Structure and function of Cytoplasm

Cytoplasm, the semifluid substance of a cell that is external to the nuclear membrane and internal to the cellular membrane. In eukaryotes (i.e., cells having a nucleus), the cytoplasm contains all the organelles with the cell nucleus. The cytoplasm is about 80% water and usually colorless. The main components of the cytoplasm are:

① the mitochondria, which are the sites of energy production through ATP (adenosine triphosphate) synthesis; ② the endoplasmic reticulum, the site of lipid and protein synthesis; ③ the Golgi apparatus, the site where proteins are modified, packaged, and sorted in preparation for transport to their cellular destinations; ④ lysosomes and ⑤ peroxisomes, sacs of digestive enzymes that carry out the intracellular digestion of macromolecules such as lipids and proteins; ⑥ the cytoskeleton, a network of protein fibres that give shape and support to the cell; ⑦ cytosol, the fluid mass that surrounds the various organelles, and ⑧ the nucleus.

Cell organelles

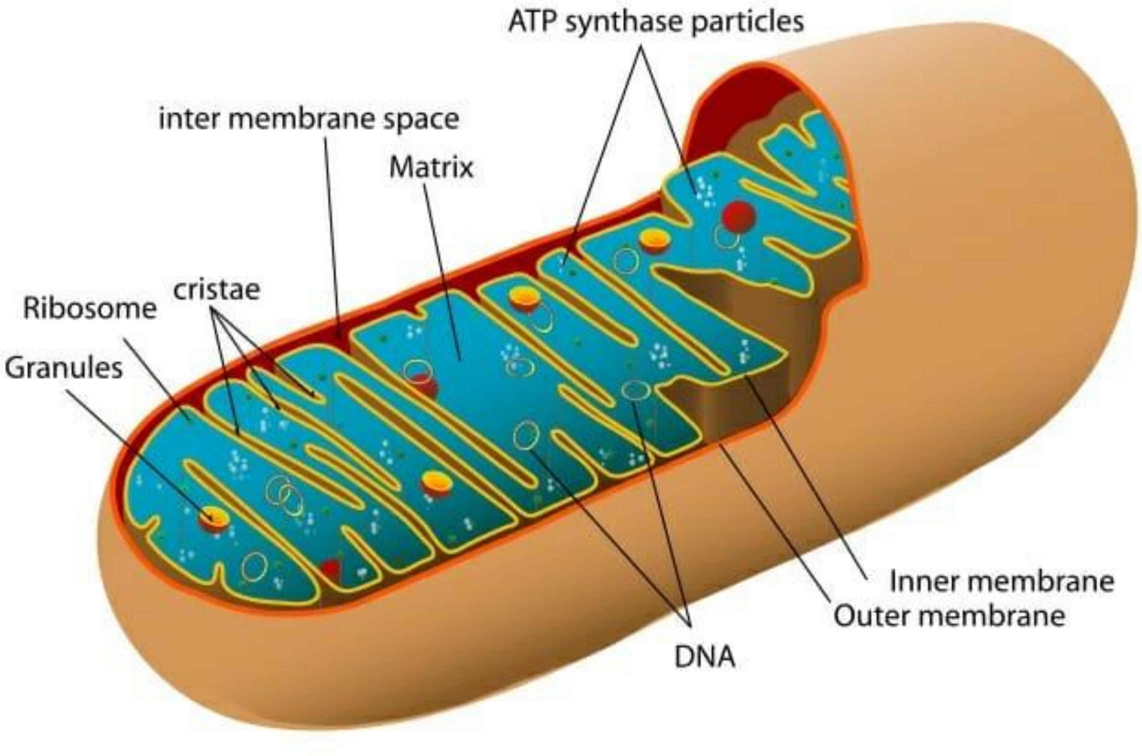
Cell organelles are classified as membranous, that is membrane-bound, and non-membranous.

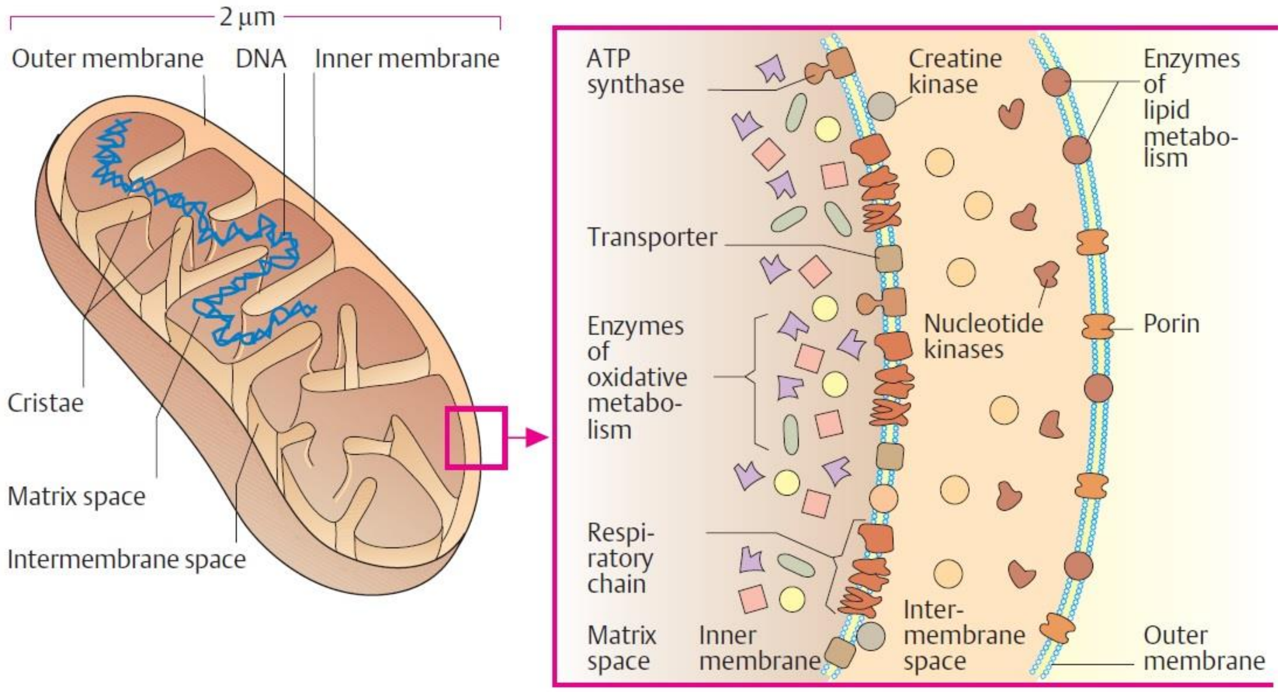
Membranous cell organelles	Non-Membranous cell organelles
• Golgi complex • Endoplasmic reticulum—rough and smooth • Mitochondria • Lysosomes • Peroxisomes • Endosomes	• Ribosomes • Cytoskeleton—microtubules, Microfilaments and intermediate Filaments

1-Mitochondrion Structure

Mitochondria are small membrane-bound organelles that are usually about 1 – 10 microns in length. They can be **spherical** or **rod-shaped**. The mitochondrion is enclosed by two membranes that separate it from the cytosol and the rest of the cell components. The membranes are lipid bilayers with proteins embedded within the layers. The inner membrane is folded to form cristae; this increases the surface area of the membrane and maximizes cellular respiration output. The region between the two membranes is the **intermembrane space.**

Inside the inner membrane is the mitochondrial matrix, and within the matrix there are ribosomes, other enzymes, and mitochondrial DNA. The mitochondrion can reproduce and synthesize proteins independently. It contains the enzymes necessary for transcription, as well as the transfer RNAs and ribosomes required for translation and protein formation.





Mitochondrion Function

Mitochondria are involved in breaking down sugars and fats into energy through aerobic respiration (cellular respiration). This metabolic process creates ATP, the energy source of a cell, through a series of steps that require oxygen. Cellular respiration involves three main stages:

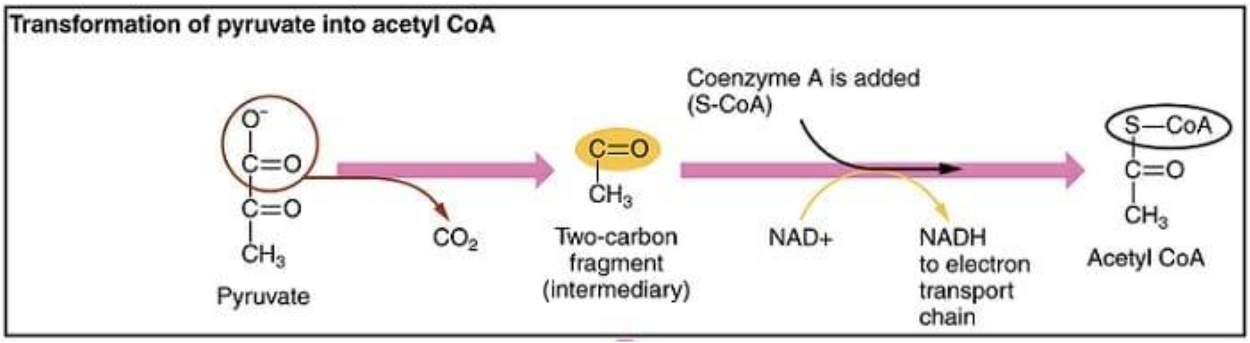
I. Glycolysis

Glycolysis is the process in which one glucose molecule is broken down to form two molecules of pyruvic acid (also called pyruvate). The glycolysis process is a multi-step metabolic pathway that occurs in the cytoplasm of animal cells, plant cells, and the cells of microorganisms. At least six enzymes operate in the metabolic pathway. **Glycolysis** produces **2 ATP**, **2 NADH**, and **2 pyruvate molecule.**

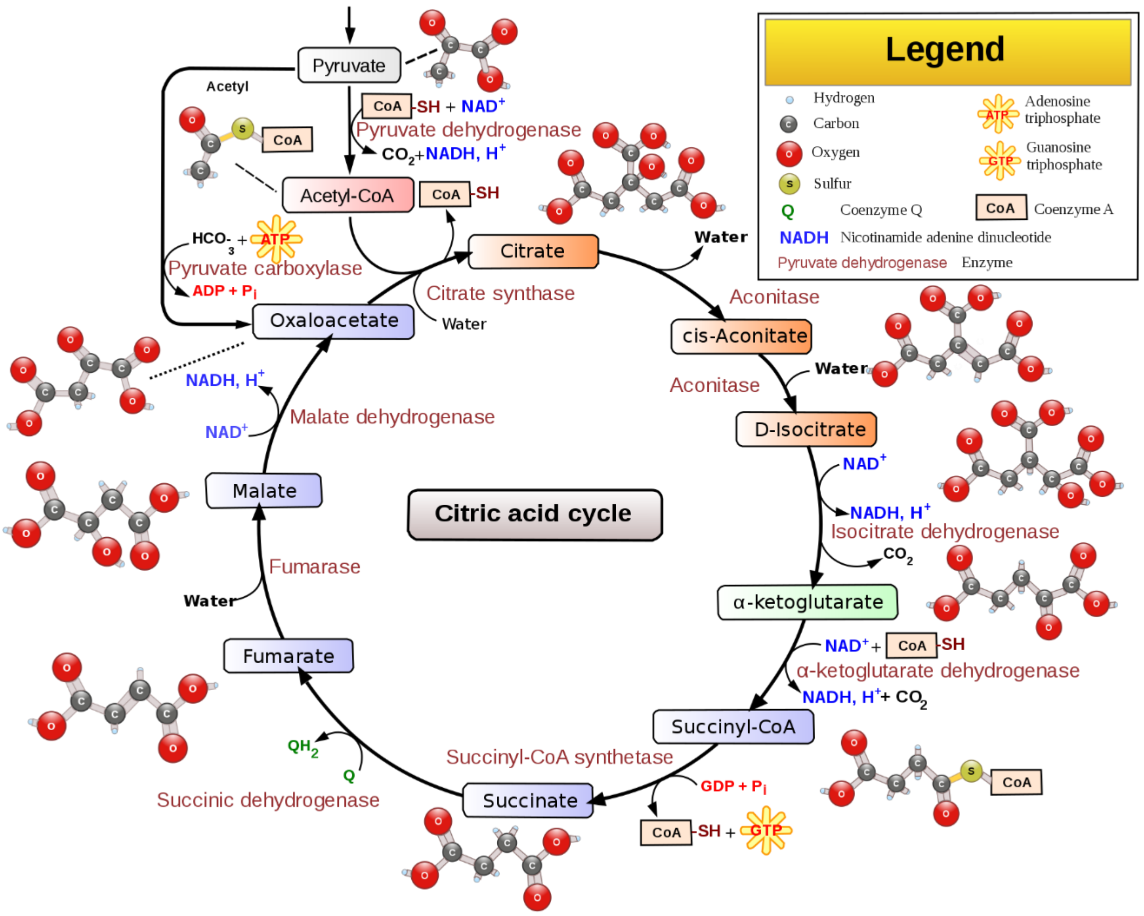
$C_6H_{12}O_6$ + 2 NAD^+ + 2 ATP ---------> 2 pyruvic acid + 2 ATP + 2 NADH + 2 H^+

II. **Krebs cycle**

In the presence of oxygen, the pyruvate molecules that are produced in glycolysis enter the mitochondrion. The citric acid cycle, or Krebs cycle, occurs in the **mitochondrial matrix**. The citric acid cycle results in the formation of NADH (from NAD^+) which transports electrons to the final stage of cellular respiration. The citric acid cycle produces **two ATP molecules.** Pyruvate enters the mitochondrion and is converted into **acetyl coenzyme A**. This conversion is catalysed by enzymes, produces **NADH**, and releases CO_2. The acetyl group then enters the citric acid cycle, a series of eight enzyme-catalysed steps that begins with citrate and ends in oxaloacetate.



The addition of the acetyl group to oxaloacetate forms citrate and the cycle repeats. The breakdown of citrate into oxaloacetate releases a further two CO_2 molecules and one molecule of ATP (through substrate-level phosphorylation). The majority of the energy is in the reduced coenzymes NADH and $FADH_2$. NAD+ accepts **a hydrogen ion** (H+) and **two electrons** (2e−), while FAD accepts **two hydrogen** ion (H+) and **two electrons** (2e−), as it becomes reduced to NADH + H+. These molecules are then transported to the **electron transport chain**.



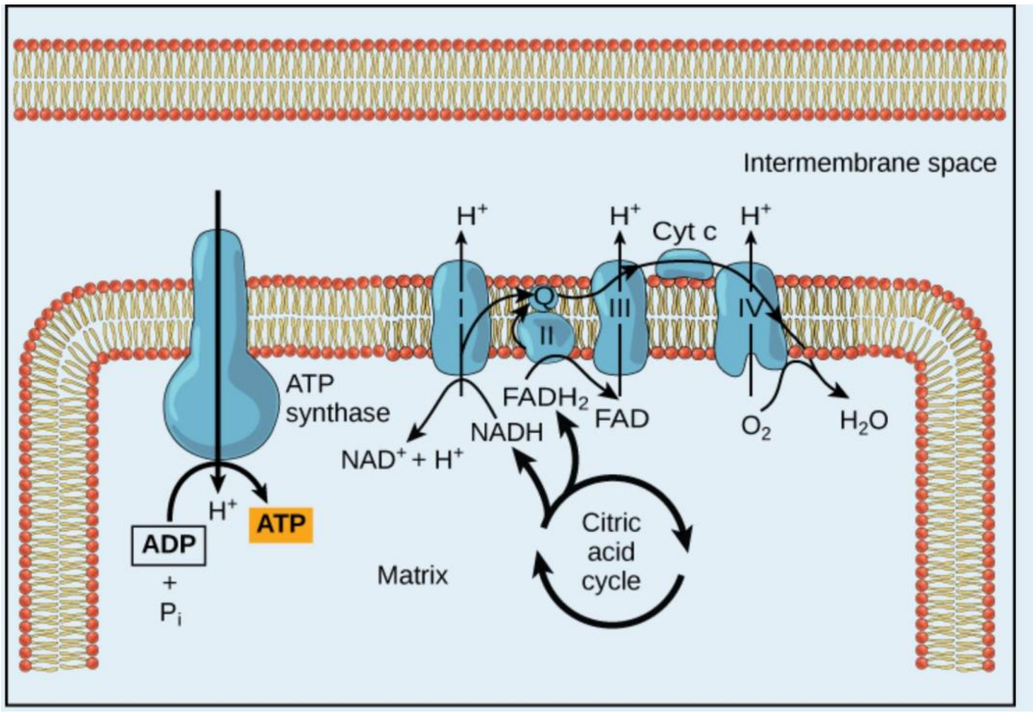
Results of the Krebs Cycle

After the second turn through the Krebs cycle, the original glucose molecule has been broken down completely. All six of its carbon atoms have combined with oxygen to form carbon dioxide. The energy from its chemical bonds has been stored in a total of 16 energy-carrier molecules. These molecules are:

- 4 ATP (including 2 from glycolysis)
- 10 NADH (including 2 from glycolysis)
- 2 $FADH_2$

III. **Oxidative Phosphorylation** or **Electron transport chain.**

Oxidative phosphorylation occurs in the inner membrane of the mitochondrion. The electron transport chain is made up of five multi-protein complexes (I to IV) that are repeated hundreds to thousands of times in the cristae of the inner membrane.



2-Endoplasmic Reticulum

The general structure of the endoplasmic reticulum is a network of membranes called cisternae. These sac-like structures are held together by the cytoskeleton. The phospholipid membrane encloses the cisternal space (or lumen), which is continuous with the perinuclear space but separate from the cytosol.

I. Rough endoplasmic reticulum

The surface of the rough endoplasmic reticulum (often abbreviated RER or Rough ER) is studded with protein-manufacturing ribosomes giving it a "rough" appearance. However, the ribosomes are not a stable part of this organelle's structure as they are constantly being bound and released from the membrane.

The functions of the rough endoplasmic reticulum can be summarized:

1- The synthesis and export of proteins and membrane lipids.
2- Manufacture of lysosomal enzymes with a mannose-6-phosphate marker added in the cis-Golgi network.
3- Integral membrane proteins that stay embedded in the cell membrane.

4- Have enzymes that can added carbohydrate chains to protein forming glycoprotein.

II. Smooth endoplasmic reticulum

Smooth endoplasmic reticulum (SER) is an irregular network of folded membranes that are devoid of ribosomes.

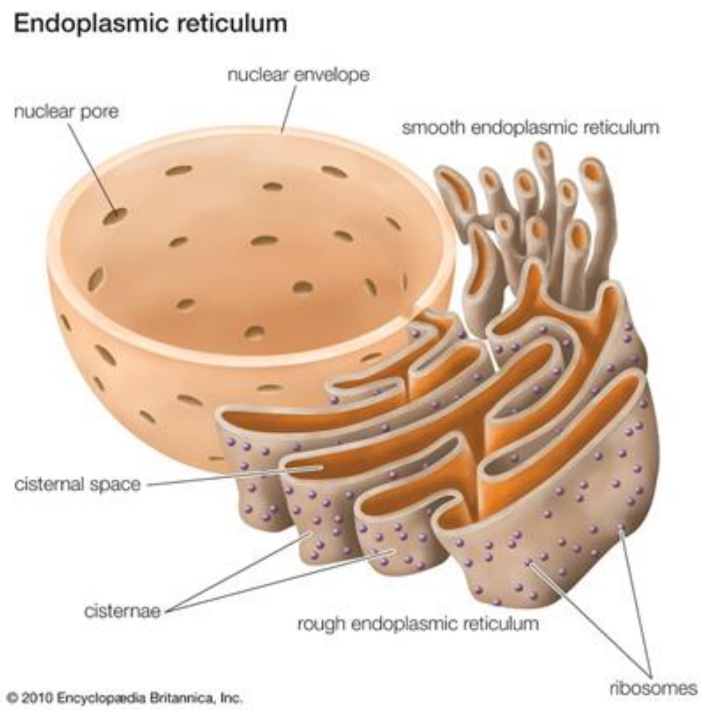
The functions of the smooth endoplasmic reticulum can be summarized:

1- The smooth ER is important in the synthesis of lipids, such as cholesterol and phospholipids, which form all the membranes of the cell.

2- In addition, it is important for the synthesis and secretion of steroid hormones from cholesterol and other lipid precursors.

3- In addition, it is involved in carbohydrate metabolism. For instance, the final reaction of gluconeogenesis occurs in the lumen of the smooth ER since it contains the enzyme glucose-6-phosphatase.

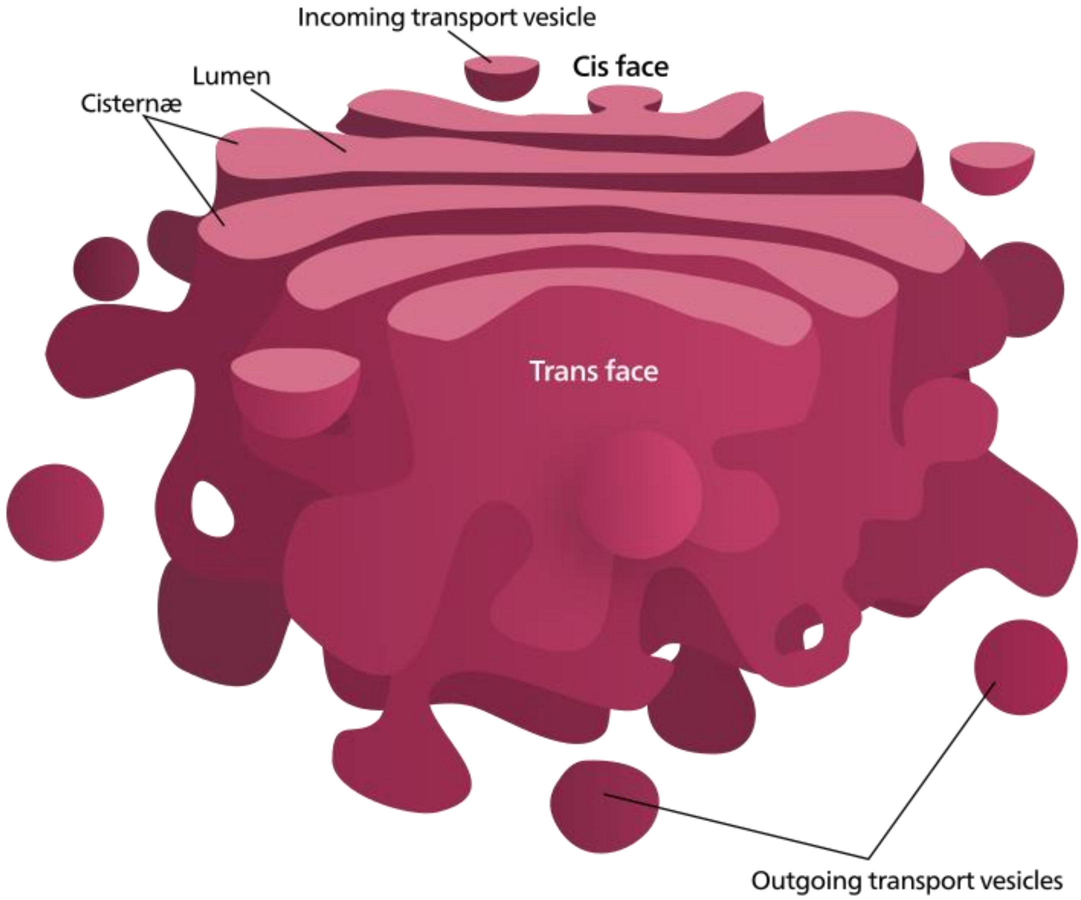
4- They are also abundant in liver cells and help in detoxification of drugs.



Golgi apparatus

The Golgi apparatus, also known as the Golgi complex, Golgi body, or simply the Golgi, is an organelle found in most eukaryotic cells. Part of the endomembrane system in the cytoplasm, the Golgi apparatus packages proteins into membrane-bound vesicles inside the cell before the vesicles are sent to their destination.

Proteins synthesized in the ER are packaged into vesicles, which then fuse with the Golgi apparatus. These cargo proteins are modified and destined for secretion via exocytosis or for use in the cell. The Golgi body can be thought of as similar to a post office: it packages and labels items which it then sends to different parts of the cell or to the extracellular space.



3-Cytoskeleton

Cytoskeleton, a system of filaments or fibres that is present in the cytoplasm of eukaryotic cells. The cytoskeleton organizes other constituent of the cell, maintains the cell's shape, and is responsible for the locomotion of the cell itself and the movement of the various organelles within it. It is a complex, dynamic network of interlinking protein filaments that extends from the cell nucleus to the cell membrane. The cytoskeletal matrix is a dynamic structure composed of three main proteins, which are capable of rapid growth or disassembly dependent on the cell's requirements.

The three main structural components of the cytoskeleton are **microtubules** (formed by tubulins), **microfilaments** (formed by actins) and **intermediate filaments**. All three components interact with each other non-covalently

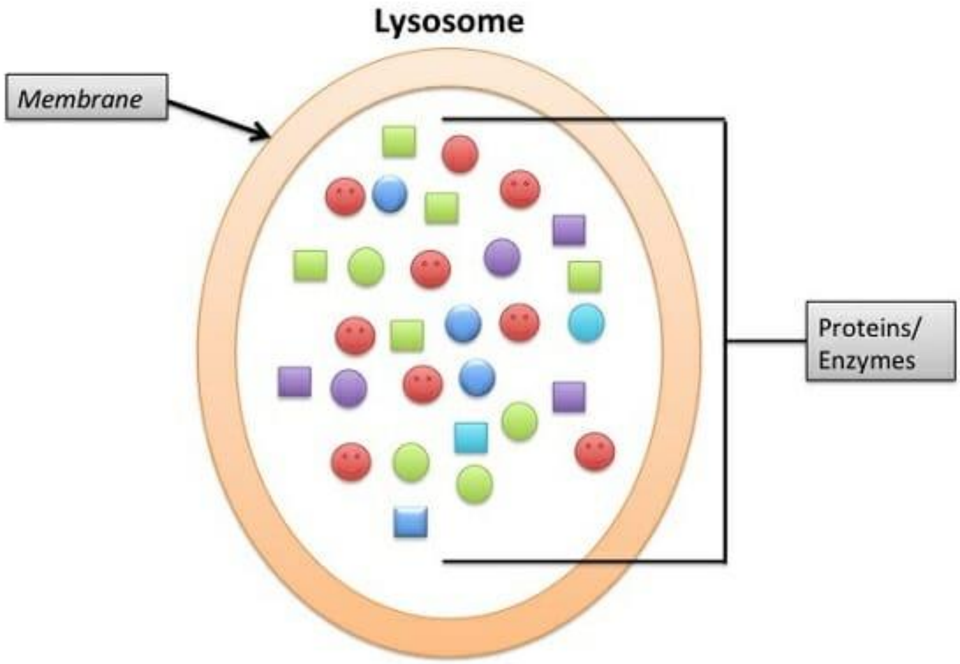
<u>Functions:</u>

Microtubules help in maintenance of cell shape, intracellular transport and formation of mitotic spindles during mitosis.

5. Lysosomes

Lysosomes act as the waste disposal system of the cell by digesting obsolete or un-used materials in the cytoplasm, from both inside and outside the cell. Material (complex molecules such as carbohydrates, lipids, proteins, and nucleic acids) from outside the cell is taken-up through endocytosis, while material from the inside of the cell is digested through autophagy. Lysosomes are known to contain more than 60 different enzymes, and have more than 50 membrane proteins. Enzymes of the lysosomes are synthesised in the rough endoplasmic reticulum.

Synthesis of lysosomal enzymes is controlled by nuclear genes. Mutations in the genes for these enzymes are responsible for more than 30 different human genetic disorders, which are collectively known as lysosomal storage diseases. These diseases result from an accumulation of specific substrates, due to the inability to break them down. These genetic defects are related to several neurodegenerative disorders, cancers, cardiovascular diseases, and aging-related diseases.

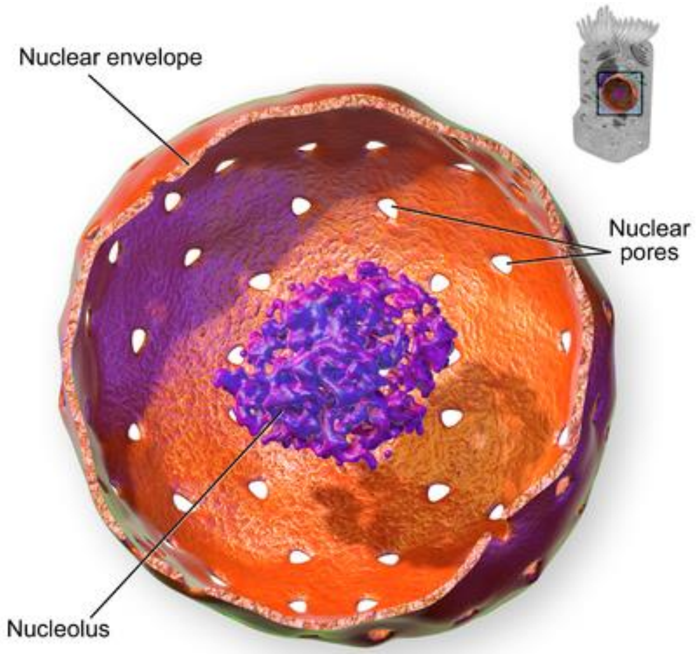


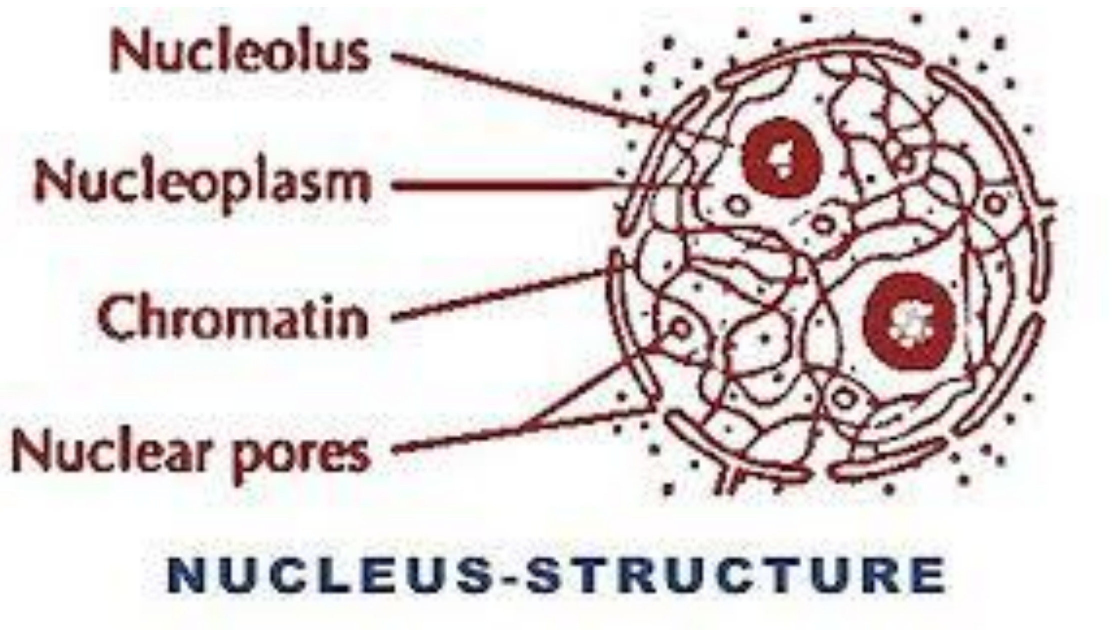
6. Nucleus

The nucleus is a membrane-bound organelle that contains genetic material (DNA) of eukaryotic organisms. As such, it serves to maintain the integrity of the cell by facilitating transcription and replication processes. It's the largest organelle inside the cell taking up about a tenth of the entire cell volume. This makes it one of the easiest organelles to identify under the microscope. Some eukaryotic cells lack a nucleus and are referred to as enucleate cells (e.g. erythrocytes) while others may have more than one nucleus (e.g. slime moulds).

Function

The nucleus provides a site for genetic transcription that is segregated from the location of translation in the cytoplasm, allowing levels of gene regulation that are not available to prokaryotes. The main function of the cell nucleus is to control gene expression and mediate the replication of DNA during the cell cycle.



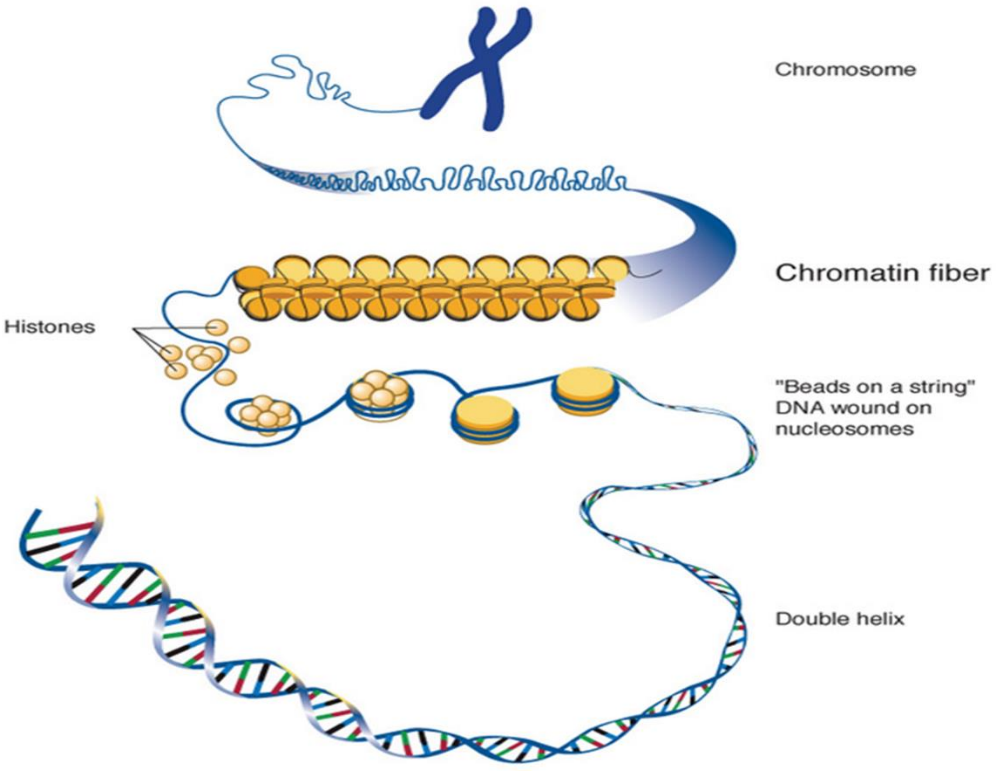


Chromatin

Chromatin is a complex of macromolecules found in cells, consisting of DNA, protein, and RNA. The primary functions of chromatin are (1) to package DNA into a more compact, denser shape, (2) to reinforce the DNA macromolecule to allow mitosis. (3) to prevent DNA damage, and (4) to control gene expression and DNA replication.

Chromosomes

● A chromosome consists of a highly folded and condensed single DNA molecule. The associated proteins help in organization of the DNA.
● Chromosomes are best seen during cell division when they reach maximum condensation.
● Each chromosome consists of a short arm (p) and a long arm (q); they are connected to each other by a constricted region known as centromere.
● After DNA replication, chromosomes consist of a pair of identical chromatids joined by a centromere.



Nucleus chemical composition:

- 9-12 percent DNA
- 15 percent histone
- 65 percent enzymes, neutral proteins and acid proteins
- 5 percent RNA
- 3 percent lipids

Some of the main functions of the nucleus include:

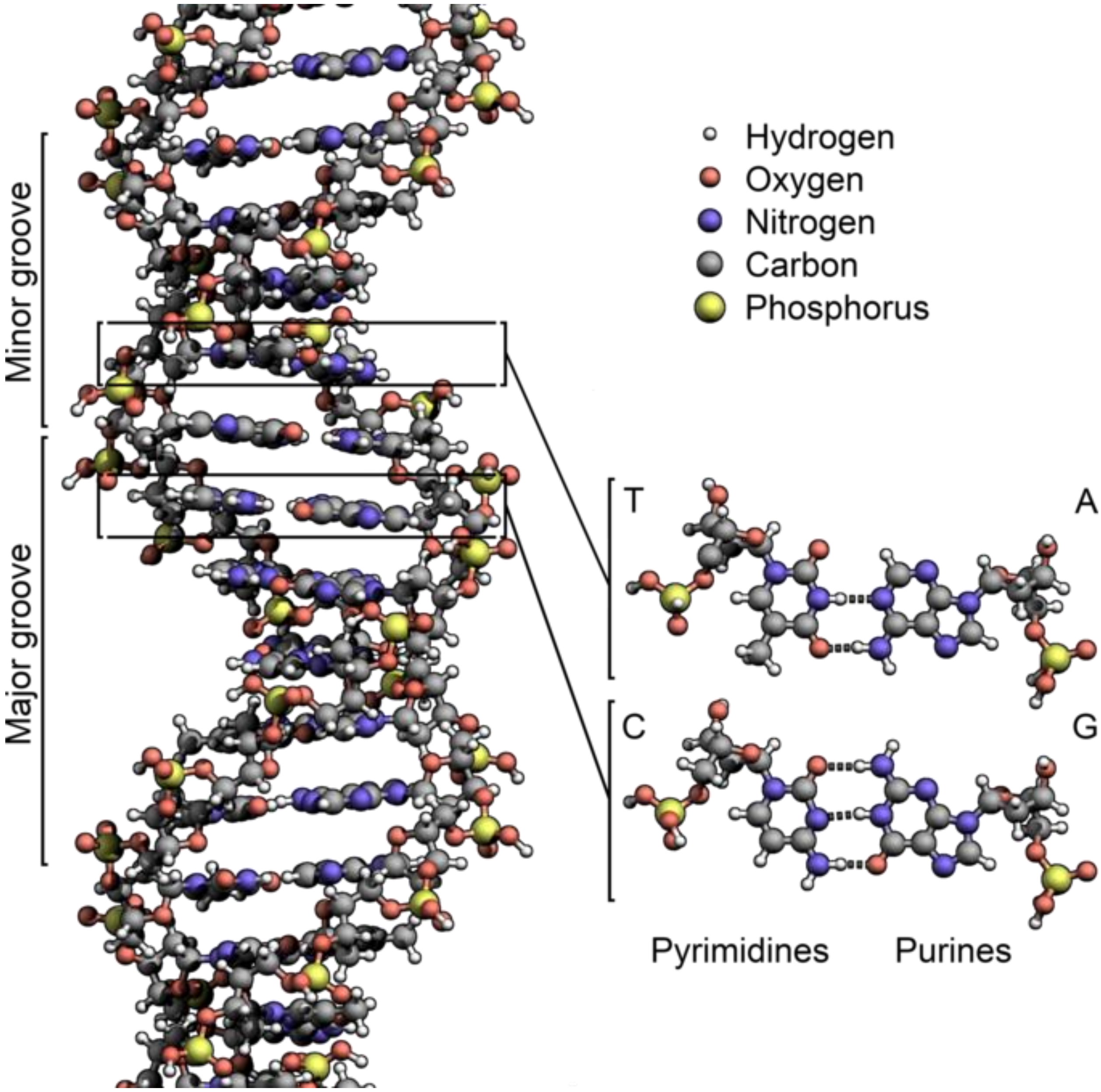
- Protein synthesis, cell division, and differentiation
- Control the synthesis of enzymes involved in cellular metabolism
- Controlling hereditary traits of the organism
- Store DNA strands, proteins, and RNA
- Site of RNA transcription - e.g. mRNA required for protein synthesis

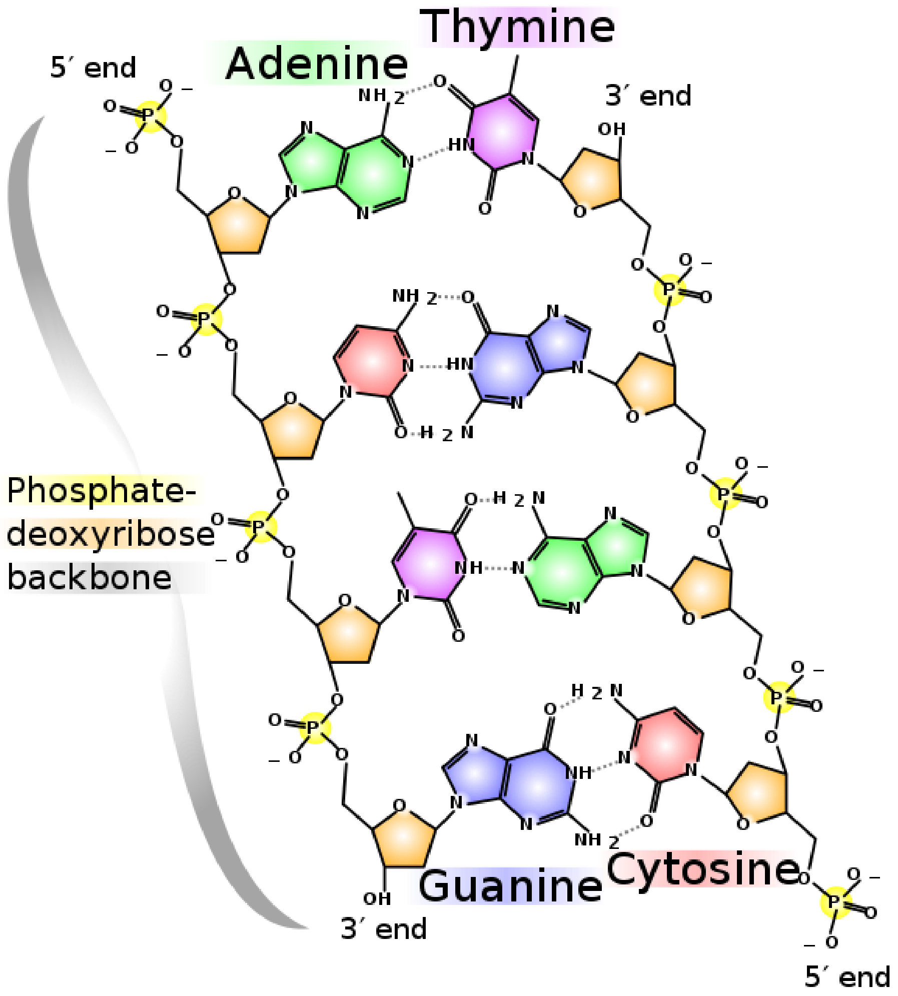
Deoxyribonucleic acid (DNA)

Deoxyribonucleic acid (DNA) is a molecule composed of two chains that coil around each other to form a double helix carrying genetic instructions for the development, functioning, growth and reproduction of all know organisms and many viruses. DNA and ribonucleic acid (RNA) are nucleic acids; alongside proteins, lipids and complex carbohydrates (polysaccharides), nucleic acids are one of the four major types of macromolecules that are essential for all known forms of life.

The two DNA strands are also known as polynucleotides as they are composed of simpler monomeric units called nucleotides. Each nucleotide is composed of one of four nitrogen- containing nucleobases (cytosine [C], guanine [G], adenine [A] or thymine [T]), a sugar called deoxyribose, and a phosphate group. The nucleotides are joined to one another in a chain by covalent bonds between the sugar of one nucleotide and the phosphate of the next, resulting in an alternating sugar-phosphate backbone.

The nitrogenous bases of the two separate polynucleotide strands are bound together, according to base pairing rules (A with T and C with G), with hydrogen bonds to make double-stranded DNA. The complementary nitrogenous bases are divided into two groups, pyrimidines and purines. In DNA, the pyrimidines are thymine and cytosine; the purines are adenine and guanine.

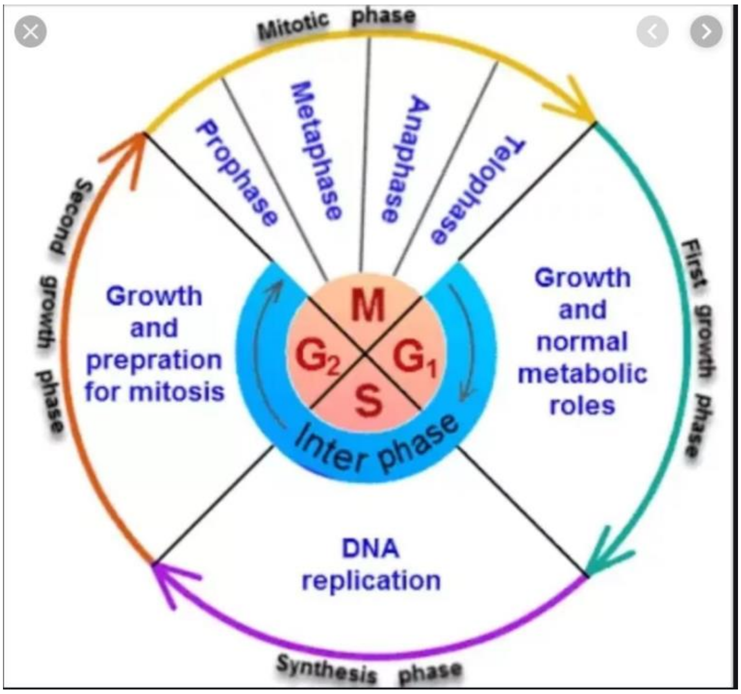




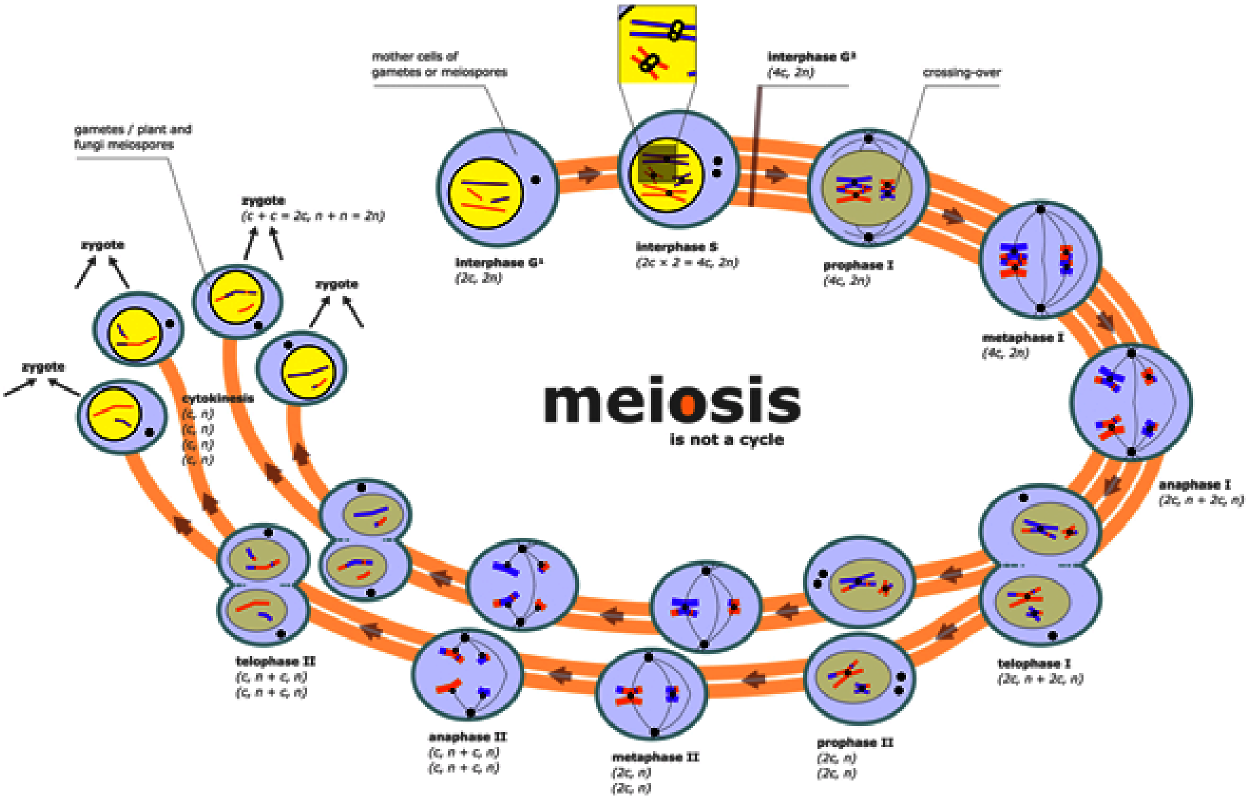
How do cells divide?

There are two types of cell division: mitosis and meiosis. Most of the time when people refer to “cell division,” they mean mitosis, the process of making new body cells. Meiosis is the type of cell division that creates egg and sperm cells.

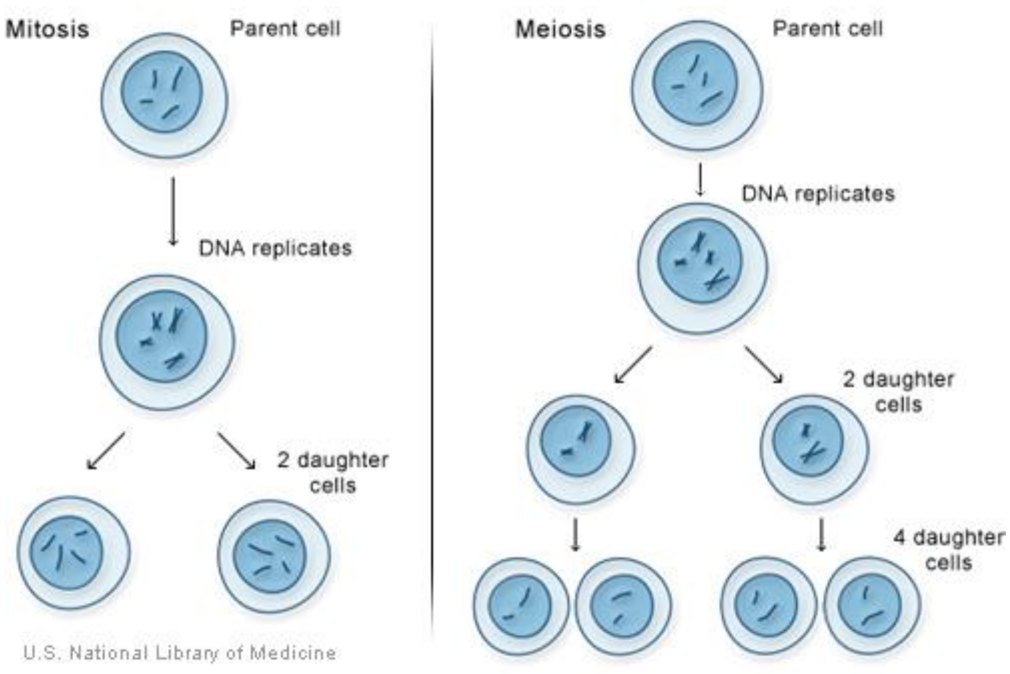
Mitosis is a fundamental process for life. During mitosis, a cell duplicates all of its contents, including its chromosomes, and splits to form two identical daughter cells. Because this process is so critical, the steps of mitosis are carefully controlled by a number of genes. When mitosis is not regulated correctly, health problems such as cancer can result.



The other type of cell division, meiosis, ensures that humans have the same number of chromosomes in each generation. It is a two-step process that reduces the chromosome number by half—from 46 to 23—to form sperm and egg cells. When the sperm and egg cells unite at conception, each contributes 23 chromosomes so the resulting embryo will have the usual 46. Meiosis also allows genetic variation through a process of DNA shuffling while the cells are dividing.



Mitosis and meiosis, the two types of cell division.



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