

## The cell, and function

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### INTRODUCTION TO THE CELL

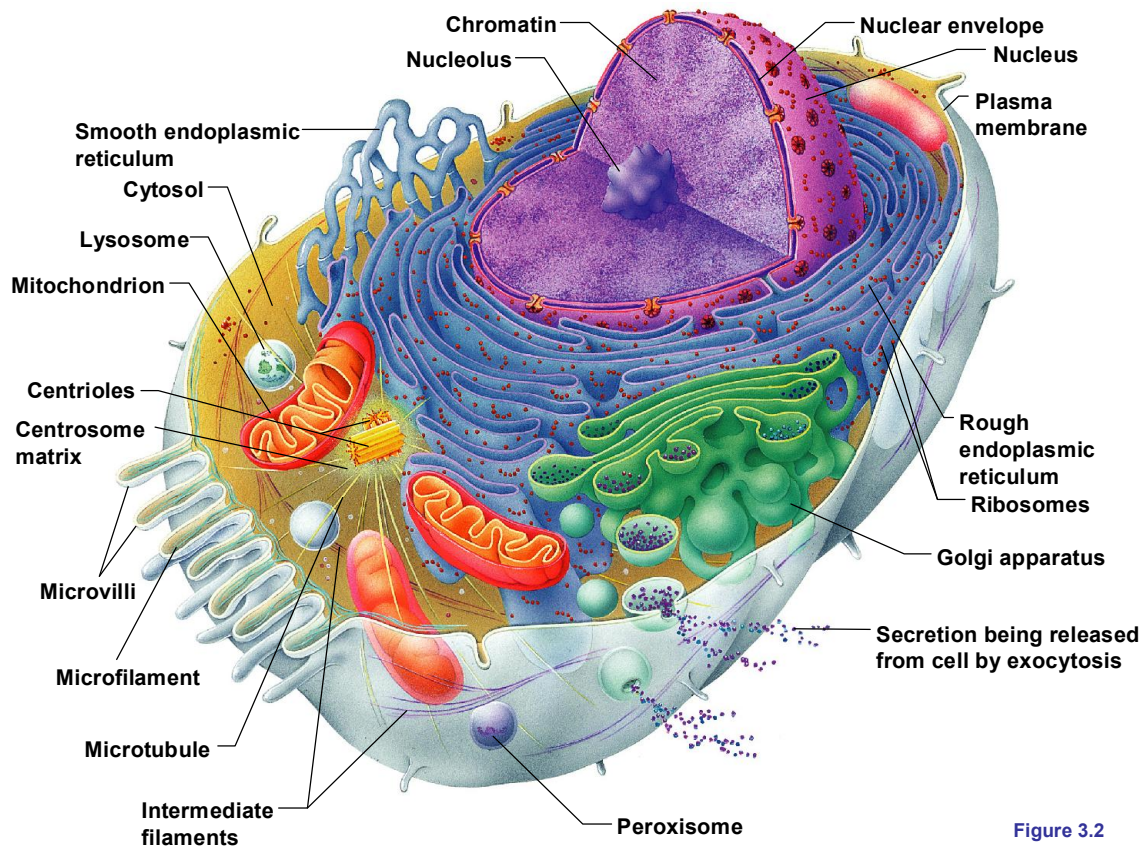


Figure 3.2

A cell is the fundamental organizational unit of life capable of reproduction. Not long ago, the cell was considered to be a fairly simple structure that contained a nucleus and various enzymes.

Today, however, the cell is known to be an extremely complex entity. With the advent of electron microscopy in the early 1940's, several distinct cellular structures called organelles were clearly recognized).

There are many different types, sizes, and shapes of cells in the body. For descriptive purposes, the concept of a "generalized cell" is introduced. It includes features from all cell types. A cell consists of three parts:

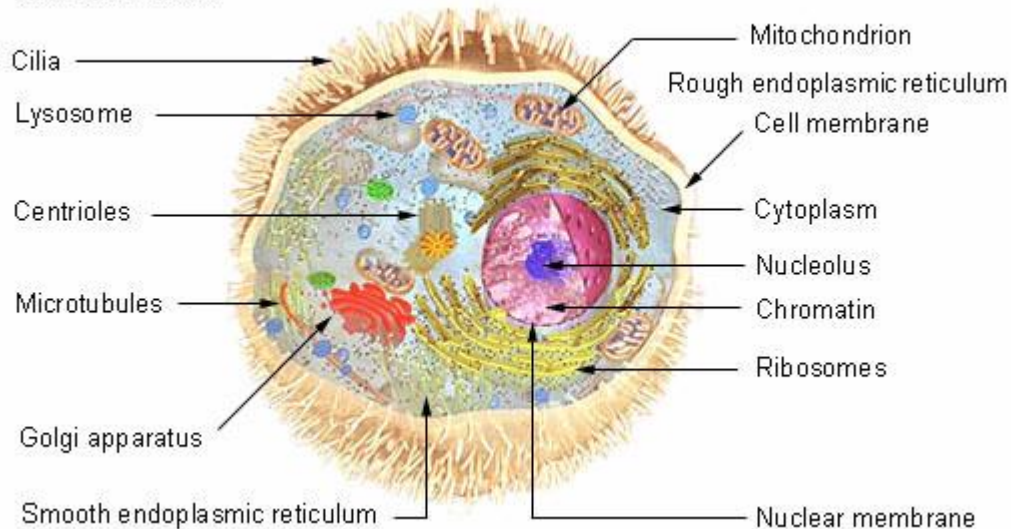
- the cell membrane,
- the nucleus,
- and between the two, the cytoplasm.
- Within the cytoplasm lie intricate arrangements of fine fibers and hundreds or even thousands of miniscule but distinct structures called organelles.

## The cell and tissue

A typical animal cell contains the following structures:

- **nucleus,**
- **nucleolus,**
- **nuclear membrane,**
- **centrioles,**
- **endoplasmic reticulum,**
- **golgi apparatus,**
- **ribosomes, mitochondria,**
- **lysosomes,**
- **vacuoles,**
- **and the cell membrane (unit membrane).**

### Cell Structure



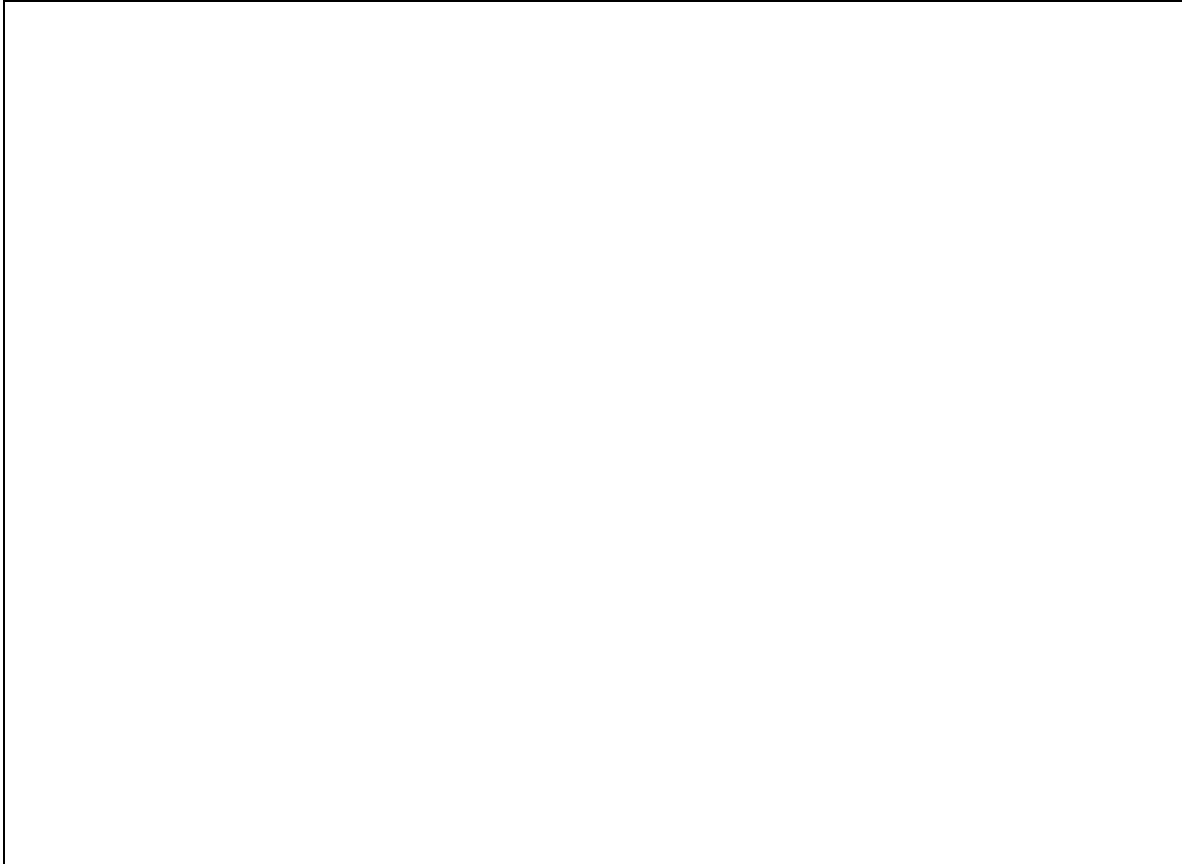
- The cell is the basic structural and functional unit of life
- Organismal activity depends on individual and collective activity of cells
- Biochemical activities of cells are dictated by subcellular structure

Continuity of life has a cellular basis

Key developments in the evolution of cells:

- 1) The development of replicating proteins which could conserve the basic chemical building blocks necessary for life
- 2) The development of a hydrophobic membrane around these proteins, allowing:
  - a) The separation of internal from external environments.
  - b) The selective movement of molecules and ions in both directions across the membrane.

### STRUCTURAL COMPONENTS OF A CELL



#### Differences Between Extracellular and Intracellular Fluids.

- The extracellular fluid contains large amounts of *sodium, chloride, and bicarbonate ions* plus nutrients for the cells, such as *oxygen, glucose, fatty acids, and amino acids*.
- It also contains *carbon dioxide* that is being transported from the cells to the lungs to be excreted, plus other cellular waste products that are being transported to the kidneys for excretion.
- The intracellular fluid differs significantly from the extracellular fluid; specifically, it contains large amounts of *potassium, magnesium, and phosphate ions* instead of the sodium and chloride ions found in the extracellular fluid.
- Special mechanisms for transporting ions through the cell membranes maintain the ion concentration differences between the extracellular and intracellular fluids.

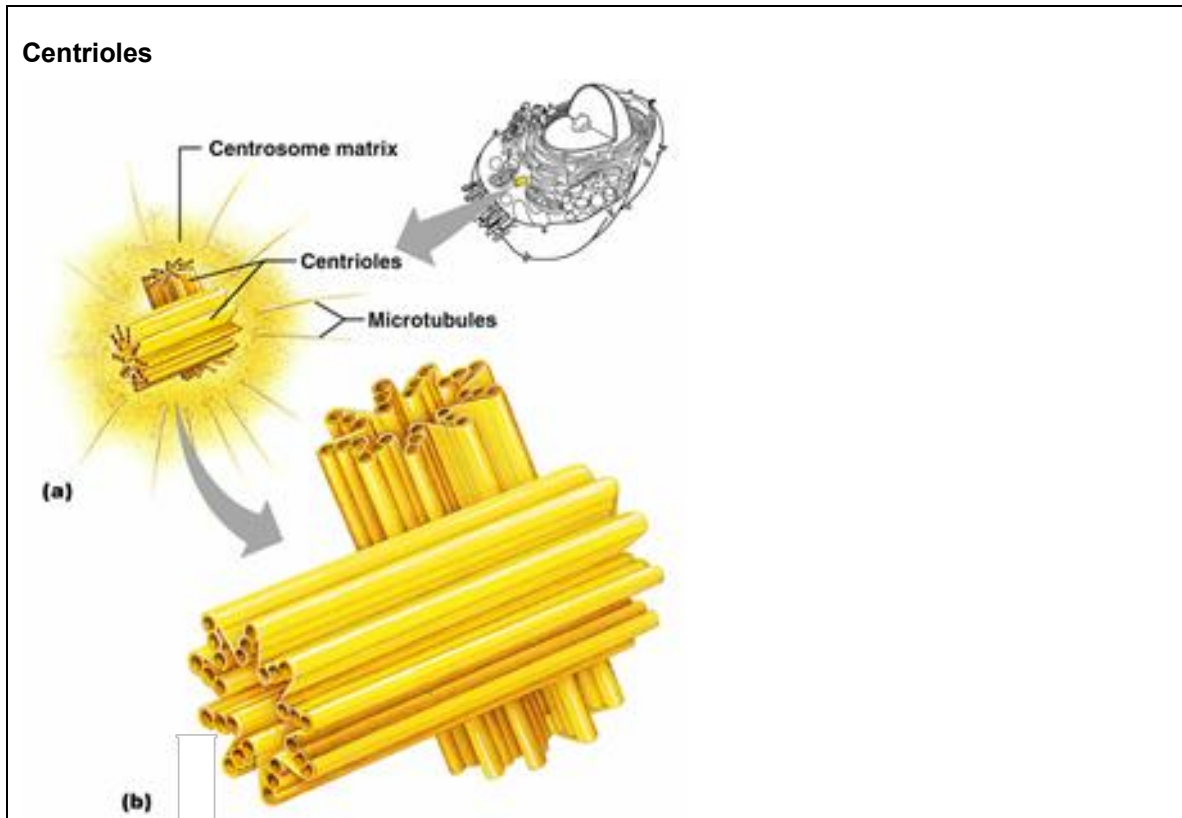
**Cell structure:**

a. **Nucleus.**

- The nucleus plays a central role because it is from this structure that information is distributed which guides the life processes of the cell.
- In particular, **the nucleus plays a central role in cellular reproduction.**
- **Two types of structures found in the nucleus are chromosomes and nucleoli.**
- **Chromosomes are distinct only during cell division.**
- They are composed of both nucleic acid and protein, and contain genes (basic hereditary units).
- **Nucleoli are darkly staining ovoid bodies whose chief chemical constituent is ribonucleic acid (RNA).**
- When protein synthesis is occurring in the cell, nucleoli are involved in interactions between the nucleus and cytoplasm.

b. **Centrioles.**

- Centrioles are found **in pairs in the cytoplasm.**
- They are cylindrical bodies oriented at right angles to one another.
- **Their primary function is to assist in the division of the cell.**
- Small barrel-shaped organelles located in the centrosome near the nucleus
- Pinwheel array of nine triplets of microtubules
- Organize mitotic spindle during mitosis
- Form the bases of cilia and flagella



**c. Endoplasmic Reticulum.**

- The endoplasmic reticulum was so named because it was once thought to be confined entirely to the endoplasm (that part of the cytoplasm close to and surrounding the nucleus).
- It is now known to extend to the peripheral regions of the cell and is sometimes attached to the cell membrane.
- It is a complex network of thin membrane-bound cavities that vary considerably in shape.
- These minute canals and vesicles (sacs) function as a kind of circulatory system to transfer materials throughout a cell.
- The endoplasmic reticulum functions in protein synthesis by serving as a site of attachment for the ribosomes, which in turn are the site of protein synthesis.
- The endoplasmic reticulum (**ER**) is a network of flattened sacs and branching tubules that extends throughout the cytoplasm in plant and animal cells.
- These sacs and tubules are all interconnected by a single continuous membrane so that the organelle has only one large, highly convoluted and complexly arranged **lumen** (internal space).
- Usually referred to as the endoplasmic reticulum cisternal space, the lumen of the organelle often takes up more than 10 percent of the total volume of a cell.
- The endoplasmic reticulum membrane allows molecules to be selectively transferred between the lumen and the cytoplasm, and since it is connected to the double-layered nuclear envelope, it further provides a pipeline between the nucleus and the cytoplasm.

## The cell and tissue

- There are two basic kinds of endoplasmic reticulum morphologies: rough and smooth. The surface of rough endoplasmic reticulum is covered with ribosomes,
- Specialized functions:
  - a. Protein translation,
  - b. folding, and transport of proteins to be used in the cell membrane (e.g., transmembrane receptors and other integral membrane proteins),
  - c. or to be secreted (exocytosed) from the cell (e.g., digestive enzymes);
  - d. sequestration of calcium;
  - e. and production and storage of glycogen, steroids, and other macromolecules.
  - f. The endoplasmic reticulum is part of the endomembrane system. **The basic structure and composition of the ER membrane is similar to the plasma membrane.**

- **Rough endoplasmic reticulum**

- The surface of the rough endoplasmic reticulum is studded with protein-manufacturing ribosomes giving it a "rough" appearance (hence its name).
- But it should be noted that these ribosomes are not resident of the endoplasmic reticulum incessantly.
- The ribosomes only bind to the ER once it begins to synthesize a protein destined for sorting.
- The membrane of the rough endoplasmic reticulum is continuous with the outer layer of the nuclear envelope.
- Although there is no continuous membrane between the rough ER and the Golgi apparatus, membrane bound vesicles shuttle proteins between these two compartments.
- The rough endoplasmic reticulum works in concert with the Golgi complex to target new proteins to their proper destinations.

- **Smooth endoplasmic reticulum**

The smooth endoplasmic reticulum has functions in several metabolic processes, including synthesis of lipids, metabolism of carbohydrates and calcium concentration, and attachment of receptors on cell membrane proteins.

It is connected to the nuclear envelope.

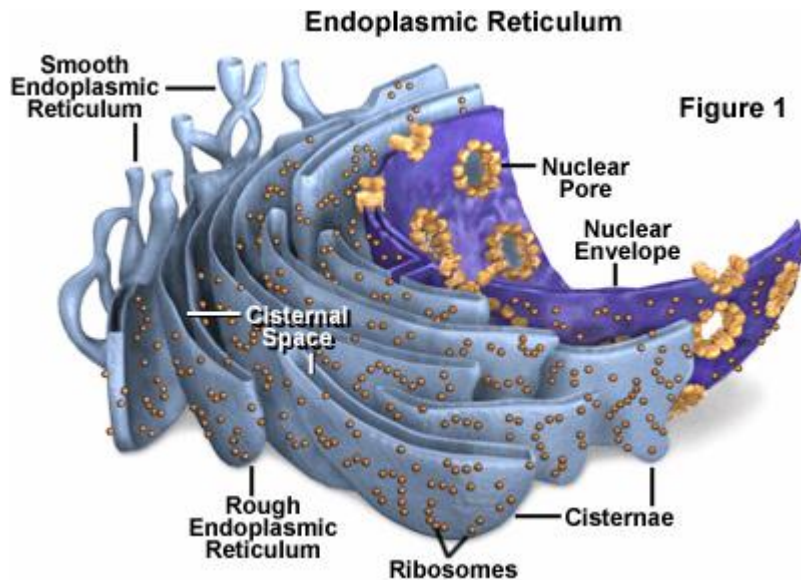
- **The network of smooth endoplasmic reticulum allows increased surface area for the action or storage of key enzymes and the products of these enzymes.**
- **The smooth endoplasmic reticulum is known for its storage of calcium ions in muscle cells.**

- **Sarcoplasmic reticulum**

The sarcoplasmic reticulum is a special type of smooth ER found in striated muscle.

The only structural difference between this organelle and the smooth endoplasmic reticulum is the medley of protein they have, both bound to their membranes and drifting within the confines of their lumens.

This fundamental difference is indicative of their functions: the smooth ER built to synthesize molecules and the sarcoplasmic reticulum built to store and pump calcium ions.



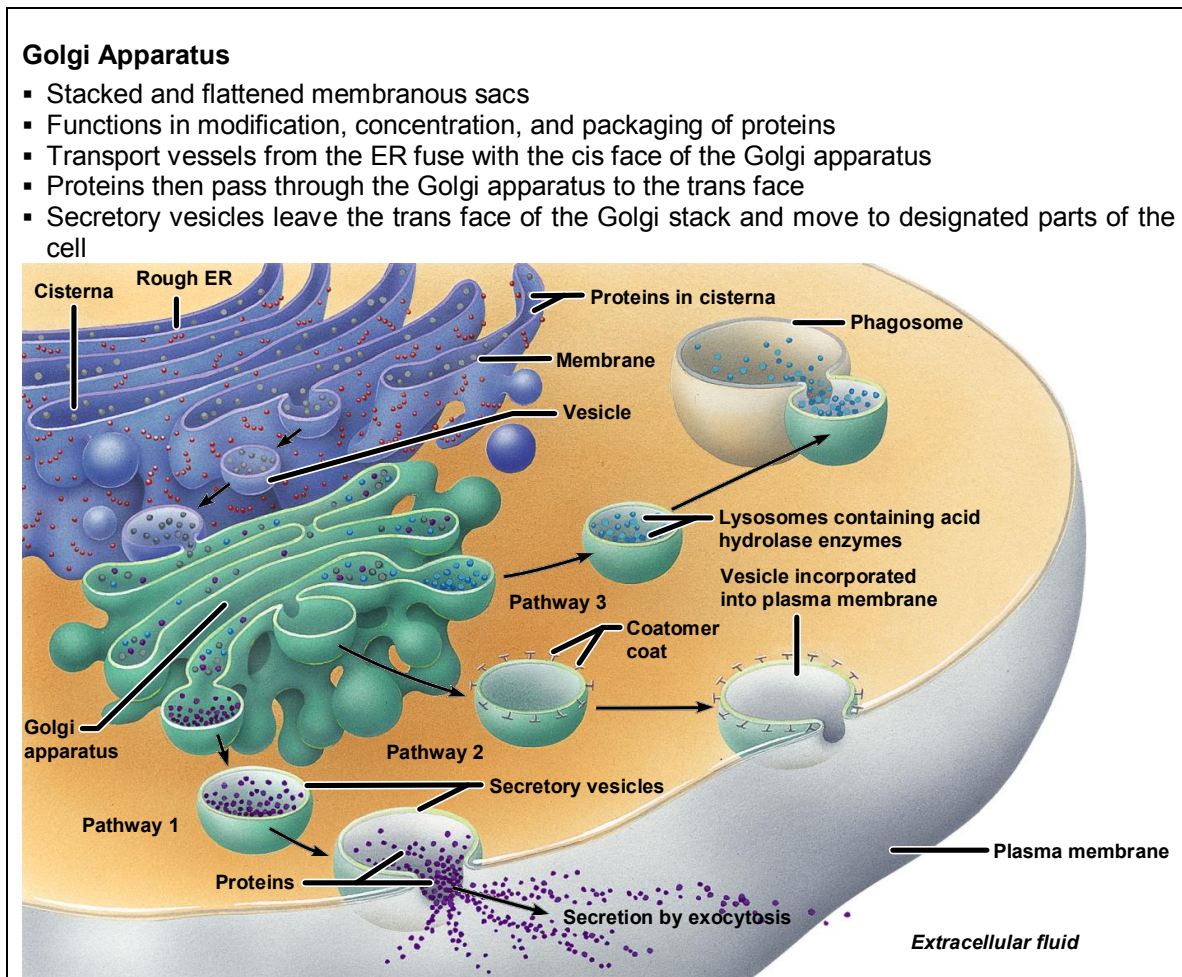
#### Other functions

- **Insertion of proteins into the endoplasmic reticulum membrane:** Integral proteins must be inserted into the endoplasmic reticulum membrane after they are synthesized. Insertion into the endoplasmic reticulum membrane requires the correct topogenic sequences.
- **Glycosylation:** Glycosylation involves the attachment of oligosaccharides.
- **Disulfide bond formation and rearrangement:** Disulfide bonds stabilize the tertiary and quaternary structure of many proteins.
- **Calcium storage:** The smooth endoplasmic reticulum serves as a major storage and release site of intracellular calcium ions. This is of particular importance in striated muscles (which contains a modified smooth endoplasmic reticulum called the sarcoplasmic reticulum) which must be able to continually contract.

#### d. Golgi Apparatus.

- The golgi apparatus is similar to the endoplasmic reticulum in that it is a canalicular system.
- The surface membranes of the canals and vesicles, however, are always smooth.
- This greatly contrasts with the outer surfaces of the endoplasmic reticulum, which are frequently encrusted with rough granules.
- **The function of the golgi apparatus is subject to debate, however, it is frequently associated with temporary storage of secretory materials and preparation of these for final secretion.**
- The golgi apparatus may also synthesize certain compounds, for enzymes have been extracted from membranes of the complex.

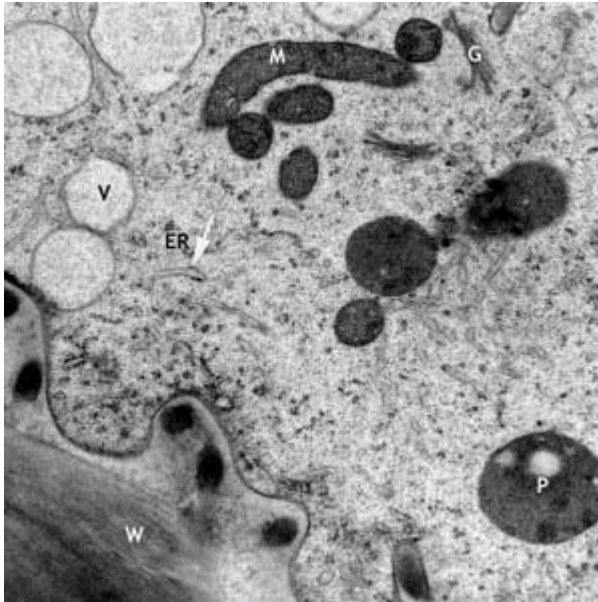




**e. Cytoplasm.**

- The cytoplasm is the fluid or semifluid contained inside the cell membrane, but outside the nucleus.
- The cytoplasm functions as a medium to contain many substances; such as fats, proteins, glucose, water, and electrolytes.
- The clear fluid portion of the cytoplasm is called **hyaloplasm**.
- Located within the cytoplasm are the organelles that perform highly specific functions in the cell.
- The cytoplasm consists of cytosol and the cellular organelles, except the cell nucleus.
- The cytosol is made up of water, salts, organic molecules and many enzymes that catalyze reactions.
- The cytoplasm plays an important role in a cell, serving as a "molecular chowder" in which the organelles are suspended and held together by a fatty membrane.

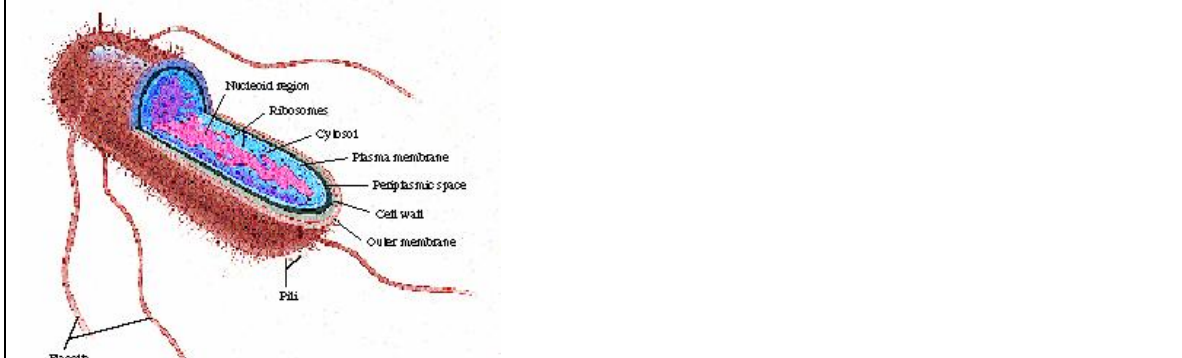




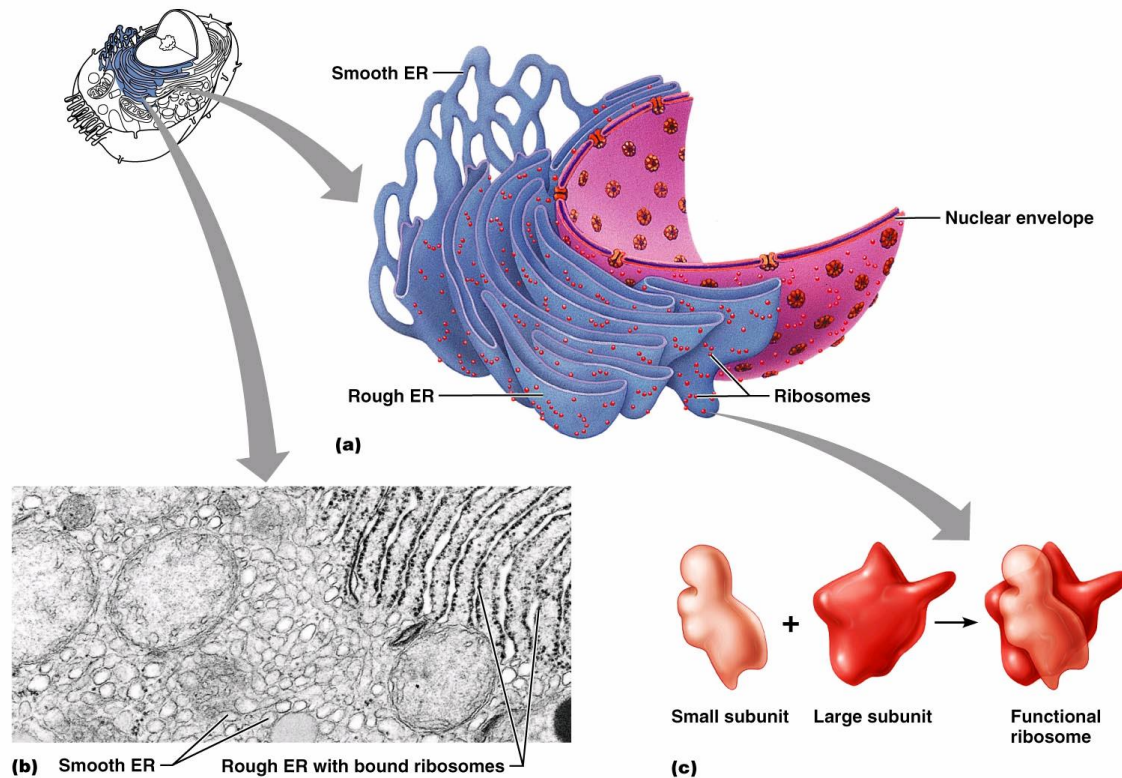
**f. Ribosomes.**

- Ribosomes are the site of protein synthesis and are referred to as "protein factories" of the cell.
- They are found either attached to the endoplasmic reticulum or in small groups in the cytoplasm called polyribosomes.
- A ribosome is composed mainly of RNA. [of ribosomal RNA and ribosomal proteins]
- It translates messenger RNA (mRNA) into a polypeptide chain (e.g., a protein).
- It can be thought of as a factory that builds a protein from a set of genetic instructions.
- Ribosomes can float freely in the cytoplasm (the internal fluid of the cell) or bound to the endoplasmic reticulum, or to the nuclear envelope.
- **Prokaryotes have 70S ribosomes**, each consisting of a **small (30S)** and a **large (50S) subunit**. Their large subunit is composed of a 5S RNA subunit (consisting of 120 nucleotides), a 23S RNA subunit (2900 nucleotides) and 34 proteins. The 30S subunit has a 16S RNA subunit bound to 21 proteins.
- **Eukaryotes have 80S ribosomes**, each consisting of a small (**40S**) and large (**60S**) subunit. Their large subunit is composed of a 5S RNA (120 nucleotides), a 28S RNA (4700 nucleotides), a 5.8S subunit (160 nucleotides) and ~49 proteins. The 40S subunit has a 18S RNA and ~33 proteins

**Prokaryotes** [bacteria] are organisms without a cell nucleus or indeed any other membrane-bound organelles, in most cases unicellular (in rare cases, multicellular).



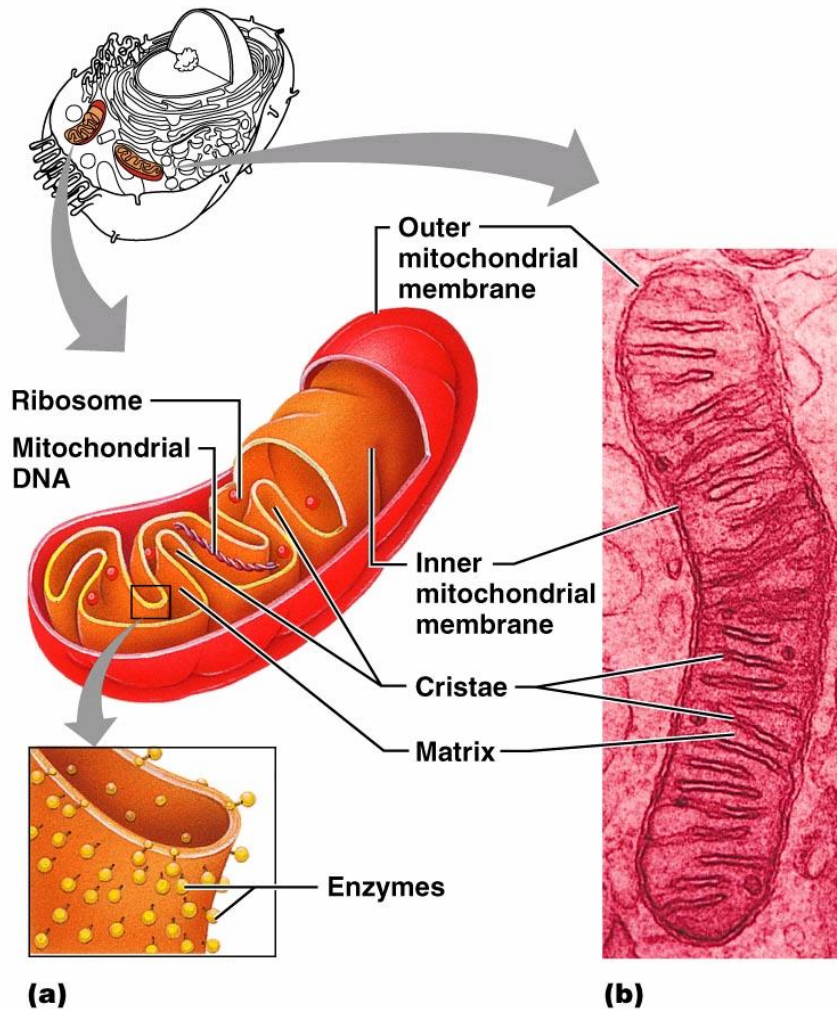
**Eukaryote:** Animals, plants, fungi, and protists are eukaryotes organisms with a complex cell or cells, in which the genetic material is organized into a membrane-bound nucleus or nuclei.



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**g. Mitochondria.**

- In living preparations, mitochondria are in constant motion and either vibrate in place or migrate to other portions of the cell.\
- Mitochondria possess double membranes; the inner membrane has tiny projections called **cristae**, which extend into the lumen (hollow tube) of the mitochondria.
- **Cristae greatly increase surface area within the organelle.**
- Mitochondria are found in areas of greatest cellular activity and are commonly referred to as "powerhouses" of the cell.
- Almost every oxidative enzyme of the cell is present on the inner surfaces of the mitochondrion.
- Here nutrients and oxygen react to provide energy in the form of a substance called adenosine triphosphate (ATP).
- ATP molecules then diffuse throughout the cell and provide energy wherever it is needed for cellular functions. This process is known as cellular respiration.



**h. Lysosomes.**

- Lysosomes are small bodies containing hydrolytic enzymes.
- If lysosomes should suddenly rupture, autolysis or self-destruction of the cell occurs.
- However, when lysosomes function properly, they play an important role in intracellular digestion.
- For example, a lysosome can fuse with a food vacuole, and digestion occurs within the composite structure formed.
- Products of digestion can then be utilized by the cell.

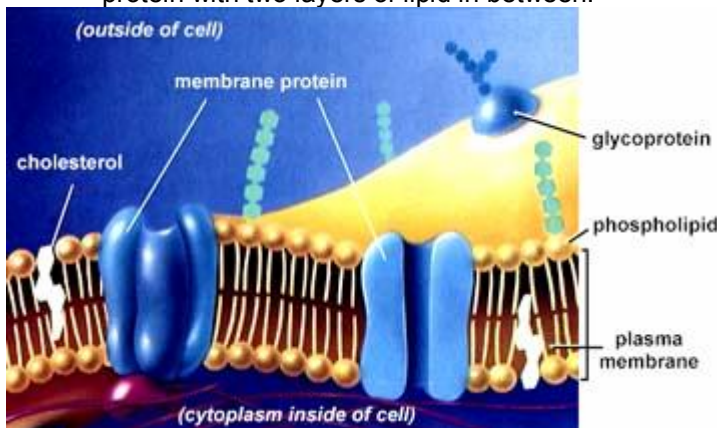
### Lysosomes

- Spherical membranous bags containing digestive enzymes
- Digest ingested bacteria, viruses, and toxins
- Degrade nonfunctional organelles
- Breakdown glycogen and release thyroid hormone
- Breakdown nonuseful tissue
- Breakdown bone to release  $\text{Ca}^{2+}$
- Secretory lysosomes are found in white blood cells, immune cells, and melanocytes

i. **Vacuoles.** Vacuoles are best described as small storage areas for water, electrolytes, and food particles.

j. **Cell Membrane.** (Animal cells do not have cell walls; they have cell membranes only. Plant cells have both.)

- A cell membrane or unit membrane is quite complex, having the capacity to selectively absorb certain constituents from the cell's surrounding environment and release waste materials and other unwanted products into the environment.
- The precise ultrastructure of a cellular membrane is still under considerable debate.
- Its structure varies from one membrane to another, making it difficult to describe a typical unit membrane.
- It is generally accepted that a unit membrane consists of an inner and outer layer of protein with two layers of lipid in between.





### **Plasma Membrane**

- Separates intracellular fluids from extracellular fluids
- Plays a dynamic role in cellular activity
- Glycocalyx is a glycoprotein area abutting the cell that provides highly specific biological markers by which cells recognize one another

### **Fluid Mosaic Model**

- Double bilayer of lipids with imbedded, dispersed proteins
  - Bilayer consists of phospholipids, cholesterol, and glycolipids
  - **Glycolipids are lipids with bound carbohydrate**
  - **Phospholipids have hydrophobic and hydrophilic bipoles**
- 

### **Functions of Membrane Proteins**

- Transport
  - Enzymatic activity
  - Receptors for signal transduction
- 

### **Functions of Membrane Proteins**

- Intercellular adhesion
  - Cell-cell recognition
  - Attachment to cytoskeleton and extracellular matrix
- 

### **Plasma Membrane Surfaces**

- Differ in the kind and amount of lipids they contain
  - Glycolipids are found only in the outer membrane surface
  - 20% of all membrane lipid is cholesterol
- 

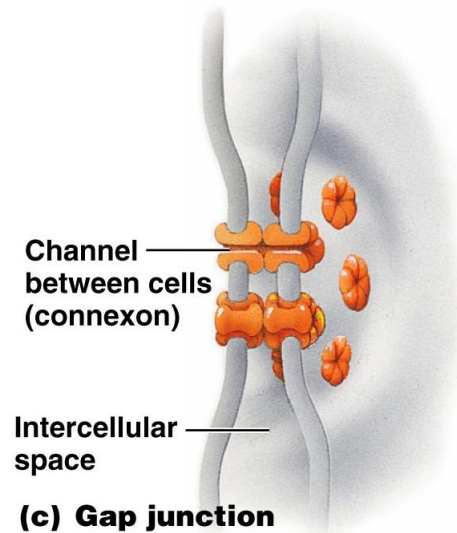
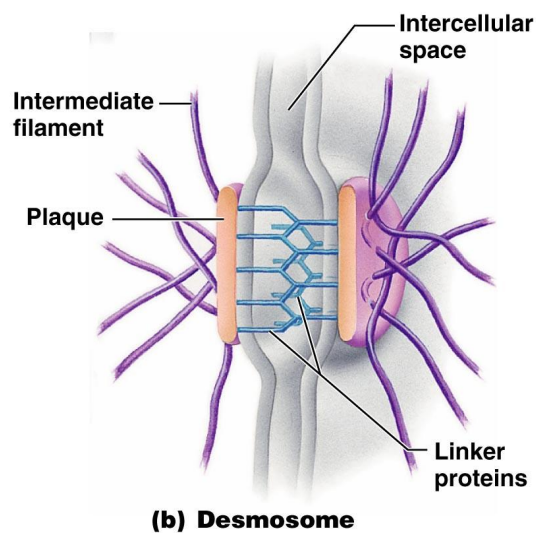
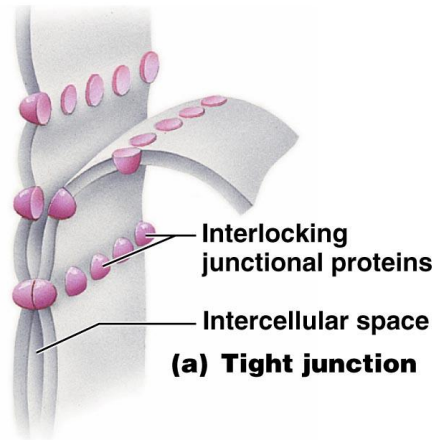
### **Lipid Rafts**

- Make up 20% of the outer membrane surface
  - Composed of sphingolipids and cholesterol
  - Are concentrating platforms for cell-signaling molecules
- 

### **Membrane Junctions**

- Tight junction – impermeable junction that encircles the cell
- Desmosome – anchoring junction scattered along the sides of cells
- Gap junction – a nexus that allows chemical substances to pass between cells.





### Endomembrane System

- System of organelles that function to:
  - **Produce, store, and export biological molecules**
  - **Degrade potentially harmful substances**
- System includes:
  - **Nuclear envelope, smooth and rough ER, lysosomes, vacuoles, transport vesicles, Golgi apparatus, and the plasma membrane**

### Endomembrane System

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### Peroxisomes

- Membranous sacs containing oxidases and catalases
  - Detoxify harmful or toxic substances
  - Neutralize dangerous free radicals
  - **Free radicals – highly reactive chemicals with unpaired electrons (i.e.,  $O_2^-$ )**
- 

### Cytoskeleton

## The cell and tissue

- The “skeleton” of the cell
  - Dynamic, elaborate series of rods running through the cytosol
  - Consists of microtubules, microfilaments, and intermediate filaments
- 

### **Microtubules**

- Dynamic, hollow tubes made of the spherical protein tubulin
- Determine the overall shape of the cell and distribution of organelles

### **Microfilaments**

- Dynamic strands of the protein actin
  - Attached to the cytoplasmic side of the plasma membrane
  - Braces and strengthens the cell surface
  - Attach to CAMs and function in endocytosis and exocytosis
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### **Intermediate Filaments**

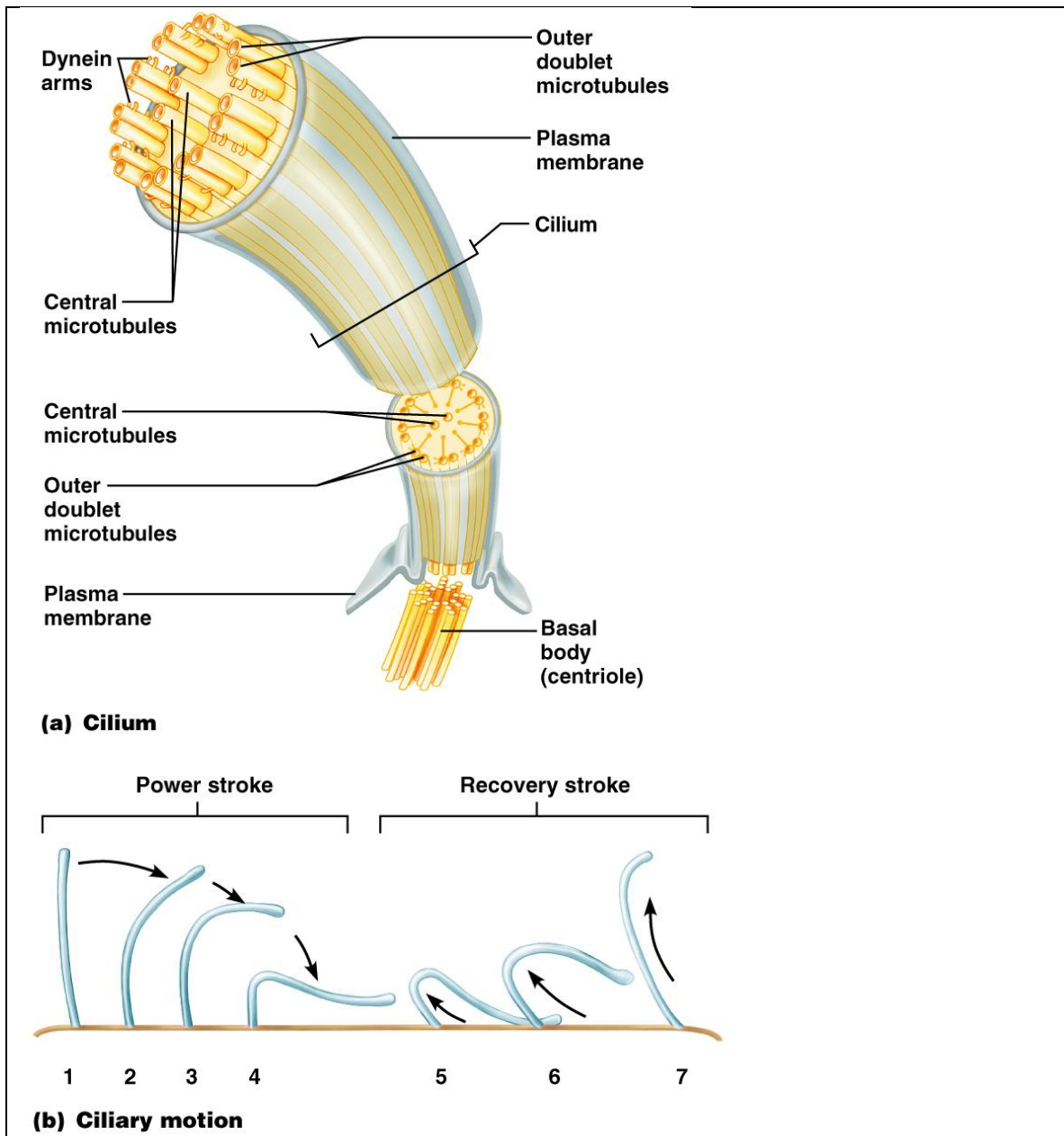
- Tough, insoluble protein fibers with high tensile strength
  - Resist pulling forces on the cell and help form desmosomes
- 

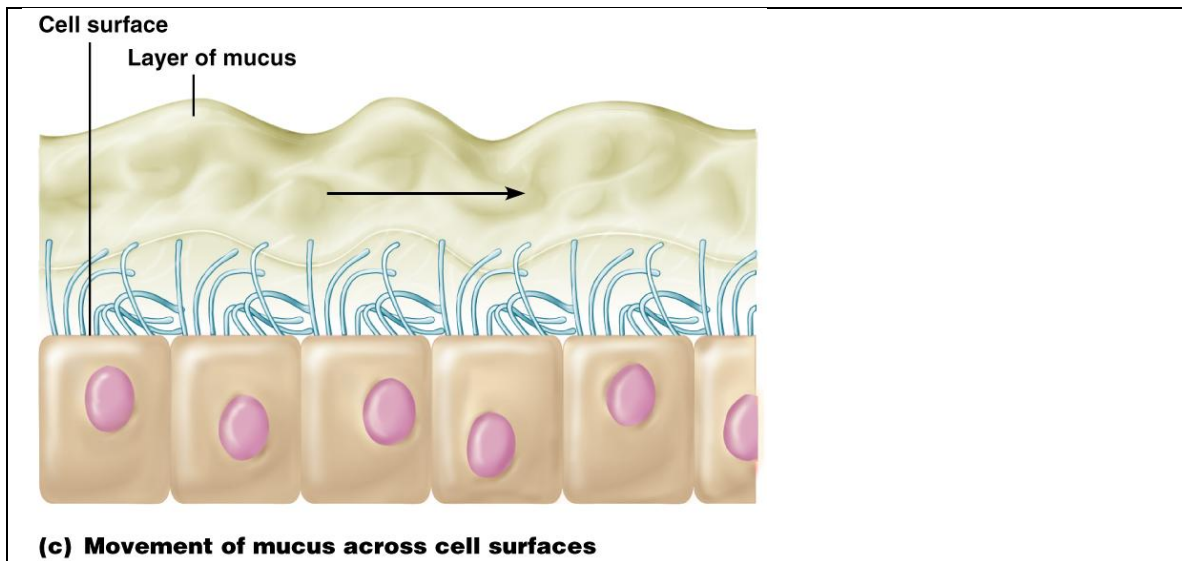
### **Motor Molecules**

- Protein complexes that function in motility
  - Powered by ATP
  - Attach to receptors on organelles
- 

### **Cilia**

- Whip-like, motile cellular extensions on exposed surfaces of certain cells
- Move substances in one direction across cell surfaces



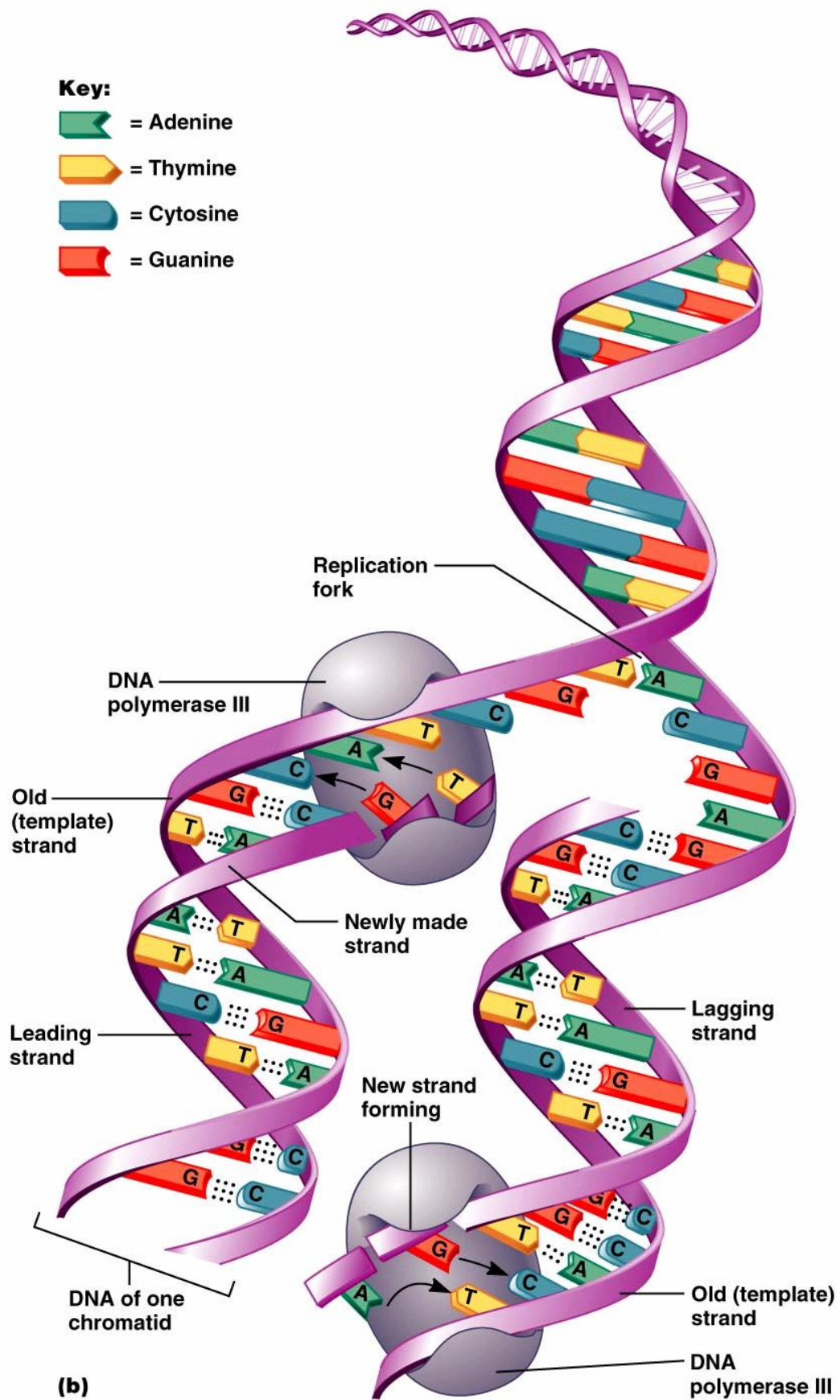


## THE STRUCTURE OF DEOXYRIBONUCLEIC ACID AND RIBONUCLEIC ACID

Prior to our discussion of protein synthesis, we will first discuss the structure of molecules responsible for producing proteins.

- **Deoxyribonucleic Acid.**

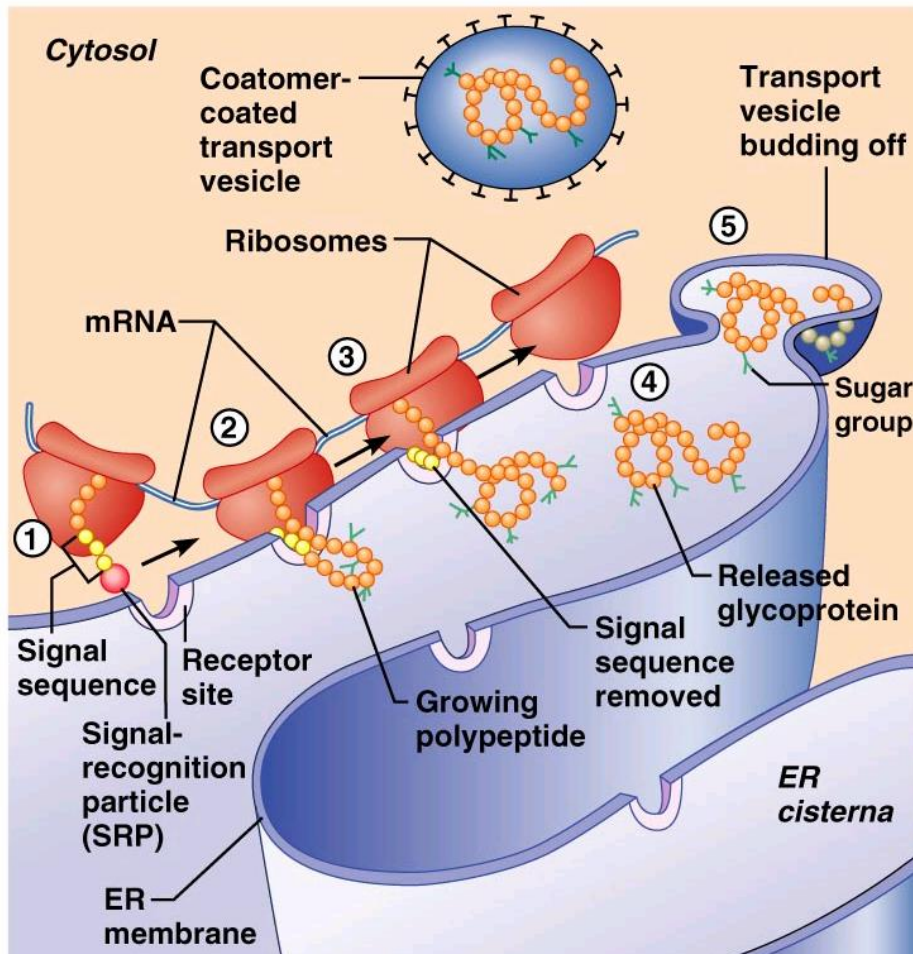
- Deoxyribonucleic acid (DNA), like other large organic molecules,
- is composed of a relatively simple building block compound, called a nucleotide.
- **A nucleotide includes three parts:**
  - a phosphate group, a five- carbon sugar called deoxyribose,
  - and an organic nitrogen-containing base.
- There are four different types of nucleotides that occur in DNA, the type of each depending upon which of four nitrogenous bases are included in its structure. The four nitrogenous bases are
  - adenine,
  - guanine,
  - thymine,
  - and cytosine.
- **Adenine and guanine are purine bases, characterized by a double-ring structure.**
- **Cytosine and thymine are pyrimidines, which have only a single ring.**
- A typical DNA molecule is double-stranded and helical and has been simply described as appearing like a ladder twisted into a form of a helix (spiral).
- The sides of the ladder are composed of alternating molecules of phosphate and sugar while the rungs of the ladder are each composed of two nitrogenous bases.
- Since the width of the DNA molecule is the same, a purine base is always attached to a pyrimidine in forming a rung of the ladder like structure.
- More specifically, adenine is always bonded to thymine, cytosine to guanine.





**b. Ribonucleic Acid.**

- Ribonucleic acid (RNA), like DNA, is composed of a basic unit called a nucleotide.
- The RNA nucleotide is similar to the nucleotide of DNA in that it contains a phosphate group, a ribose sugar, and an organic nitrogen-containing base.
- The four nitrogenous bases include
  - adenine,
  - guanine,
  - cytosine,
  - and uracil.



**c. Differences. Three main differences between DNA and RNA are:**

- (1) Deoxyribonucleic acid is double-stranded while RNA has one strand.
- (2) Deoxyribonucleic acid contains deoxyribose; RNA contains ribose.
- (3) Deoxyribonucleic acid contains thymine as one of its four nitrogenous bases while uracil has replaced thymine in RNA.

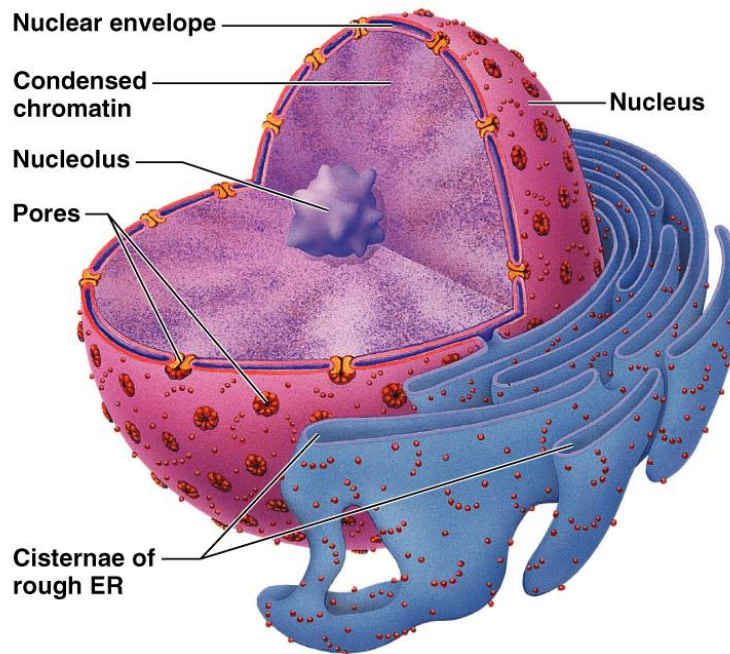
**Roles of the Three Types of RNA**

- **Messenger RNA (mRNA)** – carries the genetic information from DNA in the nucleus to the ribosomes in the cytoplasm
- **Transfer RNAs (tRNAs)** – bound to amino acids base pair with the codons of mRNA at the ribosome to begin the process of protein synthesis



### **Nucleus**

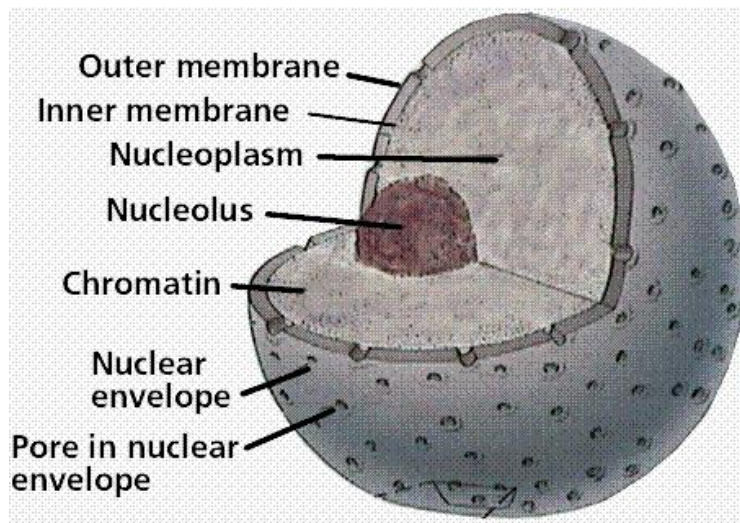
- Contains nuclear envelope, nucleoli, chromatin, and distinct compartments rich in specific protein sets
- Gene-containing control center of the cell
- Contains the genetic library with blueprints for nearly all cellular proteins
- Dictates the kinds and amounts of proteins to be synthesized



**(a)**

### **Nuclear Envelope**

- Selectively permeable double membrane barrier containing pores
- Encloses jellylike nucleoplasm, which contains essential solutes
- Outer membrane is continuous with the rough ER and is studded with ribosomes
- Inner membrane is lined with the nuclear lamina, which maintains the shape of the nucleus
- Pore complex regulates transport of large molecules into and out of the nucleus

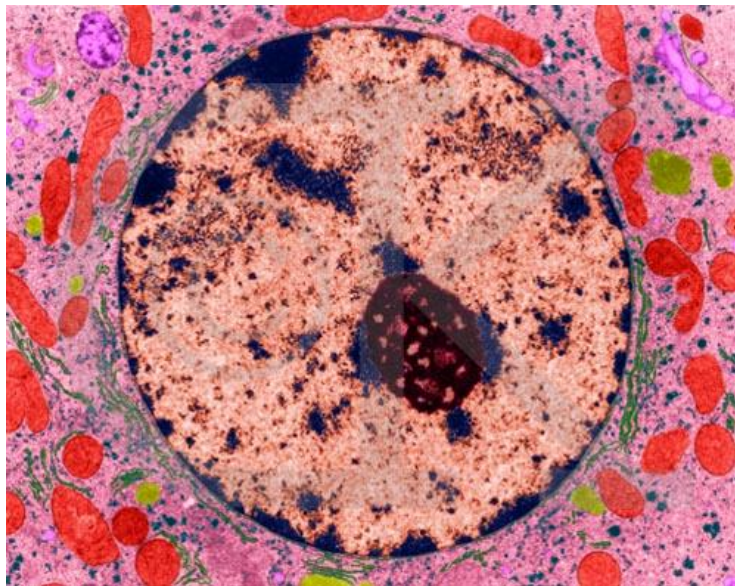


### **Nucleoli**

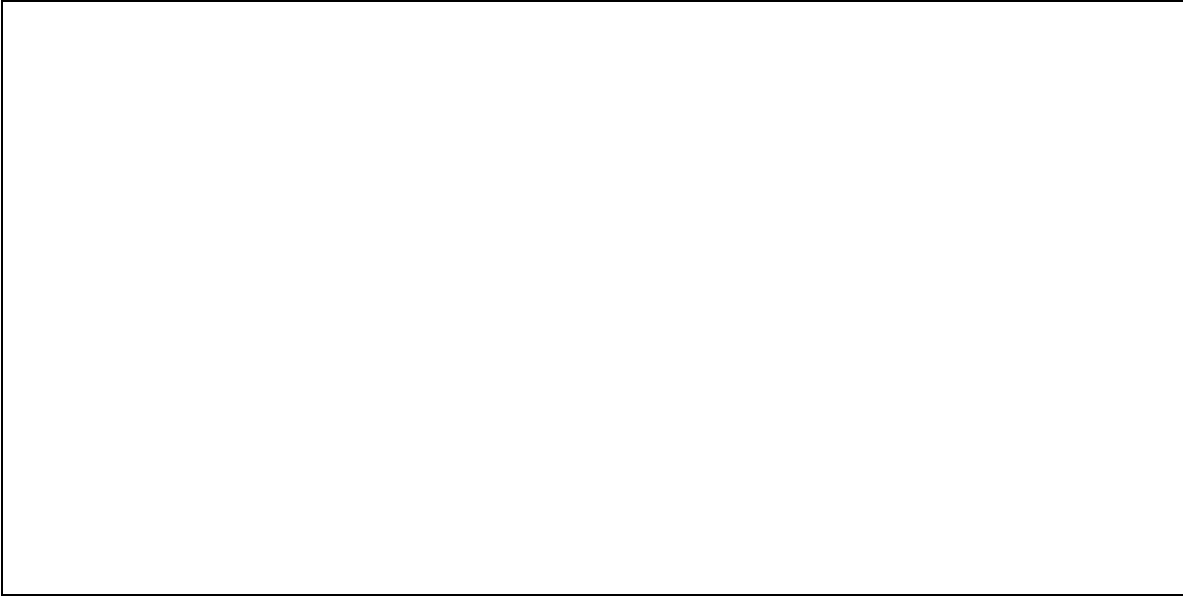
- Dark-staining spherical bodies within the nucleus
- Site of ribosome production

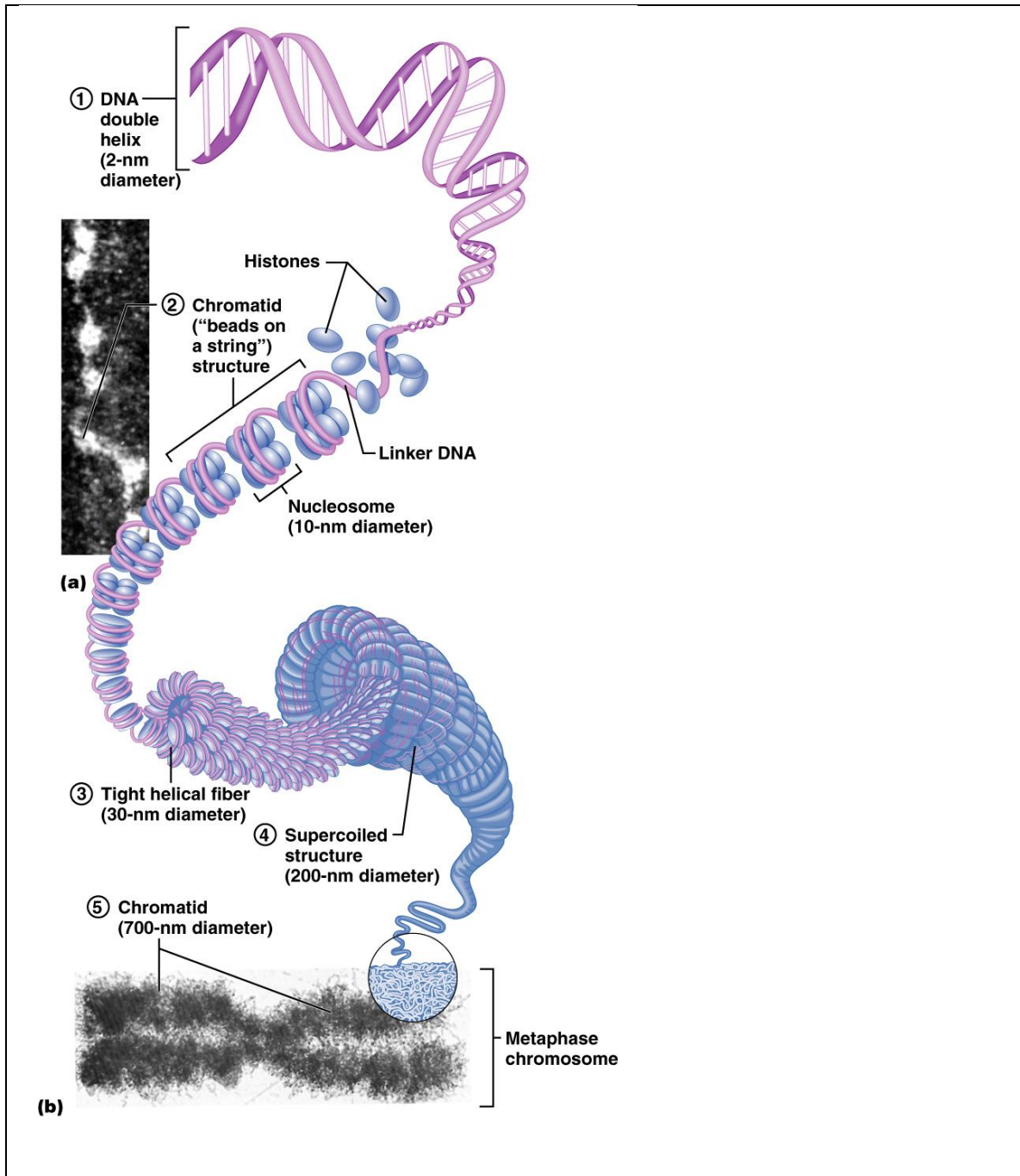
### **Chromatin**

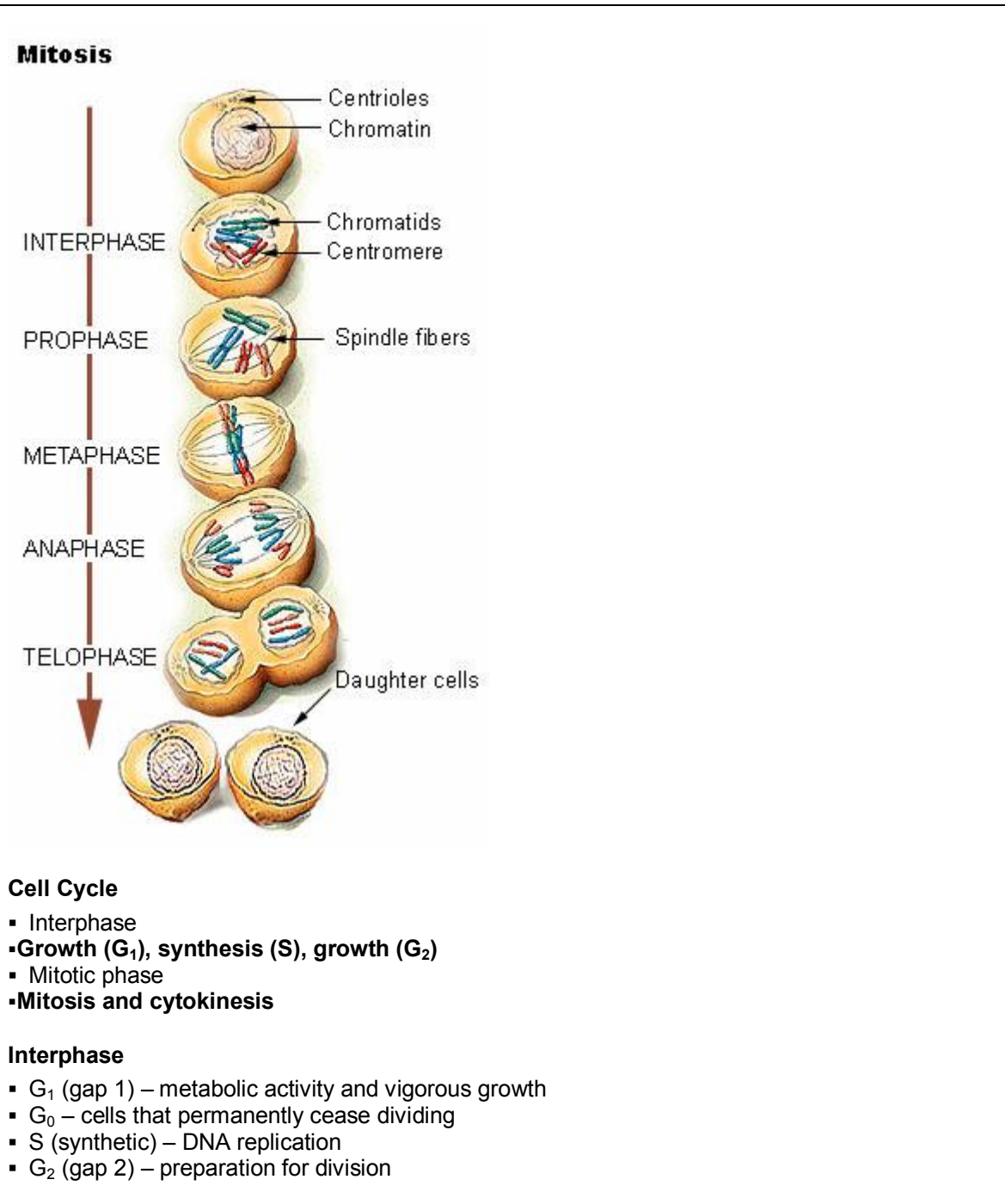
- Threadlike strands of DNA and histones
- Arranged in fundamental units called nucleosomes
- Form condensed, barlike bodies of chromosomes when the nucleus starts to divide

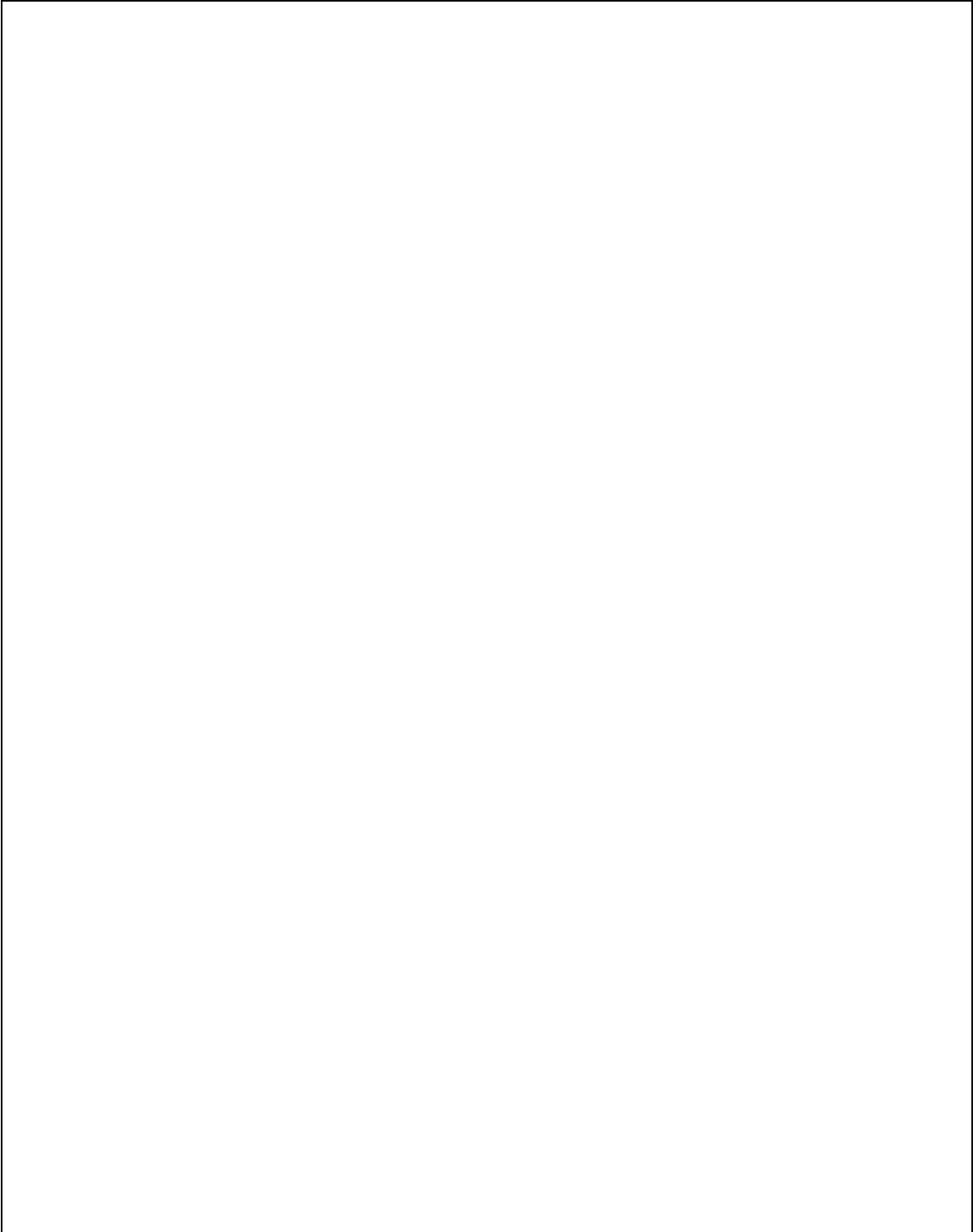


## The cell and tissue







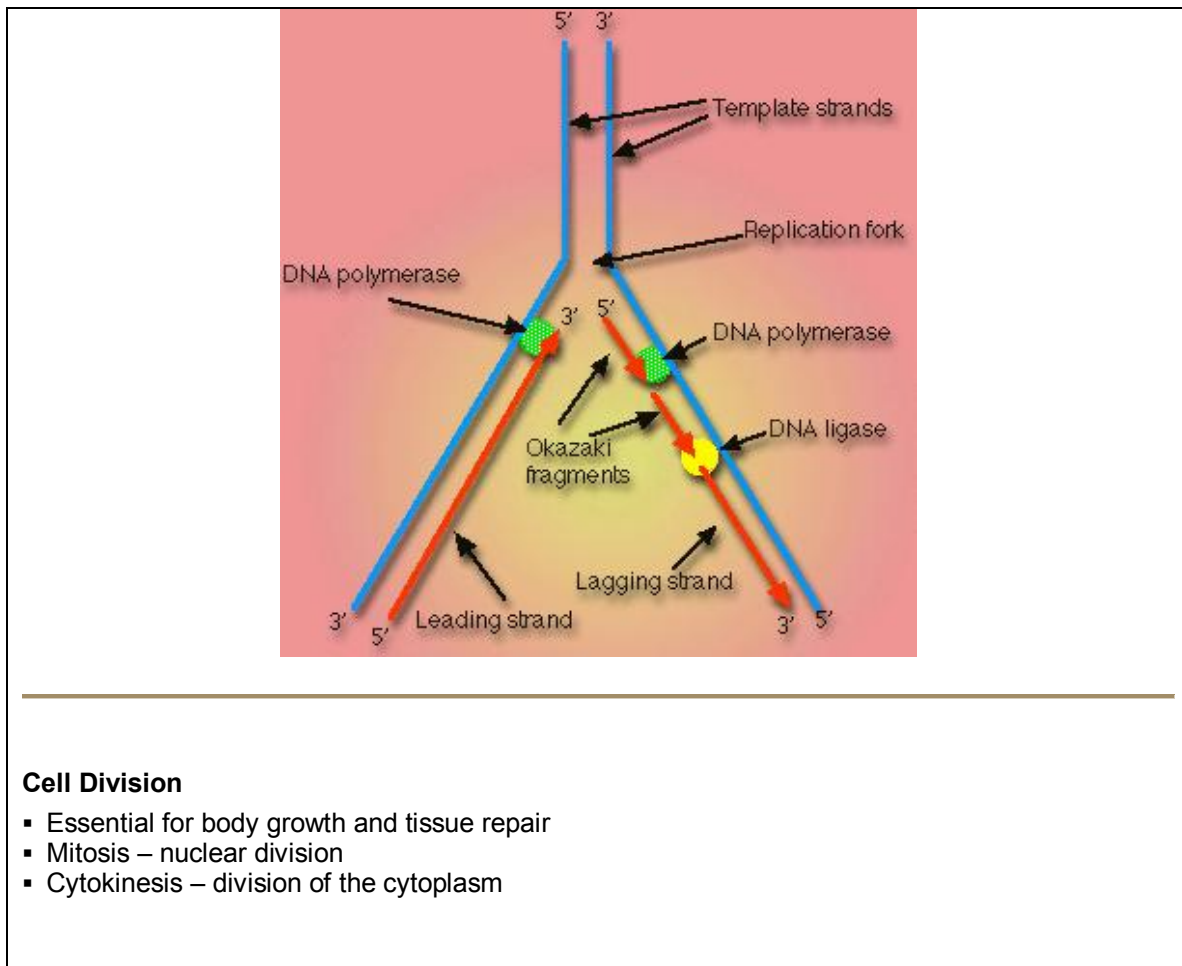


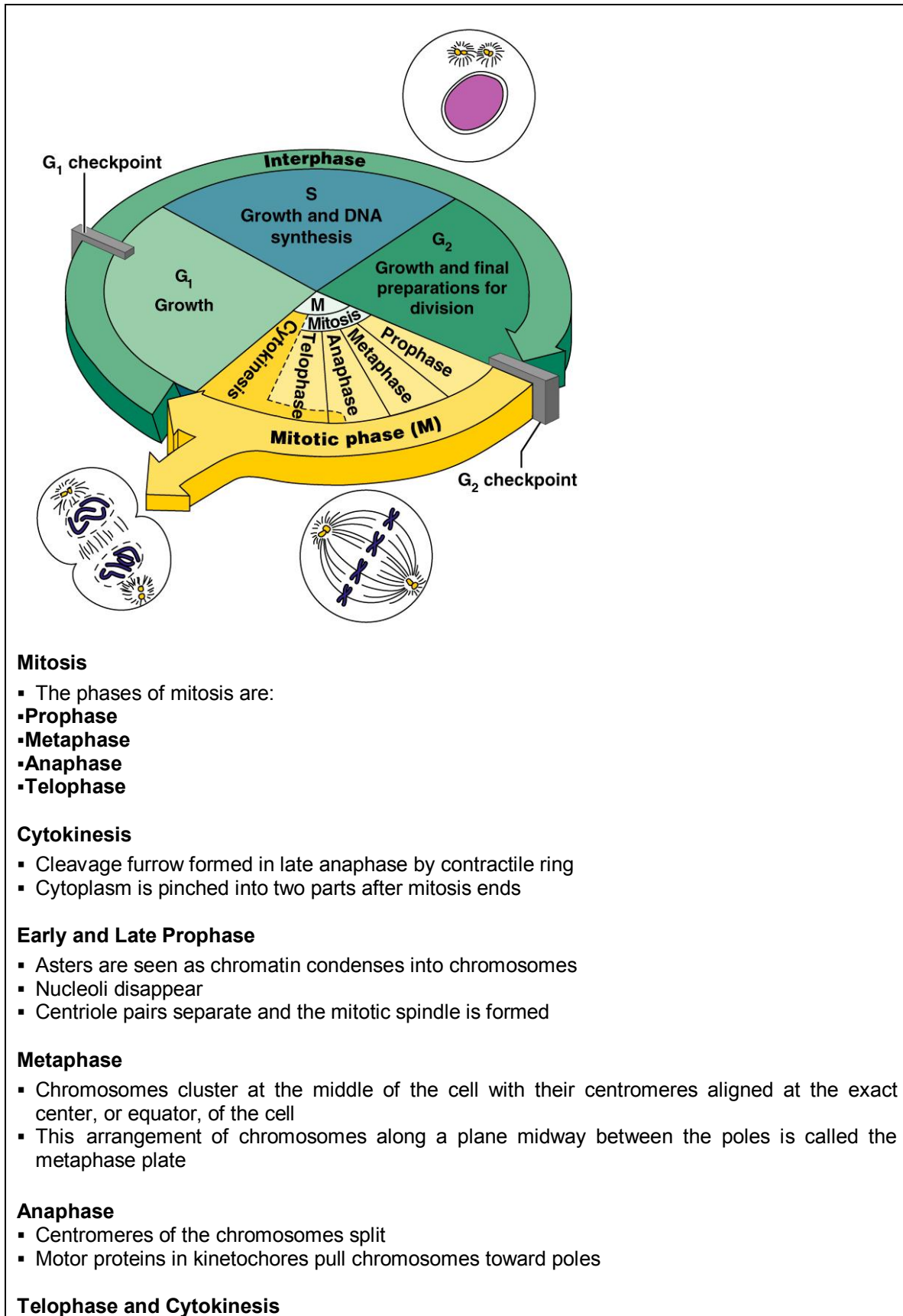


### **DNA Replication**

- DNA helices begin unwinding from the nucleosomes
- Helicase untwists the double helix and exposes complementary strands
- The site of replication is the replication bubble
- Each nucleotide strand serves as a template for building a new complementary strand
- The replisome uses RNA primers to begin DNA synthesis
- DNA polymerase III continues from the primer and covalently adds complementary nucleotides to the template
- Since DNA polymerase only works in one direction:
  - **A continuous leading strand is synthesized**
  - **A discontinuous lagging strand is synthesized**
  - **DNA ligase splices together the short segments of the discontinuous strand**
- Two new telomeres are also synthesized
- This process is called semiconservative replication

## The cell and tissue



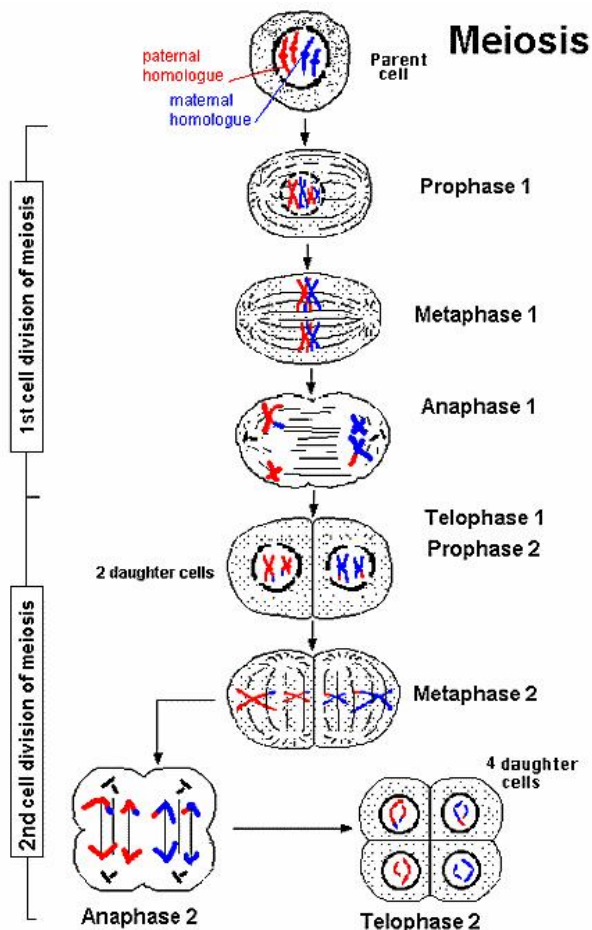


- New sets of chromosomes extend into chromatin
- New nuclear membrane is formed from the rough ER
- Nucleoli reappear
- Generally cytokinesis completes cell division

### Control of Cell Division

- Surface-to-volume ratio of cells
- Chemical signals such as growth factors and hormones
- Contact inhibition
- Cyclins and cyclin-dependent kinases (Cdks) complexes

### Meiosis



Meiosis is the type of cell division by which germ cells (eggs and sperm) are produced. Meiosis involves a reduction in the amount of genetic material.

Meiosis comprises two successive nuclear divisions with only one round of DNA replication. Four stages can be described for each nuclear division.

- **Interphase:** Before meiosis begins, genetic material is duplicated.
- **First division of meiosis**
  - **Prophase 1:** Duplicated chromatin condenses. Each chromosome consists of

two, closely associated sister chromatids. Crossing-over can occur during the latter part of this stage.

- **Metaphase 1:** Homologous chromosomes align at the equatorial plate.
- **Anaphase 1:** Homologous pairs separate with sister chromatids remaining together.
- **Telophase 1:** Two daughter cells are formed with each daughter containing only one chromosome of the homologous pair.
- **Second division of meiosis: Gamete formation**
  - **Prophase 2:** DNA does not replicate.
  - **Metaphase 2:** Chromosomes align at the equatorial plate.
  - **Anaphase 2:** Centromeres divide and sister chromatids migrate separately to each pole.
  - **Telophase 2:** Cell division is complete. Four haploid daughter cells are obtained.

One parent cell produces four daughter cells. Daughter cells have half the number of chromosomes found in the original parent cell and with crossing over, are genetically different.

Meiosis differs from mitosis primarily because there are two cell divisions in meiosis, resulting in cells with a haploid number of chromosomes.

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### Protein Synthesis

- DNA serves as master blueprint for protein synthesis
- Genes are segments of DNA carrying instructions for a polypeptide chain
- Triplets of nucleotide bases form the genetic library
- Each triplet specifies coding for an amino acid

### Roles of the Three Types of RNA

- Messenger RNA (mRNA) – carries the genetic information from DNA in the nucleus to the ribosomes in the cytoplasm
- Transfer RNAs (tRNAs) – bound to amino acids base pair with the codons of mRNA at the ribosome to begin the process of protein synthesis
- Ribosomal RNA (rRNA) – a structural component of ribosomes

### Transcription

- Transfer of information from the sense strand of DNA to RNA
- Transcription factor
- **Loosens histones from DNA in the area to be transcribed**
- **Binds to promoter, a DNA sequence specifying the start site of RNA synthesis**
- **Mediates the binding of RNA polymerase to promoter**

### Transcription: RNA Polymerase

- An enzyme that oversees the synthesis of RNA
- Unwinds the DNA template
- Adds complementary ribonucleoside triphosphates on the DNA template
- Joins these RNA nucleotides together
- Encodes a termination signal to stop transcription

### Initiation of Translation

- A leader sequence on mRNA attaches to the small subunit of the ribosome
- Methionine-charged initiator tRNA binds to the small subunit
- The large ribosomal unit now binds to this complex forming a functional ribosome

### **Genetic Code**

- RNA codons code for amino acids according to a genetic code

### **Information Transfer from DNA to RNA**

- DNA triplets are transcribed into mRNA codons by RNA polymerase
- Codons base pair with tRNA anticodons at the ribosomes
- Amino acids are peptide bonded at the ribosomes to form polypeptide chains
- Start and stop codons are used in initiating and ending translation

### **Other Roles of RNA**

- Antisense RNA – prevents protein-coding RNA from being translated
- MicroRNA – small RNAs that interfere with mRNAs made by certain exons
- Riboswitches – mRNAs that act as switches regulating protein synthesis in response to environmental conditions

### **Cytosolic Protein Degradation**

- Nonfunctional organelle proteins are degraded by lysosomes
- Ubiquitin attaches to soluble proteins and they are degraded in proteasomes

### **Extracellular Materials**

- Body fluids and cellular secretions
- Extracellular matrix

### **Developmental Aspects of Cells**

- All cells of the body contain the same DNA but develop into all the specialized cells of the body
- Cells in various parts of the embryo are exposed to different chemical signals that channel them into specific developmental pathways
- Genes of specific cells are turned on or off (i.e., by methylation of their DNA)
- Cell specialization is determined by the kind of proteins that are made in that cell
- Development of specific and distinctive features in cells is called cell differentiation
- Cell aging

• **Wear and tear theory attributes aging to little chemical insults and formation of free radicals that have cumulative effects throughout life**

• **Genetic theory attributes aging to cessation of mitosis that is programmed into our genes**

- **Ribosomal RNA (rRNA) – a structural component of ribosomes**



### **Cytoplasm**

- Cytoplasm – material between plasma membrane and the nucleus
- Cytosol – largely water with dissolved protein, salts, sugars, and other solutes
- Cytoplasmic organelles – metabolic machinery of the cell
- Inclusions – chemical substances such as glycosomes, glycogen granules, and pigment

### **Cytoplasmic Organelles**

- Specialized cellular compartments
- Membranous
- **Mitochondria, peroxisomes, lysosomes, endoplasmic reticulum, and Golgi apparatus**
- Nonmembranous
- **Cytoskeleton, centrioles, and ribosomes**

### **Mitochondria**

- Double membrane structure with shelf-like cristae
- Provide most of the cell's ATP via aerobic cellular respiration
- Contain their own DNA and RNA

### **Ribosomes**

- Granules containing protein and rRNA
- Site of protein synthesis
- Free ribosomes synthesize soluble proteins
- Membrane-bound ribosomes synthesize proteins to be incorporated into membranes

### **Endoplasmic Reticulum (ER)**

- Interconnected tubes and parallel membranes enclosing cisternae
- Continuous with the nuclear membrane
- Two varieties – rough ER and smooth ER

### **Rough (ER)**

- External surface studded with ribosomes
- Manufactures all secreted proteins
- Responsible for the synthesis of integral membrane proteins and phospholipids for cell membranes

### **Signal Mechanism of Protein Synthesis**

- mRNA – ribosome complex is directed to rough ER by a signal-recognition particle (SRP)
- SRP is released and polypeptide grows into cisternae
- The protein is released into the cisternae and sugar groups are added

### **Signal Mechanism of Protein Synthesis**

- The protein folds into a three-dimensional conformation
- The protein is enclosed in a transport vesicle and moves toward the Golgi apparatus

### **Smooth ER**

- Tubules arranged in a looping network
- Catalyzes the following reactions in various organs of the body
- **In the liver – lipid and cholesterol metabolism, breakdown of glycogen and, along with the kidneys, detoxification of drugs**
- **In the testes – synthesis of steroid-based hormones**

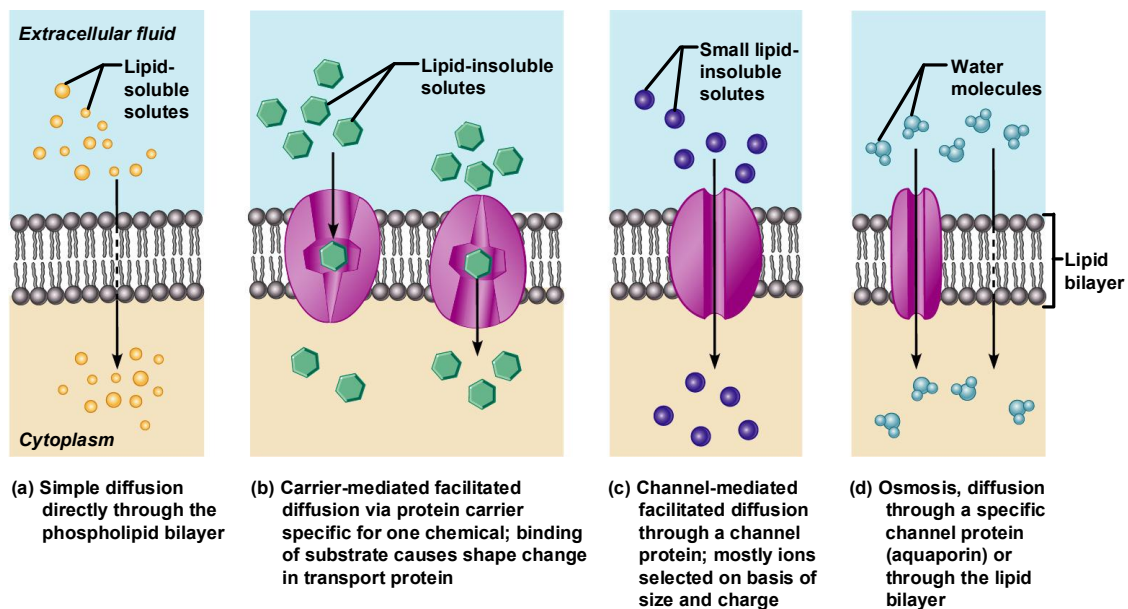
### **Smooth ER**

- Catalyzes the following reactions in various organs of the body (continued)
- In the intestinal cells – **absorption, synthesis, and transport of fats**
- In skeletal and cardiac muscle – **storage and release of calcium**

## DIFFUSION

The continuous movement of molecules among each other in liquids or in gases is called diffusion; the diffusion of solute particles is from an area of greater concentration to an area of lower concentration. The following are related concepts:

## Diffusion Through the Plasma Membrane



- Brownian Movement.** All molecules and ions in the fluids of the body are in constant motion. Each particle in solution moves in its own particular way. The motion is now **called Brownian movement**, and it occurs in all types of fluids including those of the human body. Brownian movement is due to the collisions of the molecules of the dispersion medium (usually a fluid), against colloidal particles.
- This motion can sometimes be seen occurring inside a living cell. Brownian movement depends on the size of the particles and the viscosity of the medium. Rapidity of the movement is proportional to the temperature; the higher the temperature, the more rapid is the agitation and the greater the movement of the molecules.

**b. Molecular Collisions.** The motion of molecules never ceases. When a moving molecule hits another, it propels the second molecule. This striking of a second molecule decreases the energy of the first molecule and adds energy to the second molecule. Now the second molecule moves more rapidly than before, while the first molecule slows down in speed of movement. Molecules can be propelled first in one direction and then immediately in another. shows the movement of a single molecule during a fraction of a second. It shows the molecule being bounced off other

## The cell and tissue

molecules. Ions, molecules, and colloids diffuse in a similar manner; however, heavier particles diffuse more slowly than lighter ones.

c. **Solvent and Solutes.** A solvent is a substance that is used to dissolve or uniformly disperse one or more other substances. A solvent is usually the liquid component of a solution and is present in greater amounts than the solute. It follows then, that a solute is that substance that is dissolved in a solvent. A solute is usually present in much smaller amounts than the solvent. An example would be a gram of salt dissolved in a liter of water. In this case, the water is the solvent and the salt is the solute. A solution may be composed of one or more solutes.

d. **Concentration Gradient.** The difference in concentration of a solute, on opposite sides of a membrane or from top to bottom of a centrifuge tube, is called the concentration gradient. When there is a concentration gradient, the solute tends to migrate from the area of higher concentration to the area of lower concentration, which tends to make the concentration equal in all areas. The size of the gradient is directly proportional to the net rate of diffusion of that solute.

### **Passive Membrane Transport: Diffusion**

- Simple diffusion – nonpolar and lipid-soluble substances
- **Diffuse directly through the lipid bilayer**
- **Diffuse through channel proteins**

### **Passive Membrane Transport: Diffusion**

- Facilitated diffusion
- **Transport of glucose, amino acids, and ions**
- **Transported substances bind carrier proteins or pass through protein channels**

### **Carrier Proteins**

- Are integral transmembrane proteins
- Show specificity for certain polar molecules including sugars and amino acids

### **Passive Membrane Transport: Osmosis**

- Occurs when the concentration of a solvent is different on opposite sides of a membrane
- Diffusion of water across a semipermeable membrane
- Osmolarity – total concentration of solute particles in a solution

Tonicity – how a solution affects cell volume

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## **Passive Membrane Transport – Review**

Process	Energy Source	Example
Simple diffusion	Kinetic energy	Movement of O <sub>2</sub> through membrane
Facilitated diffusion	Kinetic energy	Movement of glucose into cells
Osmosis	Kinetic energy	Movement of H <sub>2</sub> O in & out of cells
Filtration	Hydrostatic pressure	Formation of kidney filtrate

### **Passive Membrane Transport: Filtration**

- The passage of water and solutes through a membrane by hydrostatic pressure
- Pressure gradient pushes solute-containing fluid from a higher-pressure area to a lower-pressure area

### **Effects of Solutions of Varying Tonicity**

- Isotonic – solutions with the same solute concentration as that of the cytosol
- Hypertonic – solutions having greater solute concentration than that of the cytosol
- Hypotonic – solutions having lesser solute concentration than that of the cytosol

### **Active Transport**

- Uses ATP to move solutes across a membrane
- Requires carrier proteins

### Types of Active Transport

- Symport system – two substances are moved across a membrane in the same direction
- Antiport system – two substances are moved across a membrane in opposite directions

### Types of Active Transport

- Primary active transport – hydrolysis of ATP phosphorylates the transport protein causing conformational change
- Secondary active transport – use of an exchange pump (such as the  $\text{Na}^+$ - $\text{K}^+$  pump) indirectly to drive the transport of other solutes

### Types of Active Transport

## Active Membrane Transport – Review

Process	Energy Source	Example
Active transport of solutes	ATP	Movement of ions across membranes
Exocytosis	ATP	Neurotransmitter secretion
Endocytosis	ATP	White blood cell phagocytosis
Fluid-phase endocytosis	ATP	Absorption by intestinal cells
Receptor-mediated endocytosis	ATP	Hormone and cholesterol uptake
Endocytosis via caveoli	ATP	Cholesterol regulation
Endocytosis via coatomer vesicles	ATP	Intracellular trafficking of molecules

### Vesicular Transport

- Transport of large particles and macromolecules across plasma membranes
- **Exocytosis – moves substance from the cell interior to the extracellular space**
- **Endocytosis – enables large particles and macromolecules to enter the cell**

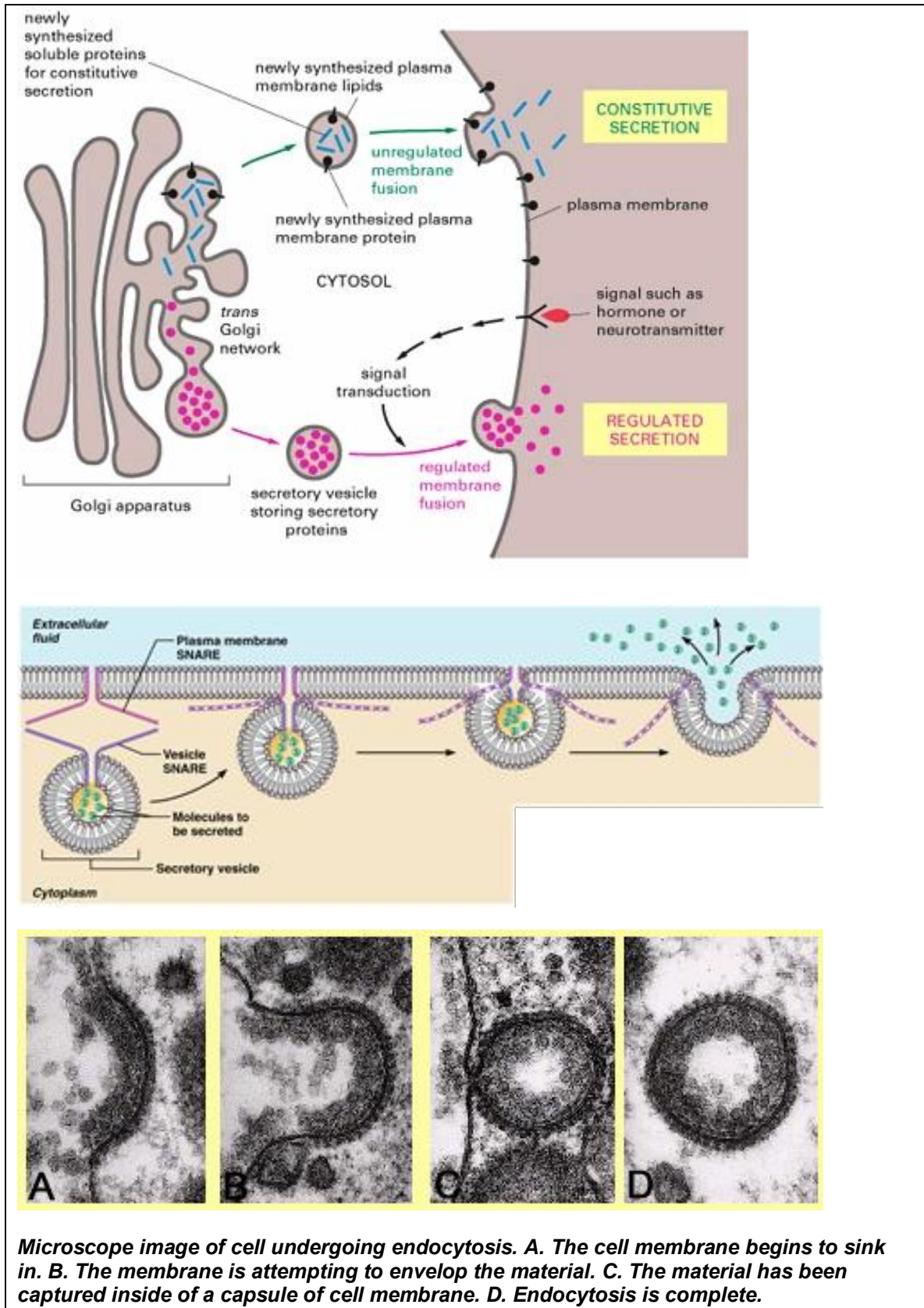
### Vesicular Transport

- Transcytosis – moving substances into, across, and then out of a cell
- Vesicular trafficking – moving substances from one area in the cell to another
- Phagocytosis – pseudopods engulf solids and bring them into the cell's interior

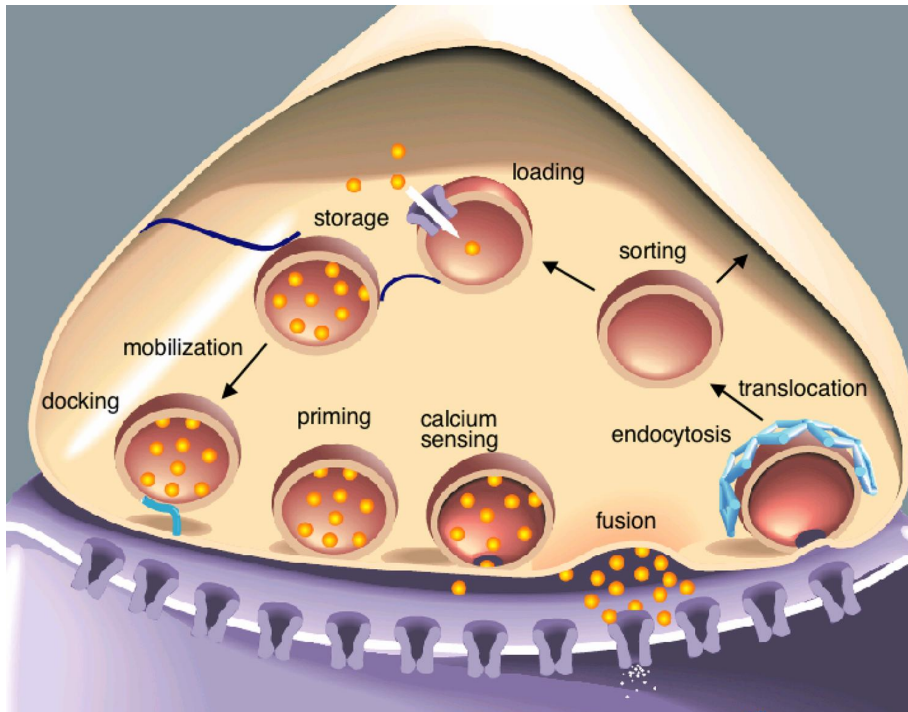
### Vesicular Transport

- Fluid-phase endocytosis – the plasma membrane infolds, bringing extracellular fluid and solutes into the interior of the cell
- Receptor-mediated endocytosis – clathrin-coated pits provide the main route for endocytosis and transcytosis
- Non-clathrin-coated vesicles – caveolae that are platforms for a variety of signaling molecules

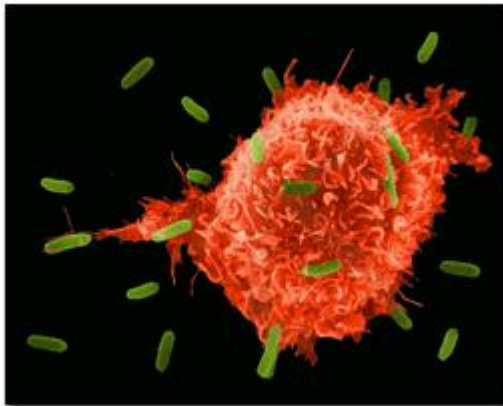
### Exocytosis







#### PHAGOCYTOSIS :



White blood cells use phagocytosis to remove foreign particles from the blood stream. These cells will literally engulf foreign particles that are the same size as itself. There are two types of white blood cells which act as phagocytes: macrophages and polymorphic leucocytes. To be phagocytosed, particles need to bind to the receptors on the phagocyte. Then the particle is engulfed and absorbed

#### Membrane Potential

- Voltage across a membrane
- Resting membrane potential – the point where  $K^+$  potential is balanced by the membrane potential
- Ranges from  $-20$  to  $-200$  mV
- Results from  $Na^+$  and  $K^+$  concentration gradients across the membrane
- Differential permeability of the plasma membrane to  $Na^+$  and  $K^+$

- Steady state – potential maintained by active transport of ions

#### **Generation and Maintenance of Membrane Potential**

##### **Cell Adhesion Molecules (CAMs)**

- Anchor cells to the extracellular matrix
- Assist in movement of cells past one another
- Rally protective white blood cells to injured or infected areas

##### **Roles of Membrane Receptors**

- Contact signaling – important in normal development and immunity
- Electrical signaling – voltage-regulated “ion gates” in nerve and muscle tissue
- Chemical signaling – neurotransmitters bind to chemically gated channel-linked receptors in nerve and muscle tissue
- G protein-linked receptors – ligands bind to a receptor which activates a G protein, causing the release of a second messenger, such as cyclic AMP

##### **Operation of a G Protein**

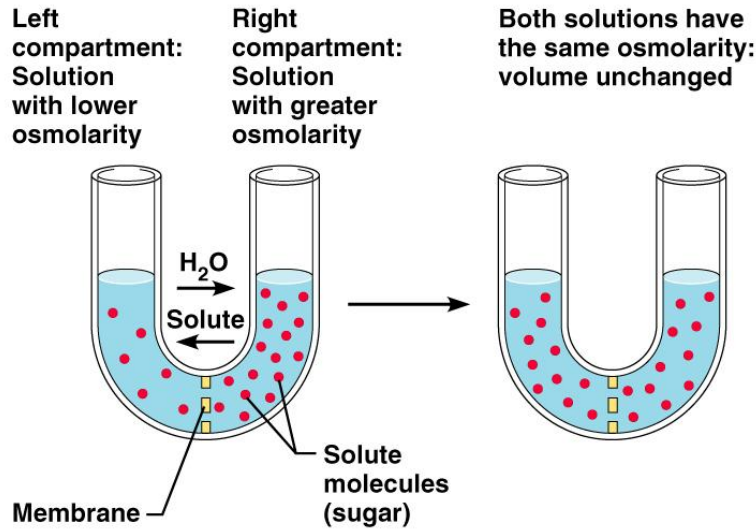
- An extracellular ligand (first messenger), binds to a specific plasma membrane protein
- The receptor activates a G protein that relays the message to an effector protein

##### **Operation of a G Protein**

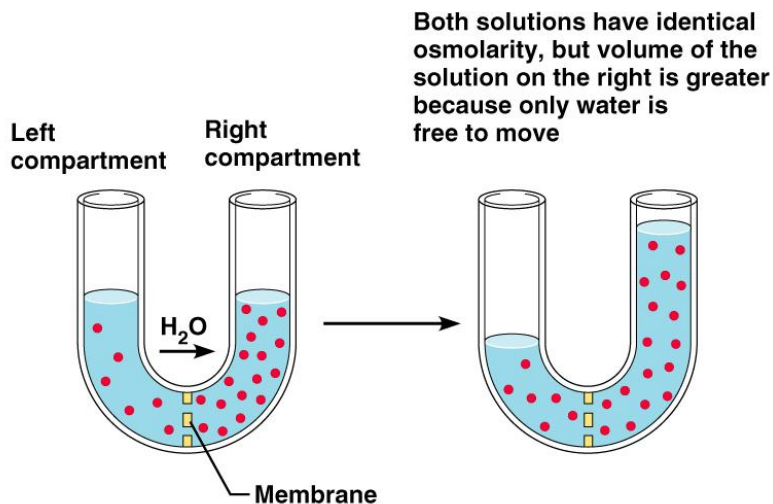
- The effector is an enzyme that produces a second messenger inside the cell
- The second messenger activates a kinase
- The activated kinase can trigger a variety of cellular responses

#### **OSMOSIS**

a. **Definition.** Osmosis is the movement of solvent (usually water) from a solution of lesser solute concentration through a membrane to a solution of greater solute concentration. **Figure 1–5 demonstrates the effect of osmotic pressure.** The pressure of the water molecules entering the solution on the left must be counterbalanced by the hydrostatic pressure due to the increased height of the solution on the left. Once equilibrium has been achieved, the height of the solution may be used to determine its osmotic pressure. Osmosis can be used to understand actions of solutions of varying concentrations (interstitial fluids, plasma) on surrounding cells.



**(a) Membrane permeable to both solute molecules and water**

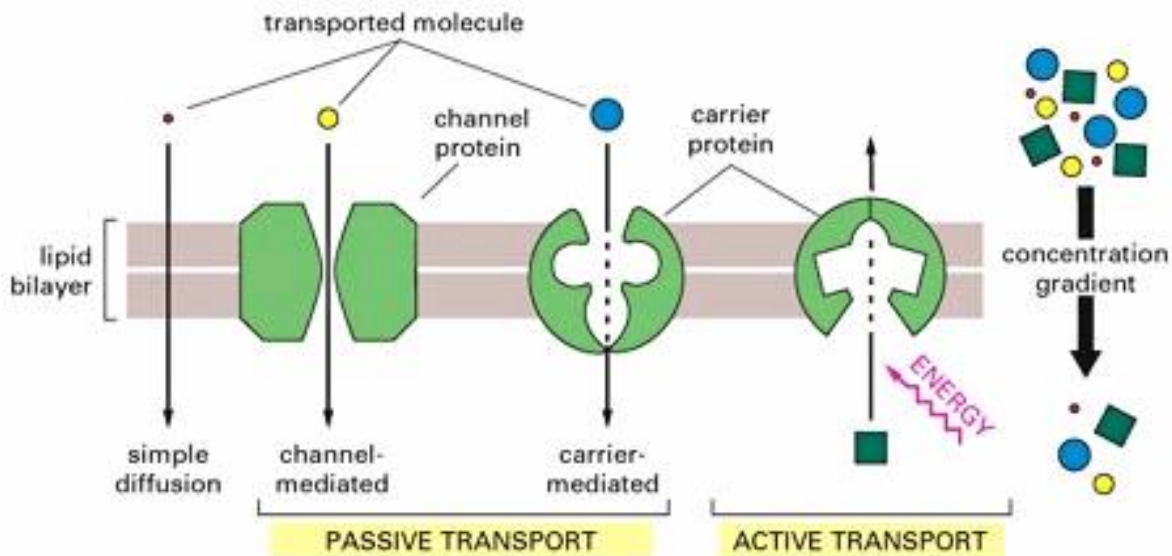


**(b) Membrane impermeable to solute molecules, permeable to water**

**b. Isotonic Solutions.** An isotonic solution is one in which the concentration of the surrounding fluid, and the osmotic pressure outside a cell, is equal to the concentration and the osmotic pressure inside the cell. The cell retains its original shape. The cytoplasm remains unchanged and there is no osmosis.

**c. Hypotonic Solutions.** When the concentration and osmotic pressure are lower in the surrounding fluid than in the cell, the cell begins to take up water, and the surrounding solution is said to be hypotonic. The cell begins to take up water by osmosis through a semipermeable membrane (the cell membrane) and greatly enlarges by swelling. When the fluid inside the cell becomes diluted sufficiently to equal the concentration outside the cell, further osmosis ceases (figure 1–6 A).

d. **Hypertonic Solutions.** When a cell is placed in a highly concentrated solution that has a higher osmotic pressure than that of the inside of the cell, the cell loses water from its cytoplasm and the surrounding solution is said to be hypertonic. Until the two concentrations are equal, water passes from the cell to the surrounding medium by osmosis (figure 1–6 B) and the cell shrinks.



## ACTIVE TRANSPORT

Active transport means the movement of materials through the cell membrane by energy-requiring chemical processes rather than by simple diffusion.

a. **Energy Expenditure.** Active transport requires a considerable amount of energy for two reasons:

(1) Energy is required to initiate the carrier system and begin the chemical reactions.

(2) A considerable amount of energy is used to transport a substance from a medium of low concentration to one of high concentration. An example is the transport of potassium from the extracellular fluid to the intracellular fluid and sodium from intracellular fluid to extracellular fluid by the sodium/potassium ion pump.

b. **Concentration Control.** There exists a control mechanism that determines how much of a substance should be concentrated. This process also is genetically controlled.

## TISSUE FLUID

a. **General.** Fluid outside the vascular system, bathing the cells, is interstitial fluid. This extracellular fluid that constitutes the liquid environment of cells is composed of the interstitial fluid and the circulating blood plasma. Capillaries provide a continuous living membrane that separates blood from the tissues. This semipermeable membrane permits the passage of water

## The cell and tissue

and crystalloids (see note below) from the blood, but does not permit the plasma proteins to pass through. Since most of the cells of the body lie outside of blood vessels, there must be a means of providing all of the cells with food materials and relieving them of their waste materials. The walls of the arteries are too thick to allow materials to diffuse through them. Arteries carry blood to the capillaries, and the thin walls of the capillaries allow water, food materials, and oxygen to nourish the individual cells. The relationship between the intercellular substance and the tissue fluid is different in different parts of the body. At some sites, where the intercellular substance is a sol, the tissue fluid is the medium in which the colloidal amorphous substance is dispersed. At other sites the amorphous substance exists as rigid gels.

**NOTE:** A crystalloid is a substance whose particles are small enough to pass through animal membranes.

**NOTE:** A colloid is similar to a solution; the suspended particles are too large to pass through an animal membrane but they are still so small that they do not settle out.

**NOTE:** A sol is a colloid system in which the particles are suspended in a liquid.

b. **Formation of Tissue Fluid.** Arteries are under a great deal of hydrostatic pressure, which would be an ideal means for pushing fluid out through the cellular wall. However, the walls of the arteries are so very thick, because they are under so much pressure, that no material can diffuse through them. In fact, these walls are so thick that the outer side must be fed by fluid from an outside source. Arteries feed into arterial capillaries. The walls of these capillaries are so very thin that the hydrostatic pressure within their arterial ends is sufficient to drive fluid out through the endothelium. The arterial ends of capillaries are the most important source of tissue fluid in the body.

c. **Absorption.** If tissue fluid were only produced and not absorbed by some mechanism, the body would swell enormously. There are two mechanisms that together absorb tissue fluid at the same rate that it is produced.

(1) Venous ends of capillaries. The hydrostatic pressure of the capillaries must be great enough to force fluid out when another factor is seeking to draw tissue fluid back into the capillary. The attraction that blood has for tissue fluid is due to the fact that the osmotic pressure of blood is slightly higher than that of the tissue fluid. Hydrostatic pressure is greater at the arterial side of the capillary so fluid is forced out at this point. At the venous end of the capillary, the osmotic pressure of the blood is greater than the hydrostatic pressure of the capillary; thus, tissue fluid is absorbed.

(2) Lymphatics. That portion of tissue fluid that is not absorbed by blood capillaries is collected by the lymphatics, and once it has gained entrance here, it is known as lymph. These lymphatic vessels drain into larger vessels and eventually into two main trunks that return all the lymph into large veins near the heart. A little colloid living membrane that separates blood from the tissues. This semipermeable membrane permits the passage of water and crystalloids (see note below) from the blood, but does not permit the plasma proteins to pass through. Since most of the cells of the body lie outside of blood vessels, there must be a means of providing all of the cells with food materials and relieving them of their waste materials. The walls of the arteries are too thick to allow materials to diffuse through them. Arteries carry blood to the capillaries, and the thin walls of the capillaries allow water, food materials, and oxygen to nourish the individual cells. The relationship between the intercellular substance and the tissue fluid is different in different parts of the body. At some sites, where the intercellular substance is a sol, the tissue fluid is the

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d. **Edema.** A swelling of tissue due to an excess of tissue fluid is called edema. The cells and structures within the tissue are greatly spread apart in this condition. The amount of stretching from within is different in various tissues. Tissue edema is rather self-limiting in that when a certain point is reached, the hydrostatic pressure of the fluid in the stretched tissue is almost as great as that of the capillaries. Because of this, the formation of tissue fluid is almost stopped. As the tissue swells, the lymphatic vessels are pulled apart to keep them open. Some of the causes of edema are as follows:

(1) Increased hydrostatic pressure in blood capillaries. A buildup of hydrostatic pressure in the capillaries is almost always due to some obstruction to the free drainage of blood into the veins and back to the heart.



## The cell and tissue

(2) Lymphatic obstruction. Since some of the tissue fluid is drained off by the lymphatics, any obstruction to the lymphatic system would lead to an increase in tissue fluid.

(3) Insufficient colloid in the blood. The fact that fluid is absorbed at the venous end of capillaries depends on the increased osmotic pressure of the blood. Since the increase of osmotic pressure in the blood is due to the colloid content, any depletion of the colloids would result in a lower osmotic pressure. The colloids of the blood are proteins. Protein starvation would deplete the colloids and result in edema. A draining off of proteins also occurs in certain diseases of the kidneys and proteins are passed out in the urine. Large amounts of protein can also be lost by their seeping away from large injured areas.

(4) Increased permeability of blood capillary endothelium. Endothelial membranes are composed of living tissues. Because they are living, they keep colloids from diffusing into the tissue fluid. If capillaries become injured, they will permit colloids to escape into the tissue fluid. When colloids leak out of the capillaries, they raise the osmotic pressure of the tissue fluid until it becomes the same as that in the capillaries. When they become equal, tissue fluid is not returned at the venous ends of the capillaries and tissue fluid builds up. If capillary injury is over a large area, a condition develops known as surgical shock. There is only a certain amount of fluid in the vessels of the circulatory system. It is possible, with a massive injury, to deplete the circulatory system to the point where it can no longer function. As the plasma continues to escape, there is less and less fluid, with the result that the chambers of the heart do not fill properly between heart contractions. The result is collapse of the circulatory system and death

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