Chapter-1

Structure of Chromosomes, Cell Cycle and Cell Division

1.1 WHAT ARE CHROMOSOMES?

- The nucleus contains most of the cell's DNA which is organized into discrete units called chromosomes.
- Each chromosome contains one long DNA molecule associated with many proteins. This complex of DNA and proteins is called the chromatin.
- Chromosomes are high coiled and condensed chromatin fibers.

1.2 DISCOVERY OF CHROMOSOMES

- Chromosomes in animals were first studied in 1882 by a German scientist, Walther Flemming.
- The microscope he used was of old type and through it; he saw minute threads that appeared to be dividing lengthwise. Flemming called their division mitosis.

1.3 CHROMATIN

The chromatin material that constitutes the fiber is formed of two substances:

1. **DNA** (deoxyribonucleic acid) – about 40%
2. **Histones** (a particular type of protein) –about 60%

i. Molecular structure of DNA

- The shape of the DNA molecule was first studied by Rosalind Franklin in 1953. However, the structure was finally worked out by Watson and crick in the same year.
- A single DNA molecule is very large, and hence it is described as a **macromolecule.**
- Each single DNA strand is composed of repeating **nucleotides** which are made of three components, **phosphate, sugar** and a **nitrogenous base** attached to the sugar inwards which extends to join (by a hydrogen bond) the complementary **nitrogenous base** from the other stand.

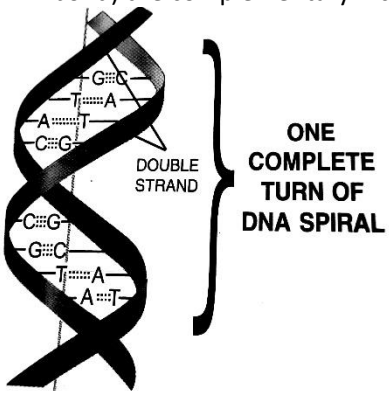
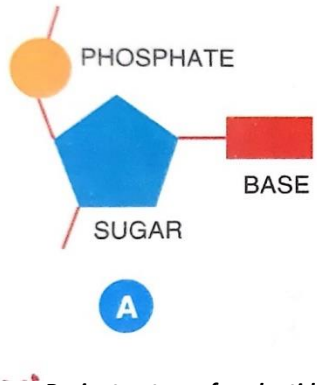
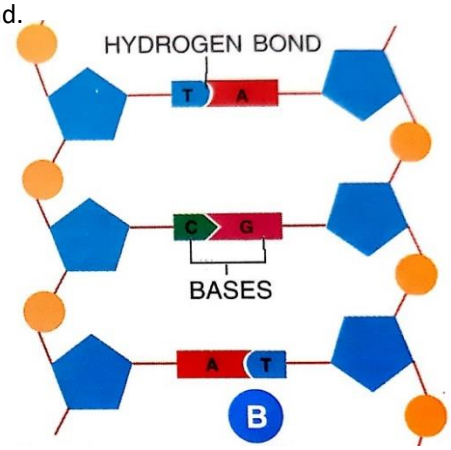


Figure 1 Helix structure of DNA



Basic structure of nucleotide.

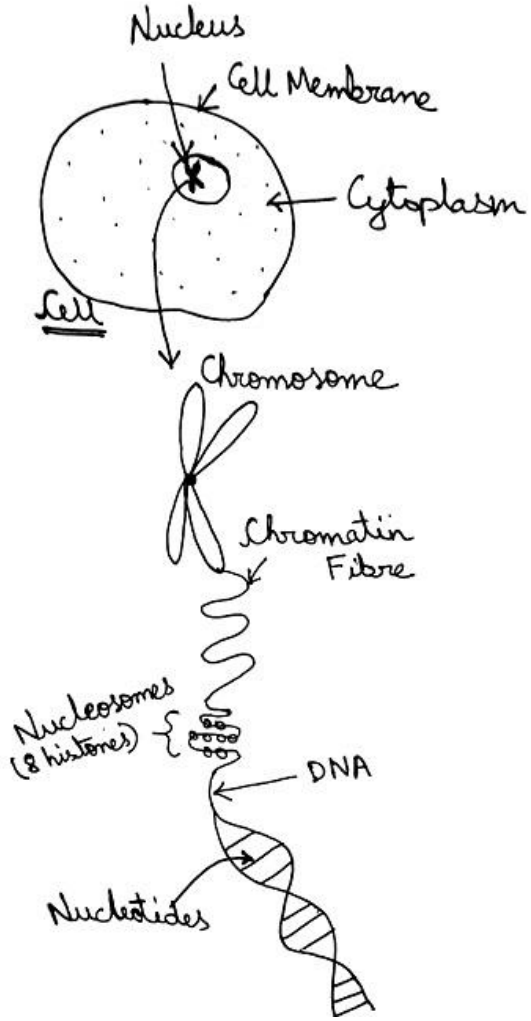


Two parallel strands of a part of DNA.

- Four types of nitrogenous bases are found in the DNA. These are Adenine (A), Guanine (G), Cytosine (C) and Thymine (T). Adenine pairs with Thymine with two hydrogen bonds. Guanine pairs with Cytosine with three hydrogen bonds i.e. A=T and G≡C.

ii. Histone proteins

- Histones are the proteins that help in the coiling and packages of DNA into structural units called **nucleosomes.**
- The DNA strand winds around a core of eight **histone proteins** (called the histone octamer).
- Single human chromosomes may have about a million nucleosomes!
- Each human cell contains approximately 2 meters of DNA if stretched end-to-end. However, the nucleus of human cell is only about 6 µm in diameter.
- The entire chromatin fiber is coiled and super-coiled something like the coils and supercoils we see in a typical telephone cord to eventually form chromosomes.



Structure of a chromosome, chromatin fibre and DNA

1.4 STRUCTURE OF CHROMOSOMES

Each chromosome in its condensed form as visible during the start of cell division consists of two chromatids joined at some point along the length. This point of attachment is called **centromere**, and it appears as a small constricted region.

1.5 WHAT ARE GENES?

Genes are specific sequences of nucleotides on a chromosome that encode particular proteins which express in the form of some particular feature of the body.

1.6 NEED FOR NEW CELLS

➢ **For growth:** Every organism, be it a plant or an animal, begins its life as a single cell (the fertilized egg). This cell divides repeatedly to form a cluster of cells which start shaping for different functions to form tissues and organs. Thus, cell division is essential for **growth.**

➢ **For replacement:** There is always a wear and tear of cells during the normal body functions. For example, 2 million red blood cells in our body are destroyed every second. These are **replaced** by new cells formed through a division of their parent cells in the bone marrow.

➢ **For repair:** One may get cuts in the skin or fractures in the bone. **Repair** of such injuries is again through cells which divide, cover up the gaps and join the broken ends.

➢ **For reproduction**:

- Reproduction also takes place through the activity of the dividing cells.
- The reproductive organs undergo a special kind of cell division (**meiosis**) to produce sperms and eggs. The sperms and eggs receive only half the number of chromosomes of their parent cells, i.e., one chromosome from each pair.

1.7 CELL CYCLE – "Divide, grow and redivide"

1. **The cell cycle is a series of events that take place in a cell leading to the duplication of its DNA and the subsequent division of the cell to produce two daughter cells.**
2. **A cell cycle consists of two phases:**

i. **A non- dividing phase is called the interphase, and**
ii. **A dividing phase called the M-phase or simply mitosis.**

1.7.1 Interphase

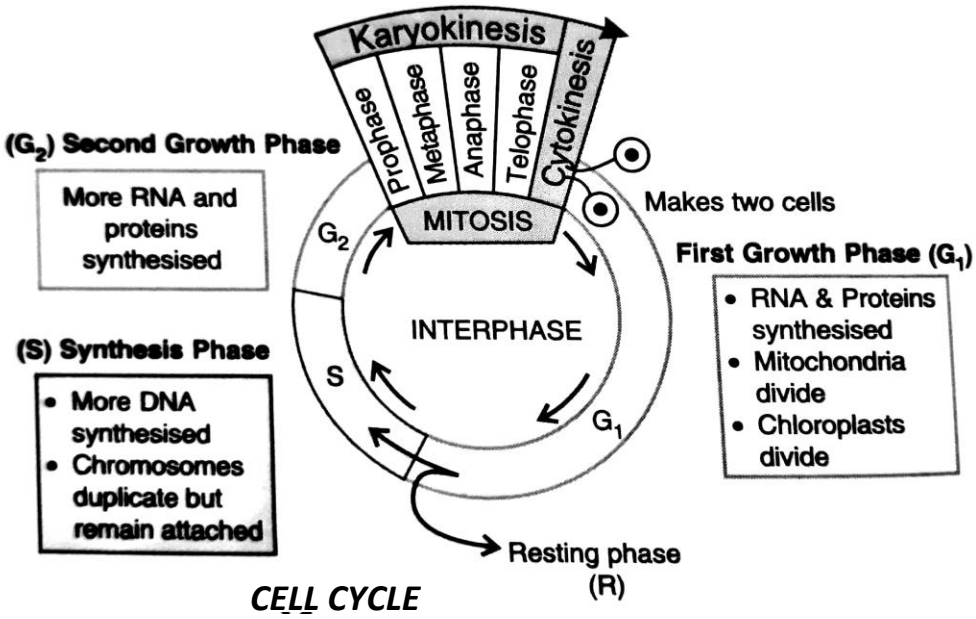
➢ The two daughter cells produced from a mother cell are relatively small, with a full- sized nucleus but relatively little cytoplasm. These cells are said to be in **interphase**. During this phase, they prepare for the next cell division and grow to the same size as their mother cell.

➢ The interphase itself has three phases – **(i) first growth phase, (ii) synthesis phase and (iii) second growth phase.**

➢ First Growth Phase (G_1) – RNA and proteins are synthesised the volume of cytoplasm increases. Mitochondria (in animal cells) and chloroplasts (in plant cells) divide- these two organelles have their own DNA.

➢ Synthesis phase (S) - More DNA is synthesised the chromosomes are duplicated.

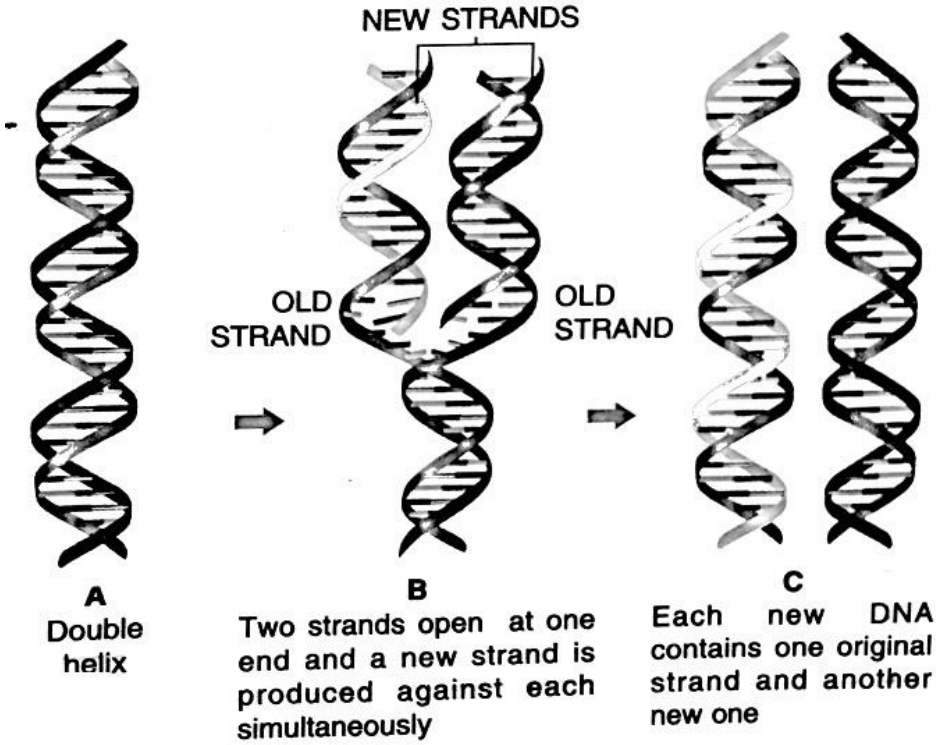
➢ Second Growth phase (G_2): This is a shorter growth phase, in which RNA and proteins necessary for cell division continue to be synthesised. Now the cell is ready to undergo cell division and enter the dividing phase of the cell cycle. After the dividing phase gets completed, the newly formed daughter cells enter into interphase again and in this way the cells cycle goes on and on.



CELL CYCLE

1.7.2 Formation of the new DNA

During the S-phase of the interphase, each DNA molecule (i.e. the chromosomes) duplicates in readiness for their equitable distribution in the two daughter cells. For replication, the DNA double helix opens at one end, making the two strands free to which new strands begin to form and the process continues in a sequence for the whole length of the DNA.



REPLICATION OF DNA

1.7.3 Can the cell cycle go on endlessly?

No! At some places it stops permanently, at some places temporarily and at others till it is needed. There is a regulatory mechanism for cell cycles.

Mechanism for cell cycle:

- **Brain** and other **nerve cells**, once formed in the embryo do not divide further. Once dead, they are not replaced.
- **Liver cells** may divide only once every one to two years to replace damaged or destroyed cells.
- **Surface skin** cells are continuously lost and replaced by the underlying cells.
- In plants, the cells at the growing points (meristems) divide very rapidly and produce new leaves, buds and flowers, etc.
- Specialized **germinal cells** in the ovary and testis in animals and in the ovary and anthers in plants undergo the other type of cell division called meiosis to produce sex cells.
- Uncontrolled non-stop cell cycles may lead to **tumours that may or may not be cancerous.**

1.8 CELL DIVISION

There are two types of cell divisions:

- Mitosis: cell division leading to the production of diploid cells for growth and development.
- Meiosis: cell division leading to the production of haploid cells or gametes (sperms or eggs).

1.8.1 MITOSIS (mitos: thread, referring to chromatin thread)

- MITOSIS is the cell division in which one parent cell divides into two identical daughter cells.
- **The same normal chromosome number is maintained at each cell division.**

Phase of mitosis: Mitosis is completed in two steps: karyokinesis and cytokinesis.

Karyokinesis (division of nucleus)

Karyokinesis of mitosis occurs in four main phases.

The four phases of mitosis are:

(i) Prophase
(ii) Metaphase
(iii) Anaphase
(iv) Telophase

(i) PROPHASE (A and B)

- Centrioles start moving apart and reach opposite poles.
- Each centriole is surrounded by radiating rays called **aster rays.**
- Chromosomes become distinct.
- Chromosomes are already duplicated as paired chromatids.
- Sister chromatids attached to each other at a small region called centromere.
- Spindle fibres appear between daughter centrioles forming the achromatic spindle.
- Nuclear membrane and nucleolus disappear.
- It is the longest phase of mitosis.

(i) METAPHASE (C)

- Each chromosome gets attached to spindle by its chromosomes.
- Chromosomes line up in one plane at equator.

(ii) ANAPHASE (D and E)

- Centromere attaching the two chromatids divides/splits.

- The two sister chromatids of each chromosome separate and are drawn apart towards opposite poles pulled by shortening of spindle fibres.
- A furrow starts in the cell membrane at the middle in animal cell.
- It is the shortest phase of mitosis.

(iii) TELOPHASE (F)

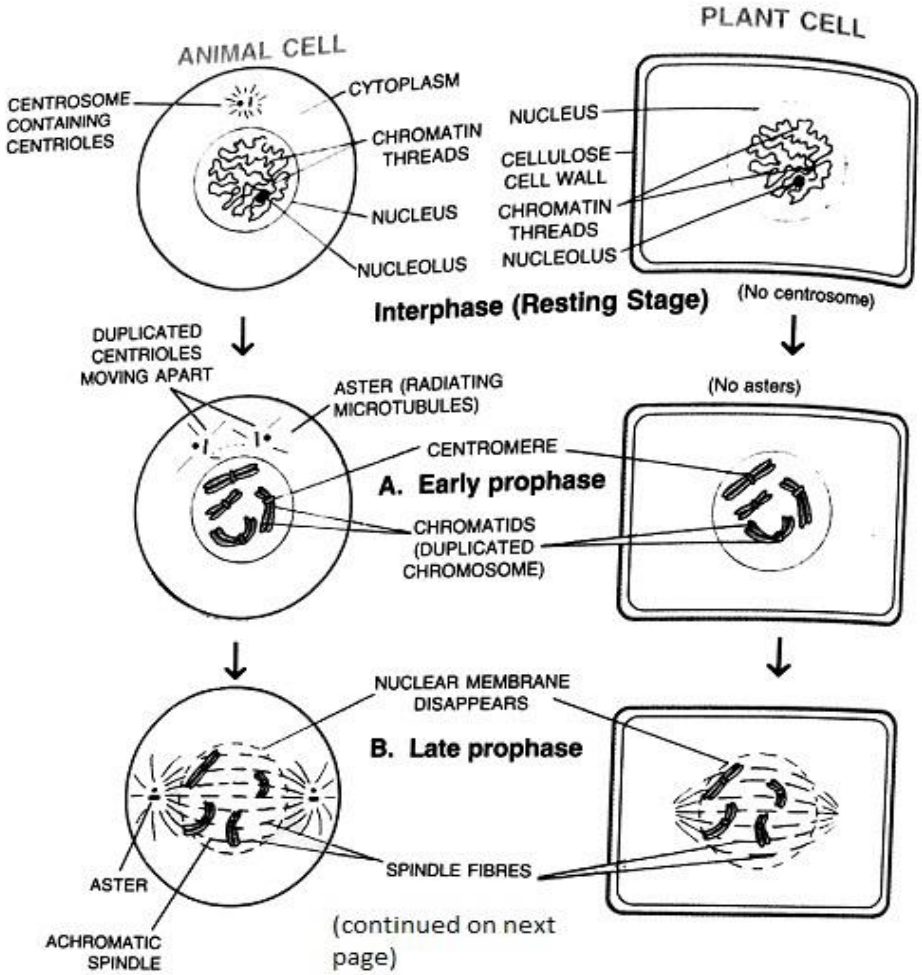
- Two sets of daughter chromosomes reach opposite poles.
- Spindle fibres disappear.
- Chromatids thin out in the form of chromatin fibres.
- Nuclear membrane is formed.
- The cleavage furrow starts deepening in the animal cells.
- Nucleoli reappear.

Cytokinesis (division of cytoplasm)

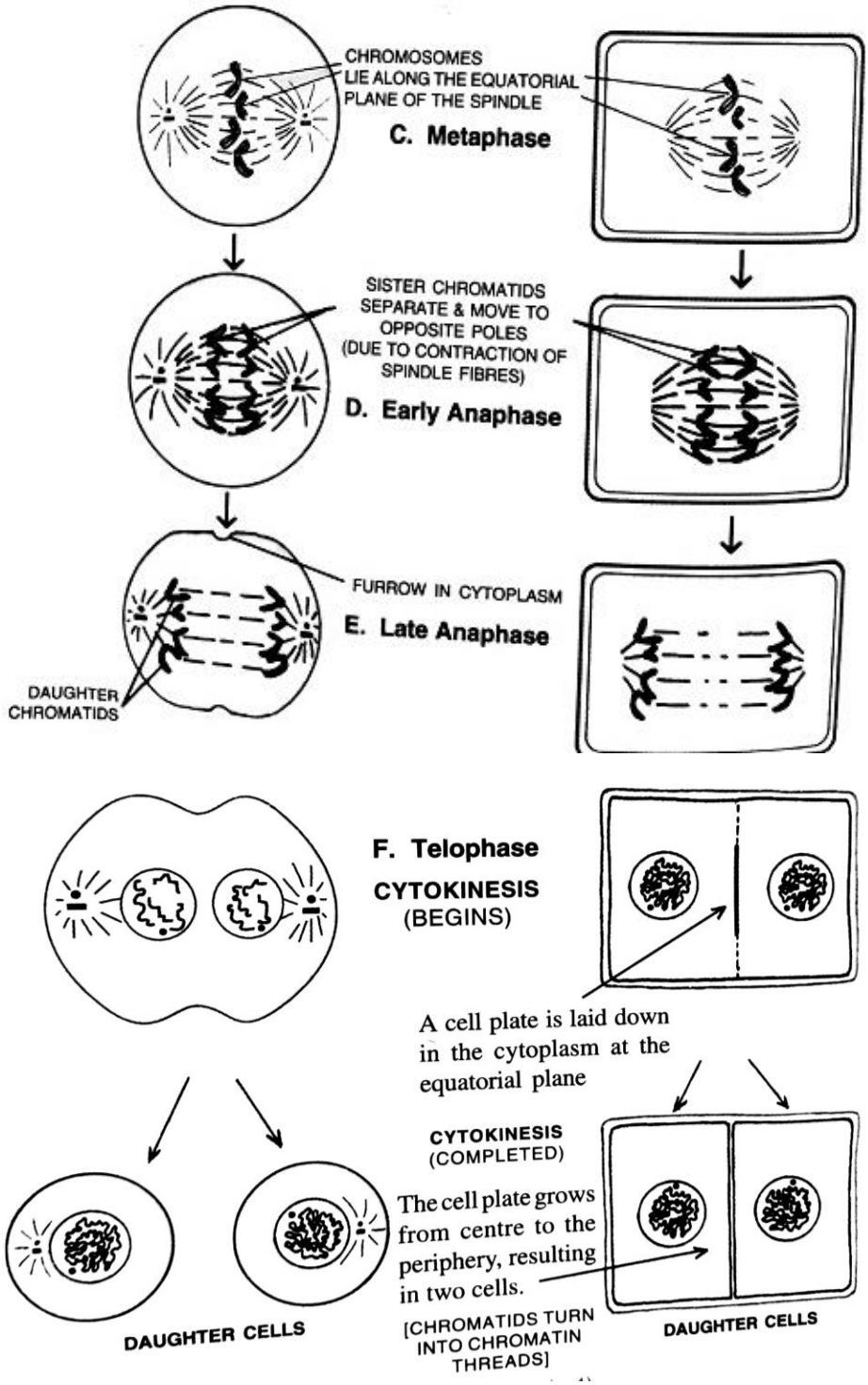
➢ At the end of telophase, a furrow appears in the cell membrane in the middle, which deepens and finally splits the cytoplasm into two, thus producing two new cells.

Karyokinesis and Cytokinesis

➢ All the nuclear changes that occur during cell division are collectively termed **karyokinesis** (**karyo**: nucleus) karyokinesis is followed by the division of cytoplasm **(cytokinesis).**



MITOSIS



(Continued) MITOSIS

Table: Differences between mitosis in animal and plant cell

Animals	Plants
1. Asters are formed.	1. Asters are not formed.
2. Cytokinesis by furrowing of cytoplasm.	2. cytokinesis **by cell plate** formation.
3. Occurs in most tissues throughout the body (for growth and replacement).	3. occurs mainly at the growing tips (for lengthening) and sides (for increase in girth).

MITOCHONDRIA AND CHLOROPLASTS IN CELL DIVISION

- Both mitochondria and chloroplasts have their own **DNA** (containing certain genes).
- They also contain their own ribosomes which help in producing the particular proteins of these two organelles.
- Both of these divides of their own by simple fission, just splitting into two and are partitioned between the two daughter cells produced by mitosis.
- Mitochondrial division is also guided by the genes in the nucleus and through the cytoplasmic ribosomes.

HOW OLD ARE SOME OF OUR BODY CELLS?

- Cells of the **eye lens, nerve cells** of the cerebral cortex and most **muscle cells** last a life time but once dead are not replaced.
- **Skin cells** are replaced every two weeks or so.
- **Red blood cells** last for about 120 days and are replaced.
- **Bone cells** are replaced every 10 years or so in adults.
- **Epithelial cells** lining the gut last only 5 days.
- Average life of **other gut cells** is about 15 years.
- **Liver cells** are replaced every 300-500 days.

1.9 MEIOSIS (Reproduction division producing gametes)

- Meiosis is the kind of cell division that produces the sex cells or the gametes.
- It takes place in the reproductive organs (testis and ovary) in humans to produce sperms and ova.in the flowering plants, it takes place in the anthers and the ovary to produce pollen grains and ovules.
- The most significant aspect of meiosis (meiosis: diminution) is that the number of chromosomes in the sex cells is halved.
- For example, out of the 23 pairs of chromosomes in humans, only single chromosomes i.e. one member of each pair (haploid) are passed on to the sex cells. This is essential because when the male and female gametes fuse during fertilization, the normal double (diploid) number of chromosomes (in pairs) is reacquired.

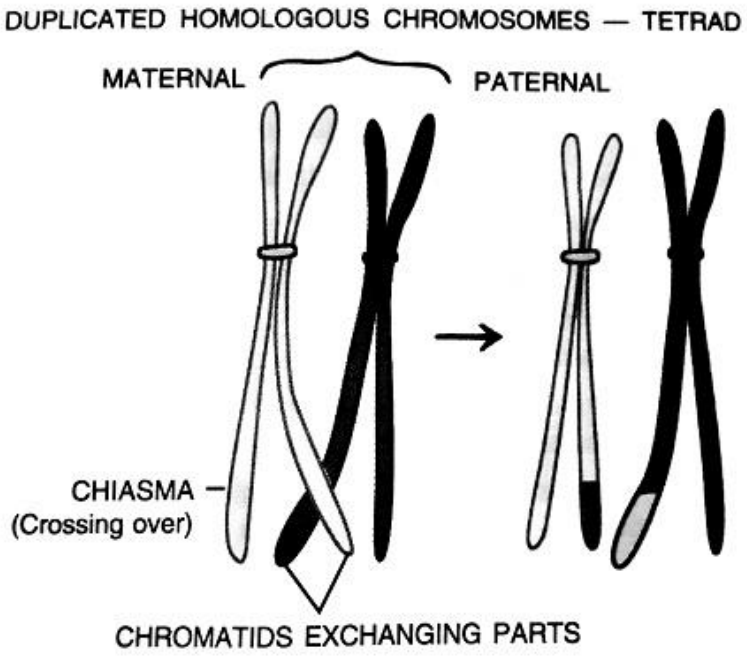
1.9.1 Significance of meiosis

1. **Chromosomes number is halved** in gametes (sex cells), so that on fertilization, the normal number (2n) is restored.

2. It provides for **mixing up of genes** which occurs in two ways:

(i) **The maternal and paternal chromosomes get mixed** up during the first (reduction) division as they separate from the homologous pairs.

(ii) While the maternal and paternal chromosomes are separating, the chromatids material very often gets exchanged between the two members of a homologous pair. This is known as **crossing over** (as shown in fig.) which results in genetic recombination.



	Mitosis	Meiosis
1. *Where it occurs*	in the **somatic** (body) **cells**.	in **reproductive cells**.
2. *What for*	to provide **for growth and replacement**.	only **for gamete formation**.
3. *When it occurs*	continuously **throughout life**.	only in **reproductively active age**.
4. *Number of daughter cells produced*	**two daughter cells**.	**four daughter cells**.
5. *Number of chromosomes passed on to each daughter cell*	**full set of chromosomes** is passed on to each daughter cell. This is the **diploid** (2n) number of chromosomes.	Only **half the number of chromosomes** (only one member from each pair) is passed on to each daughter cell. This is the **haploid** (n) number of chromosomes.
6. *Number of nuclear divisions*	**a single nuclear division** after chromosome duplication.	**two nuclear divisions** after chromosome duplication.
7. *Identity of chromosomes and genes in daughter cell*	**identical**.	**randomly assorted** between the gametes produced. This results in genetic variations.