STRUCTURAL & FUNCTIONAL DETAILS OF CELL

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Overview

- Cells: The Basic Units of Living Organisms
- Major cell types
- Parts of cell: Cell membrane, organelles & cytoskeleton.
- Functions of each organelles

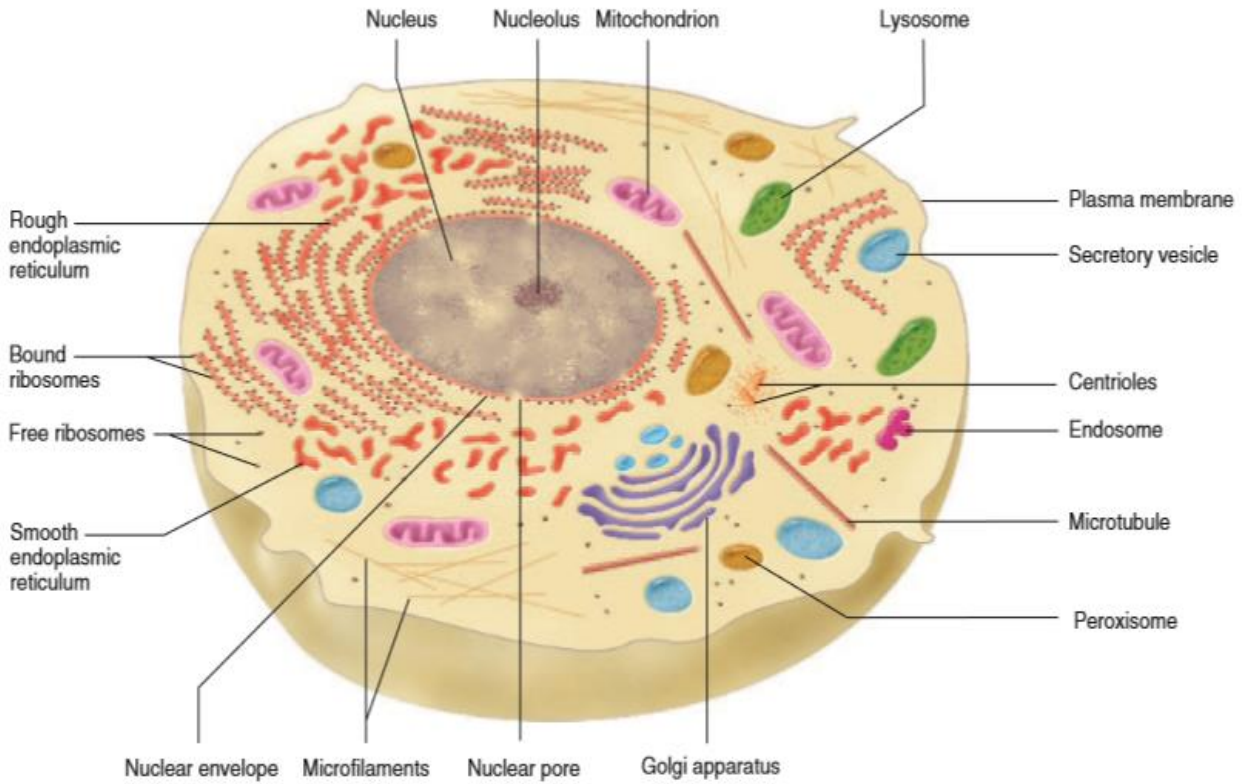
- The simplest **structural units** into which a complex multicellular organism can be divided and **still retain the functions characteristic of life** are called cells.

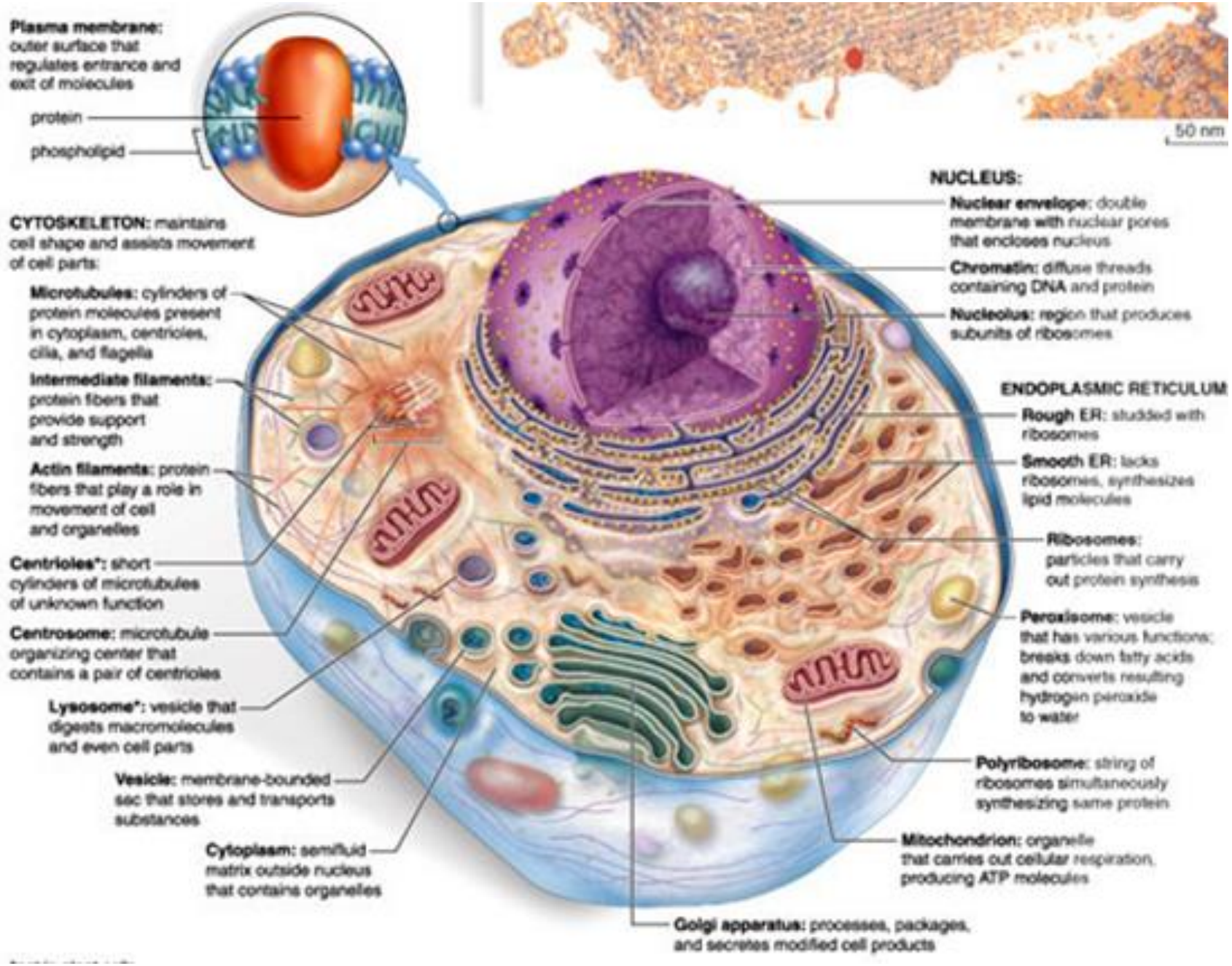
For example, a human liver cell and an amoeba are remarkably similar.

- Cells are grouped together which has specialized function, called **tissues**. Eg: blood, muscle, bone.
- Different tissues are grouped together to form **organs**. Eg: heart, brain, stomach.
- Organs grouped together; **systems** which maintain the **homeostasis** (constancy of internal environment/interstitial fluid i.e core temperature, water & electrolyte concentration, pH, Oxygen, carbon dioxide level, glucose level etc.)
- Deviation of homeostasis is illness, so **integrated working of all body systems** which maintain the homeostasis ensure survival
- Though body systems are described separately during study, but in reality they work interdependently and **body is as a whole in itself**.

SYSTEM	MAJOR ORGANS OR TISSUES	PRIMARY FUNCTIONS
Circulatory	Heart, blood vessels, blood (Some classifications also include lymphatic vessels and lymph in this system.)	Transport of blood throughout the body's tissues
Respiratory	Nose, pharynx, larynx, trachea, bronchi, lungs	Exchange of carbon dioxide and oxygen; regulation of hydrogen ion concentration
Digestive	Mouth, pharynx, esophagus, stomach, intestines, salivary glands, pancreas, liver, gallbladder	Digestion and absorption of organic nutrients, salts, and water
Urinary	Kidneys, ureters, bladder, urethra	Regulation of plasma composition through controlled excretion of salts, water, and organic wastes
Musculoskeletal	Cartilage, bone, ligaments, tendons, joints, skeletal muscle	Support, protection, and movement of the body; production of blood cells
Immune	White blood cells, lymph vessels and nodes, spleen, thymus, and other lymphoid tissues	Defense against foreign invaders; return of extracellular fluid to blood; formation of white blood cells
Nervous	Brain, spinal cord, peripheral nerves and ganglia, special sense organs	Regulation and coordination of many activities in the body; detection of changes in the internal and external environments; states of consciousness; learning; cognition
Endocrine	All glands secreting hormones: Pancreas, testes, ovaries, hypothalamus, kidneys, pituitary, thyroid, parathyroid, adrenal, intestinal, thymus, heart, and pineal, and endocrine cells in other locations	Regulation and coordination of many activities in the body, including growth, metabolism, reproduction, blood pressure, electrolyte balance, and others
Reproductive	Male: Testes, penis, and associated ducts and glands Female: Ovaries, fallopian tubes, uterus, vagina, mammary glands	Production of sperm; transfer of sperm to female Production of eggs; provision of a nutritive environment for the developing embryo and fetus; nutrition of the infant
Integumentary	Skin	Protection against injury and dehydration; defense against foreign invaders; regulation of temperature

- All cells within the body contain a **nucleus** except *mature Red Blood Cell*.
- The cell is therefore effectively divided into two compartments: the **nucleus and the cytoplasm**; an aqueous solution containing numerous organic molecules (carbohydrate, protein, lipids), ions (Na^+ K^+ Ca^+ Cl^-,cytoskeletal elements (microfilaments, microtubles, centrosome) and a number of organelles**.**




Plasma membrane: outer surface that regulates entrance and exit of molecules
protein
phospholipid
50 nm
CYTOSKELETON: maintains cell shape and assists movement of cell parts:
Microtubules: cylinders of protein molecules present in cytoplasm, centrioles, cilia, and flagella
Intermediate filaments: protein fibers that provide support and strength
Actin filaments: protein fibers that play a role in movement of cell and organelles
Centrioles*: short cylinders of microtubules of unknown function
Centrosome: microtubule organizing center that contains a pair of centrioles
Lysosome*: vesicle that digests macromolecules and even cell parts
Vesicle: membrane-bounded sac that stores and transports substances
Cytoplasm: semifluid matrix outside nucleus that contains organelles
NUCLEUS:
Nuclear envelope: double membrane with nuclear pores that encloses nucleus
Chromatin: diffuse threads containing DNA and protein
Nucleolus: region that produces subunits of ribosomes
ENDOPLASMIC RETICULUM
Rough ER: studded with ribosomes
Smooth ER: lacks ribosomes, synthesizes lipid molecules
Ribosomes: particles that carry out protein synthesis
Peroxisome: vesicle that has various functions; breaks down fatty acids and converts resulting hydrogen peroxide to water
Polyribosome: string of ribosomes simultaneously synthesizing same protein
Mitochondrion: organelle that carries out cellular respiration, producing ATP molecules
Golgi apparatus: processes, packages, and secretes modified cell products

- About **200 distinct kinds** of cells identified in the body in terms of differences in structure and function.
- four categories of cell emerge as per the function:

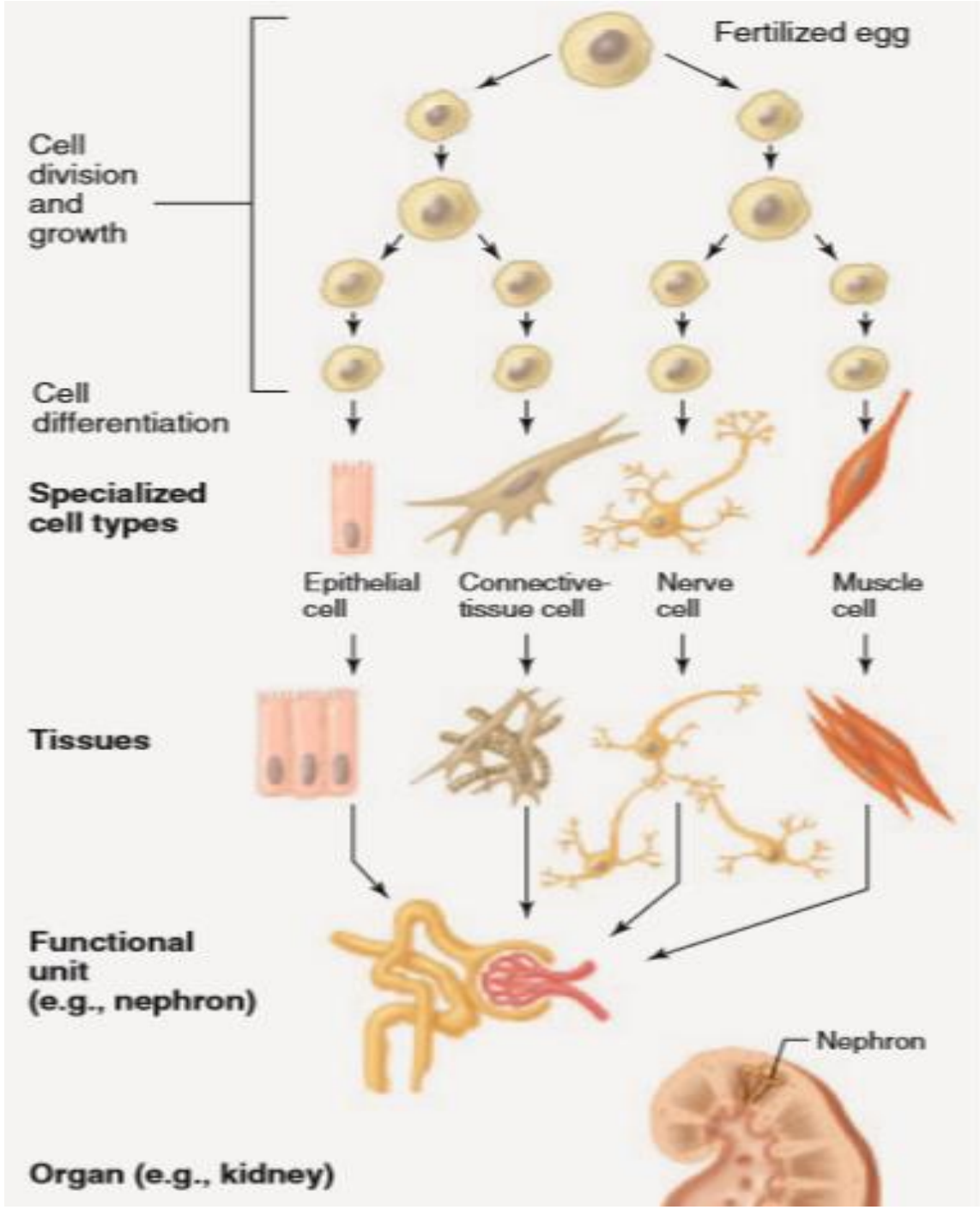
(1) muscle cells,

(2) nerve cells,

(3) epithelial cells, and

(4) connective tissue cells

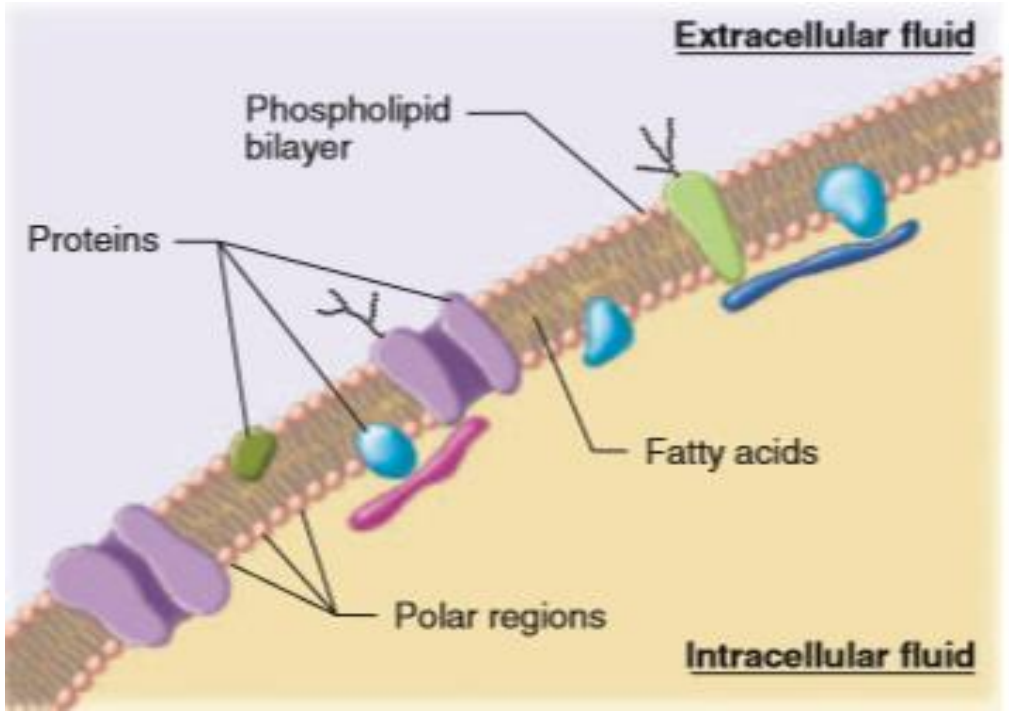
over 75 trillion cells in human body


Fertilized egg
Cell division and growth
Cell differentiation
Specialized cell types
Epithelial cell
Connective-tissue cell
Nerve cell
Muscle cell
Tissues
Functional unit (e.g., nephron)
Nephron
Organ (e.g., kidney)

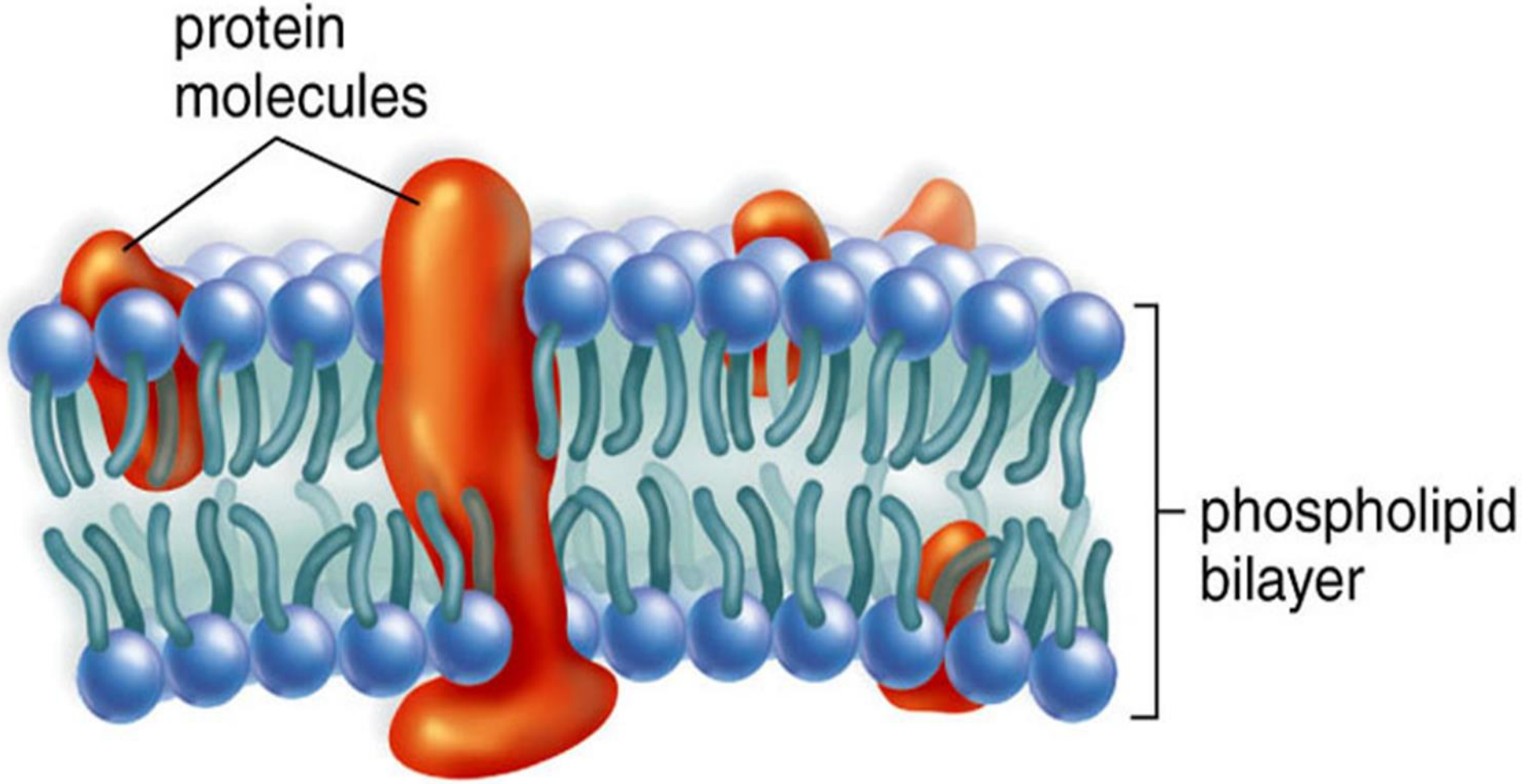
- Muscle cells are specialized to generate the mechanical forces that **produce movement**. They may be attached to bones and produce movements of the limbs or trunk. Muscle cells also **surround many of the tubes** in the body—blood vessels, intestine, bronchi whose contraction changes the diameter of these tubes.
- Nerve cells are specialized to **initiate and conduct electrical signals**, often over long distances. Thus, nerve cells provide a major means of controlling the activities of other cells. Also helpful in memory, learning, consciousness and perception.
- Epithelial cells are specialized for the **selective secretion** (glands) and **absorption** of ions and organic molecules (In stomach, intestine, tubules of nephron), and for **protection**. They are located mainly at the surfaces that (1) cover the body or individual organs or (2) line the walls of various tubular and hollow structures within the body.
- Connective tissue cells **connect, anchor, and support the structures of the body**. Some are found in the loose meshwork of cells and fibers underlying most epithelial layers; other types include fat-storing cells, bone cells, red blood cells and white blood cells.

- Biological Membranes: form a major structural element in cells which consist of a **double layer of lipid molecules** with its polar region (hydrophilic) at a bilayer surface and its nonpolar rings (hydrophobic) in the interior in which proteins, cholesterol are embedded.

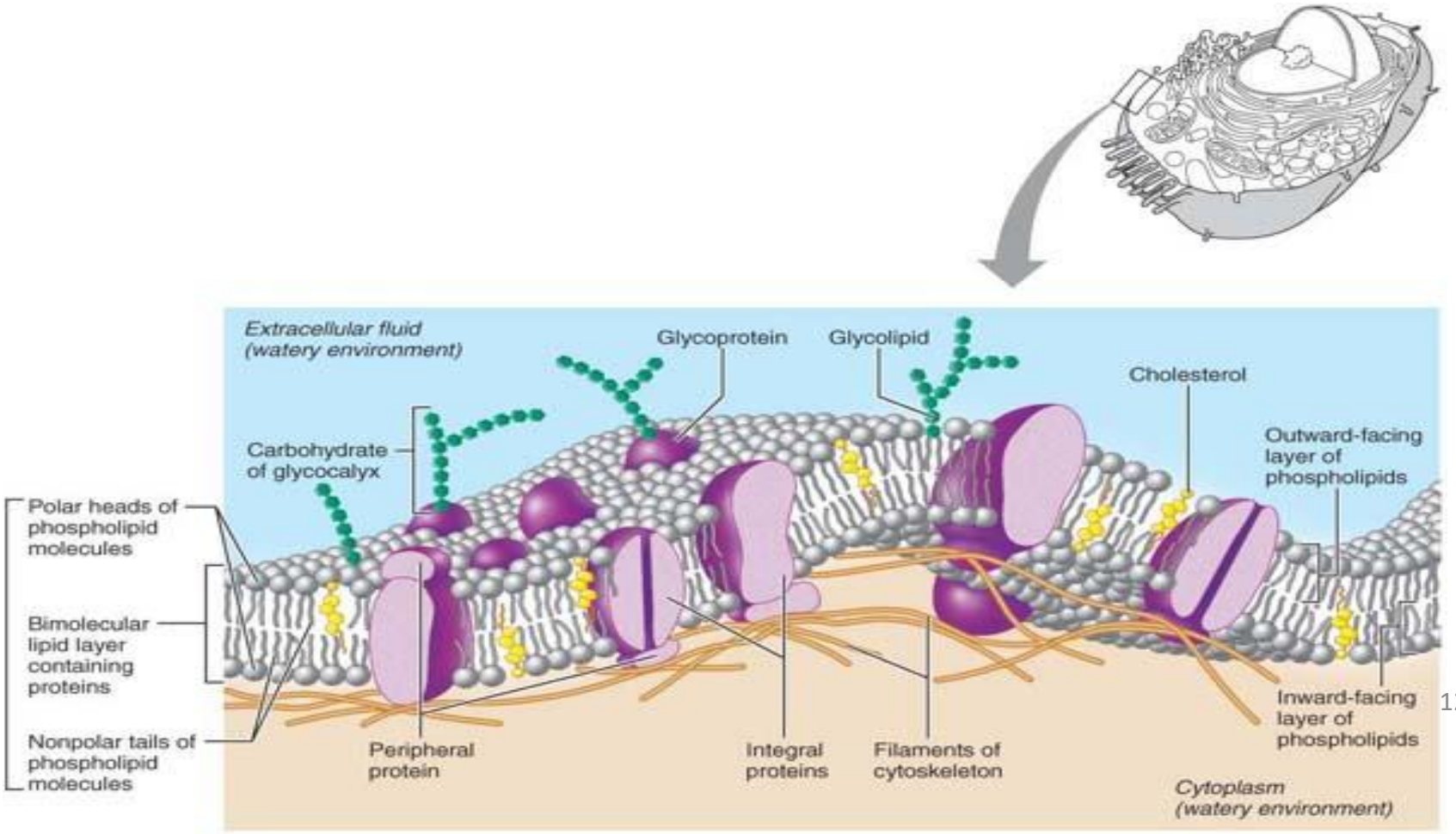
Functions:



- Regulate the **passage** of substances into and out of cells and between cell organelles and cytosol.
- **Detect** chemical messengers arriving at the cell surface. (**act as receptor** for hormone)
- **Link** adjacent cells together by membrane junctions.
- **Anchor** cells to the extracellular matrix.



- **The fluid mosaic model** of membrane structure depicts the plasma membrane as an exceedingly thin (**7–10 nm**) structure composed of a **double layer**, or bilayer, **of lipid molecules** with **protein molecules dispersed in it**. The proteins, many of which float in the fluid lipid bilayer, form a constantly changing mosaic pattern; hence the name of the model.



The cell membrane is a semipermeable, bilayered structure **made of four major organic molecules**, as follows:

1. **Phospholipid:** Creates the semi-permeability of the membrane; makes up the majority of the two layers of the membrane. A phospholipid molecule consists of a glycerol molecule bonded to two fatty acids and one phosphate.
2. **Glycolipid:** Gives the cell its identity; located only in the outer layer. A glycolipid molecule consists of a glycerol molecule bonded to two fatty acids and one carbohydrate.
3. **Cholesterol:** Appears to control the rate of flow of material in and out of the cell.
4. **Protein:** Many will form channels to allow larger molecules to enter into the cell.

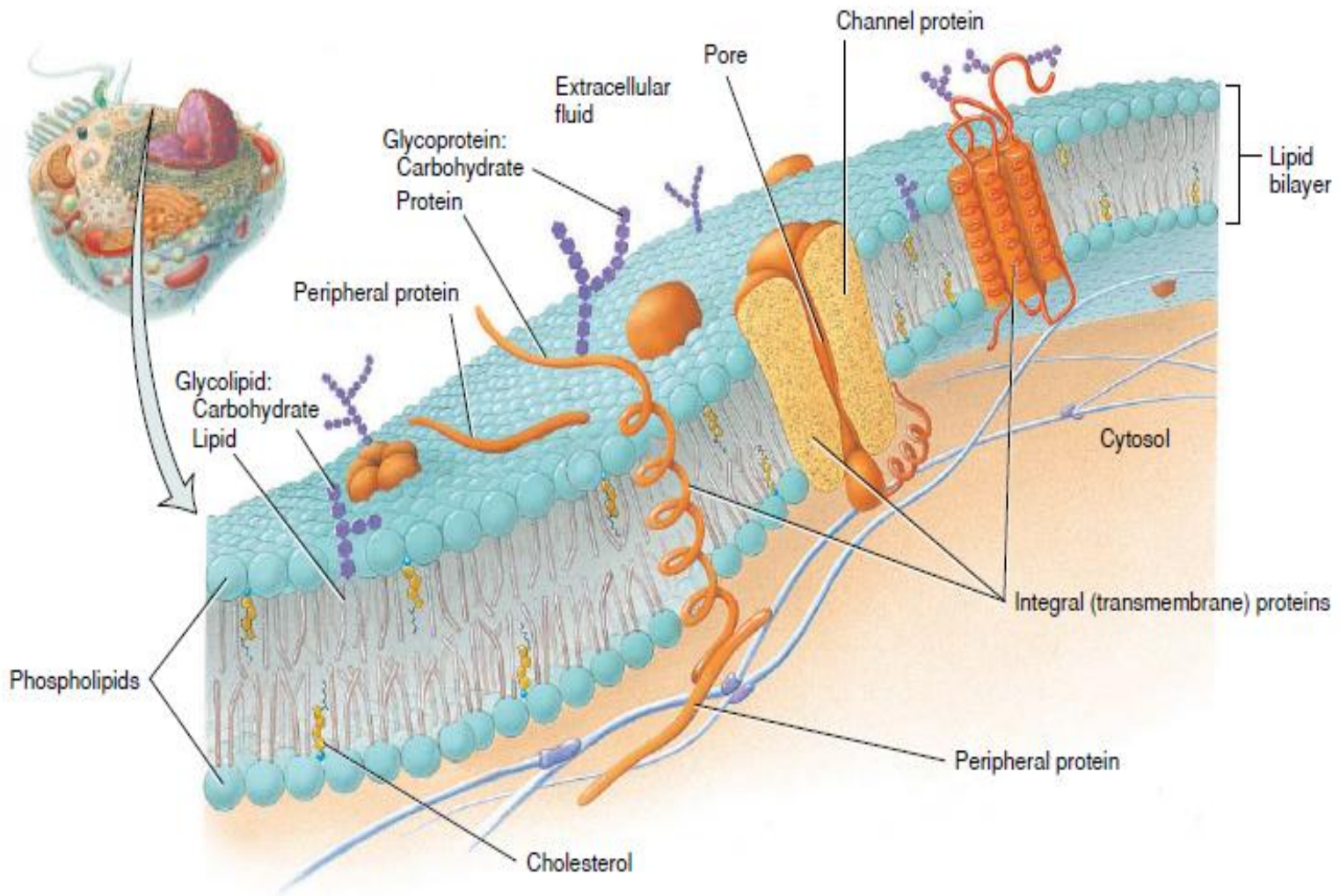
Which membrane structure creates the "pores" of a cell?
Protein

Figure 3.2 The fluid mosaic arrangement of lipids and proteins in the plasma membrane.

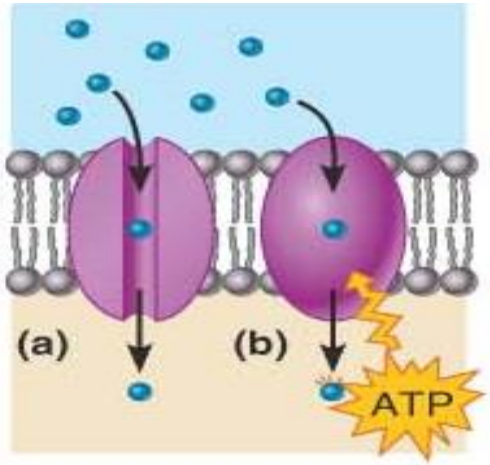
Membranes are fluid structures because the lipids and many of the proteins are free to rotate and move sideways in their own half of the bilayer.

FUNCTIONS OF THE PLASMA MEMBRANE

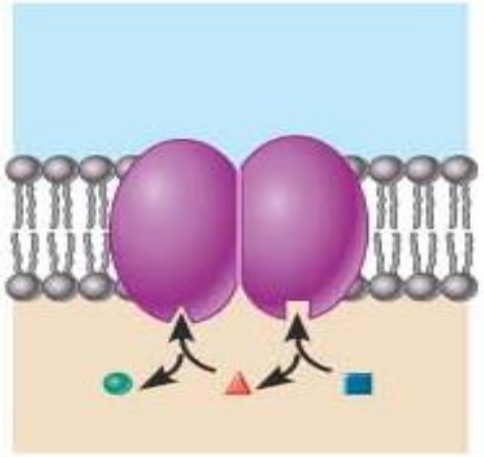
1. Acts as a barrier separating inside and outside of the cell.
2. Controls the flow of substances into and out of the cell.
3. Helps identify the cell to other cells (e.g., immune cells).
4. Participates in intercellular signaling.



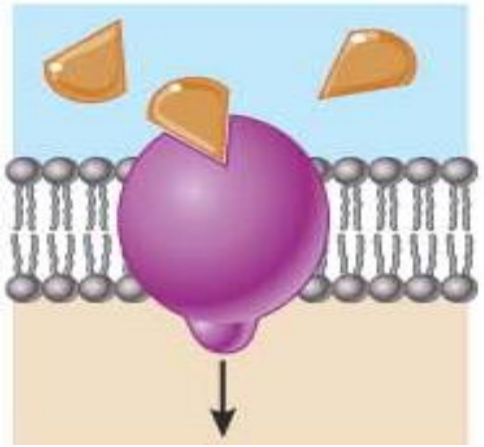
Functions of plasma membrane



Transport
(a) A protein that spans the membrane may provide a hydrophilic channel across the membrane that is selective for a particular solute. **(b)** Some transport proteins hydrolyze ATP as an energy source to actively pump substances across the membrane.

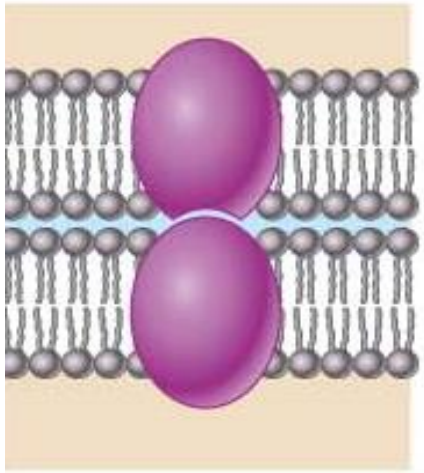


Enzymatic activity
A protein built into the membrane may be an enzyme with its active site exposed to substances in the adjacent solution. In some cases, several enzymes in a membrane act as a team that catalyzes sequential steps of a metabolic pathway as indicated (right to left) here.

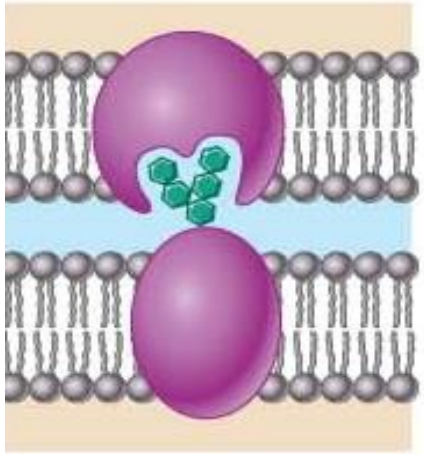


Receptors for signal transduction
A membrane protein exposed to the outside of the cell may have a binding site with a specific shape that fits the shape of a chemical messenger, such as a hormone. The external signal may cause a conformational change in the protein that initiates a chain of chemical reactions in the cell.

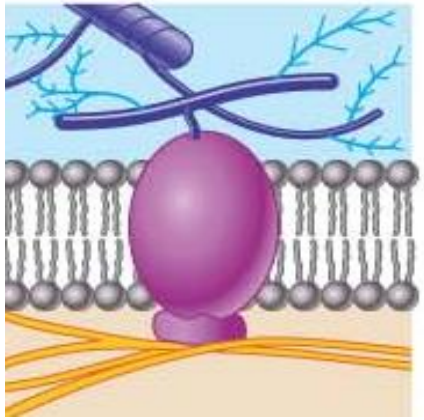
Functions of plasma membrane



Intercellular joining
Membrane proteins of adjacent cells may be hooked together in various kinds of intercellular junctions. Some membrane proteins (CAMs) of this group provide temporary binding sites that guide cell migration and other cell-to-cell interactions.



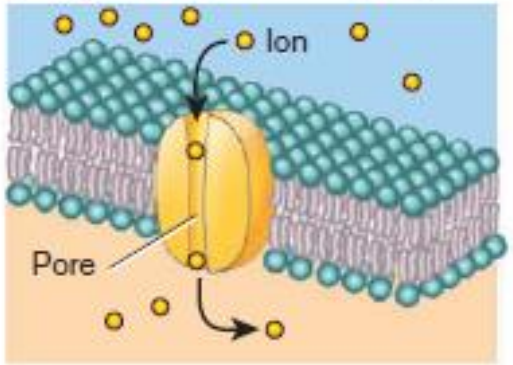
Cell-cell recognition
Some glycoproteins (proteins bonded to short chains of sugars) serve as identification tags that are specifically recognized by other cells.



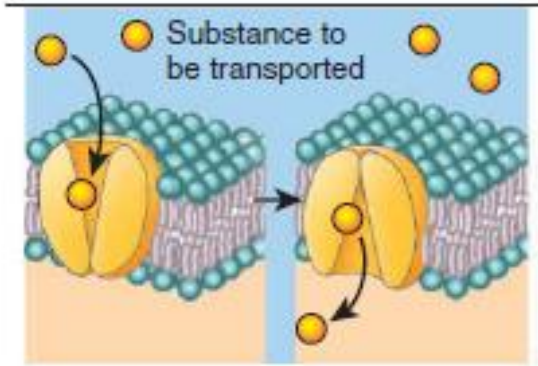
Attachment to the cytoskeleton and extracellular matrix (ECM)
Elements of the cytoskeleton (cell's internal supports) and the extracellular matrix (ECM) may be anchored to membrane proteins, which help maintain cell shape and fix the location of certain membrane proteins. Others play a role in cell movement or bind adjacent cells together.

Membrane proteins largely reflect the functions a cell can perform.

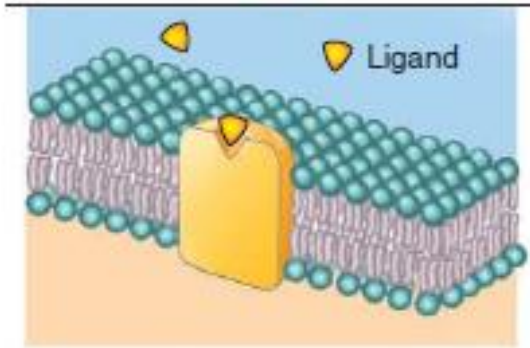
Extracellular fluid | Plasma membrane | Cytosol



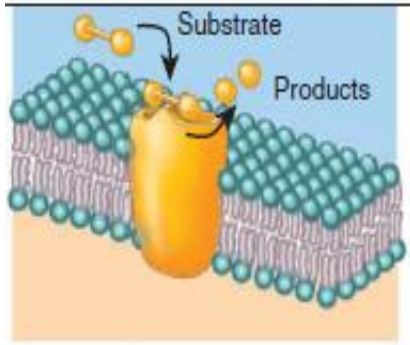
Ion channel (integral)
Forms a pore through which a specific ion can flow to get across membrane. Most plasma membranes include specific channels for several common ions.



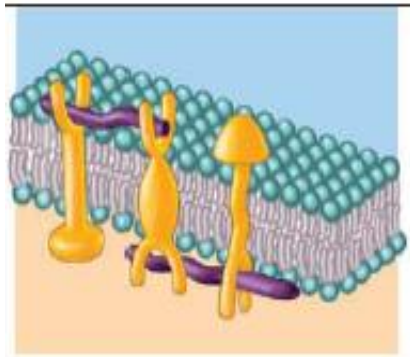
Carrier (integral)
Transports a specific substance across membrane by undergoing a change in shape. For example, amino acids, needed to synthesize new proteins, enter body cells via carriers. Carrier proteins are also known as *transporters*.



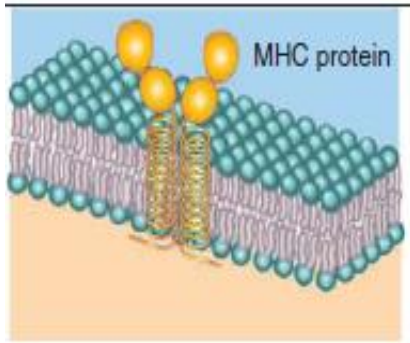
Receptor (integral)
Recognizes specific ligand and alters cell's function in some way. For example, antidiuretic hormone binds to receptors in the kidneys and changes the water permeability of certain plasma membranes.



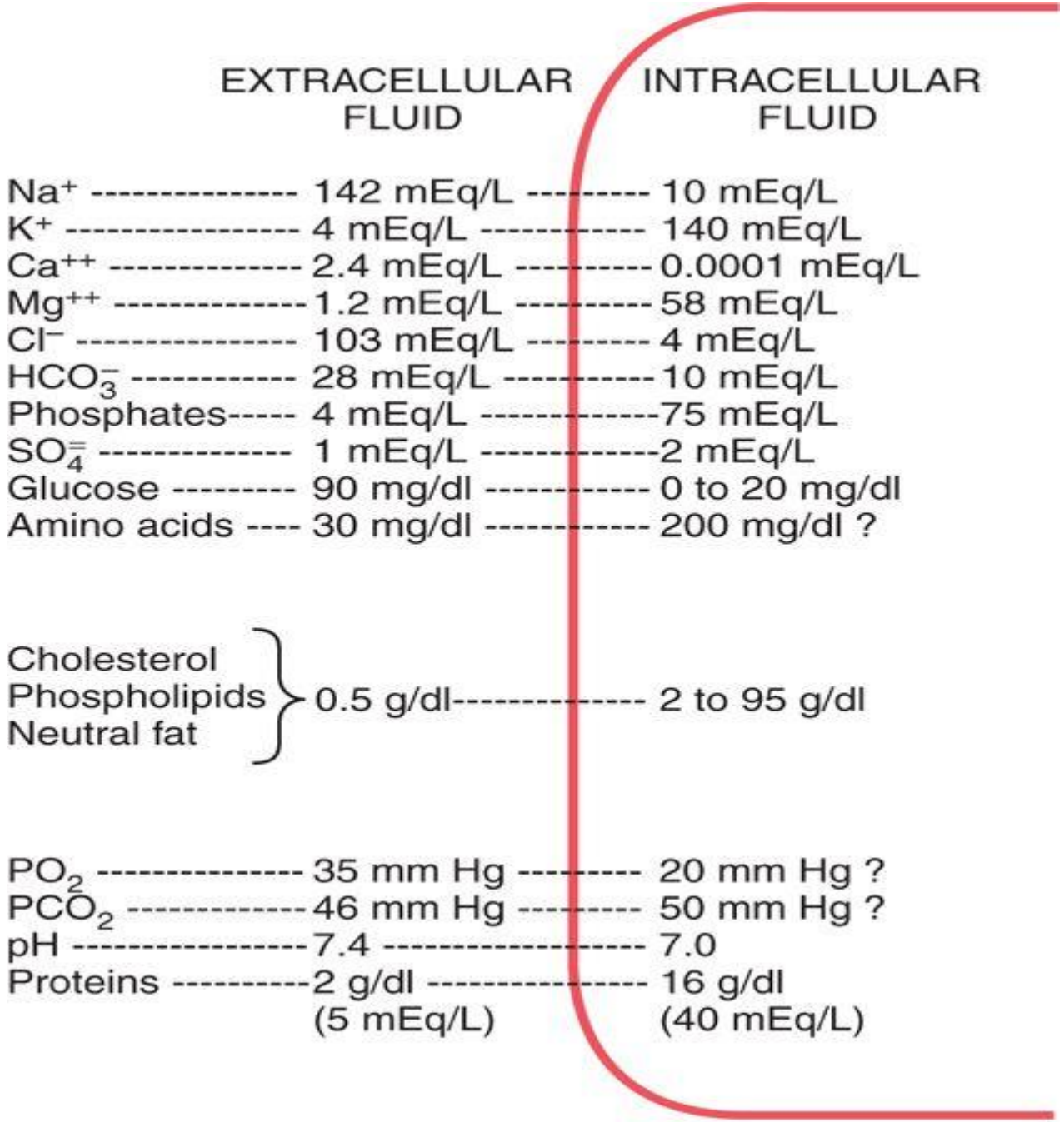
Enzyme (integral and peripheral)
Catalyzes reaction inside or outside cell (depending on which direction the active site faces). For example, lactase protruding from epithelial cells lining your small intestine splits the disaccharide lactose in the milk you drink.



Linker (integral and peripheral)
Anchors filaments inside and outside the plasma membrane, providing structural stability and shape for the cell. May also participate in movement of the cell or link two cells together.



Cell identity marker (glycoprotein)
Distinguishes your cells from anyone else's (unless you are an identical twin). An important class of such markers are the major histocompatibility (MHC) proteins.



Hall: Guyton and Hall Textbook of Medical Physiology, 12th Edition

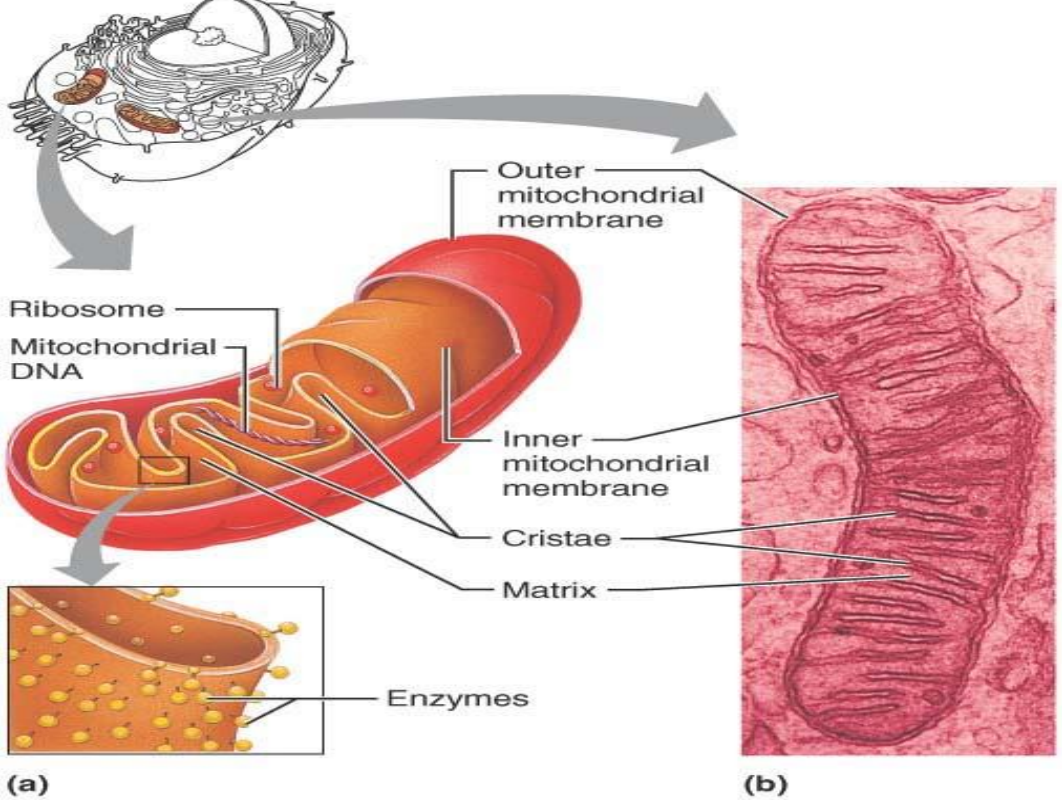
Cell organelles

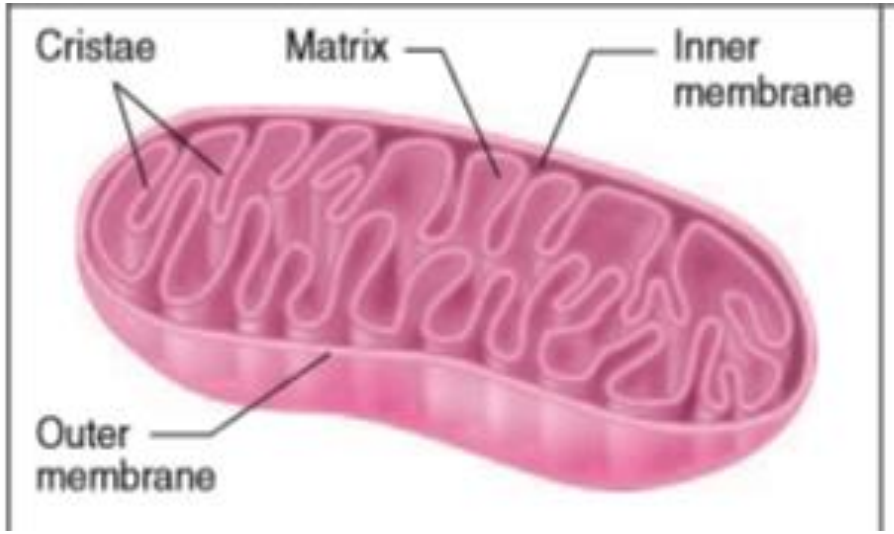
- The cytoplasmic organelles ("**little organs**") are specialized cellular compartments, each performing its own job to maintain the life of the cell.
- Some organelles, the **nonmembranous organelles**, lack membranes, **eg.cytoskeleton, centrioles, and ribosomes**.

- However, **most organelles are bounded by a membrane similar in composition to the plasma membrane** eg.
  - **mitochondria,**
  - **peroxisomes,**
  - **lysosomes,**
  - **endoplasmic reticulum, and**
  - **Golgi apparatus.**

Mitochondria

- **Aaerobic cellular respiration**.
- They contain their **own DNA and RNA** and are able to reproduce themselves.
- Busy cells like **kidney and liver cells have hundreds of mitochondria**

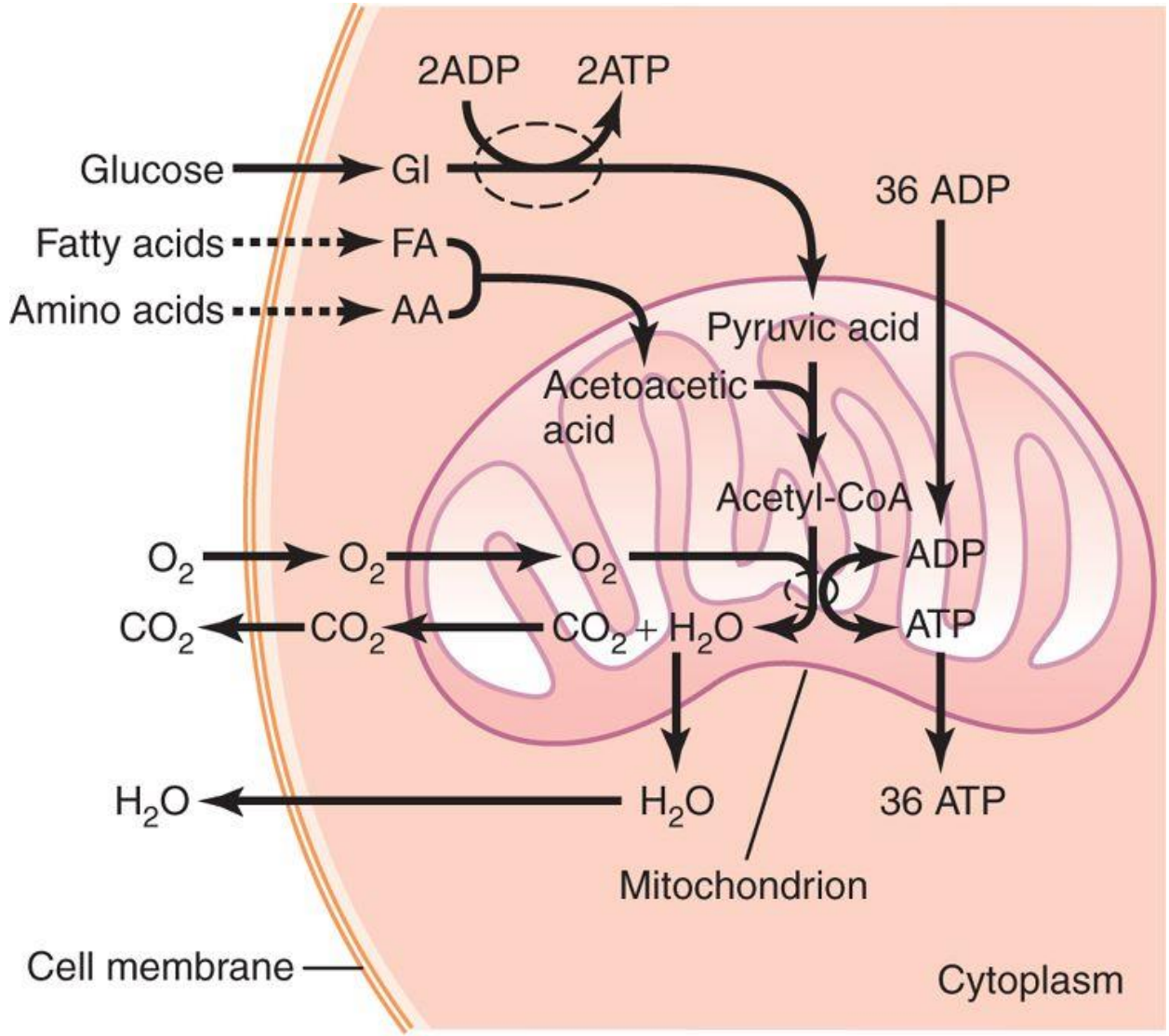




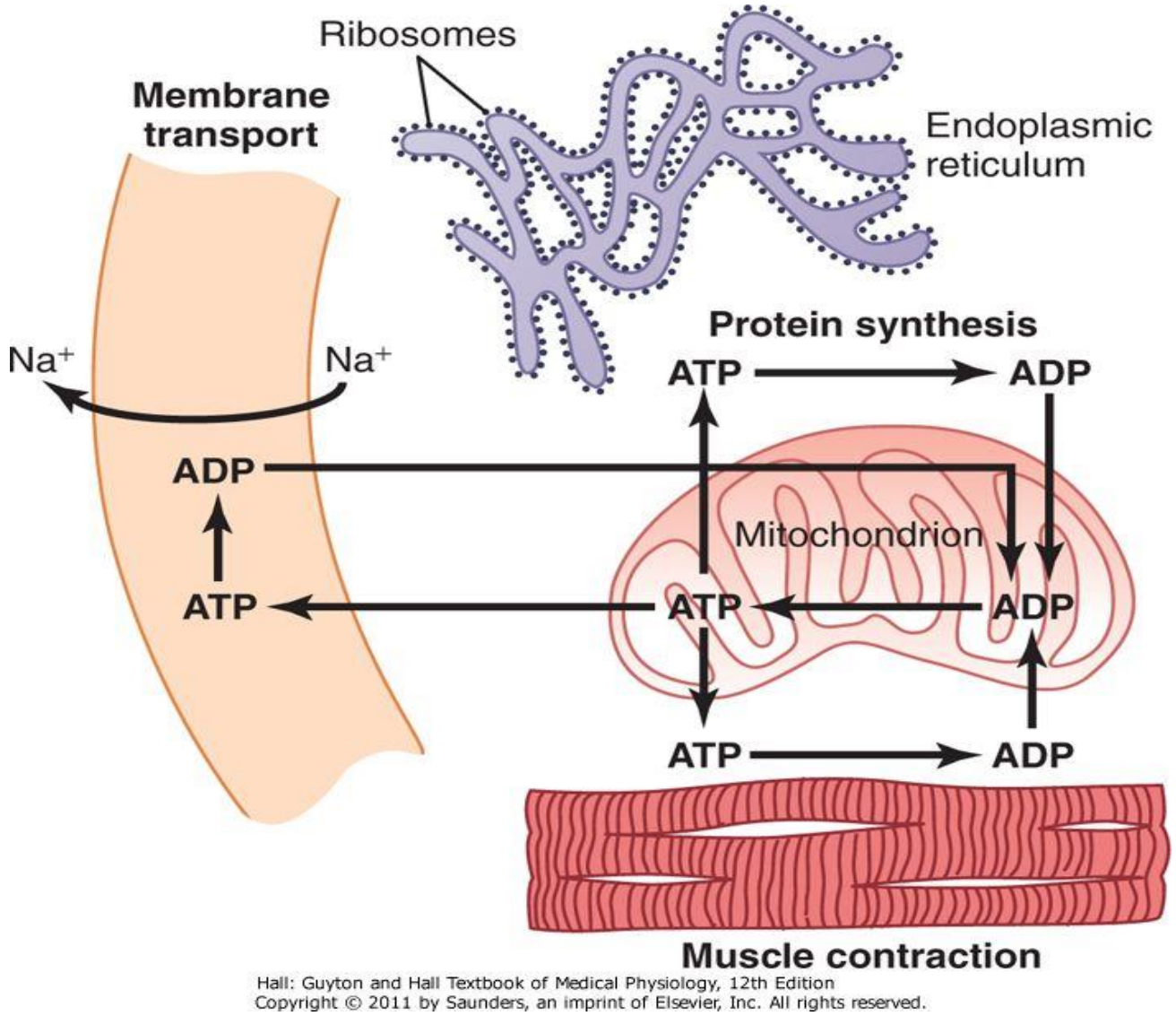
Mitochondrion

Structure: Rod- or oval-shaped body surrounded by two membranes. Inner membrane folds into matrix of the mitochondrion, forming cristae.

Function: Major site of ATP production, O_2 utilization, and CO_2 formation. Contains enzymes of Krebs cycle and oxidative phosphorylation.



- Formation of adenosine triphosphate (**ATP**) in the cell, showing that **most of the ATP is formed in the mitochondria.**



Use of adenosine triphosphate (**ATP) (formed in the mitochondrion**) to **provide energy for three major cellular functions**: **membrane transport, protein synthesis, and muscle contraction**. ADP, adenosine diphosphate.

Nucleus: (Command centre of cell)

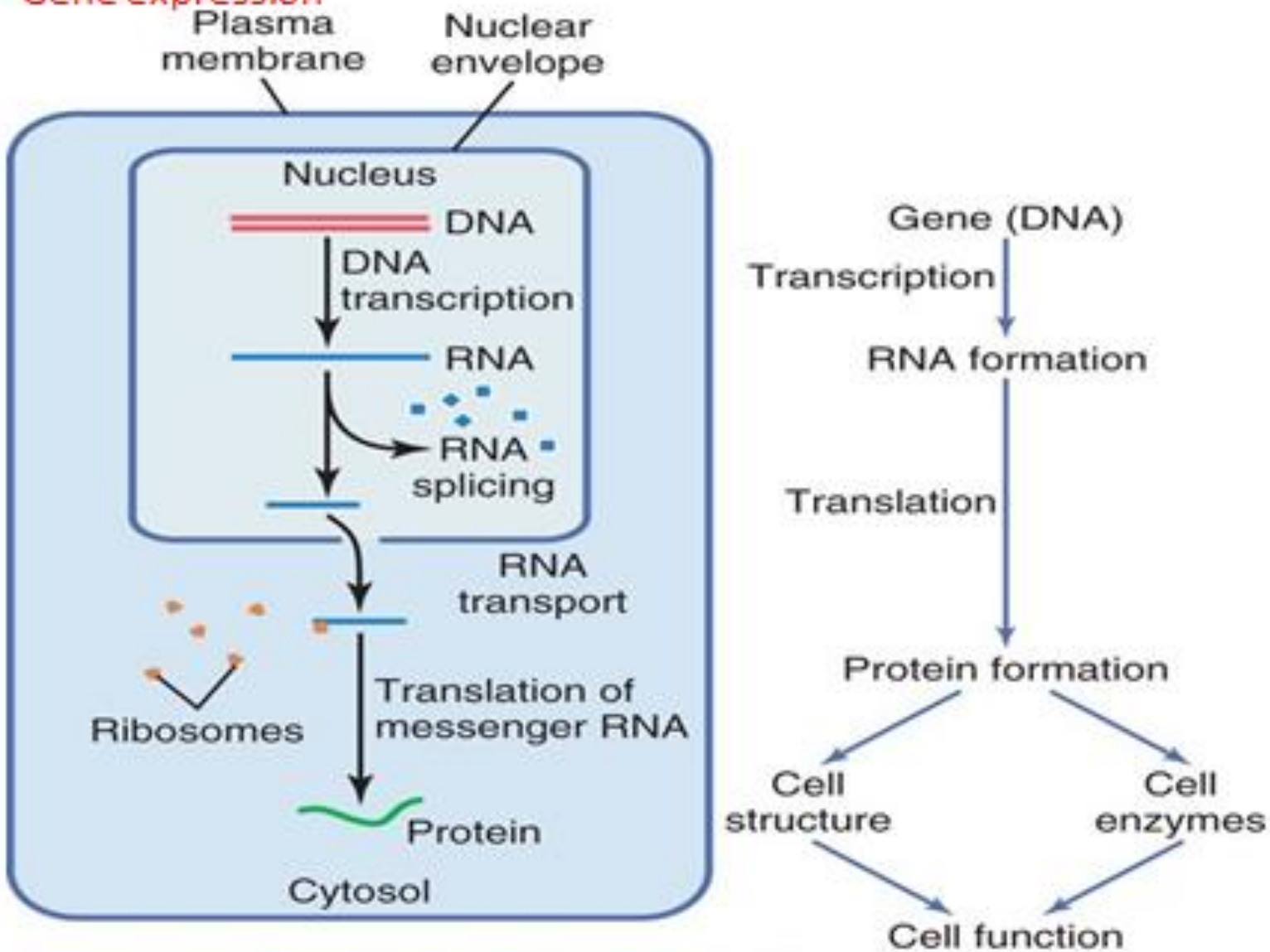
➢ Almost all cells contain a single nucleus but mature **RBC nil whereas skeletal muscle cells ; multiple nuclei.**

➢The **largest of the membrane-bound** cell organelles containing coiled strands of **DNA known as chromatin**. These condense to form chromosomes at the time of cell division.

Functions:

- Stores and transmits **genetic information**(directs all the metabolic activities of cell) in the form of DNA.
- Genetic information passes from the nucleus to the cytoplasm, where **amino acids are assembled into proteins**.

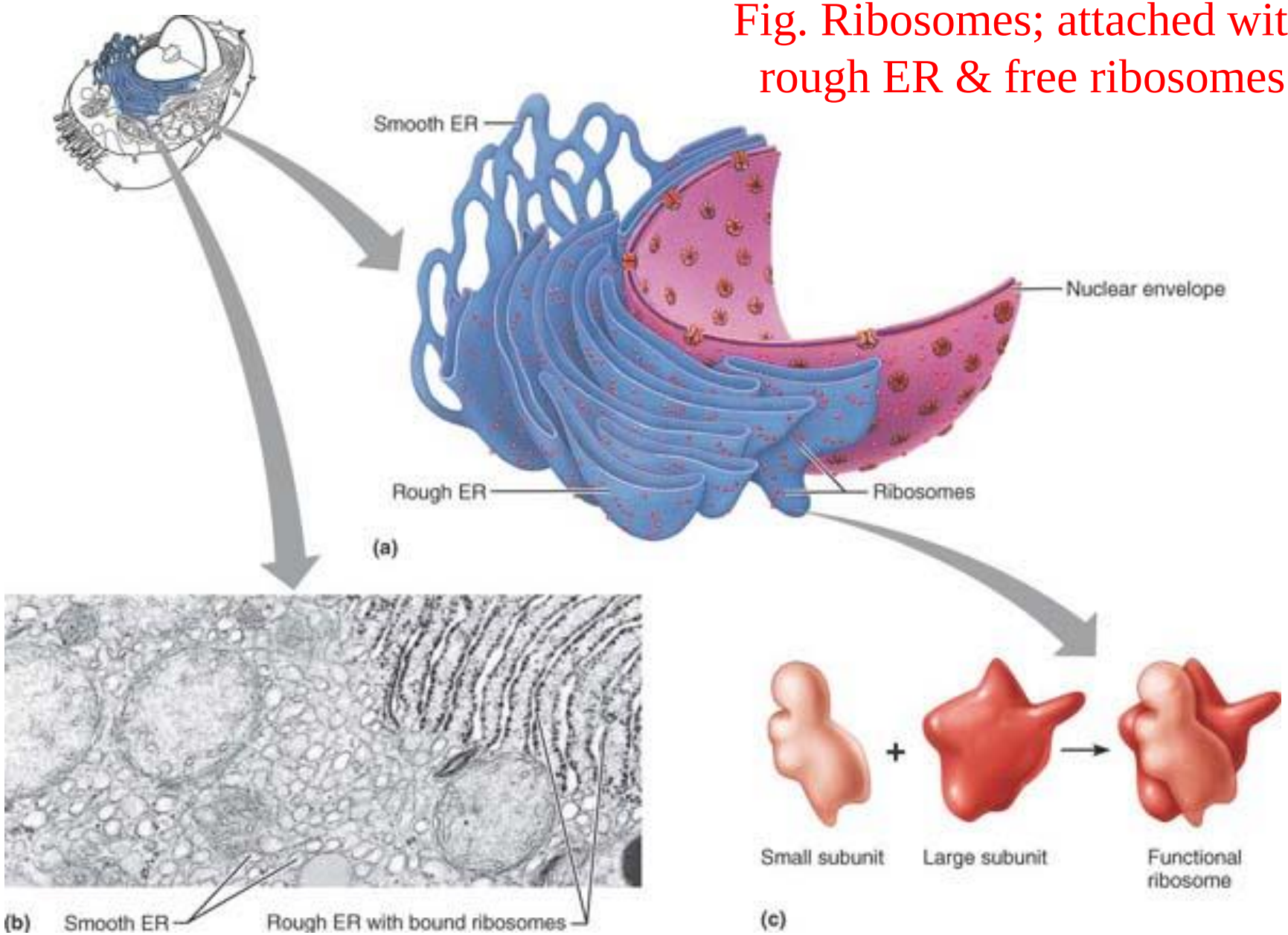
Gene expression



Ribosomes

- Composed of **RNA and proteins**. Ribosomes are either bound to the organelle called **rough (granular)** endoplasmic reticulum **or are found free in the cytoplasm**.
- **Synthesize proteins** from amino acids **using RNA**
- The proteins synthesized on the **free ribosomes** are called **enzymes** (**required for metabolism**) which are released into the cytosol **whereas the proteins synthesized by ribosomes attached to the rough endoplasmic reticulum** pass into the lumen of the reticulum and are then transferred to yet another organelle, the **Golgi apparatus**. They are ultimately secreted from the cell or distributed to other organelles i.e exported.

Fig. Ribosomes; attached with rough ER & free ribosomes



Rough Endoplasmic Reticulum:

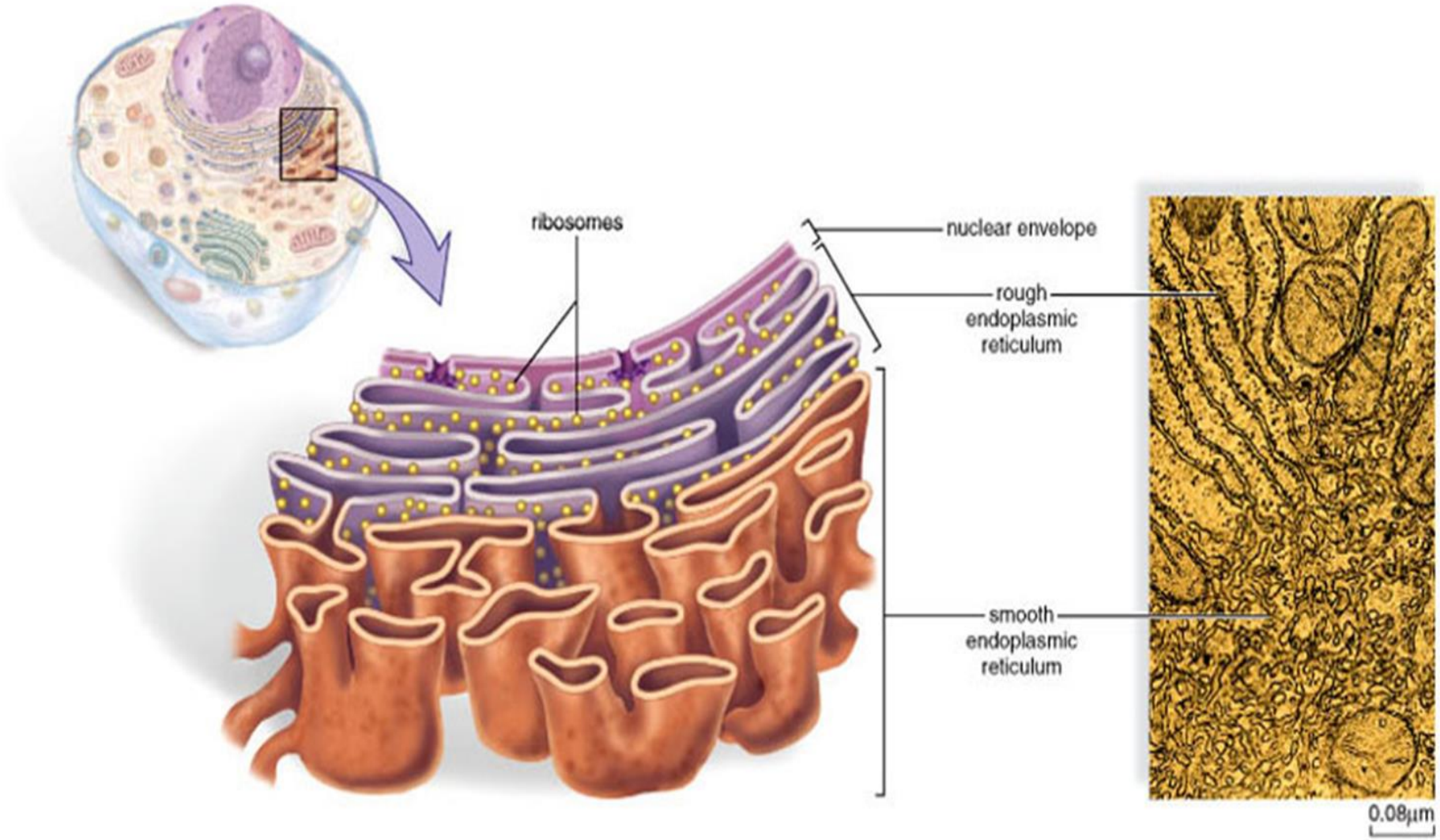
- Extensive membranous **network of flattened sacs**. Encloses a space that is continuous throughout the organelle.
- **Has ribosomal particles attached to its cytosolic surface.**

Function:

Proteins synthesized on the attached ribosomes enter the lumen of the reticulum from which they are ultimately distributed to other organelles or secreted from cell.

➢ The rough ER is particularly **abundant and well developed in most secretory cells, antibody-producing plasma cells, and liver cells, which produce most blood proteins.**

➢It is also the **cell's "membrane factory"** because integral proteins and phospholipids that form part of all cellular membranes are manufactured there.



Smooth ER

Structure: Highly branched **tubular network** that **does not have attached ribosomes but may be continuous with the granular** endoplasmic reticulum.

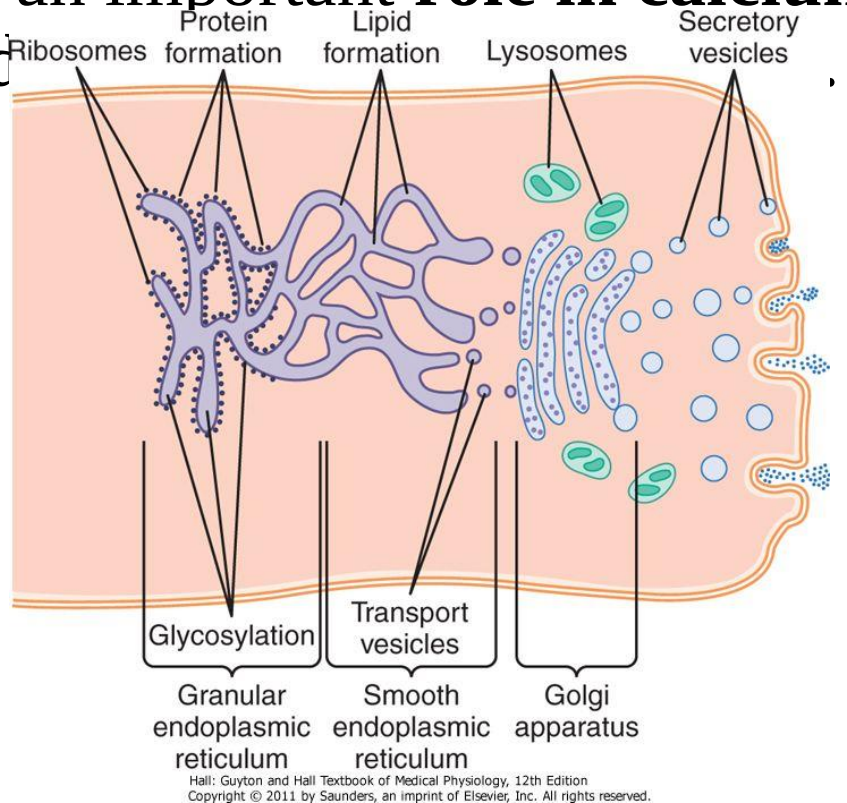
Its enzymes (all integral proteins forming part of its membranes) play **no role in protein synthesis**. Instead, they catalyze reactions **involved with the following processes**.

1. **Lipid metabolism**, cholesterol synthesis, and synthesis of the lipid components of lipoproteins (in liver cells).
2. **Synthesis of steroid-based hormones** such as sex hormones (testosterone-synthesizing cells of the testes are full of smooth ER)
3. Absorption, synthesis, and **transport of fats (in intestinal cells)**

4. **Detoxification of drugs,** certain pesticides, and carcinogens (in liver and kidneys).

5. **Breakdown of stored glycogen** to form free glucose (in liver cells especially).

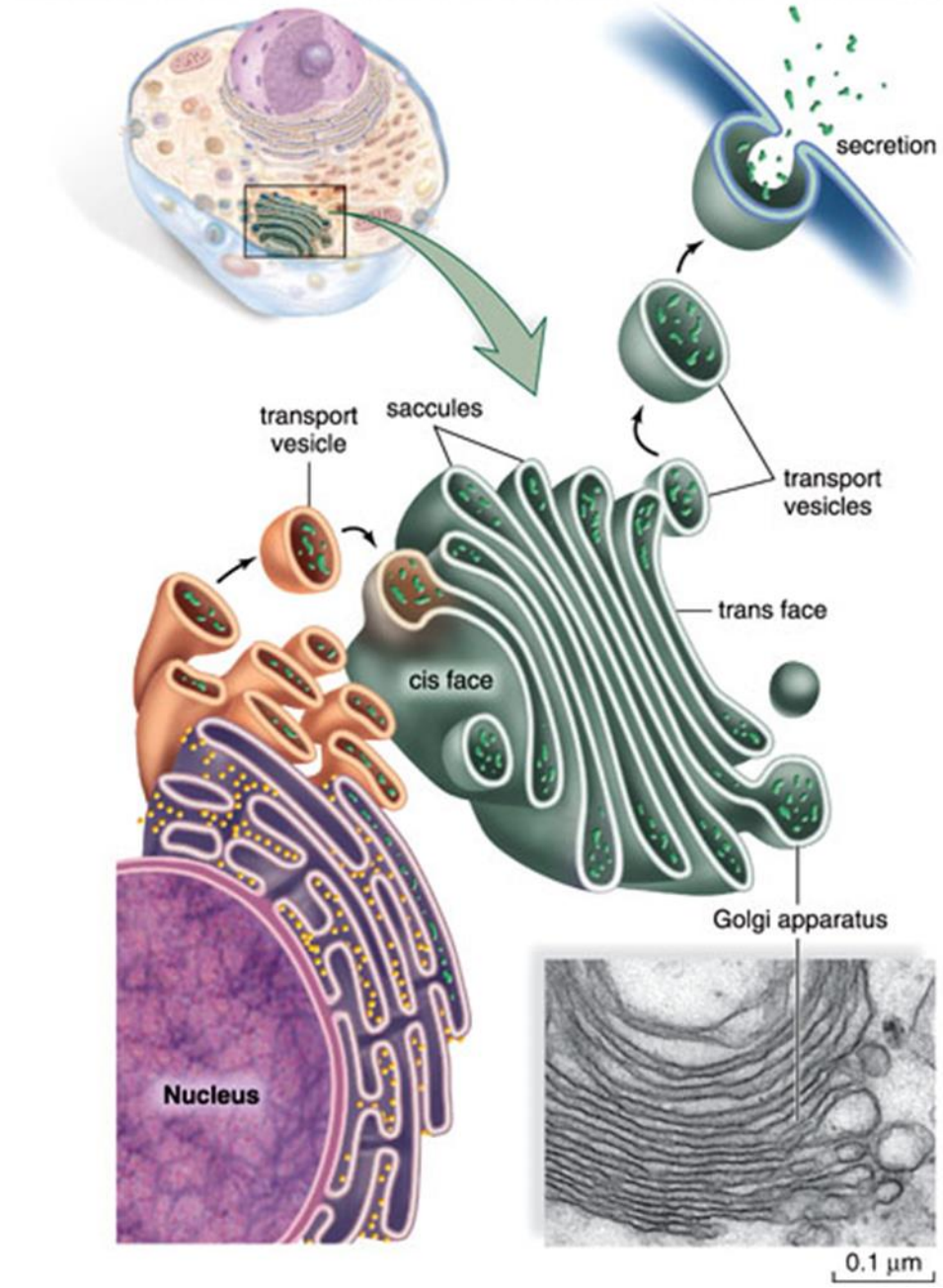
Additionally, skeletal and cardiac muscle cells have an elaborate smooth ER (called the **sarcoplasmic reticulum**) that plays an important **role in calcium ion storage and release c**

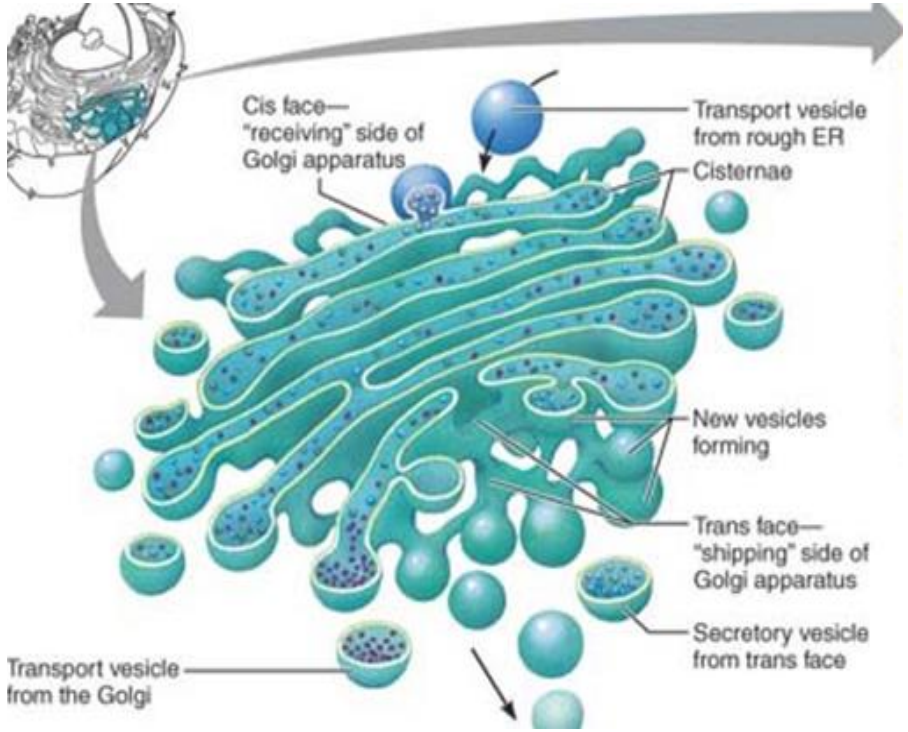


Golgi apparatus

- Consists of **stacked and flattened membranous sacs**, shaped like **hollow dinner plates, associated with swarms of tiny membranous vesicles.**
- The Golgi apparatus is the principal "**traffic director**" **for cellular proteins**.
- Its **major function** to **modify, concentrate, and package the proteins and lipids made at the rough ER**.
- The transport vesicles that **bud off from the rough ER move to and fuse with the membranes at its convex cis face**, the "receiving" side of the Golgi apparatus.
- Inside the apparatus, the **proteins are modified**: Some **sugar** groups are trimmed while others are added, and in some cases, **phosphate groups** are added.
- The various proteins are "**tagged" for delivery to a specific address, sorted, and packaged in at least three types of vesicles that bud from the concave trans face** (the "shipping" side) of the Golgi stack.

Golgi Apparatus

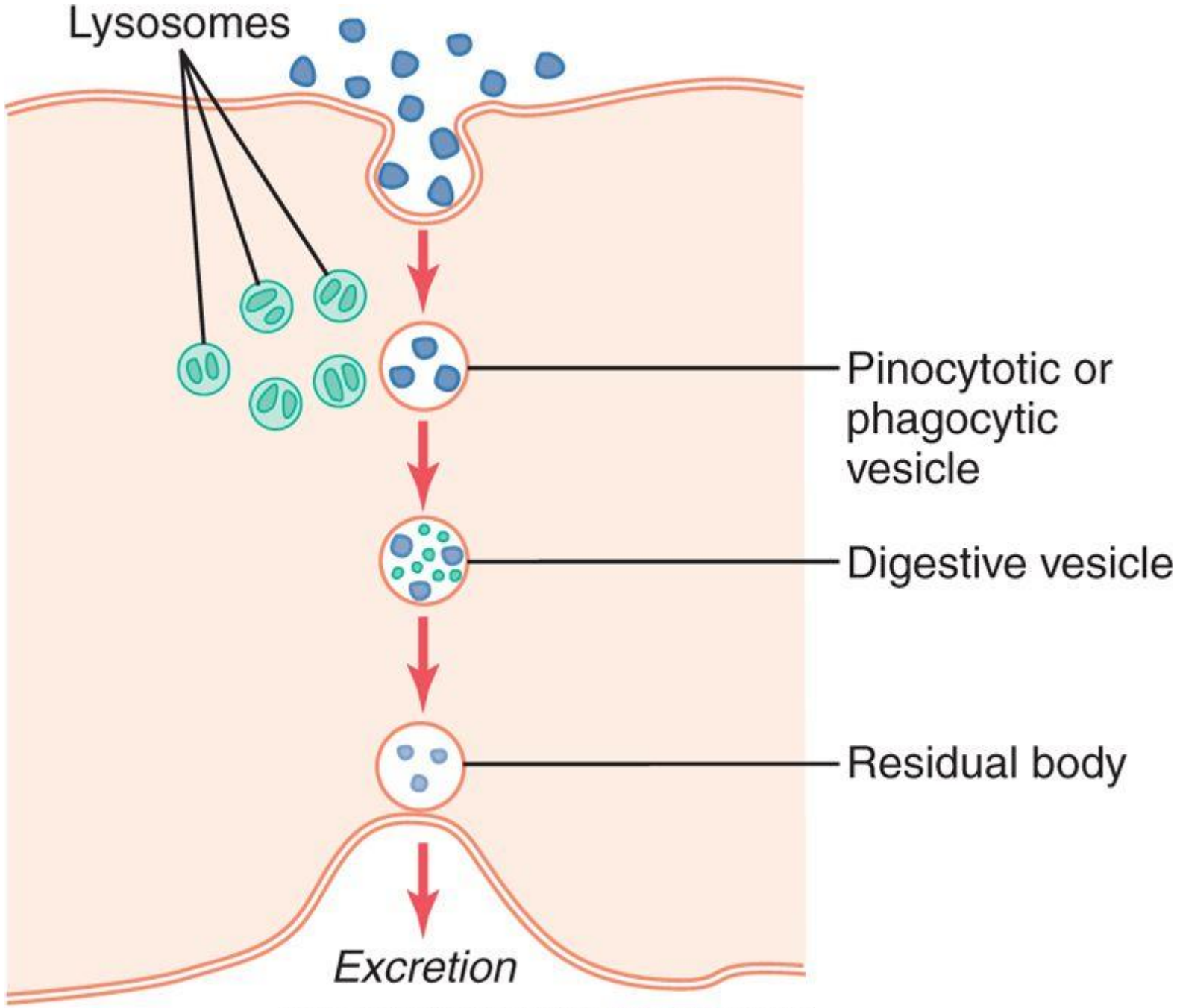




Lysosomes

- Lysosomes are **single membrane** spherical or oval organelles **formed by Golgi apparatus**. Lysosomes are large and **abundant in phagocytes**, the cells that dispose of invading bacteria and cell debris.
- The fluid within a lysosome is **highly acidic** and involved in breaking down fragments of organelles and large molecules.
- Lysosomes act as "**cellular stomachs,**" breaking down bacteria and the debris from dead cells that have been engulfed by a cell.
- The lysosomal membrane is adapted to serve lysosomal functions in two important ways:

(1) It **contains H^+ (proton) "pumps," ATPases** that **gather hydrogen ions from the surrounding cytosol to** maintain the organelle's acidic pH, and



(2) It **retains the dangerous acid hydrolases while permitting the final products of digestion to escape so that they can be used by the cell or excreted**

- Lysosome in **WBC contain enzymes** that digest foreign material such as microbes- **immunity.**
- Hence, lysosomes provide **sites where digestion can proceed safely within a cell.**

Lysosomes function as a cell's "devastation crew" by

- **Digesting** particles taken in by endocytosis, particularly ingested **bacteria, viruses, and toxins**.
- **Degrading** worn-out or nonfunctional organelles.
- Performing **metabolic functions**, such as glycogen breakdown and release.

- ❖**Breaking down nonuseful tissues**, such as the webs between the fingers and toes of a developing fetus and the uterine lining during menstruation
- ❖**Breaking down bone to release calcium ions into the blood**

- ➢The lysosomal membrane is ordinarily **quite stable**, but it becomes **fragile when the cell is injured or deprived of oxygen and when excessive amounts of vitamin A are present**.
- ➢**Lysosomal rupture** results in s**elf-digestion of the cell**, a process called **autolysis**. Autolysis is the **basis for desirable destruction of cells**

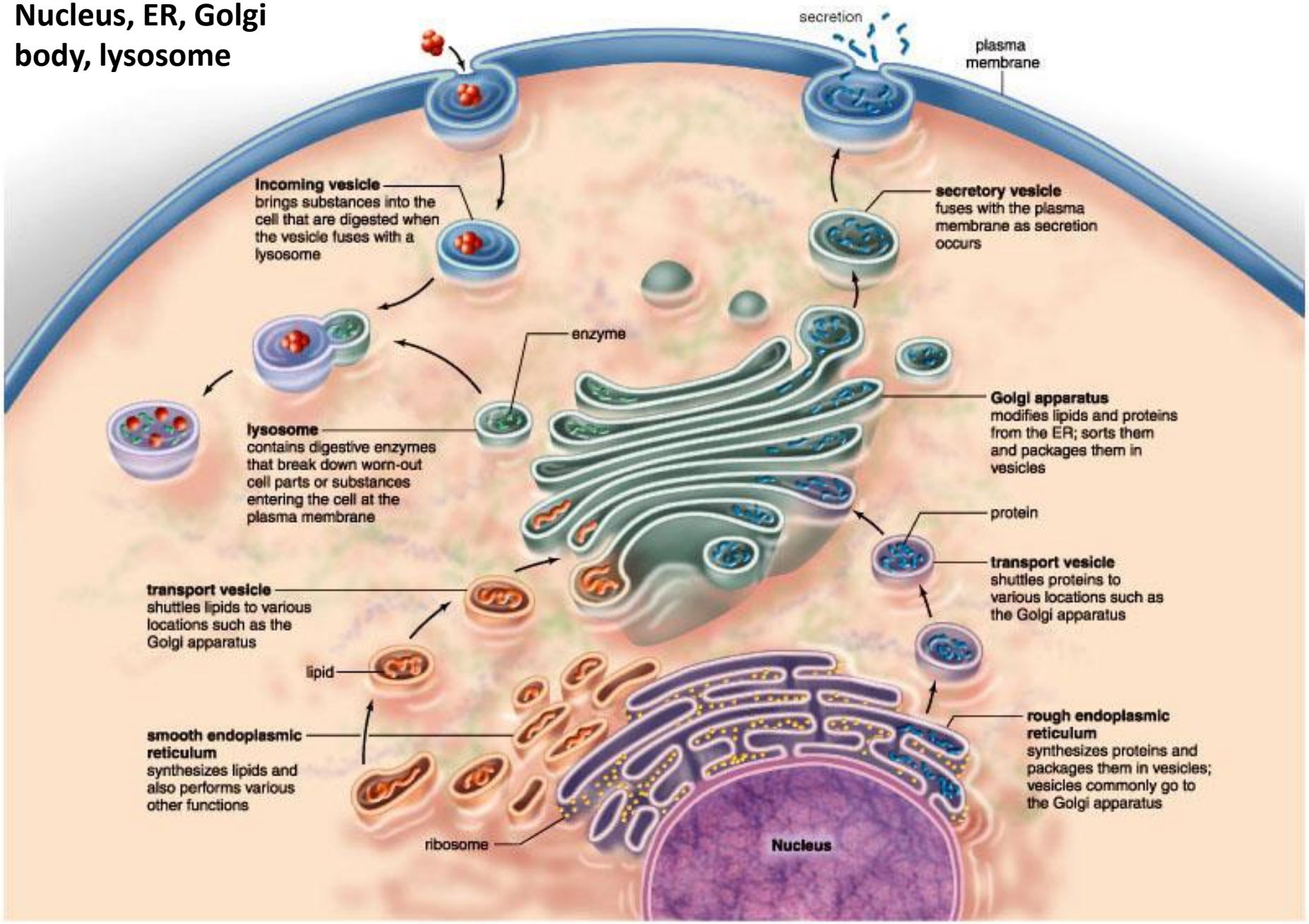
SUMMARY: LYSOSOME

- Membrane-bound vesicles (not in plants)
  - Produced by the Golgi apparatus
  - Low pH
  - Contain lytic enzymes
    - Digestion of large molecules
    - Recycling of cellular resources
    - Apoptosis (programmed cell death, like tadpole losing tail)

- Some genetic diseases
  - Caused by defect in lysosomal enzyme
  - Lysosomal storage diseases (Tay-Sachs)

Endomembrane System: A Visual Summary

Nucleus, ER, Golgi body, lysosome



ENDOMEMBRANE SYSTEM

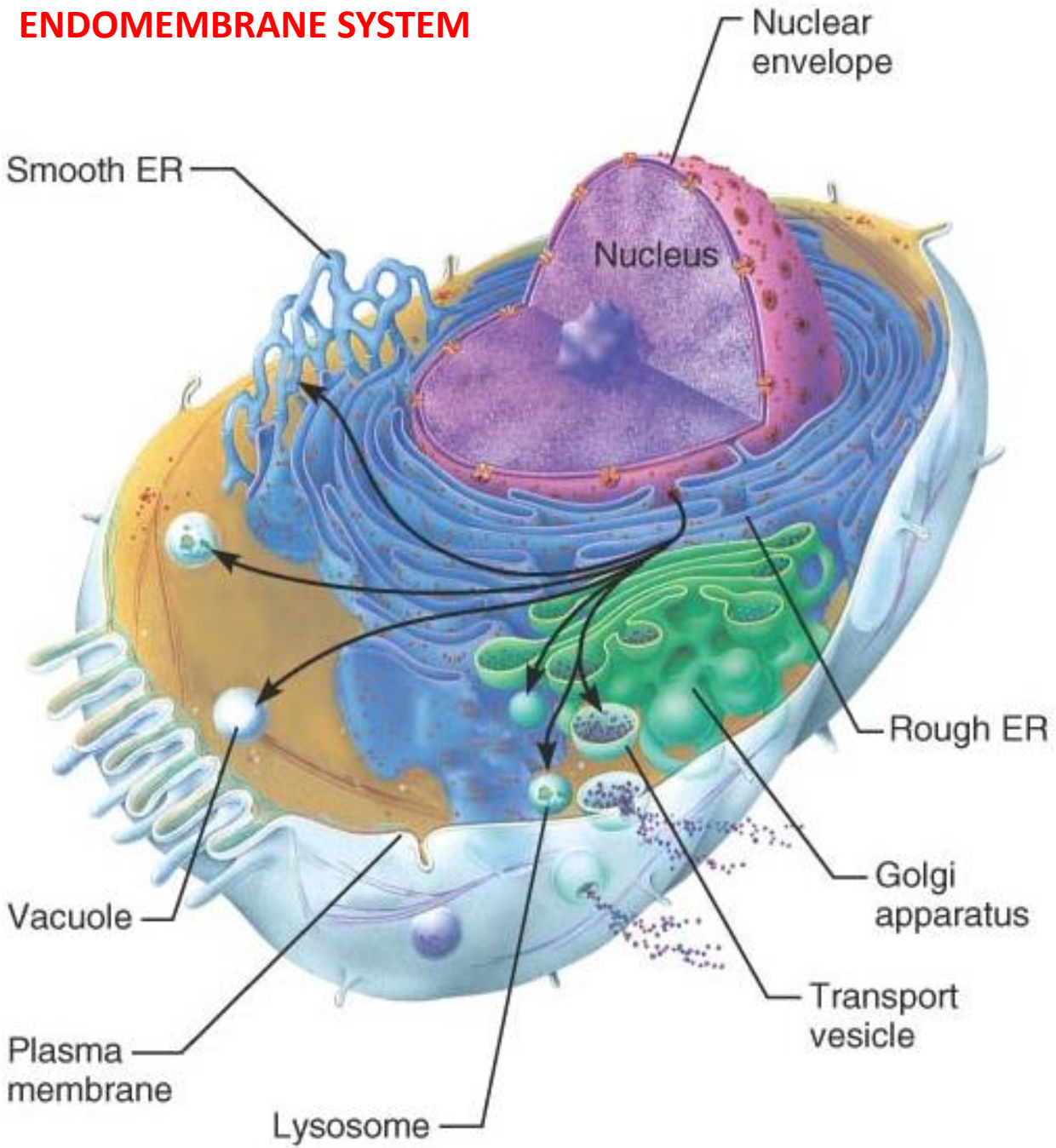


FIGURE 3.23 **The endomembrane system.**

Peroxisomes

- Like lysosomes, peroxisomes are moderately dense oval bodies enclosed by a **single membrane**.
- **Peroxisomes** ("**peroxide bodies**") are membranous sacs containing a **variety of powerful enzymes**, the most important of which are **oxidases and catalases**
- Oxidases **use molecular oxygen (O_2) to detoxify** harmful substances, including **alcohol and formaldehyde**.
- However, their most important function is **to neutralize dangerous free radicals,** highly reactive chemicals with **unpaired electrons that can damage the structure of biological molecules**.
- **Oxidases convert free radicals to hydrogen peroxide, which is also reactive** and dangerous but is **quickly converted to water by catalase enzymes**

- Peroxisomes are especially **numerous in liver and kidney cells,** which are very active in **detoxification**.
- Although peroxisomes look like small lysosomes, they are ***self-replicating organelles formed by a simple pinching in half of preexisting peroxisomes.***
- Unlike lysosomes, they **do not arise by budding from the Golgi apparatus**.

Summary: Peroxisome

Similar to lysosomes

- Membrane-bounded vesicles
- Enclose enzymes

However

- Enzymes synthesized by free ribosomes in cytoplasm (instead of ER)
- Active in lipid metabolism

Catalyze reactions that produce hydrogen peroxide H_2O_2

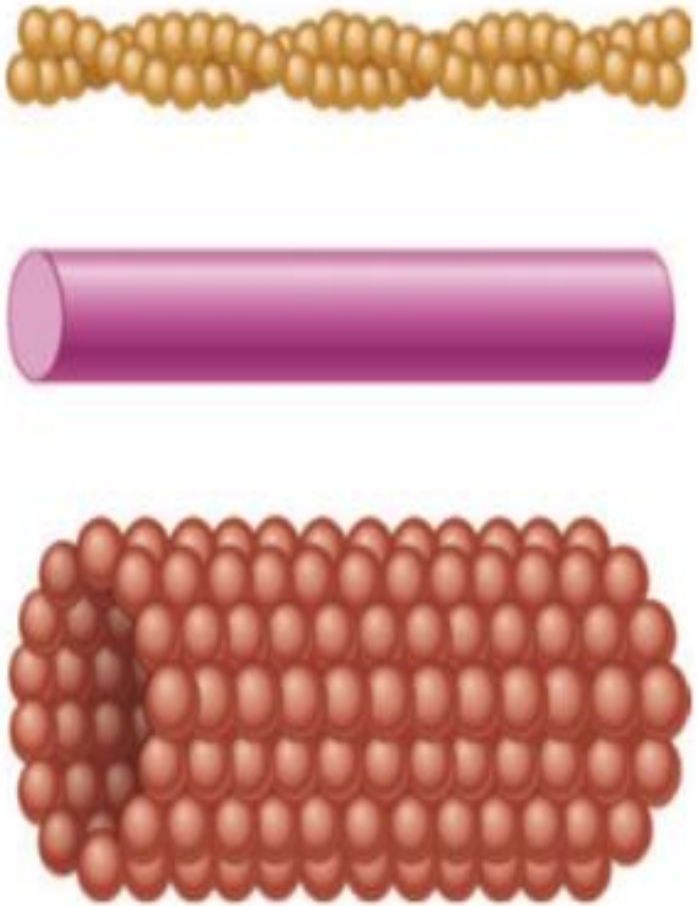
Break down Toxic

Broken down to water & O_2 by catalase

Cytoskeleton:

The **cytoskeleton**, literally, "**cell skeleton**," is an elaborate **series of rods running through the cytosol**.

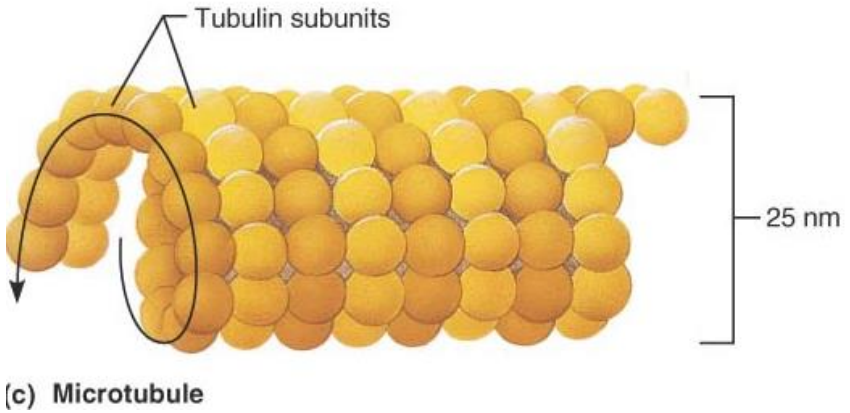
- The cytoplasm of most cells contains a variety of **protein filaments' network** called cytoskeleton, like the bony skeleton of the body, it is associated with processes that **maintain and change cell shape and produce cell movements.**
- There are **three classes** of cytoskeletal filaments, based on their diameter and the types of protein they contain:
  - **microtubules,**
  - **microfilaments, and**
  - **intermediate filaments**.
- **None** of these is **membrane covered**



Cytoskeletal filaments	Diameter (nm)	Protein subunit
Microfilament	7	Actin
Intermediate filament	10	Several proteins
Microtubule	25	Tubulin

Microtubules

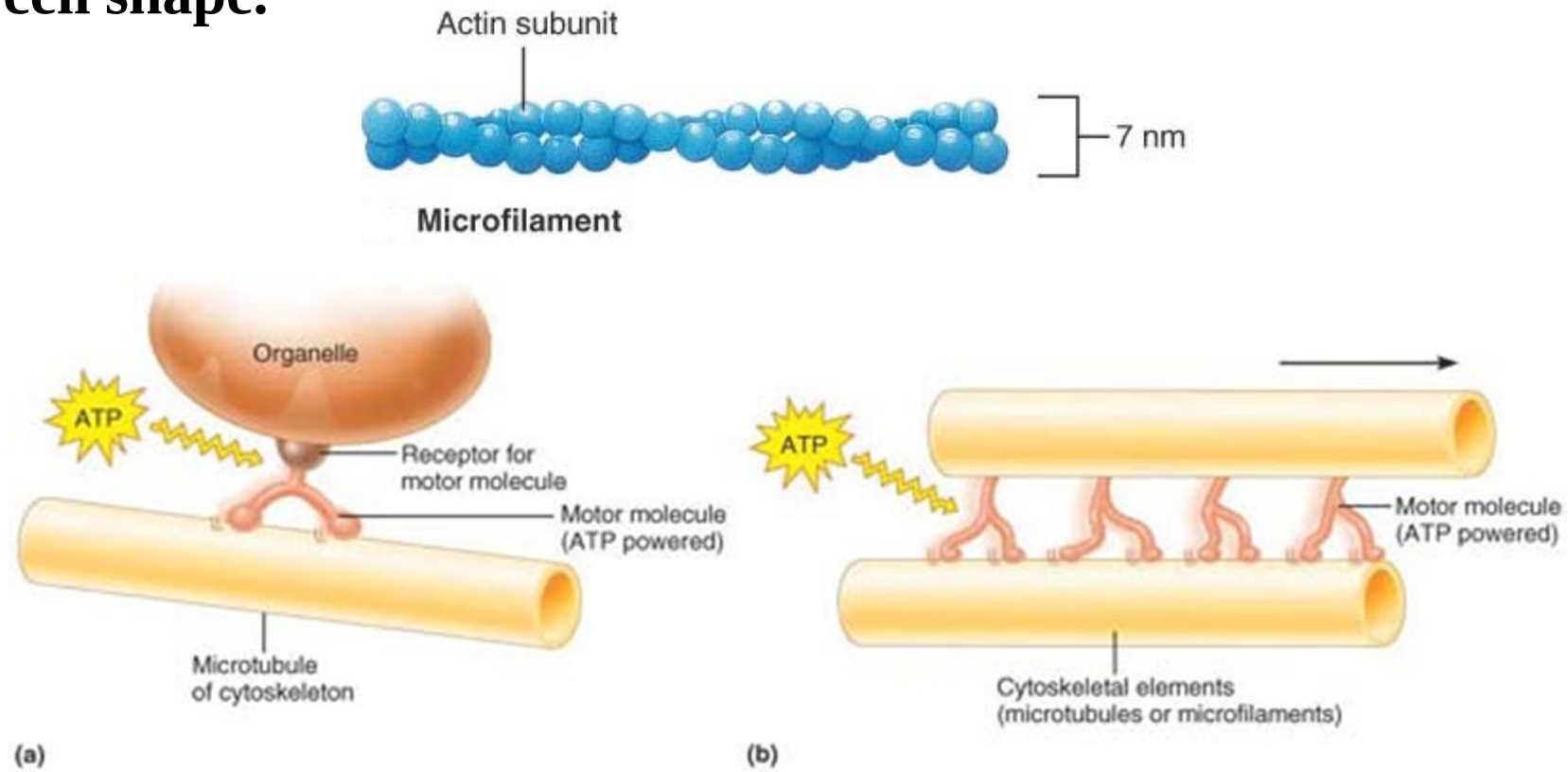
- **radiate from** a small region of cytoplasm near the nucleus called the **centrosome or cell center**.
- These stiff but bendable microtubules **determine the overall shape of the cell, as well as the distribution of cellular organelles.**
- Mitochondria, lysosomes, and secretory granules attach to the microtubules **like ornaments hanging from tree branches**.
- These **attached organelles are continually pulled along the microtubules and repositioned** by **tiny protein machines called motor proteins** (**kinesins, dyneins**, and others) that **act like train engines** by inching along or moving "hand-over-hand"



(c) Microtubule

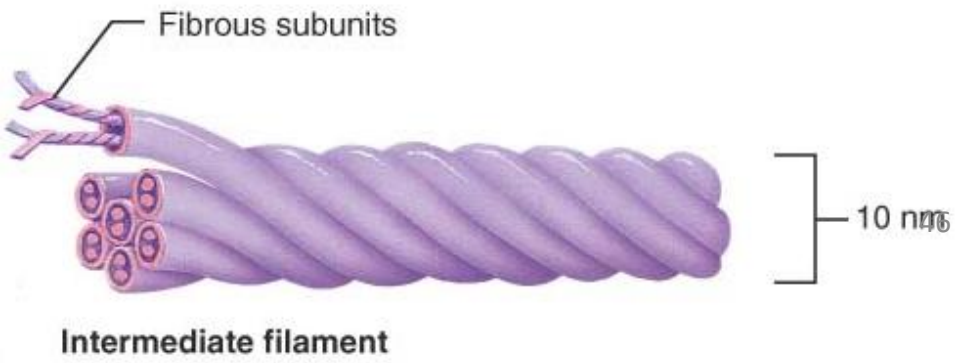
Microfilament

- Nearly **all cells have a fairly dense cross-linked network of microfilaments attached to the cytoplasmic side of their plasma membrane that strengthens the cell surface**.
- Most microfilaments are **involved in cell motility or changes in cell shape.**



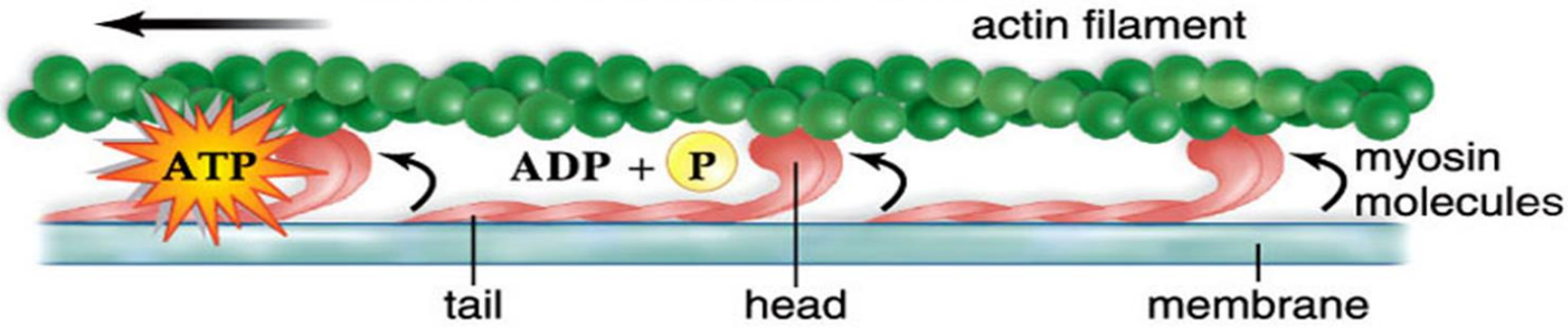
Intermediate filaments

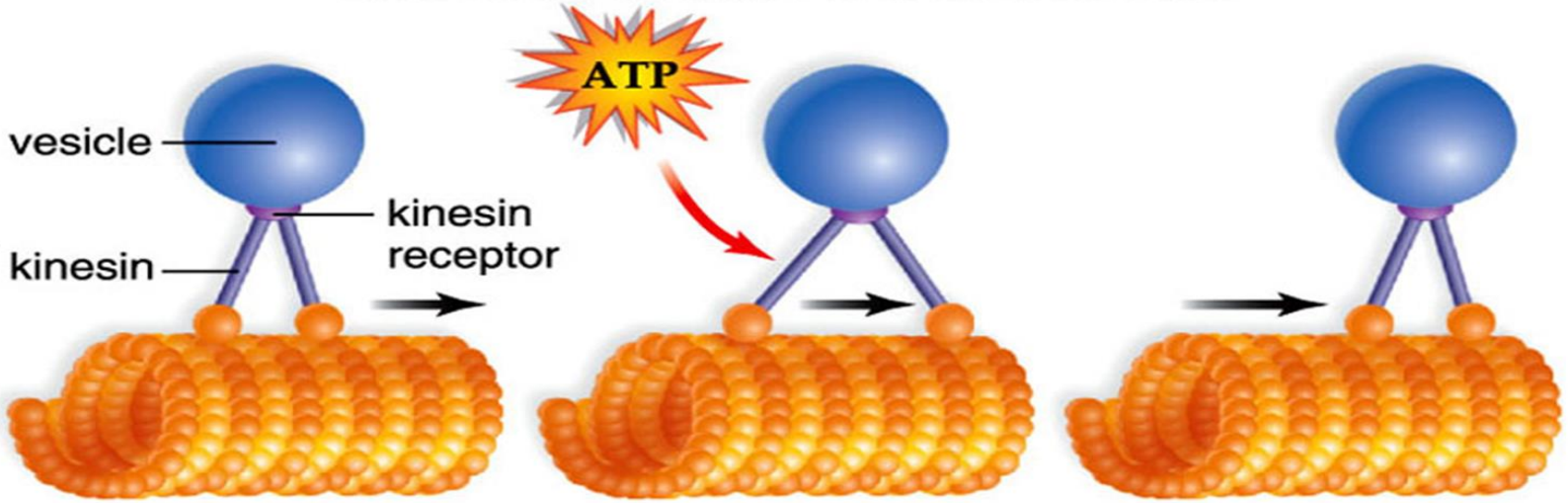
- **Tough, insoluble protein** fibers that have a diameter between those of microfilaments and microtubules
- Constructed like **woven ropes**, intermediate filaments are the **most stable and permanent of the cytoskeletal elements** and have high tensile strength.
- Unlike microtubules and microfilaments, intermediate filaments **do not bind ATP** or **do not serve as "tracks" for molecular motors to transport intracellular substances**.
- They **attach to desmosomes**, and their main job is to act as **internal guy-wires exerted on the cell.**



Cytoskeleton

- Maintains cell shape
- Assists in movement of cell and organelles





vesicle moves, not microtubule

Centrosome and Centrioles

- **Microtubules are anchored** at one end in a region near the nucleus called the **centrosome** that contains **paired centrioles**, small, barrel-shaped organelles **oriented at right angles** to each other.
- The centrosome matrix is best known for its **generation of microtubules and its role of organizing the mitotic spindle** in cell division.
- **Each centriole** consists of **a pinwheel array of nine triplets of microtubules, arranged to form a hollow tube**.
- Centrioles also **form the bases of cilia and flagella**.

CYTOSKELETON

Nicknames: Scaffolding,
Highways

- Maintains cell shape.
- Protects the cell.
- Enables some cell movement (using structures such as flagella and cilia).
- Plays important roles in intra-cellular transport (the movement of vesicles and organelles).
- Plays important role in cell division.

SUMMARY: Cell Organelles & function

- **Nucleus:** Consists of 46 chromosomes, which are made of DNA molecules.
- **Nucleolus:** Located in the nucleus; produces RNA.
- **Ribosomes:** Produce protein; can be free or fixed to endoplasmic reticulum.
- **Golgi apparatus:** Modifies the protein that is produced by ribosomes. Many times, it will add a carbohydrate to the protein, thus producing a glycoprotein. It also produces lysosomes, which consist of enzymes.
- **Lysosomes:** Vacuoles that contain enzymes. Enzymes will digest organic molecules.
- **Mitochondria:** Produces 95% of the ATP required for cell activity; produces cholesterol.
- **Rough endoplasmic reticulum:** Network of channels passing throughout the cytoplasm; have ribosomes attached to them (fixed ribosomes).
- **Smooth endoplasmic reticulum:** Produces lipids and carbohydrates; do not have ribosomes attached to them.