Unit 1. CELL THEORY. PROKARYOTES AND EUKARYOTES. CELL STRUCTURE.

Discovery of a cell

Robert Hooke was the first who discovered a cell in 1665. He examined (under a coarse, compound microscope[1]) very thin slices of cork and saw a multitude of tiny pores that he remarked looked like the walled compartments of a honeycomb. Because of this association, Hooke called them cells, the name they still bear. However, Hooke did not know their real structure or function. His cell observations gave no indication of the nucleus and other organelles found in most living cells.

Anton van Leeuwenhoek is another scientist who saw these cells soon after Hooke did. He made a microscope containing improved lenses that could magnify objects almost 300-fold, or 270x. Using this microscope, he described cells in a drop of pond water. Leeuwenhoek probably saw bacteria (1670). Leeuwenhoek was also the first person who observed clearly and described red blood cells in humans and other animals, as well as sperm cells.

The cells in animal tissues were observed after plants because the tissues were so fragile to be prepared for studying. Biologists believed that there was a fundamental unit to life, but were unsure what this was. Only over a hundred years later, this fundamental unit was connected to cellular structure and existence of cells in animals or plants. Henri Dutrochet made this conclusion. He stated, “the cell is the fundamental element of organization”. Besides, Dutrochet also claimed that cells were not just a structural unit, but also a physiological unit.

Cell theory

The cell theory is a widely accepted explanation of the relationship between cells and living things.

Credit for developing cell theory is usually given to three scientists: *Theodor Schwann, Matthias Jakob Schleiden*, and *Rudolf Virchow*. In 1839, Schwann and Schleiden

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[1] A compound microscope was defined by having two or more lenses in a hollow tube.

suggested that cells were the basic unit of life. In 1858, Rudolf Virchow concluded that all cells come from pre-existing cells.

Classical interpretation:

1. All living organisms are made up of one or more cells.
2. Cells are the basic unit of life.
3. All cells arise from pre-existing cells.

Modern interpretation:

1. All known living things are made up of one or more cells.
2. All living cells arise from pre-existing cells by division.
3. The cell is the fundamental unit of structure and function in all living organisms.
4. The activity of an organism depends on the total activity of independent cells.
5. Energy flow (metabolism and biochemistry) occurs within cells.
6. Cells contain DNA, which is found specifically in the chromosome and RNA found in the cell nucleus and cytoplasm.
7. All cells are basically the same in chemical composition in organisms of similar species.

Types of cells

Cells are of two distinct types: ***prokaryotic*** and ***eukaryotic***. Organisms of the domains *Bacteria* and *Archaea* consist of prokaryotic cells. *Protists, fungi, animals,* and *plants* all consist of eukaryotic cells.

Structure of prokaryotic cell

Prokaryotes (from Greek pro- before + karyon, referring to the cell nucleus) are organisms without a cell nucleus (= karyon), or any other membrane-bound organelles. Most are unicellular, but some prokaryotes are multicellular. They are the smallest of all organisms ranging from 0.5 to 2.0 µm in diameter. Enclosing the cell is the cell envelope – generally consisting of a *plasma membrane* covered by a *cell wall* which, for some bacteria, may be further covered by a third layer called a *capsule*. Inside the cell is the cytoplasmic region that contains the genome (DNA), ribosomes and various sorts of inclusions. The genetic material is a *nucleoid*. It consists of a single chain of DNA that is not enclosed by a membrane. Prokaryotes can carry elements called *plasmids* (encode additional genes, such as antibiotic resistance genes). Some prokaryotes may have *flagella* and *pili* on the cell's surface. These are structures (not present in all prokaryotes) made of proteins that facilitate movement and communication between cells (fig.4). Prokaryotic cells reproduce through asexual reproduction. They usually are divided by binary fissions (breaking in half, forming two identical daughter cells) or budding (daughter cells grow out of the parent and gradually increase in size).

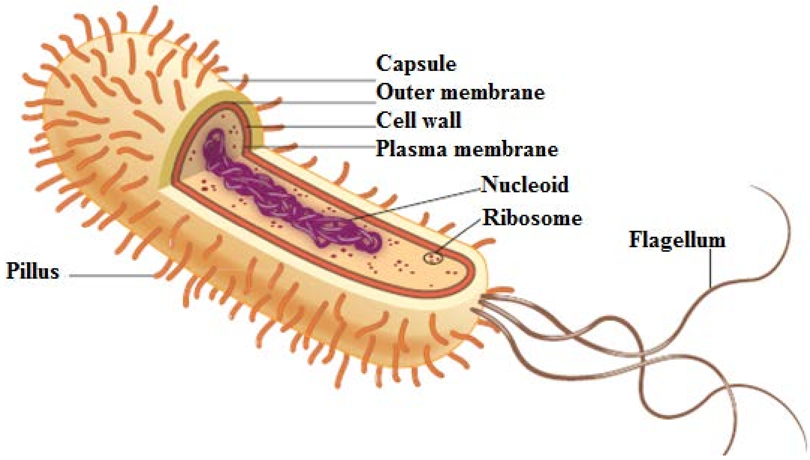

Fig. 4. Bacterial cell[2]

Structure of eukaryotic cell

Eukaryotes (from Greek ευ, meaning good/true, and κάρυον, referring to the nucleus).

The main parts of eukaryotic cell: *plasma membrane, nucleus, cytoplasm.*

<u>Plasma membrane</u>

In 1972, S. Singer and G. Nicolson proposed the Fluid Mosaic Model of membrane structure. According to this model, cell membranes are composed of a phospholipid bilayer with globular proteins partially or wholly embedded in the bilayer.

The phospholipid bilayer has a *fluid* consistency and the *mosaic* pattern of a membrane is dependent on the proteins, which vary in structure and function.

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Phospholipids spontaneously arrange themselves into a bilayer. The hydrophilic (water loving) polar heads of the phospholipid molecules face the outside and inside of the cell where water is found, and the hydrophobic (water fearing) nonpolar tails face each other (fig.5).

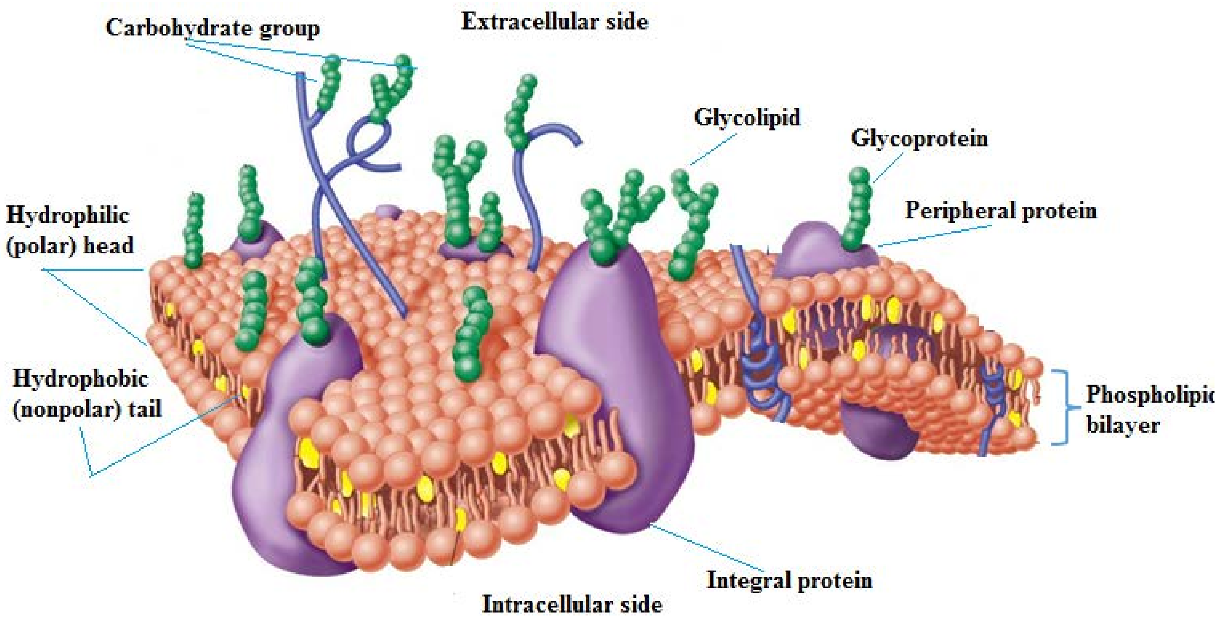

Fig. 5. Fluid-mosaic model of biomembrane[3]

The proteins in a membrane may be ***peripheral*** proteins or ***integral*** proteins. Peripheral proteins occur either on the outside or the inside surface of the membrane. Integral proteins are found within the membrane and have hydrophobic regions embedded within the membrane and hydrophilic regions that project from both surfaces of the bilayer: hydrophobic and hydrophilic.

The integral proteins largely determine a membrane's specific functions. Some of them are *channel proteins* through which a substance can simply move across the membrane; others are *carrier proteins* that com-bine with a substance and help it to move across the membrane. Still others are receptors; each type of *receptor protein* has a shape that allows a specific molecule to bind to it. The binding of a molecule, such as a hormone (or other signal molecule), can cause the protein to change its shape and bring about a cellular response. Some plasma membrane proteins are *enzymatic proteins* that carry out

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metabolic reactions directly. The peripheral proteins associated with the membrane often have a structural role in that they help stabilize and shape the plasma membrane.

On the external surface of the membrane, carbohydrate groups join with some lipids to form glycolipids. Carbohydrate groups may also join with proteins to form glycoproteins.

The plasma membrane is *asymmetrical*: the two halves are not identical. The carbohydrate chains of the glycolipids and proteins occur only on the outside surface.

Glycolipids and glycoproteins function as cell identity markers or as the “fingerprints” of the cell. The possible diversity of the chain is enormous. Glycolipids and glycoproteins vary from species to species, from individual to individual of the same species, and even from cell to cell in the same individual. Therefore, they make cell–cell recognition possible.

Animal cells, plant cells, prokaryotic cells, and fungal cells have plasma membranes. Eukaryotic cells also contain internal membranes and membrane-bound organelles.

Function of plasma membrane:

1. The maintenance of physical integrity of the cell
2. The barrier between the inside of a cell and the environment outside
3. Assistance in holding of cytoskeleton
4. Selective permeability
5. Active transport
6. Exocytosis/ Endocytosis
7. Markers and signaling during cell comunication
8. Metabolic activities

Nucleus

The eukaryotic cell's genetic instructions are housed in the nucleus. The main components of the nucleus (fig.6):

Nuclear envelope encloses the nucleus, separating its contents from the cytoplasm. It is a double membrane. The two membranes, each a lipid bilayer with associated proteins, are separated by a space of 20 40 nm.

Nuclear pores .The envelope is perforated by pore structures that are about 100 nm in diameter.

Nuclear lamina. Except at the pores, the nuclear side of the envelope is lined by the nuclear lamina, a netlike array of protein laments that maintains the shape of the nucleus by mechanically supporting the nuclear envelope.

Chromatin. Within the nucleus, the DNA is organized into discrete units called chromosomes, structures that carry the genetic information. Each chromosome contains one long DNA molecule associated with many proteins. The complex of DNA and proteins making up chromosomes is called chromatin. When a cell is not dividing, stained chromatin appears as a diffuse mass (decondensed) in micrographs; before cell division chromatin becames condensed.

Nucleolus (plural, nucleoli). Here a type of RNA called ribosomal RNA (rRNA) is synthesized from instructions in the DNA. Also in the nucleolus, proteins imported from the cytoplasm are assembled with rRNA into large and small subunits of ribosomes. These subunits then exit the nucleus through the nuclear pores to the cytoplasm, where a large and a small subunit can assemble into a ribosome. Sometimes there are two or more nucleoli (it depends on the species and the stage in the cell s reproductive cycle).

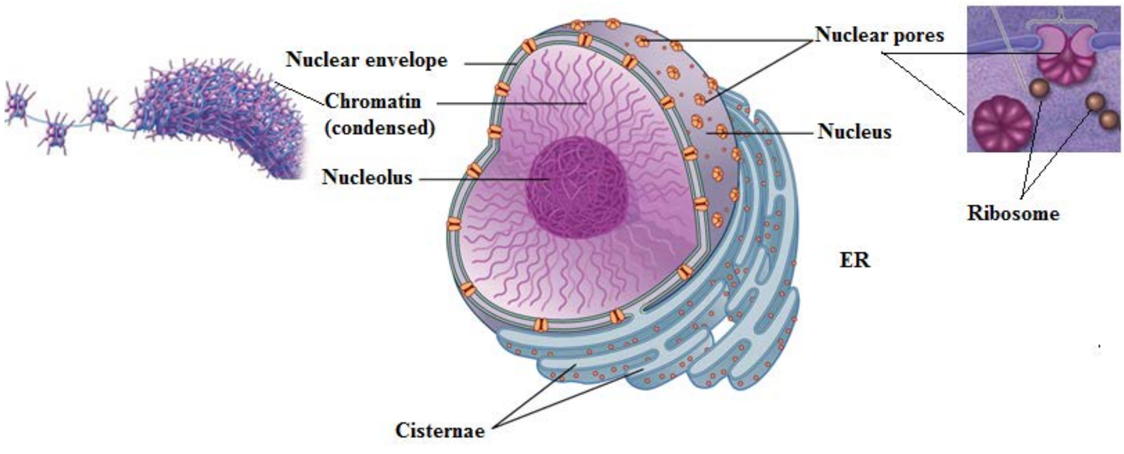

Fig. 6. The main components of the nucleus

<u>Cytoplasm</u>

Cytoplasm is the semi-fluid substance that fills the space between the cell membrane and the cellular organelles. The physical nature of cytoplasm is colloidal. It has a high percentage of water and particles of various shapes and sizes are suspended in it. Chemically cytoplasm contains 90% water and 10% include a mixture of organic and inorganic compounds in various proportions. Most of the cellular activities occurs in the cytoplasm. The outer clear and glassy layer of the cytoplasm is called the *ectoplasm* or the cell cortex and the inner granular mass is called the *endoplasm*. The constituents of cytoplasm are cytosol, organelles and cytoplasmic inclusions.

Cytosol makes up about 70% of the volume of the cell. It is composed of water, salts and organic molecules. Cytosol is composed of a mixture of cytoskeleton filaments, organic and inorganic molecules that are dissolved and water.

Cytoplasmic inclusions are tiny particles suspended in the cytosol. A vast range of inclusion are present in different cell types. The inclusions range from calcium oxalate crystals or silicon dioxide crystals in plants to storage granules of materials like starch, glycogen, etc.

Organelles are specialized structures of the cell, which perform specific function. Organelles are also known as cell compartments. Organelles are divided into *membrane-bound* and *no membrane-bound* organelles.

Membrane-bound organelles: endoplasmic reticulum, mitochondria, Golgi apparatus, lysosomes, vacuoles, peroxisome and plastids in plant cells.

No membrane-bound organelles: ribosome, centrosome, microtubules and microfilaments.

Endoplasmic reticulum (ER)

Structure. ER consists of a network of membranous tubules and sacs called cisternae. There are two types of ER: smooth ER is named because its outer surface lacks ribosomes; rough ER is studded with ribosomes on the outer surface of the membrane and thus appears rough through the electron microscope (fig.7).

Function. Smooth ER: synthesis of lipids, metabolism of carbohydrates; rough ER: synthesis of proteins.

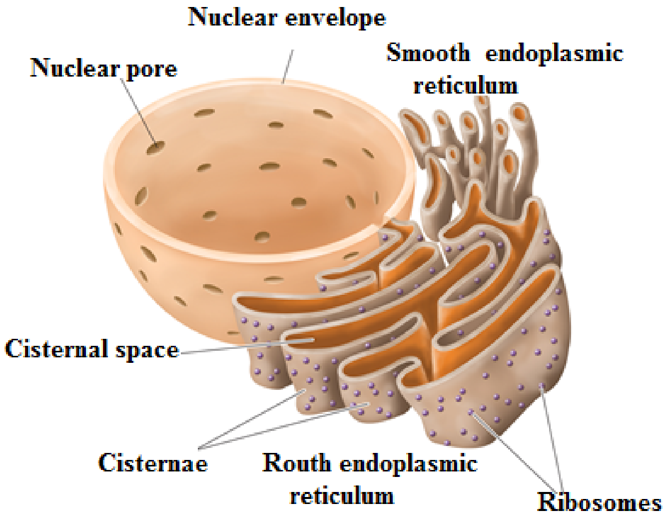

Fig. 7. Endoplasmic reticulum[4]

Mitochondria (singular, *mitochondrion*)

Structure. Bounded by double membrane; inner membrane has infoldings (cristae); it has own DNA thus it's semi-autonomous organelle (fig.8).

Function. Cellular respiration.

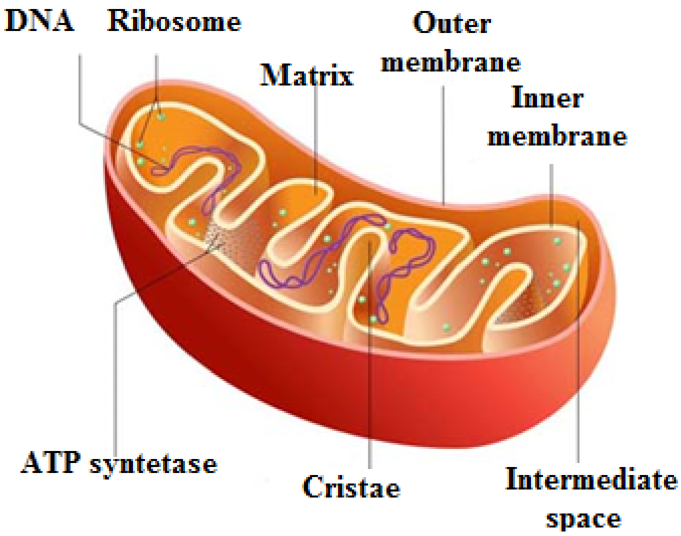

Fig. 8. Mitochondrion[5]

Golgi apparatus

Structure. Stacks of flattened membranous sacs (fig.9).

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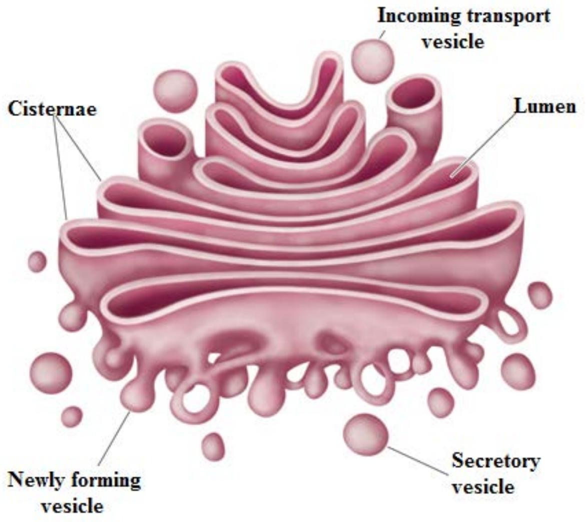

Fig. 9. Golgi apparatus[6]

Function. Modification of proteins, carbohydrates on proteins, and phospholipids; synthesis of many polysaccharides; sorting of Golgi products, which are then released in vesicles.

Lysosome

Structure. Membranous sac of hydrolytic enzymes (in animal cells) (fig.10).

Function. Breakdown of ingested substances, cell macromolecules and damaged organelles for recycling.

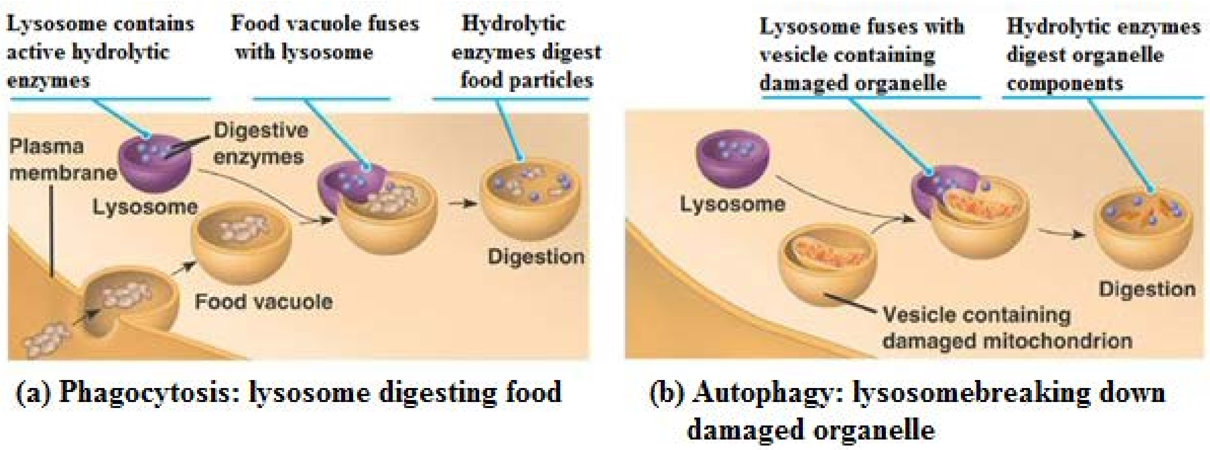

Fig. 10. Function of lysosome: (a) Phagocytosis; (b) Autophagy[7]

Vacuoles

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Structure. Large vesicles derived from the endoplasmic reticulum and Golgi apparatus. Thus, vacuoles are an integral part of a cell s endomembrane system.

Function. Digestion, storage, waste disposal, water balance, cell growth, and protection.

Peroxisome

Structure. Specialized metabolic compartment bounded by a single membrane.

Function. They help in digesting long chains of fatty acids and amino acids and help in synthesis of cholesterol.

Plastids

Structure. Plastids are cellular organelles found only in the plant cell. Plastids are of three types - chloroplasts, chromoplasts and leucoplasts.

- ✓ Chloroplasts are elongated disc shaped organelles which contains chlorophyll. Chlorophyll is present in green plants which helps them make food by the process of photosynthesis, which uses energy from the sunlight is converted into chemical energy (fig.11).

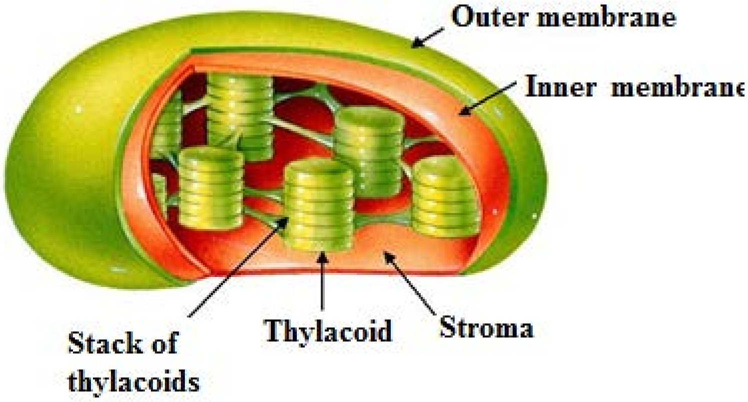

Fig. 11. Structure of chloroplast[8]

- ✓ Chromoplasts are plastids which are found in fruits and are yellow, orange and red in color.
- ✓ Lecuoplasts are colorless plastids. They found in roots, seeds and underground stems.

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Function. Chloroplast is a trap of solar energy for the process of photosynthesis. Chromoplasts gives color to flowers and fruits, which helps in pollination by attracting pollinating agents like insects and birds. Leucoplasts acts as storage for food in the form of carbohydrates, fats and proteins.

Ribosome

Structure. Two subunits made of ribosomal RNA and proteins; can be free in cytosol or bound to ER (fig.12).

Function. Protein synthesis.

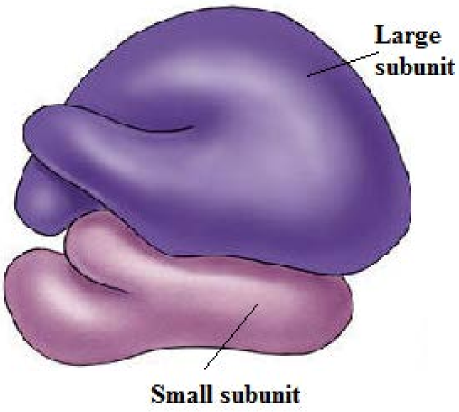

Fig. 12. Structure of ribosome

Centrosome** and **Centrioles

Structure. Within the centrosome is a pair of centrioles. The two centrioles are at right angles to each other, and each is made up of nine sets of three microtubules (fig.13).

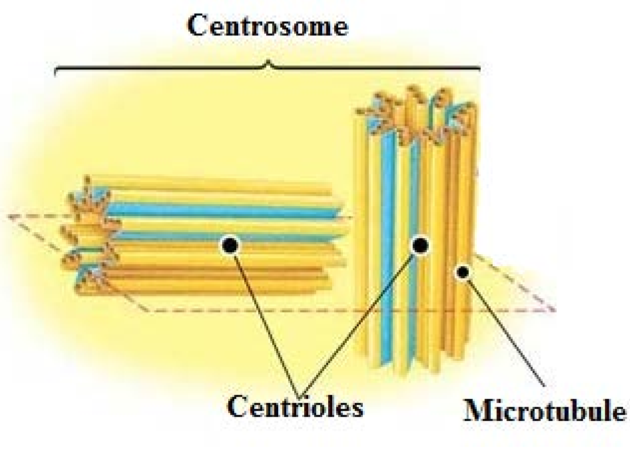

Fig. 13. Structure of Centrosome and Centrioles[9]

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Function. At the time of cell division, centrosome directs the poles of spindle apparatus and help in cell division. In animal cells, microtubules grow out from a centrosome, a region that is often located near the nucleus and is considered a microtubule-organizing center.

Cytoskeleton

Structure. It is composed of three types of molecular structures: microtubules, microfilaments and intermediate filaments (fig. 14).

Microtubules. Hollow tubes; wall consists of 13 columns of tubulin molecules. D - 25 nm with 15-nm lumen.

Microfilaments. Two intertwined strands of actin, each a polymer of actin subunits. D – 7nm.

Intermediate filaments. Fibrous proteins supercoiled into thicker cables. D – 8-12nm.

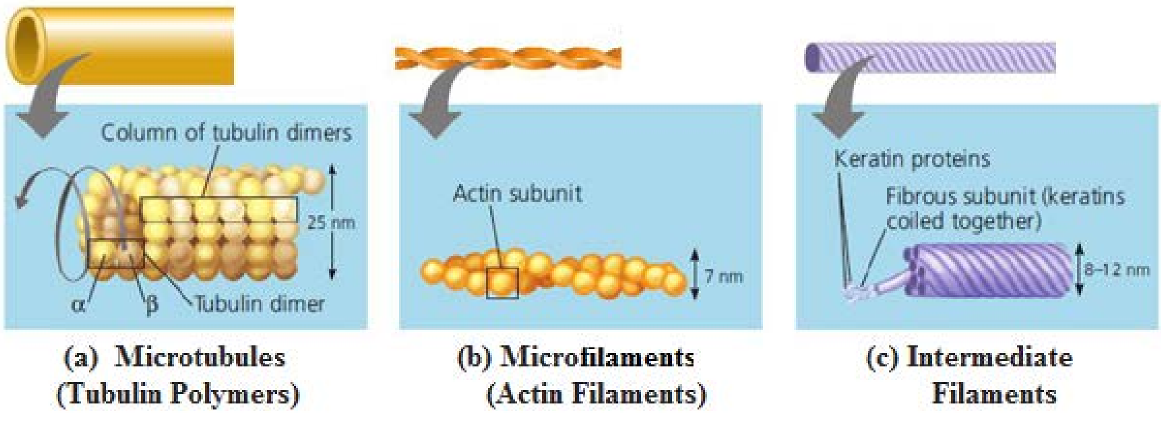

Fig. 14. Cytoskeleton: microtubules (a), microfilaments (b), and intermediate filaments (c)[10]

Function. They give structural support and maintain the shape of the cell.

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Microtubules. Maintenance of cell shape (compression-resisting girders), cell motility, chromosome movements in cell division.

Microfilaments. Maintenance of cell shape, muscle contraction, cell motility, cell division (cleavage furrow formation).

Intermediate filaments. Maintenance of cell shape, anchorage of nucleus and certain other organelles, formation of nuclear lamina.

Cell wall

Structure. The cell wall is a rigid layer that surrounds the plant cells. Plant cell wall consists of three layers: the primary cell wall, secondary cell wall and the middle lamella. Cell wall is composed of cellulose, pectin, glycoproteins, hemicellulose (fig.15).

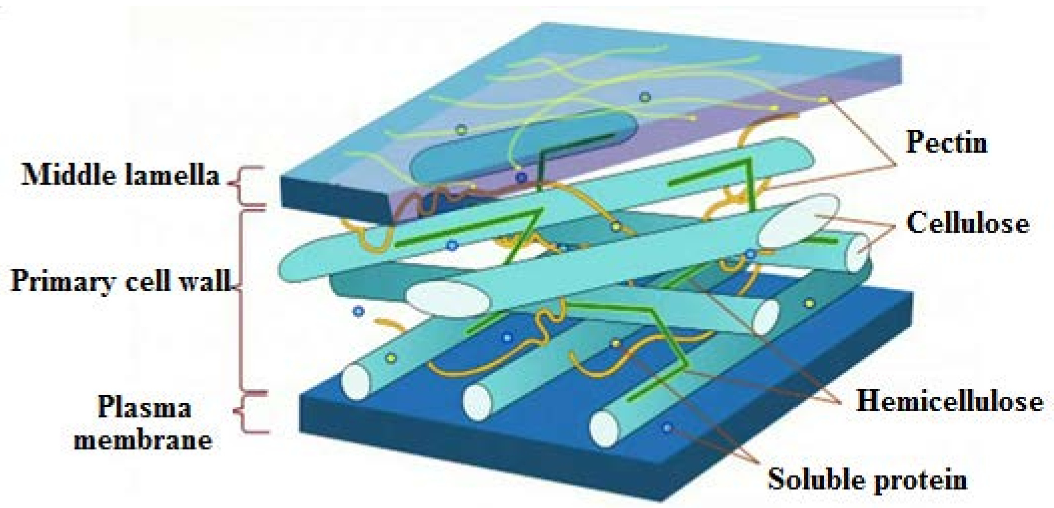

Fig. 15. Structure of cell wall[11]

Function. To provide rigidity, strength, protection against mechanical stress and infection.

General view of animal and plant cells are shown below (fig.16,17).

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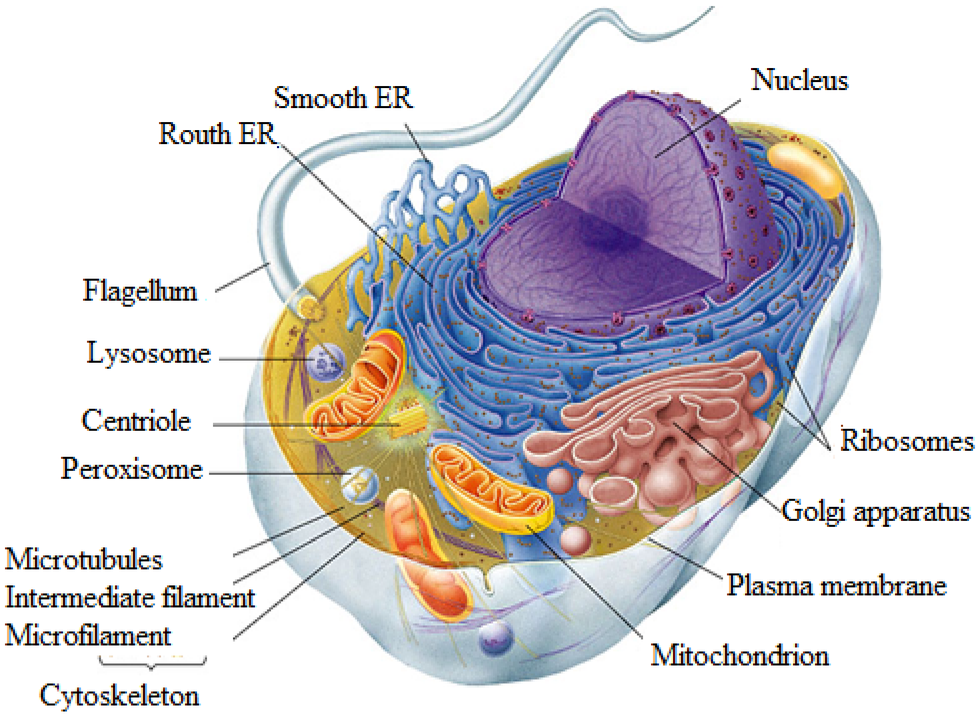

Fig. 16. Structure of eukaryotic cell (animal cell)[12]

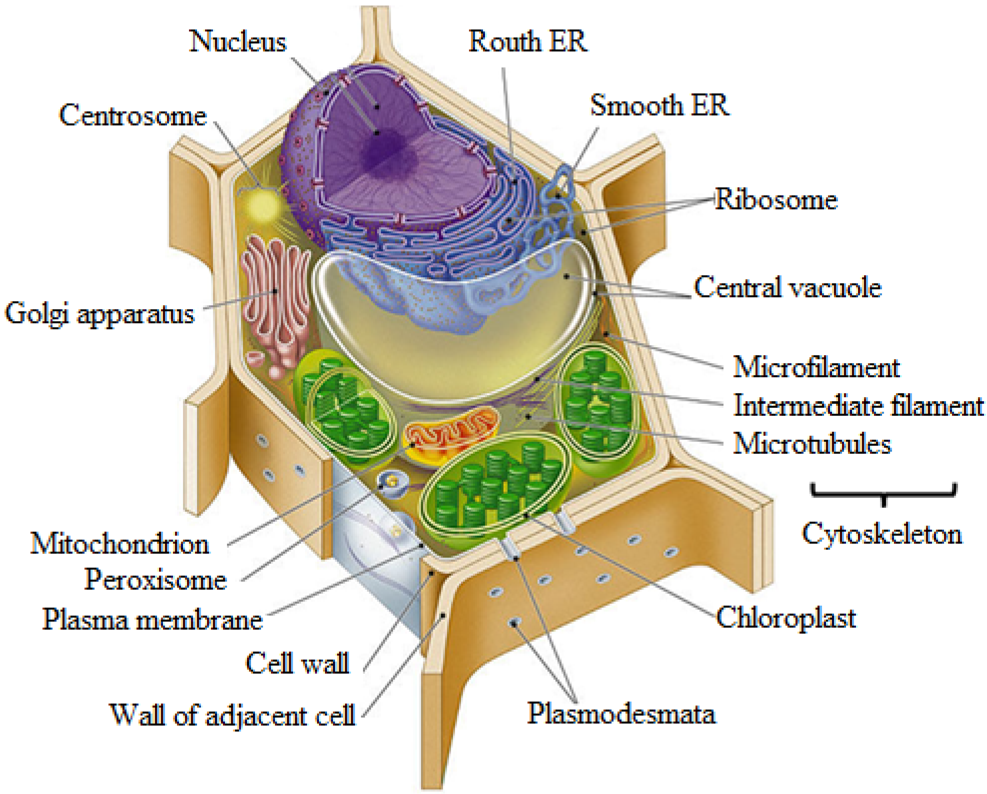

Fig. 17. Structure of eukaryotic cell (plant cell)[13]

Table 1

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The principal differences between Prokaryotic and Eukaryotic cells

Characteristic	***Prokaryotic cell***	***Eukaryotic cell***
Size	D ≈ 0,2-2nm	D ≈ 10-100 nm
Nucleus	No nuclear membrane	True nucleus with nuclear membrane and nucleoli
Genetic material	Single circular chain of DNA (nucleoid) without histones	Linear chromosomes with histones
Membrane-bound organelles	Absent	Present
Ribosome	Smaller (70S)	Larger (80S)
Cytoplasm	No cytoskeleton	Cytoskeleton
Plasma membrane	No carbohydrates	Carbohydrates serve as receptors
Cell wall	Usually present (typical bacterial cell wall includes peptidoglycanes)	Present in plant cell (includes cellulose)
Cell division	Amitosis, binary fission	Mitosis, meiosis

Table 2

The principal differences between an animal cell and a plant cell

Animal cell	***Plant Cell***
Animal cells are usually smaller is size.	Plant cells are usually larger in size.
Cell wall is completely absent.	Cell wall is present.
Vacuoles are absent usually. If present, they are small organelles, they are temporary and they serve as organelles for excretion or secretion.	Vacuoles are prominent and large organelles in the plant cell. One or more vacuoles may be present. The central space in the cell may be occupied by a large single vacuole.
Plastids are absent.	Plastids are present. They may of three types chromoplasts, chloroplasts and leucoplasts.
Centrosome is present.	Centrosome is absent in plant cells. Instead of centrosome, there are two small clear areas called polar caps are present.
Golgi complex is prominent and highly complex, it is present near the nucleus of the cell.	Golgi apparatus is present in form subunits called dictyosomes.

CELL CYCLE. CELL DIVISION. MITOSIS. MEIOSIS

The continuity of life is based on the reproduction of cells, or ***cell division.*** Cell division plays several important roles in life:

1. Reproduction
2. Growth and development
3. Tissue renewal

The cell division process is an integral part of the ***cell cycle***, the life of a cell from the time it is first formed from a dividing parent cell until its own division into two daughter cells.

Phases of the Cell Cycle (fig. 18):

1. Interphase
2. Mitosis (M phase, nuclear division)
3. Cytokinesis (cytoplasmic division)

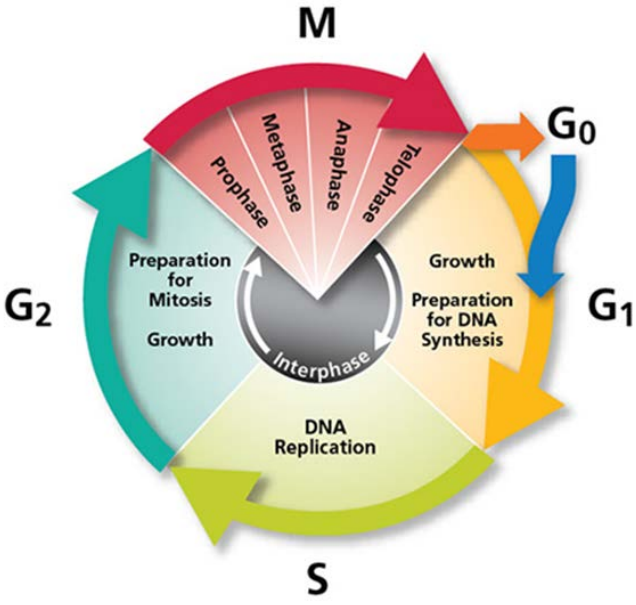

Fig. 18. Phases of the Cell Cycle

Interphase

Interphase ("resting stage) accounts for about 90% of the cycle. During interphase, a cell that is about to divide grows and copies its chromosomes in preparation for cell division. Interphase generally lasts at least 12 to 24 hours in mammalian tissue. Interphase can be divided into subphases: gap 1 **(G 1),** synthesis **(S),** and gap 2 **(G 2)** (tabl.3).

Table 3

Subphases of Interphase

G_1 ("Gap One")	The period of molecular synthesis where a newly formed cell turns on a variety of genes on its DNA to make proteins, which in turn churn the metabolism of the cell, produce and breakdown carbohydrates, lipids, etc., and transform energy from food into ATP. The cell grows and enlarges.
S ("synthesis")	During this phase the chromatin (DNA and proteins) becomes synthetically active. Using elaborate teams of enzymes, the DNA molecules of each chromosome are copied by semiconservative DNA synthesis.
G_2 ("Gap Two")	The cells prepare for division. Many different proteins are synthesized, especially those that will act as spindle fibers. Stocks of energy are accumulated and many organelles, such as mitochondria, also grow and divide, increasing in number. Towards the end of G2, the cell gets ready for the M phase.

Mitosis (M phase)

The primary purpose of mitosis is to distribute the replicated chromosomes, dividing one cell nucleus into two nuclei, so that each daughter cell receives the same complement of chromosomes.

Mitosis is conventionally broken down into five stages: prophase, prometaphase, metaphase, anaphase and telophase.

Prophase (fig. 19)

- ✓ The chromatin fibers condense (each duplicated chromosome appears as two identical sister chromatids joined at their centromeres.
- ✓ The nucleoli begin to disappear.
- ✓ The mitotic spindle begins to form.
- ✓ The centrosomes move apart toward opposite poles.

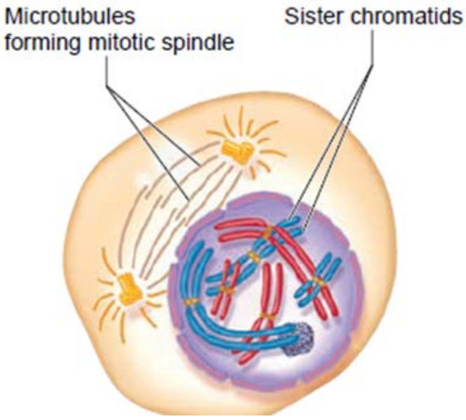

Fig. 19. Prophase

Prometaphase (fig. 20)

- ✓ Nuclear envelope breaks down.
- ✓ Microtubules from the centrosomes invade the nucleus.
- ✓ Sister chromatids attach to microtubules from opposite centrosomes.

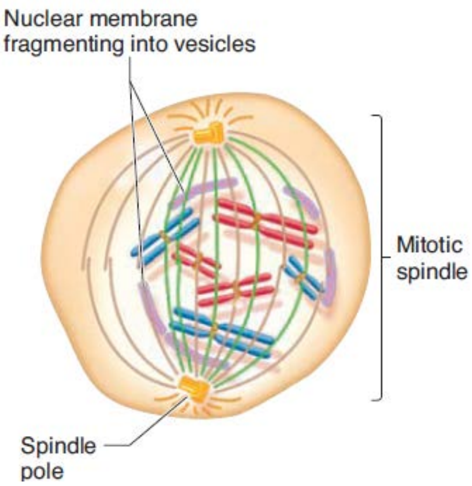

Fig. 20. Prometaphase

Metaphase (fig.21)

- ✓ The centrosomes are at opposite poles of the cell.
- ✓ The chromosomes align on the *metaphase plate*
- ✓ Each pair of chromatids is attached to both poles by kinetochore microtubules.

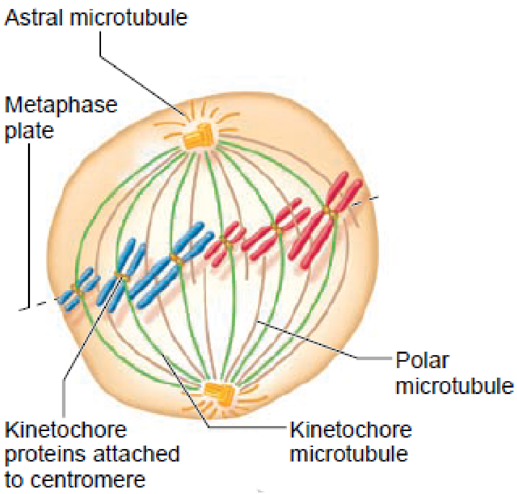

Fig. 21. Metaphase

Anaphase (fig.22)

The two liberated daughter chromosomes begin moving toward opposite ends of the cell as their kinetochore microtubules shorten.

By the end of anaphase, the two ends of the cell have equivalent and complete collections of chromosomes.

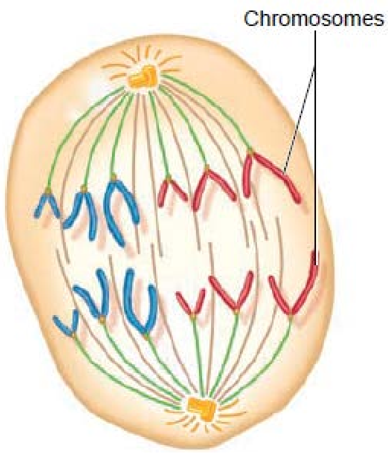

Fig. 22. Anaphase

Telophase (fig.23)

- ✓ Nuclear membranes and nucleoli re-form.
- ✓ Spindle fibers disappear.
- ✓ Chromosomes uncoil and become a tangle of chromatin.

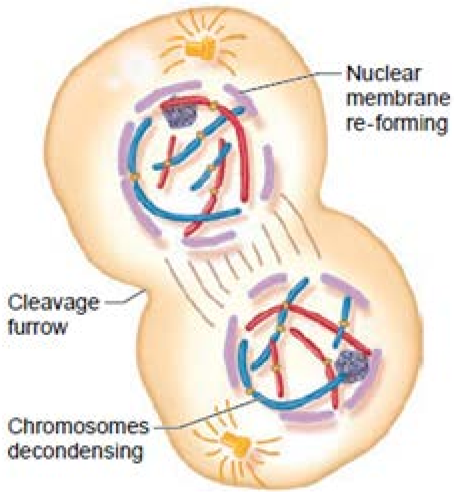

Fig. 23. Telophase

Cytokinesis

The division of the cytoplasm is usually well under way by late telophase, so the two daughter cells appear shortly after the end of mitosis. In animal cells, cytokinesis involves the formation of a cleavage furrow, which pinches the cell in two (fig.24 (a)). In plant cells, cytokinesis is accomplished by the formation of a membranous cell plate between the daughter cells; eventually, walls composed of cellulose are built on either side of the cell plate (fig.24 (b)).

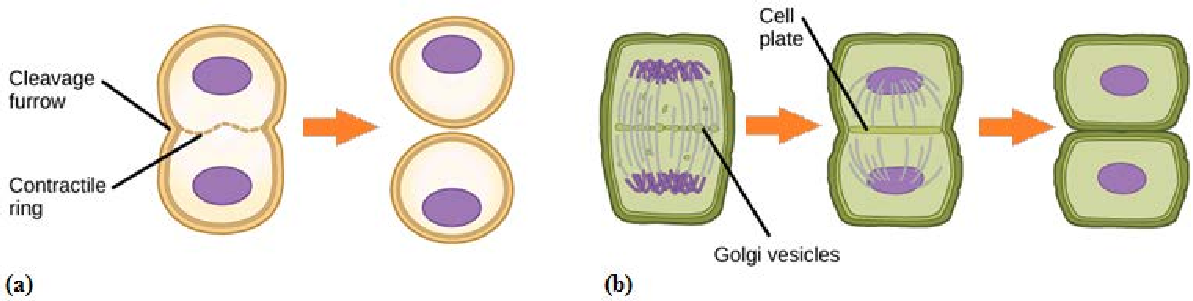

Fig. 24. Cytokinesis: (a) animal cell, (b) plant cell

<u>The outcomes of and biological significance of Mitosis</u>

Mitosis always produces two cells that are genetically identical to each other and the original cell.

Cellular Organization of the Genetic Material

In eukaryotes, genetic material is housed (mostly) in the nucleus and tightly packaged into linear chromosomes. Chromosomes are made up of a DNA-protein complex called chromatin. During most of a cell's life cycle, DNA exists as a mass of loose strands. While the DNA is spread throughout the nucleus, the cell performs the functions needed for survival. During this time, the DNA is duplicated, or copied. Before division, the chromosomes compact by means chromatin packaging. There are up to six levels of chromatin packaging to fit into the nucleus of one cell:

1. Nucleosome (10 nm chromatin fibers)
2. Solenoid (30 nm chromatic fibers)
3. Radial Loop Domains (300 nm chromatin fibers)
4. Interphase Chromosome (700 nm)
5. Metaphase Chromosome (1400 nm)

Structure of metaphase chromosome

During cell division (at metaphase) chromosome has X-shaped structure called a *metaphase chromosome*. It consists of two sister chromatides. *Centromere* divides a chromosome in two arms (short arm – *p*, long arm – *q*) (fig.25).

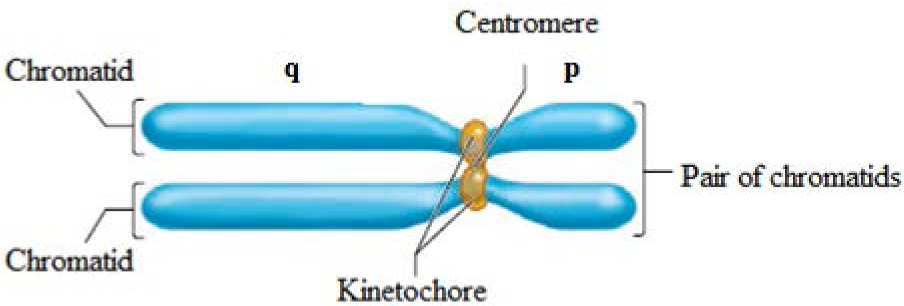

Fig. 25. Structure of metaphase chromosome

The *kinetochore* is a group of proteins that are bound to the centromere. Fibers of mitotic spindle attaches to this during mitosis.

Depending on the position of the centromere, chromosomes are classified as *metacentric, submetacentric, acrocentric,* or *telocentric* (tabl. 4).

Table 4

Centromere locations and the chromosome designations

Centromere location	***Designation***	***Metaphase shape***
Middle	Metacentric	
Between middle and end	Submetacentric	
Closer to end	Acrocentric	
At end	Telocentric	

Chromatin packing also offers an additional mechanism for controlling gene expression. Specifically, cells can control access to their DNA by modifying the structure of their chromatin. Highly compacted chromatin ***heterochromatin*** is not accessible to the enzymes involved in DNA transcription, replication, or repair**.** The less condensed regions, ***euchromatin***, are associated with genes being actively transcribed (fig.26).

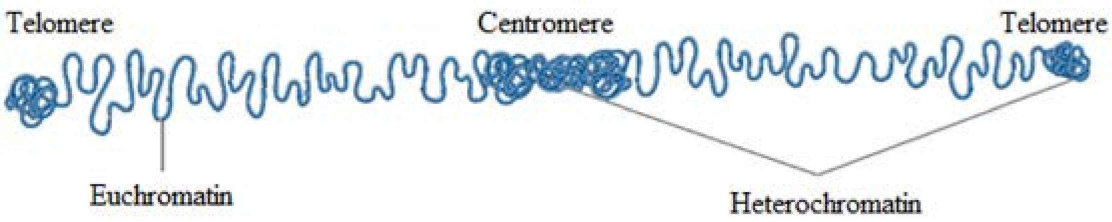

Fig. 26. Euchromatin and Heterochromatin

Within each species of organism, the number of chromosomes is constant. For example, humans have 46 chromosomes.

All somatic cells contain an identical number of chromosomes. This represents the *diploid number* (2n) of chromosome. With the exception of sex chromosomes, each chromosome exists in pair, called pare of ***homologous chromosomes***. It means for each chromosome exhibiting a specific length and centromere placement, another exists with identical features.

In comparison with somatic cells, germ cells (gametes) are typically ***haploid*** (1n), which means they contain half the number of chromosomes as diploid cells (For example, a diploid human cell contains 46 chromosomes, but a sperm or egg contains only 23 chromosomes). During the process known as ***meiosis*** (from the Greek meaning less), haploid cells are produced from a cell that was originally diploid.