Course Syllabus:

1. Genetic Transmissions. √
2. Mendelian Genetics. √
3. Transmission and inheritance of chromosomes. (today)
4. Linkage and Mapping.
5. Mendelien Genetics in Corn (Zea mays). (28-29/10) ….Student presentations and open discussion
6. Extensions of Mendel's laws.

Objectives:

By doing this course well, you will be able to:

- Know the composition of the nucleus
- Define the meaning of chromosomes
- Distinguish between polyploid, diploidy and haploidy
- Distinguish between the phases of the cell cycle
- Describe chromosomes and their role in mitosis.
- Outline the phases of Meiosis.
- Compare and contrast between Mitosis and Meiosis

TRANSMISSION AND INHERITANCE OF CHROMOSOMES

NUCLEUS

The nucleus (pl. *nuclei*; from Latin *nucleus* or *nuculeus*, meaning kernel) is a membrane-enclosed organelle found in eukaryotic cells. In mammalian cells, the average diameter of the nucleus is approximately 6 micrometers (μm), which occupies about 10% of the total cell volume. It contains most of the cell's genetic material, organized as multiple long linear DNA molecules in complex with a large variety of proteins, such as histones, to form chromosomes. The genes within these chromosomes are the cell's nuclear genome. The

function of the nucleus is to maintain the integrity of these genes and to control the activities of the cell by regulating gene expression — the nucleus is, therefore, the control center of the cell. The main structures making up the nucleus are the nuclear membrane, a double membrane that encloses the entire organelle and isolates its contents from the cellular cytoplasm, and the nucleo-skeleton (which includes nuclear lamina), a network within the nucleus that adds mechanical support, much like the cytoskeleton, which supports the cell as a whole.

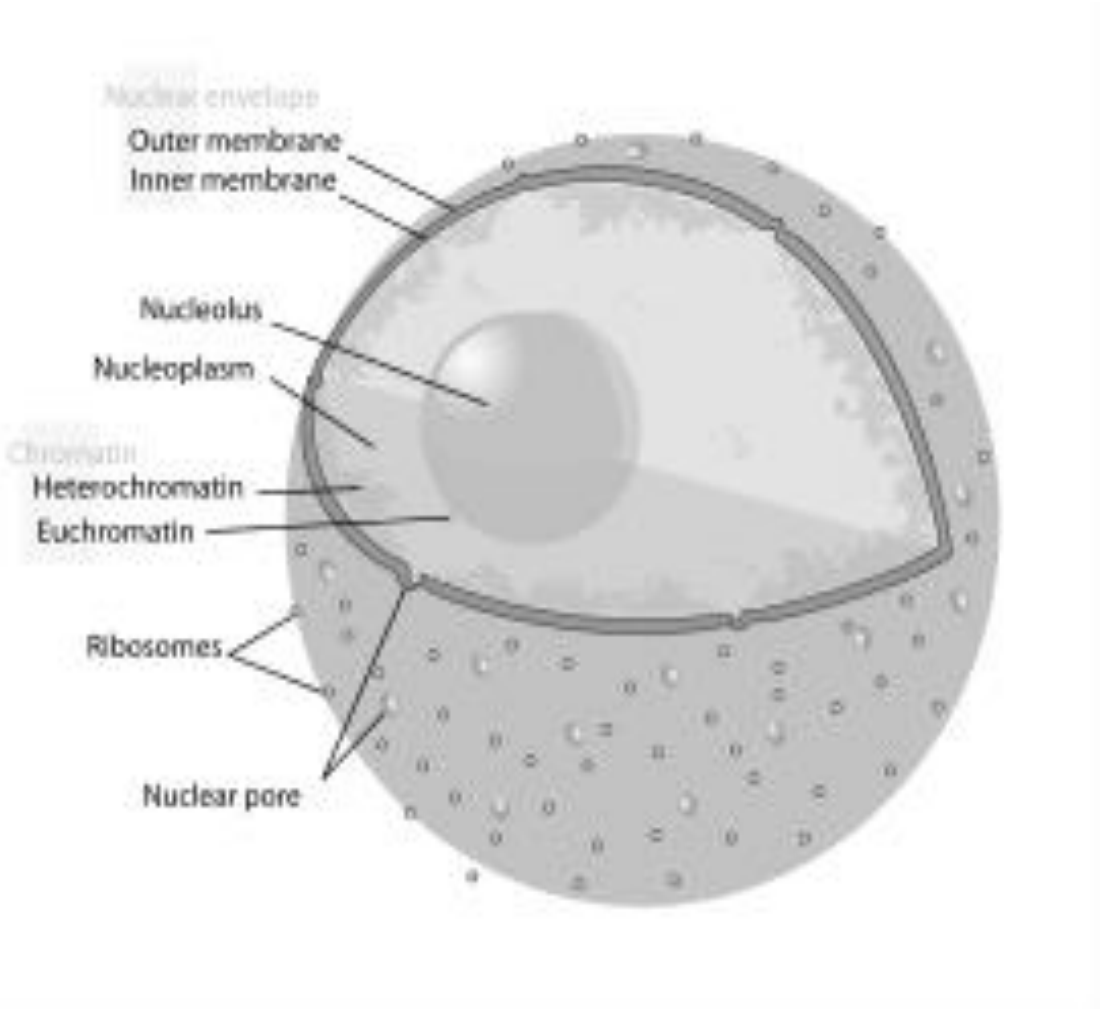
Movement of large molecules such as proteins and RNA through the pores is required for both gene expression and the maintenance of chromosomes. Because the nuclear membrane is impermeable to large molecules, nuclear pores are required that regulate nuclear transport of molecules across the envelope. The pores cross both nuclear membranes, providing a channel through which larger molecules must be actively transported by carrier proteins while allowing free movement of small molecules and ions. Nucleoporins, a family of 50 to 100 proteins, are the main components of the nuclear pore complex in eukaryotic cells. Nuclear pores in turn allow the transport of water-soluble molecules across the nuclear envelope.

The viscous liquid within it is called nucleoplasm, and is similar in composition to the cytosol found outside the nucleus. It appears as a dense, roughly spherical organelle.

The nuclear envelope, otherwise known as nuclear membrane, consists of two cellular membranes, an inner and an outer membrane, arranged parallel to one another and separated by 10 to 50 nanometers (nm). The nuclear envelope completely encloses the nucleus and separates the cell's genetic material from the surrounding cytoplasm, serving as a barrier to prevent macromolecules from diffusing freely between the nucleoplasm and the cytoplasm.

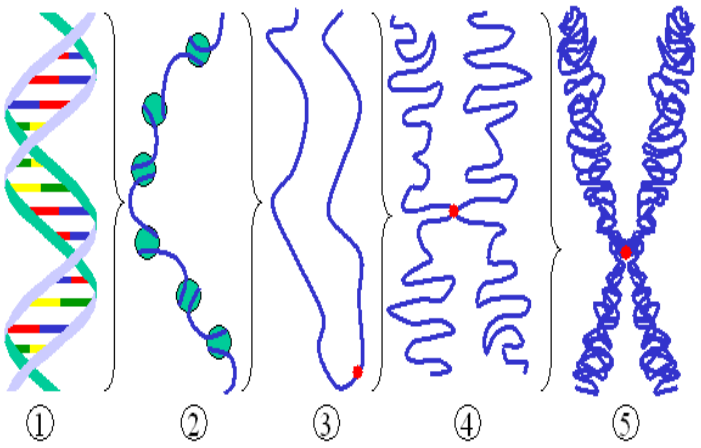
The nucleolus is a discrete densely stained structure found in the nucleus. It is not surrounded by a membrane, and is sometimes called a suborganelle. It is composed of proteins and nucleic acids found within the nucleus of eukaryotic cells. Its function is to transcribe ribosomal RNA (rRNA) and combine it with proteins to form almost-complete ribosomes. The nucleolus occupies up to about 25% of the volume of the cell nucleus. Malfunction of nucleoli can be the cause of several human diseases.

There are two types of chromatin: Euchromatin is the less compact DNA form, and contains genes that are frequently expressed by the cell. The other type, heterochromatin, is the more compact form, and contains DNA that is infrequently transcribed.

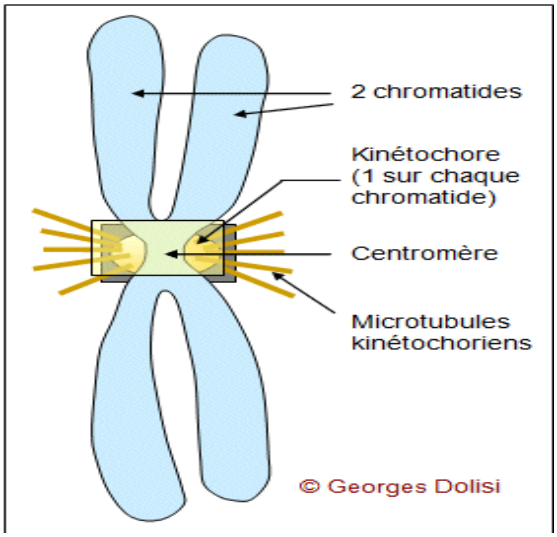


CHROMOSOMES

Chromosomal DNA encodes most or all of an organism's genetic information. A chromosome is an organized structure of DNA, protein, and RNA found in cells. It is a single piece of coiled DNA containing many genes, regulatory elements and other nucleotide sequences. DNA exists as a single, long, double-stranded fiber extending chromosome's entire length. Chromosomes also contain DNA-bound proteins, which serve to package the DNA and control its functions. In eukaryotes, nuclear chromosomes are packaged by proteins (complex of DNA and protein) into a condensed structure called chromatin that condenses during cell division. This allows the very long DNA molecules to fit into the cell nucleus. The structure of chromosomes and chromatin varies through the cell cycle. Chromosomes are even more condensed than chromatin and are an essential unit for cellular division.



Chromosomes may exist as either duplicated or unduplicated. Unduplicated chromosomes are single linear strands contains one DNA molecule, which may be several inches long, whereas duplicated chromosomes contain two identical copies (called chromatids or sister chromatids) joined by a centromere. The centromere is a constricted region of the chromosome containing a specific DNA sequence, to which is bound 2 discs of protein called kinetochores.



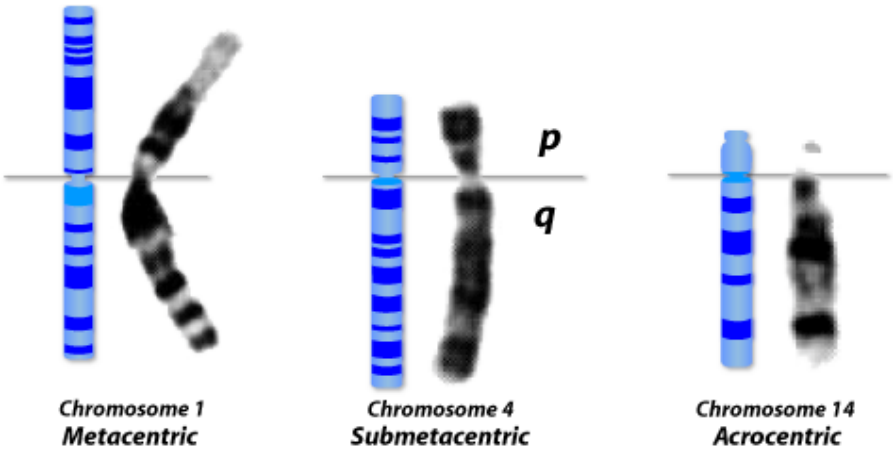
The cell may be either polyploidy (?n) or diploid (2n) or haploid (n)**:**

Polyploid- A cell possessing numerous copies of each chromosome.

Diploid - A cell possessing two copies of each chromosome (human/plant body cells). Most eukaryotes have between 10 and 50 chromosomes in their body cells. Human cells have 46 chromosomes: 22 nearly-identical pairs (autosomes) and a pair of sex chromosome.

Haploid - A cell possessing a single copy of each chromosome (human/plant sex cells).

Each chromosome has two arms, labeled p (the shorter of the two) and q (the longer). The p arm is named for "petit" meaning 'small'; the q arm is named q simply because it follows p in the alphabet. Chromosomes are classified according to centromere position to Metacentric, Sub-metacentric and Acrocentric (telocentric)**.**



Metacentric: These are X-Shaped chromosomes, have centromere in the middle so that the two arms of the chromosomes are almost equal. A chromosome is metacentric if its two arms are roughly equal in length.

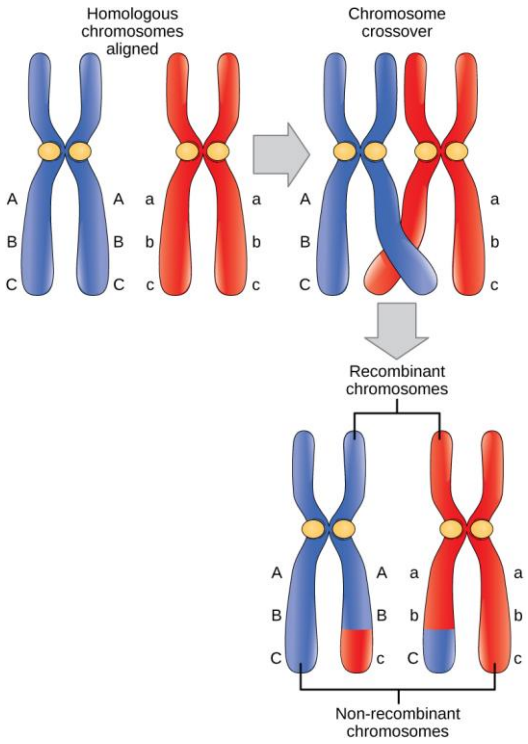
Submetacentric: If arms' lengths are unequal, the chromosome is said to be submetacentric. The centromere is near the middle of the chromosome one arm is shorter than other.

Acrocentric: If the p (short) arm is so short that it is hard to observe, but still present, then the chromosome is acrocentric (the "acro-" =the Greek word for "peak") when the centromere is located at the terminal end of the chromosome. If the chromosome's centromere is located closer to its end than to its center, it may be described as subtelocentric.

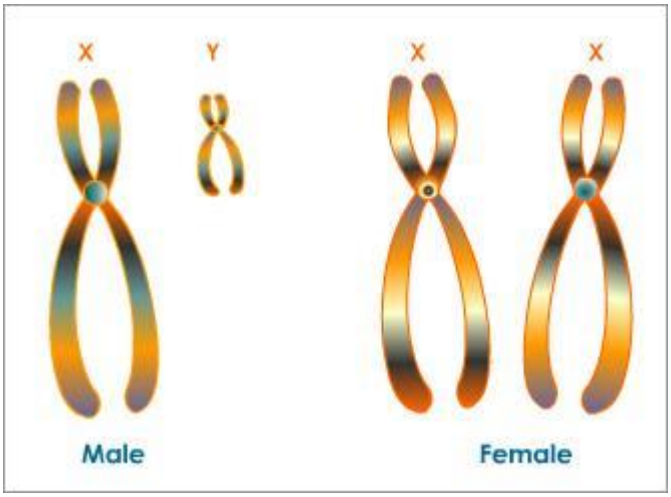
Types of Chromosomes:

Chromosomes may be either non-homologous, homologous or sex chromosomes.

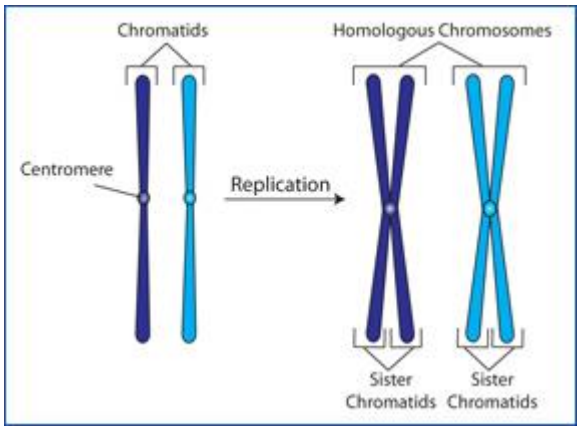
Non-homologous chromosomes: look different and control different traits.



Sex chromosomes: Are distinct from each other in their characteristics and are represented as X and Y to determine the sex of the individual, XX being female, XY being male.

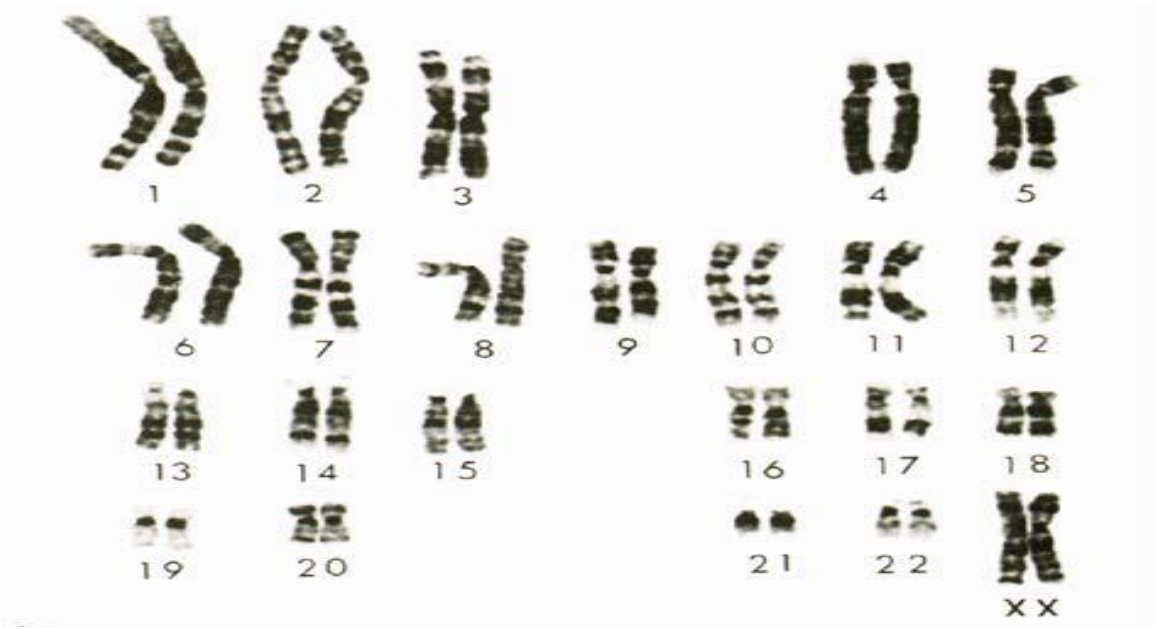


Homologus chromosomes: look the same, occur in pairs, control the same traits. May code for different forms of each trait and have independent origin - each one was inherited from a different parent as the 22 pairs of autosomes in human.



A **karyotype** (Greek *karyon* = kernel, seed or nucleus) is the number and appearance of chromosomes in the nucleus of a eukaryotic cell. The term is also used for the complete set of chromosomes in a species, or an individual organism. Karyotypes describe the number of chromosomes, and what they look like under a light microscope. Chromosomes are arranged in a karyotype for the purpose of analysis. Classification of the

chromosomes is based on their size, centromere position and banding patterns that are specific for each chromosome.

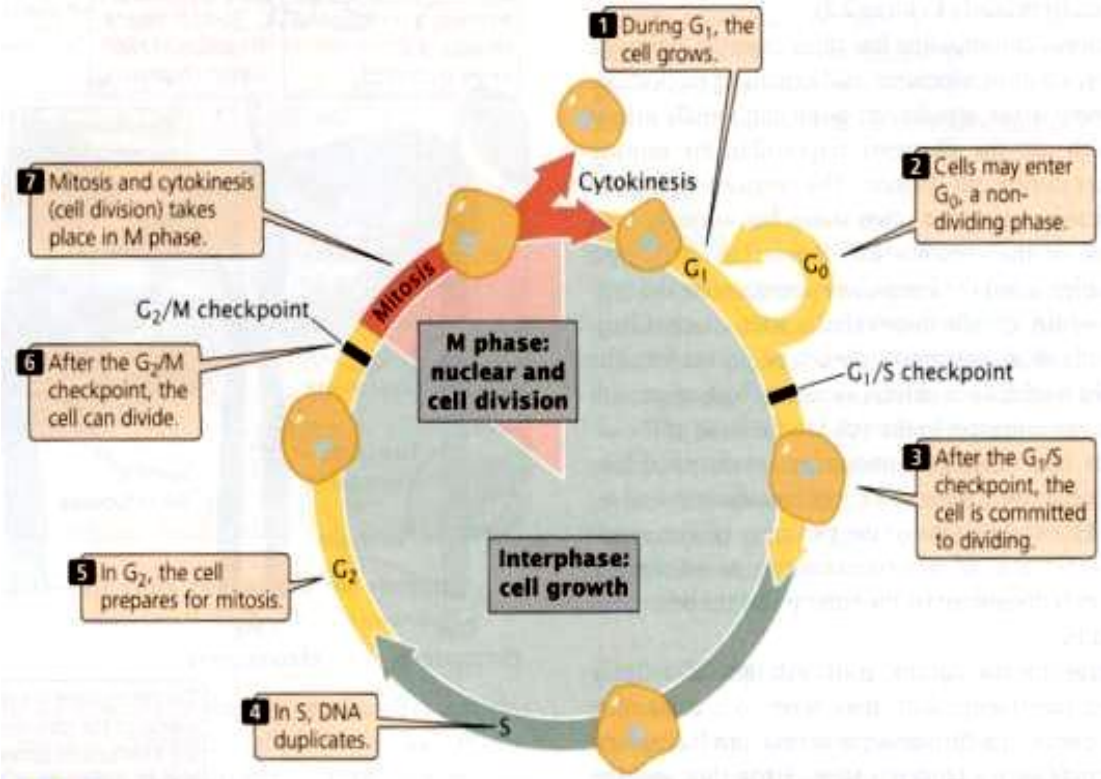


CELL CYCLE AND HOW THE CELL DIVIDE?

Cells spend a small part of their life dividing. Cell division is very tightly controlled, ensuring that everything happens at the right time and in the right order. Cell cycle includes 2 main events: Cellular and nuclear divisions.

Cellular division refers to the long growth period that ends with the cell division (Cytokinesis). Nuclear divisions refer to long interphase followed by short real division (Mitosis).

The cell cycle involves 2 stages: interphase (G1, S and G2) and mitosis (M) followed by Cytokinesis (C). The period between M and S is called G_1; that between S and M is G_2 (figure below).



2.9 The cell cycle consists of interphase (a period of cell growth) and M phase (the period of nuclear and cell division).

INTERPHASE

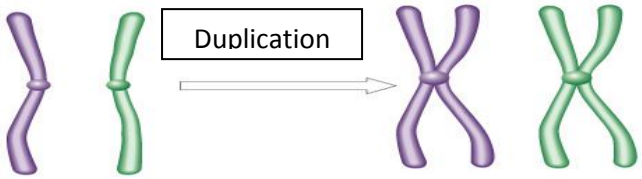
The time between two successive mitotic divisions is known as Interphase. Eukaryotic cells spend most of their time (about 90%) in interphase. During interphase, the genetic material in the nucleus is in form of chromatin (uncoiled DNA), which appears only as dark granules within the nucleus. This appearance may be because they are uncoiled into long, thin strands. Both nucleolus and nuclear membranes are present and clearly visible.

The interphase involves 3 stages called G1, S and G2, respectively. The duration of each stage depends on the cell type.

G1 stage (gap1, Pre-DNA synthesis): This stage lasting about 4 hours in some eukaryotic cells. The cells become metabolically active (1^{ry} growth) producing RNA and ribosomes for protein synthesis; the organelles begin to increase in numbers, and the nucleus and cytoplasm enlarge to reach

their mature size. The chromosomes are 2n in number, fully extended with single in structure. If the cells will never divide again i.e. permanently arrested in G1 stage, it will refer as G0 stage (Prolonged G1 stage).

S stage (DNA synthesis): DNA and histone syntheses lasting 6-8 hours in some eukaryotic cells. DNA and histone are the main component of chromatids. At the end of this stage, the chromosomes have been duplicated and became 2n double in structure (figure below).

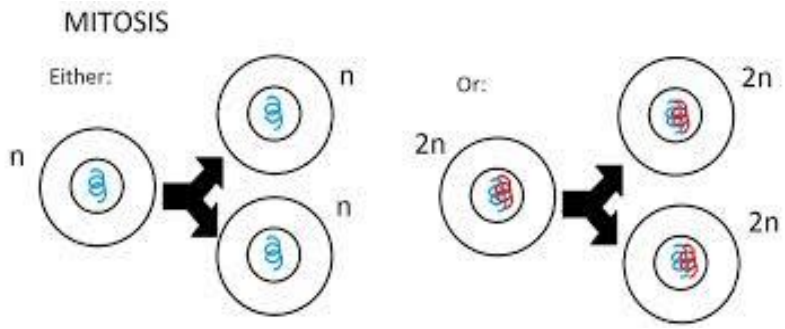


Two unduplicated chromosomes **Two duplicated chromosomes**

G2 stage (gap2, Post-DNA synthesis): This stage lasting about 4 hours in some eukaryotic cells. In which the cell synthesis certain component required for mitosis as proteins of spindle fibers and go to the final preparations of the cell (2^{nd} growth) before divisions. The cells checks also that their entire DNA has been correctly copied.

MITOSIS AND CELL DIVISION

It is the process by which a cell produces two identical daughter cells with complete set of chromosomes. This means that all the chromosomes must be duplicated and separated into two full sets, one at each end of the cell that is splitting in two. The other material that makes up the cell also splits in two.



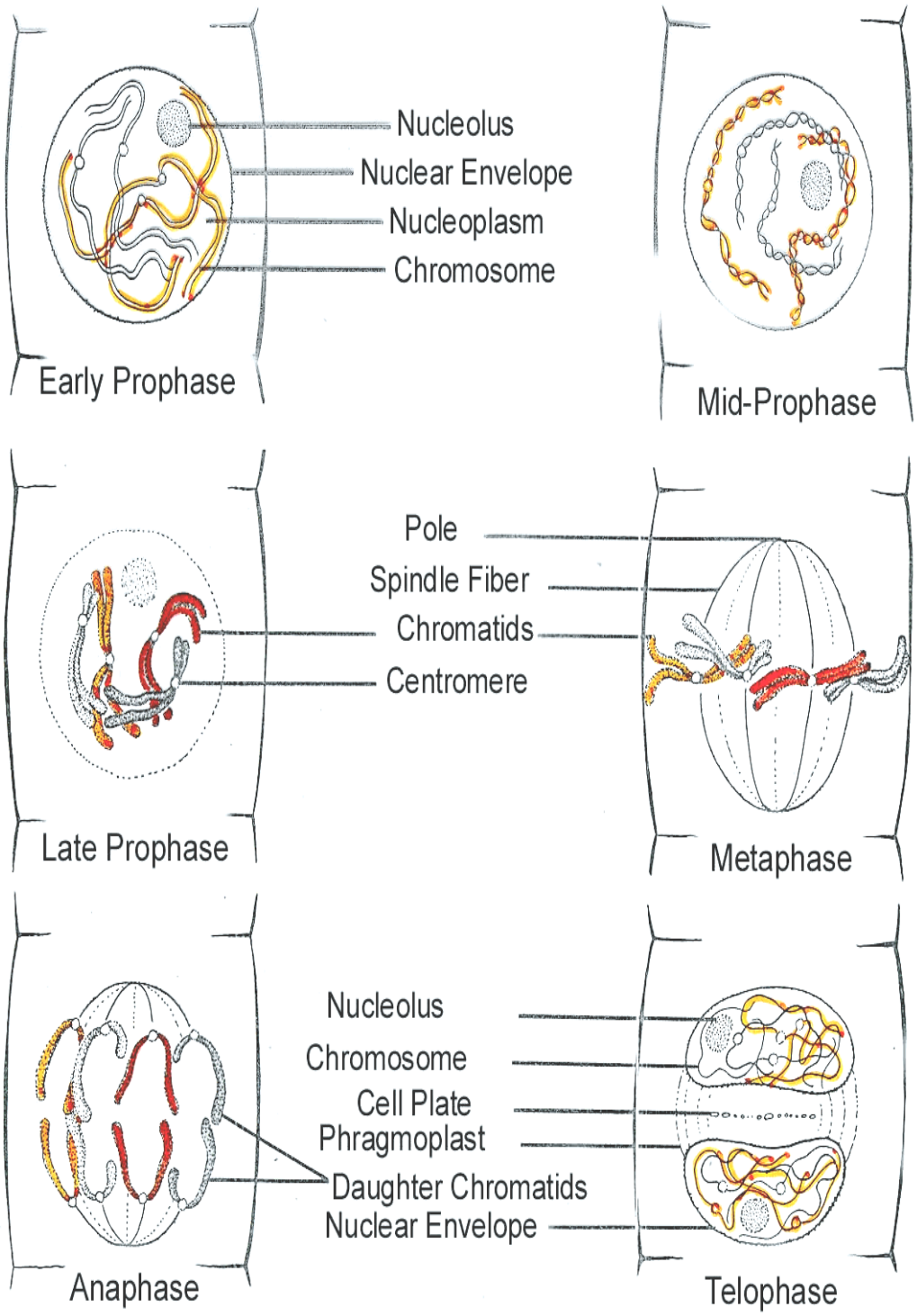
This actual division stage may last for about 2 hours in some eukaryotic cells. Mitosis occurs in four stages known as Prophase, Metaphase, Anaphase and Telophase (figure below).

Prophase: when the genetic material in the cell, which is normally loosely bundled, condenses (coiled) to form distinguishable thin, thread-like chromosomes. Each chromosome has duplicated and now consists of two identical sister chromatids. The sister chromatids condense and thickened until they appear joined in a single place known as centromere. The chromosomes are 2n double in structure. Both nuclear envelope and nucleoli start to disappear. The mitotic spindles begin to form.

Metaphase: when the chromosomes align themselves along the cell spindle in the middle of the cell (equator, equatorial plates), ready to separate. The metaphase chromosome appears as two sister chromatids and the centromere, which hold them together. The regions at both ends of chromosome are the telomeres. The chromosomes are 2n double in structure. The mitotic spindle is fully formed and the chromosomes are attached to their centromeres by their kinetochore (Figure above).

Anaphase: Sister chromatids split apart at their centromere, begin to separate and move to opposite poles of the spindle, segregating one of the two sister chromatids to each daughter cell (at opposite ends of the cell). In this case, each chromatid became a chromosome. The chromosomes are 2n single in structure.

Mitosis


Nucleolus
Nuclear Envelope
Nucleoplasm
Chromosome
Early Prophase
Mid-Prophase
Pole
Spindle Fiber
Chromatids
Centromere
Late Prophase
Metaphase
Nucleolus
Chromosome
Cell Plate
Phragmoplast
Daughter Chromatids
Nuclear Envelope
Anaphase
Telophase

Anaphase: Sister chromatids split apart at their centromere, begin to separate and move to opposite poles of the spindle, segregating one of the two sister chromatids to each daughter cell (at opposite ends of the cell). In this case, each chromatid became a chromosome. The chromosomes are 2n single in structure.

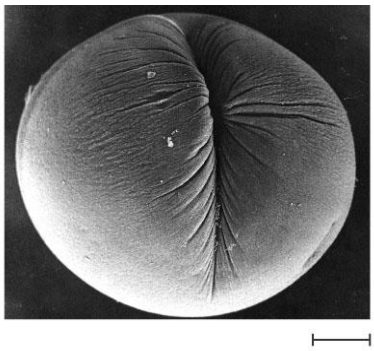
Telophase: A complete set of chromosomes reach each pole of the cell and the cell prepares to split in two identical daughter cells. The mitotic spindles begin to disappear when the nucleolus and the nuclear envelop reappear. The chromosomes are 2n single in structure.

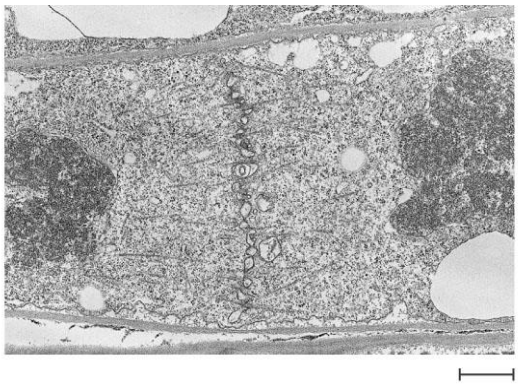
CYTOKINESIS

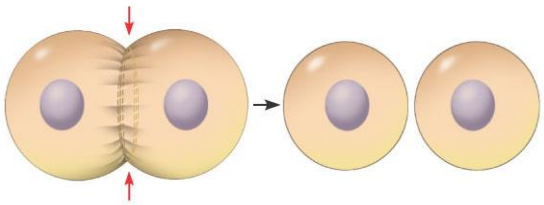
It usually initiates during the late stages of mitosis (at the end of telophase), and sometimes meiosis, splitting a cell in two, to ensure that chromosome number is maintained from one generation to the next.

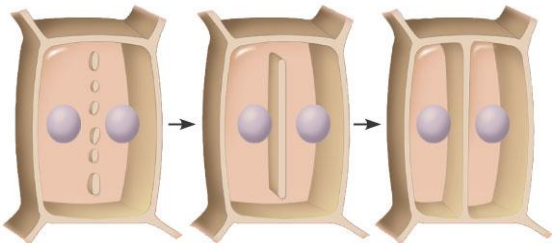
In animal, the cell membranes on opposite sides of the cell become pinched-in allowing for the cell to divide. The initial structure that forms is called a cleavage furrow. The cleavage furrow continues to pinch in, until the two sides are touching. At this point, there will be two new cells. In plant cells, a structure known as a cell plate begins to grow and elongate in the center of the cell, with each end heading toward the opposite cell walls. This linear wall-like structure continues to grow until it reaches the actual cell walls. Once the cell plate has divided the cell into two cells, it will continue to develop into a new cell wall (figure). This stage is followed by a stage of G1-interphase.

Note: The cytoplasm and organelles are usually shared approximately equally between the daughter cells.









Cleavage of an animal cell

Cell plate formation in a plant cell

Importance of Mitosis:

Following are the occasions in the lives of organism where mitosis happens:

Asexual Reproduction: Some organisms produce genetically similar offspring through asexual reproduction. For example; hydra reproduces asexually by budding. The cells at the surface of hydra undergo mitosis and form a mass called bud. Mitosis continues in the cells of bud and it grows into a new individual. The same division happens during asexual reproduction or vegetative propagation in plants and microbes.

Development and growth: The number of cells within an organism increase by mitosis. This is the basis of the development of a multicellular body from a single cell i.e., zygote and also the basis of the growth of a multicellular body. In the fetus, babies and growing children mitosis occurs in most tissues. While in adults, however, most tissues do not proliferate but mitosis occurs regularly at the following sites:

1. Red bone marrow – for production of blood cells (erythropoiesis)
2. Lymphoid tissue - formation of lymphocytes (lymphooiesis)
3. Testes – for spermatogenesis (production of spermatozoa)
4. Epidermis - replacement of superficial skin cells
5. Hair follicles - hair growth
6. Gastro-intestinal tract - renewal of epithelium

In plants, mitotic cell division mainly takes place in special regions called meristems. They are either present in Shoot apex or axillary buds or root tips of the plants for development and growth.
Cell Replacement: In some parts of body, e.g. skin and digestive tract, cells are constantly sloughed off and replaced by new ones. New cells are formed by mitosis and so are exact copies of the cells being replaced. Similarly, RBCs have short life span (only about 4 months) and new RBCs are formed by mitosis.
Regeneration: Some organisms can regenerate their parts of bodies. The production of new cells is achieved by mitosis. For example; sea star regenerates its lost arm through mitosis.

Clinical Applications:

Cancer cells undergo uncontrolled cell proliferation. As such, they are defects of the control of the cell cycle. Oncogenes (الجينات المسرطنه) are mutations in the genes that normally control the cell cycle. Chemotherapy of cancers is aimed towards interrupting the cell cycle and preventing the cancer cells from proliferating. As a side effect, however, also the normal sites of cell proliferation are affected resulting in hair loss, intestinal disorders, anaemia and infertility, which return back in normal state after ending the treatment.

Additional Knowledge:

1. **Normal cell cycle check point**

Cell cycle checkpoints are control mechanisms that ensure the fidelity of cell division in eukaryotic cells. These checkpoints verify whether the processes at each phase of the cell cycle have been accurately completed before progression into the next phase. Multiple checkpoints have been identified, though some of them are less understood than others.

An important function of many checkpoints is to assess DNA damage, which is detected by sensor mechanisms. When damage is found, the checkpoint uses a signal mechanism either to stall the cell cycle until repairs are made or, if repairs cannot be made, to target the cell for destruction via apoptosis (effector mechanism). All the checkpoints that assess DNA damage appear to utilize the same sensor-signal-effector mechanism. The first checkpoint is located at the end of the cell cycle's G_1 phase, just before entry into S phase, making the key decision of whether the cell should divide, delay division, or enter a resting stage. The second checkpoint is located at the end of G_2 phase, triggering the start of the M phase (mitotic phase). In order for this checkpoint to be passed, the cell has to check a number of factors to ensure the cell is ready for mitosis. If this checkpoint is passed, the cell initiates the many molecular processes that signal the beginning of mitosis. The mitotic spindle checkpoint occurs at the point in metaphase where all the chromosomes should/have aligned at the mitotic plate and be under bipolar tension. The tension created by this bipolar attachment is what is sensed, which initiates the anaphase entry.

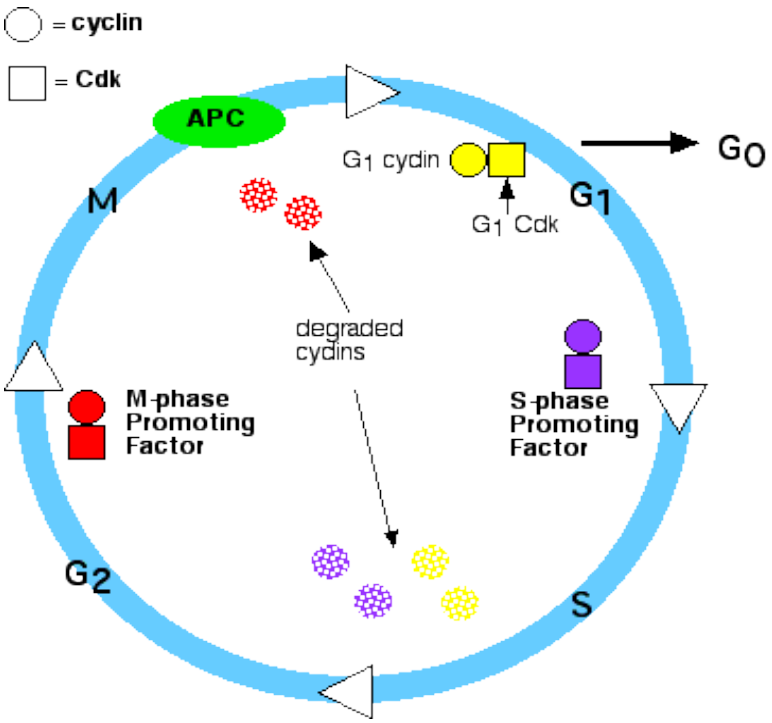
The passage of a cell through the cell cycle is controlled by proteins in the cytoplasm. Among the main players in animal cells are Cyclins: G_1 cyclins (D cyclins), S-phase cyclins (cyclins E and A) and mitotic cyclins (B cyclins). Their levels in the cell rise and fall with the stages of

the cell cycle. Cyclin-dependent kinases (Cdks): G_1 Cdk (Cdk4), S-phase Cdk (Cdk2) and M-phase Cdk (Cdk1) levels in the cell remain fairly stable, but each must bind the appropriate cyclin (whose levels fluctuate) in order to be activated. They add phosphate groups to a variety of protein substrates that control processes in the cell cycle. The anaphase-promoting complex (APC). (The APC is also called the cyclosome, and the complex is often designated as the APC/C.) The APC/C triggers the events leading to destruction of cohesin (as described below) thus allowing the sister chromatids to separate and degrades the mitotic (B) cyclins.

Steps in the cycle

A rising level of G_1-cyclins bind to their Cdks and signal the cell to prepare the chromosomes for replication. A rising level of S-phase promoting factor (SPF) — which includes A cyclins bound to Cdk2 — enters the nucleus and prepares the cell to duplicate its DNA (and its centrosomes). As DNA replication continues, cyclin E is destroyed, and the level of mitotic cyclins begins to rise (in G_2). Translocation of M-phase promoting factor (the complex of mitotic [B] cyclins with the M-phase Cdk [Cdk1]) into the nucleus initiates assembly of the mitotic spindle, breakdown of the nuclear envelope and cessation of all gene transcription condensation of the chromosomes. These events take the cell to metaphase of mitosis. At this point, the M-phase promoting factor activates the anaphase-promoting complex (APC/C) which allows the sister chromatids at the metaphase plate to separate and move to the poles (= anaphase), completing mitosis. Separation of the sister chromatids depends on the breakdown of the cohesin that has been holding them together: Cohesin breakdown is caused by a protease called separase (also known as separin). Separase is kept inactive until late metaphase by an

inhibitory chaperone called securin. Anaphase begins when the anaphase promoting complex (APC/C) destroys securin (by tagging it with ubiquitin for deposit in a proteasome) thus ending its inhibition of separase and allowing separase to break down cohesin. destroys B cyclins. This is also done by attaching them to ubiquitin which targets them for destruction by proteasomes. Turns on synthesis of G_1 cyclins (D) for the next turn of the cycle. Degrades geminin, a protein that has kept the freshly-synthesized DNA in S phase from being re-replicated before mitosis. This is only one of the mechanisms by which the cell ensures that every portion of its genome is copied once — and only once — during S phase. Some cells deliberately cut the cell cycle short allowing repeated S phases without completing mitosis and/or cytokinesis. This is called endoreplication and is described on a separate page.



Cancer Cell Cycle

Cancer results from a series of molecular events that fundamentally alter the normal properties of cells. In cancer cells the normal control systems that prevent cell overgrowth and the invasion of other tissues are disabled. These altered cells divide and grow in the presence of signals that normally inhibit cell growth; therefore, they no longer require special signals to induce cell growth and division. As these cells grow they develop new characteristics, including changes in cell structure, decreased cell adhesion, and production of new enzymes.

These heritable changes allow the cell and its progeny to divide and grow, even in the presence of normal cells that typically inhibit the growth of nearby cells. Such changes allow the cancer cells to spread and invade other tissues.

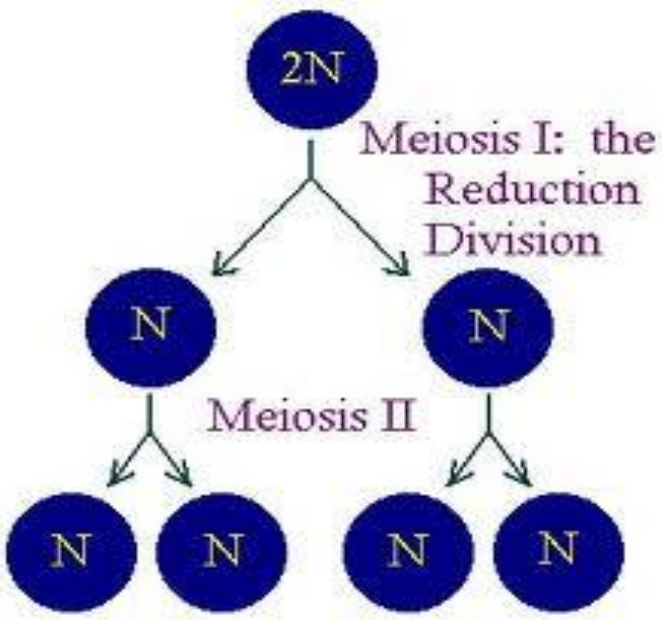
The abnormalities in cancer cells usually result from mutations in protein-encoding genes that regulate cell division. Over time more genes become mutated. This is often because the genes that make the proteins that normally repair DNA damage are themselves not functioning normally because they are also mutated. Consequently, mutations begin to increase in the cell, causing further abnormalities in that cell and the daughter cells. Some of these mutated cells die, but other alterations may give the abnormal cell a selective advantage that allows it to multiply much more rapidly than the normal cells. This enhanced growth describes most cancer cells, which have gained functions repressed in the normal, healthy cells. As long as these cells remain in their original location, they are considered benign; if they become invasive, they are considered malignant. Cancer cells in malignant tumors can often metastasize, sending cancer cells to distant sites in the body where new tumors may form.

MEIOSIS AND SEXUAL REPRODUCTION

Meiosis is a special type of cell division necessary for sexual reproduction in eukaryotes, such as animals, plants and fungi. The number of sets of chromosomes in the cell undergoing meiosis is reduced to half the original number, typically from two sets (diploid) to one set (haploid) known as gametes. In many organisms, including all animals and land plants (but not some other groups such as fungi), gametes are called sperm in males and egg cells or ova in females. Since meiosis has halved the number of sets of chromosomes, when two gametes fuse during fertilization, the number of sets of chromosomes in the resulting zygotes restored to the original number.

Meiotic division occurs in two stages, meiosis I and meiosis II, dividing the cells once at each stage. The first stage begins with a diploid cell that has two copies of each type of chromosome, one from each the mother and father (homologous chromosomes). All homologous chromosomes pair up and may exchange genetic material with each other in a process called crossing over. Each pair then separates as two haploid cells are formed, each with one chromosome from every homologous pair.

In the second stage, each chromosome splits into two, with each half, called a sister chromatid, being separated into two new cells, which are still haploid. This occurs in both of the haploid cells formed in meiosis I. Therefore from each original cell, four genetically distinct (genetically different) haploid cells are produced. These cells can mature into gametes.



Meiosis I (reduction division)

In this process the original diploid cell (2n) produces two haploid cells (n). Meiosis I occurs in four stages known as Prophase I, Metaphase I, Anaphase I and Telophase I (figure below).

Prophase I: It is the longest phase of meiosis. During prophase I, DNA is exchanged between homologous chromosomes in a process called homologous recombination. This often results in chromosomal crossover. The new combinations of DNA created during crossover are a significant source of genetic variation, and may result in beneficial new combinations of alleles. The paired and replicated chromosomes are called bivalents or tetrads, which have two chromosomes and four chromatids, with one chromosome coming from each parent. The process of pairing the homologous chromosomes is called synapsis. At this stage, non-sister chromatids may cross-over at points called chiasmata (plural; singular chiasma).

It is subdivided into the following 5 substages (figure below):

Leptotene: The first stage of prophase I is the leptotene stage, also known as leptonema, from Greek words meaning "thin threads". In this stage of

prophase I, individual chromosomes—each consisting of two sister chromatids—change from the diffuse state they exist in during the cell's period of growth and gene expression, and condense (supercoil) into visible strands within the nucleus. Leptotene is of very short duration and progressive condensation and coiling of chromosome fibers takes place. The nuclear envelope and nucleoli disappear and the spindle fibers begin to form. In animals, centrioles begin migration to opposite poles.

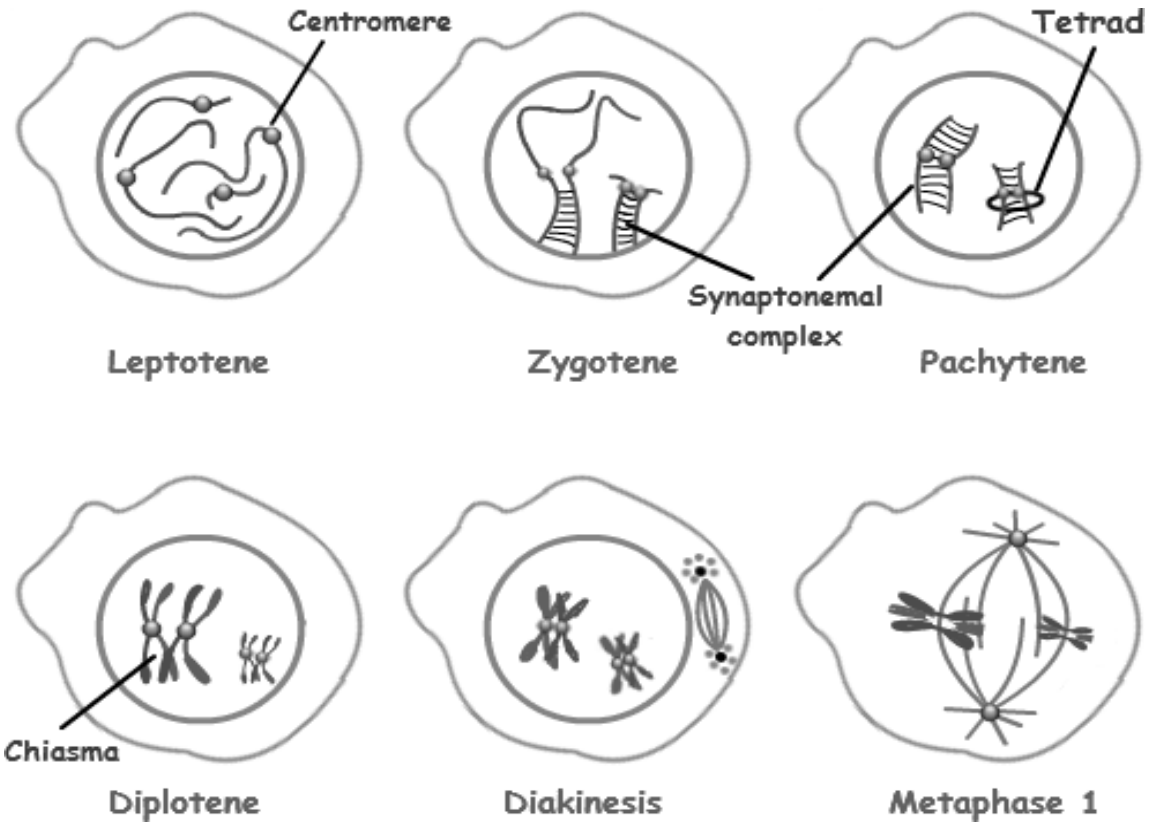
Zygotene: The zygotene stage, also known as zygonema, from Greek words meaning "paired threads", occurs as the chromosomes approximately line up with each other into homologous chromosome pairs. This is called the bouquet or ladder-like stage because of the way the telomeres cluster at one end by synaptonemal proteins. At this stage, the synapsis (pairing/coming together) of homologous chromosomes takes place. Pairing is brought about in a zipper-like fashion. Individuals of a pair are equal in length and in position of the centromere. Thus pairing is highly specific and exact. The paired chromosomes are called bivalent or tetrad chromosomes.

Pachytene: The pachytene stage, also known as pachynema, from Greek words meaning "thick threads", is the stage when chromosomal crossover (crossing over) occurs. Non-sister chromatids of homologous chromosomes may exchange segments over regions of homology. Sex chromosomes, however, are not wholly identical, and only exchange information over a small region of homology. At the sites where exchange happens, chiasmata form. The exchange of information between the non-sister chromatids results in a recombination of information (mixed info) ; each chromosome has the complete set of information it had before.

Diplotene: During the diplotene stage, also known as diplonema, from Greek words meaning "two threads", the synaptonemal complex degrades

and homologous chromosomes separate from one another a little. The chromosomes themselves uncoil a bit, allowing some transcription of DNA. However, the homologous chromosomes of each bivalent remain tightly bound at chiasmata, the regions where crossing-over occurred. The chiasmata remain on the chromosomes until they are separated in anaphase I. The chromosomes are 2n and double in structure (or n bivalent).

Diakinesis: Chromosomes condense further during the diakinesis stage, from Greek words meaning "moving through". This is the first point in meiosis where the four parts of the tetrads are actually visible. Sites of crossing over entangle together, effectively overlapping, making chiasmata clearly visible. Chiasmata appear to "peristalse" to the tips of the chromatids, where they remain attached. This process is known as terminalization, thus we get ring or rod bivalents. Some intermediate chiasmata may be formed due to incomplete terminalization in same chromosomes. The chromosomes are 2n and double in structure (or n bivalent). Other than this observation, the rest of the stage closely resembles prometaphase of mitosis; the nucleoli disappear, the nuclear membrane disintegrates into vesicles, and the meiotic spindle begins to form and attach to kinetochores.



Metaphase I: Homologous pairs move together along the metaphase plate: As kinetochore microtubules from both centrioles attach to their respective kinetochores, the homologous chromosomes align along an equatorial plane that bisects the spindle, due to continuous counterbalancing forces exerted on the bivalents by the microtubules emanating from the two kinetochores of homologous chromosomes. The physical basis of the independent assortment of chromosomes is the random orientation of each bivalent along the metaphase plate, with respect to the orientation of the other bivalents along the same equatorial line. Complete disappearance of nuclear membrane and nucleolus. The chromosomes are 2n and double in structure (or n bivalent).

Anaphase I: Spindle fibers separate homologs, carrying them to opposite poles, but sister chromatids are still connected at the centromere. At each pole, n number with double structure are received. The cell elongates in preparation for division down the center.

Telophase I: The first meiotic division effectively ends when the chromosomes arrive at the poles. Each daughter cell now has half the number of chromosomes but each chromosome consists of a pair of chromatids. The microtubules that make up the spindle network disappear, and a new nuclear membrane surrounds each haploid set. The chromosomes uncoil back into chromatin. Sister chromatids remain attached during telophase I.

Cytokinesis, the pinching of the cell membrane in animal cells or the formation of the cell wall in plant cells, occurs, completing the creation of two daughter cells.

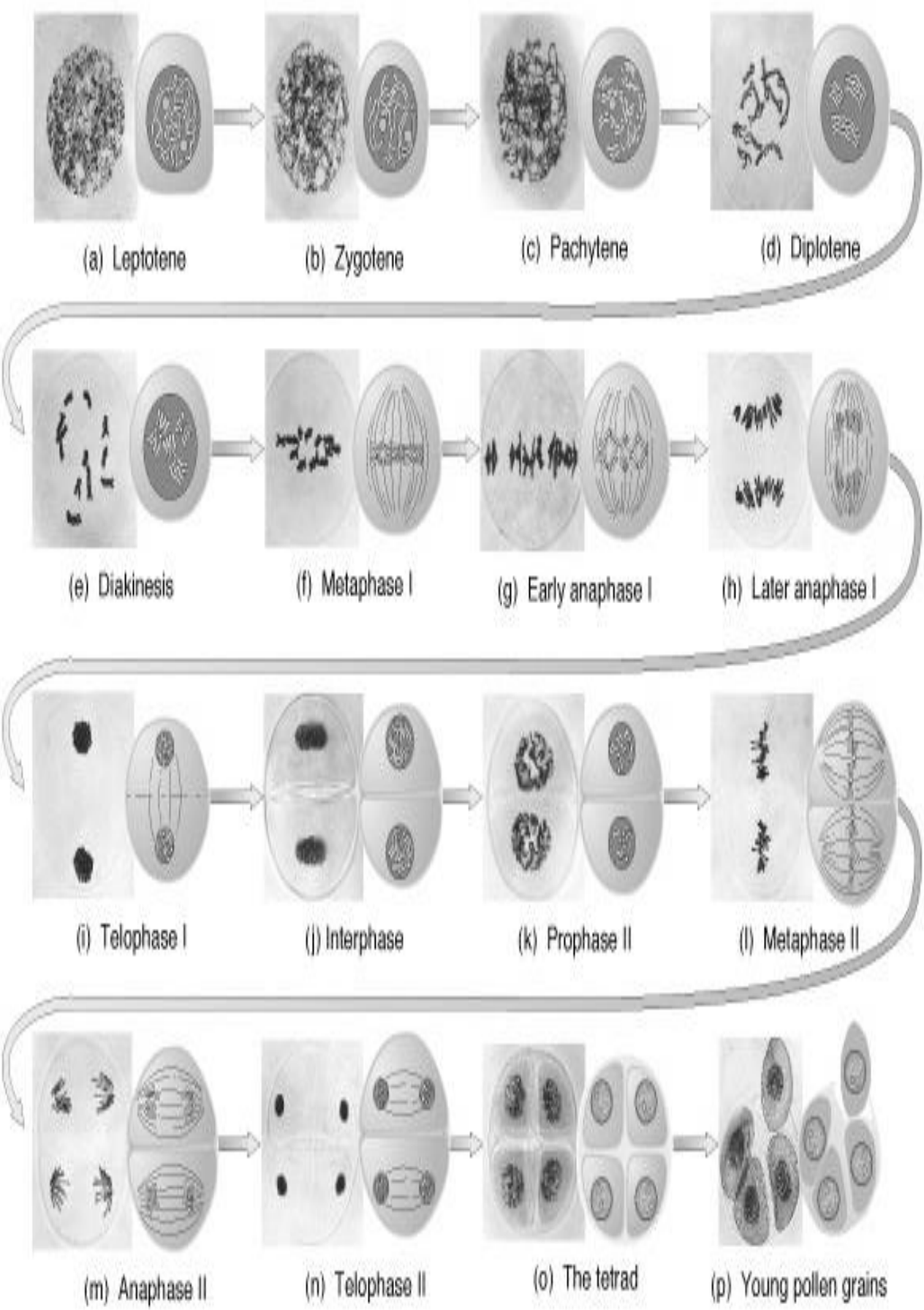
Cells may enter a period of rest known as interkinesis or interphase II. No DNA replication occurs during this stage.

Meiosis II (similar to mitosis)

In this process the two haploid cells (n) produces 4 haploid (n) genetically different gametes. This division is physically the same as mitosis, though the genetics of the cells are different. Meiosis II occurs in four stages known as Prophase II, Metaphase II, Anaphase II and Telophase II (figure below).

In prophase II: we see the disappearance of the nucleoli and the nuclear envelope again as well as the shortening and thickening of the chromatids. Centrioles move to the polar regions and arrange spindle fibers for the second meiotic division.

In metaphase II, the centromeres contain two kinetochores that attach to spindle fibers from the centrosomes (centrioles) at each pole. In case of ♀ mother cells: the new equatorial metaphase plate is parallel to the spindle of metaphase I. In case of ♂ mother cells: the new equatorial metaphase plate is perpendicular (rotated by 90 degrees) to the previous plate of metaphase I.


(a) Leptotene
(b) Zygotene
(c) Pachytene
(d) Diplotene
(e) Diakinesis
(f) Metaphase I
(g) Early anaphase I
(h) Later anaphase I
(i) Telophase I
(j) Interphase
(k) Prophase II
(l) Metaphase II
(m) Anaphase II
(n) Telophase II
(o) The tetrad
(p) Young pollen grains

This is followed by anaphase II, where the centromeres are cleaved, allowing microtubules attached to the kinetochores to pull the sister chromatids apart. The sister chromatids by convention are now called sister chromosomes as they move toward opposing poles (n single structure to each direction).

The process ends with telophase II, which is similar to telophase I, and is marked by uncoiling and lengthening of the chromosomes and the disappearance of the spindle. Nuclear envelopes reform and cleavage or cell wall formation eventually produces a total of four daughter cells, each with a haploid set of chromosomes which are single structure.

Cytokinesis, the pinching of the cell membrane in animal cells or the formation of the cell wall in plant cells occurs. Meiosis is now complete and ends up with four new daughter cells.

Gametogenesis: It includes the formation of ♂ gametes (spermatogenesis in animals and microsporogenesis in plants) or the formation of ♀ gametes (oogenesis in animals and megasporogensis in plants) i.e. all the sex cells whether are in plants or animals undergo meiosis.

Importance of Meiosis:

Meiosis generates genetic diversity through:

1. the exchange of genetic material between homologous chromosomes during Prophase I-Meiosis I.
2. the random alignment of chromosomes in Meiosis I and Meiosis II.

Meiosis maintain the chromosome number in sexually reproducing organisms.

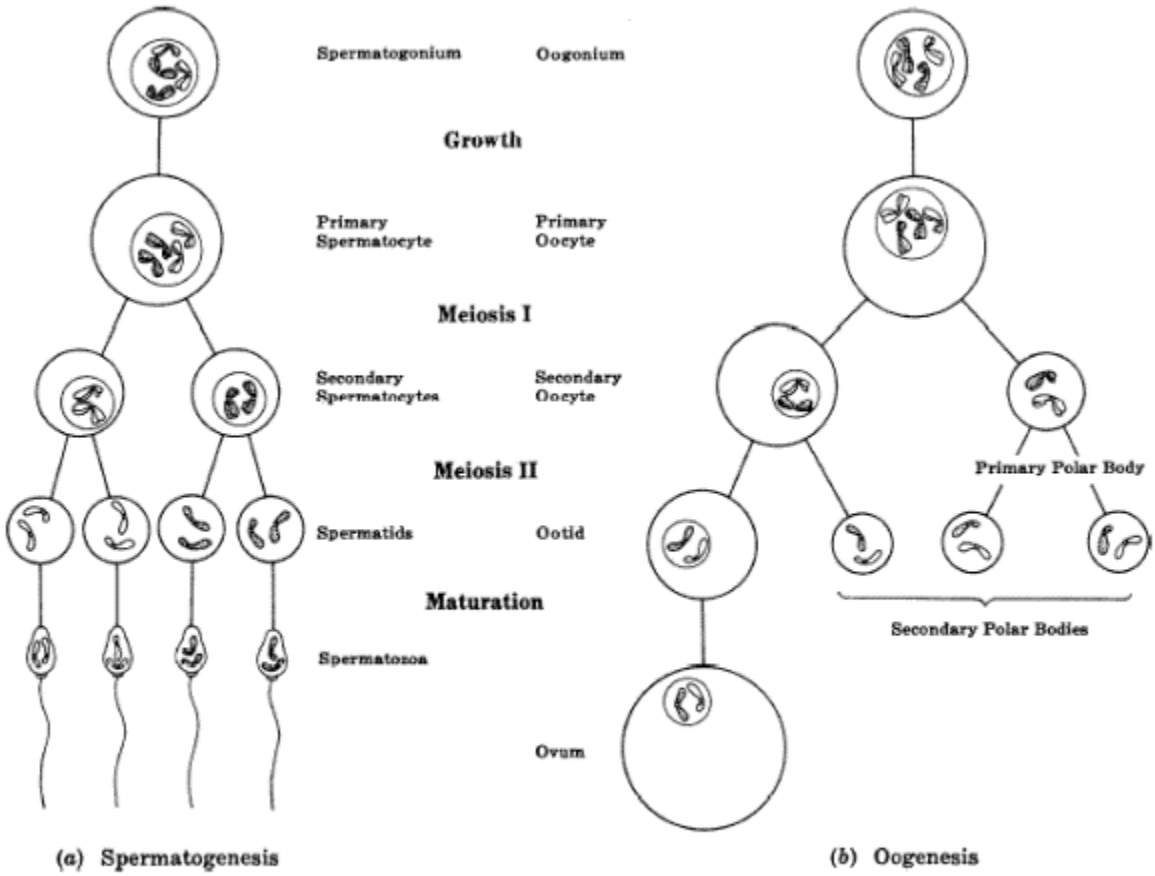
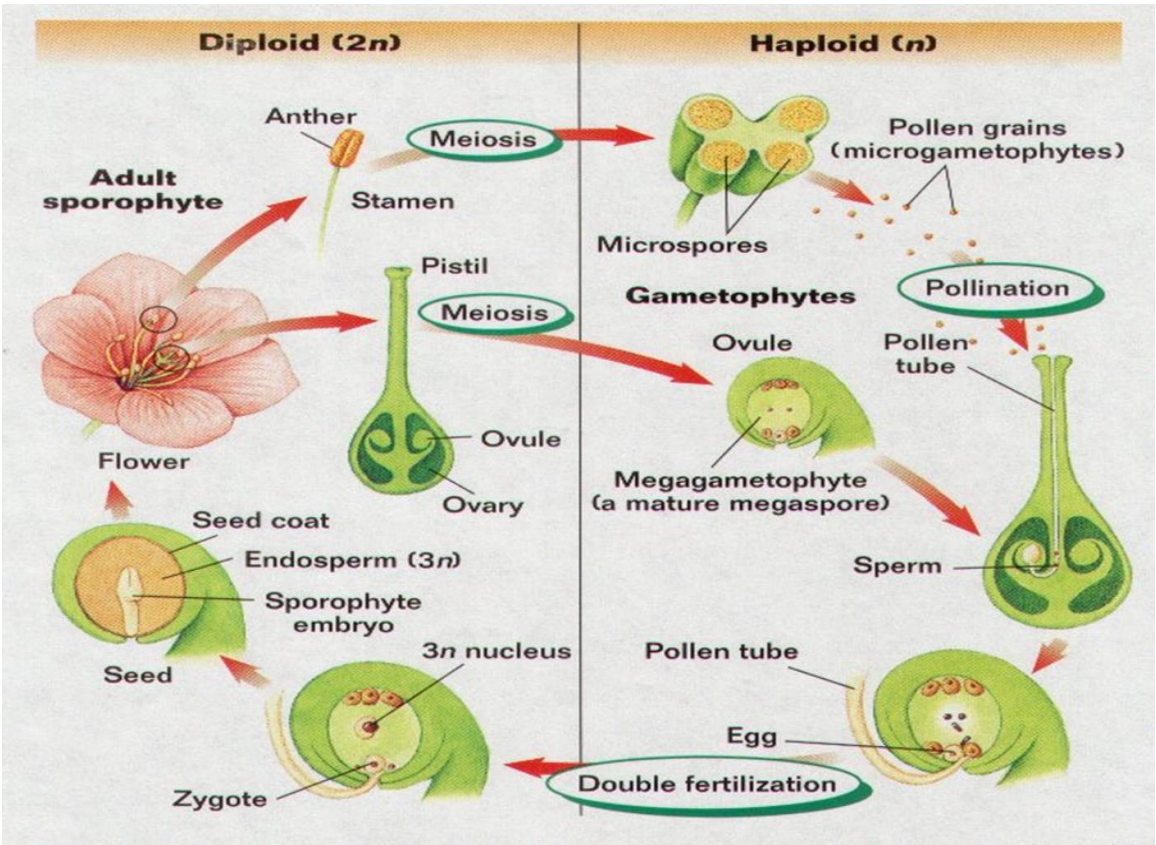


Fig. 1-6. Animal gametogenesis. The number of chromatids in each chromosome at each stage may not be accurately represented. Also, crossovers have been deleted from this figure for the sake of simplicity; thus, if two gamete cells appear to contain identical chromosomes, they are probably dissimilar because of crossovers.



Differences between Mitosis and Meiosis:

	Mitosis	**Meiosis**
Number of divisions	1	2
Number of daughter cells	2	4
Genetically identical?	Yes	No
Chromosome #	Same as parent	Half of parent
Where	Somatic cells	Germ cells
Synapsis and crossing over	Absent	Present
Centromere in Anaphase	Divided at anaphase	Not divided at anaphase I but at Anaphase II
When	Throughout life	At sexual maturity
Role	Growth and repair	Sexual reproduction

Animations:

1. **Cell cycle**

http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation__how_the_cell_cycle_works.html

2. **Mitosis**

http://highered.mcgraw-hill.com/sites/0072495855/student_view0/chapter2/animation__mitosis_and_cytokinesis.html

3. Meiosis

http://highered.Mcgraw-hill.Com/sites/0072495855/student_view0/chapter28/animation__how_meiosis_works.Html

For more reading: (in Botany Department Library)

1. The world of the cell:international edition, 6th edition, 2006, Becker, Kleinsmith and Hardin (eds.).
2. Biology, 8th edition, 2008, Losos, Mason and Singer (eds.)