INTRODUCTORY BIOLOGY AND MICROBIOLOGY

BY

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Meiosis and Sexual Life Cycles

Introduction

- The transmission of traits from one generation to the next is called inheritance or hereditary (from the Latin word *heres*, heir).
- Along with inherited similarity there is also variation. The question is: What are the biological mechanisms leading to the hereditary similarity and variation? This can be answered through genetics.
- Genetics is the scientific study of heredity and hereditary variation. The other question is what is actually inherited?

Inheritance of Genes

- Parents endow their offspring with coded information in the form of hereditary units called ***genes***.
- The genes we inherit from our parents make our genetic linkage to the parents and account for family resemblances such as shared eye color or chick dimples.
- Our genes program the specific traits that emerge as we develop from fertilized eggs into adults.
- The genetic information is in the DNA, which is a polymer of four different nucleotides.

- In animals and plants, reproductive cells called gametes are the vehicles that transmit genes from one generation to the next.
- During fertilization, male and female gametes (sperm and eggs) unite, thereby passing on genes of both parents to their offspring.
- Except for small amount of DNA in mitochondria and chloroplast, the DNA of a eukaryotic cell is packaged into chromosomes within the nucleus.

- Every living species has a characteristic number of chromosomes. For example, humans have 46 chromosomes in almost all their cells.
- Each chromosome consist of a single long DNA molecule coiled in association with various proteins.
- Each chromosomes has hundreds of thousands of genes each of which is a specific sequence of nucleotides within the DNA molecule.

- A gene's specific location along the length of a chromosome is called the gene's *locus* (from latin word, meaning "place"; plural *loci*).

Comparison of Asexual and Sexual Reproduction

- Only organisms that reproduce asexually produce offspring that are exact copies of themselves.
- In asexual reproduction, a single individual is the sole parent and passes copies of all its genes to its offspring.
- The genomes of the offspring are exact copies of the parent's genome. This is possible through mitosis in the parent.

- Asexual reproduction is common in single celled organisms, however, some multicellular organisms are also capable of reproducing a sexually.
- An individual that reproduces asexually gives rise to a clone, a group of genetically identical individuals.
- Genetic differences usually arise in asexually reproducing organisms as a result of changes in the DNA due to mutation.
- In sexual reproduction, two parents give rise to offspring that have combination of genes inherited from the two parents.

- In contrast to a clone, offspring of sexual reproduction vary genetically from their siblings and both parents.
- They are variations on a common theme of family resemblance i.e. not exact replicas.
- The variation is as a result of the behavior of chromosomes during the sexual life cycle. *This is the gist of lecture 3.*

- A life cycle is the generation-to-generation sequence of stages in the reproductive history of an organism, from conception to production of its own offspring.
- Our discussion will be based on humans as example to track the behavior of chromosomes through sexual life cycle.
- To fully understand this we must first look at chromosome count in human somatic (body) cells and gametes and later own discuss the behavior of chromosomes in the sexual life cycle of a human being.

Sets of Chromosomes in Human cells

- In humans, each body cell, other than those involved in gamete formation, has 46 chromosomes.
- Examination of a micrograph of the 46 human chromosomes from a single cell in mitosis reveals that there are two chromosomes of 23 types.
- This can be seen when the chromosomes are arranged in pairs starting with the longest chromosomes.
- The ordered display is called a ***karyotype.***

- Two chromosomes composing a pair that have the same length, centromere position and staining pattern are called ***homologous chromosomes or homologs.***
- There are two distinct chromosomes referred to as X and Y, which are exception to the pattern of homologous chromosomes in the human somatic cells.
- Human females have homologous pair of X chromosomes (XX), but males have one X and one Y chromosomes (XY)
- Only small parts of X and Y are homologous. Most of the genes carried on the X chromosome do not have counterparts on the tiny Y chromosome.

- Because they determine an individuals sex, the X and Y chromosomes are called sex chromosomes, others are called autosomes.
- The 46 chromosomes in our somatic cells are actually two sets of 23 chromosomes - a maternal set (from our mother) and a paternal set (from our father).
- The number of chromosomes in a single set is represented by n. Any cell with two chromosome sets (*i.e. set from mother and set from father*) is called diploid cell and has a diploid number of chromosomes, abbreviated as 2n.

- In humans the diploid number is 46 therefore 2n = 46.
- Unlike somatic cells, gametes (sperm and eggs) contain a single chromosome set. Such are called haploid cells, and each has a haploid number of chromosomes (n).
- For humans the haploid number is 23 (n = 23).
- The set of 23 consists of 22 autosomes and a single sex chromosome.
- An unfertilized egg contains an X chromosome but the sperm may contain an X or a Y chromosome.

- **NOTE**: Each sexually reproducing organism has a characteristic diploid and haploid number of chromosomes. Drosophila melanogaster *2n = 8*, *n = 4*, Dog *2n = 78*, *n = 39*, human *2n = 46*, *n = 23*.

Behavior of Chromosome Sets in Human Life Cycle

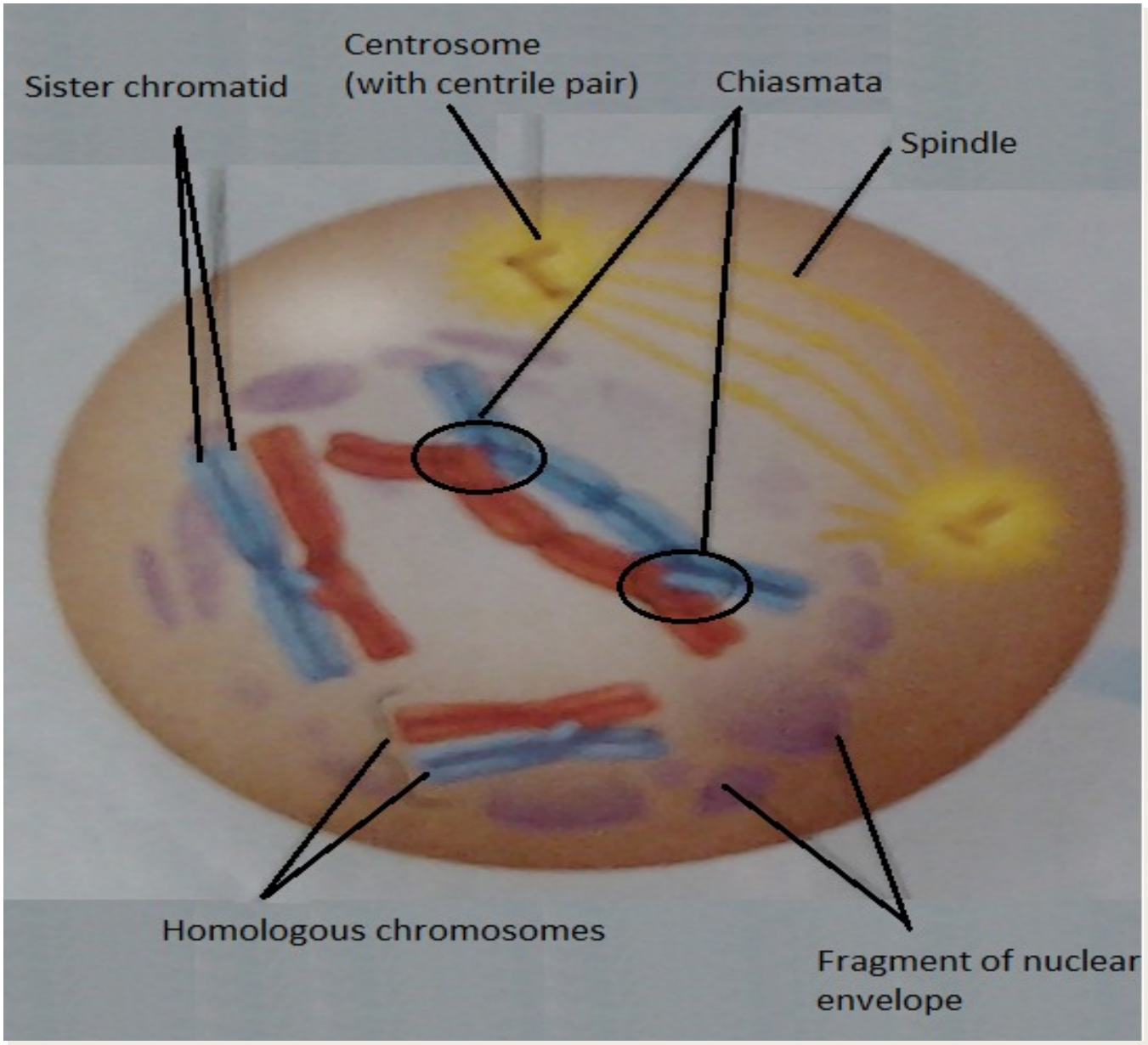
- The human life cycle begins when a haploid sperm from the father fuses with a haploid egg from the mother.
- This union of gametes, culminating into fusion of their nuclei, is called fertilization.
- The resulting fertilized egg or zygote, is diploid because it contains two haploid sets of chromosomes carrying genes representing maternal and paternal family lines.
- As a human develops into a mature adult, mitosis of the zygote generates all the somatic cells.

- The only cells of human body not produced by mitosis are the gametes, which develop from specialized cells called the germ cells in the gonads - ovaries in females and testes in males.
- In sexually reproducing organisms gametes are formed by a modified type of cell division called ***meiosis***. This type of cell division reduces the number of sets of chromosomes from two to one in the gametes.
- In animals meiosis occurs only in the ovaries or testes. As a result of meiosis each human sperm and egg is haploid (n = 23).

- Fertilization restores the diploid condition by combining two haploid sets of chromosomes.
- Fertilization and meiosis alternate in sexual life cycles, maintaining a constant number of chromosomes in each species from one generation to the next.
- Assignment: Give an account of the three types of life cycle that exists

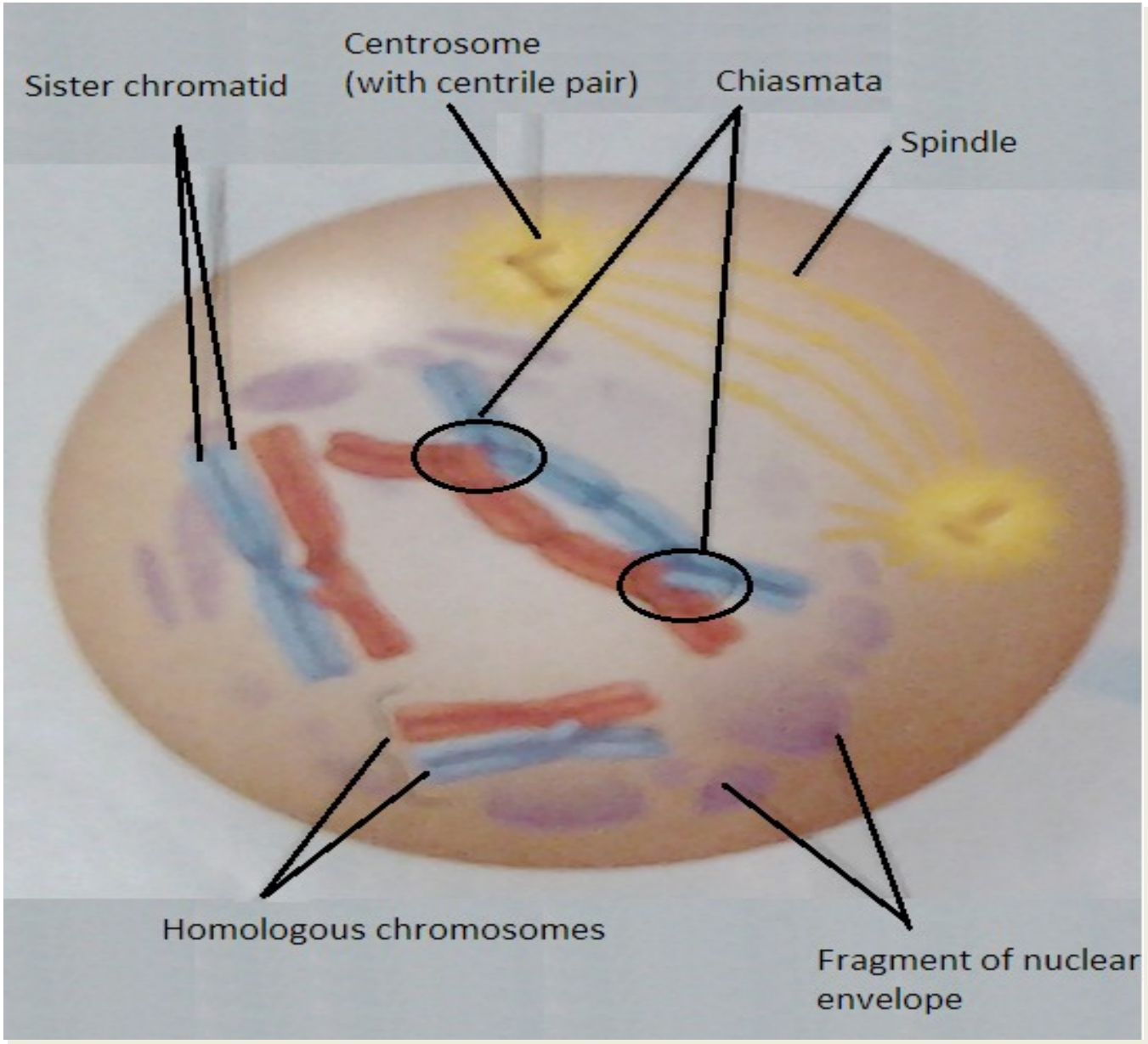
The Stages of Meiosis

- Meiosis is the mechanism for gamete formation and involves a two-stage division process.
- Meiosis, like mitosis, is preceded by the replication of chromosomes. However, this single replication is followed by two consecutive cell divisions called meiosis I and meiosis II.
- These two divisions results in four daughter cells each with only half as many chromosomes as the parent cell.
- In the next discussion we are looking at stages of meiosis with an example of a cell whose diploid number is 6.


Sister chromatid
Centrosome
(with centrile pair)
Chiasmata
Spindle
Homologous chromosomes
Fragment of nuclear
envelope

Meiosis I: Separate homologous chromosomes

- Prior to meiosis, homologous chromosomes replicate forming sister chromatids.
- i. Prophase I
  - In prophase I, sister chromatids pair up forming what is called a tetrad.
  - Chromosomes begin to condense and homologs loosely pair along their lengths.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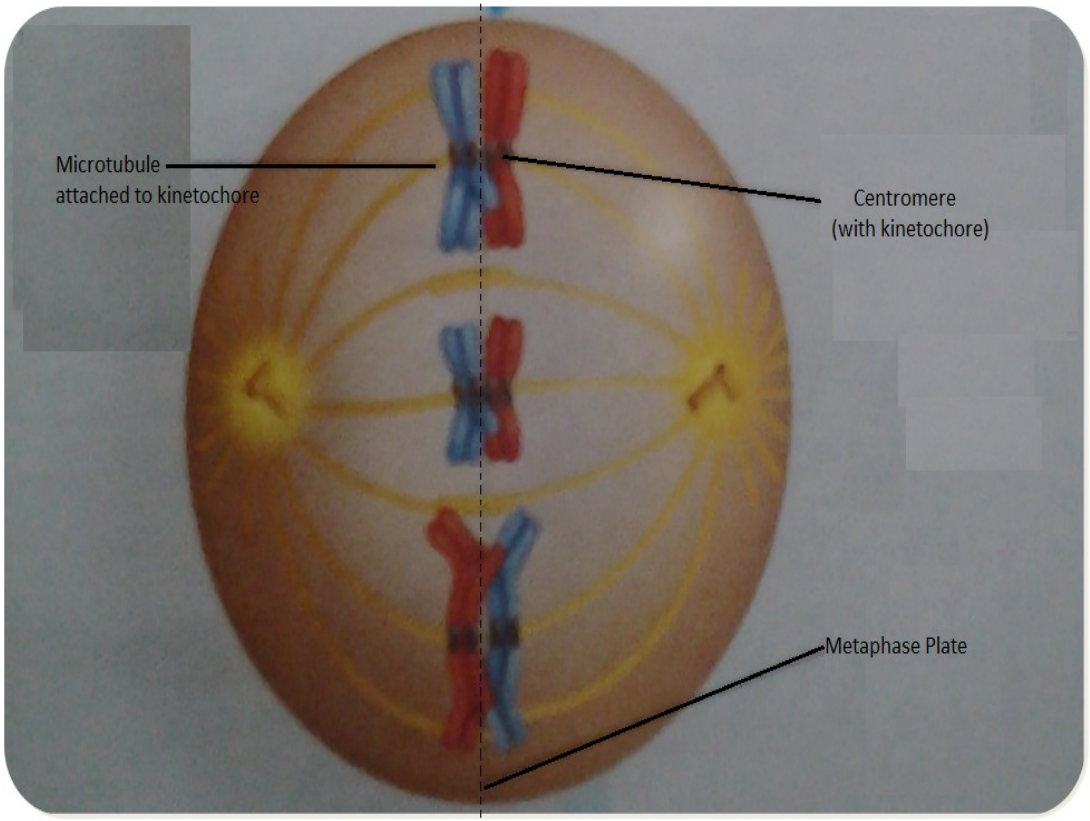
- Crossing over (i.e. the exchange of corresponding segments of DNA molecules by non-sister chromatids - as genetic recombination) is completed while homologs are in synapsis, holding tightly together by proteins along their lengths.
- Synapsis ends in mid-prophase and chromosomes in each pair move a part slightly.
- Each homologous pair has one or more chiasmata, points where crossing over has occurred and the homologs are still associated due to cohesion between sister chromatids (Chromatid cohesion).

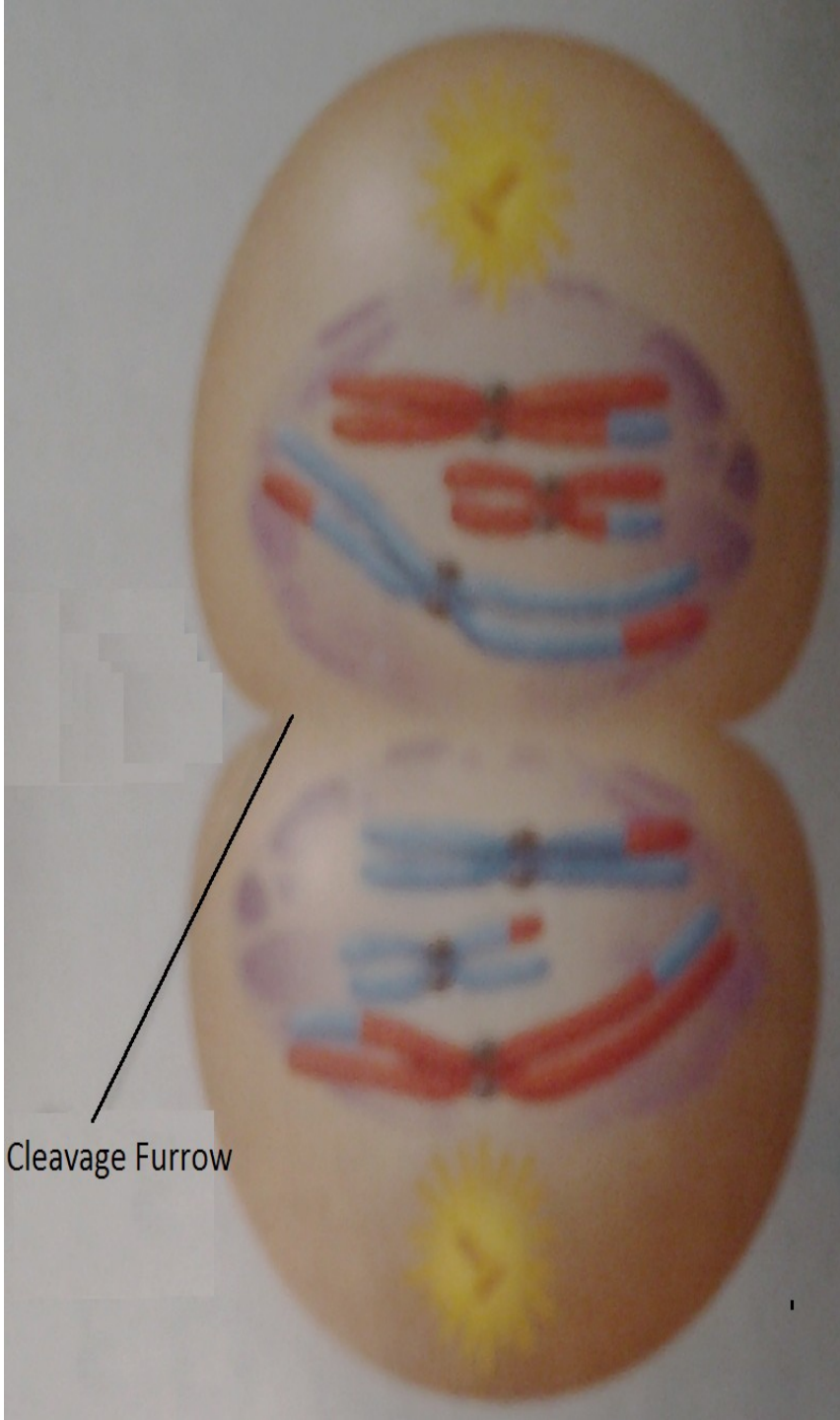
- Centrosomes movement, spindle formation and nuclear envelope breakdown occurs as in mitosis.
- In late prophase I, microtubules from one pole or the other attach to the two kinetochores, protein structures at the centromeres of the two homologs. The homologous pair then move towards the metaphase plate.

- Metaphase I
  - Pairs of homologous chromosomes are now arranged on the metaphase plate with one chromosome in each pair facing each pole.
  - Both chromatids of one homolog are attached to kinetochore microtubules from one pole, those of the other homolog are attached to microtubules from the opposite pole.



- Anaphase I
  - Breakdown of proteins responsible for sister chromatid cohesion along chromatid arms allows homologs to separate.
  - The homologs move toward opposite poles, guide by the spindle apparatus
  - Sister chromatid cohesion persists at the centromere, causing chromatids to move as a unit toward the same pole.

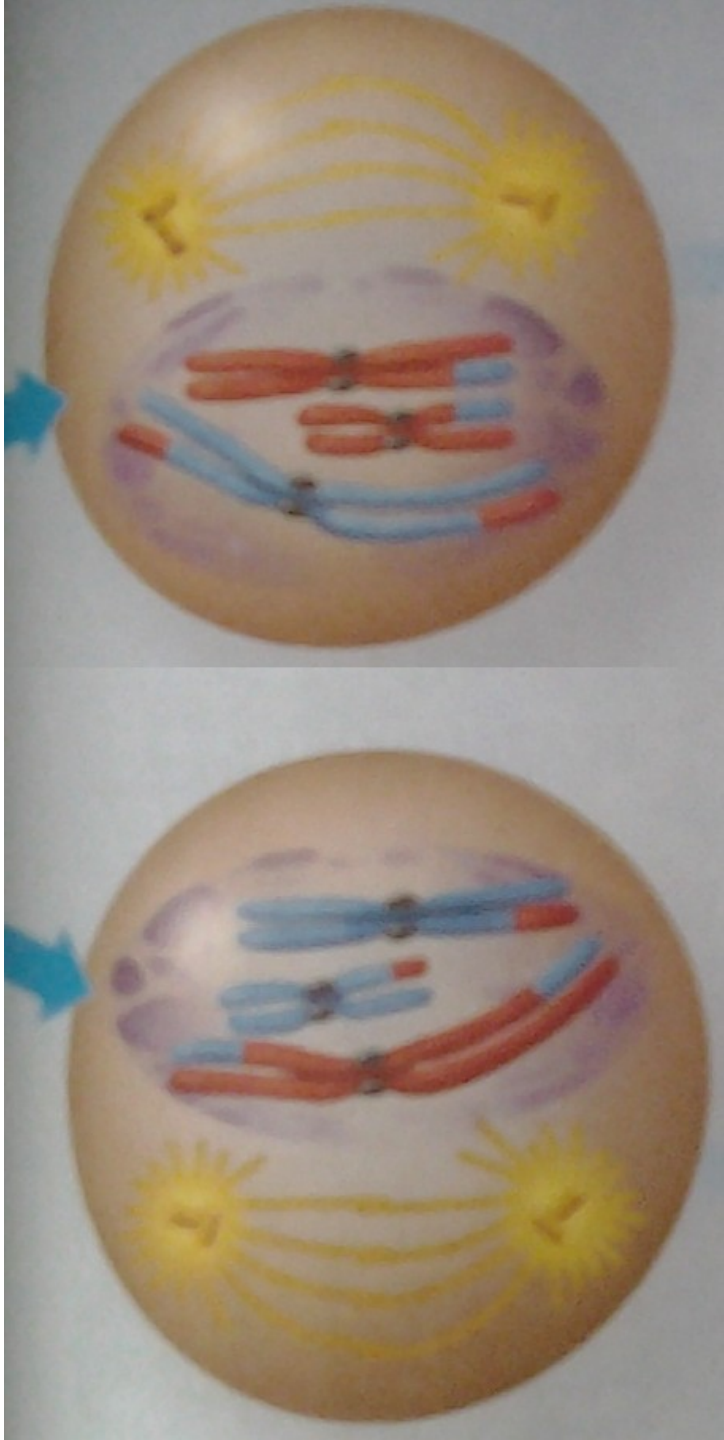
- Telophase I and Cytokinesis
  - At the beginning of this phase, each half of the cell has complete haploid set of chromosomes. Each chromosome is composed of two sister chromatids, one or both chromatids include regions of non-sister chromatid DNA.
  - Cytokinesis usually occurs simultaneously with telophase I, forming two haploid daughter cells.



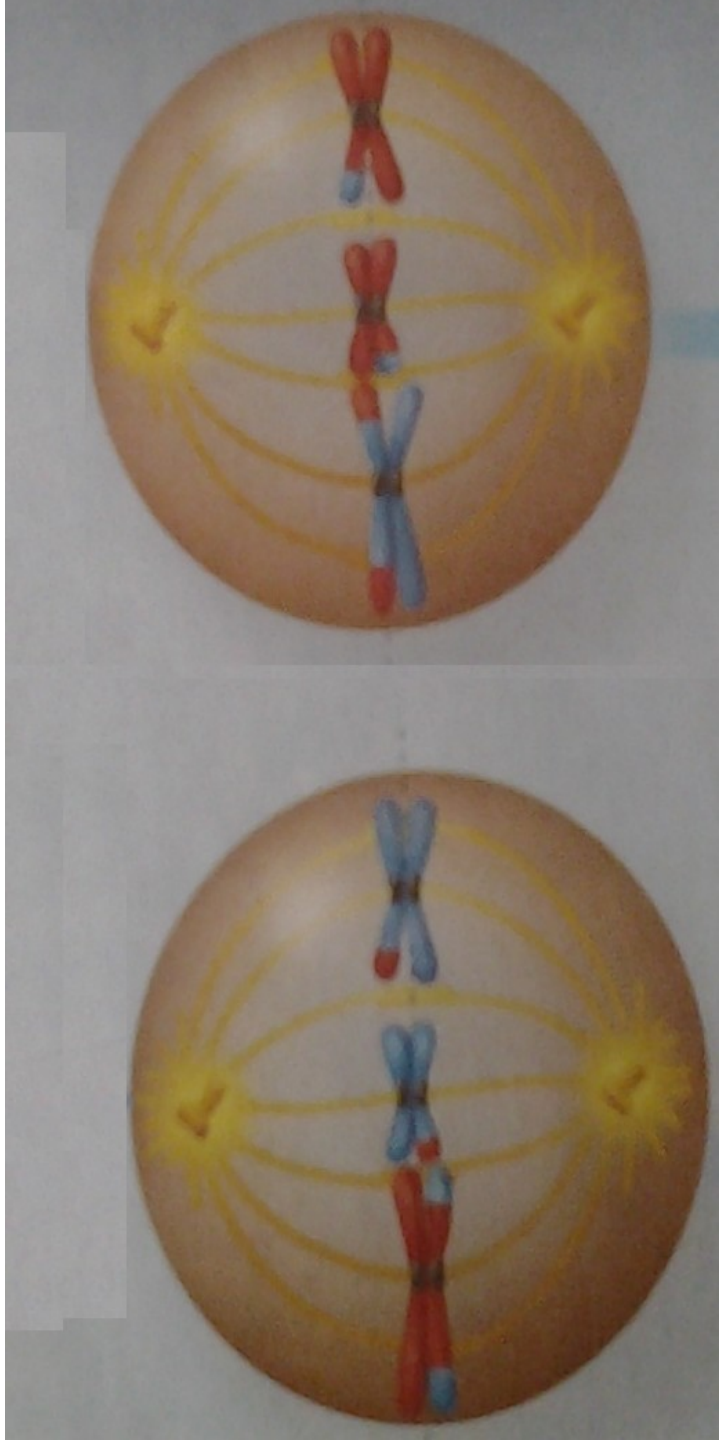
- In animal cells, cleavage furrow forms while in plant cells metaphase plate forms.
- No replication occurs between meiosis I and II.

Meiosis II

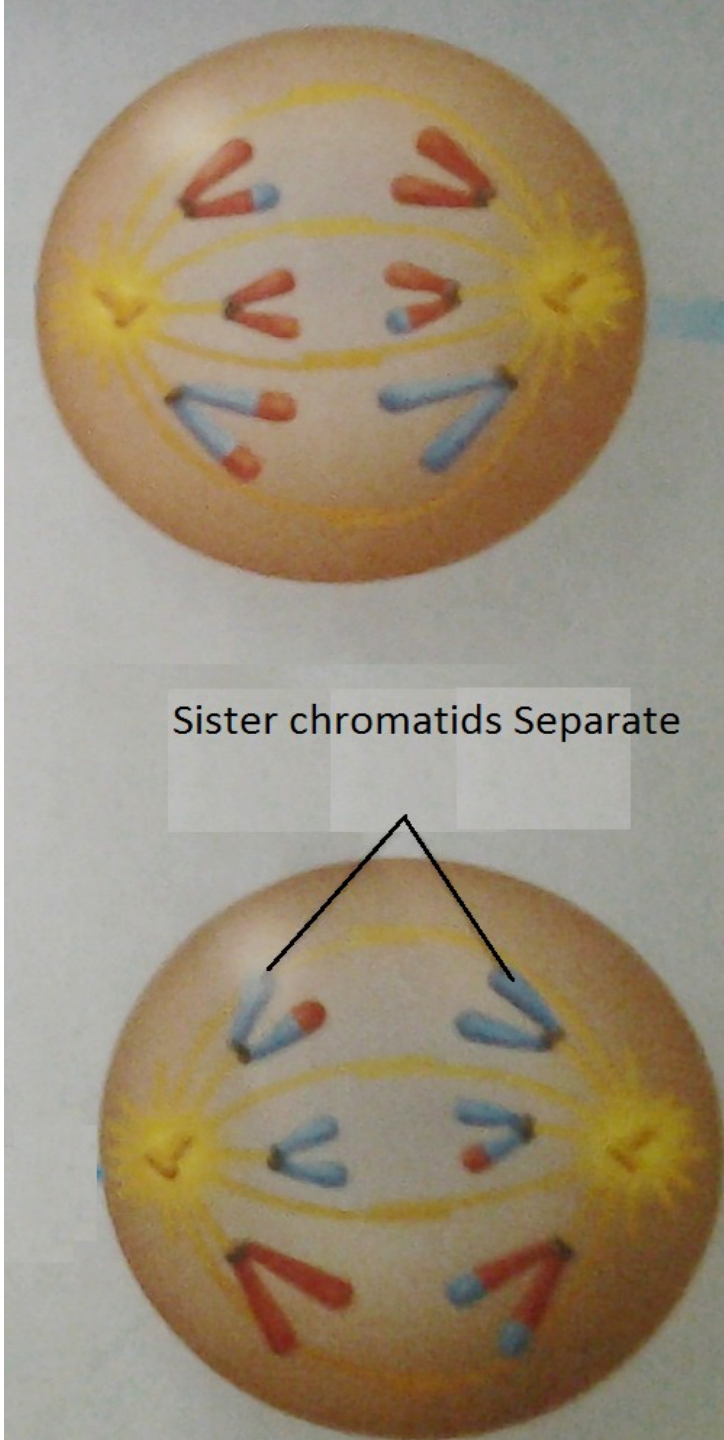
- Prophase II
  - A spindle apparatus forms.
  - In late prophase II chromosomes, each still composed of two chromatids associated at the centromere, move towards the metaphase plate.



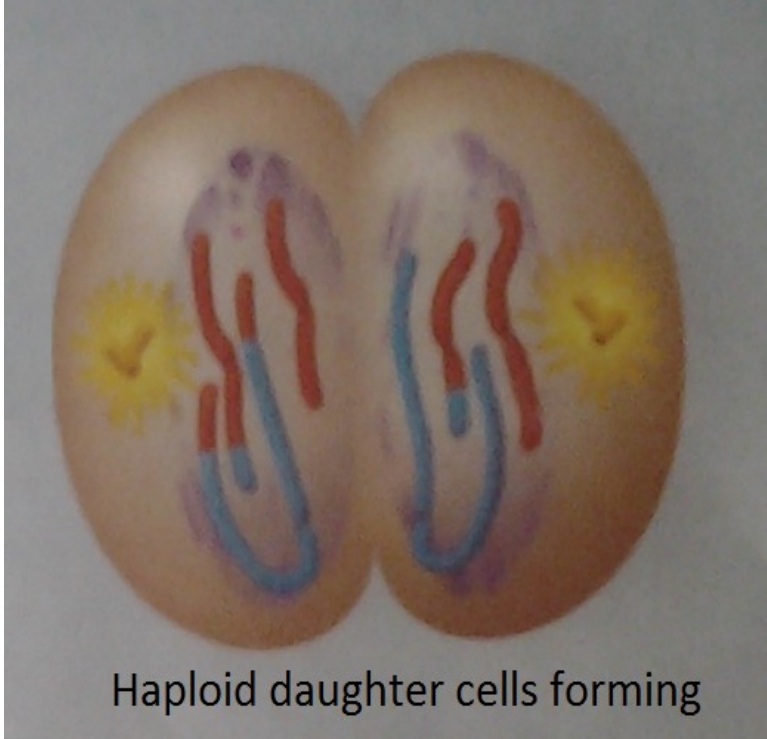
- Metaphase II
  - The chromosomes are positioned on the metaphase plate.
  - Because of crossing over I meiosis I, the two sister chromatids of each chromosome are not genetically identical.
  - The kinetochores of sister chromatids are attached to microtubules extending from opposite poles.



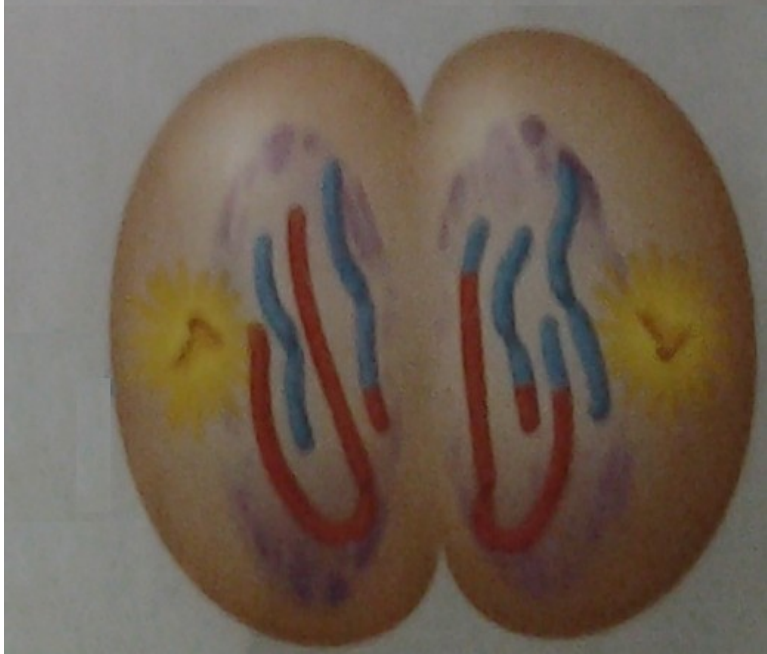
- Anaphase II
  - Breakdown of proteins holding the sister chromatids together at the centromere allows the chromatids to separate.
  - The chromatids move toward opposite poles as individual chromosomes.



- Telophase II and Cytokinesis
  - Nuclei form, the chromosomes begin decondensing and cytokinesis occurs.
  - The meiototic division of one of the parent cells produces four daughter cells, each with haploid set of (unreplicated) chromosomes.
  - Each of the four daughter cells is genetically distinct from the other daughter cells and from the parent cell.



Haploid daughter cells forming



Comparison of Mitosis and Meiosis in Diploid Cells		
Property	Mitosis	Meiosis
DNA replication	Occurs during interphase before mitosis begins	Occur 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 homolgous chromosomes	Does not occur	Occurs during prophase I along with crossing over between nonsister chromatids; resulting chiasmata holds pairs together due to sister chromatid cohesion.
Number of daughter cells and genetic composition	Two, each diploid and genetically identical to parent cell	Four, each haploid, containing half as many chromosomes as the parent cell, genetically different from the parent cell and from each other.

Comparison of Mitosis and Meiosis in Diploid Cells		
Property	Mitosis	Meiosis
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.

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