MITOSIS AND MEIOSIS - THEIR SIGNIFICANCE AND DIFFERENCES BETWEEN THEM

Mitosis occurs only in eukaryotes. Prokaryotes (i.e., archaea and bacteria) divide via binary fission. Mitosis is the process by which the somatic cells of all multicellular organisms multiply. Somatic cells are the nonreproductive cells of which an organism is composed.

In addition, plants produce gametes by mitosis. Gametes are sexual reproductive cells, that is, there are two types, male and female. In sexual reproduction, a male gamete combines with a female gamete and the resulting, merged cell then divides repeatedly by mitosis to eventually produce a mature organism. Plants also make asexual reproductive cells called spores (by *meiosis*, not mitosis). One spore does not have to combine with another spore for reproduction to occur. A single spore, produced by meiosis, develops into a mature organism by *mitosis*.

Why mitosis?

1. Growth. The number of cells within an organism increases by mitosis and this is the basis of growth in multicellular organisms.
2. Cell Replacement. Cells are constantly sloughed off, dying and being replaced by new ones in the skin and digestive tract. When damaged tissues are repaired, the new cells must be exact copies of the cells being replaced so as to retain normal function of cells.
3. Regeneration. Some animals can regenerate parts of the body, and production of new cells are achieved by mitosis.
4. Vegetative Reproduction. Some plants produce offspring which are genetically similar to themselves. These offspring are called **clones**.

Consequence of mitotic division

- **No variation** in genetic information
- No variation in chromosome number due to the **semi-conservative replication** of DNA and **equal distribution** of DNA.
- The cell divides **once**.
- Two **identical daughter cells** are formed.

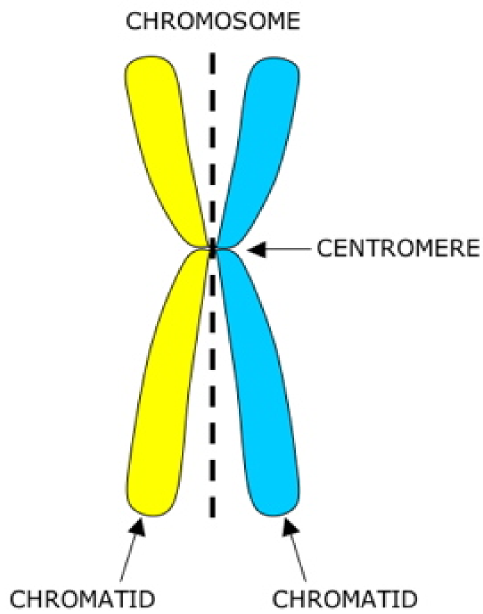
Mitosis produces two daughter cells that are identical to the parent cell. If the parent cell is haploid (N), then the daughter cells will be haploid. If the parent cell is diploid, the daughter cells will also be diploid.

$N \rightarrow N$

$2N \rightarrow 2N$

A chromatid is one of the two halves of a replicated chromosome (see diagram at right). The two chromatids that make up a chromosome are called "sister chromatids," They are joined at the centromere and are genetically identical because, during interphase, one sister of each chromatid pair is produced by directly copying the other, pre-existing sister. They therefore contain identical alleles at all loci. In contrast, two homologous chromosomes (chromosomes that have the same set of loci in the same order) usually do not have identical alleles at all loci. They are inherited from different parents and are not direct copies of each other.

The two sister chromatids of each chromosome are segregated into separate cells in both mitosis and meiosis, but they remain together throughout meiosis I. It is only during the second meiotic division (meiosis II) that they finally are separated and distributed into separate cells. As soon as the joined chromatids are separated they are no longer called sisters because they are no longer connected to each other. Instead they are now called unreplicated chromosomes.



Stages of Mitosis

The process of mitosis is divided into 6 stages.

Interphase

Prophase

Metaphase

Anaphase

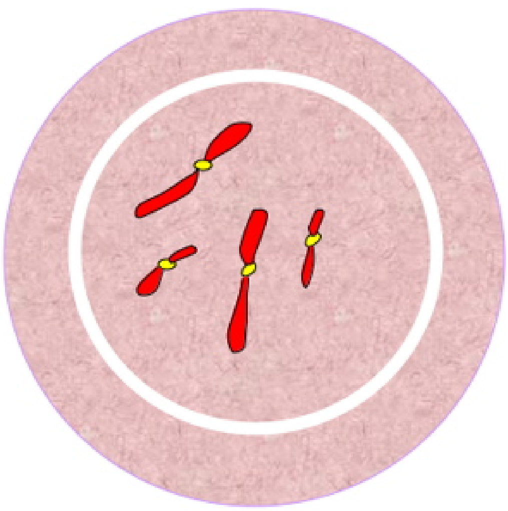
Telophase and

Cytokinasis.

Interphase

At Interphase, there is only one cell, but after cytokinasis there are two identical cells. Before mitosis can take place, the cell need to store enough energy to drive the chemical processes during the cell division. During this period of time, there is intense cellular activity. The cell grows in size. The length of the grow phase varies between a few hours to a few months. We the cell has stored enough energy, it is ready to divide itself.

The interphase, or growth, period of the cell cycle alternates with the mitotic phase of the cycle. It's the period when the cell is *not* undergoing mitotic division. So it is *not* part of mitosis. When it begins, the chromosomes (red) have not yet replicated (i.e., each chromosome has a single chromatid), but by the beginning of prophase replication is complete. Thus, the picture shown here represents the chromosomes as they are in the first stage of interphase before replication has occurred, G_1 phase (G_1 stands for first gap). During the next stage, S phase (synthesis), the chromosomes replicate, and by the beginning of the third, G_2 phase (G_2 stands for second gap), replication is complete.

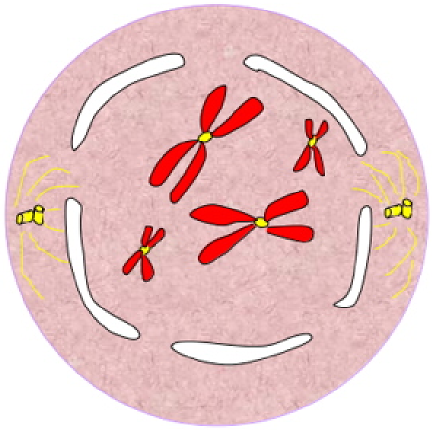


Parent Cell (Interphase - G_1)

In this diagram the chromosomes are shown as if they were visible, simply to show that they have not replicated. However, during G_1, S, and G_2 they are not actually visible under a light microscope, both because they are uncondensed and because they are still enclosed in the nuclear membrane.

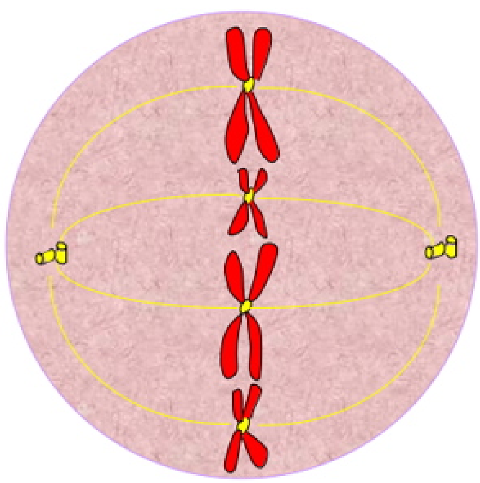
Prophase

Prophase is the first of the four stages of mitosis. Early during this stage the chromosomes (shown in red in the diagram) become visible with a light microscope as they condense (i.e., as they shorten, coil, and thicken). Also, the spindle (yellow strands) begins to extend outward from each of two centers of extension. This starlike configuration is called an *aster*. In animal cells one pair of centrioles (represented by the yellow cylinders in the diagram) is present at each centers of extension. As prophase progresses, the nuclear membrane (white) begins to break up and disappear. Each chromosome has been duplicated and so is composed of two *sister chromatids* containing identical genetic information.



METAPHASE

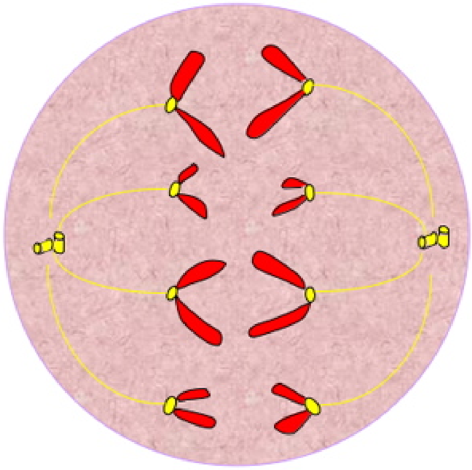
During this, the second stage of mitosis, the chromosomes line up in the middle of the cell, halfway between the centrioles on an imaginary plane called the "metaphase plate" The spindle fibers (yellow strands) attach to the centromeres (shown as yellow ovals).



ANAPHASE

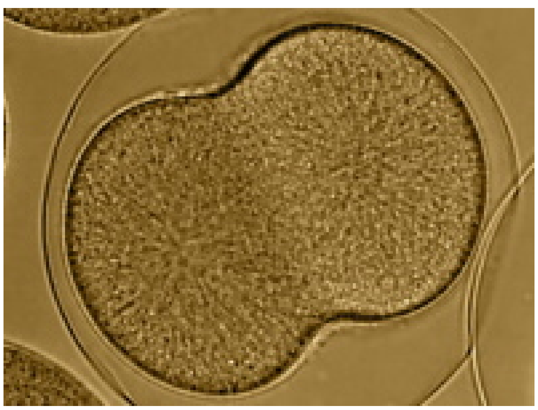
During the third of the four stages of mitosis, the two chromatids of each chromosome are pulled apart by the spindle and dragged toward opposite poles of the cell (i.e., toward the opposite centrioles). The arms of each chromosome can be seen dragging behind as the it is dragged along by its centromere.

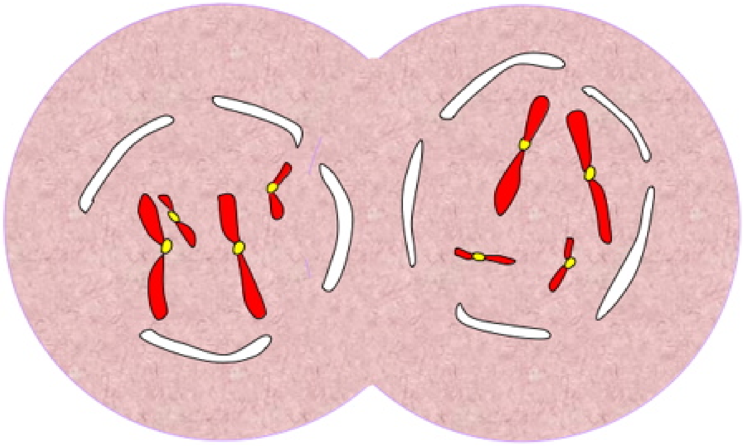
Note: To be called a chromatid, a chromatid must be attached to its sister. When the chromosomes divide at the beginning of anaphase, the sister chromatids are no longer sisters because they are no longer connected. Once they are separated, they are called unreplicated chromosomes. Unreplicated chromosomes will come up again in the Interphase section below.



TELOPHASE

During the last of the four stages of mitosis, telophase, the chromosomes have reached the poles and the nuclear membrane begins to appear. During telophase in animal cells, a cleavage furrow appears (see photo below). By the end of this stage of mitosis, the cell has divided in two along the plane defined by the furrow. In most plants, instead of a cleavage furrow, a "cell plate" forms, dividing the cell into two daughter cells.





CYTOKINESIS

While cytokinesis is one of the steps in the cell cycle, it is *not* one of the phases of mitosis. It is the division of the cytoplasm, as opposed to karyokinesis, which is division of the nucleus (the cytoplasm is all of the contents of the cell outside the nucleus). Division of the cytoplasm occurs in both mitosis and meiosis.

After mitosis, the cell returns to interphase, which recall, is the growth stage of the cell cycle between successive mitoses (interphase is the stage during which DNA synthesis, or replication, occurs). Cytokinesis and karyokinesis are now complete and there are two daughter cells. The nuclear membrane has reformed. The chromosomes have decondensed once again and are now re-enclosed in an intact nuclear membrane.

Significance of mitosis

The significance of mitosis is its ability to produce daughter cells which are exactly the same a the parent cell. It is important for three reasons:

1. **Growth**

   If a tissue wants to get bigger by growth needs new cells that are identical to the existing ones. Cells division must therefore be by mitosis.

2. **Repair**

   Damaged cells have to be replaced by exact copies of the organism so that it repairs the tissues to their former condition. Mitosis is the means by which this is achieved.

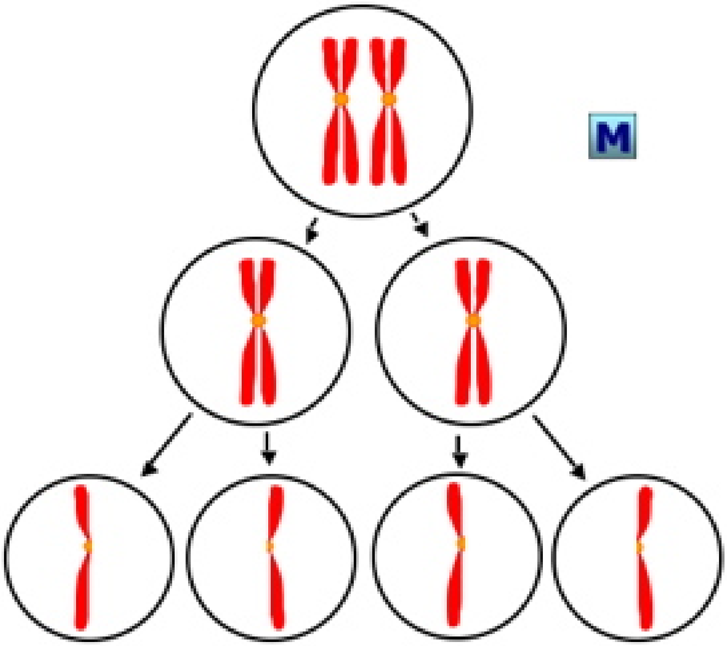
3. **Asexual reproduction**

   If a species is good at colonizing a habitat, there might be no point, in producing offspring which are different from the parents, because they might be less effective at survival. Therefore it might be better, in the short term, to make a colony which is similar to the parents. In simple animals and most plants this is achieved by mitotic division.

MEIOSIS

When does Meiosis Occur?

Meiosis occurs only in eukaryotes. Meiosis takes place at some point in the life cycle of the typical sexual organism because, by reducing the chromosome number by one half, it compensates for the doubling of the chromosome number caused by fertilization. In animals, meiosis occurs during the production of gametes (sperm and eggs). In plants, it takes place when spores are produced (plant gametes are produced by mitosis). Prokaryotes (i.e., archaea and bacteria) reproduce via binary fission.



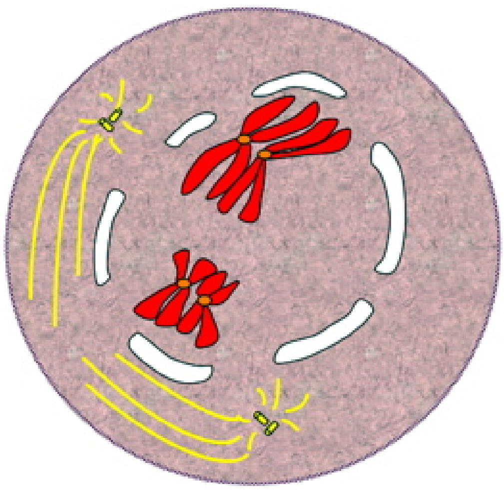
The names of the eight stages of meiosis are: prophase I, metaphase I, anaphase I, telophase I, prophase II, metaphase II, anaphase II, and telophase II. The first four steps (the ones ending in "I") are the phases of the first meiotic division, meiosis I. The last four (those ending in "II") are those of the second meiotic division, meiosis II.

Prophase I

Prophase I is the first stage of meiosis. During this phase, the chromosomes (shown in red in the diagram, below right) become visible as they shorten, coil, and thicken. Also, the spindle (yellow strands in diagram) begins to extend outward from two centers of expansion. In animal cells a pair of centrioles can be seen in each of these centers (plants lack centrioles). The nuclear membrane (shown in white) breaks up and disappears. Each chromosome is composed of two sister chromatids containing identical genetic information. The information is the same because one sister chromatid is produced by copying the other. The sister chromatids are joined by a centromere (orange).

The two members of each chromosome pair are called *homologous chromosomes* or simply *homologs*. During prophase I they join along their lengths (i.e., they synapse) to form a *tetrad* (or *bivalent*). Each of the two tetrads shown in the drawing, then, is represented as two x-shaped chromosomes aligned along their lengths and connected with each other. This is a simplified diagram, the actual situation is more complicated:

Prophase I is by far the most complicated phase of meiosis. It is much longer in meiosis than in mitosis. During this stage, homologous chromosomes join (synapse) along their lengths and exchange DNA. Prophase I is itself divided into the five substages which are explained and diagrammed below.

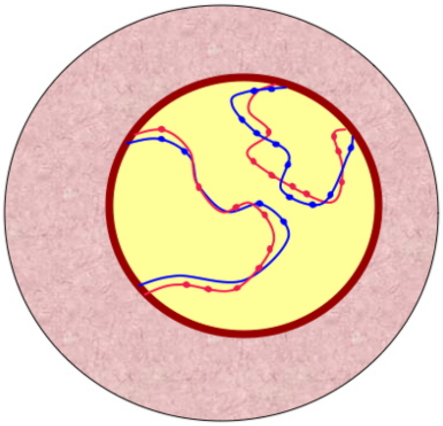


Leptotene

The chromosomes have appeared within the nuclear membrane (shown in the diagram at right as a tan circle with a brown border), but are not yet fully condensed. In the diagram the two chromosomes of paternal origin are indicated in red, those of maternal origin, in blue. Each is a thin thread of DNA (*lepto-* is Greek for *thin* and -tene is Greek for ribbon or band) along which clearly defined beads of local coiling (chromomeres) can be seen. The chromosomes, while they have this threadlike form, are called chromatonemata (sing. chromonema; *-nema* is Greek for *thread*). The chromosomes appear single because the sister chromatids are still so tightly bound to each other that they cannot be separately seen. During this stage both ends (telomeres) of each chromosome are turned toward, and probably attached to, the same region of the nuclear membrane. Leptotene is also known as

(1) *leptonema*; and as

(2) the *bouquet stage* because all the telomeres tend to contact the nuclear membrane in one spot so that the looped chromosomes balloon out from that point like flower petals.

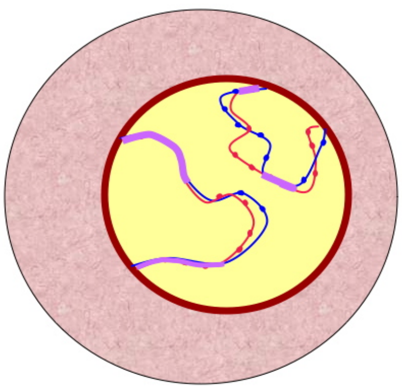


Zygotene (also known as *zygonema*)

During this stage, homologous chromosomes (or homologs for short) begin to unite (synapse) by coming into approximate alignment (*zygo-* is Greek for *union, fusing,* or *yoking*). Synapsis, the process of fusion that occurs between homologous chromosomes, begins at various points along the chromosomes and extends outward, zipper-fashion, until complete. When synapsis is finished, the fused homologous chromosomes look like single chromosomes under the light microscope. These chromosomes that look single, but that are actually double, are called *bivalents.* The interface where two homologous chromosomes ("homologs" for short) unite is called a *synaptonemal complex*, which can be seen under an electron microcope

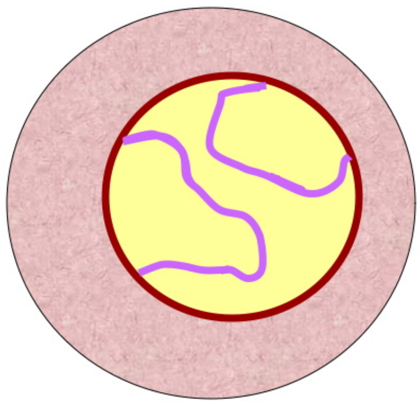
In the diagram of early zygotene (above right), the regions where the paternal and maternal homologs have fused is shown in purple. In the next diagram, representing late zygotene, both homolog pairs have fused over their entire lengths (so they are shown entirely in purple).

Once the the homolog pairs synapse they are called *tetrads* (each has four chromatids; *tetra* is Greek for *four*) or *bivalents*. *Bivalent* is the preferred term, but *tetrad* is, nonetheless, the word more commonly used in most introductory biology classes. *Bivalent* is the better choice because there are equivalent names for other situations. For example, an unfused homolog is called a univalent. Three fused homologs, a common situation in plants, is called a trivalent, etc.



Pachytene

(also known as *pachynema*). During pachytene the two sister chromatids of each chromosome separate from each other. This makes the chromosomes look thicker (*pachy*- is Greek for *thick*). Homologs are still paired at this point. Non-sister chromatids remain in contact throughout pachytene and a kind of localized breakage of the DNA occurs, which is followed by exchanges of DNA between them. This process is called "crossing over." Crossing over produces "cross-over chromatids" each composed of distinct blocks of DNA, some blocks derived from the mother, others from the father.



Diplotene (also known as *diplonema*)

At the beginning of this stage each chromatid of each chromosome is still fused to a chromatid of that chromosome/s homolog (recall that sister chromatids are already separate at this point). As diplotene progresses, these initially fused non-sister chromatids begin to separate from each other. However, they cannot separate completely because they are still connected by two strands of DNA at each of the points where exchanges took place. At each cross-over site, the two strands form an x-shaped structure called a chiasma (pl. chiasmata). The chiasmata then begin moving toward the ends of the chromatids. This process of sliding toward the ends is known as *terminalization.*

In oocytes, a special, extremely prolonged form of diplotene occurs called *dictyotene.* The primary oocyte undergoes the first three of the substages of prophase I (leptotene, zygotene, and pachytene) during late fetal life. The process is then suspended during diplotene until puberty or thereafter. Therefore, in oocytes dictyotene (and consequently prophase I) can last months or even years, depending on the type of organism in question.

Diakinesis

During this, the last stage of Prophase I, the nucleolus disappears, terminalization reaches completion, and the chromosomes coil tightly, and so become shorter and thicker. The nuclear envelope begins to disappear.

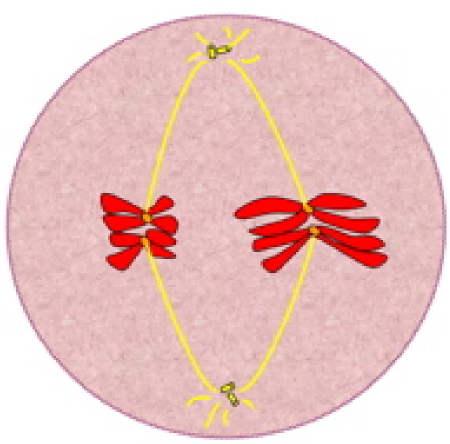
(click here to see more details). Note that the two homologs making up a chromosome pair are not expected to be genetically identical, as in the case of sister chromatids, because they are not direct copies of each other and they are inherited from different parents.

When the chromosomes synapse during prophase, each gene in each chromosome is brought into contact with the same gene on that chromosome's homolog. During this process of synapsis, the two homologs of each pair exchange segments of DNA in a process known as *crossing over*. As a result, the gene combinations on each chromosome can be changed. (For example, suppose one homolog initially contained genes for brown eyes and brown hair. After crossing over, it could contain genes for *blue* eyes and brown hair, where the gene for blue eyes was taken from its homolog.

While prophase I is proceeding, the spindle's two centers of expansion move to the opposite ends of the cell (i.e., to the "poles") and the spindle lengthens and extends toward the "metaphase plate," an imaginary plane defining the middle plane of the cell, halfway between the centriole pairs. The tetrads also move toward the metaphase plate.

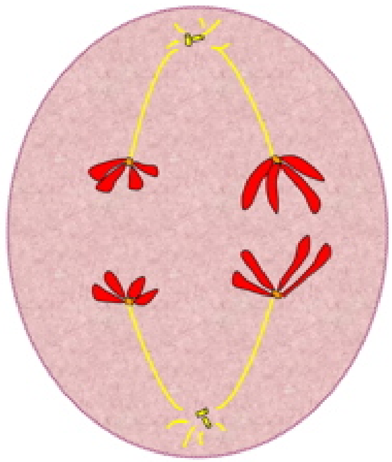
METAPHASE I

In the second phase of the first meiotic division, metaphase I, the tetrads align on the "metaphase plate," halfway between the poles of the cell. Next, the spindle fibers attach to the centromeres of each chromosome. Both spindle fiber attachment points (kinetochores) of each sister chromatid pair are turned toward the same pole. As a result, both kinetochores attach to spindle fibers from the *same* pole. This is a major difference between meiosis and mitosis. It causes the two members of each chromosome pair to be separated from each other during the next stage of meiosis, anaphase I (in mitotic metaphase, the two kinetochores of each sister chromatid pair attach to spindle fibers from *opposite* poles, so each chromatid separates from its sister during anaphase).



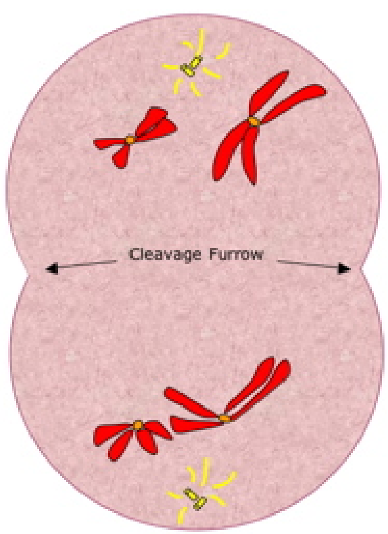
ANAPHASE I

In the third stage, anaphase I, the cell lengthens as it begins the process of division. Homologs of each chromosome pair move toward opposite poles, drawn by the microtubles of the spindle apparatus (this contrasts with mitosis, where the sister chromatids from each homolog separate and move toward opposite poles).



TELOPHASE I

In this, the fourth stage of meiosis, the chromosomes reach the poles. At each pole, now, there is a complete haploid set of chromosomes (but each chromosome still has two sister chromatids). During telophase I, a cleavage furrow appears. By the end of this stage the cell has divided in two along the plane defined by the furrow. This separation of the cytoplasm is called cytokinesis*.* In some organisms the nuclear membrane reappears briefly at this point (this intermediate stage is called interkinesis), but in others the daughter cells begin immediately to prepare for the second meiotic division.



CYTOKINESIS

Cytokinesis is not one of the stages or phases of meiosis or mitosis. It is the process of division that the cytoplasm undergoes when it is distributed into daughter cells (as opposed to karyokinesis, which is division of the nucleus). The cytoplasm is all of the contents of the cell other than the nucleus. The cytoplasm lies outside the nucleus and is bounded by the plasma membrane. The liquid portion of cytoplasm is called cytosol.

Interkinesis

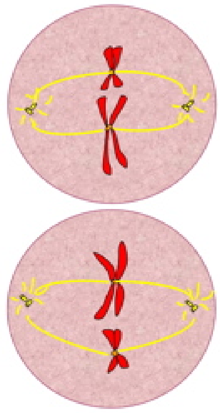
In many organisms, after meiosis I, the daughter cells begin immediately to prepare for the second meiotic division. In others, however, the nuclear membrane reappears between telophase I and prophase II, and there is a period of rest. This period, during which the membrane is again visible, is called interkinesis. Each chromosome is still composed of two chromatids.

PROPHASE II

Prophase II begins with the two daughter cells produced by the first meiotic division. As in Prophase I, the chromosomes are condensed and not yet attached to the spindle apparatus. If there was an interkinesis, then the nuclear membranes begin to break down again during this stage. The centrioles have replicated and are moving toward the poles.

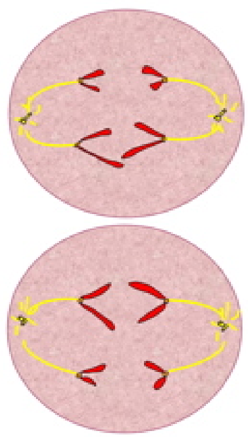
METAPHASE II

In metaphase II the chromosomes move to the equator ("metaphase plate") of each of the two daughter cells produced by the first meiotic division. This time, unlike metaphase I, the two kinetochores of each centromere attach to spindle fibers from opposite poles



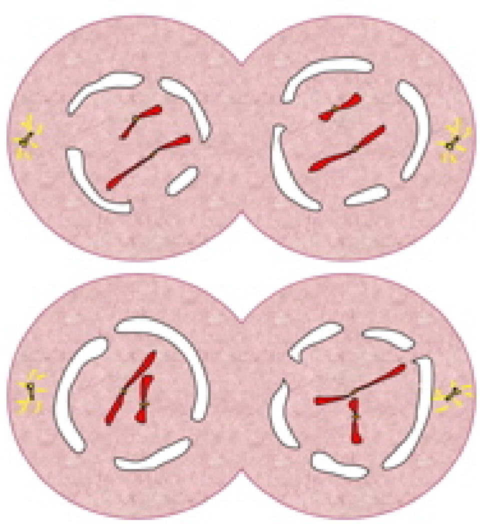
ANAPHASE II

During the seventh stage of meiosis, anaphase II (the third stage of the second division), the sister chromatids of each chromosome separate and move toward opposite poles.



TELOPHASE II

During telophase II, the sister chromatids reach opposite poles, cytokinesis occurs, the two cells produced by meiosis I divide to form four haploid daughter cells, and the nuclear membranes (white in the diagram) reform.



Significance of Meiosis

The long term survival of a species depends on its ability to adapt to a changing environment. To do this the offspring need to be different from their parents and each other. These are three ways in which variety occurs because of meiosis.

a. Production and fusion of haploid gametes

The variety of offspring is increased by mixing the genotype of one parent with that of the other. It involves the production of special sex cells, called gametes, which fuse together to produce a new organism. Each gamete contains half the number of chromosomes of the adult. It is important that meiosis, which halves the number of chromosomes in daughter cells, happens at some stage in the life cycle of a sexually reproducing organism. Therefore Meiosis is important in order for variety in organisms, and allowing them to evolve.

b. The creation of genetic variety by the random distribution of chromosomes during metaphase 1

When the pairs of homologous chromosomes arrange themselves on the equator of the spindle during metaphase 1 of meiosis, they do it randomly. Even though each one of the pair determines the same general features, they're detail of the feature is different. The randomness of this distribution and independent assortment of these chromosomes produces new genetic combinations.

c. The creation of genetic variety by crossing over between homologous chromosomes

During prophase 1 of meiosis, equal portions of homologous chromosomes may be swapped. In this way new genetic combinations are made and linked genes separated. The variety which meiosis brings vital for to the process of evolution. By providing a varied stock of individuals it allows the natural selection of those best suited to the existing conditions and makes sure that species constantly change and adapt when these conditions change. This is the main biological significance of meiosis.

	Meiosis	**Mitosis**
Definition	A type of cellular reproduction in which the number of chromosomes are reduced by half through the separation of homologous chromosomes in a diploid cell.	A process of asexual reproduction in which the cell divides in two producing a replica (exact copy) with an equal number of chromosomes (One cell becomes two)

Function	Growth, Repair, asexual Reproduction	Cellular Reproduction (cell division during which the cell nucleus divides)
Type of Reproduction	Sexual	Asexual
Discovered by	Oscar Hertwig	Walther Flemming
Creates	Sex cells only	Makes everything other than sex cells (Somatic Cells)
Occurs in	Humans, animals, plants	all organisms
Produces	four haploid daughter cells	two diploid daughter cells
Genetically	different	identical
Steps	Proceded by Interphase	Proceded by Interphase
Chromosome Number	Reduced by half (homologous pairs seperate)	Remains the same
Number of Divisons	2 nuclear and cytoplasmic divisions	1 division of the nucleus in Cytokinesis