Anatomy and Physiology

An Introduction to the Human Body

For 3rd Medical Physics Students

Dr Salma Ali Alqazzaz

1.1 Overview of Anatomy and Physiology

Human anatomy is the scientific study of the body's structures. Some of these structures are very small and can only be observed and analysed with the assistance of a microscope. Other larger structures can readily be seen, manipulated, measured, and weighed, figure 1-1. The word "anatomy" comes from a Greek root that means "to cut apart." Human anatomy was first studied by observing the exterior of the body and observing the wounds of soldiers and other injuries. Later, physicians were allowed to dissect bodies of the dead to augment their knowledge. When a body is dissected, its structures are cut apart in order to observe their physical attributes and their relationships to one another. Human physiology is the scientific study of the chemistry and physics of the structures of the body and the ways in which they work together to support the functions of life. Your study of anatomy and physiology will make more sense if you continually relate the form of the structures you are studying to their function.

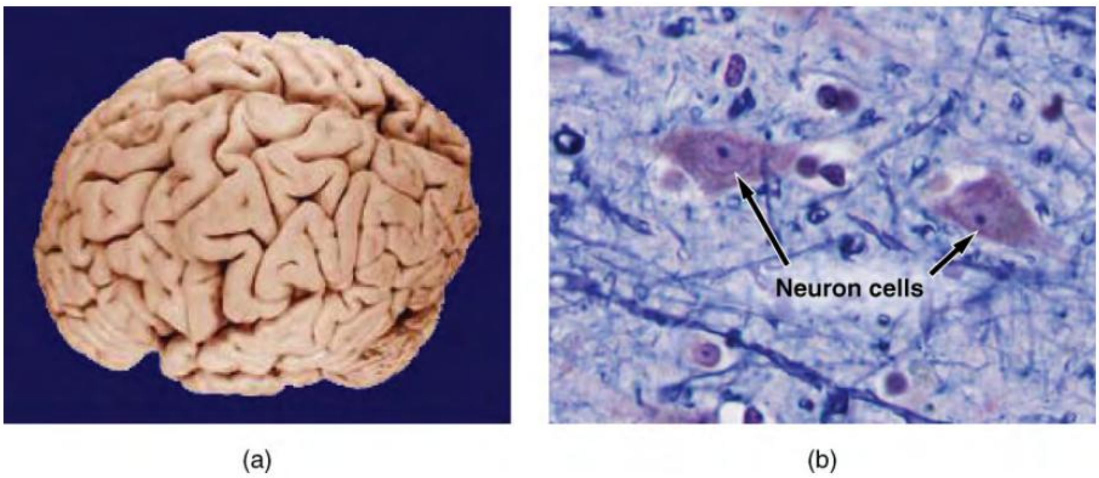

Fig1-1: Gross and Microscopic Anatomy (a) Gross anatomy considers large structures such as the brain. (b) Microscopic anatomy can deal with the same structures, though at a different scale. This is a micrograph of nerve cells from the brain.

1.2 Structural Organization of the Human Body

The structure of the human body is described in terms of six levels of organization. The structures of the body in terms of fundamental levels of organization that increase in complexity: subatomic particles, atoms, molecules, organelles, cells, tissues, organs, organ systems, organisms and biosphere, see figure 1-2.

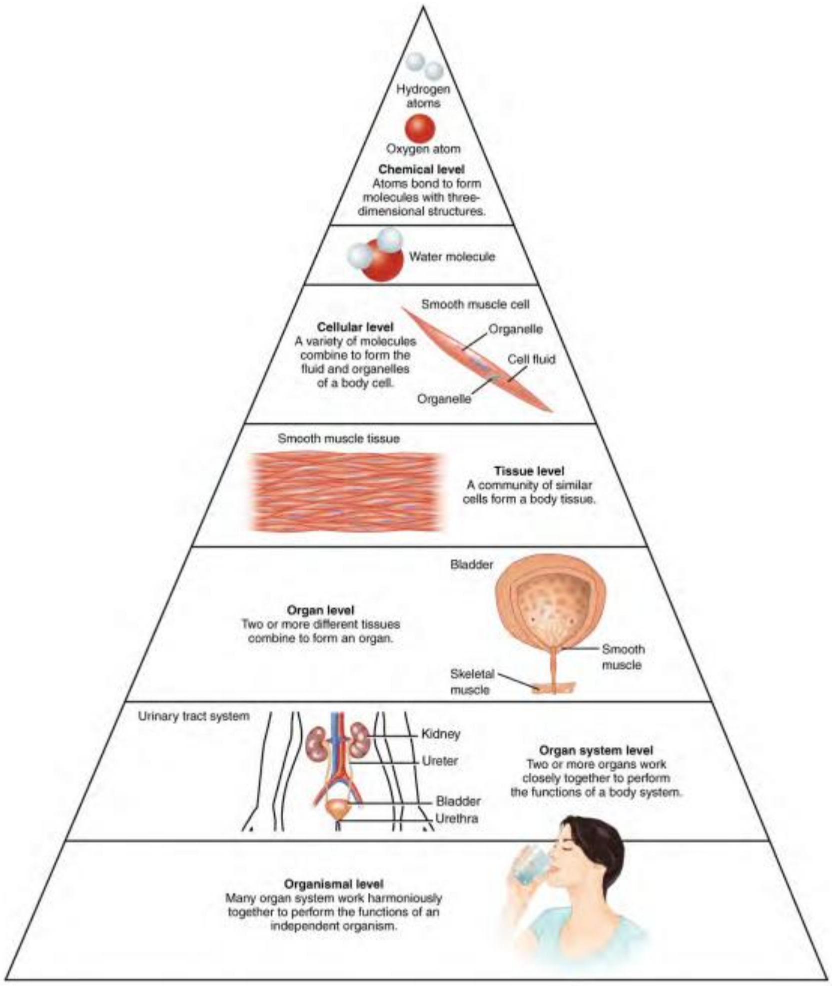

Fig 1-2: Levels of Structural Organization of the Human Body The organization of the body often is discussed in terms of six distinct levels of increasing complexity, from the smallest chemical building blocks to a unique human organism.

1- subatomic particles, atoms and molecules: All matter in the universe is composed of one or more unique pure substances called elements, familiar examples of which are hydrogen, oxygen, carbon, nitrogen, calcium, and iron. The smallest unit of any of these pure substances (elements) is an atom. Atoms are made up of subatomic particles such as the proton, electron and neutron. Two or more atoms combine to form a molecule, such as the water molecules, proteins, and sugars found in living things. Molecules are the chemical building blocks of all body structures

2- A cell is the smallest independently functioning unit of a living organism. All living structures of human anatomy contain cells, and almost all functions of human physiology are performed in cells or are initiated by cells. A human cell typically consists of flexible membranes that enclose cytoplasm, a water-based cellular fluid together with a variety of tiny functioning units called organelles. In humans, as in all organisms, cells perform all functions of life.

3- Tissue is a group of many similar cells (though sometimes composed of a few related types) that work together to perform a specific function.

4- An organ is an anatomically distinct structure of the body composed of two or more tissue types. Each organ performs one or more specific physiological functions.

5- An organ system is a group of organs that work together to perform major functions or meet physiological needs of the body. Figure 1-3, Figure 1-4.

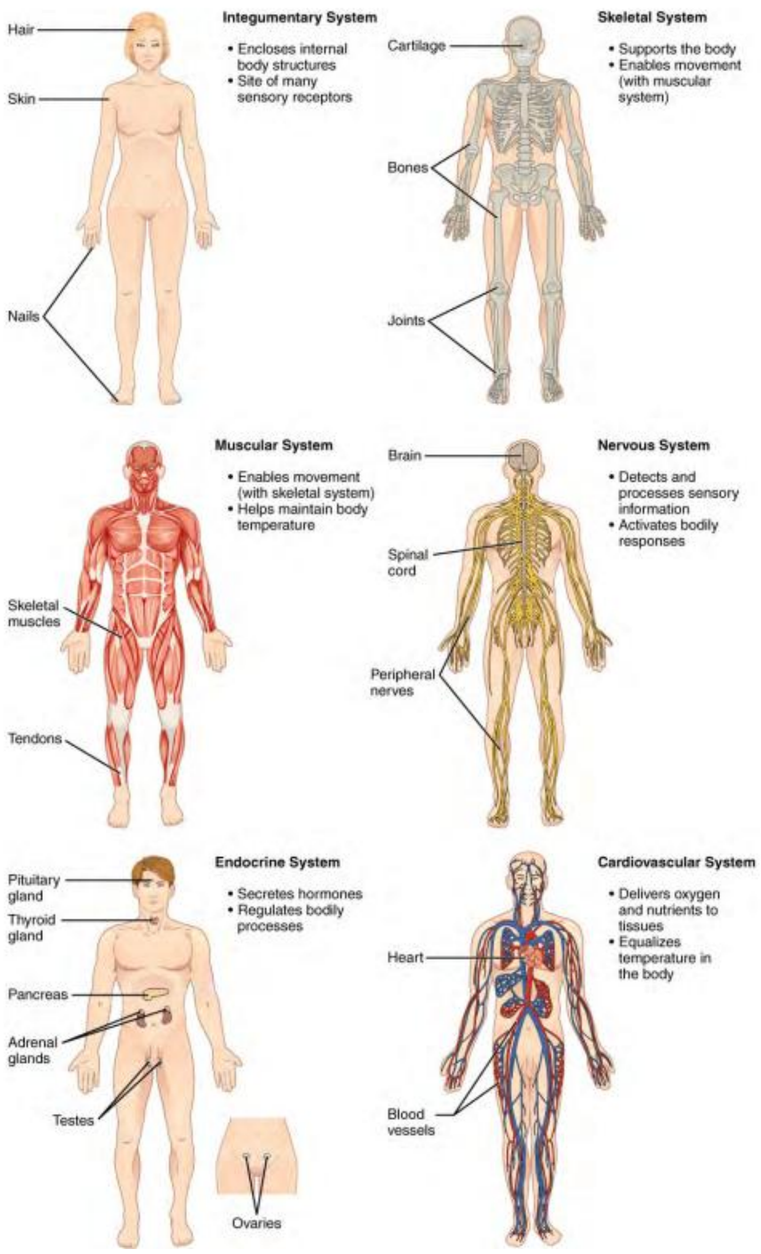

Fig 1-3: Organ Systems of the Human Body Organs that work together are grouped into organ systems.

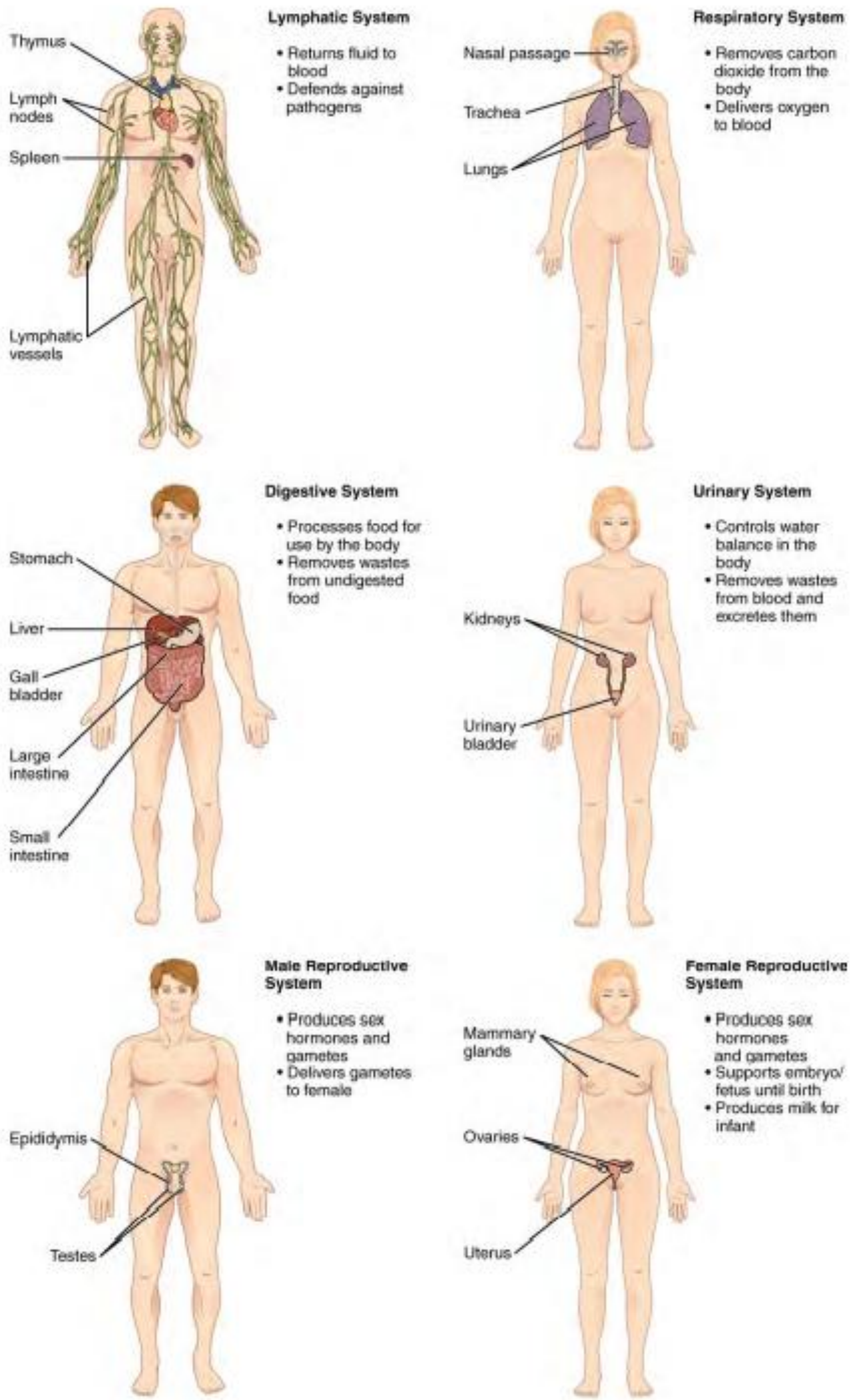

Fig 1-4: Organ Systems of the Human Body that work together are grouped into organ systems

Chapter2: The Cellular Level Of Organization

2.1 The Cell Membrane

Despite differences in structure and function, all living cells in multicellular organisms have a surrounding cell membrane. As the outer layer of your skin separates your body from its environment, the cell membrane (also known as the plasma membrane) separates the inner contents of a cell from its exterior environment. This cell membrane provides a protective barrier around the cell and regulates which materials can pass in or out.

2.1.1 Structure and Composition of the Cell Membrane

The cell membrane is an extremely pliable structure composed primarily of back-to-back phospholipids (a "bilayer"). Cholesterol is also present, which contributes to the fluidity of the membrane, and there are various proteins embedded within the membrane that have a variety of functions. A single phospholipid molecule has a phosphate group on one end, called the "head," and two side-by-side chains of fatty acids that make up the lipid tails, Figure 2.1.

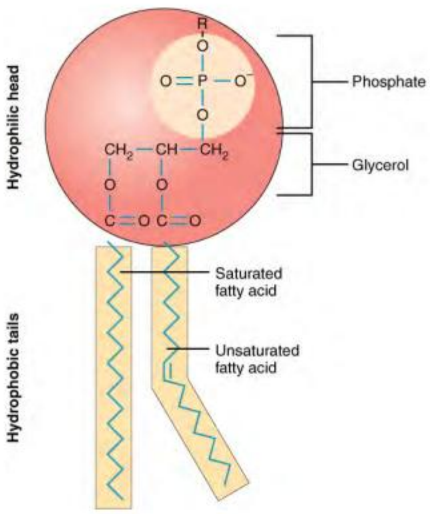

Fig 2.1: Phospholipid Structure A phospholipid molecule consists of a polar phosphate "head," and a non-polar lipid "tail,"

The cell membrane consists of two adjacent layers of phospholipids. The lipid tails of one layer face the lipid tails of the other layer, meeting at the interface of the two layers. The phospholipid heads face outward, one layer exposed to the interior of the cell and one layer exposed to the exterior, Figure 2.2.

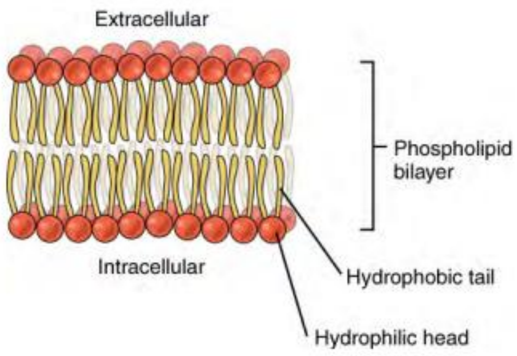

Fig 2.2: The phospholipid bilayer consists of two adjacent sheets of phospholipids, arranged tail to tail. The hydrophobic tails associate with one another, forming the interior of the membrane. The polar heads contact the fluid inside and outside of the cell.

2.1.2 Membrane Proteins

The lipid bilayer forms the basis of the cell membrane, but it is peppered throughout with various proteins. Two different types of proteins that are commonly associated with the cell membrane are the integral proteins and peripheral protein, Figure 2-3.

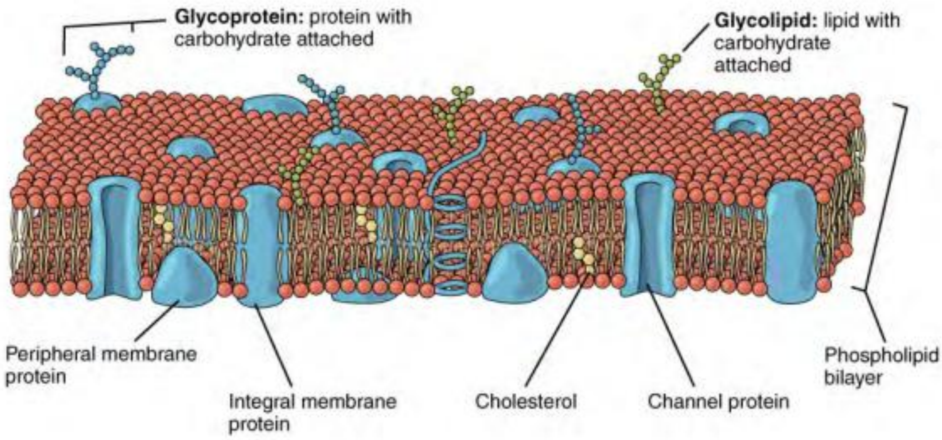

Fig 2-3: The cell membrane of the cell is a phospholipid bilayer containing many different molecular components, including proteins and cholesterol, some with carbohydrate groups attached.

2.1.3 Transport across the Cell Membrane

The cell membrane has ability to regulate the concentration of substances inside the cell. These substances include ions such as Ca^{++}, Na^{+} , K^{+} , and $Cl^{–}$; nutrients including sugars, fatty acids, and amino acids; and waste products, particularly carbon dioxide (CO_2), which must leave the cell. The membrane's lipid bilayer structure provides the first level of control. The phospholipids are tightly packed together, and the membrane has a hydrophobic interior. There are two general methods for all substances that move through the membrane based on whether or not energy is required:

1. **Passive transport** is the movement of substances across the membrane without the expenditure of cellular energy.
2. **Active transport** is the movement of substances across the membrane using energy from adenosine triphosphate (ATP).

In order to understand how substances move passively across a cell membrane, it is necessary to understand concentration gradients and diffusion.

1. **A concentration gradient** is the difference in concentration of a substance across a space. Molecules (or ions) will spread/diffuse from where they are more concentrated

to where they are less concentrated until they are equally distributed in that space. (When molecules move in this way, they are said to move down their concentration gradient). For example, inside a closed bathroom. If a bottle of perfume were sprayed, the scent molecules would naturally diffuse from the spot where they left the bottle to all corners of the bathroom, and this diffusion would go on until no more concentration gradient remains.

2. **Diffusion** is the movement of particles from an area of higher concentration to an area of lower concentration. For example, a spoonful of sugar placed in a cup of tea. Eventually the sugar will diffuse throughout the tea until no concentration gradient remains.

In both cases, if the room is warmer or the tea hotter, diffusion occurs even faster as the molecules are bumping into each other and spreading out faster than at cooler temperatures. Having an internal body temperature around 98.6° F thus also aids in diffusion of particles within the body.

Consider substances that can easily diffuse through the lipid bilayer of the cell membrane, such as the gases oxygen (O2) and CO2. O2 generally diffuses into cells because it is more concentrated outside of them, and CO2 typically diffuses out of cells because it is more concentrated inside of them. Neither of these examples requires any energy on the part of the cell, and therefore they use passive transport to move across the membrane. Because cells rapidly use up oxygen during metabolism, there is typically a lower concentration of O2 inside the cell than outside. As a result, oxygen will diffuse from the interstitial fluid directly through the lipid bilayer of the membrane and into the cytoplasm within the cell. On the other hand, because cells produce CO2 as a by-product of metabolism, CO2 concentrations rise within the cytoplasm; therefore, CO2 will move from the cell through the lipid bilayer and into the interstitial fluid, where its concentration is lower. This mechanism of molecules spreading from where they are more concentrated to where they are less concentration is a form of passive transport called simple diffusion, Figure 2-4

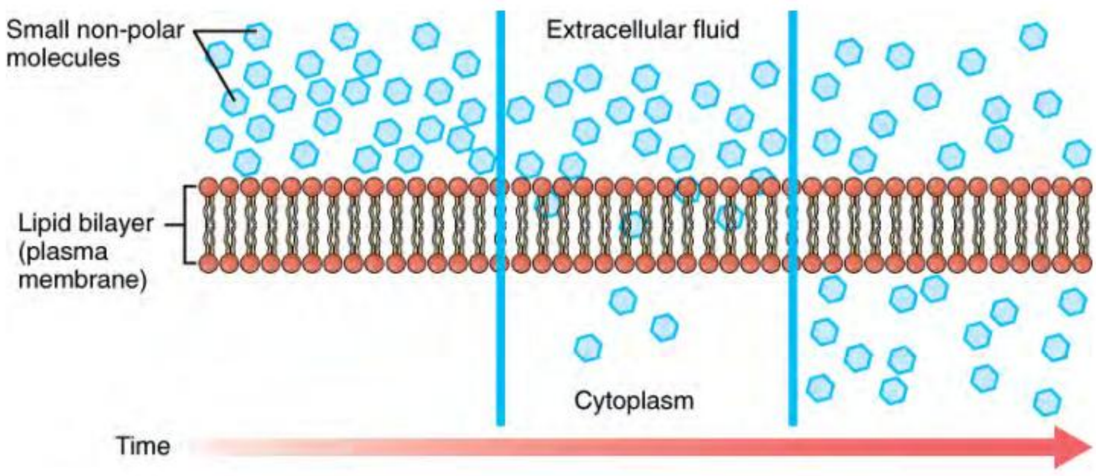

Fig 2-4: Simple Diffusion across the Cell (Plasma) Membrane The structure of the lipid bilayer allows only small substances such as oxygen and carbon dioxide to pass through the cell membrane, down their concentration gradient, by simple diffusion.

Solutes dissolved in water on either side of the cell membrane will tend to diffuse down their concentration gradients, but because most substances cannot pass freely through the lipid bilayer of the cell membrane, their movement is restricted to protein channels and specialized transport mechanisms in the membrane.

Facilitated diffusion is the diffusion process used for those substances that cannot cross the lipid bilayer due to their size and/or polarity (Figure 2-5). A common example of facilitated diffusion is the movement of glucose into the cell, where it is used to make ATP. Although glucose can be more concentrated outside of a cell, it cannot cross the lipid bilayer via simple diffusion because it is both large and polar. To resolve this, a specialized carrier protein called the glucose transporter will transfer glucose molecules into the cell to facilitate its inward diffusion.

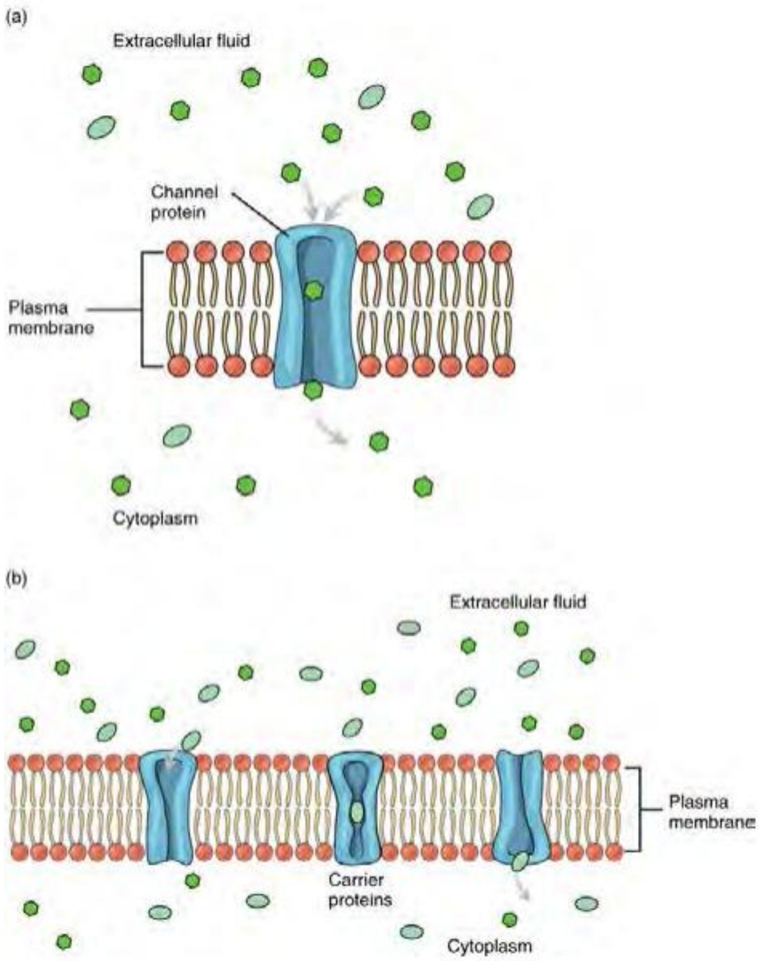

Fig 2-5: (a) Facilitated diffusion of substances crossing the cell (plasma) membrane takes place with the help of proteins such as channel proteins and carrier proteins. Channel proteins are less selective than carrier proteins, and usually mildly discriminate between their cargo based on size and charge. (b) Carrier proteins are more selective, often only allowing one particular type of molecule to cross.

As an example, even though sodium ions (Na+) are highly concentrated outside of cells, these electrolytes are polarized and cannot pass through the nonpolar lipid bilayer of the membrane. Their diffusion is facilitated by membrane proteins that form sodium channels (or "pores"), so that Na+ ions can move down their concentration gradient from outside the cells to inside the cells. There are many other solutes that must undergo facilitated diffusion to move into a cell, such as amino acids, or to move out of a cell, such as wastes. Because facilitated diffusion is a passive process, it does not require energy expenditure by the cell.

Water also can move freely across the cell membrane of all cells, either through protein channels or by slipping between the lipid tails of the membrane itself.

Osmosis is the diffusion of water through a semipermeable membrane (Figure 2-6). The movement of water molecules is not itself regulated by cells, so it is important that cells are exposed to an environment in which the concentration of solutes outside of the cells (in the extracellular fluid) is equal to the concentration of solutes inside the cells (in the cytoplasm). Two solutions that have the same concentration of solutes are said to be isotonic (equal tension). When cells and their extracellular environments are isotonic, the concentration of water molecules is the same outside and inside the cells, and the cells maintain their normal shape (and function). Osmosis occurs when there is an imbalance of solutes outside of a cell versus inside the cell.

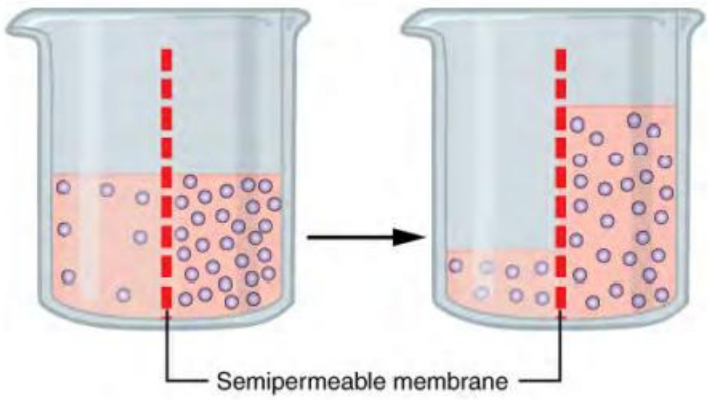

Fig 2-6: Osmosis is the diffusion of water through a semipermeable membrane down its concentration gradient. If a membrane is permeable to water, though not to a solute, water will equalize its own concentration by diffusing to the side of lower water concentration (and thus the side of higher solute concentration). In the beaker on the left, the solution on the right side of the membrane is hypertonic.

Hypertonic is a solution that has a higher concentration of solutes than another solution. water molecules tend to diffuse into a hypertonic solution (Figure 2-7). Cells in a hypertonic solution will shrivel as water leaves the cell via osmosis.

Hypotonic is a solution that has a lower concentration of solutes than another solution. water molecules tend to diffuse out of a hypotonic solution. Cells in a hypotonic solution will take on too much water and swell.

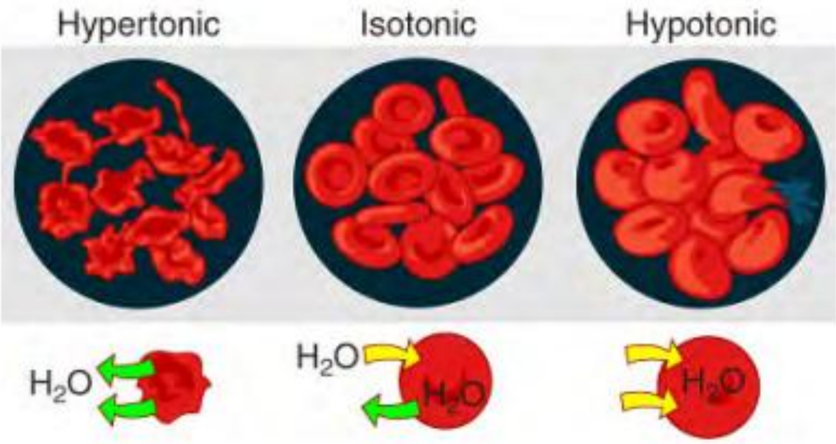

Fig 2-7: A hypertonic solution has a solute concentration higher than another solution. An isotonic solution has a solute concentration equal to another solution. A hypotonic solution has a solute concentration lower than another solution.

Another mechanism besides diffusion to passively transport materials between compartments is filtration. Unlike diffusion of a substance from where it is more concentrated to less concentrated, filtration uses a hydrostatic pressure gradient that pushes the fluid and the solutes within it from a higher pressure area to a lower pressure area. Filtration is an extremely important process in the body. For example, the circulatory system uses filtration to move plasma and substances across the endothelial lining of capillaries and into surrounding tissues, supplying cells with the nutrients. Filtration pressure in the kidneys provides the mechanism to remove wastes from the bloodstream.

Active Transport

For all of the transport methods described above, the cell expends no energy. Membrane proteins that aid in the passive transport of substances do so without the use of ATP. During active transport, ATP is required to move a substance across a membrane, often with the help of protein carriers, and usually against its concentration gradient. One of the most common types of active transport involves proteins that serve as pumps. The word "pump" probably conjures up thoughts of using energy to pump up the tire of a bicycle or a basketball. Similarly, energy from ATP is required for these membrane proteins to transport substances—molecules or ions—across the membrane, usually against their concentration gradients (from an area of low concentration to an area of high concentration).

Sodium-potassium pump is also called Na+ /K+ ATPase, transports sodium out of a cell while moving potassium into the cell. The Na+ /K+ pump is an important ion pump found in the membranes of many types of cells. These pumps are particularly abundant in nerve cells, which are constantly pumping out sodium ions and pulling in potassium ions to maintain an electrical gradient across their cell membranes, figure 2-8.

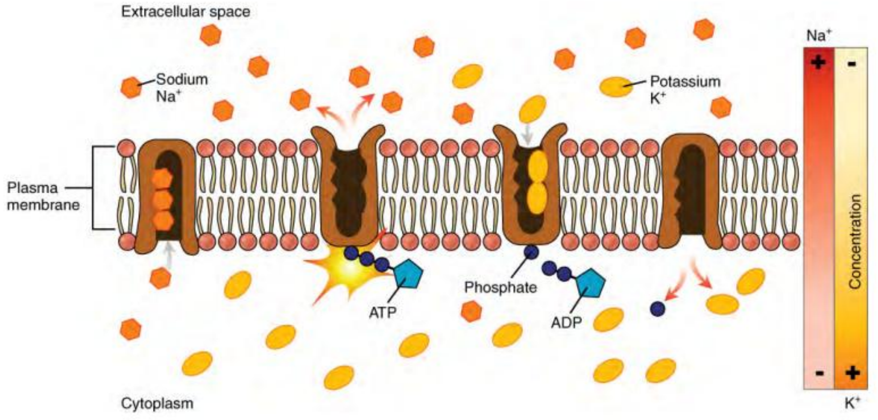

Figure 2-8: The sodium-potassium pump is found in many cell (plasma) membranes. Powered by ATP, the pump moves sodium and potassium ions in opposite directions, each against its concentration gradient. In a single cycle of the pump, three sodium ions are extruded from and two potassium ions are imported into the cell.

Endocytosis (bringing "into the cell") is the process of a cell ingesting material by enveloping it in a portion of its cell membrane, and then pinching off that portion of membrane (Figure 2-9). Once pinched off, the portion of membrane and its contents becomes an independent, intracellular vesicle. A vesicle is a membranous sac—a spherical and hollow organelle bounded by a lipid bilayer membrane. Endocytosis often brings materials into the cell that must to be broken down or digested.

1- **Phagocytosis** ("cell eating") is the endocytosis of large particles. For example immune system (white blood cell).

2- **pinocytosis** ("cell drinking") brings fluid containing dissolved substances into a cell through membrane vesicles. Cells in the kidney can use pinocytosis to separate nutrients and fluids from the urine that will be expelled from the body.

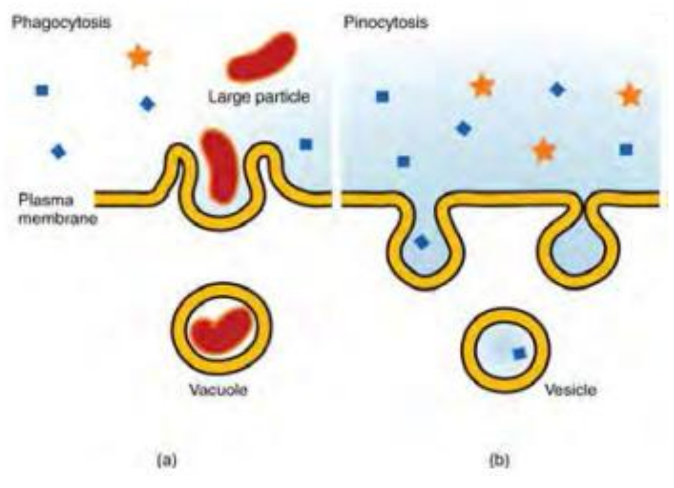

Fig 2-9: Endocytosis is a form of active transport in which a cell envelopes extracellular materials using its cell membrane. (a) In phagocytosis, which is relatively nonselective, the cell takes in a large particle. (b) In pinocytosis, the cell takes in small particles in fluid.

Exocytosis (taking "out of the cell") is the process of a cell exporting material using vesicular transport (Figure 2-10). Many cells manufacture substances that must be secreted, like a factory manufacturing a product for export. These substances are typically packaged into membrane-bound vesicles within the cell. When the vesicle membrane fuses with the cell membrane, the vesicle releases its contents into the interstitial fluid. The vesicle membrane then becomes part of the cell membrane. Cells of the stomach and pancreas produce and secrete digestive enzymes through exocytosis (Figure 2-11).

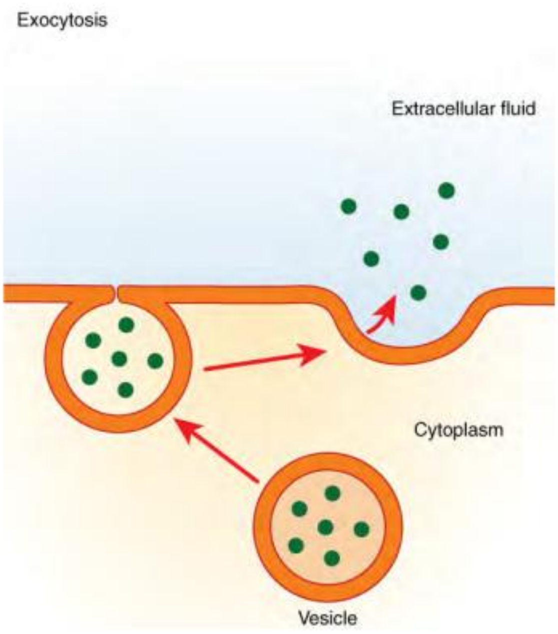

Fig 2-10: Exocytosis is much like endocytosis in reverse. Material destined for export is packaged into a vesicle inside the cell. The membrane of the vesicle fuses with the cell membrane, and the contents are released into the extracellular space.

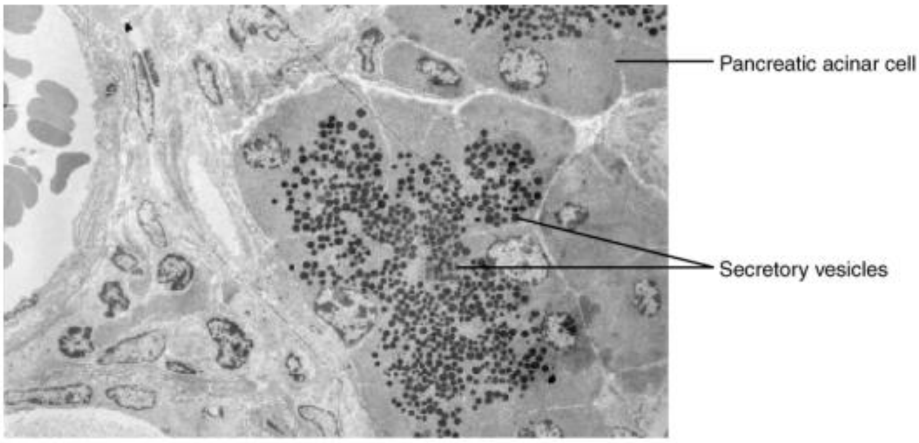

Fig 2-11: The pancreatic acinar cells produce and secrete many enzymes that digest food. The tiny black granules in this electron micrograph are secretory vesicles filled with enzymes that will be exported from the cells via exocytosis. LM × 2900.