

## **MODULE 3- ADAPTATION OF ANATOMICAL PRINCIPLES FOR BIOENGINEERING DESIGN**

### **Introduction**

- The human body is observed to be a biological machine made of body systems; groups of organs that work together to produce and sustain life.
- Organ systems are: Skeletal system, Muscular system, cardiovascular system, Respiratory system, Nervous system, Digestive system, Urinary system, Endocrine system, Lymphatic system, Reproductive system, Integumentary system.
- Bio-design is the use of living organisms in machine design.
- Its processes can be used in the creation of fashion, textiles, furniture and architecture.
- Bio-design (actual or conceptual) embodies an emerging design movement which incorporates the use of living materials, or 'moist media,' such as fungi, algae, yeast, bacteria, and cultured tissue. This can be as part of standard crafting methods or the more complex fields of biomimicry and synthetic biology. The idea is to create a product whose properties are enhanced as a result of the use of these living materials.

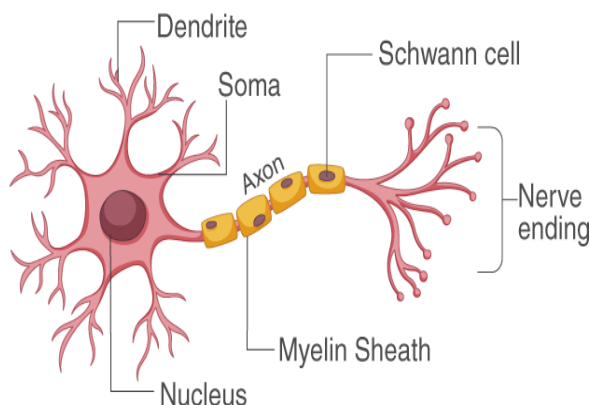
### **Brain as a CPU system**

- The brain is a complex organ that controls thought, memory, emotion, touch, motor skills, vision, breathing, temperature, hunger and every process that regulates our body.
- Together, the brain and spinal cord that extends from it make up the central nervous system, or CNS.
- In computers, most of the information processing takes place very rapidly, but they are done so in serial fashion: all of the information is processed by a single central processing unit (CPU) that performs one operation after another.
- Both CPU and brain use electrical signals to send messages. The brain uses chemicals to transmit information; the computer uses electricity. Even though electrical signals travel at high speeds in the nervous system, they travel even faster through the wires in a computer. Both transmit information. So the brain's neurons are much slower than a computer's integrated circuits.
- CPU can also simulate parallel processing by subdividing its various tasks into subtasks and alternating rapidly among them. But the brain's power comes from it being a machine that performs massively parallel processing.
- The brain does not have a CPU. Instead, it has millions of neurons that combine signals simultaneously.

## Architecture

- Neurons are the most common type of brain cell. The average human brain contains about 86 billion neurons.
- At one end, each neuron has a cell body surrounded by dendrite branches.
- An axon connects the cell body to the axon terminal at the other end of the neuron.
- Schwann cells surround the axon. They provide a fatty coating called the myelin sheath.
- The basic architecture of the brain is constructed through a process that begins early in life and continues into adulthood.
- Simpler circuits come first and more complex brain circuits build on them later. Genes provide the basic blueprint, but experiences influence how or whether genes are expressed. Plasticity, or the ability for the brain to reorganize and adapt, is greatest in the initial years of life and decreases with age.
- The brain, along with the spinal cord, constitutes the central nervous system. It is responsible for thoughts, interpretation and origin of control for body movements.

### STRUCTURE OF NEURON



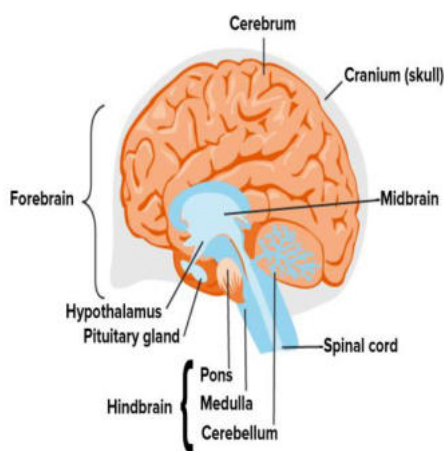
**The Nervous System** has two main parts: The central nervous system is made up of the brain and spinal cord. The peripheral nervous system is made up of nerves that branch off from the spinal cord and extend to all parts of the body.

## Central Nervous System

Central Nervous System (CNS) is often called the central processing unit of the body.

**Brain** is the largest and central organ of the human nervous system and the control unit of the nervous system, which helps us in discovering new things, remembering and understanding, making decisions, and a lot more. The human brain is composed of three major parts

- Forebrain:** The anterior part of the brain consists of Cerebrum, Hypothalamus and Thalamus.
- Midbrain:** The smaller and central part of the brainstem consists of Tectum and Tegmentum.



(iii) **Hindbrain:** The central region of the brain composed of Cerebellum, Medulla and Pons.

## **Spinal Cord**

- The spinal cord is a cylindrical bundle of nerve fibres and associated tissues enclosed within the spine and connect all parts of the body to the brain.
- It begins in continuation with the medulla and extends downwards. It is enclosed in a bony cage called vertebral column and surrounded by membranes called meninges.
- The spinal cord is concerned with spinal reflex actions and the conduction of nerve impulses to and from the brain.

## **Peripheral Nervous System**

Peripheral nervous system involves the parts of the nervous system outside the brain and the spinal cord. It develops from the central nervous system which connects different parts of the body with the CNS. It carries out both voluntary and involuntary actions with the help of peripheral nerves.

PNS includes two types of nerve fibres

1. Afferent nerve fibres – These are responsible for transmitting messages from tissues and organs to the CNS.
2. Efferent nerve-fibres – These are responsible for conveying messages from CNS to the corresponding peripheral organ.

PNS is further classified as

**Somatic neural system (SNS):** It is the neural system that controls the voluntary actions in the body by transmitting impulses from CNS to skeletal muscle cells. It consists of the somatic nerves.

**Autonomic Nervous System (ANS):** The autonomic nervous system relays impulses from the central nervous system to the involuntary organs and smooth muscles of the body (involuntary actions like digestion, respiration, salivation, etc.).

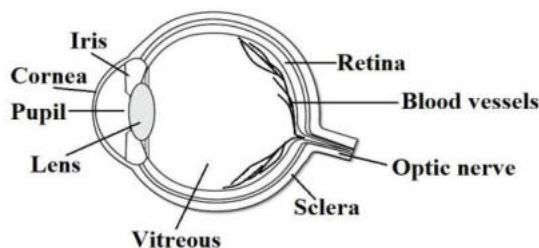
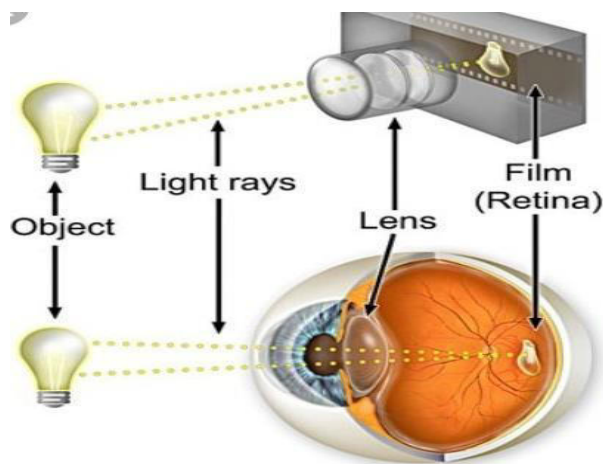
## **Signal transmission**

- Neurons transmit electrical signals called impulses.
- A nerve impulse is the electric signals that pass along the dendrites to generate a nerve impulse or an action potential.
- They flow through the axon from the dendrites and the cell body toward the axon terminal.
- Impulses jump from the axon end of one neuron to the dendrite end of the next. To do this, the signal has to cross a tiny gap called a synapse.
- Travelling from neuron to neuron, impulses move between brain regions at different speeds.
- An action potential is created due to the movement of ions in and out of the cell. It specifically involves sodium and potassium ions. They are moved in and out of the cell

through sodium and potassium channels and sodium-potassium pump.

### Eye as a Camera System

- The human eye is a wonderful instrument, relying on refraction of light and lenses to form images. There are many similarities between the human eye and a camera.
- Eye functions with a diaphragm to control the amount of light that gets through to the lens. This acts like shutter in a camera. The image is produced is real and inverted.
- In a camera, the film is used to record the image. In the eye, the image is focused on the retina (the light-sensitive membrane in the eye) and a system of *rods and cones* is the front end of an image-processing system that converts the image to electrical impulses and sends the information along the optic nerve to the brain.
- The way the eye focuses light is interesting because most of the refraction that takes place is not done by the lens itself, but by the aqueous humour, a liquid on top of the lens.



### Architecture of rod and cone cells

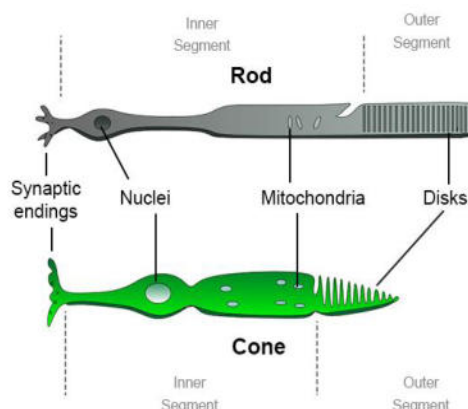
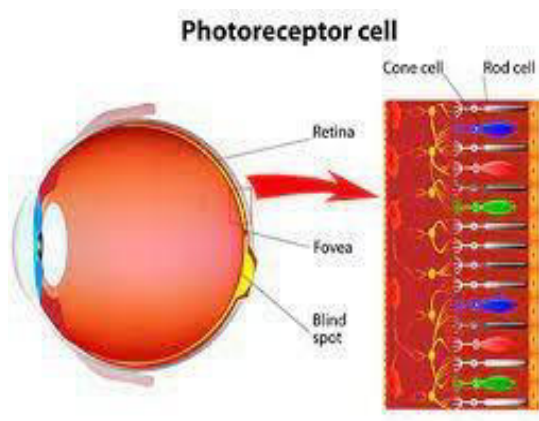
The human retina has two types of photoreceptors to gather light namely rods and cones. While rods are responsible for vision at low light levels (scotopic vision), cones are responsible for vision at higher light levels (photopic vision). The light levels where both are functional are known as mesopic.

#### Rods

- Rod cells are highly sensitive to light and function in night vision.
- Populated at the periphery of the retina.
- Contain rhodopsin pigment which are rich in vitamin A, and are responsible for the night vision hence making rods sensitive to light.

#### Cones

- Cone cells are capable of detecting a wide spectrum of light photons and are responsible for colour vision.
- They are populated in the central fovea region and mostly found in retina.
- Help distinguish colour and other fine details and are cone-shaped
- They are of three types – long-wavelength sensitive cones(L-cones), middle- wavelength sensitive cones (M-cones) and short-wavelength sensitive cones (S-cones)
- These contain iodopsin pigment known as violet pigment.

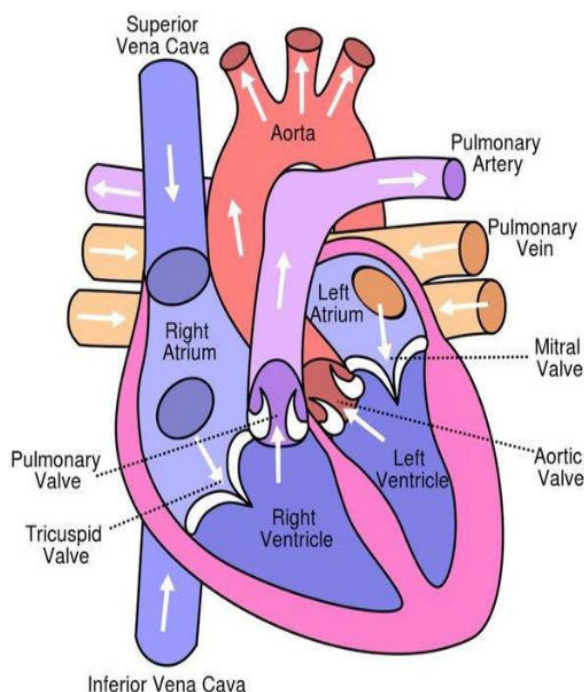


## Heart as a Pump System

Heart is sort of like a pump, or two pumps in one. The right side of your heart receives blood from the body and pumps it to the lungs. The left side of the heart does the exact opposite: It receives blood from the lungs and pumps it out to the body.

## Architecture of heart

- The heart is a fist-sized muscular organ made up of cardiac muscles. Heart, blood and a network of arteries, veins, and other blood vessels make the cardiovascular system.
- The heart is the key structure of a circulatory system because it is the motor or pumping organ which helps in circulation of blood throughout the body as per requirement.
- The heart is located in the thoracic cavity between the lungs and protected by a thick wall called pericardium.
- It is divided into four chambers namely- right and left atria and left and right ventricles.



Atria are present on the top and ventricles are the chambers at the bottom.

- Interatrial septum is a thin wall which separates the right and left atria whereas two ventricles are divided by the interventricular septum.
- Valves are the fibrous tissues which ensure the unidirectional flow of blood in the heart. The valve present between the right atrium and ventricle is known as tricuspid valve and this prevents the backward flow of blood from the right ventricle to the right atrium. Bicuspid valve (mitral valve) is the valve that separates the left atrium and ventricle.

### **Working of heart as pump**

- The human heart is very strong and is capable of pumping blood up to 30 feet distance. An average heart beats maximum of 70-80 beats per minute and is considered healthy.
- The efficiency of the heart can be maintained and improved by performing physical activity.
- The heart is called a double pump because; in each side it pumps blood to a different circulation.
- Deoxygenated blood from the body first enters the right atrium. The blood then flows through the tricuspid valve into the right ventricle. When the heart beats, the ventricle pushes blood through the pulmonic valve into the pulmonary artery. The pulmonary artery carries blood to the lungs where it “picks up” oxygen. It then leaves the lungs to return to the heart through the pulmonary vein.
- The oxygenated blood enters the left atrium. It drops through the mitral valve into the left ventricle. The left ventricle then pumps blood through the aortic valve and into the aorta. The aorta is the artery that feeds the rest of the body through a system of blood vessels.
- Blood returns to the heart from the body via two large blood vessels called the superior vena cava and the inferior vena cava. This blood carries little oxygen, as it is returning from the body where oxygen was used. The vena cava pump blood into the right atrium and the cycle begins all over again.

### **Lungs as Purification System**

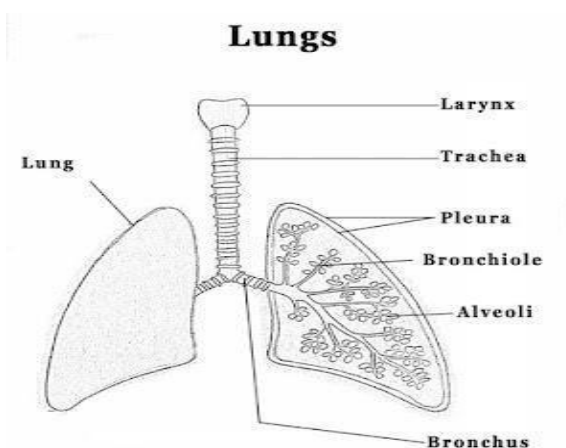
The lungs and respiratory system allow us to breathe. They bring oxygen into our bodies (called inspiration, or inhalation) and send carbon dioxide out (called expiration, or exhalation). This exchange of oxygen and carbon dioxide is called respiration.

Respiratory system performs other roles like

- Bringing air to the proper body temperature.
- Moisturizing it to the right humidity level.
- Protecting body from harmful substances (coughing, sneezing, filtering, or swallowing them).
- Supporting your sense of smell.
- As a filter against endogenous and exogenous emboli, preventing them from accessing systemic circulation.
- Pulmonary epithelium forms the first line of defense against inhaled particles.
- Pulmonary endothelial cells are responsible for the uptake, metabolism, and biotransformation of several exogenous and endogenous substances.
- Pulmonary endothelial binding of some drugs can alter their pharmacokinetics.

### Architecture of lungs

- Lungs are a pair of respiratory organs located in the chest cavity protected by rib cage.
- They are spongy elastic and are enclosed by two membranes called Pleura. Space between the two membranes of the Pleura is filled with fluid. Pleura protect the lungs from injury.



- Right lung is larger than the left lungs and it is made of three lobes while the left lung has only two lobes.
- A pipe like structure called Trachea carries the air from Nose through Neck, thoracic cavity and opens into two lungs through two branches called Bronchi.
- The walls of Trachea are supported by several 'C' shaped cartilaginous rings which prevent it from collapsing and closing.
- Bronchus divides into fine Bronchioles which open into tiny balloon like structures called Alveoli.
- Alveoli, also known as air space or air sacs, are millions of hollow cup-shaped cavities found in the lungs where exchange of oxygen and carbon dioxide takes place.

## **Mechanism of Working- Lungs**

- Arteries carry pure oxygenated blood from the heart to other parts of the body.
- Veins carry impure venous blood back from other parts of the body to the right side of the heart.
- This impure blood goes to the lungs for purification.
- When the breath is inhaled, oxygen from the air comes in contact with the impure blood and the blood takes up oxygen.
- The purified blood is carried to the heart by the veins.

## **Breathing**

In breathing, there are two processes: exhalation and inspiration.

### *External Respiration*

The exchange of oxygen and carbon dioxide between the mouth and the air in the lungs is known as external respiration. External respiration, often recognized as breathing, encompasses drawing air into the lung that is inhalation and as well as expelling air into the environment which is the exhalation process.

### *Internal Respiration*

Internal respiration is the process of exchanging oxygen and carbon dioxide between the body's capillaries and alveoli. The blood vessels exchange gases with the alveoli's gases which occur through the epithelium layer of alveoli.

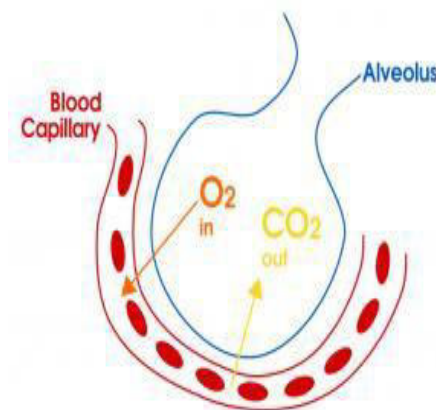
## **Exchange of Gases**

- Gaseous exchange is the exchange of oxygen and carbon dioxide between the lungs and blood.
- It is the biological process by which gases enter or exit the bloodstream across cell membranes.
- Gas exchange occurs constantly between the blood and the cells throughout the body, as well as between the blood and the air inside the lungs.

## **Transport of Gases in Respiration-Gas Exchange Mechanism**

The capability of haemoglobin (in RBCs) to carry (transport) oxygen and carbon dioxide as blood flows through the body is referred to as transport of gases.

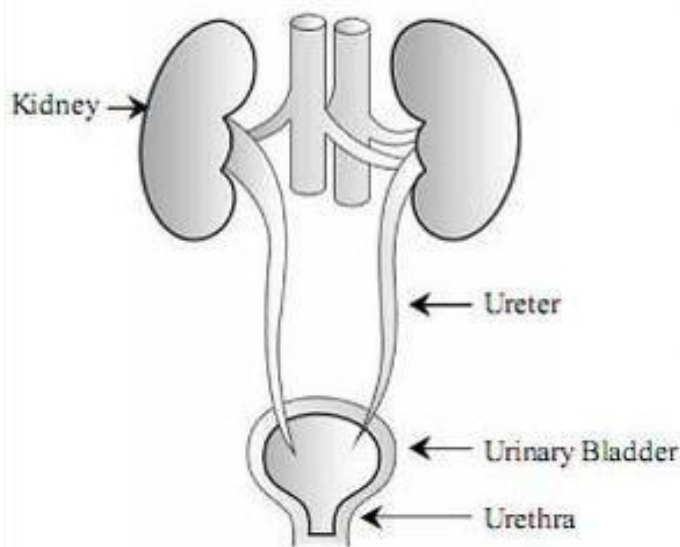
- Transport of Oxygen:** The alveoli-capillary membrane allows oxygen to pass through and dissolve in the plasma. After that, it enters RBCs and attaches to haemoglobin molecules. It carries both oxygen and carbon dioxide and transports the majority of it. Oxyhaemoglobin is formed when haemoglobin and oxygen mix. Oxyhaemoglobin synthesis is reversible, allowing Hb and oxygen to separate which allows oxygen to enter tissues. The capacity of the blood to carry oxygen is influenced by the level of dissolved oxygen in the plasma, the number of Hb, and the inclination of haemoglobin to bind with oxygen.
- Transport of Carbon Dioxide:** Carbon dioxide is carried in the bloodstream in three different forms: dissolved, bonded to haemoglobin, and as bicarbonate ions ( $\text{HCO}_3^-$ ). Due to the larger solubility coefficients of carbon dioxide in blood, its dissolved form (7%) is more than oxygen (oxygen is 1.5 per cent). RBCs absorb the majority of dissolved  $\text{CO}_2$ .  $\text{CO}_2$  binds to proteins (globin) in the blood as well.  $\text{HbCO}_2$  is formed when  $\text{CO}_2$  and haemoglobin (Hb) mix (carbaminohemoglobin).



## Kidney as a filtration system

### Architecture

- ☐ The kidneys are located at upper and back side of the abdomen, on either side of the spine. They are protected from damage by the lower ribs.
- ☐ The kidneys lie deep inside the abdomen so normally one cannot feel them.
- ☐ The kidneys are a pair of bean shaped organs. Each kidney weighs approximately 150- 170 grams.
- ☐ Urine formed in the kidneys flow down to urinary bladder and then through the

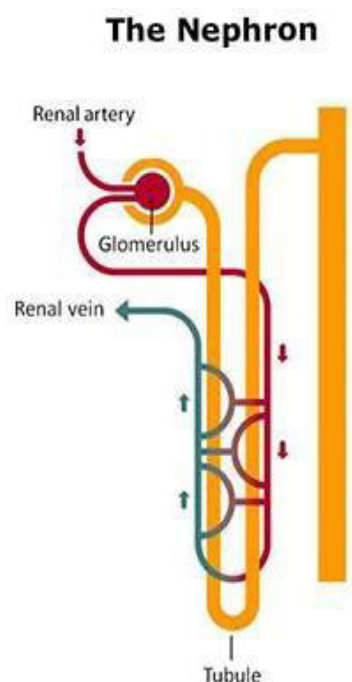


ureters. Each ureter is about 25 cm long and is a hollow tube- like structure.

- The urinary bladder is a hollow organ made up of muscles, which lie in the lower and anterior part of the abdomen. It acts as a reservoir of urine.
- Healthy kidneys filter about a half cup of blood every minute, removing wastes and extra water to make urine

### Mechanism of filtration

- Blood flows into the kidney through the renal artery.
- Each of kidneys is made up of about a million filtering units called nephrons. Renal artery's large blood vessel branches into smaller and smaller blood vessels until the blood reaches the nephrons.
- Each nephron includes a filter, called the glomerulus, and a tubule.
- The nephrons work through a two-step process: the glomerulus filters blood, and the tubule returns needed substances to blood and removes wastes.
- As blood flows into each nephron, it enters a cluster of tiny blood vessels— the glomerulus.
- The thin walls of the glomerulus allow smaller molecules, wastes, and fluid— mostly water—to pass into the tubule. Larger the molecules, such as proteins and blood cells, stay in the blood vessel.
- A blood vessel runs alongside the tubule.
- As the filtered fluid moves along the tubule, the blood vessel reabsorbs almost all of the water, along with minerals and nutrients your body needs.
- The tubule helps remove excess acid from the blood. The remaining fluid and wastes in the tubule become urine.



*Note:*

- *Blood circulates through your kidneys many times a day.*
- *In a single day, kidneys filter about 150 quarts of blood.*
- *Only 1 to 2 quarts become urine.*
- *When the kidney doesn't function properly, chronic kidney disease occurs.*