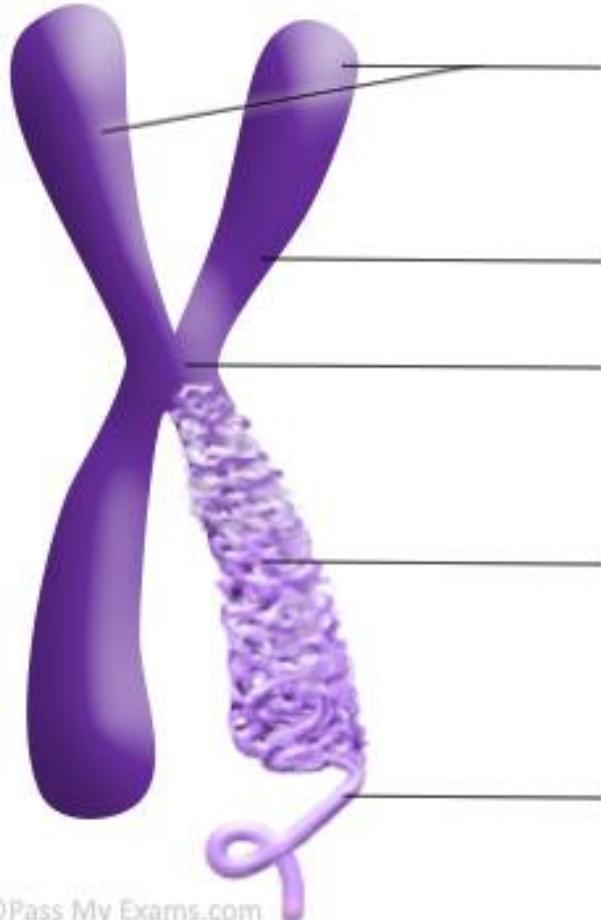
**Figure 3.24** **Packing of DNA into a chromosome in a dividing cell.** When packing is complete, two identical DNA molecules and their histones form a pair of chromatids, which are held together by a centromere.



A chromosome is a highly coiled and folded DNA molecule that is combined with protein molecules.

# Structure of the chromosome

## One Chromosome



### Two Identical Chromatids

One is an exact copy of the other and each contains one DNA molecule.

### p arm – short arm structure

### Centromere – constricted point of the chromosome

### q arm – long arm structure

### DNA molecule – long string like DNA molecule formed into a compact structure by proteins called histones.

# Chromosome

- ❑ The term 'chromosome' was coined by Waldeyer (1898).
- ❑ The shape and size of chromosomes are variable. However, the size and number of chromosomes remain constant for a particular species

# Eukaryotic chromosome

- A typical eukaryotic chromosome consists of:
- **Chromonemata:** These are filamentous thread-like structures.
- They represent chromatids in the early stages of condensation.
- **Chromomeres:** These are bead-like structures which are linearly arranged on the chromosomes.

## Eukaryotic chromosome cont `d

- ❑ These are tightly folded regions of the DNA and more clearly visible in the polytene chromosome.
- ❑ They are not visible during metaphase as the chromosome is tightly coiled

# Chromatids

- ❑ A chromosome has two symmetrical structures at metaphase called chromatids which are held together by the centromere.
- ❑ Chromatids from one mother chromosome are called sister chromatids and chromatids from two different chromosomes are called nonsister chromatids

# Primary Constriction of Chromosome

- ❑ It is a narrow and constricted area of the chromosome which contains the centromere.
- ❑ Centromere is concerned with the movement of chromosomes during cell division.
- ❑ Fibrils of microtubules attach to it during cell division.

# Primary Constriction of Chromosome

## cont'd

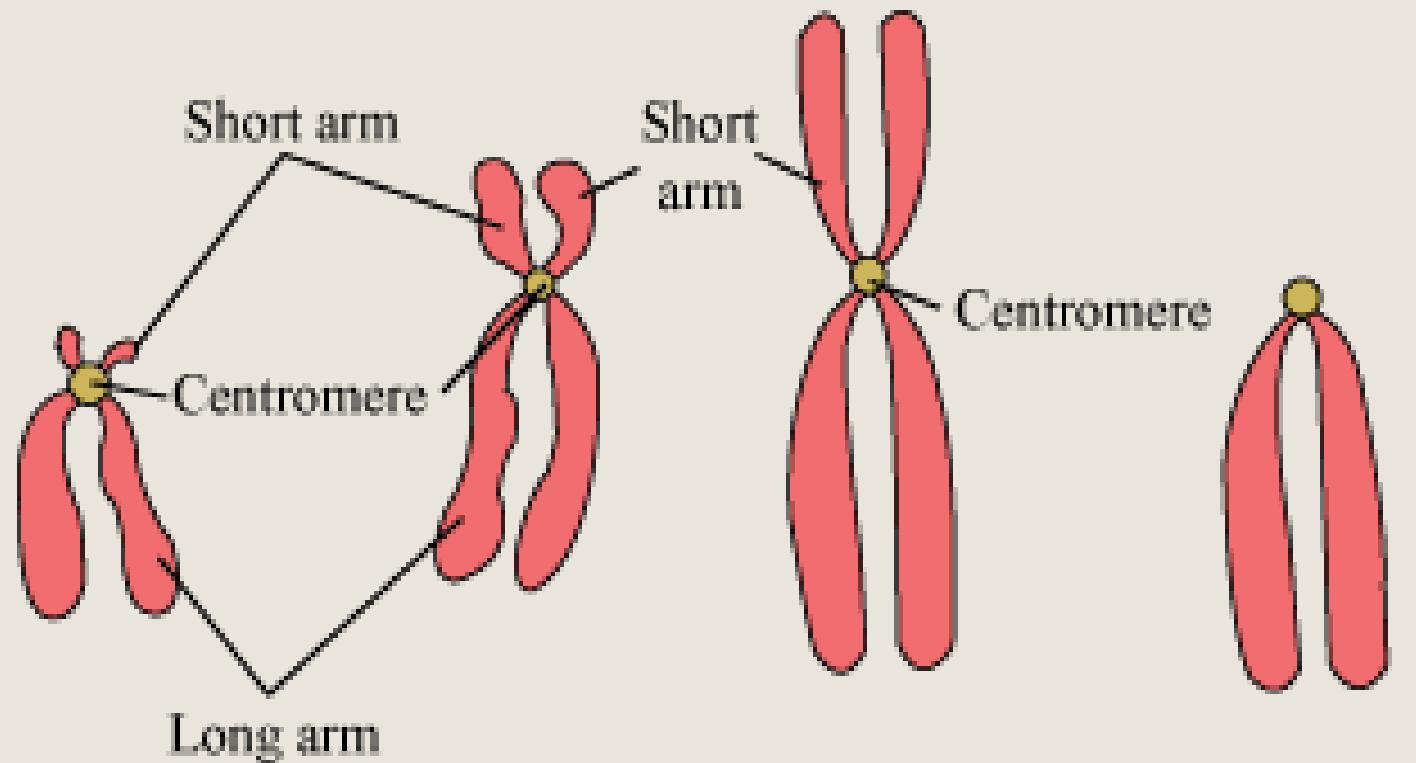
- Centromere contains a cup-like structure called kinetochore (0.20--0.25  $\mu\text{m}$ ).
- Kinetochore is the implantation site to which spindle microtubules are attached.
- The position of centromere on the chromosome is fixed and determines the shape of the chromosomes,

# **Types of chromosome based on the position of centromere**

- (a) **Telocentric:** Centromere is terminal in position.
- (b) **Acrocentric:** Centromere is sub terminal in position.
- (c) **Metacentric:** Centromere is located in the middle of the chromosome.

# Types of chromosome based on the position of centromere

- ❑ (d) **Sub metacentric:** Centromere is located slightly away from the middle point



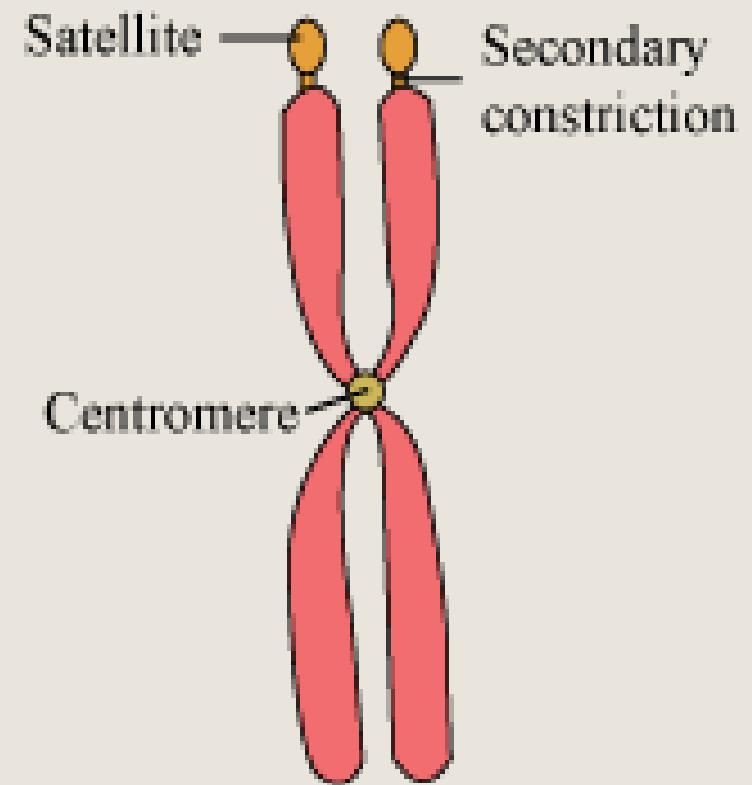
Acrocentric

Submetacentric

Metacentric

Telocentric

Types of chromosomes



Chromosome showing  
satellite region

# **Types of chromosome based the number of centromeres**

- ❑ Depending on the number of centromere, a chromosome may be:
  - (a) **Acentric:** Without centromere
  - (b) **Monocentric:** With one centromere
  - (c) **Dicentric:** With two centromeres
  - (d) **Polycentric:** With more than two centromeres
  - (e) **Diffused:** Centromeres are indistinct

## **Secondary Constriction**

- ❑ In addition to primary constriction, there is a secondary constriction.
- ❑ The difference between primary and secondary chromosomes can be observed during anaphase as a chromosome can bend only at the site of primary constriction.
- ❑ Secondary constrictions are constant in position and hence are useful in identifying particular chromosome in a set.

# Secondary Constriction cont'd

- Secondary constriction may arise because the rRNA genes are transcribed very actively and thus interfere with chromosomal condensation.
- It contains the genes coding for 5.8S, 18S and 28S rRNA which induce formation of nucleolus. Hence, is named as nucleolar organiser region.
- In human beings, chromosomes 13, 14, 15, 21 and 22 are nucleolar chromosomes

# Satellite

- ❑ Satellites are round or elongated or knob-like appendages of chromosomes.
- ❑ Satellite is produced if secondary constriction is present in the distal region of the chromosome.

## Satellite cont'd

- The shape and size of satellites remain constant.
- It is attached with rest of the chromosome by a thin chromatin filament

# Telomere

- ❑ Telomeres are the specialised ends of a chromosome which exhibit structural and physiological polarity.
- ❑ They are non-sticky ends of chromosomes.
- ❑ They confer stability to chromosomes.
- ❑ They are synthesised by the enzyme telomerase

## Telomere cont'd

- ❑ Blackburn and Gall (1978) sequenced first telomere from *Tetrahymena thermophila*.
- ❑ Each species has characteristic telomeric repeat sequences. However, widely divergent species may have the same telomeric unit.
- ❑ The telomeric DNA in eukaryotic cells is gradually lost in successive generations

# Nucleosome Model

Under electron microscope, eukaryotic chromosome appears as a series of beads on a string and each bead is known as a nucleosome.

- ❑ Nucleosomes are the basic unit structure of eukaryotic chromosomes.
- ❑ The beads on the string represent the first level of chromosomal DNA packing.

- ❑ The nucleosome is a flat disc-shaped particle having a diameter of 10  $\mu\text{m}$  and length of 5.7  $\mu\text{m}$ .
- ❑ Nucleosome is a complex of DNA and histone protein.
- ❑ Each nucleosome consists of a histone octamer around which 1.75 turns of the DNA double helix is wrapped, which are 146 nucleotide pairs long.
- ❑ Each histone octamer consists of two flat tetramers of H-2A, H-2B, H-3 and H-4

## Nucleosome Model cont'd

- ❑ Besides H-2A, H-2B, H-3 and H-4, one more histone is found called histone, H-1, which holds the two ends of the DNA double helix around the histone octamer.
- ❑ Histone H-1 is not conserved and is tissue-specific.
- ❑ H-1 is chemically active and may react with H-1 of adjacent nucleosome to assist in coiling.

# Nucleosome Model cont'd

- ❑ Each nucleosome core particle is separated from the next by a region of linker DNA that varies in length from a few nucleotide pairs to 80 nucleotide pairs in different species.
- ❑ In each nucleosome, 142 hydrogen bonds are formed between the DNA and the histone core.
- ❑ A diploid human cell contains approximately 30 million nucleosomes

# Nucleosome Model cont'd

- ❑ It has been suggested that the formation of nucleosome converts a DNA molecule into a chromatin thread about one-third of its initial length and this gives a first level of DNA packing.
- ❑ Several models have been proposed to explain how nucleosomes are packed in 30 $\mu$ m chromatin fibre.

# Nucleosome Model cont'd

- One of these and the most consistent with the available data is a series of structural variations known as the zigzag model. This model suggests the following:
  - (a) The 30 $\mu$ m structure found in chromosome is probably a fluid mosaic of different zigzag variations.

## Nucleosome Model cont'd

(b) There is variation in the length of linker DNA, and these differences in linker length may introduce further local perturbations into the zigzag structure

# **Chemical composition of Chromosome**

- Chemically, a chromosome is made up of DNA, RNA, histone and nonhistone proteins.
- **Functions**
- Chromosomes control all cellular activities.
- They carry transmission of characters from one generation to another.

# Functions of chromosomes

- ❑ They control development and differentiation of characters.
- ❑ They help in the formation of nucleolus.
- ❑ Any change in the structure or number of chromosome leads to the formation of new characters which acts as raw material for evolution.

# Polytene Chromosome

- ❑ Polytene chromosomes are the giant chromosomes which are easily visible under light microscope.
- ❑ They are found in the tissues of dipteran larvae.
- ❑ They were first observed by Balbiani (1882) in the salivary gland of the *Chironomous*.

# Polytene Chromosome cont'd

- They are formed by endo-mitosis, i.e., duplication of DNA without nuclear division.
- They are visible during interphase.
- The cells of polytene chromosome do not undergo mitosis.

# Polytene Chromosome cont'd

- ❑ Polytene chromosomes show somatic pairing, i.e., paternal and maternal chromosomes lie side by side which permits identification of deletions, duplications and inversions.
- ❑ All the polytene chromosomes may remain attached to a common chromocentre.

# Polytene chromosome cont'd

- ❑ Polytene chromosomes contain darkly stained dark bands and clear zones of interbands.
- ❑ Bands are Feulgen positive and are regions of high DNA concentration.
- ❑ Interbands are Feulgen negative and are regions of low DNA concentration.
- ❑ There are approximately 5,000 bands and 5,000 interbands in the genome of *Drosophila*.

## Polytene Chromosome cont'd

- ❑ The banding patterns of polytene chromosome of *D. melanogaster* were studied by C B Bridges in 1935.
- ❑ At certain times, bands become enlarged to form swellings called puffs (Balbiani rings).
- ❑ Puffing is due to uncoiling of individual chromosomes in a band.

# Polytene Chromosome cont'd

- ❑ Puffs represent active sites of RNA synthesis.  
Polytene chromosomes are very suitable for  
*in situ* hybridisation

# Lampbrush Chromosome

- ❑ Lampbrush chromosomes are found in the diplotene stage of meiosis of all animals and are the largest known chromosome.
- ❑ They are so named because of their brush-like appearance.
- ❑ They were first observed by Flemming (1882) in the oocytes of salamander and the name Lampbrush was given by Ruckert (1992).

## Lampbrush chromosomes cont'd

- ❑ Lampbrush chromosomes are extensible and elastic. They can be stretched to 2x2 of their original length.
- ❑ They are best seen in the oocytes of salamander due to their high DNA content.
- ❑ They are present in the form of bivalents in which maternal and paternal chromosomes are held together by chiasmata.
- ❑ Each bivalent contains a centromere.

# Lampbrush chromosomes cont'd

- ❑ Each bivalent contains four chromatids which are represented by axial filaments.
- ❑ Axial filaments consist of DNA.
- ❑ The axial filaments become tightly coiled to form chromomeres.
- ❑ Lateral loops come out from chromomeres.
- ❑ There are approximately 10,000 loops per chromosome set.

## Lampbrush chromosomes cont'd

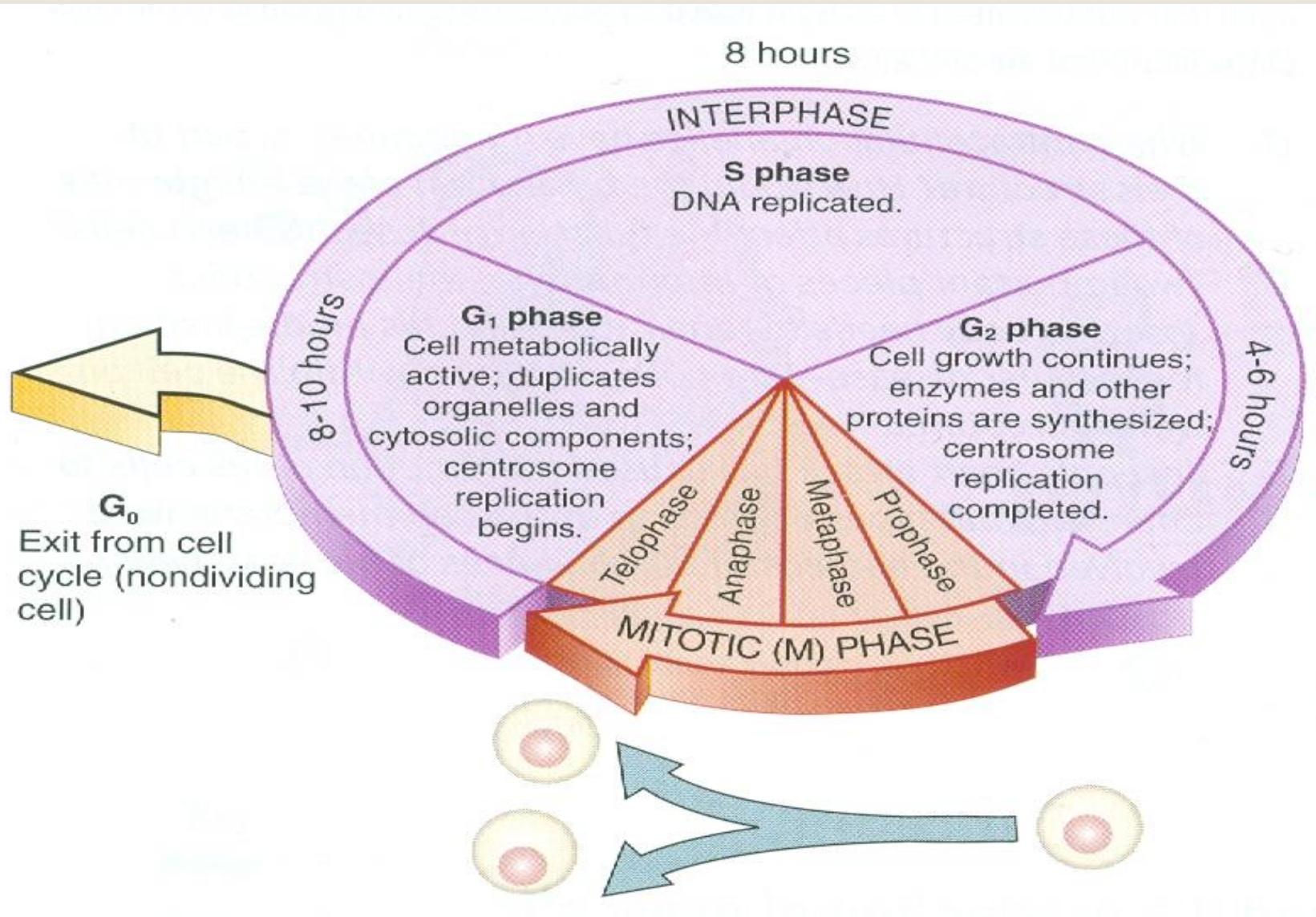
- Loops are symmetrical and each loop appears at constant position.
- Each loop has an axis made up of DNA.
- Loop DNA appears to be thick as it is covered with nonhistone proteins as well as nascent RNA molecules.
- Telomeres are lacking in lateral loops

## Lampbrush chromosomes cont'd

- Lampbrush chromosomes are an excellent material for *in situ* hybridisation of cloned DNA to RNA.
- Loops are the sites of RNA synthesis.

# Cell Cycle

- ❑ A series of events that occur in a cell and results in its division and duplication is known as cell cycle.
- ❑ Each cell has a cell cycle clock which determines that a cell should or should not divide.
- ❑ A cell cycle takes 12-24 hours for most mammalian cells and approximately 20-30 minutes in *E. coli* cells.



In a complete cell cycle, a cell duplicates its contents and divides into two identical cells.

# Cell Cycle cont'd

- Non-dividing cells are not considered to be in the cell cycle.
- The time required to complete one cell cycle (from the starting one cell division to the beginning of the next) is known as the generation time.
- The cell cycle is divided into two parts, viz., interphase and dividing phase

# Cell Cycle cont'd

- ❑ **Interphase**
- ❑ It is the longest phase of the cell cycle and is the period between two consecutive cell divisions.
- ❑ Mammalian nerve cells have the longest interphase as they do not divide after birth.
- ❑ During interphase, the cell becomes enlarged.
- ❑ This phase is characterised by high rate of metabolism

## **Cell cycle cont'd**

- Interphase is divided into three phases:
- **G<sub>1</sub> Phase**
- It is the first growth phase which is also known as the first gap phase.
- It is a crucial decision point.
- The timing of G<sub>1</sub> phase is most variable even in different cells of the same species.
- During this phase, synthesis of RNA and proteins takes place

# Cell cycle cont'd

## S Phase

- ❑ It is the synthetic phase during which replication of DNA occurs.
- ❑ Histone proteins are synthesised during this phase.
- ❑ Duplication of centrioles takes place.
- ❑ Each chromosome is made of two chromatids

## S phase cont'd

- ❑ It takes approximately 10 hours to replicate the 3 billion bits of information contained in the nucleus of a single human cell.

# Cell cycle cont'd

- **$G_2$  Phase**
- It is the second growth phase which is also known as the second gap phase or premitotic phase.
- Synthesis of RNA and proteins occurs during this phase.
- Replication of cell organelles and condensation of chromosomes takes place.
- The cell continues to increase in size.

## G<sub>2</sub> phase cont'd

- ❑ During G<sub>2</sub> phase, a cell contains two times (4C) the amount of DNA present in the original diploid cell (2C).
- ❑ The lengths of S phase and G<sub>2</sub> phase are almost equal.

# Cell cycle cont'd

- **G<sub>0</sub> State**
- A cell after cell division may withdraw from the cell cycle and enter into the resting phase called G<sub>0</sub> state or it may enter into the G<sub>1</sub> phase of the cell cycle.
- Cells in the G<sub>0</sub> state are viable and metabolically active.

## Go state cont'd

- ❑  $G_0$  cells not only simply represent the absence of signals for mitosis but also an active repression of genes needed for mitosis.
- ❑ Most of the lymphocytes in human blood are in the  $G_0$  state.
- ❑ Cells in culture can also be in the  $G_0$  state

## **G<sub>0</sub> state cont'd**

- ❑ Cancer cells cannot enter the Go state.
- ❑ On stimulation, Go cells enter the G<sub>1</sub> phase

# **Cell Cycle Checkpoints**

- In a cell cycle, the following three checkpoints have been identified:

## **1. G<sub>1</sub> Checkpoint**

- It is the most important checkpoint in the cell cycle which is also known as restriction point.
  - It detects damaged DNA and prevents entry into the S phase.

# G<sub>1</sub> Checkpoint

- G<sub>1</sub> checkpoint blocks entry into the S phase by inhibiting S-Cdk complex
- p53 levels are increased in damaged cells and block entry into the S phase.

# G<sub>1</sub> Checkpoint

- ❑ A p53 mutation is the most frequent mutation that leads to cancer.
- ❑ A p27 is a protein that binds to cyclin and CDK blocking entry to the S phase

## 2. G<sub>2</sub> Checkpoint

- ❑ It prevents the cell from entering mitosis (M phase).
- ❑ It is triggered by Maturation-Promoting Factor (MPF) which is a cyclin CDK complex.

## G<sub>2</sub> Checkpoint cont`d

- ❑ The cdc 2 cyclin B kinase is a key molecule in regulating this transition.
- ❑ Damage to DNA after the S phase inhibits the action of CDK I, thus preventing the cell from proceeding from G<sub>2</sub> to mitosis.

### 3. Spindle Checkpoint (M-phase Checkpoint)

- ❑ It detects any failure of spindle fibres to attach to kinetochores and arrest the cell in metaphase.
- ❑ It detects incorrect alignment of the spindle itself and blocks cytokinesis.
- ❑ It triggers apoptosis, if the damage is irreparable.

# Spindle Checkpoint (M-phase Checkpoint)

- In mammals and in yeast, the spindle checkpoint is inactivated by mutants in MAD and BUB genes.
- Colchicine, which inhibits spindle assembly, manifests the presence of the spindle check point.

# Spindle Checkpoint (M-phase Checkpoint)

- ❑ A cell cycle is mainly controlled by two classes of regulatory proteins, viz., cyclins and cyclin dependent kinases. Leland, Hartwell, Hunt and Nurse were awarded the Nobel Prize in Physiology or Medicine in 1995 for their discovery of these key molecules

# Cell Division

- ❑ The process by which a cell divides to form new cells is known as cell division.
- ❑ Cell division is the basic feature of life.
- ❑ Mature new cells arise from the pre-existing cells, so a cell divides to form new cells.
- ❑ Cell divisions take place for growth, reproduction and repair work of the body

# Cell Division cont'd

- ❑ The main aim of cell division is to maintain the original genome.
- ❑ A human body may undergo approximately 10,000 trillion divisions in an entire lifetime.
- ❑ Cell division is mainly of two types, viz., **mitosis and meiosis**

# Mitosis

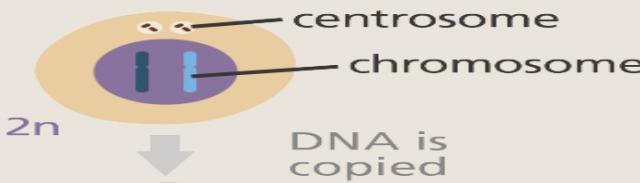
- ❑ Mitosis is a type of cell division in which two daughter cells are formed from a single cell, having the number of the chromosomes as found in the original mother cell.
- ❑ Mitosis takes place both in somatic as well as reproductive cells.
- ❑ The term 'mitosis' was given by Flemming (1882).
- ❑ A cell undergoing mitosis is called mitocyte.

# Mitosis cont'd

- ❑ Mitosis may be acentric (without centromere) as in plants or centric (with centromere) as in animals.
- ❑ Generally, the process of mitosis is completed within 2 hours.
- ❑ The steps of mitosis are controlled by different genes and if mitosis is not regulated properly, it may in health problems such as cancer

# The mitotic process

## Interphase



## Prophase



## Metaphase



## Anaphase



## Telophase & Cytokinesis



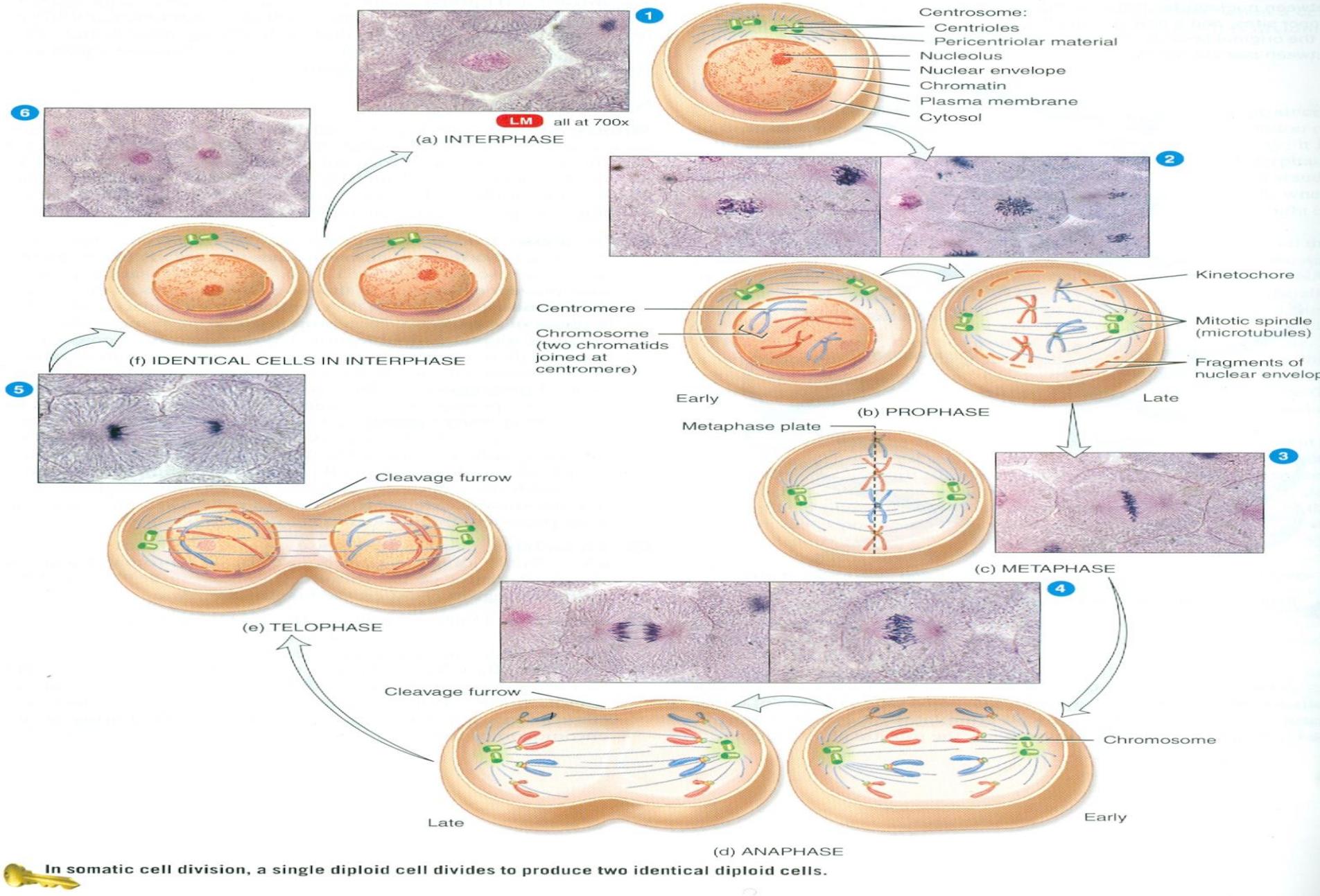
2n

Two identical daughter cells



2n – diploid

**Figure 3.31 Cell division: mitosis and cytokinesis.** Begin the sequence at 1 at the top of the figure and read clockwise to complete the process.



# Mitosis cont'd

- ❑ The process of mitosis involves two steps:
- ❑ Karyokinesis
- ❑ Cytokinesis
- ❑ Karyokinesis: Karyokinesis is the division of the nucleus. It involves the following stages

# Karyokinesis

## (a) Prophase

- ❑ Prophase is the first and longest stage of mitosis.
- ❑ The cell becomes spheroid and there is an increase in viscosity and refractivity.
- ❑ Each chromosome consists of two chromatids jointed together by a centromere.

# Prophase cont`d

- ❑ The two centrioles start to move in opposite poles of the cell.

## Prophase cont'd

- ❑ Around each centriole, radiating fibres appear called asters.
- ❑ Asters are cytoplasmic in origin.
- ❑ The two asters are connected by spindle fibres.
- ❑ Spindles are formed from microtubules and are made up of tubulin.
- ❑ The aster, centrioles and spindle together form the mitotic apparatus.

# Metaphase

- ❑ Nuclear membrane and nucleolus disappear.
- ❑ The chromosome becomes arranged on equatorial plate.
- ❑ The chromosomes attain their full contraction.
  
- ❑ Metaphase is the most suitable stage for studying the morphological characterisation, banding and counting of the chromosomes

# Anaphase

- ❑ Anaphase is the most dynamic and shortest stage of mitosis.
- ❑ The centromere divides. The sister chromatids separate and move towards opposite poles.
- ❑ Each chromatid has its own centromere.
- ❑ At the end of anaphase, there is a group of chromosomes at each pole

# Anaphase cont'd

- ❑ Mitotic anaphase has the same number of chromosomes as metaphase but half number of chromatids.
- ❑ The chromosomes may assume shape of 'J', 'V' or rod-like

# Telophase

- ❑ It is the last stage of mitosis.
- ❑ Chromosomes at each pole begin to uncoil.
- ❑ Nuclear membrane and nucleolus appeared around each group of chromosomes, resulting in the formation of two daughter nuclei.

## 2. Cytokinesis

- ❑ Cytokinesis is the division of the cytoplasm
- ❑ In animal cells, cytokinesis takes place by cleavage furrow.
- ❑ In plant cells, cytokinesis takes place by the formation of cell plates.

# **Significance of Cytokinesis**

- ❑ Mitosis helps in the growth of the organs and the body.
- ❑ Mitosis is a means of reproduction in lower organisms.
- ❑ It maintains genetic constitution of the organisms.

# Significance of Cytokinesis

- ❑ Mitosis maintains nucleo-cytoplasmic ratio.
- ❑ Mitosis helps in repairing of injured tissues by replacing dead cells by new cells.

# Mitotic Poison

- ❑ Chemicals that cause anomalies in cell division are known as mitotic poison.
- ❑ These chemicals interfere with spindles, centrioles and centrosomes.
- ❑ These chemicals produce nondisjunction.

## Mitotic Poison cont'd

- ❑ Colchicine (obtained from the plant *Colchium autumnale*) vinblastine and vincristine inhibit microtubules assembly, whereas diazepam prevents separation of centrioles.
- ❑ Microorganisms remain unaffected by mitotic poison as they lack spindle apparatus

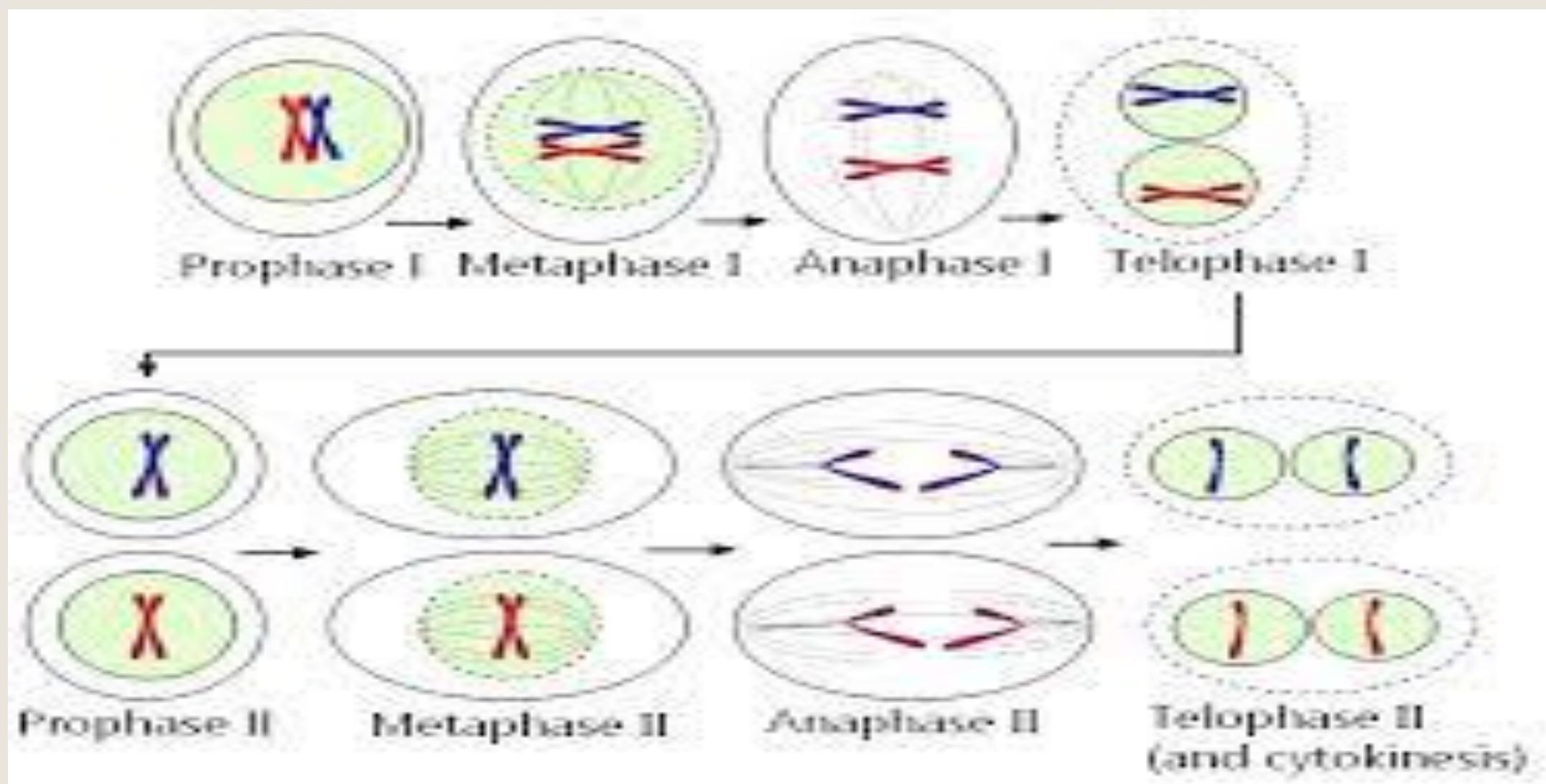


# MEIOSIS

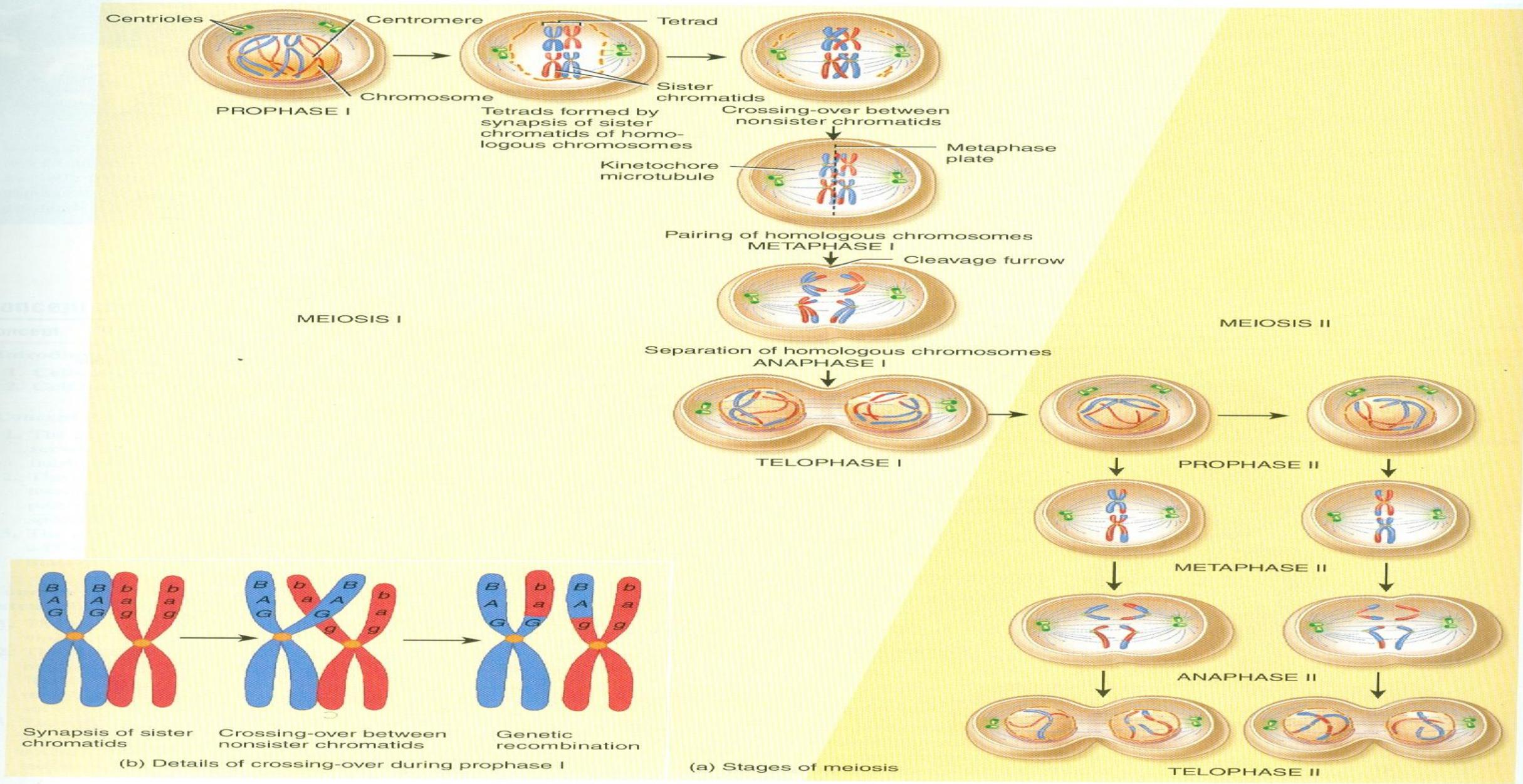
# Meiosis

- ❑ Meiosis is a special type of cell division as a result of which four daughter cells are formed, in which the number of chromosomes is reduced to half of that in the original cell.
- ❑ Meiosis occurs in reproductive cells.
- ❑ A cell undergoing meiosis is called meiocyte.
- ❑ Meiosis is also known as reduction division as it reduces the chromosome number to half

# The meiotic process



**Figure 3.32 Meiosis, reproductive cell division.** Details of events are discussed in the text.

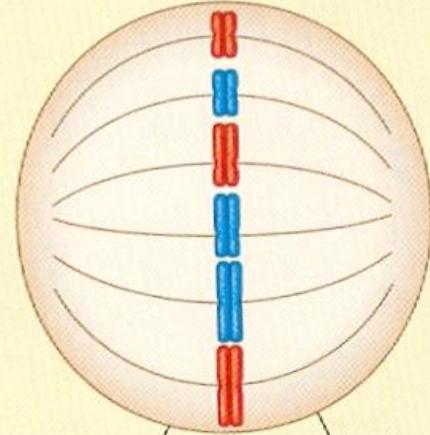


In reproductive cell division, a single diploid starting cell undergoes meiosis I and meiosis II to produce four haploid daughter cells.

## MITOSIS

### Prophase

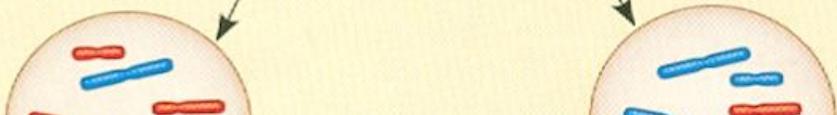
Replicated chromosome  
(two sister chromatids)



### Metaphase

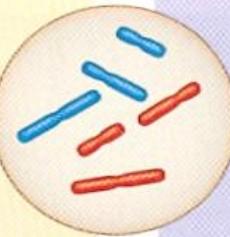
Chromosomes line up individually at the metaphase plate

Sister chromatids separate during anaphase



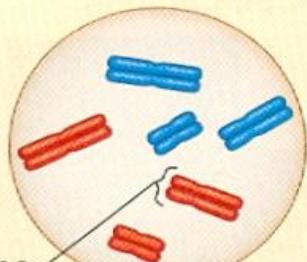
## Parent cell

(before chromosome replication)



$2n = 6$

Chromosome replication

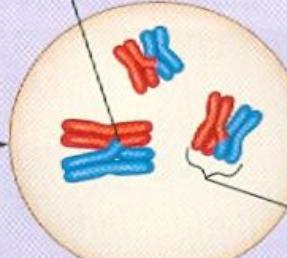


## MEIOSIS

### MEIOSIS I

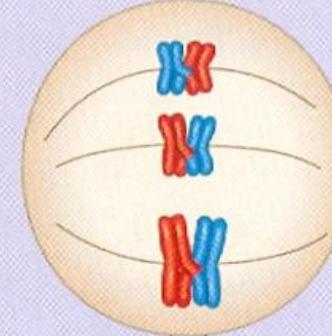
#### Prophase I

Homologous chromosome pair held together by chiasma and sister chromatid cohesion



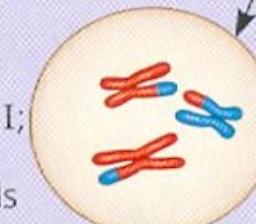
Chromosome replication

Chromosomes line up by homologous pairs at the metaphase plate



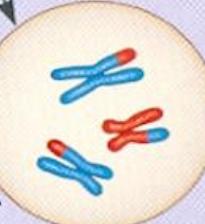
#### Metaphase I

Homologs separate during anaphase I; sister chromatids remain attached



#### Anaphase I Telophase I

Haploid  
 $n = 3$



Daughter cells of

# Meiosis cont'd

- ❑ Meiosis involves two nuclear divisions with only one replication of DNA.
- ❑ Meiosis is essential for sexual reproduction.
- ❑ Meiosis was first discovered and described in the eggs of sea urchin by Oscar Hertwig in 1876.
- ❑ The term 'meiosis' was coined by Farmer and Moore (1905)

## Meiosis cont'd

- ❑ Bdelloid rotifers have lost the ability to perform meiosis division, while meiosis does not occur in archaea or bacteria.
- ❑ Meiosis may be:
- ❑ Gametic: It is also known as terminal meiosis. It occurs at the time of gamete formation and is found in animals.
- ❑ Zygotic: It is also known as initial meiosis and occurs immediately after zygote formation: It is found in lower plants.

## Meiosis cont'd

- Sporic: It is also known as intermediate meiosis. Meiosis division occurs in between the formation of zygote and gamete, resulting in the formation of haploid megasporangia and microsporangia. Such type of meiosis is a characteristic of higher plants and some thallophytes.
- Meiosis involves two divisions

# The two divisions of meiosis

- ❑ **Heterotypic division:** It is the first division as a result of which the chromosome number is reduced to half. It is also known as reductional division.
- ❑ **Homotypic division:** It is the second division which is totally mitotic in nature.

# **Heterotypic division of Meiosis**

- . **Heterotypic division:** It involves the following stages:
  - (i) Interphase:** Before meiosis begins, the genetic material is duplicated.
  - (ii) Prophase I:** It is the longest and most important phase of the meiosis. It is divided into six substages:

# Divisions of Prophase 1

## a) Leptotene

- ❑ Chromosomes become more distinct.
- ❑ Chromosomes bear bead-like structures called chromomeres.
- ❑ The number, size and position of chromomeres are characteristic on a chromosome.

## Divisions of Prophase 1 cont'd

- a) Leptotene cont'd
- Chromosome; may develop a basket-like arrangement called bouquet and this stage is called bouquet stage.
- Some plant cells form a tangle of threads called synizetic knot (e.g., *Trillium*).

## (b) Zygote

- ❑ Chromosomes become shorter and thicker,
- ❑ Pairing of homologous chromosomes takes place.
- ❑ Paired chromosomes are called bivalents and the process of pairing is called synapsis.
- ❑ The number of bivalents is half of the number of diploid chromosomes.

## (b) Zygotene cont'd

- The pairing of homologous chromosomes may begin from the centromere (procentric), or from either ends (proterminal), or from anywhere (at random).
- Of the two homologous chromosomes, one is derived from the male parent and other from the female parent.

## (b) Zygote cont'd

- As a result of pairing, a tripartite structure is formed called synaptonemal complex.
- Synaptonemal complex first appeared during zygote.
- Synaptonemal complex is lacking in the meiosis of male diptera.

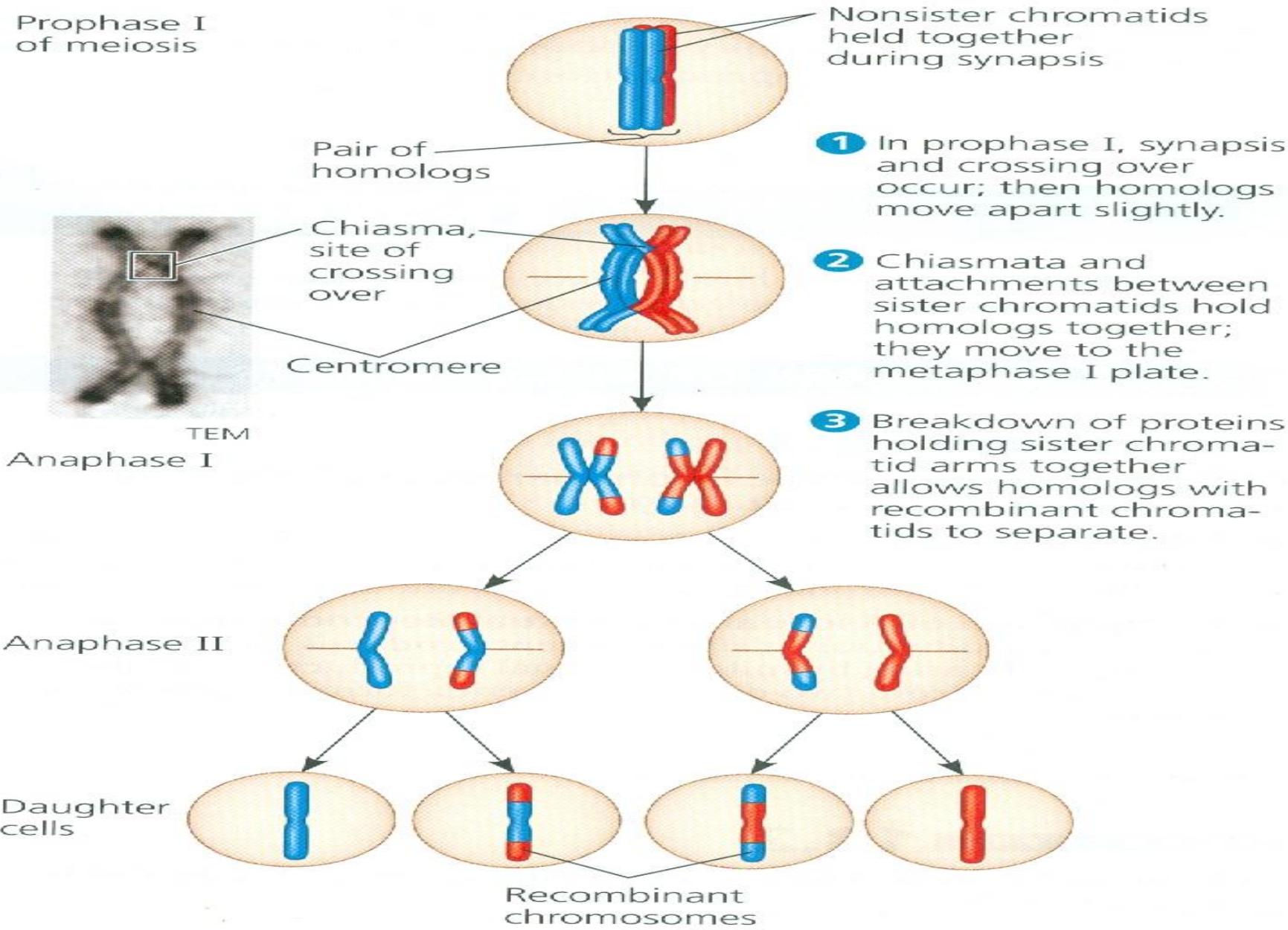
## (c) Pachytene

- ❑ Each bivalent splits longitudinally, so in each bivalent the number of chromatids is four (tetravalent). This stage is called tetrad stage.
- ❑ Exchange of chromatids takes place between nonsister chromatids. This process of exchange of chromatids is known as crossing over

## (c) Pachytene

- ❑ As a result of crossing over, a cross-shaped (X) structure is formed, called chiasmata.
- ❑ Pachytene is the longest stage in mammalian spermatogenesis.
- ❑ Pachytene may last for days, weeks or even years.

Prophase I  
of meiosis



▲ **Figure 13.12** The results of crossing over during meiosis.

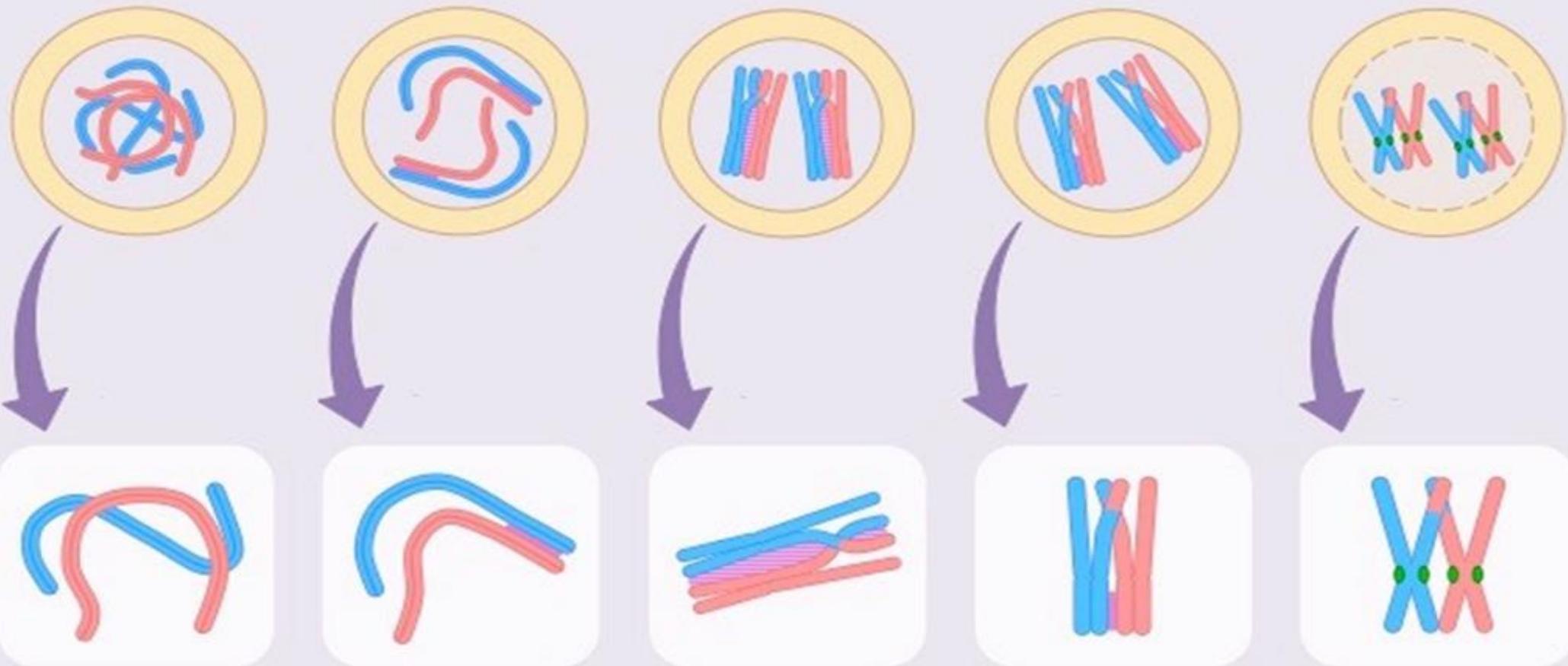
## (d) Diplotene

- Separation of homologous chromosomes begins. This process is known as terminalisation.
- Due to contracting tendency of chromosomes, the chiasmata are pulled towards the ends of paired homologous chromosomes.
- Synaptonemal complex begins to break down.
- Diplotene may last for months or years.

## (e) Diakinesis

- ❑ The process of terminalisation is completed.
- ❑ Chromosomes condense and thicken.
- ❑ Nuclear membrane and nucleolus begin to disintegrate

**LEPTOTENE → ZYGOTENE → PACHYTENE → DIPILOTENE → DIAKINESIS**



**Prophase begins**  
Chromosomes  
start to condense

**Synapsis begins**  
Synaptonemal  
complex forms

**Crossing over**  
DNA exchanged by  
non-sister chromatids

**Synapsis ends**  
Chiasma visible  
within bivalent

**Prophase ends**  
Nuclear membrane  
disintegrates

# Metaphase I

- ❑ Formation of spindle begins.
- ❑ Bivalents become arranged on equatorial plate.
- ❑ Bivalents are arranged in such a way that their arms lie over the equator while the centromeres are directed towards the poles.

# Metaphase I cont`d

- ❑ There is a 50-50 chance for the daughter cells to get the mother's or father's homologue as orientation is random, with either homologue on a side.

# Anaphase I

- ❑ The homologous chromosomes separate from each other and move to opposite poles.
- ❑ Each pole has haploid number of chromosomes. In this stage, reduction in the number of chromosomes takes place.
- ❑ There is no division of centromeres

# Telophase I

- ❑ Telophase I is similar to telophase of mitosis except that there is only one set of (replicated) chromosome in each cell.
- ❑ Nuclear membrane and nucleolus reappear around each group of the haploid set of chromosomes at each pole.
- ❑ Thus, two daughter haploid nuclei are formed; each with two chromatids.
- ❑ Sometimes telophase is absent.

## **Meiotic divisions cont'd**

- ❑ Cytokinesis results in the formation of two daughter cells having haploid number of chromosome.

# Meiotic divisions cont'd

- **Interkinesis**
- The period between telophase I and prophase II is called interkinesis.
- It is quite a short period or completely absent.
- In *Trillium* and *Odonata*, there is no telophase I and interphase.

# **Homotypic Division of Meiosis**

- ❑ It is similar to mitosis but lacks the S phase. It involves the following stages:

## **1. Prophase I**

- ❑ The chromosomes condense and each chromosome consists of two chromatids, viz" one parental and the other recombinant.
- ❑ Nuclear membrane and nucleolus disappear.
- ❑ DNA does not replicate

## **2. Metaphase 11**

- ❑ Spindle fibres are formed.
- ❑ Chromosomes arrange on the equatorial plate.

## **1. Anaphase 11**

- ❑ The two chromatids of chromosome separate and move towards the opposite poles.
- ❑ Centromere divides, so each chromatid has its own centromere.

# Telophase 11

- ❑ Nuclear membrane and nucleolus reappear around each group of chromosomes.
- ❑ Thus, four haploid daughter nuclei are formed.
- ❑ Lastly, cytokinesis takes place as a result of which four haploid daughter cells are formed.

# Significance of Meiosis

- ❑ Meiosis is a means of gametes formation
- ❑ Meiosis maintains constancy in chromosome number from generation to generation
- ❑ It produces genetic variation due to crossing over in organisms which acts as raw material for evolution

## SUMMARY

Property	Mitosis	Meiosis
DNA replication	Occurs during interphase before mitosis begins	Occurs during interphase before meiosis I begins
Number of divisions	One, including prophase, metaphase, anaphase, and telophase	Two, each including prophase, metaphase, anaphase, and telophase
Synapsis of homologous chromosomes	Does not occur	Occurs during prophase I along with crossing over between nonsister chromatids; resulting chiasmata hold pairs together due to sister chromatid cohesion
Number of daughter cells and genetic composition	Two, each diploid ( $2n$ ) and genetically identical to the parent cell	Four, each haploid ( $n$ ), containing half as many chromosomes as the parent cell; genetically different from the parent cell and from each other
Role in the animal body	Enables multicellular adult to arise from zygote; produces cells for growth, repair, and, in some species, asexual reproduction	Produces gametes; reduces number of chromosomes by half and introduces genetic variability among the gametes

▲ **Figure 13.9** A comparison of mitosis and meiosis in diploid cells.

DRAW IT

Could you draw a diagram comparing the stages of mitosis and meiosis?