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Biology

Chapter 7
Tour of the cell

Med learn

❖ Introduction

- All organisms are made of cells either they are **unicellular** (composed of one cell) or **multicellular**
- These **cells** can differ substantially from one another but **share common features**
- The cell is the **simplest** collection of matter that can be alive
- The cell is the **basic unit of structure and function**

❖ 7.1: [Biologists use microscopes and the tools of biochemistry to study cells]

- Cells are usually too small to be seen by the naked eye ➔ so, Microscopes are used to visualize cells
- Microscopes are the most important tools of cytology (the study of cell structure)
- Cell walls were **first seen** by **Robert Hooke** as he looked through a microscope at dead cells from the bark of an oak tree

- **Three important parameters in microscopy are:**

1- Magnification:

➢ The **ratio** of an objects **image** to its **real size**

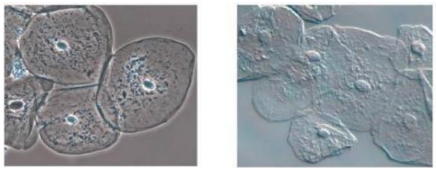
2- Resolution:

➢ It is a measure of the **clarity of the image** → it is the minimum distance between two points that can be separated and still be distinguished as separate points

3- Contrast:

➢ It is the difference in **brightness** between the light and dark areas of an image

➢ Various techniques **enhance contrast** and enable us to visualize the components of the cell by **staining or labeling**



- **Types of microscopes:**

∆ Light microscope (LM)

➢ Uses **visible light** which passes through a specimen and then through glass lenses which **refract** (bend) the light to magnify the image

➢ Has **low resolution** (**0.2 micrometer** (µm), or **200 nanometers** (nm))

➢ Light microscopy can magnify 1,000 times the size of the actual specimen

➢ Studying **living cells**

∆ Electron microscopes (EMs)

➢ Focus **a beam of electrons** through the specimen or onto its surface

➢ Has **high resolution** (can achieve a resolution of about **0.002 nm**)

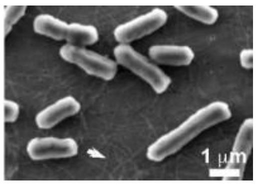
➢ The preparation methods kill the cells **(cells dead)**

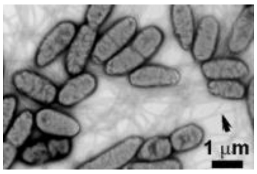
- **Two basic types of electron microscopes (EMs) are used to study subcellular structures:**

֍ Scanning electron microscopes (SEMs)

➢ The electron beam scans the surface of the sample

➢ The sample is coated with a thin film of **gold providing 3D images**

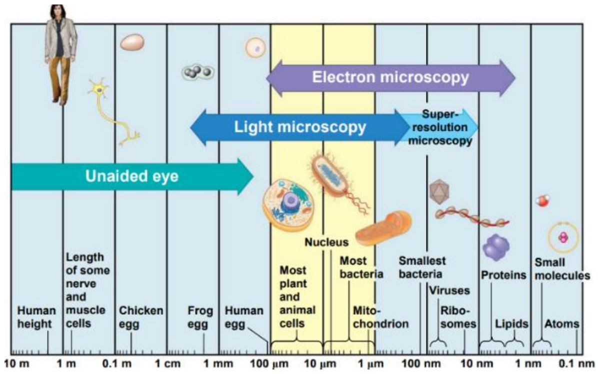




⊛ Transmission electron microscopes (TEMs)

- Focus the electron beam <u>through</u> a specimen
- The sample is stained with atoms of <u>**heavy metals** providing **2D images**</u>
- TEMs are **used** mainly to study the **internal structure of cells**

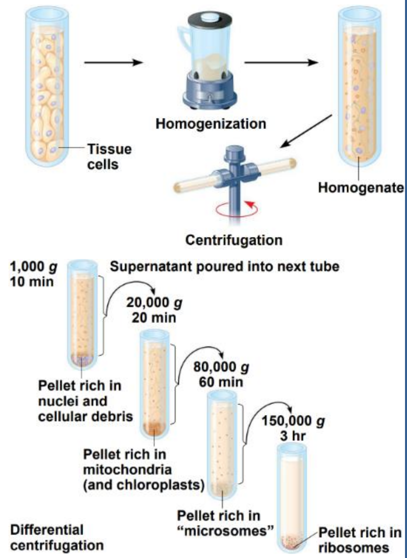
- Recent advances in <u>light microscope</u>:
  - **Labeling** individual cells with **fluorescent** markers improve the level of detail that can be seen
  - **Confocal microscopy and deconvolution microscopy** provide sharper images of three-dimensional tissues and cells
  - New techniques for labeling cells improve resolution
  - **Super-resolution microscopy** allows one to distinguish structures as small as **10–20 nm across**



✓ Notes:

- The resolution of standard light microscopy is **too low to study organelles** we require an EM to study them
- Viruses <u>can't</u> be seen by light microscope

☐ Cell fractionation



- A useful technique for studying cell structure and function which **takes cells apart and separates the major organelles from one another**
- The equipment that is used for this task is the **centrifuge** which **fractionate** cells into their component parts, enable scientists to determine the functions of organelles
- The centrifuge separates the cell components according to their **volume and level of speed**
- At each speed, the resulting force causes a subset of the cell components to settle to the bottom of the tube, forming **pellets:**
  - ✓ At **slower** speed → pellet with **larger components**
  - ✓ At **higher** speed → pellet with **smaller components**

❖ 7.2: [Eukaryotic cells have internal membranes that compartmentalize their functions]

- The <u>basic structural and functional unit</u> of every organism is <u>**cell**</u>
- Basic features of all cells:
  - **Plasma membrane**
  - Semifluid, jelly-like substance called **cytosol**
  - **Chromosomes** (carry genes)
  - **Ribosomes** (synthesize proteins)

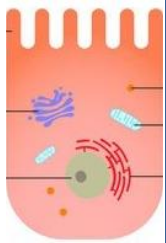
- Cells are of **two** distinct types ➔ Prokaryotes & Eukaryotes

Prokaryotes	Eukaryotes
• Includes **Bacteria & archaea**	• Includes **protists, fungi, animals and plants**
• No nucleus → DNA reside in a **nucleoid** (unbound region)	• Have **nucleus** → DNA reside in a nucleus bound by a double membrane)
• **No** membrane bound **organelles**	• Have membrane bound **organelles** within the cytoplasm
• **Smaller and less complex**	• **Larger & more complex**

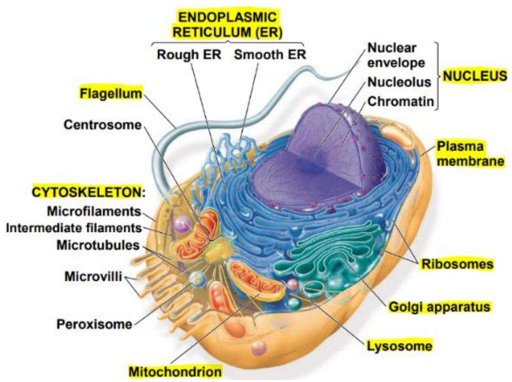
✓ **Note:**

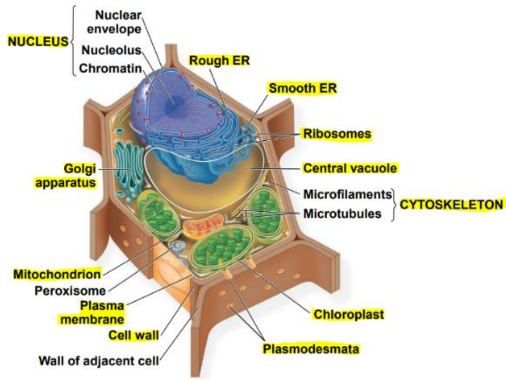
- **Cytoplasm** is the <u>interior of the cell</u> (in eukaryotes it refers only to the space between nucleus and plasma membrane)
- The **smallest cells** known are **bacteria** called **<u>mycoplasmas</u>**, with diameters between (0.1-1.0) µm

- **The plasma membrane** is a <u>selective barrier</u> that allows sufficient <u>passage</u> of oxygen, nutrients, and waste to service the volume of every cell
  - ➢ The number of molecules cross the membrane depends on its <u>surface area</u>
  - ➢ Normally, as a cell increases in size its volume grows proportionately more than its surface area
  - ➢ But, is cells that <u>exchange a lot of material</u> with their surroundings (such as **intestinal cells**) ➔ it is important to have a high ratio of surface area to volume ➔ so they have **<u>microvilli</u>** (which are long, thin projections on their surfaces) which <u>increase surface area without an appreciable increase in volume</u>



- Eukaryotic cells have <u>internal membranes</u> that divide the cell into compartments called **organelles**
  - ➢ Plant and animal cells have mostly the same organelles
  - ➢ The basic fabric of most biological membranes is a <u>double layer of phospholipids</u> and other lipids with <u>diverse proteins</u> embedded in this lipid bilayer or attached to it
  - ➢ Each type of membrane has a **unique composition of lipids and proteins** suited to that membrane's specific functions





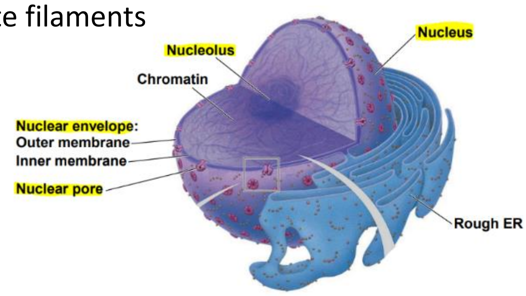
❖ 7.3: [The eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosomes]

- The **<u>nucleus</u>** houses <u>most of the cell's DNA</u> & genes of the eukaryotic cell
  - ➢ <u>Some genes</u> are located in **mitochondria** and **chloroplasts**
  - ➢ Usually, the nucleus is the most conspicuous organelle, about 5 µm in diameter

- The **nuclear envelope** is a double membrane, each membrane consists of a lipid bilayer with associated proteins, are separated by a space of 20–40 nm
    - The nuclear envelope encloses the nucleus separating its contents from the cytoplasm
    - The nuclear envelope is perforated by pores
    - The nuclear envelope is connected to the rough ER

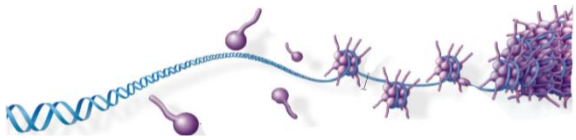
- Pores are lined with a structure called a **"pore complex"** which regulates the entry and exit of molecules (such as proteins and RNAs, as well as large complexes of macromolecules) from the nucleus
    - Pores connect the inner and outer membranes of the nuclear envelope
    - They are about 100 nm in diameter

- **Nuclear lamina** is a structure lining the nuclear side of the envelope, composed of **protein filaments** that **provide mechanical support** to the nuclear envelope (**maintains the shape** of the nucleus)
    - In animal cells, the protein filaments are called intermediate filaments



- **Nuclear matrix** is **a framework of protein** fibers extending throughout the nuclear interior

- The **nuclear lamina** + **matrix** → help organize the genetic material to function efficiently



- In the nucleus, **DNA** is organized into discrete units called **chromosomes** which carry the genetic information

- Each chromosome contains one long DNA molecule associated with many proteins → called **chromatin**

➢ Some of these proteins **coil the DNA** molecule of each chromosome **reducing its length** allowing it to **fit into the nucleus**

➢ When a cell is not dividing, chromatin appears as a **diffuse mass** and the chromosomes cannot be distinguished from one another

➢ As cell prepares to divide, chromatin condenses to form **discrete chromosomes** becoming thick enough to be distinguished from each other

✓ **Notes:**

- A **somatic** human cell has **46** chromosomes in its nucleus, the **sex** cells (eggs and sperm) have **23** chromosomes only
- A fruit fly cell has **8** chromosomes in most cells and **4** in the sex cells

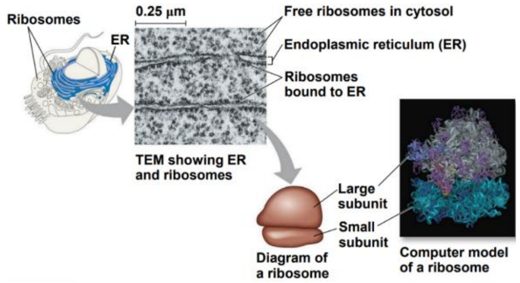
- **The nucleolus** is a prominent structure within the non-dividing nucleus where the ribosomal RNA (rRNA) is synthesized

➢ rRNA & some proteins (synthesized and **imported** from the cytoplasm) assemble with each other forming the large and small subunits of ribosomes → then **exit the nucleus** (through nuclear pores) to the cytoplasm where they form **ribosomes**

- **Ribosomes** are cellular complexes made of rRNA & protein in which they carry out **protein synthesis**
- Cells that have high rates of protein synthesis, have particularly **large numbers of ribosomes** as well as **prominent nucleoli** (which play an important role in ribosome assembly)

➢ Such as human **pancreas cell** which have high rates of protein synthesis

- Ribosomes can be found in two forms (locations):
  - **Free ribosomes** in the <u>cytosol</u>
  - **Bound ribosomes** on the outside surface of the <u>endoplasmic reticulum</u> or the cytoplasmic (outer) side of the <u>nuclear envelope</u>



- Both **bound** and **free** ribosomes <u>are structurally identical</u>, BUT:
  - **Free ribosomes** function in building proteins destined to <u>work within the cytosol</u> (such as enzymes that catalyze the first steps of sugar breakdown)
  - **Bound ribosomes** function in generally building proteins that are destined <u>for insertion into membranes</u> (for packaging within certain organelles such as **lysosomes**) or <u>for export from the cell</u>

- Cells that are specialized in protein secretion (such as pancreas cell that secrete digestive enzymes) frequently have a **high proportion of bound ribosomes**

❖ 7.4: [The endomembrane system regulates protein traffic and performs metabolic functions]

- **Endomembrane system:** is a membranous system of interconnected tubules and flattened **sacs** called cisternae, and the **membrane-bounded organelles** of the eukaryotic cell, consists of:
  - Nuclear envelope
  - Endoplasmic reticulum
  - Golgi apparatus
  - Lysosomes
  - Vacuoles and vesicles
  - Plasma membrane

- The membranes of this system are related either through <u>direct physical continuity</u> or by the transfer of membrane segments as tiny <u>vesicles</u> (sacs made of membrane)

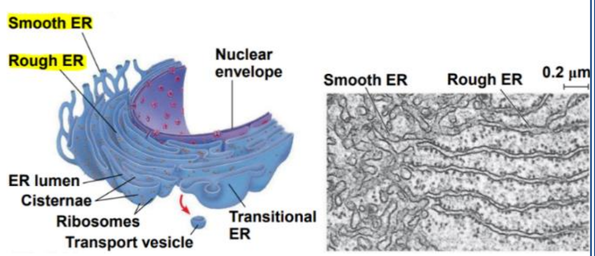
- These various **membranes are not identical in structure and function**
  - ➢ They differ in <u>thickness</u>, <u>molecular composition</u>, and types of <u>chemical reactions</u> carried out in a given membrane

⊛ The Endoplasmic Reticulum: Biosynthetic Factory

- Endoplasmic = within the cytoplasm / Reticulum = little net
- **The endoplasmic reticulum (ER)** is an <u>extensive network of membranes</u> which represents more than half the total membrane in the eukaryotic cells

- The ER consists of A network of **membranous tubules and flattened sacs** called **cisternae**
  - ➢ The **internal compartment (cavity)** called **lumen** or **cisternal space**
  - ➢ The two membranes of the **nuclear envelope** are continuous with the <u>lumen</u> of the ER

- There are 2 distinct regions of the ER that differ in structure and function:
  1. **Smooth ER (SER):** smooth because its outer surface <u>lacks ribosomes</u>
  2. **Rough ER (RER):** appears rough because it is studded <u>with ribosomes on its outer membrane</u>

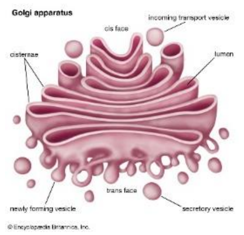


- **Function of SER:**
  - **Synthesis of lipids**, including **oils**, **steroids**, new membrane **phospholipids**, **sex hormones** of vertebrates and **steroid hormones** which secreted by the adrenal glands
    - ✓ The cells that synthesize and secrete these hormones (in the testes and ovaries for example) are rich in smooth ER, a structural feature that fits the function of these cells
  - **Detoxify drugs and poisons (Detoxification)** especially in liver cells, by **adding hydroxyl groups** to drug molecules, making them **more soluble** and easier to flush from the body
    - ✓ The sedative phenobarbital and other barbiturates are examples of **drugs metabolized by SER in liver**
    - ✓ In fact, barbiturates, alcohol, and many other drugs induce the proliferation of smooth ER and its associated detoxification enzymes, thus increasing the rate of detoxification
  - **Storage of calcium ions** for **muscle contraction** & the **secretion of vesicles**
  - **Metabolism of carbohydrates**

- **Function of RER:**
  - Has bound ribosomes which **secrete glycoproteins** → the carbohydrates are attached to the proteins **in the ER lumen** by enzymes
    - ✓ Glycoproteins are proteins with carbohydrates covalently bonded
  - **Distributes transport vesicles** carrying secretory proteins surrounded by membranes, that bud like bubbles from a specialized region called **transitional ER**
  - **Is a membrane factory for the cell** by adding membrane proteins and phospholipids to its own membrane, to transport vesicles to other components of the endomembrane system

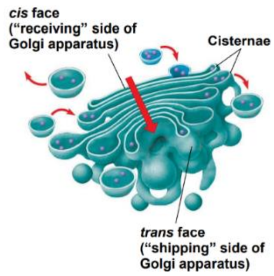
❋ The Golgi Apparatus: Shipping and Receiving Center

- Many transport vesicles after leaving the ER they travel to the Golgi apparatus
- **The Golgi apparatus** consists of **flattened membranous** sacs called cisternae
- **The Golgi apparatus functions:**
  - **Modifies products of the ER**
  - Manufactures (**synthesize**) certain macromolecules, such as **polysaccharides**: pectins and other non-cellulose polysaccharides are made in the Golgi of plant cells, **secretory non-protein products**)
  - **Sorts and packages materials into transport vesicles**
  - **Alter membrane phospholipids**



- The Golgi apparatus is especially extensive in **cells specialized for secretion**

- The two sides of a Golgi are:
  - The **cis face** (receiving side) located near the ER
  - The **trans face** (shipping side) ➔ located near the plasma membrane, it's the side where Golgi secrete its products (vesicles pinch off and travel to other sites or transport vesicles that eventually fuse with the plasma membrane)



- Products of the ER leave it by transport vesicles & **fuse with the cis** face of Golgi for **modification** during their transit from the cis region to the trans region
  - For example, glycoproteins formed in the ER have their carbohydrates modified, first in the ER itself, and then as they pass through the Golgi
  - The Golgi removes some sugar monomers and substitutes others, producing a large variety of carbohydrates

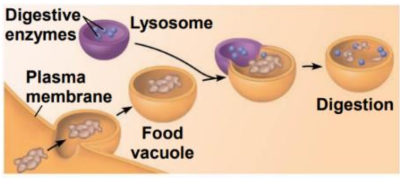
- Golgi is a dynamic structure according to the cisternal maturation model
  - The cisternae of the Golgi actually progress forward from the cis to the trans face, carrying and modifying their cargo as they move
- Recent research suggests the central regions of the cisternae may remain in place, while the outer ends are more dynamic

- Golgi targets its products for various parts of the cell by **adding molecular identification tags**, such as phosphate groups to the Golgi products aid in sorting
- Transport vesicles budded from the Golgi may have **external molecules** on their membranes that recognize docking sites on the surface of specific organelles or on the plasma membrane

❁ Lysosomes: Digestive Compartments

- **Lysosome** is a membranous sac of **hydrolytic enzymes** used to digest (hydrolyze) macromolecules
- Lysosomal enzymes work best in the acidic environment inside the lysosome
  - If a lysosome breaks, opens or leaks its contents, the released enzymes are not very active because the cytosol has a near-neutral pH
  - However, excessive leakage from a large number of lysosomes can destroy a cell by self-digestion
- Hydrolytic enzymes and lysosomal membrane are made by **rough ER** then transferred to the Golgi apparatus for further processing → then budding from the trans face of the Golgi apparatus
- How the proteins of the inner surface of the lysosomal membrane are spared (protect) themselves from the digestive enzymes and destruction?
  - The **three-dimensional shapes of these proteins** protect weak bonds from enzymatic attack
- The main function of lysosomes is **intracellular digestion**

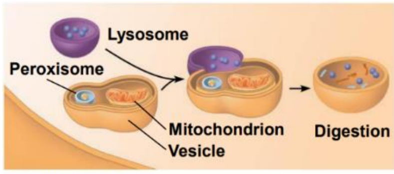
- Some types of cells (such as Amoebas and many other unicellular eukaryotes) can engulf another cell or food particles by **phagocytosis**
  - ➢ The engulfed material forms a food vacuole then fuses with a lysosome → enzymes digest the food
  - ➢ Digested products (including simple sugars, amino acids, and other monomers) pass into the cytosol and become nutrients for the cell



(a) Phagocytosis

- Some human cells such as **macrophages** (a type of white blood cell) also carry out phagocytosis
  - ➢ So, they defend the body by engulfing and destroying bacteria and other invaders

- Lysosomes also recycle the cell's organic material in a process called **autophagy**
  - ➢ During autophagy a **damaged organelle** becomes surrounded by a **double** membrane → then a lysosome fuses with the outer membrane of this vesicle → lysosomal enzymes dismantle the inner membrane with the enclosed material → the resulting small organic compounds are released to the cytosol for reuse



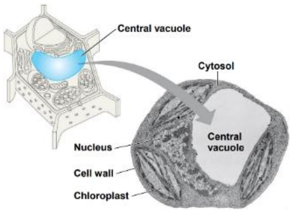
(b) Autophagy

- **Tay-Sachs disease:** A disease in which a **lipid-digesting enzyme is missing or inactive**, and the brain becomes impaired by an accumulation of lipids in the cells

֍ Vacuoles: Diverse Maintenance Compartments

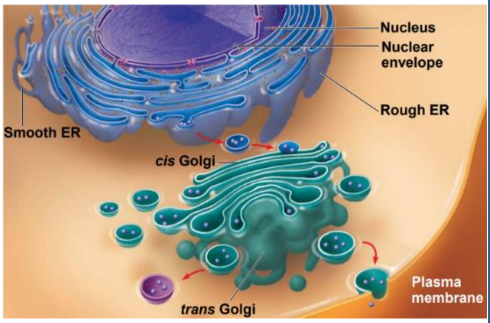
- **Vacuoles:** are large vesicles derived from the ER and Golgi apparatus
- The solution inside a vacuole differs in composition from the cytosol

- Vacuoles perform a variety of **functions** in different kinds of cells:
  - **Food vacuoles** formed by phagocytosis
  - **Contractile vacuoles** (in many freshwater protists), maintain a suitable concentration of ions and by that pump excess water out of the cell
  - **vacuoles carry out enzymatic hydrolysis** and they are considered as a type of lysosomes
  - **The central vacuole** (in mature plant cells) **holds** organic compounds and water such as the proteins stockpiled in the storage cells in seeds
    - ✓ The central vacuole is formed by the coalescence (fusion) of smaller vacuoles
    - ✓ Its function is to allow plant cells to enlarge as it absorbs water
    - ✓ **Cell sap:** The solution inside the central vacuole and it is the main storehouse of inorganic ions (including potassium and chloride)



  - **Vacuoles contain pigments** such as the red and blue pigments of petals that help attract pollinating insects to flowers

֍ Endomembrane System: Conclusion



- The endomembrane system is a complex and dynamic player in the cell's compartmental organization
- Membranes and proteins produced by the ER move via transport vesicles to the Golgi ➔ Golgi pinches off transport vesicles and other vesicles that give rise to lysosomes, other types of specialized vesicles, and vacuoles
  - The lysosome is available for fusion with another vesicle → for digestion
  - A transport vesicle carries proteins to the plasma membrane → for secretion
  - The plasma membrane → expands by fusion of vesicles; proteins are secreted from the cell