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Cell Physiology

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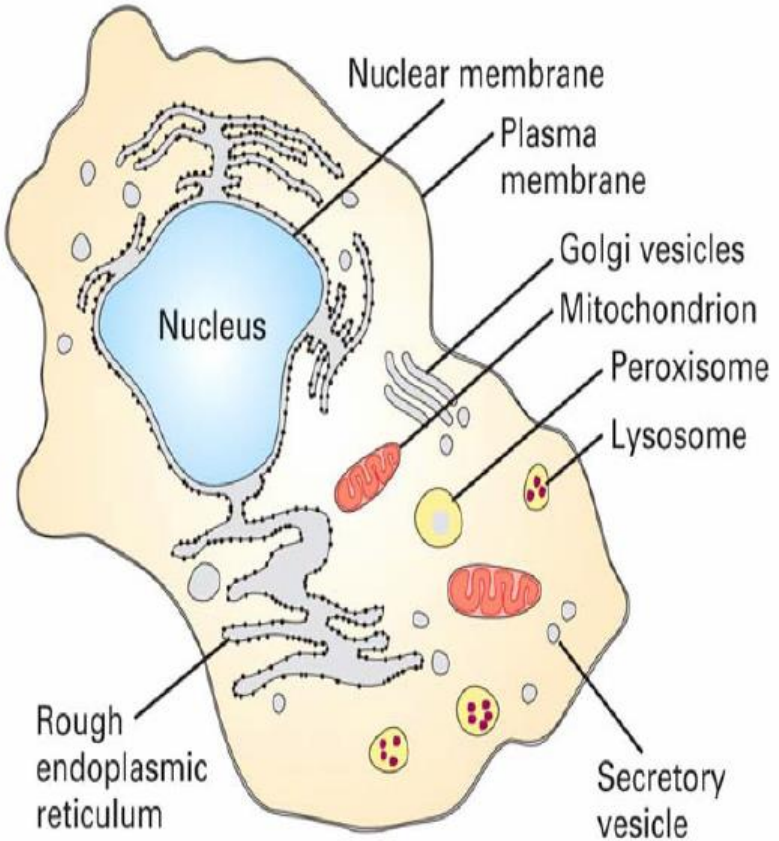
CELL PHYSIOLOGY

CELLS ARE THE BASIC UNIT OF LIFE

Functional Organization of the Human Body and Control of the "Internal Environment"

- The goal of physiology is to explain the physical and chemical factors that are responsible for the origin, development, and progression of life.
- In *human physiology,* we attempt to explain the specific characteristics and mechanisms of the human body that make it a living being.

- The basic living unit of the body is the cell. Each organ is an aggregate of many different cells held together by intercellular supporting structures.
- Each type of cell is specially adapted to perform one or a few particular functions.
- Although the many cells of the body often differ markedly from one another, all of them have certain basic characteristics that are alike.



GENERAL PRINCIPLES

Organization of the Body:

The cells that make up the bodies of all but the simplest multicellular animals, both aquatic and terrestrial, exist in an "internal sea" of **extracellular fluid (ECF)** enclosed within the integument of the animal.

From this fluid, the cells take up O_2 and nutrients. In animals with a closed vascular system, the ECF is divided into two components: the **interstitial fluid** and the circulating **blood plasma.** The plasma and the cellular elements of the blood, principally red blood cells, fill the vascular system.

The interstitial fluid is that part of the ECF that is outside the vascular system, bathing the cells. About a third of the **total body water (TBW)** is extracellular; the remaining two-thirds are intracellular **(intracellular fluid).**

Body Composition :

In the average young adult male, 18% of the body weight is protein and related substances, 7% is mineral, and 15% is fat. The remaining 60% is water.

- Differences Between ECF and ICF

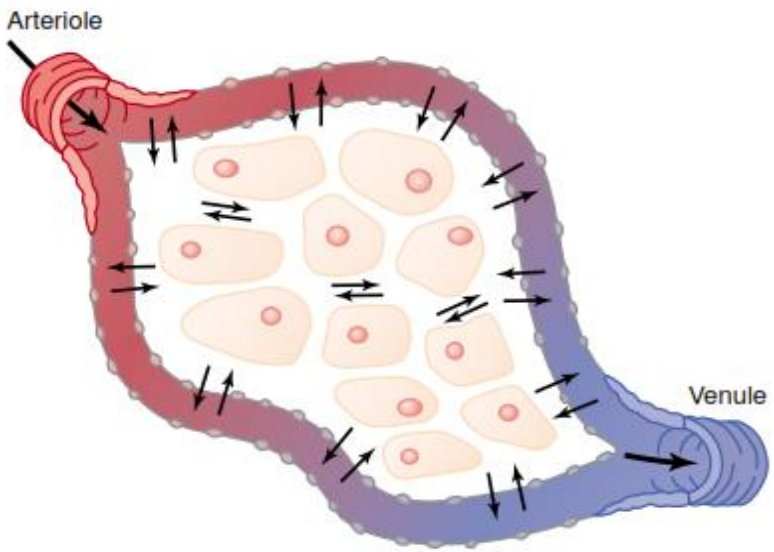
- The **ECF** contains **large** amounts of ***sodium, chloride,*** and ***bicarbonate ions*** plus **nutrients** for the cells, such as ***oxygen, glucose, fatty acids***, and ***amino acids***. It **also** contains ***carbon dioxide*** that is being **transported** from the cells to the **lungs** to be **excreted**, plus other **cellular waste products** that are being **transported** to the **kidneys** for excretion.
- The **ICF** differs **significantly** from the **ECF**; specifically, it contains **large** amounts of ***potassium, magnesium,*** and ***phosphate ions*** instead of the sodium and chloride ions found in the **ECF**.

- **“Homeostatic” Mechanisms of the Major Functional Systems**
- **Homeostasis:**
  - The term ***homeostasis*** is used by physiologists to **mean *maintenance of nearly constant conditions in the internal environment*.**
  - Essentially **all organs and tissues** of the body **perform functions** that help **maintain these constant conditions**.

- **ECF Transport and Mixing System - The Blood Circulatory System**

- **ECF** is **transported** through all **parts** of the body in **two stages**:
- The **first** stage is **movement of blood** through the body in the **blood vessels**.
- The **second** is movement of **fluid** between the **blood capillaries** and the ***intercellular spaces*** between the **tissue cells**.
- The **walls** of the **capillaries** are **permeable** to **most molecules** in the **plasma** of the blood, with the **exception** of the **large** plasma protein **molecules**.

- Therefore, **large** amounts of **fluid** and **its dissolved** constituents ***diffuse*** **back** and **forth between** the **blood** and the **tissue spaces**. This **process** of diffusion is **caused** by **kinetic motion** of the **molecules** in both the **plasma** and the **interstitial fluid**.



Origin of Nutrients in the ECF

- **Respiratory System:**

- Each time the blood **passes** through the **body**, it **also** flows through the **lungs**.
- The blood **picks up oxygen** in the **alveoli**.
- The **membrane** between the **alveoli and the lumen** of the pulmonary **capillaries**, the ***alveolar membrane***, is **only 0.4 to 2.0** micrometers thick, and **oxygen diffuses** by molecular motion through **the pores** of this membrane **into the blood** in the **same manner** that **water and ions diffuse** through **walls of the tissue capillaries**.

Origin of Nutrients in the ECF (Continued

- **Gastrointestinal Tract:**

- A **large portion** of the **blood pumped** by the heart also **passes** through the **walls** of the **GIT**.
- Here **different dissolved nutrients**, including ***carbohydrates, fatty acids,*** and ***amino acids,*** are **absorbed** from the ingested food **into** the **ECF** of the blood.

- **Liver and Other Organs That Perform Primarily Metabolic Functions:**

- **Not all** substances **absorbed** from the **GIT can be used** in their absorbed form **by the cells**. The **liver** changes the **chemical compositions** of many of these **substances** to more **usable forms**, and other tissues of the body such as **fat** cells, **GIT mucosa**, **kidneys**, and **endocrine** glands **helps modify** the absorbed substances or **store them** until they are needed.

- **Musculoskeletal System:**

- Sometimes the **question** is asked, how does the musculoskeletal system **fit** into the **homeostatic** functions of the body? The answer is obvious and simple: Were it not for the muscles, **the body could not move** to the appropriate **place** at the appropriate **time to obtain** the foods **required for nutrition**.
- The musculoskeletal system **also provides motility** for **protection against adverse surroundings**, **without which** the **entire body**, along with its homeostatic mechanisms, **could be destroyed** instantaneously.

Removal of Metabolic End Products

- **Removal of Carbon Dioxide by the Lungs:**

- **At the same time** that **blood picks** up **oxygen** in the lungs, ***carbon dioxide* is released** from the **blood into** the lung **alveoli**; the respiratory movement of **air into and out of the lungs** carries the carbon dioxide **to the atmosphere**.

- Carbon dioxide is the most **abundant** of all the end products of metabolism.

Removal of Metabolic End Products **(Continued)**

- **Kidneys:**

- **Passage** of the blood **through the kidneys removes from the plasma** most of the **other** substances besides **carbon dioxide** that are not needed by the cells.
- **These** substances **include different end products** of cellular **metabolism**, such as **urea and uric acid**; they **also include excesses of ions and water** from the food **that might have accumulated** in the **ECF**.

Removal of Metabolic End Products **(Continued)**

- The **kidneys** perform their **function** by:
- **1- Filtering** large quantities of **plasma** through the **glomeruli into the tubules**.
- **2-Reabsorbing into** the **blood** those **substances needed** by the body, such as **glucose, amino acids, appropriate amounts of water**, and **many of the ions**. Most of the **other substances** that are **not needed** by the body, especially the metabolic end products such as **urea**, are **reabsorbed poorly** and **pass through the renal tubules into the urine**.

Regulation of Body Functions

- **Nervous System:**

- The nervous system is composed of three major parts:
- 1 - The ***sensory input portion***.
- 2 - The ***central nervous system*** (or ***integrative portion***).
- 3 - The ***motor output portion***.
- **Sensory receptors detect the state of the body or the state of the surroundings**. For instance, **receptors** in the **skin apprise** one whenever an **object touches** the skin at any point.

Regulation of Body Functions (Continued)

- The **CNS** is **composed** of the **brain and spinal cord**.
- The **brain** can **store information, generate thoughts, create ambition**, and **determine reactions** that the **body performs** in **response** to the **sensations**.
- Appropriate **signals** are then **transmitted** through the **motor output portion** of the nervous system to **carry out one's desires**.
- A **large segment** of the **NS** is called the ***autonomic system***.
- It **operates** at a **subconscious level** and **controls** many **functions** of the **internal organs**.

Regulation of Body Functions (Continued)

- **Hormonal System of Regulation:**
- There are **eight** major ***endocrine glands*** that **secrete chemical** substances called ***hormones***.
- **Hormones** are **transported** in the **ECF** to **all** parts of the **body** to **help regulate** cellular **function**. For instance, **thyroid** hormone **increases the rates** of most **chemical reactions** in all cells, thus helping **to set** the **tempo** of bodily activity. **Insulin controls glucose** metabolism; **adrenocortical** hormones control **sodium ion, potassium ion**, and **protein metabolism;** and **parathyroid** hormone controls **bone calcium and phosphate**.
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Regulation of Body Functions (Continued)

- Thus, the **hormones** are a **system of regulation** that **complements** the **NS**.
- The **NS regulates** mainly **muscular and secretory activities** of the body, whereas the **hormonal system regulates** many **metabolic functions**.

The Cell and Its Functions

Organization of the Cell

A typical cell, as seen by the light microscope has two major parts, the **nucleus** and the **cytoplasm**.

The nucleus is separated from

the cytoplasm by a **nuclear membrane**, and the cytoplasm is separated from the surrounding fluids by a **cell membrane**, also called the **plasma membrane**.

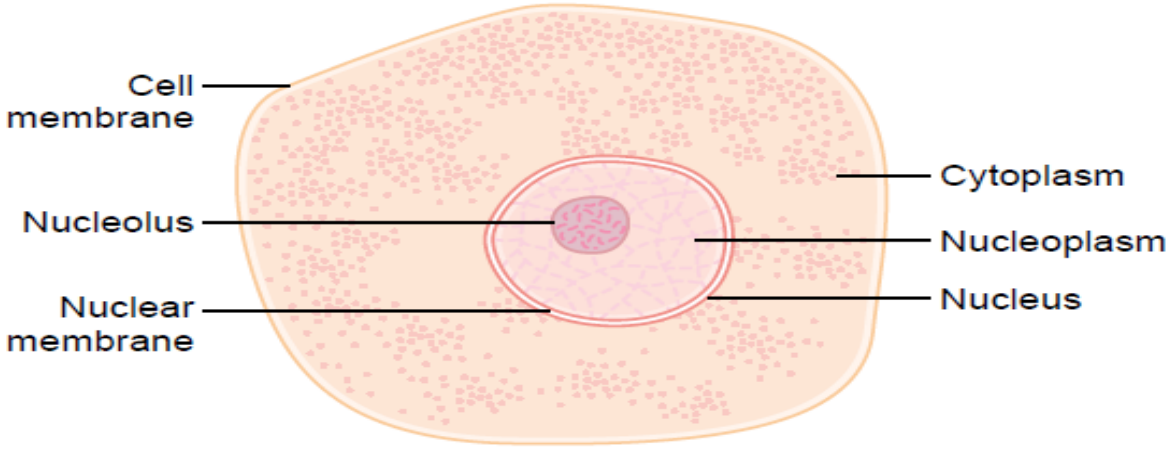


Figure 2–1

Structure of the cell as seen with the light microscope.

The different substances that make up the cell are collectively called ***protoplasm***.

Protoplasm is composed mainly of five basic substances: water, electrolytes, proteins, lipids, and carbohydrates.

Physical Structure of the Cell

The cell not only contain fluid, enzymes, and chemicals; it also contains highly organized physical structures, called ***intracellular organelles***.

The physical nature of each organelle is as important as the cell's chemical constituents for cell function. For instance, without one of the organelles, the **mitochondria**, more

than 95 percent of the cell's energy release from nutrients would cease immediately.

Cell Membrane

The cell membrane is a thin semi-permeable membrane that surrounds the cytoplasm of a cell, enclosing its contents.

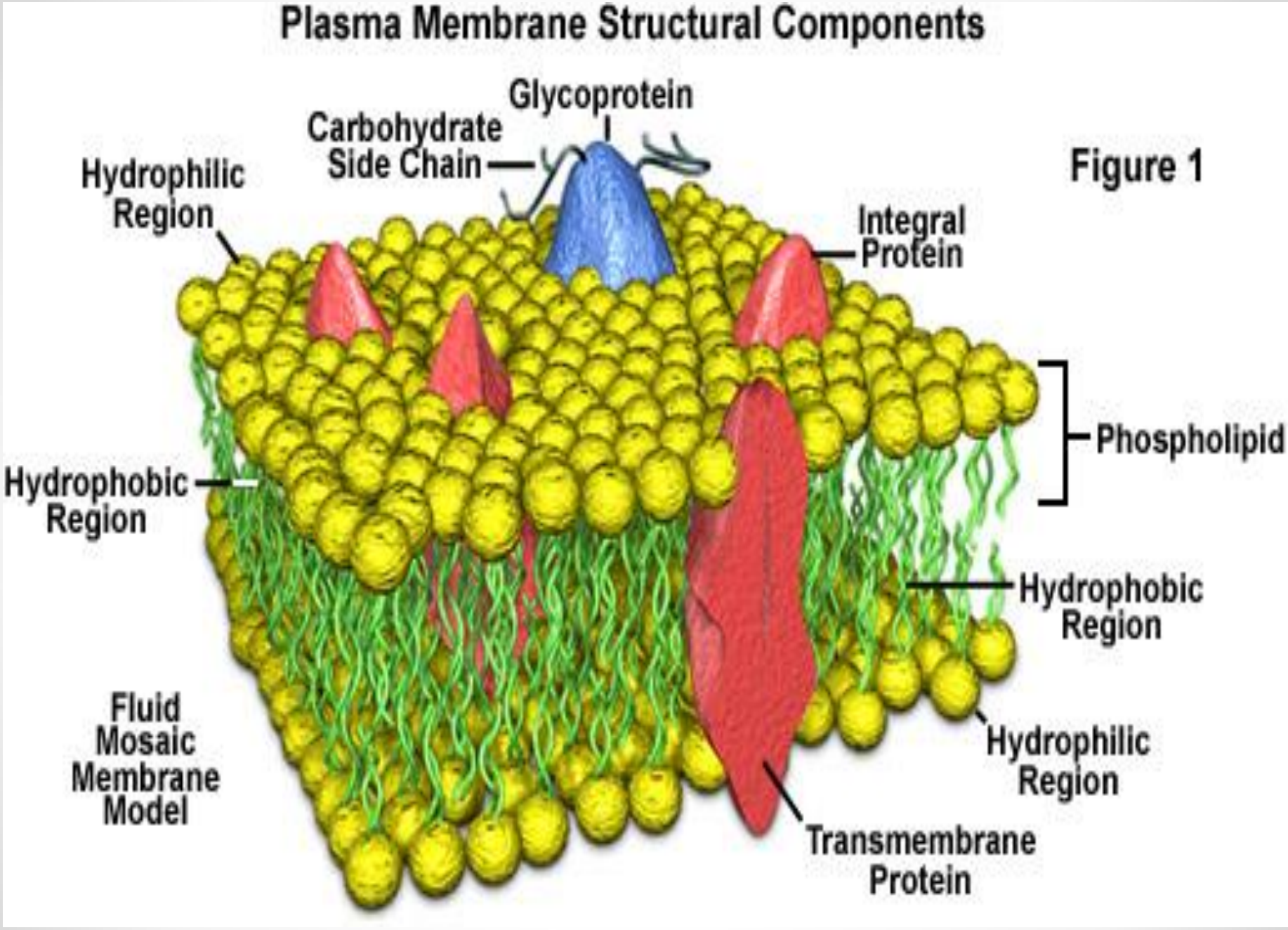
Its function is to protect the integrity of the interior of the cell by allowing certain substances into the cell, while keeping other substances out.

It also serves as a base of attachment for the cytoskeleton in some organisms and the cell wall in others.

Thus the cell membrane also serves to help support the cell and help maintain its shape.

The cell membrane is primarily composed of a mix of proteins and lipids. While lipids help to give membranes their flexibility, proteins monitor and maintain the cell's chemical climate and assist in the transfer of molecules across the membrane.

Phospholipids are a major component of cell membranes. They form a lipid bilayer in which their hydrophillic (attracted to water) head areas spontaneously arrange to face the aqueous cytosol and the extracellular fluid, while their hydrophobic (repelled by water) tail areas face away from the cytosol and extracellular fluid. The lipid bilayer is semi-permeable, allowing only certain molecules to diffuse across the membrane.


Plasma Membrane Structural Components
Glycoprotein
Carbohydrate Side Chain
Hydrophilic Region
Figure 1
Integral Protein
Phospholipid
Hydrophobic Region
Hydrophobic Region
Fluid Mosaic Membrane Model
Hydrophilic Region
Transmembrane Protein

There are many different proteins embedded in the membrane.

They exist as separate globular units and many pass through the membrane **(integral proteins),** whereas others **(peripheral proteins)** study the inside and outside of the membrane.

Some are **cell adhesion molecules** that anchor cells to their neighbors or to basal laminas.

There are proteins that function as **pumps,** actively transporting ions across the membrane.

Other proteins function as **carriers,** transporting substances down electrochemical gradients by facilitated diffusion.

Still others are **ion channels,** which, when activated, permit the passage of ions into or out of the cell.

Proteins in another group function as **receptors** that bind neurotransmitters and hormones, initiating physiologic changes inside the cell.

Proteins also function as **enzymes,** catalyzing reactions at the surfaces of the membrane.

In addition, some glycoproteins function in antibody processing and distinguishing self from non-self.

Underlying most cells is a thin, fuzzy layer plus some fibrils that collectively make up the **basement membrane** or, more properly, the **basal lamina.**

The basal lamina and, more generally, the extracellular matrix is made up of many proteins that hold cells together, regulate their development, and determine their growth.

Cell Adhesion Molecules

Cells are attached to the basal lamina and to each other by **cell adhesion molecules (CAMs)**.

These adhesion proteins have attracted great attention in recent years because they are important in embryonic development and formation of the nervous system and other tissues; in holding tissues together in adults; in inflammation and wound healing; and in the metastasis of tumors.

Many pass through the cell membrane and are anchored to the cytoskeleton inside the cell. Some bind to like molecules on other cells (homophilic binding), whereas others bind to other molecules (heterophilic binding).

Many bind to **laminins,** a family of large cross-shaped molecules with multiple receptor domains in the extracellular matrix

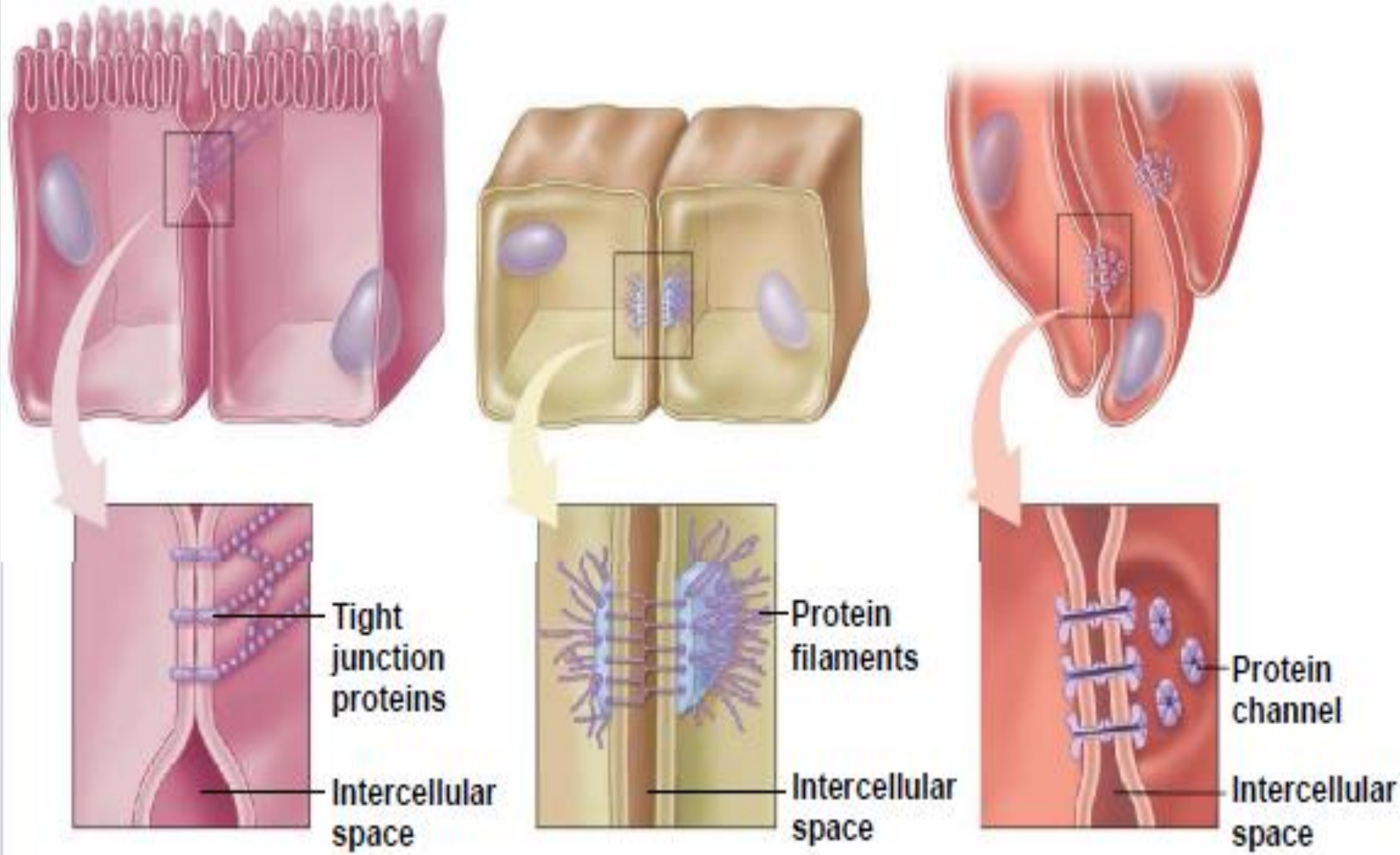
Intercellular Connections

Two types of junctions form between the cells that make up tissues: junctions that fasten the cells to one another and to surrounding tissues, and junctions that permit the transfer of ions and other molecules from one cell to another.

The types of junctions that tie cells together and endow tissues with strength and stability include the:

1- **Tight junction ,**which is also known as the **zonula occludens** ,tight junctions between epithelial cells are also essential for transport of ions across epithelia

2-The **desmosomes** and **zonula adherens** (hold cells together, and the **hemidesmosome** attach cells to their basal laminas.



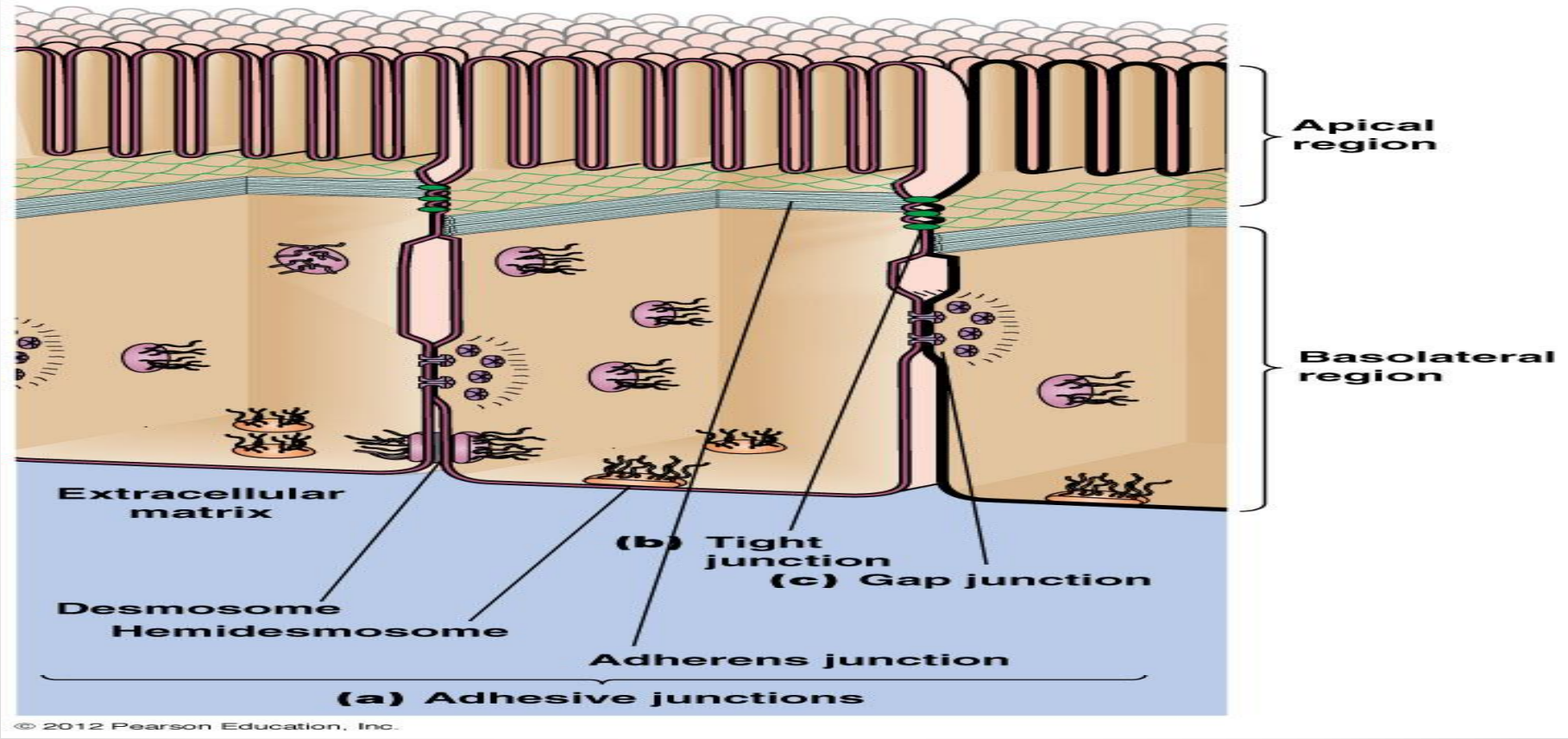
a) Tight junctions form leak-proof seals between cells.

b) Adhesion junctions anchor two cells together, yet allow flexibility of movement.

c) Gap junctions provide for the direct transfer of water and ions between adjacent cells.

3-Gap Junctions

At gap junctions, the intercellular space narrows from 25 nm to 3 nm, and hexagonal arrays of protein units **connexons** in the membrane of each cell are lined up with one another.



Ribosomes and the Granular Endoplasmic Reticulum

- Attached to the outer surfaces of many parts of the endoplasmic reticulum are large numbers of minute granular particles called *ribosomes*.
- *Where these are* present, the reticulum is called the *granular endoplasmic reticulum.*
- *The ribosomes are composed of* mixture of RNA and proteins, and they function to synthesize **new protein** molecules in the cell.

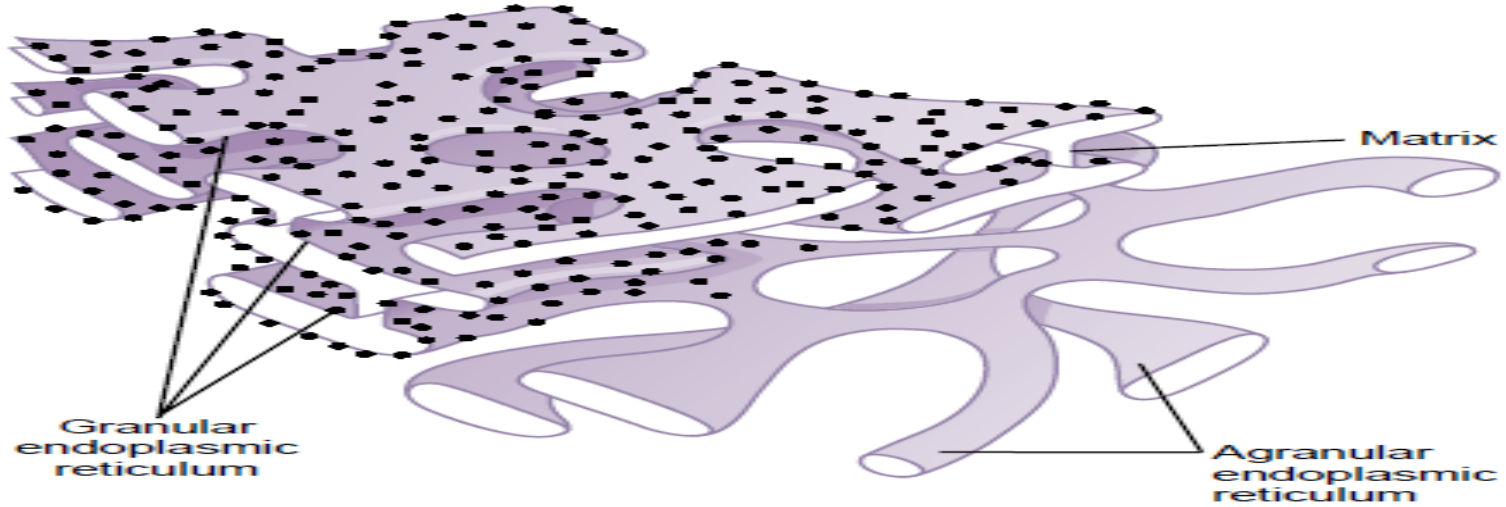


Figure 2–4

Structure of the endoplasmic reticulum. (Modified from DeRobertis EDP, Saez FA, DeRobertis EMF: Cell Biology, 6th ed. Philadelphia: WB Saunders, 1975.)

Agranular Endoplasmic Reticulum

- Part of the endoplasmic reticulum has no attached ribosomes. This part is called the *agranular, or smooth, endoplasmic reticulum.*
- The agranular reticulum functions for the synthesis of **lipid** substances and for other processes of the cells promoted by intrareticular enzymes.

Golgi Apparatus

- The Golgi apparatus, is closely related to the endoplasmic reticulum. It has membranes similar to those of the **agranular** endoplasmic reticulum.
- This apparatus is prominent in **secretory** cells, where it is located on the side of the cell from which the secretory substances are extruded.

- The Golgi apparatus functions in association with the endoplasmic reticulum. In this way, substances entrapped in the **endoplasmic reticulum (ER) vesicles** are transported from the endoplasmic reticulum to the Golgi apparatus.

The transported substances are then processed in the Golgi apparatus to form lysosomes, secretory vesicles, and other cytoplasmic components

Lysosomes:, are vesicular organelles that form by breaking off from the Golgi apparatus and then dispersing throughout the cytoplasm.

The lysosomes provide an *intracellular digestive system that allows the cell to digest*

(1) damaged cellular structures,

(2) food particles that have been ingested by the cell, and

(3) unwanted matter such as bacteria.

It is surrounded by a typical lipid bilayer membrane and is filled with large numbers of small granules, which are protein aggregates of as many as 40 different *hydrolase (digestive) enzymes.*

*A **hydrolytic enzyme** is* capable of splitting an organic compound into two or more parts by combining hydrogen from a water molecule with one part of the compound and combining the hydroxyl portion of the water molecule with the other part of the compound.

Peroxisomes

Peroxisomes are similar physically to lysosomes, but they are different in two important ways.

First, they are believed to be formed by self-replication (or perhaps by budding off from the smooth endoplasmic reticulum) rather than from the Golgi apparatus.

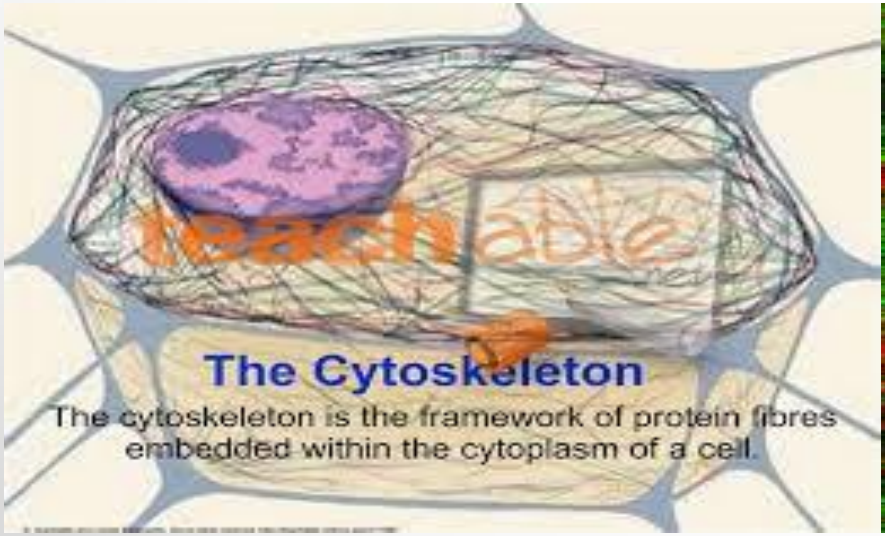
Second, they contain oxidases rather than hydrolases

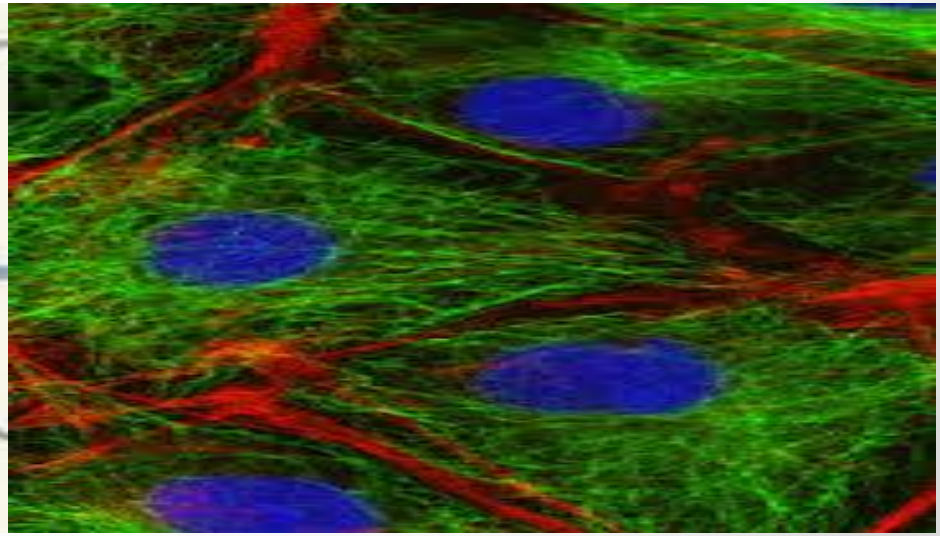
Cytoskeleton

*All cells have a **cytoskeleton,** a system of fibers that not only maintains the structure of the cell but also permits it to change shape and move.

*The cytoskeleton is made up primarily of microtubules, intermediate filaments, and microfilaments, along with proteins that anchor them and tie them together.

*In addition, proteins and organelles move along microtubules and microfilaments from one part of the cell to another propelled by molecular motors.





Mitochondria

- The mitochondria, are called the "**powerhouses**" of the cell. Without them,
- cells would be unable to extract enough energy from the nutrients, and essentially all cellular functions would cease. Mitochondria are present in all areas of each cell's cytoplasm, mitochondria are concentrated in the portions of cell that are responsible for the major share of its energy metabolism.
- The basic structure of the mitochondrion, is composed mainly of two lipid bilayer–protein membranes: an *outer membrane and* an *inner membrane.*
- Many foldings of the inner membrane form *shelves onto which oxidative enzymes* are attached. In addition, the inner cavity of the mitochondrion is filled with a ***matrix*** *that contains large* quantities of dissolved enzymes that are necessary for extracting energy from nutrients.

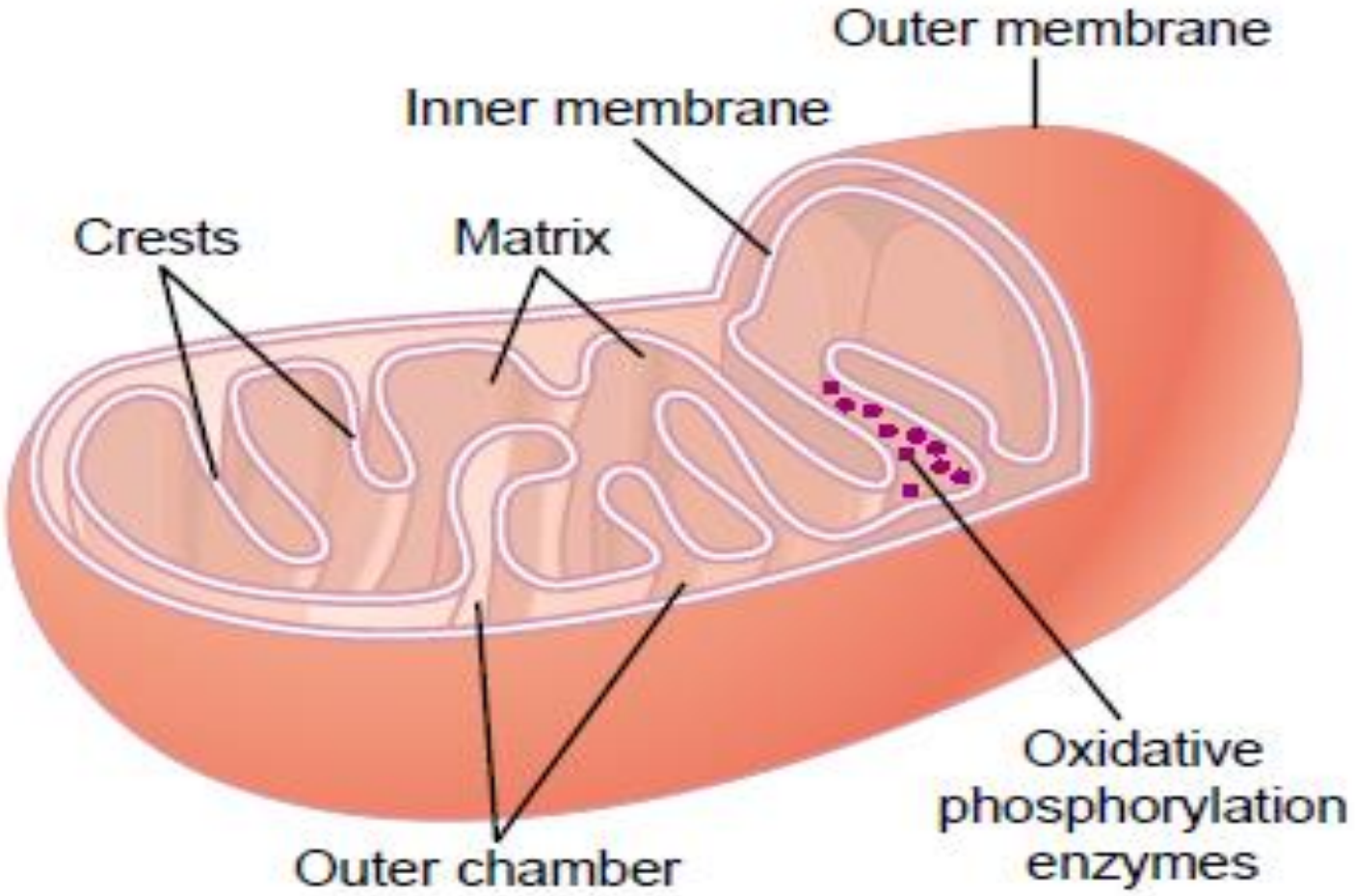


Figure 2–7

Structure of a mitochondrion. (Modified from DeRobertis EDP, Saez FA, DeRobertis EMF: Cell Biology, 6th ed. Philadelphia: WB Saunders, 1975.)

- These enzymes operate in association with the oxidative enzymes on the shelves to cause **oxidation** of the nutrients, thereby forming carbon dioxide and water and at the same time releasing energy.
- The liberated energy is used to synthesize a “high-energy” substance called ***adenosine triphosphate (ATP).***
- ATP is then transported out of the mitochondrion, and it diffuses throughout the cell to release its own energy wherever it is needed for performing cellular functions.
- Mitochondria are **self-replicative**, which means that one mitochondrion can form a second one, a third one, and so on, whenever there is a need in the cell for increased amounts of ATP. Indeed, the mitochondria contain DNA similar to that found in the cell nucleus.

Functional Systems of the Cell

If a cell is to live and grow and reproduce, it must obtain nutrients and other substances from the surrounding fluids. Most substances pass through the cell membrane by ***diffusion*** *and* ***active transport.***

Diffusion involves simple movement through the membrane caused by the **random motion** of the molecules of the substance; substances move either through cell membrane pores or, in the case of lipid soluble substances, through the lipid matrix of the membrane.

Active transport involves the actual carrying of a substance through the membrane by **a physical protein structure** that penetrates all the way through the membrane. These active transport mechanisms are so important to cell function

Very large particles enter the cell by a specialized function of the cell membrane called *endocytosis*. *The* principal forms of endocytosis are *pinocytosis and phagocytosis*.

Pinocytosis *means ingestion of minute* particles that form vesicles of extracellular fluid and particulate constituents inside the cell cytoplasm.

Phagocytosis means ingestion of large particles, such as bacteria, whole cells, or portions of degenerating tissue.

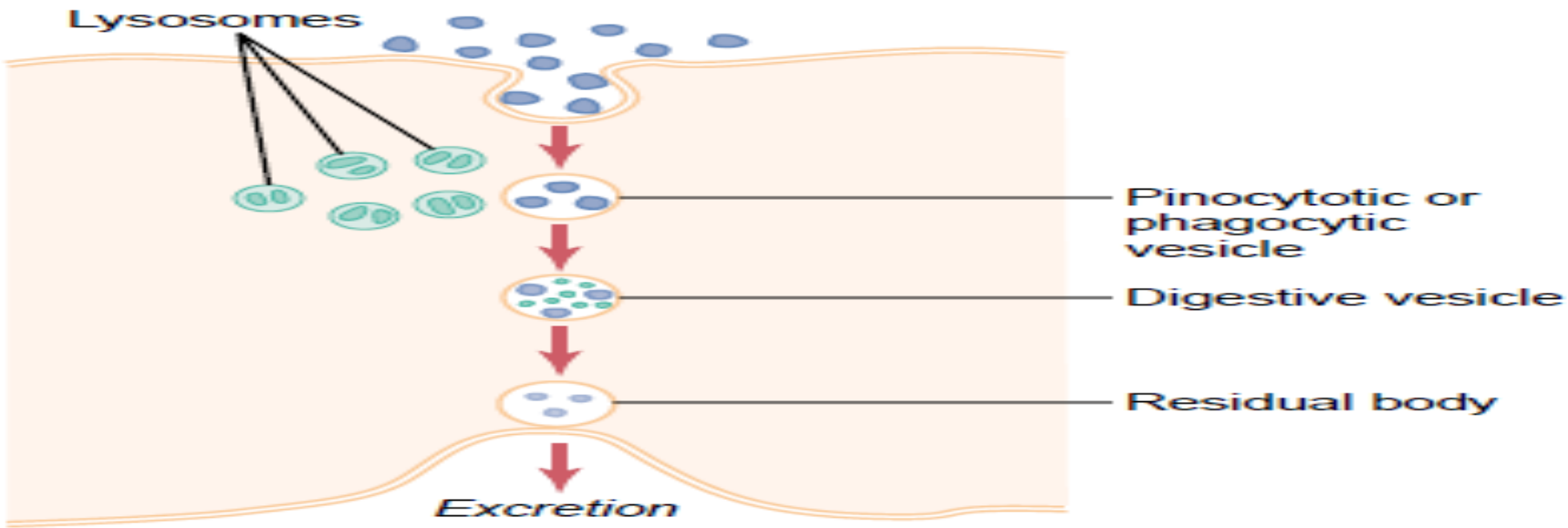


Figure 2–12

Digestion of substances in pinocytotic or phagocytic vesicles by enzymes derived from lysosomes.