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College of Science
Department of Biology

Theoretical Cytology 2020-2021

المرحلة الأولى - الدراستين الصباحية والمسائية

الفصل الدراسي الأول

تدريسي المادة :

أ.م.د. ركاد محمد خماس   ا.م.د. فاضل محمد لفتة

م.د. ماجدة هادي السعدي

Lecture 1

An Introduction to Cell Biology

The Cell

The cell (from Latin cell **meaning** small room**)** is the basic structural, functional and biological unit of all known organisms. A cell is the smallest unit of life. Cells are often called the building blocks of life. The study of cell is called Cell Biology, Cellular Biology or **Cytology.**

In 1665, the cell was discovered by **Robert Hook**. It is a small united area where all kinds of actions and reactions collectively take place. Some cells have membrane-bound organelles and some do not have. Depending upon the internal structure of the cell, two types of cells are found in an organism namely **Eukaryotic** and **Prokaryotic**. Organisms that are made up of single cells are known as single-celled **unicellular** organisms and from many cells are known as **multi-cellular** organisms.

The Cell Theory:

The cell theory includes four principles in modern biology:

1- All organisms are composed of one or more cells. While many organisms, such as the bacteria, are single-celled **unicellular**, other organisms, including humans and plants, are **multicellular** within the life processes of metabolism and heredity occur.

2- Cells are the smallest living things.

3- Addition cells are not originating at present, rather, life on earth represent a continuous line of descent from those early cells.

4- Cells arise only by the division of previously existing cell.

The functions of cells:

1- The capacity to extract energy from the environment and change it from one form to another.

2- The capacity to use this energy to build more organic molecules to maintain themselves and grow.

3- The capacity to deal with the environment selectively.

4- The capacity to reproduce.

In general, the smallest living microorganism on the earth is the **viruses** while the smallest unicellular microorganisms are the **mycoplasma**. But the biggest living organism is the Sequoia plant (red wood tree).

Prokaryotes and Eukaryotes

Biologists classify cells into two broad categories the **Prokaryotes** and **Eukaryotes**. The primary difference between a prokaryotic cell and a eukaryotic cell is the presence or absence of a nucleus, a membrane-bound structure that houses the DNA. **Prokaryotic cells** lack a nucleus, whereas **eukaryotic cells** possess a nucleus. Despite their differences, both types of cells have a **plasma membrane,** a membrane that regulates what enters and exists a cell.

Table 1: A comparison between Prokaryotic cell as in bacteria and Eukaryotic cell as a plant (Figure 1)

Prokaryotic Cell	Eukaryotic Cell
Nucleus is absent	Nucleus is present
Membrane-bound nucleus absent.	Membrane-bound Nucleus is present.
Cell wall chemically complex	Cell wall is present in plants and fungi and chemically simpler
Mitochondria absent	Mitochondria present
One chromosome is present, but not true chromosome plastids	More than one number of chromosomes is present.

Chloroplasts absent; chlorophyll scattered in the cytoplasm	Chloroplasts present in plants
Vacuoles absent	Vacuoles present
Sexual reproduction is absent divided by binary fission	Sexual reproduction is present divided by mitosis meiosis
Golgi apparatus absent	Golgi apparatus present

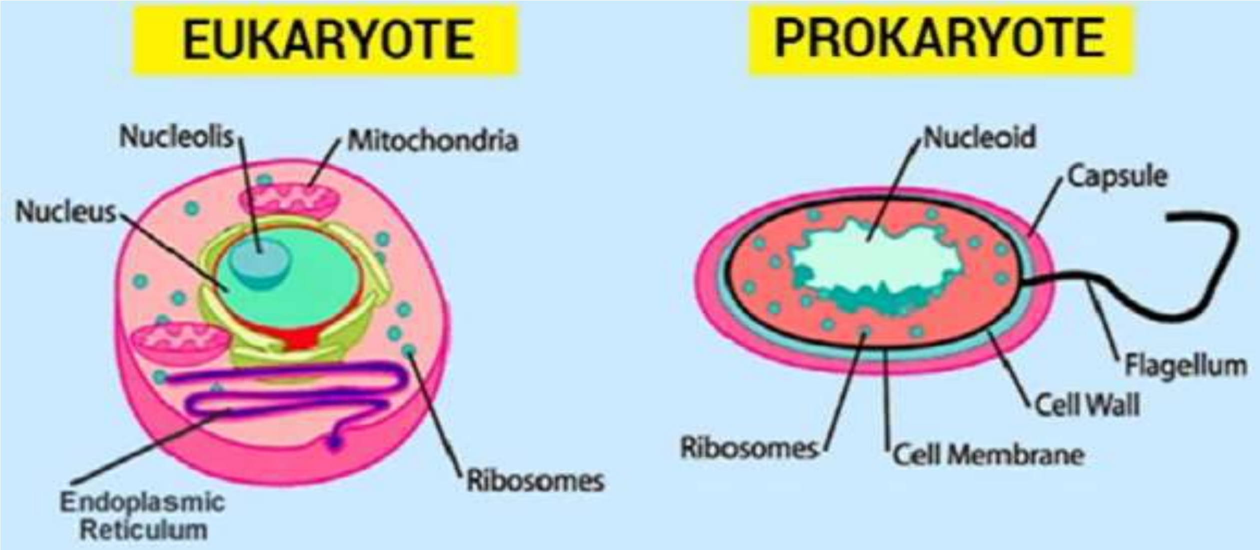


Figure1: comparison between Prokaryotic cell as in bacteria and Eukaryotic cell

Lecture2

Animal Cell and Plant Cell

- All living things are made up of cells. Animal cells and plant cells share the common components of a nucleus, cytoplasm, mitochondria and a cell membrane.
- Plant cells have three extra components, a vacuole, chloroplast and a cell wall.

Animal cells

Animals are made up of millions of cells. Animal cells have an irregular shapes and are made up of four key parts (Figure 2):

- **Nucleus** – This contains genetic material (DNA), and controls the cell's activity.
- **Cell membrane** – A flexible layer that surrounds the cell and controls the substances that enter and exit.
- **Cytoplasm** – A jelly-like substance where the chemical reactions happen.
- **Mitochondria** – This is where energy is released from the food molecules.

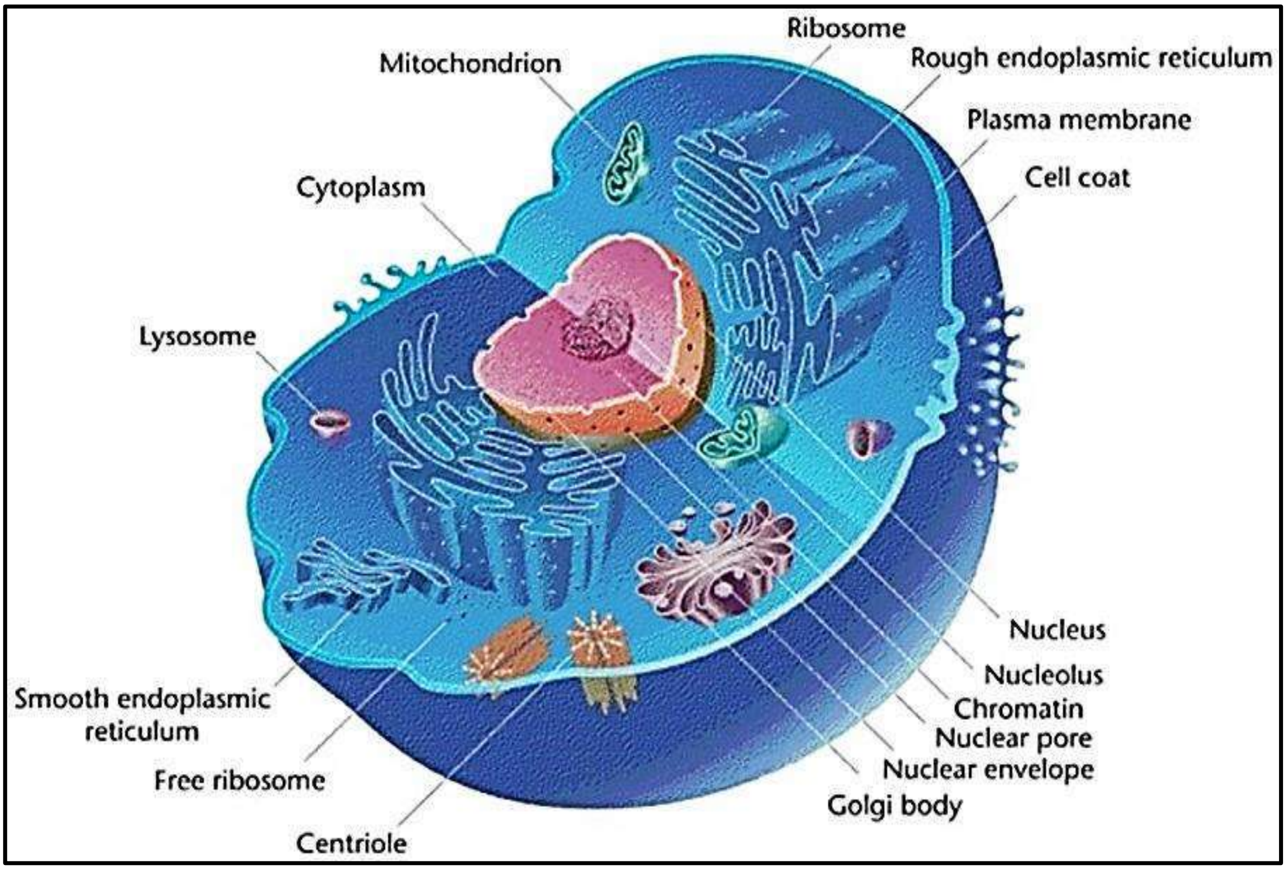


Figure 2: The animal cell.

Plant cells

Plants are also made up of millions of cells. Plant cells have a nucleus, cell membrane, cytoplasm and mitochondria too, but they also contain the following structures (Figure 3):

- **Cell wall** – A hard layer outside the cell membrane, containing cellulose to provide strength to the plant.
- **Vacuole** – A space inside the cell that is used to store substances and help the cell keep its shape.
- **Chloroplasts** – Structures that contain the green pigment **chlorophyll**, which are a key part of photosynthesis.

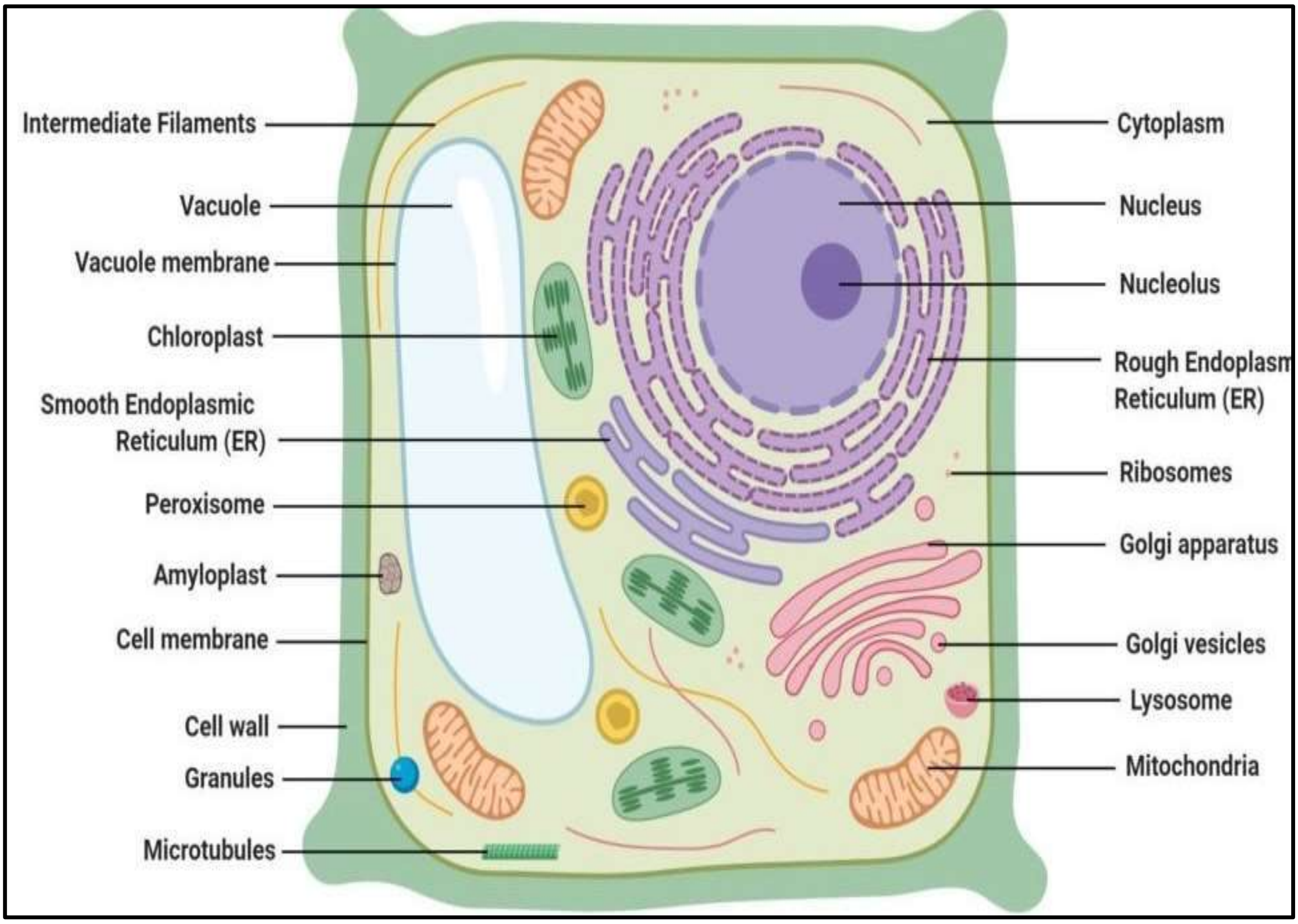


Figure 3: The plant cell

Table 2 Comparsion between Animal cell and Plant cell

Characteristic	Animal cells	Plant cells
Size and Shape	Generally smaller than plant cells with their cells ranging from 10-30um in length. Shapes vary greatly from irregular shapes to round shapes.	Larger than animal cells with the cell size ranging from 10um-100um in length. Plant cells similar in shape with most cells being rectangular or cube-shaped.
Cell Wall	They lack the cell wall but possess a plasma (cell) membrane,	They have both a cell wall that is made up of cell membrane and cellulose.
Plasma membrane	Present	Present
Ribosomes	They are present and they are used for protein synthesis and genetic coding of the protein, amino acid sequences.	They are present and they are used for protein synthesis and cellular repair mechanisms.

Endoplasmic reticulu	Present	Present
Lysosomes	lysosomes, contain digestive enzymes to break down cellular macromolecules.	rarely contain lysosomes as the plant vacuole and the Golgi bodies handle molecule degradation of waste cellular products.
Vacuoles	Present	Present
Nucleus	Present and it lies at the center of the cell	Present and it lies on the side of the cell
Centrioles	They are present with their major function involving the assistance of the cell division process.	They are absent in plant cells
Microfilaments and Microtubules	Present	Present.
Cilia and Filaments	Present; they allow movement of cells or part of the cell, for example, swimming of the sperm to the ova.	Absent in plants
Plastides	Absent	Present; they give pigmentation color to the plants and also facilitate trapping of light energy used for photosynthesis.
Golgi bodies	They have larger and fewer Golgi bodies with their major function being to process and package protein and lipid macromolecules as they are being synthesized.	They have smaller but more Golgi bodies with their major role being modification, processing, sorting and packaging proteins for cellular secretion.

Table 3 ***Comparison between Bacterial, Animal and Plant Cells*** **as shown figure 4 (For information only).**

	Bacterium	Animal	Plant
Type of Cell	Prokaryotic cells	Eukaryotic cells	Eukaryotic cells
Cell Wall	Present (protein-polysaccharide)	Absent	Present (cellulose)
Cell membrane	Present	Present	Present
Nucleus	Absent	Present	Present
Plasmids	Present	Absent	Absent
Plastids	Absent	Absent	Present
Mitochondria	Absent	Present	Present
Ribosomes	Present	Present	Present
Lysosomes	Absent	Present	Present but are few in numbers
Chromosomes	A single circle of naked DNA	Multiple units DNA associated with protein	Multiple units DNA associated with protein

ER	Absent	Present	Present
Centrioles	Absent	Present	Absent
Vacuoles	Absent	Absent or small	Usually a large single Vacuole in mature cell
Golgi Apparatus	Absent	Present	Present
Mode of Nutrition	Both heterotrophs and autotrophs	Heterotrophs	Autotrophs
Mode of Respiration	Both aerobic and anaerobic	Aerobic respiration	Aerobic respiration
Mode of Reproduction	Both sexual and asexual mode of reproduction.	Sexual reproduction in higher animals and asexual in lower animals.	Both sexual and asexual mode of reproduction.

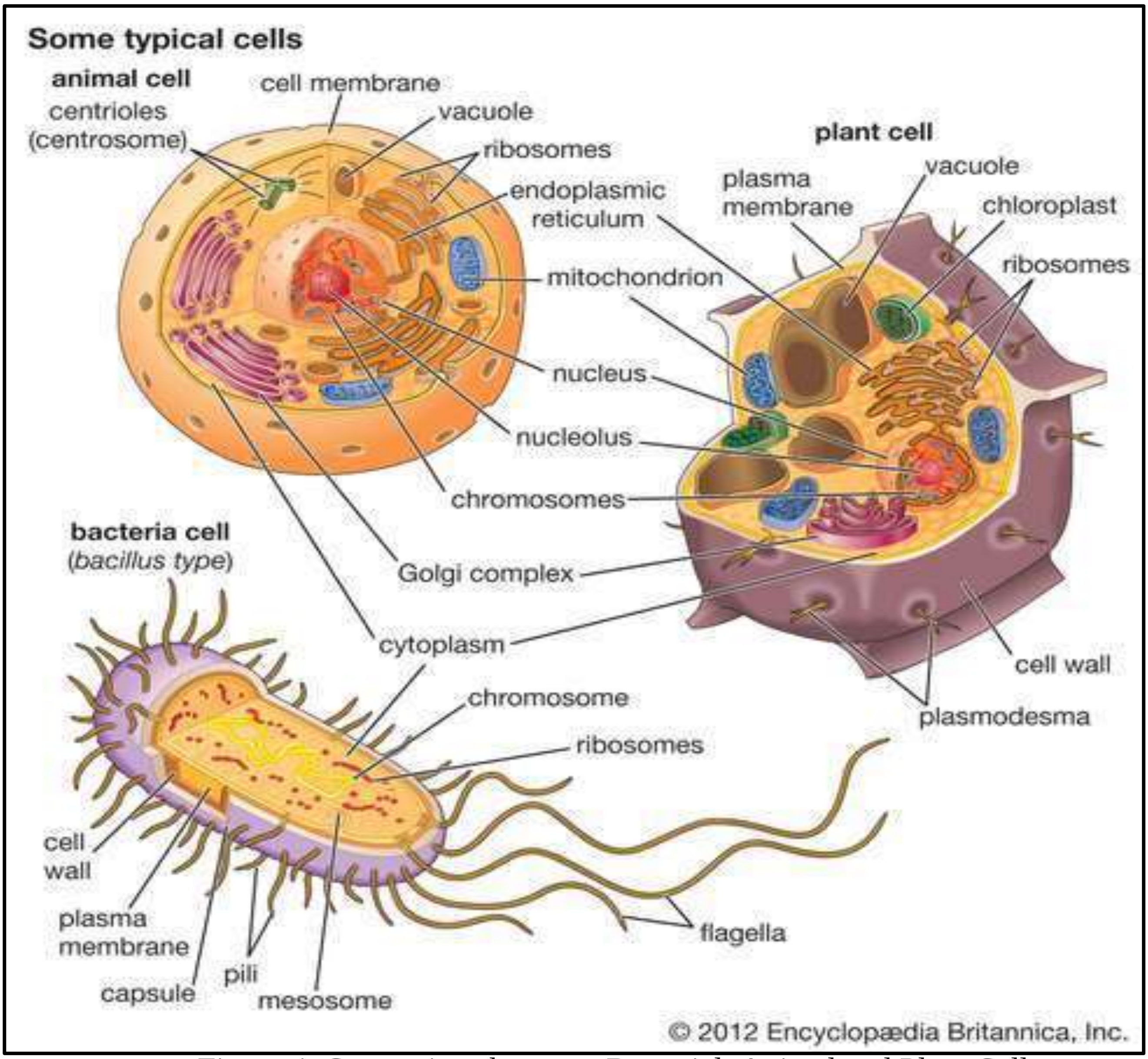


Figure 4: Comparison between Bacterial, Animal and Plant Cells

Lecture 3

Cell Contents

The Plasma Membrane

Despite differences in structure and function, all living cells in multicellular organisms have a surrounding plasma membrane (also known as the cell membrane). As the outer layer of your skin separates your body from its environment, the plasma membrane separates the inner contents of a cell from its exterior environment. The plasma membrane can be described as a phospholipid bilayer with embedded proteins that controls the passage of organic molecules, ions, water, and oxygen into and out of the cell. Wastes (such as carbon dioxide and ammonia) also leave the cell by passing through the membrane.

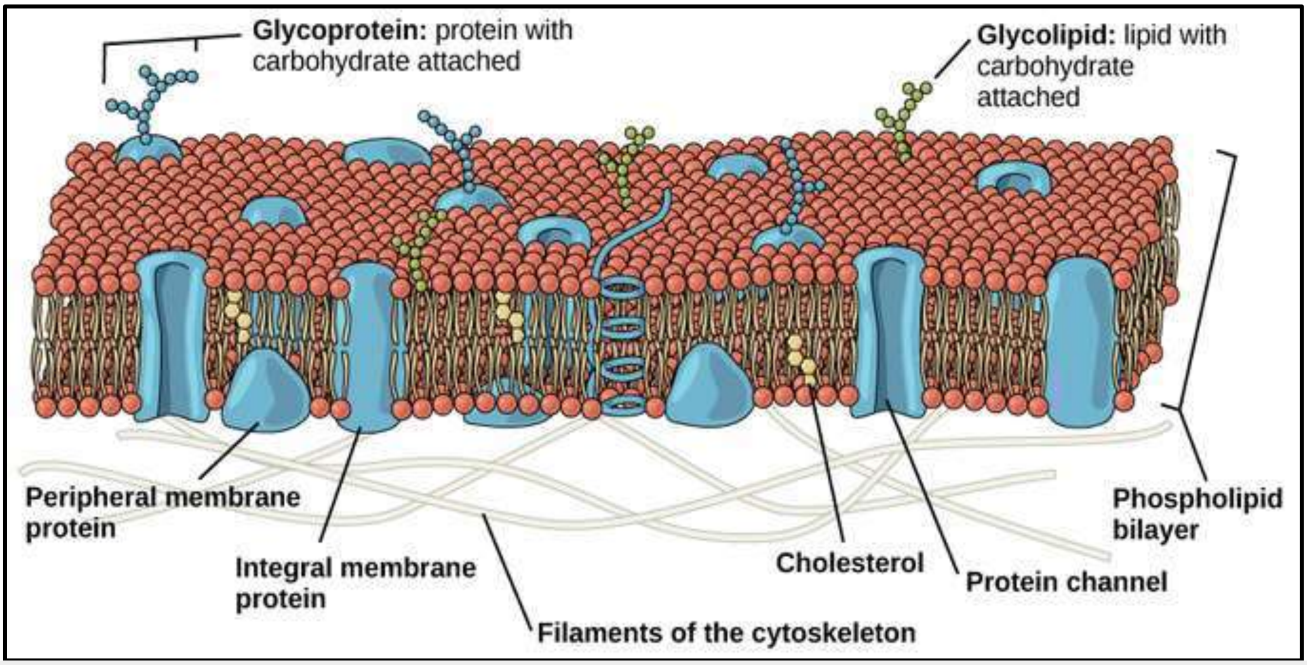


Figure1: Eukaryotic Plasma Membrane: The eukaryotic plasma membrane is a phospholipid bilayer with proteins and cholesterol embedded in it.

The cell membrane is an extremely pliable structure composed primarily of two adjacent sheets of **phospholipids**. Cholesterol, also present, contributes to the fluidity of the membrane. A single phospholipid molecule consists of a polar phosphate "head," which is hydrophilic, and a non-polar lipid “tail,” which is hydrophobic. Unsaturated fatty acids result in kinks in the hydrophobic tails. The phospholipid bilayer consists of two phospholipids arranged tail to tail. The hydrophobic tails associate with one another, forming the interior of the membrane. The polar heads contact the fluid inside and outside of the cell (Figure1).

Cell wall

A **cell wall** is a structural layer surrounding some types of cells, just outside the cell membrane. It can be tough, flexible, and sometimes rigid. It provides the cell with both structural support and protection, and also acts as a filtering mechanism. Cell walls are present in most prokaryotes (except mollicute bacteria), in algae, fungi and eukaryotes including plants but are absent in animals. A major function is to act as pressure vessels, preventing over-expansion of the cell when water enters. The composition of cell walls varies between species and may depend on cell type and developmental stage. The primary cell wall of land plants is composed of the : polysaccharides **cellulose**, hemicelluloses and pectin. Often, other polymers such as lignin, suberin or cutin are anchored to or embedded in plant cell walls. Algae possess cell walls made of glycoproteins and polysaccharides such as carrageenan and agar that are absent from land plants. In bacteria, the cell wall is composed of peptidoglycan.

Cytoplasm

All types of cells contain cytoplasm, which is a semi-fluid medium that contains water and various types of molecules suspended or dissolved in the medium. The presence of proteins accounts for the semi-fluid nature of the cytoplasm. The cytoplasm of a eukaryotic cell contains organelles, internal compartments that have specialized functions. Eukaryotic cells have many types of organelles. Organelles allow for the compartmentalization of the cell. This keeps the various cellular activities separated from one another.

The Nucleus

The **nucleus,** a prominent structure in cells, stores genetic information. Every cell in the body contains the same genes. Genes are segments of DNA that contain information for the production of specific proteins. Each type of cell has certain genes turned on and others turned off. DNA, with RNA acting as an intermediary, specifies the proteins in a cell. Proteins have many functions in cells, and they help determine a cell's specificity (Figure 2).

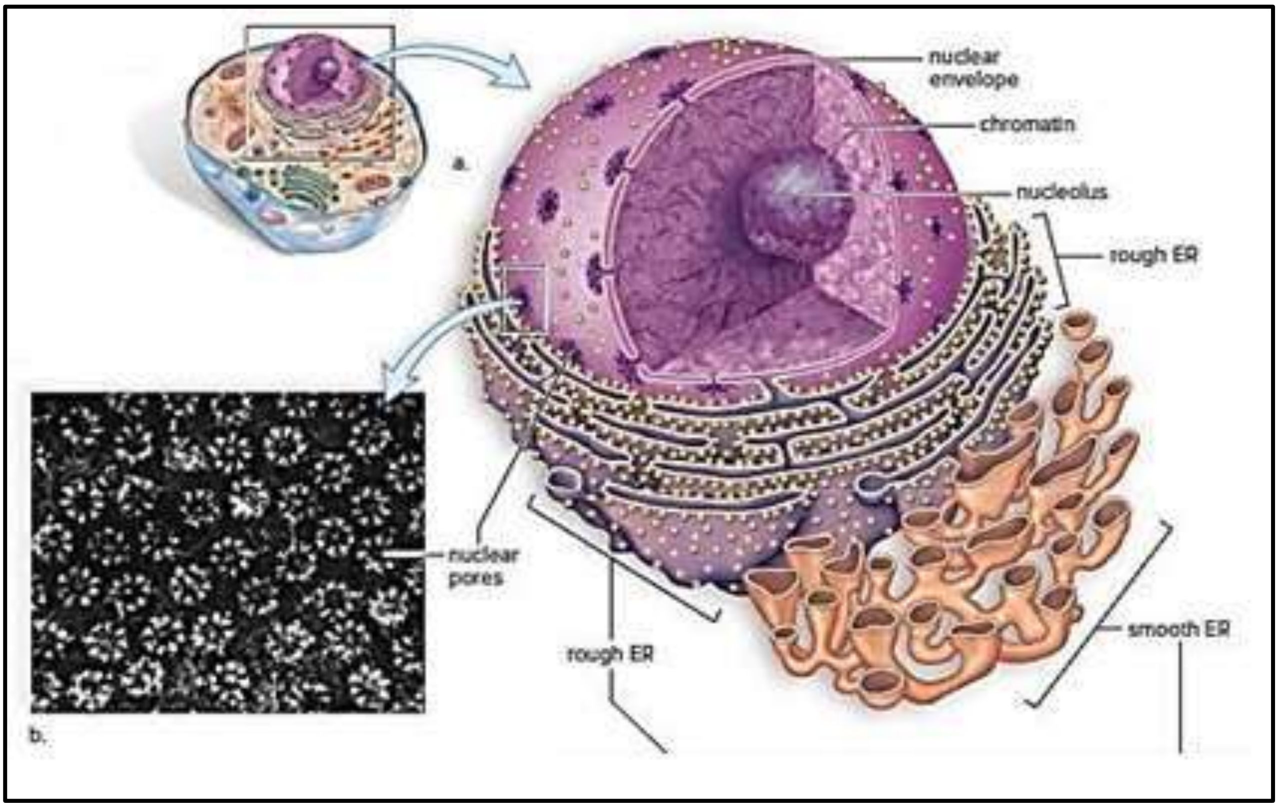


Figure 2: The nucleus and endoplasmic reticulum
a. **Nuleolus, b. nuclear envelope**

Chromatin is the combination of DNA molecules and proteins that make up the **chromosomes.** Chromatin can coil tightly to form visible chromosomes during meiosis (cell division that forms reproductive cells in humans) and mitosis (cell division that duplicates cells). Chromatin is immersed in a semifluid medium called the **nucleoplasm.** There were one or more dark regions of the chromatin, these are nucleoli (sing., **nucleolus**), where ribosomal RNA (rRNA) is produced. This is also where RNA joins with proteins to form the subunits of ribosomes. The nucleus is separated from the cytoplasm by a double membrane known as the **nuclear envelope.** This is continuous with the **endoplasmic reticulum**. The nuclear envelope has **nuclear pores** of sufficient size to permit the passage of ribosomal subunits out of the nucleus and proteins into the nucleus.

Ribosomes

Ribosomes are organelles composed of proteins and rRNA. Protein synthesis occurs at the ribosomes. Ribosomes are often attached to the endoplasmic reticulum; but they also may occur are digested by lysosomal enzymes into simpler subunits that then enter the cytoplasm. In a process called autodigestion, parts of a cell may be broken down by the lysosomes.

Mitochondria

Mitochondria (sing., mitochondrion) are often called the powerhouses of the cell. Just as a powerhouse burns fuel to produce electricity, the mitochondria convert the chemical energy of glucose products into the chemical energy of ATP molecules. In the process, mitochondria use up oxygen and give off carbon dioxide. Therefore, the process of producing ATP is called **cellular respiration.**

The inner membrane is folded to form little shelves called **cristae**. This project into the matrix, an inner space filled with a gel-like fluid (Figure 3). The matrix of a mitochondrion contains enzymes for breaking down glucose products. ATP production then occurs at the cristae. Protein complexes that aid in the conversion of energy are located in an assembly-line fashion on these membranous shelves.

The structure of a mitochondrion supports the hypothesis that mitochondria were originally prokaryotes that became engulfed by a cell. Mitochondria are bound by a double membrane. Mitochondria have their own genes—and they reproduce themselves ATP-ADP Cycle. The ATP resembles that of a rechargeable battery.

and

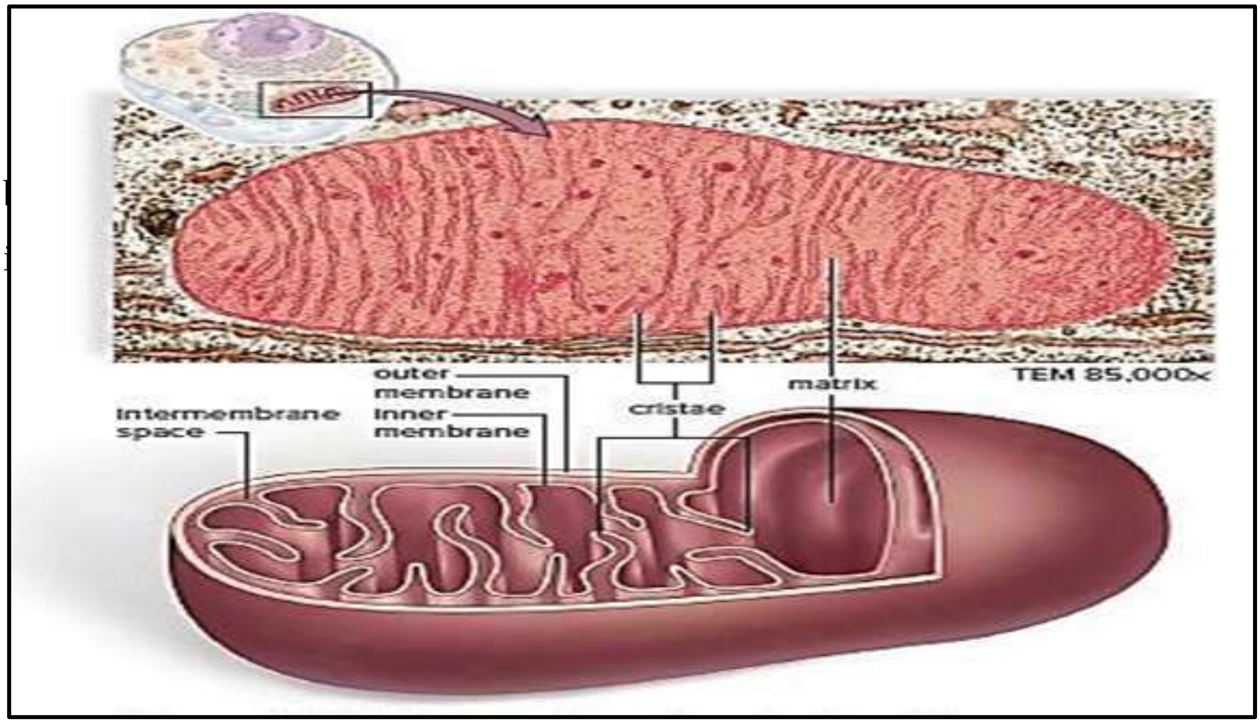


Figure 3: The structure of mitochondria

The Endoplasmic Reticulum

The **endoplasmic reticulum (ER)** has two portions. Rough ER is studded with ribosomes on the side of the membrane that ribosomes enter the interior of the ER for additional processing and modification. Some of these proteins are incorporated into the plasma membrane (for example, channel proteins), whereas others are packed into vesicles and sent to the Golgi apparatus. The smooth ER is continuous with the rough ER, but it does not have attached ribosomes (Figure 4). Smooth ER synthesizes the phospholipids and other lipids that occur in membranes. It also has various other functions, depending on the particular cell.

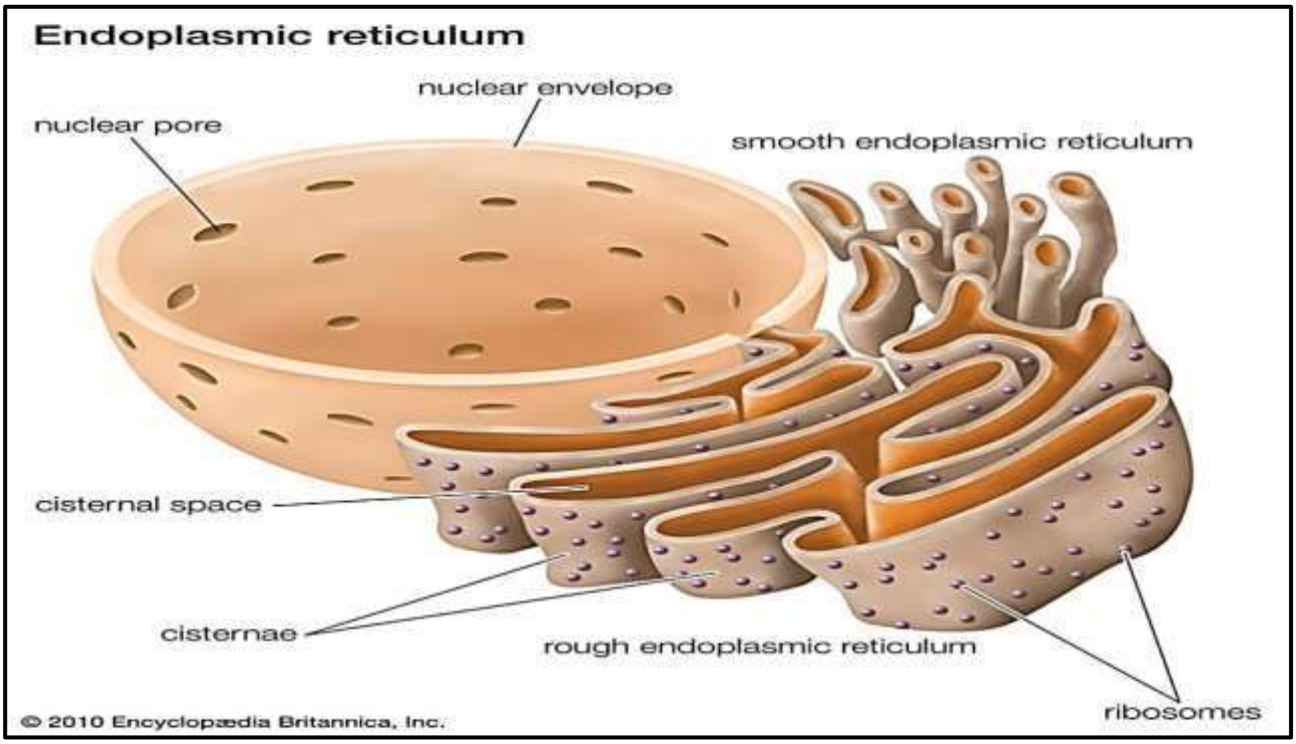


Figure 4: Endoplasmic reticulum

The Golgi apparatus

The **Golgi apparatus** is named for Camillo Golgi, who discovered its presence in cells in 1898. The Golgi apparatus consists of a stack of slightly curved saccules, whose appearance can be compared to a stack of pancakes. Here proteins and lipids received from the ER are modified. The vesicles that leave the Golgi apparatus move to other parts of the cell. Some vesicles proceed to the plasma membrane, where they discharge their contents. In all, the Golgi apparatus is involved in processing, packaging, and secretion.

Lysosomes

Lysosomes, membranous sacs produced by the Golgi apparatus, contain hydrolytic enzymes that can break down many kinds of biomolecules. A lysosome has a specific composition, of both its membrane proteins, and its luminal proteins. The lumen's pH

(~4.5–5.0) is optimal for the enzymes involved in hydrolysis. Lysosomes are found in all cells of the body but are particularly numerous in white blood cells that engulf disease-causing microbes.

Cilia and Flagella

Cilia (sing., **cilium)** and **flagella (**sing., **flagellum)** are involved in movement. The ciliated cells that line our respiratory tract sweep back up the throat the debris trapped within mucus. Similarly, ciliated cells move an egg along the uterine tube, where it may be fertilized by a flagellated sperm cell (Figure 5). Motor molecules, powered by ATP, allow the microtubules in cilia and flagella to interact and bend and, thereby, move.

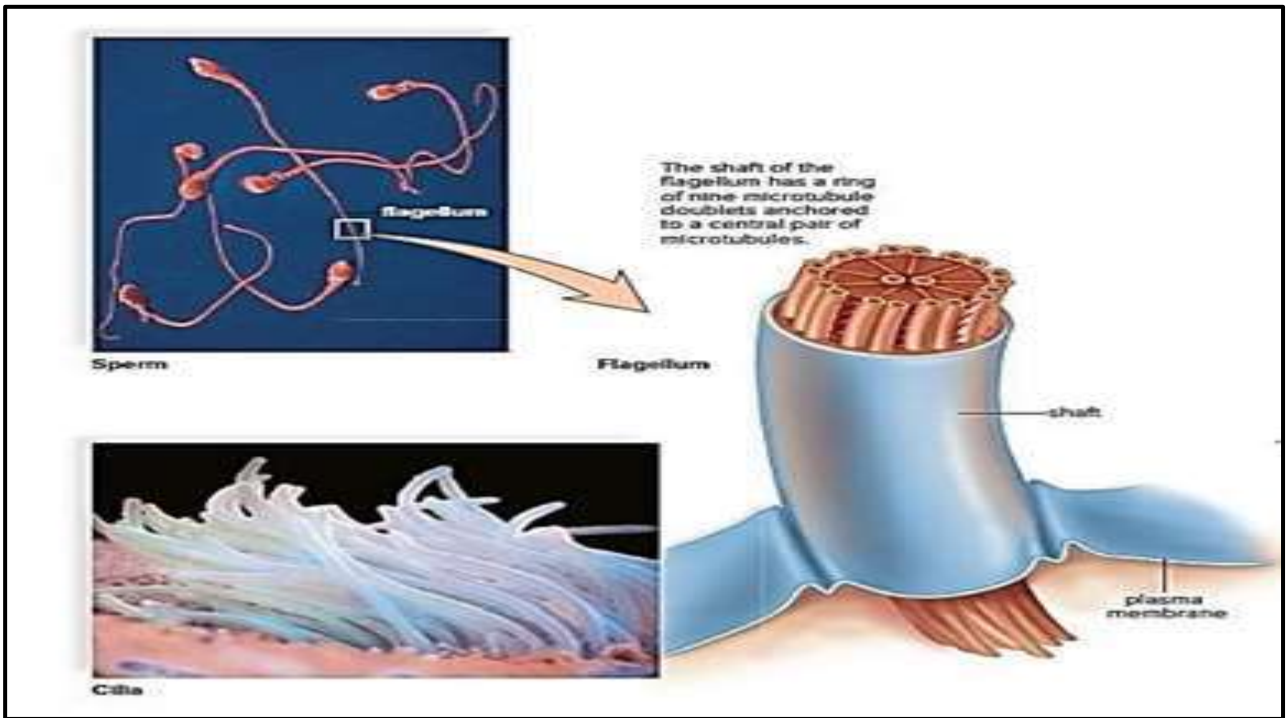


Figure 5: Structure of cilia and flagella

Centriole

In cell biology a **centriole** is a cylindrical organelle composed mainly of a protein called **tubulin**. Centrioles are found in most eukaryotic cells. A bound pair of centrioles, surrounded by a shapeless mass of dense material, called the **pericentriolar material** (PCM), makes up a structure called a **centrosome**. Centrioles are typically made up of nine sets of short microtubule triplets, arranged in a cylinder (figure 4). The main function of centrioles is to produce cilia during interphase and the aster and the spindle during cell division. Centrioles are involved in the organization of the mitotic spindle and in the completion of cytokinesis. The centrioles can self-replicate during cell division. Centrioles are a very important part of centrosomes, which are involved in organizing microtubules in the cytoplasm. The position of the centriole determines the position of the nucleus and plays a crucial role in the spatial arrangement of the cell.

The Cytoskeleton

Movement and Cell Junctions

It took a high-powered electron microscope to discover that the cytoplasm of the cell is containing by several types of protein fibers, called the **cytoskeleton**. The cytoskeleton helps maintain a cell’s shape and either anchors the organelles or assists in their movement, as appropriate. In the cytoskeleton, **microtubules** are much larger than **actin** filaments. Each is a cylinder that contains rows of a protein called **tubulin**. Microtubules help maintain the shape of the cell and act as tracks along which organelles move. During cell division, microtubules form spindle fibers, which assist in the movement of chromosomes.

Actin filaments, made of a protein called actin, are long; extremely thin fibers that usually occur in bundles or other groupings. Actin filaments are involved in movement. Microvilli, which project from certain cells, contain actin filaments.

Intermediate filaments, as their name implies, are intermediate in size between microtubules and actin filaments.

Vacuole

A vacuole is a membrane-bound organelle which is present in all plant and fungal cells and some protist, animal, and bacterial cells. Vacuoles are essentially enclosed compartments which are filled with water containing inorganic and organic molecules including enzymes in solution, though in certain cases they may contain solids which have been engulfed. Vacuoles are formed by the fusion of multiple membrane vesicles and are effectively just larger forms of these. The organelle has no basic shape or size.

Vacuole Functions

The function of vacuoles varies according to the type of cell in which they are present. In general, the functions of the vacuole include:

1) Isolating materials that might be harmful or a threat to the cell.
2) Containing waste products.
3) Containing water in plant cells.
4) Maintaining internal hydrostatic pressure within the cell.
5) Maintaining an acidic internal pH.
6) In protists, vacuoles have the function of storing food which has been absorbed by the organism and assisting in the digestive and waste management process for the cell.

In animal cells, vacuoles assist in processes of exocytosis and endocytosis, (there are some animal cells that do not have any vacuoles).

Lecture 4

The Chemistry of the Cell

Elements of Life

An **element** is one of the basic building blocks of matter; an element cannot be broken down by chemical means. Considering the variety of living and nonliving things in the world, it's remarkable that there are only **92 naturally occurring elements**. It is even **more surprising** that over **90%** of the human body is composed of just **four** elements: **C, N, O**, and **H.** Even so, other elements, such as **iron**, are important to our health. **Iron-deficiency anemia** results when the diet doesn't contain enough iron for the making of hemoglobin.

When the above mentioned and others chemical elements combined in various ways, all known **biomolecules** could be formed. **B**iomolecules can be classified into **micromolecules** and **macromolecules**.

Biological Micromolecules

The **micromolecules** are relatively smaller in size and low molecular weight than one thousand Daltons. The **micromolecules** may occur free in water or can serve as **monomers** join together by bonds to form the **polymers** or the large molecules. The most important micromolecules are **water, minerals, amino acids (**form **protein**s**), sugar such as glucose**, and nucleotides (form **nucleic acids).** The micromolecules act as **substrates for various reactions** and are also the products of **metabolism**.

Water functions as a **universal solvent** in which almost all polar and ionic substances can dissolve. Most of the cellular **metabolic reactions** carried out with the help of water. **Minerals** form only about 1-3% of a cell's composition but they are essential for **cellular activities**.

Minerals like Mg function as **cofactors** in **enzymes**, or they become a component of certain organic compounds, such as: **iron** in **hemoglobin**, **Ca** and **P** in **bones**, and **Mg** in **chlorophyll**. Also, they are essential components of various **biological fluids**.

Biological Macromolecule (Molecules of life)

Proteins, carbohydrates, nucleic acids, and lipids are the four major classes of biological **macromolecules**—large molecules necessary for life that are built from smaller organic molecules. Macromolecules are made up of single units known as **monomers** that are joined by **covalent bonds,** with the release of a water molecule, to form larger **polymers**. These types of reactions are known as **dehydration or condensation reactions**. When polymers are broken down into smaller units (monomers), a molecule of water is used for each bond broken by these reactions; such reactions are known as **hydrolysis reactions**. **Dehydration reactions** typically require an **investment of energy** for new bond formation, while **hydrolysis reactions** typically **release energy** by breaking bonds.

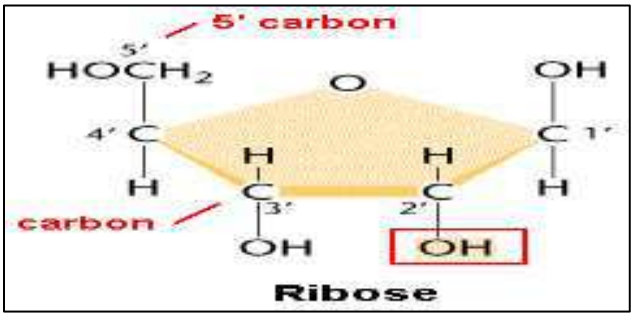
Macromolecule	Monomer	Examples
Proteins	**Amino acids**	**Enzymes, some hormones**
Lipids	**Fatty acid and glycerol**	**Butter, oil, cholesterol, beeswax**
Carbohydrates	**Monosaccharides**	**Glucose, Starch, Glycogen, Cellulose**
Nucleic Acids	**Nucleotides**	**DNA, RNA**

➢ Carbohydrates

Carbohydrates are almost used as an energy source for living organisms, including humans. In some organisms, such as plants and bacteria, carbohydrates have a **structural function**. Carbohydrate molecules all have C, H, and O atoms and the ratio of **H** to O is approximately 2:1.

Simple Carbohydrates: Monosaccharides

Monosaccharides (mono=one; saccharide= sugar) consist of only a single sugar molecule and are commonly called simple sugars. A monosaccharide can have a carbon backbone of three to seven carbons. For example, **pentoses** with **5** carbons (Ribose), and **hexoses** with **6** carbons. The most common monosaccharide, and the one that our bodies use as an immediate source of energy, is the hexose **glucose.**



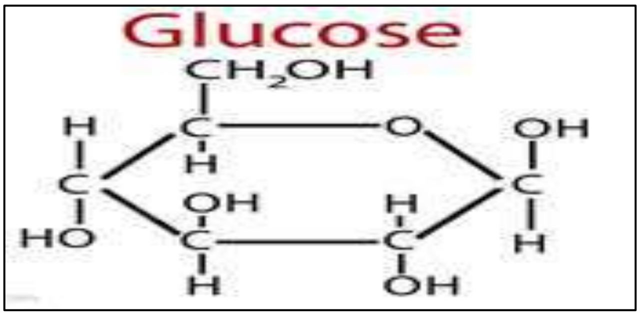
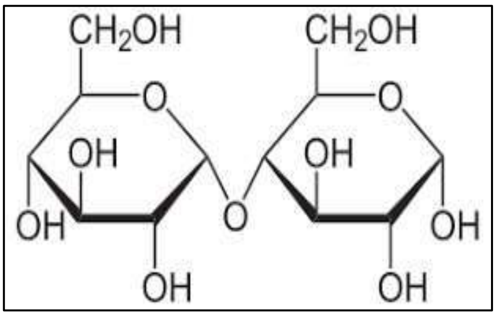


Figure 1: Ribose and Glucose molecule

2-Disaccharides

A disaccharide (di= "two"; saccharide= "sugar") is made by joining only two monosaccharides together. **Maltose** is a disaccharide formed by a dehydration reaction between two glucose molecules (Figure 2). When our hydrolytic digestive juices break down maltose, the result is two glucose molecules. When **glucose and fructose** join, the disaccharide sucrose forms, **Sucrose (**table sugar). You may also have heard of lactose, a disaccharide found in milk. **Lactose** is glucose combined with galactose.

Figure 2: Disaccharide molecules (Maltose)



3-Complex Carbohydrates: Polysaccharides

Starch, glycogen, and **cellulose** are polysaccharides (poly =many) that contain long chains of glucose subunits. The polysaccharides **starch (**in plants such as wheat, potatoes.**)** and **glycogen (in animals)** are **long polymers** of **glucose** (**several 1000s glucose molecules)**. Both starch and glycogen are used to **store glucose** to meet the **energy needs** of the cell. The polysaccharide **cellulose,** commonly called **fiber**, is found in **plant cell walls**. We are **unable to digest foods** containing cellulose; therefore, cellulose largely passes through our digestive tract as fiber, or **roughage**.

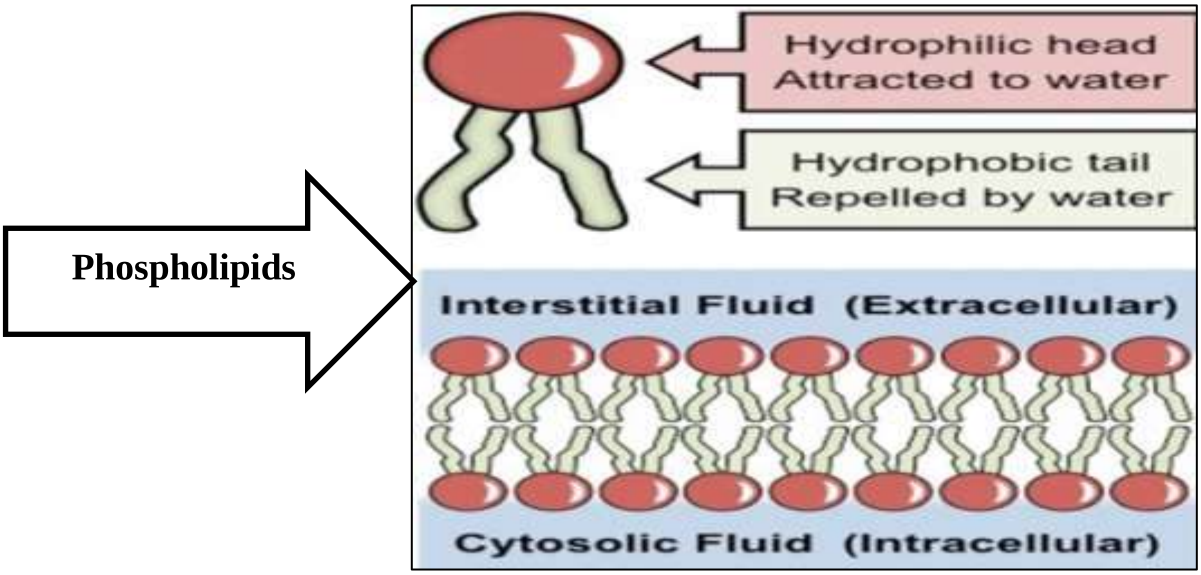
➢ Lipids

Lipids are diverse in structure and function. They do not dissolve in water due to an absence of **hydrophilic polar groups**. They contain little **O**2 and consist mostly of C and **H** atoms. Lipids contain **more energy per gram** than other biological molecules; therefore**, fats** in animals and **oils** in plants function well as energy storage molecules. Four main groups of lipids are known

- Fatty acids (saturated and unsaturated)
- Glycerides (glycerol-containing **lipids- fats and oils**)
- Nonglyceride **lipids** (sphingolipids, steroids, waxes)
- Complex **lipids** (lipoproteins, glycolipids, phospholipids)

Steroids are a large class of lipids that includes the **sex hormones**.

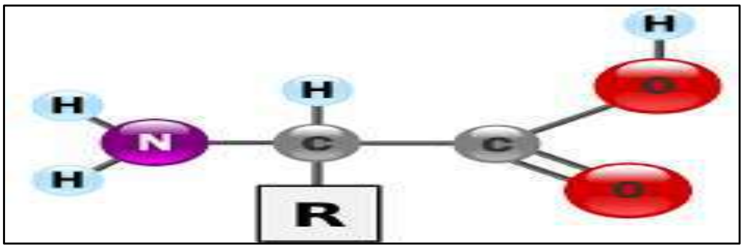
Phospholipids are the primary components of the plasma membranes in cells. They form the polar (**hydrophilic**) head of the molecule, and the rest of the molecule becomes the **nonpolar (hydrophobic)** tails. In a water environment, they spontaneously form a **bilayer** (a sort of molecular "sandwich") in which the hydrophilic heads (the sandwich "bread") face outward toward watery solutions, and the tails (the sandwich "filling") form the **hydrophobic interior**.



➢ Proteins

Proteins are macromolecules with **amino acid** subunits. The c**entral carbon atom** in an amino acid bonds to a **hydrogen atom**, an -NH2 (amino group), a -COOH (carboxyl group, an acid), and the R group (figure below).

The covalent bond between two amino acids is called a **peptide bond**. When three or more amino acids are linked by peptide bonds, the resulted chain is called a **polypeptide**.



Proteins are of primary importance in the **<u>structure and function of cells</u>**. Some of their many functions are listed in the below table:

Protein type	Examples	Functions
Digestive	**Enzymes: mylase, lipase, trypsin**	digestion of food into monomeric units
Transport	**Hemoglobin**	Carry O2 in the blood
Structural	**Actin, tubulin, keratin**	Construct different structures, like the cytoskeleton, hair, nails
Hormones	**Insulin, thyroxine**	Coordinate the activity of different body systems
Defense	**Immunoglobulins**	Protect the body from foreign pathogens
Contractile	**Actin, myosin**	Effect muscle contraction
Storage	**egg white (albumin)**	Provide nourishment in early development of the embryo

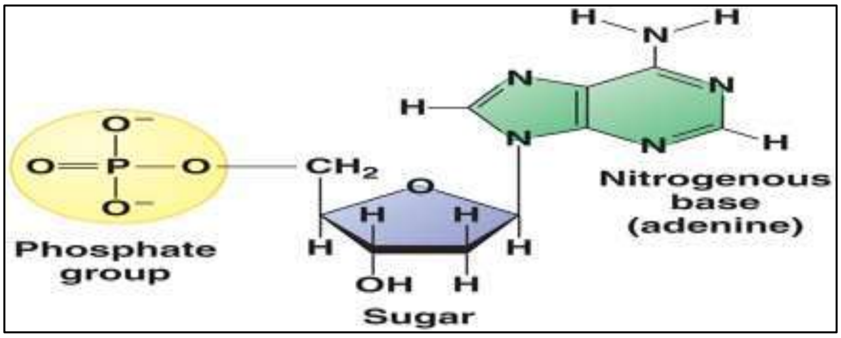
Lecture 5

➢ Nucleic Acids

Nucleic acids (DNA &RNA), which are polymers of **nucleotides,** storage and processing of the genetic information, include instructions for life, and conduct chemical reactions. The general structure of a **nucleotide** is shown in the figure below:

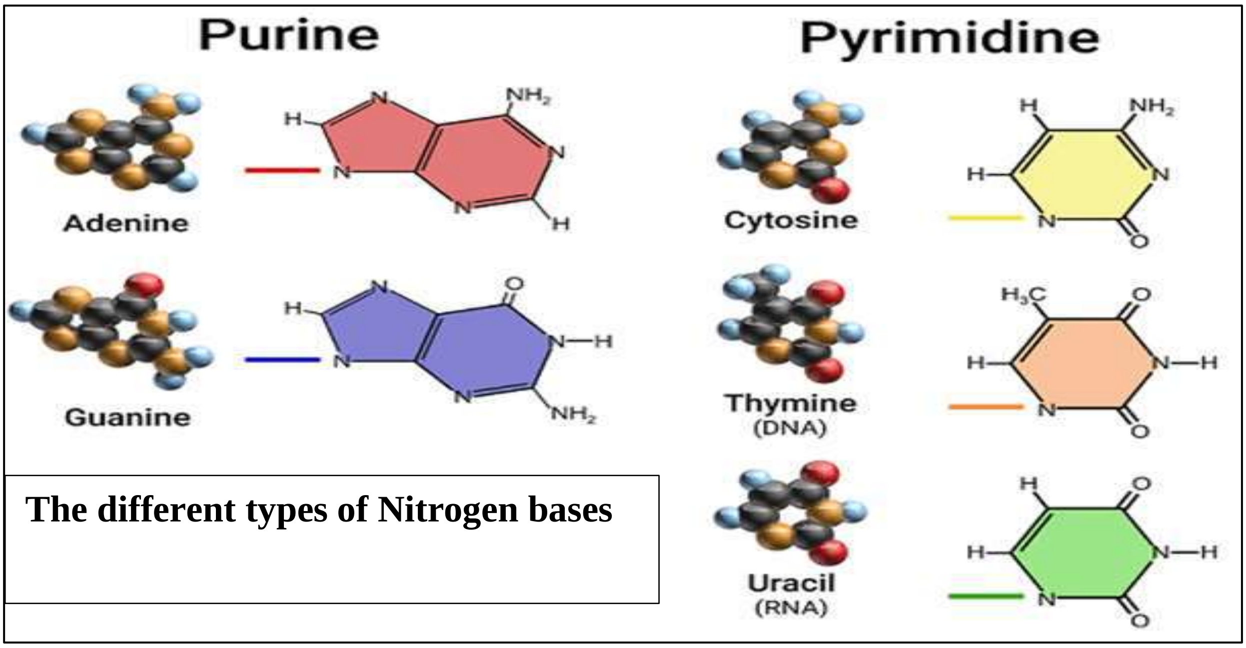
Each **nucleotide** is a molecular complex of three types of subunit molecules **phosphate**, a pentose (5-carbon) **sugar**, and a **nitrogen-containing base**. The nucleotides in DNA contain the **sugar deoxyribose**, and the nucleotides in RNA contain the **sugar ribose**; this difference accounts for their respective names.

Nucleotide's structure



Nitrogen bases are grouped into **two categories**; adenine (A) and guanine (G) constitute the **purine** category, whereas cytosine (C), thymine (T), and uracil (U) form the **pyrimidine** class.

In RNA, the base **uracil (U)** replaces the base thymine. The nucleotides link to make a polynucleotide called a **strand**, which has a backbone made up of **phosphate-sugar-phosphate-sugar**. The bases project to one side of the backbone.



The different types of Nitrogen bases

DNA (deoxyribonucleic acid)

DNA is **double-stranded**, with the two strands **twisted** about each other in the form of a double helix (see figure 2). In DNA the two strands are held together by **hydrogen bonds** between the bases. When coiled, DNA resembles a spiral staircase. When unwound, it resembles a **stepladder**. The uprights (sides) of the ladder are made entirely of **phosphate and sugar molecules**, and the rungs of the ladder exhibit complementary **base pairing**. Thymine (**T**) always pairs with adenine (**A**), and guanine

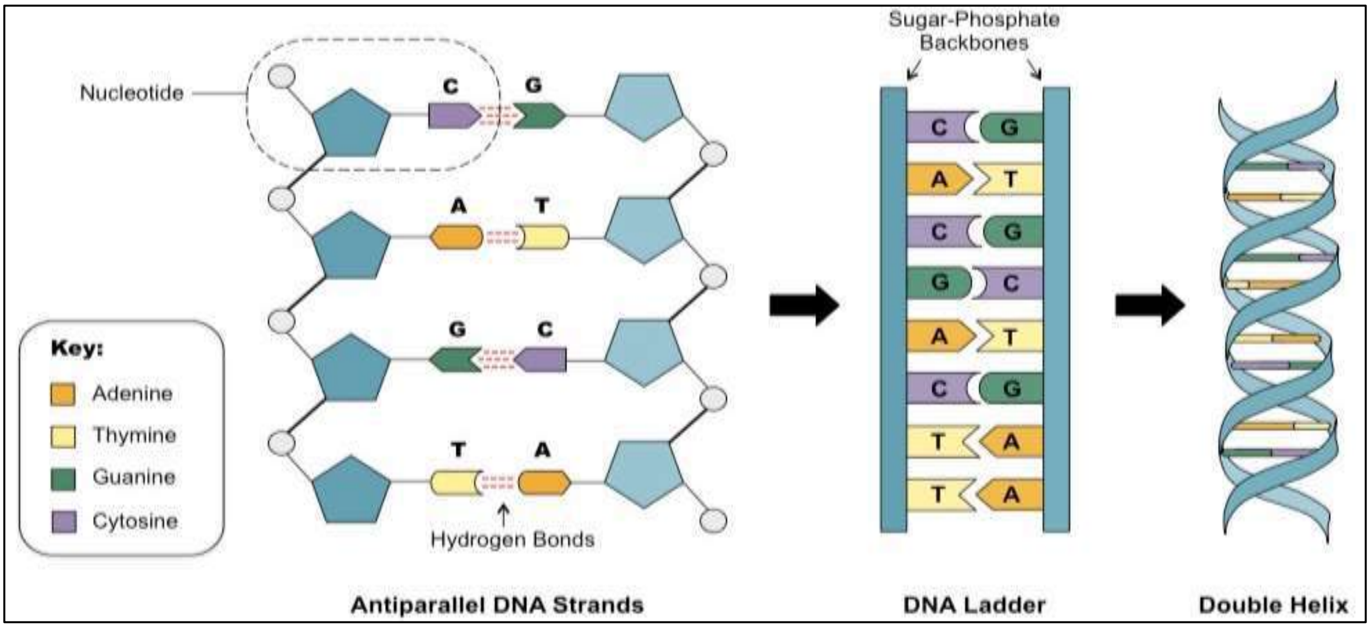


Figure 2: DNA structure

Ribonucleic acid (RNA)

RNA is single-stranded. When RNA forms, complementary base pairing with one DNA strand passes the correct sequence of bases to RNA. RNA is the nucleic acid directly involved in **protein synthesis**. **RNA** is a diverse type of nucleic acid that has multiple uses, RNA main types contains:

1-**Messenger RNA (mRNA)** is a temporary copy of a gene in the DNA that specifies what the amino acid sequence will be during the process of protein synthesis.

2-**Transfer RNA (tRNA)** is also necessary in **synthesizing proteins** and helps translate the sequence of nucleic acids in a gene into the correct sequence of amino acid during protein synthesis.

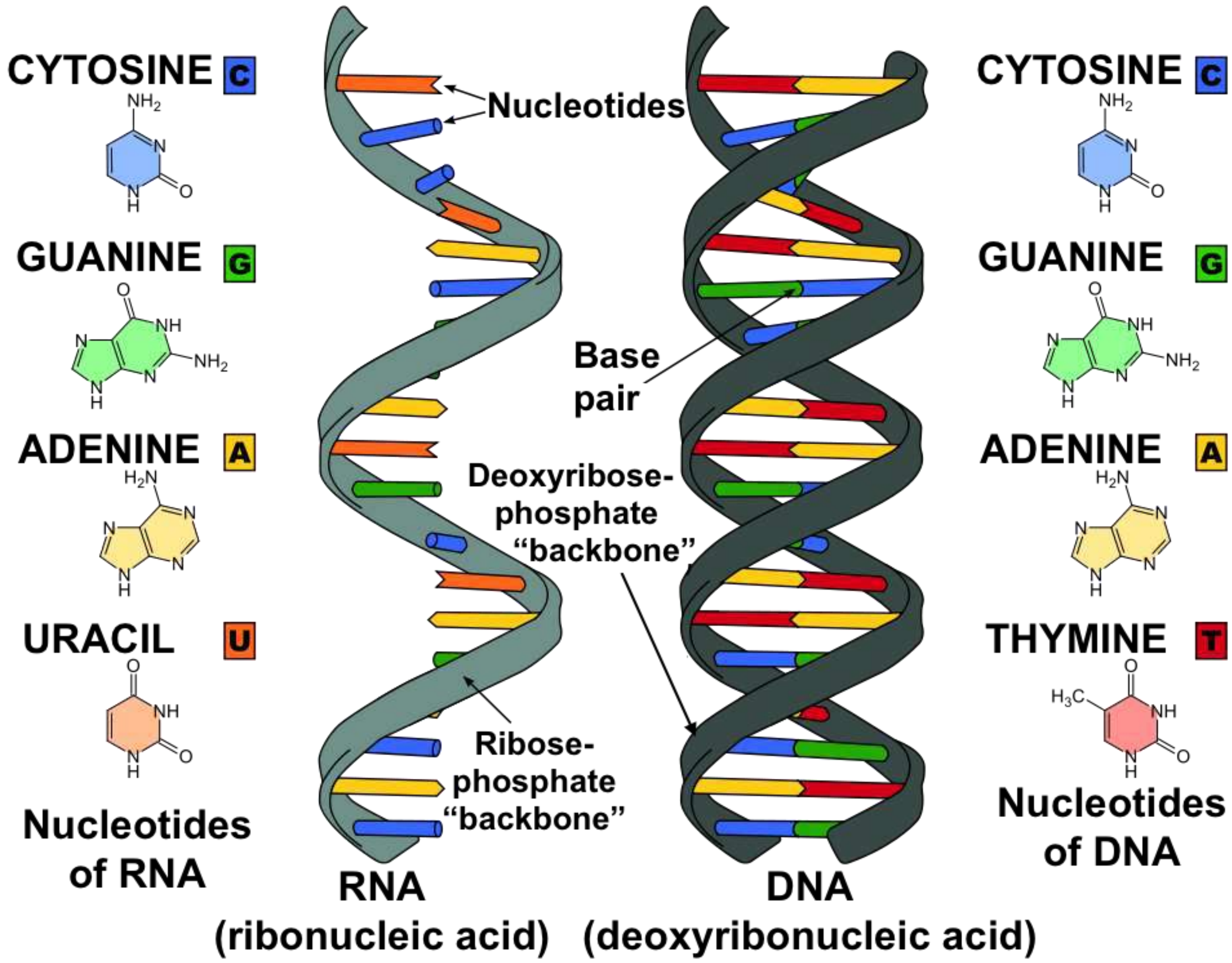
3-**Ribosomal RNA (rRNA)** is the RNA component of the ribosome, it works as an enzyme to form the peptide bonds between amino acids in a polypeptide.

Not all nucleotides are made into DNA or RNA polymers. Some nucleotides are directly involved in **metabolic functions in cells**. For example, **ATP (adenosine triphosphate)** is a nucleotide that stores large amounts of energy needed for synthetic reactions and for various other energy-requiring processes in cells.

Differences in the Structures of DNA and RNA

There are some small differences in the types of **subunits each contains** and in their final structure. These differences give DNA and RNA their unique functions in the body.

Features	**DNA**	**RNA**
Sugar	Deoxyribose Ribose	Ribose
Bases	Adenine, guanine, thymine, cytosine	Adenine, guanine, uracil, cytosine
Strands	Double-stranded with base pairing	Single-stranded
Helix	Yes	No


CYTOSINE C
NH2
N
N
H
O
GUANINE G
O
NH
N
NH2
N
N
H
ADENINE A
H2N
N
N
N
N
H
URACIL U
O
NH
N
H
O
Nucleotides of RNA
Nucleotides
Base pair
Deoxyribose-phosphate "backbone"
Ribose-phosphate "backbone"
RNA (ribonucleic acid)
DNA (deoxyribonucleic acid)
CYTOSINE C
GUANINE G
ADENINE A
THYMINE T
H3C
Nucleotides of DNA

Lecture 6

Membrane transport mechanisms

All types of cells (animal, plant, prokaryotic and fungi) surrounded by plasma membrane (cell membrane). [1]The primary function of the plasma membrane is to protect the cell from its surroundings. Plasma membrane is **selectively permeable** which means it [2]allows certain molecules-but not others-to enter the cell. Plasma membrane is composed of a phospholipid bilayer with embedded **proteins**. Proteins scattered throughout the plasma membrane (**integral proteins + peripheral proteins**) play important roles in allowing substances to enter the cell. **Carbohydrates** also attached to the outer surface of the cell membrane (**glycoproteins & glycolipids**). The function of the plasma membrane is necessary to the life of the cell and regulates the movement of ions, organic molecules and substances in and out of cells.

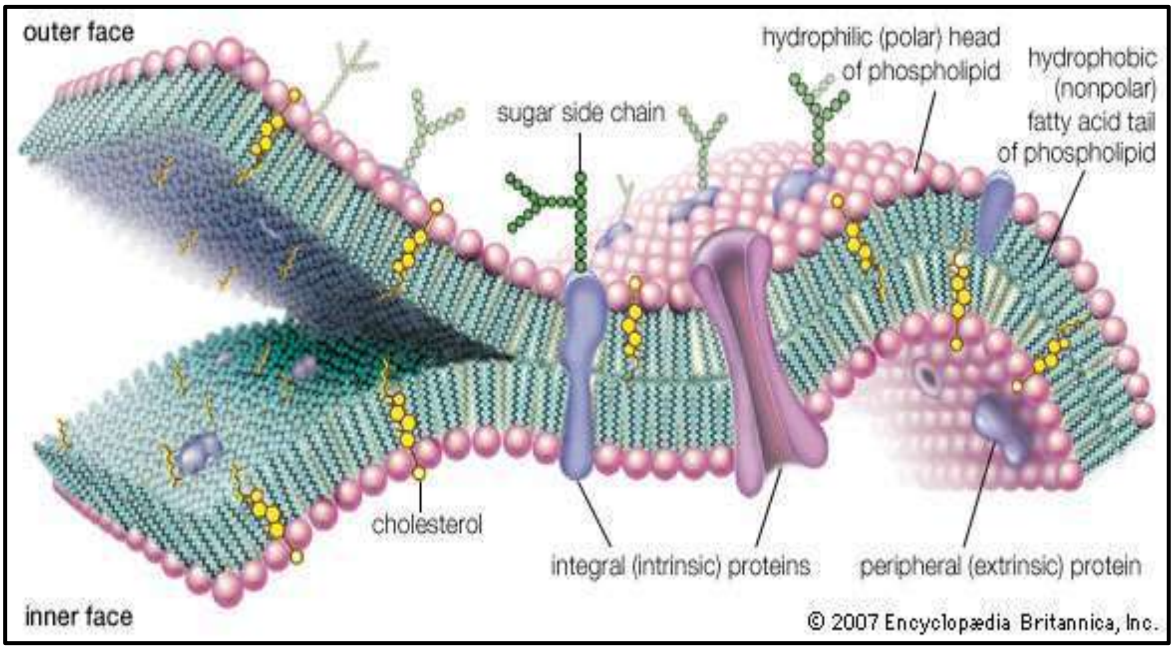


Figure 1: Cell membrane

Living cells are continuously taking in of nutrients and expelling of wastes. All of these essential cellular activities usually done through the cell membrane by two fundamental process: **passive transport** and **active transport**. **Passive transport** is a type of membrane **transport** that does not require energy to move substances across cell membranes. In **passive transport**, substances move from an area of **higher** concentration to an area of **lower** concentration in a process called diffusion.

1-Simple diffusion

Diffusion is the random movement of molecules from an area of <u>higher concentration to an area of lower concentration</u>, <u>until they are equally distributed</u>. Diffusion is a passive way with **no cellular energy is needed** (Figure 2). Oxygen diffuses across the plasma membrane, and the net movement is toward the inside of the cell. This is because a cell uses oxygen when it produces ATP molecules for energy purposes.

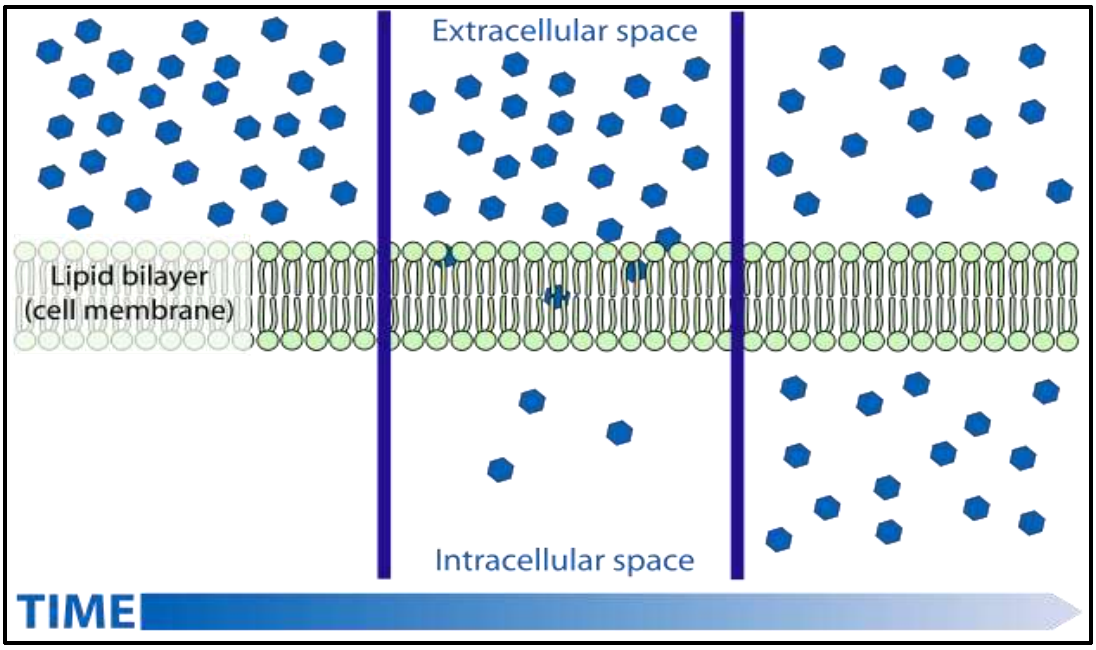


Figure 2: Simple diffusion

2- Facilitated Transport

Many solutes do not simply diffuse across a plasma membrane. They are transported by means of protein carriers within the membrane. During **facilitated transport,** a molecule is transported across the plasma membrane from the side of higher concentration to the side of lower concentration. This is a passive means of transport because the cell does not need to expend energy to move a substance down its concentration gradient. Each **carrier protein**, sometimes called a transporter, binds only to a particular molecule, such as glucose.

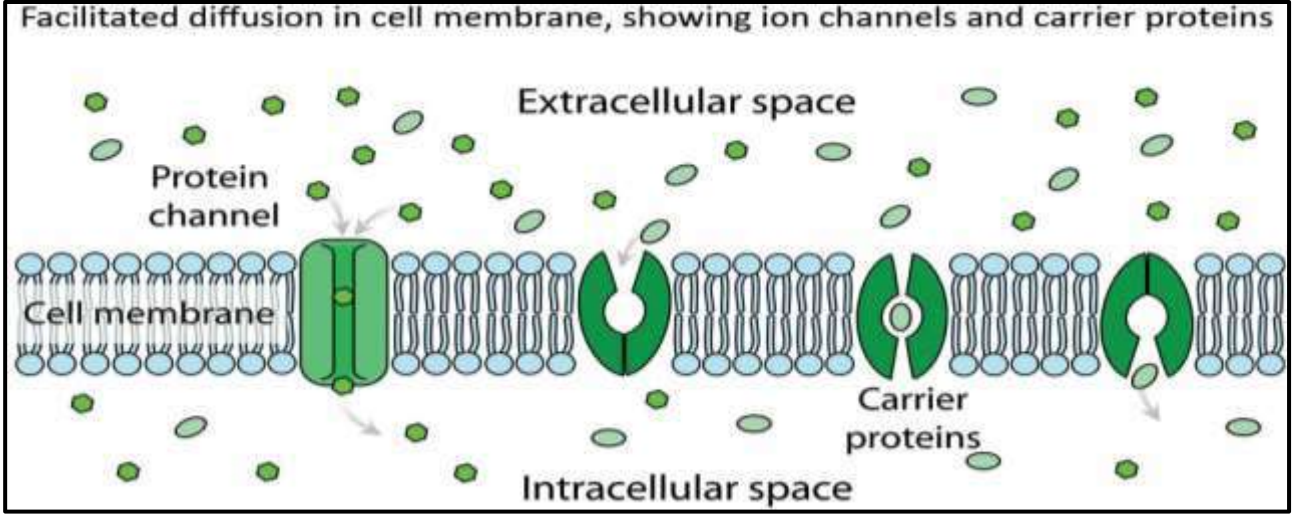


Figure 3: Facilitated Transport

3- Osmosis

Osmosis is the net movement of water across a semipermeable membrane, from an area of higher concentration to an area of lower concentration. Water tends to flow from the area that has **less solute** (and therefore more water) to the area with more solute (and therefore less water). Normally, body fluids are **isotonic to cells** which means the same concentration of non-diffusible solutes and water on both sides of the plasma membrane. Therefore, cells maintain their normal size and shape. **Intravenous solutions** given in medical situations are usually isotonic (Figure 4).

Solutions that cause cells to swell or even to burst due to an intake of water are said to be **hypotonic**. A hypotonic solution has a lower concentration of solute and higher concentration of water than the cells. If red blood cells are placed in a hypotonic solution, water enters the cells. They swell to bursting. Lysis is used to refer to the process of bursting cells. Bursting of red blood cells is termed hemolysis.

Solutions that cause cells to shrink or shrivel due to loss of water are said to be **hypertonic**. A hypertonic solution has a higher concentration of solute and lower concentration of water than do the cells. If red blood cells are placed in a hypertonic solution, water leaves the cells; they shrink. These changes have occurred due to osmotic pressure which control water movement in our bodies. For example, in the small and large intestines, osmotic pressure allows us to absorb the water in food and drink. In the kidneys, osmotic pressure controls water absorption as well.

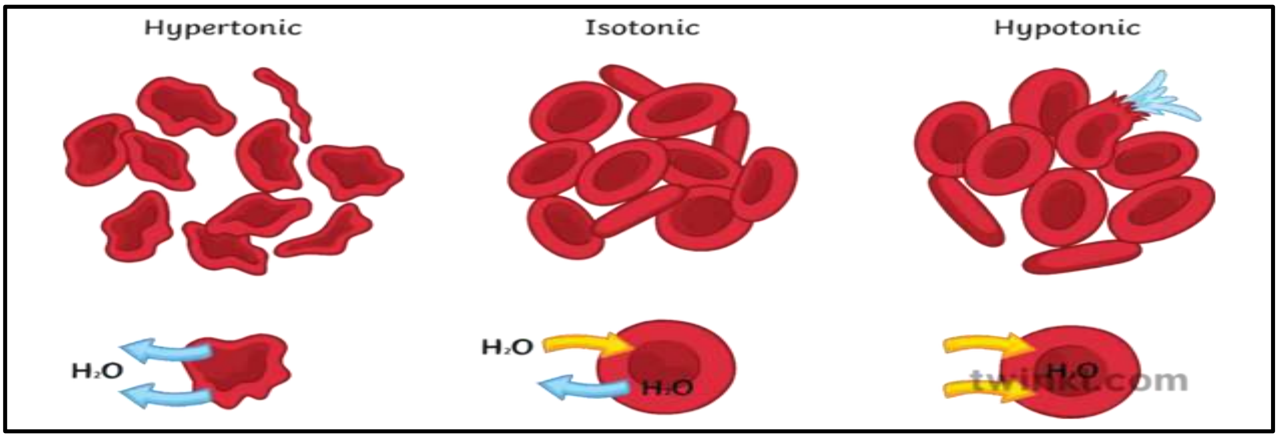


Figure 4: Osmosis

4- Active Transport

During **active transport,** a molecule is moving from a lower to higher concentration. One example is the digestive tract; sugar is completely absorbed from the gut by cells that line the intestines. Active transport requires a protein carrier and the use of cellular energy obtained from the breakdown of ATP. When ATP is broken down, energy is released. In this case, the energy is used to carry out active transport. Proteins involved in active transport often are called protein **pumps**.

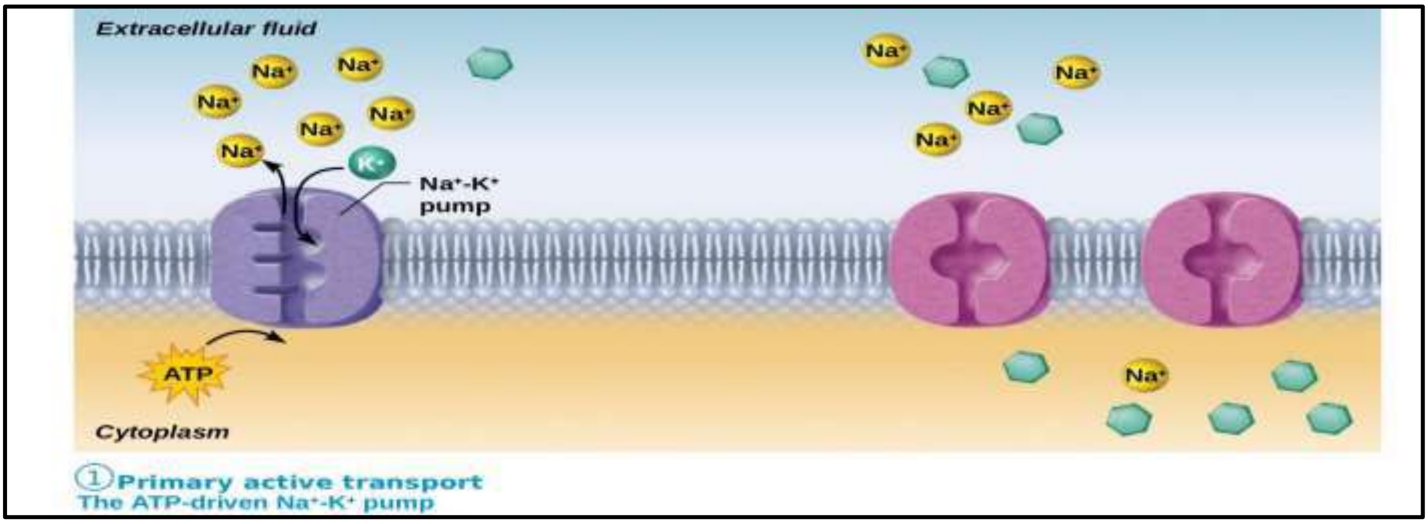


Figure 5: Active Transport

5-Endocytosis and Exocytosis

During endocytosis, a portion of the plasma membrane invaginates, or forms a pouch, to envelop a substance and fluid. Then the membrane pinches off to form an endocytic vesicle inside the cell (Figure 6). Some white blood cells are able to take up pathogens (disease-causing agents) by endocytosis. Here the process is given a special name: **phagocytosis.** Usually, cells take up molecules and fluid, and then the process is called **pinocytosis**. During exocytosis, a vesicle fuses with the plasma membrane as secretion occurs. This is the way that signaling molecules, called neurotransmitters, leave one nerve cell to excite the next nerve cell or a muscle cell.

Receptor-mediated endocytosis is targeted versions of endocytosis where **receptor** proteins in the plasma membrane ensure only specific, targeted substances are brought into the cell.

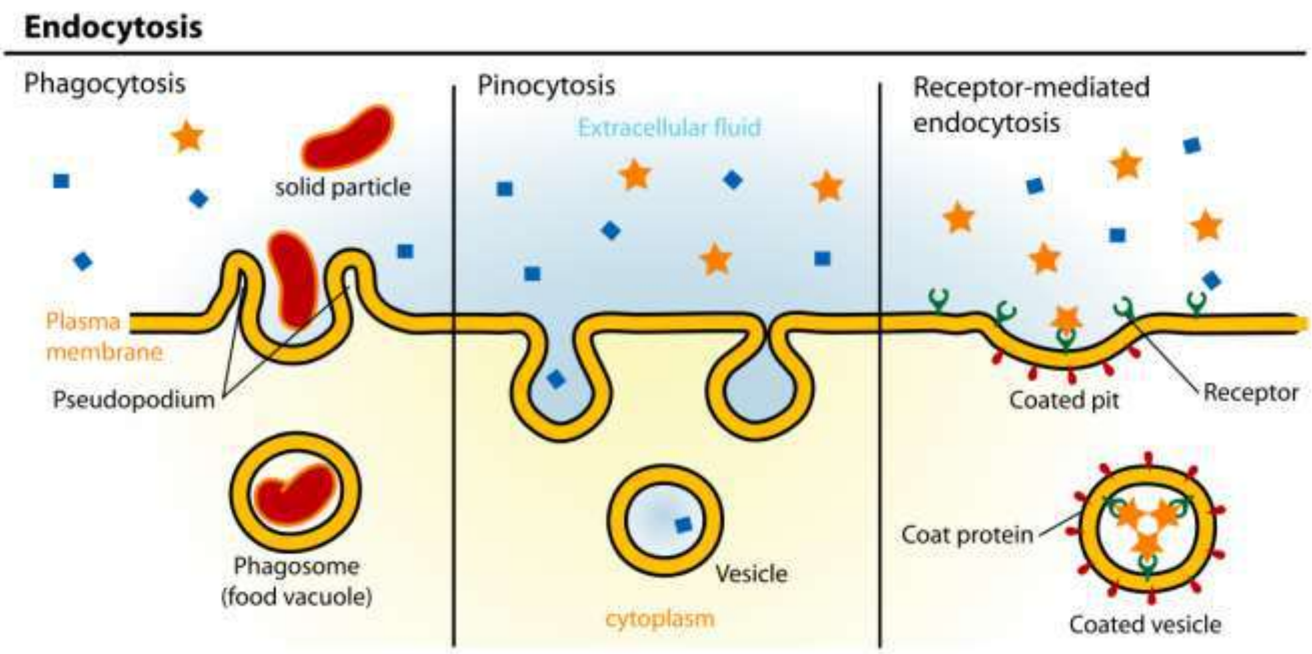


Figure 6: Endocytosis and Exocytosis

Cellular Communication

In a multicellular organism, things are much more complicated. Cells must interpret the multitude of **signals** they receive from other cells to help coordinate their behaviors. The signals that pass between living cells are simpler than the sorts of messages that humans ordinarily exchange. In a typical communication between cells, the **signaling cell** produces a particular type of **signal molecule** that is detected by the **target cell**. As in human conversation, most animal cells both send and receive signals, and they can therefore act as **both signaling cells and target cells**. Target cells possess **receptor proteins** that recognize and respond specifically to the signal molecule. **Signal transduction** begins when the receptor protein on a target cell receives an incoming extracellular signal and converts it to the intracellular signals that alter cell behavior. Cells in multicellular organisms use hundreds of kinds of extracellular molecules to send signals to one another. **The signal molecules** can be **proteins**, **peptides**, **amino acids**, **nucleotides**, **steroids**, **fatty acid derivatives**, or even **dissolved gases.**

Lecture 7

Energy-releasing pathways (cellular respiration)

Cells manage a wide range of functions in their tiny package — growing, moving, housekeeping, and so on — and most of those functions require energy. Energy-releasing pathways are set of metabolic reactions and processes in which the energy in glucose is transferred to ATP(**A**denosine **T**riphos**p**hate). These processes are summarized in the by the below equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy (36ATP)}$$

Energy-releasing pathway (also call **cellular respiration**) is a collection of three unique metabolic pathways: **glycolysis**, the **citric acid cycle**, and the **electron transport chain**. Glycolysis is an anaerobic process, while the other two pathways are aerobic. In order to move from glycolysis to the citric acid cycle, pyruvate molecules (the output of glycolysis) must be oxidized in a process called pyruvate oxidation.

Glycolysis

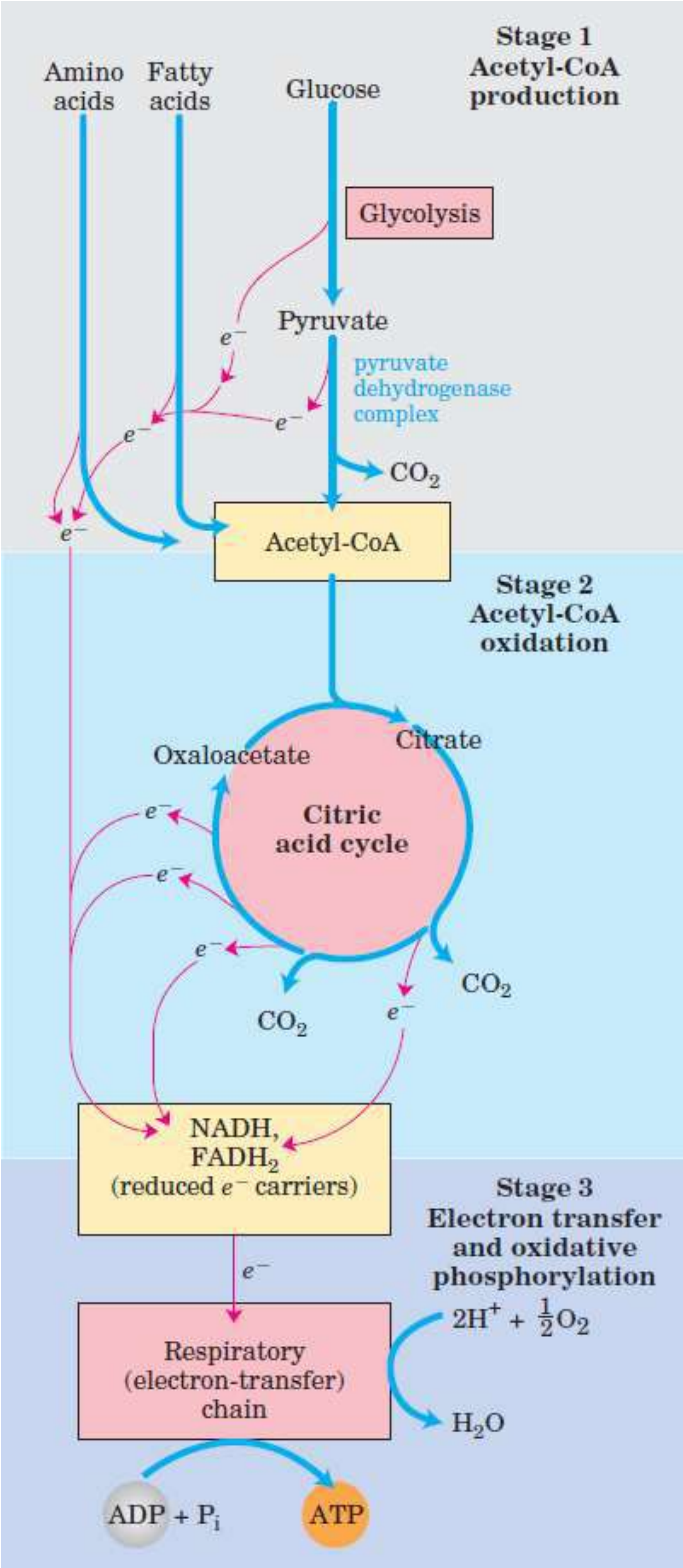
Glycolysis is the first pathway in cellular respiration. This pathway is anaerobic and takes place in the cytoplasm of the cell. This pathway breaks down [1] **glucose molecule** and produces [2] **pyruvate molecules**. Glycolysis has a **net gain** of 2 ATP molecules and 2 NADH. If O2 is available, pyruvate inters the **mitochondria**, where it is metabolized. If O2 is not available, **fermentation** occurs.

Pyruvate Oxidation

In eukaryotes, pyruvate oxidation takes place in the mitochondria. Pyruvate oxidation can only happen if oxygen is available. In this process, the pyruvate created by glycolysis is oxidized. In this oxidation process, a carboxyl group is removed from pyruvate, creating acetyl groups, which compound with coenzyme A (CoA) to form acetyl CoA. This process also releases CO_2.

Citric Acid Cycle (Krebs cycle)

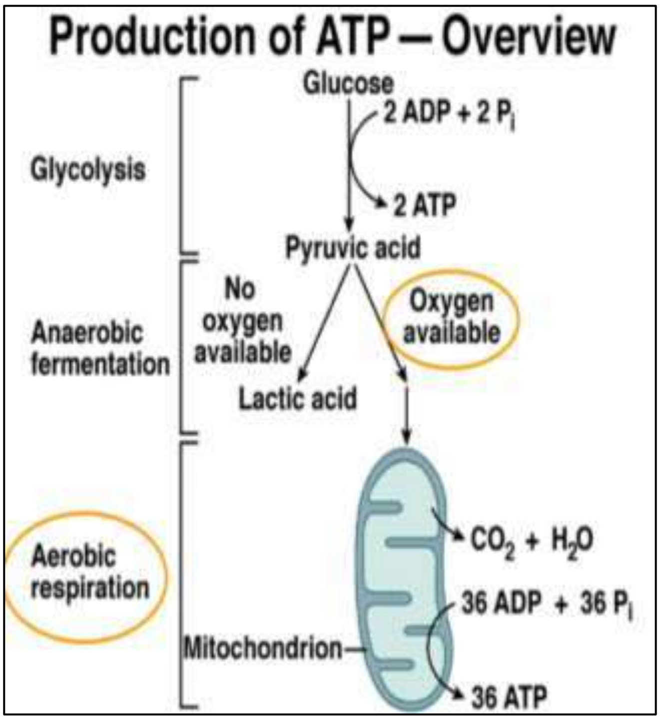
The citric acid cycle is the second pathway in cellular respiration, and it also takes place in the **mitochondria**. The citric acid cycle is considered an **aerobic pathway** because the NADH and $FADH_2$ it produces act as temporary electron storage compounds, transferring their electrons to the next pathway (electron transport chain), which uses atmospheric oxygen. Each turn of the citric acid cycle provides a **net gain** of CO_2, 1 GTP or ATP, and 3 NADH and 1 $FADH_2$.



Electron Transport Chain

Most ATP from glucose is generated in the electron transport chain. It is the only part of cellular respiration that directly consumes oxygen. In eukaryotes, this pathway takes place in the **inner mitochondrial membrane**. In prokaryotes it occurs in the **plasma membrane (Figure 7)**.

The electrons received from NADH and FADH2 are passed down through a chain of carriers until they finally received O_2, which combined with H^+ to produce water. As the electrons pass down the chain, energy is captured and stored for the ATP production.



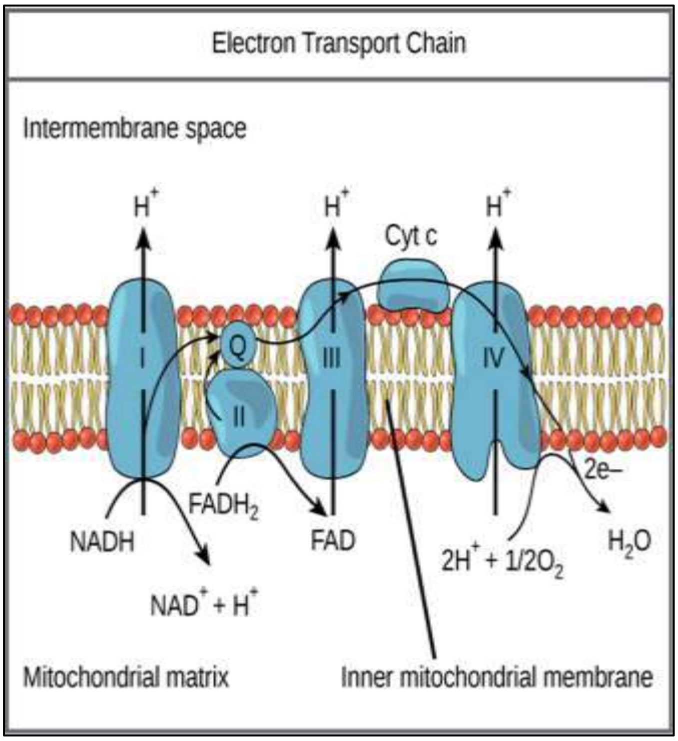


Figure 7: Cellular respiration

Lecture 8

Cell cycle

Cellular division through repeated cell cycles ensures the development of a single fertilized egg into the more than 1013 cells of the human body and the multiplication of a single bacterium into a colony consisting of millions of daughter cells during an overnight incubation. The cellular events that occur in sequence from one cell division to another are referred to as **cell cycle** (Figure1). Many variations exist in the overall duration of cell cycles depending on the cell type and the requirement of the organism.

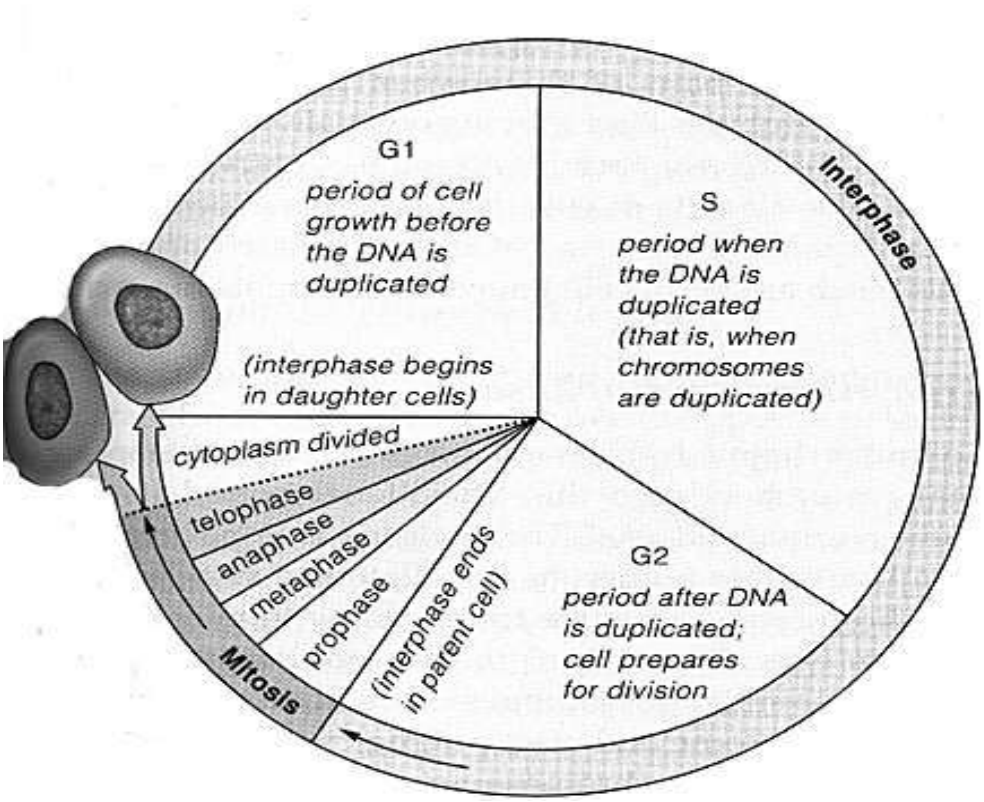


Figure 1: Phases of a Cell Cycle

A typical Eukaryotic cell cycle comprises of the following phases:

G0 Phase

This phase is also known as the ‘resting phase’. In this phase the cell is described as being quiescent, as it is neither growing nor dividing but metabolically active.

G1 (gap 1) Phase

This is also known as the growth phase. It is the most variable phase of the cell cycle in terms of length. In the G1 phase, the cell rapidly grows in size and is metabolically active with profound protein synthesis occurring. Duplication of organelles occurs, proteins (enzymes) required for DNA replication is synthesized and sufficient mitochondria are produced for the energy requirement of the next phase.

S Phase

The S phase is also known as the synthesis phase. The cell in this phase is in a low metabolic state and the major activity of the cell centers around the DNA/Genome duplication. The duplication of the DNA is necessary for the distribution of the complete of the DNA to the daughter cells ensuring that the daughter cells have genes exactly similar to the parent cells.

G2 (Gap 2) Phase

In this phase, cellular growth continues as in G1. The proteins required for the next phase (M phase) are synthesized.

M Phase

This is also called Mitosis phase. Cell division through the distribution and transfer of the earlier duplicated chromosomes into daughter cells occurs in this phase. It is usually the shortest and last for about an hour for a typical 24 hours' cycle. M phase is usually followed by cytokinesis usually after the movement of the divided chromosomes to the opposite poles by the spindle fiber.

Cytokinesis

Cytokinesis results in the cell undergoing cell cycle to be divided into two daughter cells; it involves the division of the cytoplasm. In some cycles the M phase is not followed by cytokinesis resulting in the attachment of the repeatedly formed daughter cells.

Mitotic Cell Division

The mitotic cell division is critical to some single-cell organisms such as protozoan, some fungi and algae as it is the basis for their reproduction (asexual), an in all eukaryotic organisms as it is the basis for their growth. In eukaryotic organisms, it typically occurs in the somatic cells (non-sex cells).

There are five stages in mitosis (Figure 2) which are as follows:

Interphase

Interphase divide three stages; G1, S and G2. Chromosome replication takes place in interphase. During interphase the individual chromosomes are elongated and are difficult to see under the light microscope. The DNA of each chromosome is replicated in the S phase, giving two exact copies called sister chromatids, which are held together by the replicated but unseparated centromeres.

1-Prophase

During this stage the chromosomes become visible as threads because they condense more. This is followed by progressing coiling and folding. Each prophase chromosome now consists of two adjacent chromosome threads called chromatids. The nucleolus breaks down and disappears. Electron microscopic studies have shown that the component parts of the nucleolus disperse throughout the nucleus during this stage.

At the end of prophase, the nuclear envelope breaks down into fragments. This allows the chromosomes to spread over the greater part of the cell and gives them a better chance to separate as chromatids during pole ward movement.

2- Metaphase

At metaphase the chromosomes are at their highest level of coiling and therefore appear to be shorter and thicker than in any other stage. The chromosomes move to the equator of the cell. With the attachment of the spindle fibers and the completion of the spindle itself, the chromosomes move into position in the equatorial plane of the spindle called Metaphase Plate. Alignment of the chromosomes on this plate marks the end of metaphase.

3-Anaphase

This is a stage of active and rapid movement and is the shortest of all mitotic stages. During this stage, the sister chromatid separate and move towards the opposite poles on the spindle. The physical separation of the sister chromatids and their movement to opposite poles are two separate activities.

4- Telophase

At the end of anaphase, the separated sister chromatids have been pulled to opposite poles of the cell. At that time the nuclear envelope reforms around the two daughter nuclei, the nucleoli form at the distinct site of the nuclear organizer chromosomes, and the chromosomes fuse into an indistinguishable mass of chromatin. The uncoiling of the chromatin threads aid in this process of reforming an interphase nucleus where the chromosomes lose their density and stain ability.

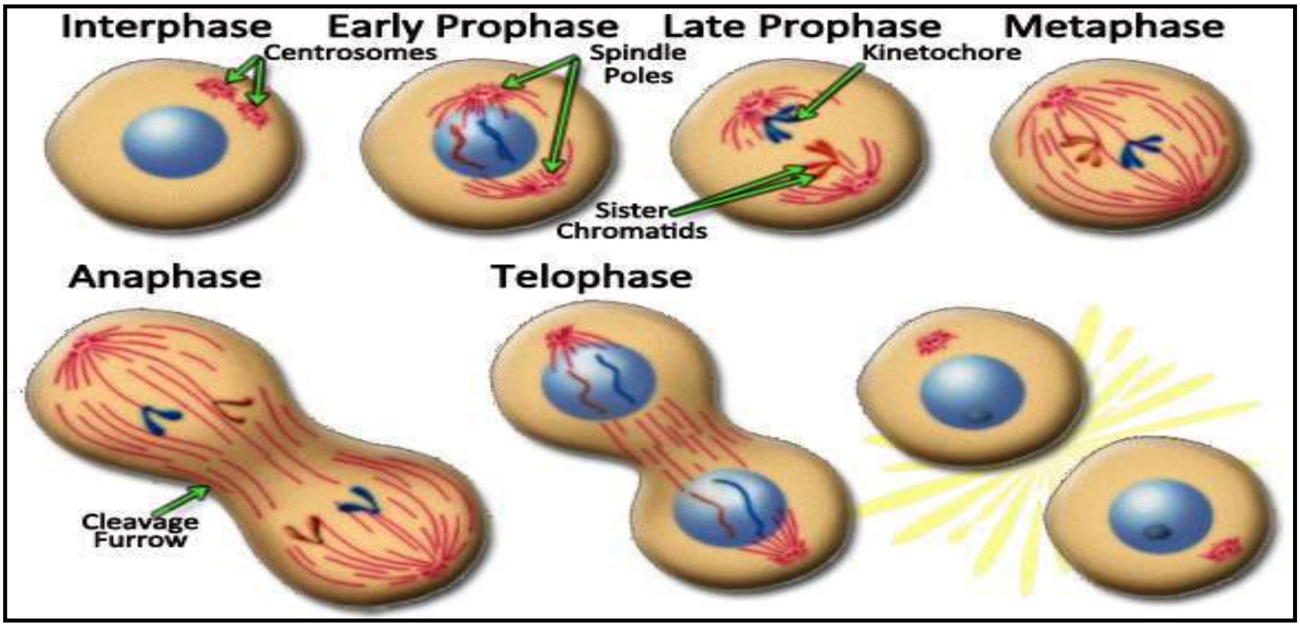


Figure 2: Mitotic cell division

Lecture 9

Meiosis

Meiosis is reduction division that takes place in the germ cells to generate male and female gametes, sperm and egg cells, respectively. Meiosis requires two cell division, **meiosis I** and **meiosis II,** to reduce the number of chromosomes from diploid **(2n)** to haploid number **(1n)**. The end products of meiosis are 4 haploid (1n) cells.

Meiosis in males is called **(Spermatogenesis)** and produce $\longrightarrow$ **sperm,**

Meiosis in females is called **(Oogenesis)** and produce $\longrightarrow$ **ova (egg),**

- Diploid cells (2n) have double structured chromosomes (46 chromosomes).

- Haploid cells (1n) have single stranded chromosomes (23 chromosomes).

- Fertilization is the fusion of a sperm (1n) and egg cell (1n) to produce a zygote,

- Zygote has a diploid chromosome (2n) number, one set from each parent.

Meiosis has two distinct stages:

1- Meiosis I 2- Meiosis II

- Meiosis I consist of 4 phases

1- Prophase I 2-Metaphase I 3-Anaphase I 4-Telophase I (Figure1).

Male germ cells (spermatocytes) and female germ cells (primary oocyte) at the beginning of meiosis I **(interphase I)**:

1- Replicate their DNA so that each chromosome consists of two sister chromatids held together at a centromere.

2- Centriole pairs also replicate.

3- Interphase I similar to mitosis interphase.

Prophase I

- Homologous chromosomes (each consisting of two sister chromatids) are paired, a process called **synapsis.**

- The structure formed is called a **tetrad** (tetrad: is **2** chromosomes or **4** chromatids).

- crossovers, are the interchange of non-sister chromatid segments between paired homologous chromosomes at cross-over point called **chiasmata,** produces genetic recombination in the offspring, (Figure 2).

Prophase I is divided into 5 subphases: Leptotene, Zygotene, Pachytene, Diplotene, and Diakinesis. Throughout these stages, the disappearance of the nucleolus, the formation of meiotic spindle between the two centrosomes in the opposite poles of the cytoplasm and the disappearance of the nuclear envelope take place sequentially.

Metaphase I

- The homologous pairs (four chromatids) align at the equator (metaphase plate) for separation.

- The centrioles are at opposite poles of the cell. The spindle fibres attach to kinetochore of the centromeres of each chromosome**.**

Anaphase I

- Homologous chromosomes separate and move to opposite poles.

- Sister chromatids remain attached at their centromeres**.**

Telophase I

The separated Chromosomes are pulled to the opposite pole

- The separated chromosomes are pulled to the opposite poles; each pole has haploid set of chromosomes.

- Nuclear envelopes reappear and Spindle fibres disappear.

- Cytokinesis (cytoplasm division) occurs and **two haploid daughter cells (1n)** are formed

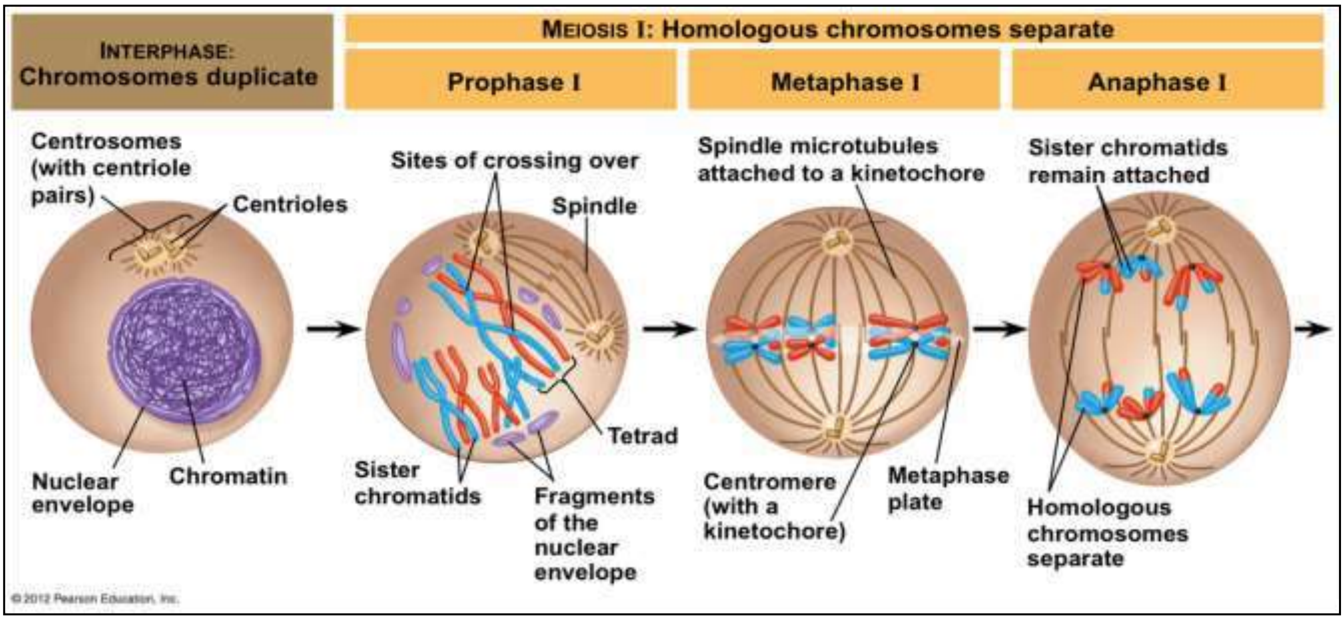


Figure 1: Meiosis I

- Meiosis II

- No interphase II (no more DNA replication)
- Meiosis II is similar to mitosis

Meiosis II consist of 4 phases

1- Prophase II 2- Metaphase II 3- Anaphase II 4- Telophase II (figure 2).

Prophase II

- Chromosomes coil and become compact
- Nuclear envelope breaks down, and the spindle apparatus forms
- Centrioles duplicated and move to opposite poles.

Metaphase II

- Duplicated chromosomes align on the equator (each duplicated chromosome: consist of **two sister chromatids** remain held together at centromere).

Anaphase II

- Centromeres are cleaved and Sister chromatids separate and move to opposite poles.

Telophase II

- Decondense chromosomes and Spindle fibres disappear
- Nuclear envelopes and nucleoli are formed
- Cytokinesis occurs and produces **four haploid daughter cells (1n).**

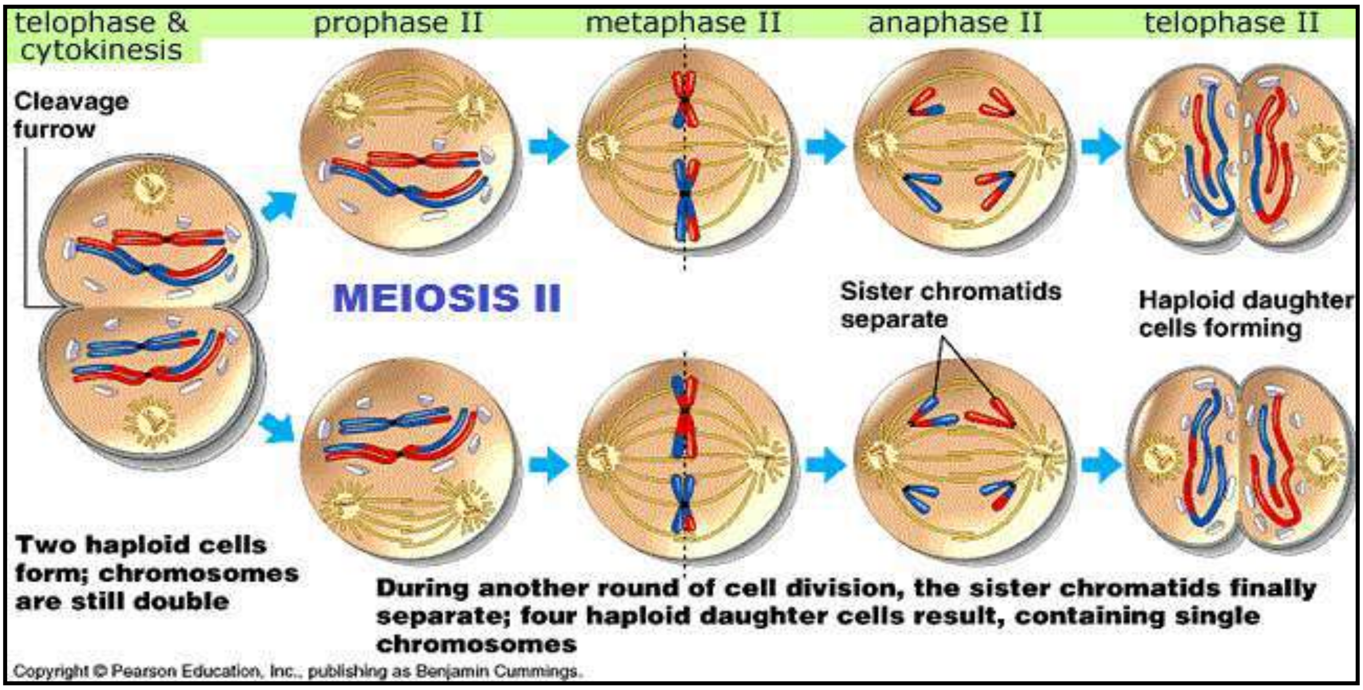


Figure 2: Meiosis II

Comparison of meiosis I with meiosis II

	meiosis I	meiosis II
1-	**Interphase I** DNA replication	No **interphase II**
2-	**Prophase I** Pairing of homologous chromosomes	**Prophase II** No pairing of chromosomes
3-	**Metaphase I** Homologous duplicated chromosomes at equator	**Metaphase II** Haploid number of duplicated chromosomes at equator
4-	**Anaphase I** Homologous chromosomes separate	**Anaphase II** Sister chromatids separate, becoming daughter chromosomes that move to the poles
5-	**Telophase I** Two haploid daughter cells	**Telophase II** Four haploid daughter cells

Lecture 10
Chromosomes Structure

Chromosomes: the microscopic threadlike part of the cell that carries the hereditary information in the form of genes consisting of DNA and associated proteins in the nucleus. Each chromosome has a constriction called the centromere, which divides chromosomes into short (p for petite) and long (q) arms (Figure 3)

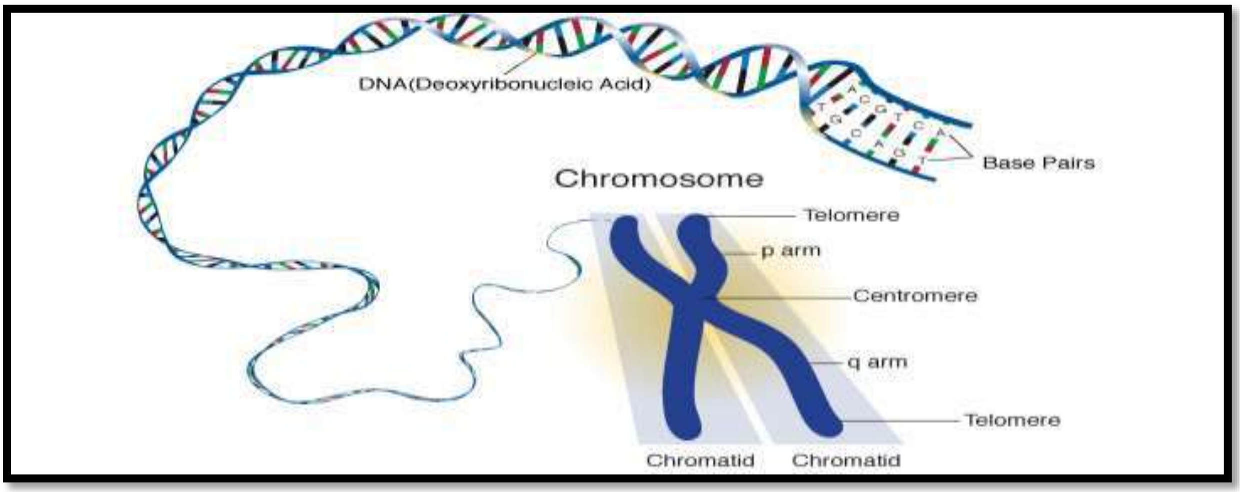


Figure 3: Chromosomes structure

The centromere: is the point of attachment of the kinetochore

Kinetochore: a protein structure that is connected to the spindle fibers.

Spindle fibers: Part of a structure that pulls the chromatids to opposite ends of the cell. During the middle stage in cell division, the centromere duplicates, and the chromatids pair separates; each chromatid becomes a separate chromosome at this point. The cell divides, and both of the daughter cells have a complete (diploid) set of chromosomes. The chromosomes uncoil in the new cells, again forming the diffuse network of chromatin.

The tip of each chromosome is the telomere it's important for sealing the end of the chromosome and maintaining stability and integrity. The telomere comprises mainly tandem DNA repeats, and the size of the telomere is maintained by an enzyme known as telomerase. Humans have 22 sets of autosomes and 2 sex chromosomes, i.e., a total of 46 chromosomes. In the nucleus, chromosomes are packed tightly, which allows a large amount of DNA to be located within a small space. Packing also plays a role in gene regulation.

Types of Chromosomes

Chromosomes are divided into two parts (p and q arms) with a constriction point called a centromere in the middle. The centromere can be located in different positions and this forms the basis for the four different classes of chromosome (Figure 4).

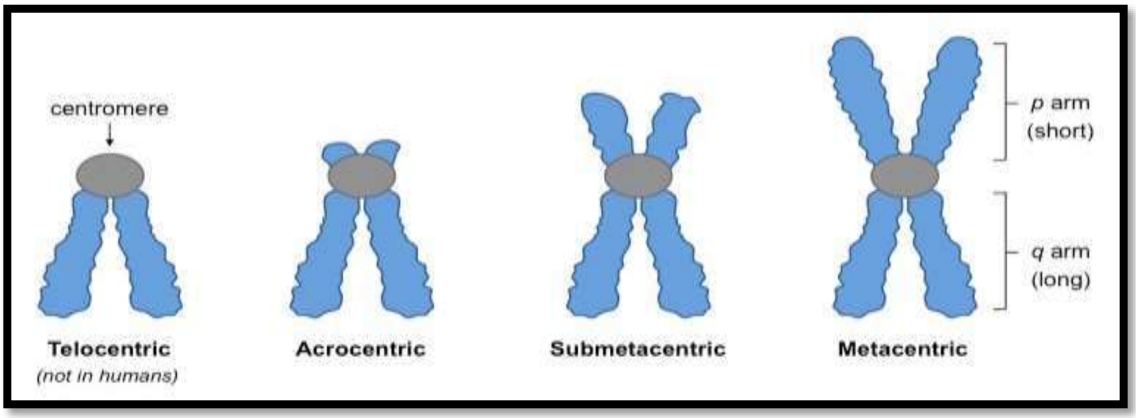


Figure 4: Types of chromosomes

Metacentric: Centromere is in middle, meaning p and q arms are of comparable length. **Submetacentric:** Centromere off-centre, leading to shorter p arm relative to q arm. **Acrocentric:** Centromere severely off-set from centre, leading to much shorter p arm. **Telocentric:** Centromere found at end of chromosome, meaning no p arm exists (chromosome not found in humans).

Virus DNA Structure

Just as in cells, the nucleic acid of each virus encodes the genetic information for the synthesis of all proteins. While the double-stranded DNA is responsible for this in prokaryotic and eukaryotic cells, only a few groups of viruses use DNA. Most viruses maintain all their genetic information with the single-stranded RNA. There are two types of RNA-based viruses. In most, the genomic RNA is termed a plus strand because it acts as messenger RNA for direct synthesis (translation) of viral protein. A few, however, have negative strands of RNA. In these cases, the virion has an enzyme, called RNA-dependent RNA polymerase (transcriptase), which must first catalyze the production of complementary messenger RNA from the virion genomic RNA before viral protein synthesis can occur.

A virus is a small collection of genetic code, either DNA or RNA, surrounded by a protein coat. A virus cannot replicate alone. Viruses must infect cells and use components of the host cell to make copies of themselves.