UNIVERSITY INSTITUTE OF ENGINEERING AND TECHNOLOGY

PROGRAM: B.E. - CSE

MONOGRAPH

SUBJECT

BIOLOGY FOR ENGNEERS (SZT-172)

SEMESTER

2ND

CHANDIGARH UNIVERSITY, GHARUAN

SYLLABUS

BIOLOGY FOR ENGINEERS
(SZT-172)

Credits: 4

Duration of Exam: 3 Hours

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Objective of Course:

- This subject is designed to impart fundamental knowledge on the structure and functions of the various systems of the human body.
- It is designed for both homeostatic mechanisms.

Course Outcomes: Learner will be able to understand…

- Analyse the gross morphology, structure and functions of various organs of the human body.
- Evaluate the various homeostatic mechanisms and their imbalances.
- Distinguish the coordinated working pattern of different organs of each system
- Analyse the interlinked mechanisms in the maintenance of normal functioning (homeostasis) of human body.

Unit-1

Introduction to Human body:

Cell, Tissue, Organ, Organ System, Structure and functions of cell, homeostasis, feedback mechanism: positive and negative, Types of tissues: Structure and function of epithelial, connective, muscular and nervous tissue, Muscle Physiology: Muscle Physiology of muscle contraction and aspects of skin resistance. **(9 Hours)**

Respiratory System: Anatomy of Respiratory System with special reference to anatomy of lungs,Mechanism of respiration, regulation of respiration, lung volumes **(6 Hours)**

Unit-2

Introduction to major organ systems- I

Circulatory System: Anatomy of Heart, Elements of conduction system, cardiac cycle, heart valves ,blood circulation: systemic and pulmonary, Composition and of blood, different types of blood cells and their functions, transmission of cardiac impulse , blood pressure and its regulation, ECG, Einthoven's triangle twelve lead system and ECG waveforms **(9 Hours)**

Biosensors and Instruments: ECG, EEG,EMG **(6Hours)**

Unit III

Introduction to major organ systems- II

Nervous System: Different parts, their functions. Reflex actions and reflex arc, functions of sympathetic and parasympathetic nervous system. Nerve conduction and action potentials.

Urinary System:- structure of nephron, function of kidney, urinary bladder, urethra, internal/external sphincters , physiology of urine formation **(8 Hours)**

Digestive System: Anatomy of the gastro-intestinal tract, gastro intestinal secretions and their functions, deglutition and defecation.

Sensory system :

Eye:- structure and function of eye, refractive medias of the eyes, working of eye, power of accommodation

Ear: Structure and functions of ear. **(7 Hours)**

Reference Books

1. Guyton, A.C. & Hall, J.E. W.B. Textbook of Medical Physiology.9th edition1996,Sanders Co.New York
2. Ganong WE. Review of Medical Physiology. Appleton and Lange, USA.
3. Tortora, G.J. and Grabowski, S.R.Principles of Anatomy and Physiology 9 th edition,2000 Collins College Publishers, Luciano, New York

Text Books Recommended

Text books:

1. Anatomy and Physiology in Health and Illness , Ross and Wilson , Churchill Livingstone, Newyork
2. Essentials of Anatomy and Physiology: Elaine N Marieb. (Pearson Education)\

CHAPTER -1

1.1 INTRODUCTION TO CELL

The living beings are comprised of a cell or number of cells. Cell biology is an integrative science including biochemistry, biophysics, molecular biology, microscopy, genetics, physiology, computer science and developmental biology and thereby reveals the size, shape, location and movements of cell components. The cell (Gr., *kytos*: cell; L., *cella*: hollow space) is the basic unit of organization or structure of all living matter and a fundamental unit of life. The cell is the smallest unit that can still carry on all life processes.

1.2 HISTORY AND EVOLUTION OF CELL

Evolution of the cell involves two processes:

- Occurrence of genetic variations which are passed on from one generation to another; and
- Selection of those genetic changes, useful for the survival and propagation of the organism.

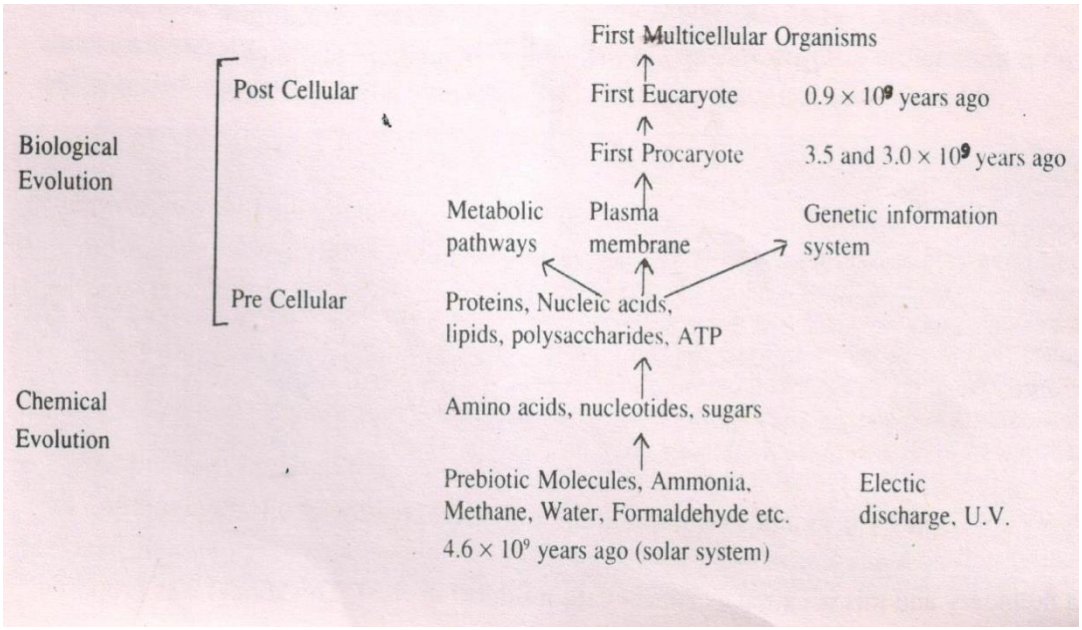


Figure1: The Origin of the Cell.

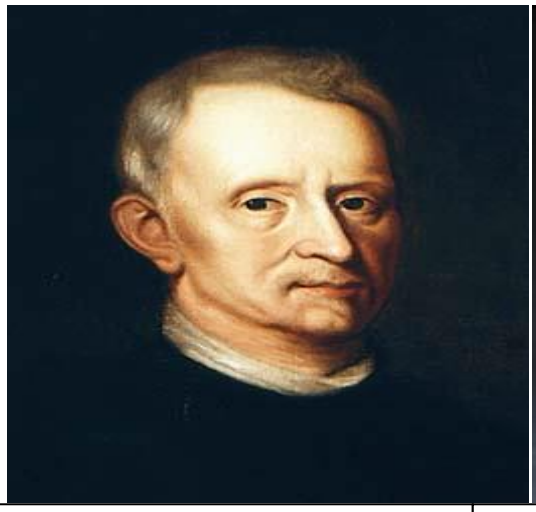
Before the 17th century, no one knew that the cells existed. In the early **17th century,** when **microscopes were invented**, the cells were seen for the first time. As the twenty-first century opens, there was an explosion of new data about the components of cells, their included structures, and how they touch & influence each other. **Anton Von Leeuwenhoek (1632-1723)**, a Dutchman, made the **1st hand-held microscope** & viewed microscopic organisms in water & bacteria from his teeth.

Leeuwenhoek's microscope comprised:

* A screw for adjusting the height of the object being examined;
* Metal plates serving as the body;
* A skewer to impale the object & rotate it; and
* The spherical lens.

Fig 1.2 Leeuwenhoek's microscope that was built in 17th century and its detailed diagrammatic view.

For the first time, the cell was observed by **Robert Hooke,** an English scientist, in a piece of thin sliced cork (from the dead bark of a spanish oak tree) under a very primitive compound microscope in **1665** which was improved by him. He actually observed the **dead plant cell walls** and named them as **"cells"** (L. *cella* = chamber) as they looked like monk's small rooms which they used to live in.



Robert Hooke (1635-1703).

Robert Hooke's microscope (1665) with magnification power of 14-42 times.

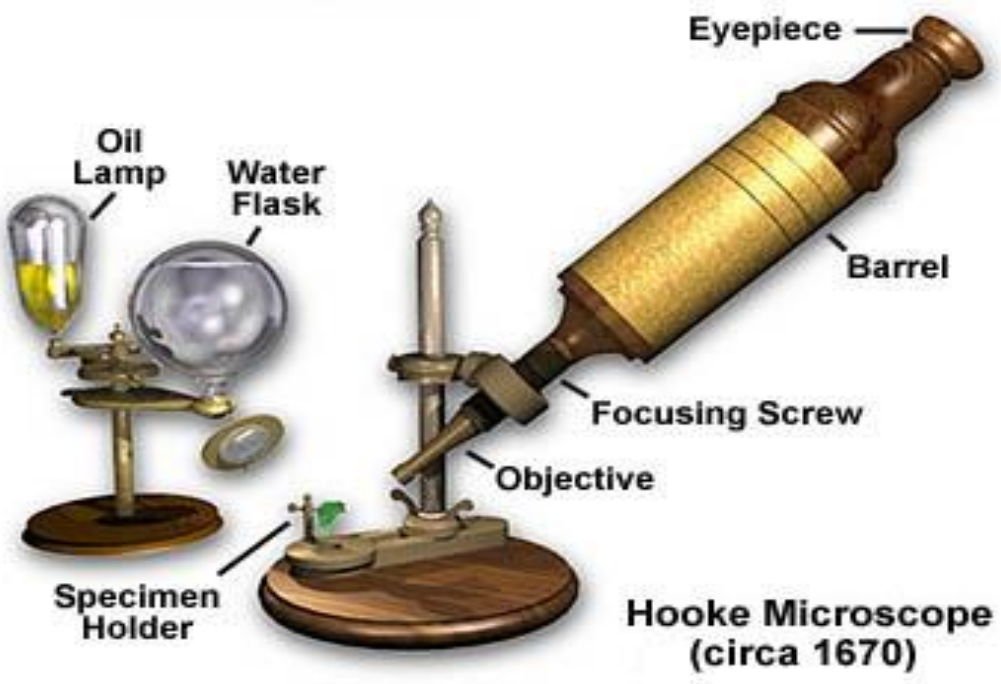


Figure1.3 : Hooke's Microscope (1665) diagrammatic.

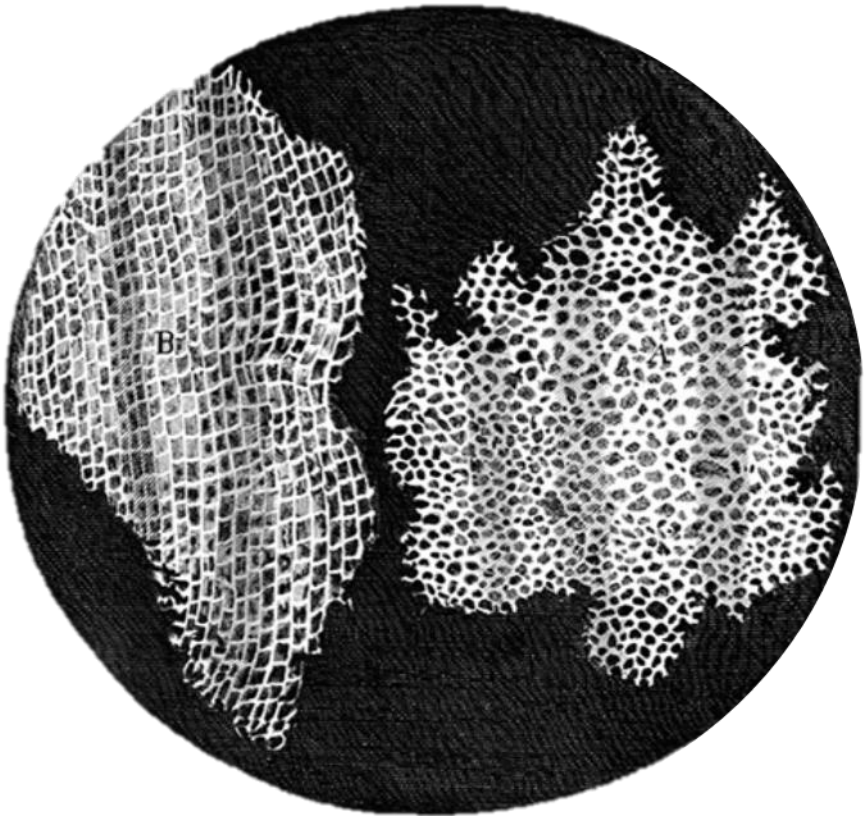


Figure1.4: Pieces of cork cells of the dead bark from an Oak tree showing tiny, empty compartments, as seen under the microscope by Hooke and published in Micrographia (1665).

1.3 CELL THEORY

In the 1830's, Matthias **Schleiden** who was a botanist & Theodore **Schwann** who was a zoologist, stated that **all living things were made of cells.** In 1855, **Rudolf Virchow** stated **that cells only arise from pre-existing cells.** Virchow's idea contradicted the idea of **spontaneous generation.**

The combined work of **Schleiden**, **Schwann** & **Virchow** is known as the **Cell Theory.**

		
Schwann	**Schleiden**	**Virchow**

1.3.1 Principles of the Cell Theory

i. All living things are made of one or more cells.
ii. Cells are the basic unit of structure & function in organisms.
iii. Cells come only from the reproduction of existing cells

1.4 DEFINITIONS OF A CELL

- **A.G. Loewy** and **P. Siekevitz** (1963) – "*a unit of biological activity delimited by a semipermeable membrane and capable of self-reproduction in a medium free of other living systems.*"
- **Wilson** and **Morrison** (1966) – "*an integrated and continuously changing system.*"
- **John Paul** (1970) – "*the simplest integrated organization in living systems, capable of independent survival.*"
- According to either definition of a cell, the viruses are not cells.
  They lack a semi-permeable membrane and cytoplasm, have genetic material, but can reproduce only within living cells. Therefore, they are not considered living in traditional sense. They are a category in themselves and are not included in the classification of the living world. They may be considered midway between the living and non-living systems. They have been classified as living chemicals. The viruses have been described further in details.

1.5 STRUCTURE OF CELL – DIVERSITY AND COMMONALITY

- **Cell diversity:** Cells are not alike and have an amazing variety of sizes, shapes and functions. The female egg cell is the largest cell in the human body and can be seen without a microscope. Bacterial cells are some of the smallest cells & are only visible with the help of a microscope.

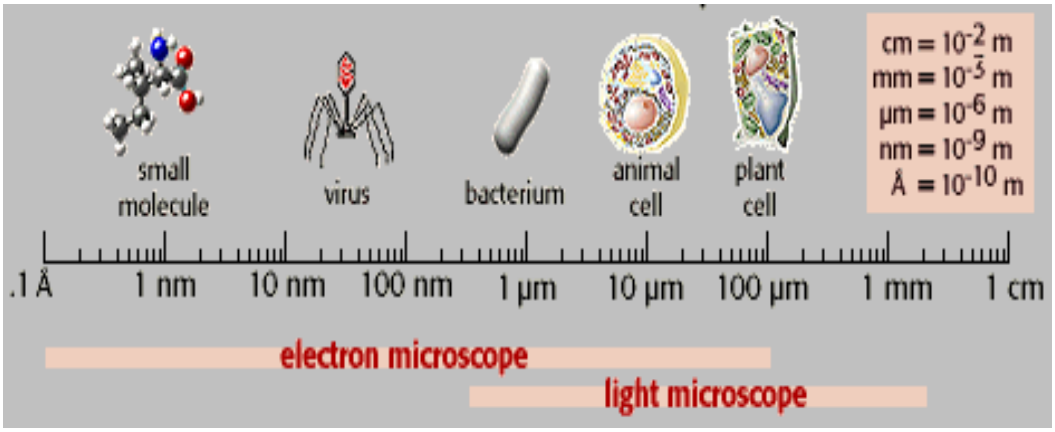


Figure 1.5 : Depicting the relative sizes of cells and their components.

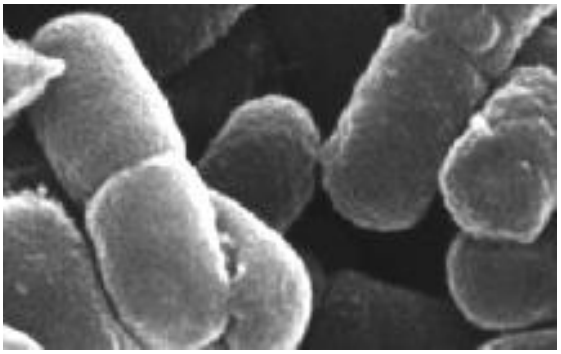


Figure 1.6: ***E. coli bacterial cell.***

- **Size:** Cells **need surface area** of their cell membrane large enough to adequately exchange materials with the environment (wastes, gases such as O_2 & CO_2 and nutrients). Cells are **limited in size by the ratio between their outer surface area & their volume.** Small cells have more surface area for their volume of cytoplasm than large cells. **As cells grow**, the amount of surface area becomes too small to allow materials to enter & leave the cell quickly enough. Cell **size is also limited** by the amount of cytoplasmic activity that the cell's nucleus can control.
- **Shape:** Cells come in a **variety of shapes,** & the **shape helps determine the function** of the cell (e.g. **Nerve cells** are long to transmit messages in the body, while **red blood cells** are disk shaped to move through blood vessels).

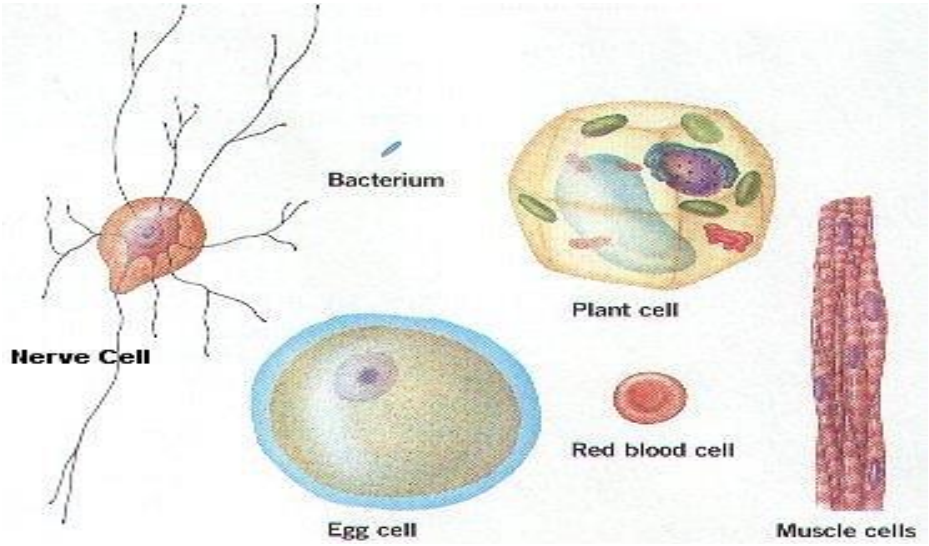


Figure 1.7: Depicting the various shapes of cells.

- **Ability to move:** Some may move rapidly and have fast-changing structures while most of them are largely stationary and structurally stable.
- Oxygen can kill some cells but is an absolute requirement for others.
- Cells in multicellular organisms are intimately involved with each other while those in unicellular organisms live in isolation or may form colonies or live in close association with other type of

organisms. For example, the bacteria that help plants in extracting nitrogen from the air or the bacteria that live in our intestines to help us digest food.

1.6 TYPES OF CELL

The biological universe consists of two types of cells named **prokaryotic** and **eukaryotic**. The terms prokaryotic and eukaryotic were suggested by **Hans Ris** (1960s) and have been accepted by all as the names for the two main divisions of the living world.

a. **Unicellular organism:** Only one celled body. E.g., Bacteria, blue-green bacteria, BGA, some other algae, Protozoa, found in the kingdom Monera, etc. **Do not have a nucleus & no membrane-bound organelles.** Most have a **cell wall** surrounding the **cell membrane** & a single, looped **chromosome** (genetic material) in the **cytoplasm.**
b. **Multicellular organism:** Many celled body. E.g., most of the plants and animals.
c. **Prokaryotic cell:** (Gr. *pro* = primitive or before; *karyon* = nucleus). Small, simple internal organization and most primitive cells which have came to exist approximately **3.5 billion years** ago. They are the first organism consisting of a single closed compartment surrounded by a plasma membrane and lacking a well defined nucleus. E.g., Mycoplasma or PPLO, bacteria, *E. coli* and Cyanobacteria or blue-green algae.
d. **Eukaryotic cell:** (Gr. *Eu* = true, typical; *karyon* = nucleus). Nucleated cells with nuclear envelope that have evolved from the prokaryotic cells approximately 1.4 billion years ago. (**Vidal**, 1983). They contain extensive internal membranes that enclose other compartments called **organelles**. The region of the cell lying between the plasma membrane and the nucleus is the **cytoplasm,** comprising the cytosol (aqueous phase) and the organelles.

1.7BASIC PROPERTIES OF CELL

Just as plants and animals are alive, so are cells. Life, in fact, is the most basic property of cells and cells are the smallest unit to exhibit this property. Unlike the parts of cells, which simply deteriorate if isolated, whole cell can be removed from a plant or an animal and cultured in a laboratory where they will grow and reproduce for extended period of time.

The structural unit called cell, is now known as the unit of life and the concept that the cell is basic unit of life is known as a cell theory. The first culture of human cells was begun by George Gey of Johns Hopkins University in 1951. The cells were obtained from a malignant tumor and named **HeLa cells** after the donor, Henrietta Lacks. HeLa cells descended by cell division from this first cell sample – are still being grown in laboratories around the world today.

1. Cells possess a Genetic Program and the Means to Use It

Organisms are built according to information encoded in a collection of genes. The human genetic program contains enough information m if converted to words, to fill millions of pages of books. This vast amount of information is packaged into a set of chromosomes that occupies the space of cell nucleus which is hundreds of times smaller than the dot on this i. Discovering the mechanisms by which cells use their genetic information, has been one of the greatest achievements of science in recent decades.

2. Cells are Capable of Self-regulation

The importance of a cell's regulatory mechanisms becomes most evident when they break down. To requiring energy, maintaining a complex, ordered state requires constant regulation. For example, failure of a cell to correct a mistake when it duplicates it DNA may result in a debilitating mutation, or a breakdown in cells growth – control safeguards can transform the cell into a cancer cell with the capability of destroying the entire organism. We are gradually learning how a cell controls its activities, but much more is left to discover.

3. Cells are Complex and Organized

The more complex a structure is, greater the number of parts that must be in their proper place, the less tolerance of errors in the nature and interaction of the parts and the more regulations that must be exerted to maintain the system. Cell is an **open system** because it allows entry and exit of matter and energy.

It takes up

- ✓ Matter (food, oxygen, water, salts) for sustenance, growth and division; and
- ✓ Energy (food) to operate the metabolic processes.

It turns out

- ✓ Matter (waste products, secretions), and
- ✓ Energy (heat).

The epithelial cells that line the intestine are tightly connected to each other like bricks in a wall. The apical ends of these cells, which face the intestinal channel, have long processes that facilitate absorption of nutrients.

Fortunately for cell and molecular biologists, evolution has moved rather slowly at the level of organization with which they are concerned.

4. Cell is a dynamic system

Exchange of matter and energy between a cell and its surrounding environment is dynamic as it varies in direction (in or out of a cell) and rate from time to time according to the requirements of the cell. By being able to regulate the entry and exit of materials into and out of it and by chemical changes in its materials, a cell attains homeostasis or steady-state condition, in which the internal levels of materials remain nearly constant.

Such an open and steady-state system is in contrast to the closed, equilibrium systems of the non-living world, which do not allow the movement of materials into and out of them.

5. Cells Store Hereditary Information in the Same Linear Chemical Codes - DNA

All living cells on the earth, without any known exception, store their hereditary information in the form of double-strand molecules of DNA. DNA guides growth, development and maintenance of tissues and organs of multicellular organisms. DNA instructions are passed from generation to generation by the process of reproduction.

6. Response to Stimuli

Organisms constantly sense changes in their surroundings and make controlled response to those changes. They achieve sensing through their receptors and response accordingly. This communication between cells and environment called homeostasis. Some cells respond to stimuli in obvious ways, a single celled protist. For example, moves away from an object in its path or moves toward a source of nutrients. Cells within a multicellular plant or animal respond to stimuli less obviously. Most cells are covered with receptors that interact with substances in the environment in highly specific ways; cells possess receptors to hormones, growth factors and extracellular materials, as well as to substances on the surfaces of other cells.

7. Plasma Membrane

Also known as a cell membrane is a phospholipid bilayer with proteins which separates the cell from its surrounding environment and functions as a selective barrier for the import and export of materials in a regulated manner. It maintains the individuality of the cell. It keeps cell contents in place and prevents their mixing up with the extracellular materials.

8. Cytoplasm

The rest of the material of the cell within the plasma membrane, not including the nucleoid region or nucleus, that comprise of a fluid section called the cytosol and the organelles and other particulates suspended in it.

9. Compartmentalization of Cell

The cells of protists, fungi, plants and animals have in their cytoplasm many membrane-bound compartments. These are called membrane-bound **organelles**. These include nucleus, mitochondria, choloroplasts, lysosomes, vacuoles and endoplasmic reticulum. The first three organelles are surrounded by double membranes, which are referred to as **envelops**, others by single membranes. The part of cytoplasm excluding the compartments is called **cytosol**. There are some organelles without a limiting membrane. These include centrioles, microtubules, microfilaments, intermediate filaments and ribosomes. They are not considered compartments. The cells having membrane-bound organelles (compartments) are called **eukaryotic cells**.

The cells of bacteria and blue-green algae do not contain membrane bound compartments in the cytoplasm. Such single compartment cells are called **prokaryotic cells**. The lack of intracellular compartmentalization shows the primitive nature of these organisms.

Both prokaryotic and eukaryotic cells have evolved from the original population of primitive cells.

Advantage of Compartmentalization: The intracellular compartments enable the cell to keep separate the diverse kinds of chemical reactions occurring in it all the time.

1.8 Multicellular Organization

Cells are **specialized** to perform one or a few functions in multicellular organisms. Cells in multicellular organisms **depend on each other**. The **levels of organization** include:
Cells → Tissues → Organs → Systems → Organism

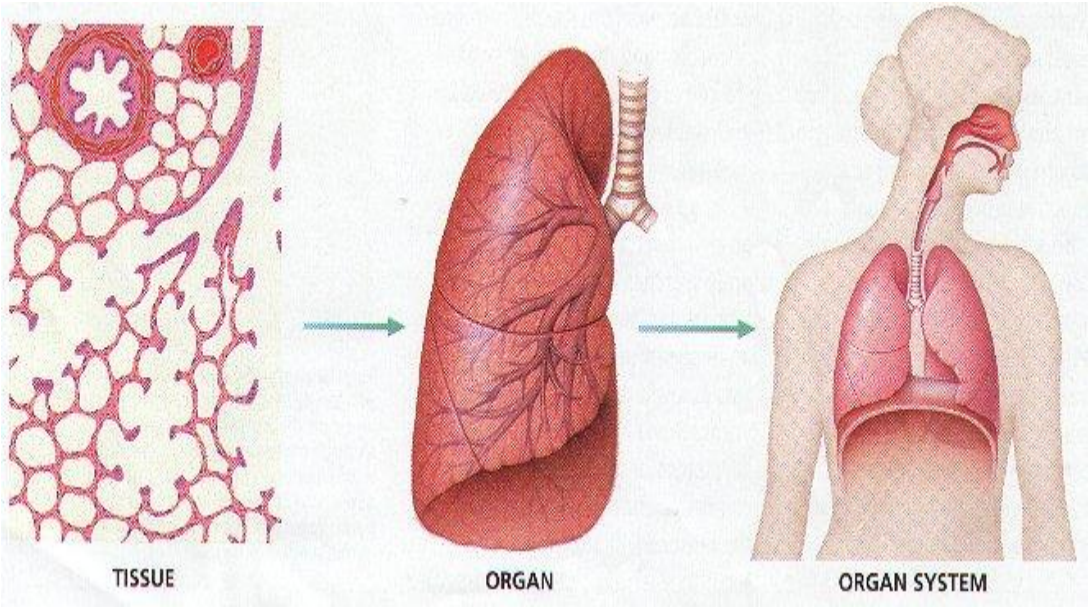


Fig 1.8 compartmentalization of organ

Tissues are groups of cells that performs a particular function (e.g. **Muscle**)

In humans, there are four basic types of tissue: **epithelial**, **connective**, **muscular**, and **nervous tissue**. There may be various sub-tissues within each of the primary tissues. **Epithelial tissue** covers the body surface and forms the lining for most internal cavities.

Organs are groups of tissues working together to do a job (e.g. **heart, lungs, kidneys, brain)**

Systems are made of several organs working together to carry out a life process **(e.g. Respiratory system for breathing)**

S. No.	Compartment (Organelle)	Boundary	Function
I.	**With Membrane**		
1.	Cytoplasm	Plasma membrane	Protein synthesis and metabolism.
2.	Nucleus	Nuclear envelope	Storage and transfer of genetic information.
3.	Mitochondria	Mitochondrial envelope	Energy production
4.	Chloroplasts	Chloroplast envelope	Photosynthesis
5.	Endoplasmic Reticulum	Folded membrane	Protein and lipid synthesis
6.	Golgi apparatus	Membrane stacks	Protein and lipid packaging
7.	Lysosomes	Unit membrane	Molecular degradation
8.	Microbodies	Unit membrane	Oxidation reactions
9.	Vacuoles	Unit membrane	Nutrient and waste storage

II.	**Without Membrane**		
10.	Ribosomes	No Membrane	Protein synthesis
11.	Microtubules	No Membrane	Form cytoskeleton
12.	Microfilaments	No Membrane	Form cytoskeleton, help in contraction and cleavage
13.	Intermediate fibres	No Membrane	Form cytoskeleton
14.	Centrioles	No Membrane	Help organize mitotic spindle and asters, provide basal bodies.
15.	Basal bodies	No Membrane	Give rise to cilia and flagella, change into centrioles.

1.9 Homeostasis is the state of steady internal conditions maintained by living things. This dynamic state of equilibrium is the condition of optimal functioning for the organism and includes many variables, such as body temperature and fluid balance, being kept within certain pre-set limits . Other variables include the pH of extracellular fluid, the concentrations of sodium, potassium and calcium ions, as well as that of the blood sugar level, and these need to be regulated despite changes in the environment, diet, or level of activity. Each of these variables is controlled by one or more regulators or homeostatic mechanisms, which together maintain life.

1.9.1Positive feedback mechanisms

A positive feedback mechanism is the exact opposite of a negative feedback mechanism. With negative feedback, the output reduces the original effect of the stimulus. In a positive feedback system, the output enhances the original stimulus. A good example of a positive feedback system is child birth. During labor, a hormone called oxytocin is released that intensifies and speeds up contractions. The increase in contractions causes more oxytocin to be released and the cycle goes on until the baby is born. The birth ends the release of oxytocin and ends the positive feedback mechanism.

Another good example of a positive feedback mechanism is blood clotting. Once a vessel is damaged, platelets start to cling to the injured site and release chemicals that attract more platelets. The platelets continue to pile up and release chemicals until a clot is formed.

1.9.2Negative feedback mechanisms

Almost all homeostatic control mechanisms are negative feedback mechanisms. These mechanisms change the variable back to its original state or “ideal value”.

A good example of a negative feedback mechanism is a home thermostat (heating system). The thermostat contains the receptor (thermometer) and control center. If the heating system is set at 70 degrees Fahrenheit, the heat (effector) is turned on if the temperature drops below

70 degrees Fahrenheit. After the heater heats the house to 70 degrees Fahrenheit, it shuts off effectively maintaining the ideal temperature.

The control of blood sugar (glucose) by insulin is another good example of a negative feedback mechanism. When blood sugar rises, receptors in the body sense a change. In turn, the control center (pancreas) secretes insulin into the blood effectively lowering blood sugar levels. Once blood sugar levels reach homeostasis, the pancreas stops releasing insulin.

1.10 Muscle Physiology

The **muscular system** is the biological system of humans that produces movement. The muscular system, in vertebrates, is controlled through the nervous system, although some muscles, like cardiac muscle, can be completely autonomous. **Muscle** is contractile tissue and is derived from the mesodermal layer of embryonic germ cells. Its function is to produce force and cause motion, either locomotion or movement within internal organs. Much of muscle contraction occurs without conscious thought and is necessary for survival, like the contraction of the heart or peristalsis, which pushes food through the digestive system. Voluntary muscle contraction is used to move the body and can be finely controlled, such as movements of the finger or gross movements that of the biceps and triceps.

Muscle is composed of muscle cells (sometimes known as "muscle fibers"). Within the cells are myofibrils; myofibrils contain sarcomeres which are composed of actin and myosin. Individual muscle cells are lined with endomysium. Muscle cells are bound together by perimysium into bundles called fascicles. These bundles are then grouped together to form muscle, and is lined by epimysium. Muscle spindles are distributed throughout the muscles, and provide sensory feedback information to the central nervous system. Skeletal muscle, which involves muscles from the skeletal tissue, is arranged in discrete groups. An example is the biceps brachii. It is connected by tendons to processes of the skeleton. In contrast, smooth muscle occurs at various scales in almost every organ, from the skin to the blood vessels and digestive tract.

1.10.1Skeletal muscle contraction

- An action potential reaches the axon of the motor neuron.
- The action potential activates voltage gated calcium ion channels on the axon, and calcium rushes in.
- The calcium causes acetylcholine vesicles in the axon to fuse with the membrane, releasing the acetylcholine into the cleft between the axon and the motor end plate of the muscle fiber.
- The skeletal muscle fiber is excited by large myelinated nerve fibers which attach to the neuromuscular junction. There is one neuromuscular junction for each fiber.
- The acetylcholine diffuses across the cleft and binds to nicotinic receptors on the motor end plate, opening channels in the membrane for sodium and potassium. Sodium rushes in, and potassium rushes out. However, because sodium is more permeable, the muscle fiber membrane becomes more positively charged, triggering an action potential.
- The action potential on the muscle fiber causes the sarcoplasmic reticulum to release calcium ions(Ca++).
- The calcium binds to the troponin present on the thin filaments of the myofibrils. The troponin then allosterically modulates the tropomyosin. Normally the tropomyosin

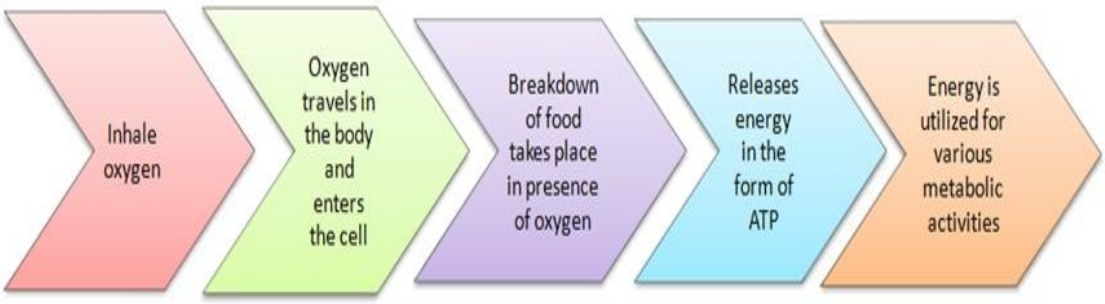
physically obstructs binding sites for cross-bridge; once calcium binds to the troponin, the troponin forces the tropomyosin to move out of the way, unblocking the binding sites.

- The cross-bridge (which is already in a ready-state) binds to the newly uncovered binding sites. It then delivers a power stroke.
- ATP binds the cross-bridge, forcing it to conform in such a way as to break the actin-myosin bond. Another ATP is split to energize the cross bridge again.
- Steps 7 and 8 repeat as long as calcium is present on thin filament.
- Throughout this process, the calcium is actively pumped back into the sarcoplasmic reticulum. When no longer present on the thin filament, the tropomyosin changes back to its previous state, so as to block the binding sites again. The cross-bridge then ceases binding to the thin filament, and the contractions cease as well.
- Muscle contraction remains as long as Ca++ is abundant in sarcoplasm.

1.11 Respiration anatomy and Mechanism

Respiration is the process in which food is broken down into smaller particles along with the liberation of energy. The energy released is utilized for various metabolic activities. In this process oxygen is inhaled inside by a living organism when they breathe in and carbon dioxide is exhaled out. Study about respiratory system for better understanding.

RESPIRATION PROCESS IN HUMANS:
In human beings, oxygen is inhaled inside the human body through nose or mouth. Oxygen is transferred to the entire body and enters the cell. Inside the cell food particles are broken down into smaller pieces in the presence of oxygen. During the breakdown of food particles, energy is released in the form of ATP. This energy released is utilized in certain metabolic activities.



Respiration equation:

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$

Respiration process can be of two types:

Aerobic
Anaerobic

Aerobic Respiration

Aerobic means “with air”. Therefore, aerobic respiration is the process of cellular respiration that uses oxygen to produce energy from food. This type of respiration is common in most of the plants and animals including humans, birds, and other mammals. While breathing, we inhale air that contains oxygen and we exhale air rich in carbon dioxide. As we breathe in, the oxygen-rich air is transported to all the parts of our body and ultimately to each cell. Inside the cell, the food, which contains glucose, is broken down into carbon dioxide and water with the help of oxygen. The process of breaking down the food particles releases energy, which is then utilized by our body. The energy released via aerobic respiration helps plants and animals, including us, grow.

The process can be simply explained with the help of the following equation:

Glucose + Oxygen → Carbon dioxide + Water + Energy

Aerobic respiration is a continuous process and it happens all the time inside the cells of animals and plants.

Anaerobic Respiration
Anaerobic means “without air”. Therefore, this type of cellular respiration does not use oxygen to produce energy. Sometimes there is not enough oxygen around for some organisms to respire, but they still need the energy to survive. Due to lack of oxygen, they carry out respiration in the absence of oxygen to produce the energy they require, which is referred to as anaerobic respiration. Anaerobic respiration usually occurs in lower plants and microorganisms. In the absence of oxygen, the glucose derived from food is broken down into alcohol and carbon dioxide along with the evolution of energy.

Glucose → Alcohol + Carbon dioxide + Energy

Anaerobic respiration is also used by multi-cellular organisms, like us, as a temporary response to oxygen-less conditions. During heavy exercise, fast running, cycling or weight lifting, our body demands high energy. As the supply of oxygen is limited, the muscle cells inside our body resort to anaerobic respiration to fulfill the energy demand.

How do you feel when you exercise too much? Have you ever wondered why you get those muscle cramps when you run very fast? Anaerobic respiration is the culprit to be blamed. Cramps occur when muscle cells respire anaerobically. Partial breakdown of glucose, due to lack of oxygen, produces lactic acid and the accumulation of lactic acid causes muscle cramps. That is why a hot shower after heavy sports relieve the cramps as it improves blood circulation in the body which in turn enhances the supply of oxygen to the cells.

Glucose → Lactic acid + Energy

Anaerobic respiration produces the relatively lesser amount of energy as compared to aerobic respiration as glucose is not completely broken down in the absence of oxygen.

1.11 Mechanism of Respiration in Human

Entire physiology of respiration involves following steps

1. Breathing or pulmonary ventilation
2. External respiration
3. Transport of O2 to tissue
4. Internal respiration
5. Transport of CO2 from tissue

1.11.1 Breathing or Pulmonary ventilation

- This is movement of air into and out of the lungs.
- Breathing supplies oxygen to the alveoli, and eliminates carbon dioxide.
- The main muscles involved in breathing are the intercostal muscles and the diaphragm.
- There are 11 pairs of intercostal muscles occupying the spaces between the 12 pairs of ribs. They are arranged in two layers, the external and internal intercostal muscles.
- The diaphragm is a dome-shaped muscular structure separating the thoracic and abdominal cavities.
- Breathing depends upon changes in pressure and volume in the thoracic cavity. Since air flows from an area of high pressure to an area of low pressure, changing the pressure inside the lungs determines the direction of airflow.
- Breathing involves two process

i. Inspiration

- It takes place when the volume of thoracic cavity is increased and the air pressure is decreased.
- Simultaneous contraction of the external intercostal muscles and the diaphragm expands the thorax.
- As the diaphragm + external intercostals contracts (moves downward) lung volume increases.

It involves following events

- First of all, external intercoastal muscle contracts and internal intercoastal muscles relaxes.
- Due to contraction of external intercoastal muscles, ribs is pulled upward, resulting in increase in thoracic cavity size
- The thoracic cavity further enlarges due to contraction of diaphragm, lowering the diaphragm and increases the size of thoracic cavity.
- With increase in size of thorax, lungs expand simultaneously.
- As lungs expands, the air pressure is reduced inside, so equalize the pressure, atmospheric air rushes inside the lungs

ii. Expiration

It takes place when the size of thoracic cavity is reduced and air pressure is increased.

involves following events

- The internal intercoastal muscle contracts and external intercoastal muscles relaxes.

- Due to contraction of internal intercoastal muscle, ribs are pulled inward, resulting in decrease in size of thoracic cavity
- Furthermore the diaphragm is pushed upward due to its relaxation
- With the decrease in size of thoracic cavity, lungs is compressed
- As lungs is compressed, pressure increases, so the air is forced outside.

2. External respiration

- This is the exchange of gases by diffusion between alveoli and blood in the alveolar capillaries, across respiratory membrane.
- Diffusion of oxygen and carbon dioxide depends on pressure differences, e.g. between atmospheric air and the blood, or blood and the tissues.
- Gas exchange during the respiration process takes place in the alveolus at its surface that separates the alveolus with the capillary.
- The exchange of O2 and CO2 occurs through diffusion which is the net movement of gas molecules from a region that has a higher partial pressure to another region that has a lower partial pressure.
- The venous blood in alveolar capillaries contains high level of CO2 and low level of O2.
- Co2 then diffuses from higher level (venous blood) to lower level (alveoli) until equilibrium is maintained. By the same process O2 diffuses from alveoli to venous blood until equilibrium.

3. Transport of Oxygen to tissue

- Oxygen is carried in the blood to the tissue in two from:

i) Oxyhaemoglobin (98.5%): it is a chemical combination of O2 with haemoglobin

Hb4 + 4O2…… Hb4O8 (oxyhaemoglobin)

ii) Solution in plasma water (1.5%): O2 dissolve in plasma of blood and carried to tissues.

- when the level of O2 is high in blood, it combines with haemoglobin to from oxyhaemoglobin.
- Oxyhaemoglobin is unstable, and under certain conditions readily dissociates releasing oxygen. Factors that increase dissociation include low O2 levels, low pH and raised temperature

4. Internal respiration

- Internal respiration is exchange of gases which takes places in tissue, so also known as cellular respiration.
- In tissue, oxygen carried in the form of Oxyhaemoglobin get dissciated to liberating free O2.

Hb4O8———dissociates to give ——— Hb + O2

- The free O2 then oxidized the glucose in the presence of respiratory enzymes to liberate CO2, water and energy.

$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + Energy$

- Energy is utilized by the tissue for its vital activities, while the CO2 is diffused from the tissue.

5. Transport of Carbondioxide from tissue to lungs

- Carbon dioxide is one of the waste products of metabolism.
- It is excreted by the lungs and is transported by three mechanisms:

i) as Carbonic acid (H_2CO_3) (7%): some CO2 dissolved in the plasma to form carbonic acid

- carbondioxide mixed with water of blood plasma to form carbonic acid.
- $CO_2 + H_2O \longrightarrow H_2CO_3$

ii) bicarbonate ions (HCO_3^-) in the plasma (70%)

- carbonic acid formed in blood plasma quickly ionizes to from bicarbonates and hydrogen ions in the presence of enzyme carbonic anhydrase.
- $CO_2 + H_2O \longrightarrow H^+ + HCO_3^-$
- bicarbonate ions combined with sodium or potassium present in blood to form sodium bicarbonate (NaHCO3) or Potasssium bicarbonate (KHCO3) and transported in this form

iii) as carbaminohaemoglobin (23%): some CO2 combines with Haemoglobin to form carbaminohaemoglobin in RBCs.

- $CO_2 + NHbNH_2 \longrightarrow$ HbNH.COOH (carbaminohaemoglobin).

finally, CO2 are carried to lungs and expelled out by expiration process of breathing.

Chapter -2

2.1Heart

The **heart** is a muscular organ in most animals, which pumps blood through the blood vessels of the circulatory system. Blood provides the body with oxygen and nutrients, as well as assists in the removal of metabolic wastes. In humans, the heart is located between the lungs, in the middle compartment of the chest.

In humans, other mammals, and birds, the heart is divided into four chambers: upper left and right atria; and lower left and right ventricles. Commonly the right atrium and ventricle are referred together as the *right heart* and their left counterparts as the *left heart*. In a healthy heart blood flows one way through the heart due to heart valves, which prevent backflow.The heart is enclosed in a protective sac, the pericardium, which also contains a small amount of fluid. The wall of the heart is made up of three layers: epicardium, myocardium, and endocardium.

The heart pumps blood with a rhythm determined by a group of pacemaking cells in the sinoatrial node. These generate a current that causes contraction of the heart, traveling through the atrioventricular node and along the conduction system of the heart. The heart receives blood low in oxygen from the systemic circulation, which enters the right atrium from the superior and inferior venae cavae and passes to the right ventricle. From here it is pumped into the pulmonary circulation, through the lungs where it receives oxygen and gives off carbon dioxide. Oxygenated blood then returns to the left atrium, passes through the left ventricle and is pumped out through the aorta to the systemic circulation−where the oxygen is used and metabolized to carbon dioxide. The heart beats at a resting rate close to 72 beats per minute. Exercise temporarily increases the rate, but lowers resting heart rate in the long term, and is good for heart health.

2.2 MEDICAL INSTRUMENTATION AND TECHNIQUES

2.2.1.ECG

What Is an Electrocardiogram (ECG, EKG)?

An electrocardiogram records the electrical signals in your heart. It's a common test used to detect heart problems and monitor the heart's status in many situations. Electrocardiograms — also called ECGs or EKGs — are often done in a doctor's office, a clinic or a hospital room.

An ECG is a noninvasive, painless test with quick results. During an ECG, sensors (electrodes) that can detect the electrical activity of your heart are attached to your chest and sometimes your limbs. These sensors are usually left on for just a few minutes.

Basic Anatomy of the Heart

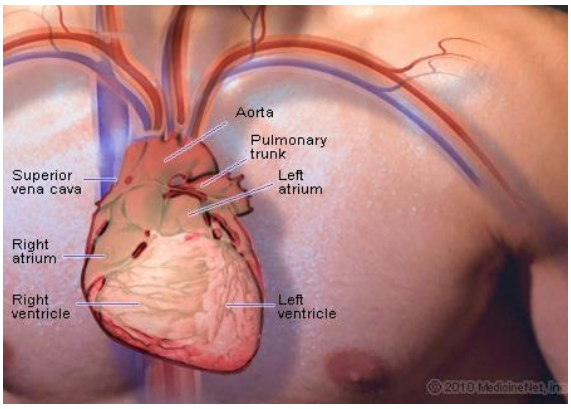


Fig 2.1 Anatomy of Heart

The heart has four chambers – the right and left atrium and the right and left ventricle.

The right side of the heart collects blood from the body and pumps it to the lungs while the left side of the heart receives blood from the lungs and pumps it to the body.

Blood flows through the body in the following way:

- Oxygen-rich blood from the lungs enters the left atrium through the pulmonary veins.
- Blood then flows into the left ventricle where it is pumped into the aorta and is distributed to the rest of the body. This blood supplies organs and cells with oxygen and nutrients necessary for metabolism.
- Blood that returns to the heart is depleted of oxygen and carries carbon dioxide, the waste product of metabolism. The blood enters the right atrium though the vena cava, where it is collected and pumped to the right ventricle.
- The right ventricle then pumps blood through the pulmonary artery to the lungs where carbon dioxide is stripped off, oxygen is replaced, and the cycle begins again.

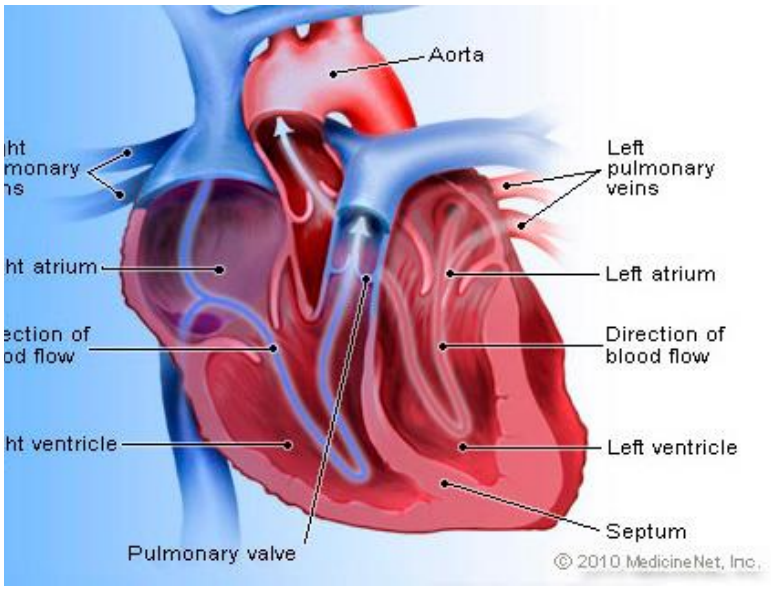


Fig 2.2 blood flow

Like any muscle, the heart requires oxygen and nutrients to function. Oxygen and nutrients are supplied by arteries that originate from the aorta. These vessels branch out to supply all the regions of the heart with oxygen rich blood.

Electrically, the heart can be divided into upper and lower chambers. An electrical impulse is generated in the upper chambers of the heart that causes the atria to squeeze and push blood into the ventricles. There is a short delay to allow the ventricles to fill. The ventricles then contract to pump blood to the body and the lungs.

Conducting system of the heart: SA means sinoatrial node. AV means atrioventricular node. RB and LB mean right and left bundle, respectively, and are the nerves that spread the electric impulse from the AV node into the ventricles.

The heart has its own automatic pacemaker called the sinaoatrial, or SA node, located in the right atrium. The SA node acts independently of the brain to generate electricity for the heart to beat.

- Normally, the impulse generated by the SA node runs through the heart's electrical grid and signals the muscle cells in the atria to beat simultaneously, allowing for a coordinated squeeze of the heart. Contraction of the atria pushes blood into the ventricles.
- The electrical signal that was generated in the SA node travels to a junction box between the atria and ventricles (the AV node) where it is delayed for a few milliseconds to allow the ventricles to fill.
- The electrical signal then travels through the ventricles, stimulating those heart muscle cells to contract. Ventricular contraction pumps blood to the body (from the left ventricle) and the lungs (from the right ventricle).
- There is a short pause to allow blood to return to the heart and fill before the electrical cycle repeats itself for the next heartbeat.

2.1.2Definition of electrocardiogram

An electrocardiogram records the electrical signals in your heart. It's a common test used to detect heart problems and monitor the heart's status in many situations. Electrocardiograms — also called ECGs or EKGs — are often done in a doctor's office, a clinic or a hospital room.

An ECG is a noninvasive, painless test with quick results. During an ECG, sensors (electrodes) that can detect the electrical activity of your heart are attached to your chest and sometimes your limbs. These sensors are usually left on for just a few minutes.

2.1.3How it works

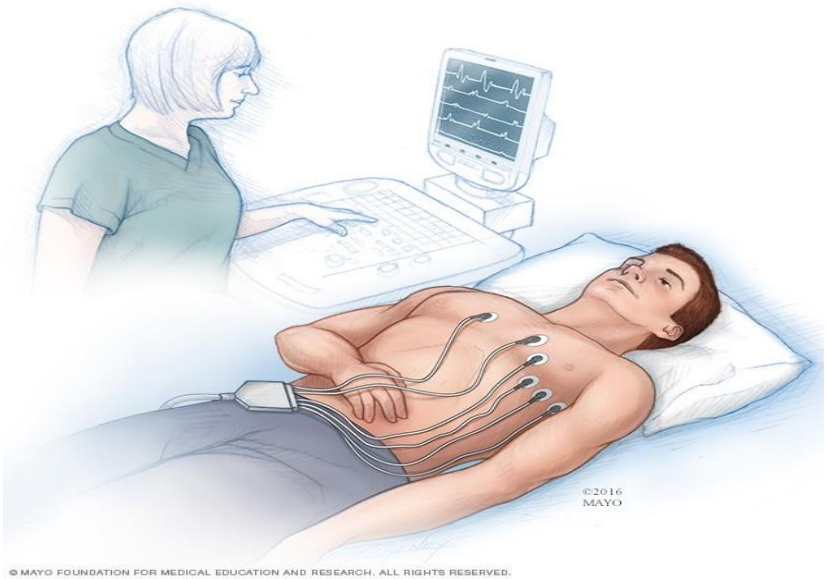
- 

Fig 2.3 Working

2.1.4Electrocardiogram

Each beat of your heart is triggered by an electrical impulse normally generated from special cells in the upper right chamber of your heart (pacemaker cells). An electrocardiogram records the timing and strength of these signals as they travel through your heart.

The Standard 12 Lead ECG : The standard 12-lead electrocardiogram is a representation of the heart's electrical activity recorded from electrodes on the body surface from 12 different areas of the heart.. The electrical activity is recorded as waves on a graph, with different patterns corresponding to each electrical phase of your heartbeat.

A 12-lead ECG consists of three bipolar limb leads (I, II, and III), the unipolar limb leads (AVR, AVL, and AVF), and six unipolar chest leads, also called precordial or V leads, (V1, V2 , V4, V5, V6).

Einthoven's triangle is an imaginary formation of three limb leads in a triangle used in electrocardiography, formed by the two shoulders and the lower limbs.Conventionally right leg is used as reference limb. Rest three limbs forrm and equilateral triangle with heart in the centre that produces zero potential when the voltages are summed.

The same three leads that form the standard leads also form the three unipolar leads known as the augmented leads. These three leads are referred to as aVR (right arm), aVL (left arm) and aVF (left leg) and also record a change in electric potential in the frontal plane

A standard ECG can record an abnormal heart rhythm only if it happens during the test.

<u>Normal electrocardiogram</u>

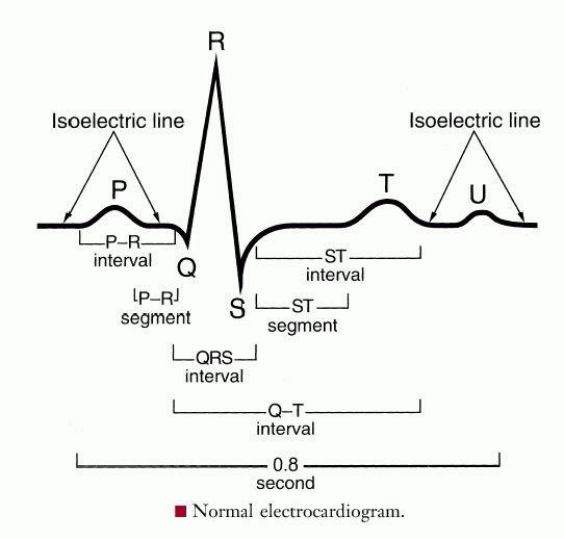


Fig 2.4 ECG waveform

Normal rhythm produces four entities — a P wave, a QRS complex, a T wave, and a U wave — that each have a fairly unique pattern.

- The P wave represents atrial depolarization.
- The QRS complex represents ventricular depolarization.
- The T wave represents ventricular repolarization.
- The U wave represents papillary muscle repolarization.

However, the U wave is not typically seen and its absence is generally ignored. Changes in the structure of the heart and its surroundings (including blood composition) change the patterns of these four entities.

2.2 Electromyogram

Electromyography (EMG) is a diagnostic procedure to assess the health of muscles and the nerve cells that control them (motor neurons).

Motor neurons transmit electrical signals that cause muscles to contract. An EMG translates these signals into graphs, sounds or numerical values that a specialist interprets.

An EMG uses tiny devices called electrodes to transmit or detect electrical signals.

During a needle EMG, a needle electrode inserted directly into a muscle records the electrical activity in that muscle.

A nerve conduction study, another part of an EMG, uses electrodes taped to the skin (surface electrodes) to measure the speed and strength of signals traveling between two or more points.

EMG results can reveal nerve dysfunction, muscle dysfunction or problems with nerve-to-muscle signal transmission.

Surface and intramuscular EMG recording electrodes

There are two kinds of EMG: surface EMG and intramuscular EMG

Surface EMG

Assesses muscle function by recording muscle activity from the surface above the muscle on the skin.

Surface electrodes are able to provide only a limited assessment of the muscle activity.

Surface EMG can be recorded by a pair of electrodes or by a more complex array of multiple electrodes.

More than one electrode is needed because EMG recordings display the potential difference (voltage difference) between two separate electrodes.

Limitations of this approach are the fact that surface electrode recordings are restricted to superficial muscles, are influenced by the depth of the subcutaneous tissue at the site of the

recording which can be highly variable depending of the weight of a patient, and cannot reliably discriminate between the discharges of adjacent muscles.

Intramuscular EMG

can be performed using a variety of different types of recording electrodes.

The simplest approach is a monopolar needle electrode.

This can be a fine wire inserted into a muscle with a surface electrode as a reference; or two fine wires inserted into muscle referenced to each other.

Diagnostic monopolar EMG electrodes are typically insulated and stiff enough to penetrate skin, with only the tip exposed using a surface electrode for reference.

EMG results are often necessary to help diagnose or rule out a number of conditions such as:

- Muscle disorders, such as muscular dystrophy
- Diseases affecting the connection between the nerve and the muscle, such as myasthenia gravis
- Disorders of nerves outside the spinal cord (peripheral nerves), such as carpal tunnel syndrome or peripheral neuropathies
- Disorders that affect the motor neurons in the brain or spinal cord, such as amyotrophic lateral sclerosis or polio
- Disorders that affect the nerve root, such as a herniated disk in the spine

EMG generally represents a noise like wave form depending on the various strength/intensity of of muscular contraction and when sent to audioamplifier produces a typical ‘ crackling ’ sound. EMG is either audio recorded or digitally displayed . it does not have a recording pen written record unlike ECG or EEG.

2.3 EEG (ELECTROENCEPHLOGRAM)

An electroencephalogram (EEG) is a test that detects electrical activity in your brain using small, flat metal discs (electrodes) attached to your scalp. Your brain cells communicate via electrical impulses and are active all the time, even when you're asleep. This activity shows up as wavy lines on an EEG recording.

OUTPUT:
EEG output is in the form of different waves with different frequencies.

Delta waves: 0.5-4 Hz
Theta waves: 4-8 Hz
Alpha waves: 8-13 Hz
1st wave to be discovered
Is one of the principal components of EEG, Indicator of state of alertness of brain ..
Indicator of depth of anesthesia in operating rooms
Beta waves: 13- 22 Hz
Gama waves: 22-30 Hz

An EEG is one of the main diagnostic tests for epilepsy. An EEG may also play a role in diagnosing other brain disorders.

An EEG can determine changes in brain activity that may be useful in diagnosing brain disorders, especially epilepsy. An EEG can't measure intelligence or detect mental illness. An EEG may be helpful for diagnosing or treating the following disorders:

- Epilepsy or other seizure disorder
- Brain tumor
- Head injury
- Brain dysfunction that may have a variety of causes (encephalopathy)
- Inflammation of the brain (encephalitis)
- Stroke
- Sleep disorders
- Dementia

PROCEDURE

- **A technician measures your head and marks your scalp** with a special pencil, to indicate where to attach the electrodes. Those spots on your scalp may be scrubbed with a gritty cream to improve the quality of the recording.
- **A technician attaches flat metal discs (electrodes) to your scalp** using a special adhesive. Sometimes, an elastic cap fitted with electrodes is used instead. The electrodes are connected with wires to an instrument that amplifies — makes bigger — the brain waves and records them on computer equipment.

Once the electrodes are in place, an EEG typically takes up to 60 minutes.

You relax in a comfortable position with your eyes closed during the test. At various times, the technician may ask you to open and close your eyes, perform a few simple calculations, read a paragraph, look at a picture, breathe deeply (hyperventilate) for a few minutes, or look at a flashing light.

- **Video is frequently recorded during the EEG.** Your body motions are captured by a video camera while the EEG simultaneously records your brain waves. This combined recording may help your doctor diagnose and treat your condition.
- **10-**20 electrode pattern is used in EEG . called as montage electrodes with 10% and 20 % spacing between known marked areas of cranium. Montage selector gives channelized output for every pair of chosen electrodes.
- Peak to peak amplitude of EEG signals is normally 50uV (less than 100 uv). Normal frequency content ranges from 0.5 to 50Hz.

2.4 BIOSENSORS

In the field of medicine, industry, agriculture, environment monitoring and biotechnology research, routine analyses using physical instruments are conducted for estimation and monitoring the levels of certain analytes. Conventional physical methods for this routine analysis do not involve the use of any living organisms or molecules of biological origin.

However, for this purpose, biological molecules or living cells have been used to develop sensitive devices that are described as '**biosensors**'. The biosensors have been considered to be superior in comparison to physical instruments due to following reasons:

i. In a biosensor, immobilized biological material is present in intimate contact of a suitable transducer, so that the biochemical signal is quickly converted into an electrical signal.
ii. The immobilization of biomolecules permits the reuse of these molecules and allows simplification of the entire apparatus.
iii. The sensing element is present in a small area and is very sensitive, thus facilitating the analysis of substances in very small quantities.

Biosensors provide a useful means for measuring a wide spectrum of analytes (e.g., gases, ions and organic compounds, or even bacteria) and are suitable for studies of complex microbial environments.

2.4.1 What is a biosensor ?

A biosensor is an analytical device for the detection of an analyte that combines a biological component with a physicochemical detector component. It consists of 2 parts:

- the *sensitive biological element* (biological material) (e.g. tissue, microorganisms, organelles, cell receptors, enzymes, antibodies, nucleic acids, etc.). The sensitive elements can be created by biological engineering.
- the *transducer* or the *detector element* that transforms the signal resulting from the interaction of the analyte with the biological element into another signal (i.e., transducers) that can be more easily measured and quantified.

  It detects, records and transmits information regarding a physiological change or the presence of various chemical or biological materials in the environment. An analyte can be a protein, toxin, sugar, antibiotic or vitamin present in the body fluid.

  Biosensor is a combination of two parts:

  a. bio-element- This part is also known as bioreceptor, biocatalyst or biological active material. It can be an enzyme, antibody, organelle, hormones, nucleic acids or whole cells.
  b. sensor-element- This part is also known as transducer. It can be carbon electrode, oxygen electrode, an ion-sensitive electrode, a photocell or a thermistor.

Biosensors were first developed by **Clark (Father of Biosensors)** in 1962.

The history of biosensors started in the year 1962 with the development of enzyme electrodes by the scientist Leland C. Clark. He used platinum (Pt) electrodes to detect oxygen. The enzyme glucose oxidase (GOD) was placed very close to the surface of platinum by physically trapping it against the electrodes with a piece of dialysis membrane. The enzyme activity changes depending on the surrounding oxygen concentration. Glucose reacts with glucose oxidase (GOD) to form gluconic acid while producing two electrons and two protons, thus reducing GOD. The reduced GOD, surrounding oxygen, electrons and protons (produced above) react to form hydrogen peroxide and oxidized GOD (the original form). This GOD can again react with more glucose. The higher the glucose content, more oxygen is consumed. On the other hand, lower glucose content results in more hydrogen peroxide. Hence, either the consumption of oxygen or the production of hydrogen peroxide can be detected by the help of platinum electrodes and this can serve as a measure for glucose concentration.

How do we know there was a detection?

If bio-element is specific for the analyte present in the sample, then analyte will bind to the bio-element. Recognition will take place and signal will be produced. If bio-element is not specific for the analyte present in sample, then analyte will not bind to the bio-element. There will be no recognition and signal will not be produced.

2.4.2 Characteristics of Biosensor

1. Selectivity is probably the most important feature of a biosensor. Selectivity means that sensor detects a certain analyte and doesn't react to admixtures and contaminants. Antigen-antibody interaction has the highest selectivity, it is analyte-specific.

2. Precision is usually characterised in terms of the standard deviation of measurements. Precision is a characteristic of any scientific device that makes quantitative

measurements. If biosensor is not accurate, then there will be fluctuations in the measurements.

3. Signal stability shows the signal drift under constant conditions which causes an error in measured concentration. Signal stability influences the precision of sensor. It is an important characteristic of a sensor that performs continuous monitoring. Signal drift is usually measured in percent per hour.

4. Sensitivity (detection limit) shows the minimal amount (or concentration) of analyte that can be detected.

5. Working range is the range of analyte concentrations in which the sensor can operate. Working range of sensor should correlate with the range of possible concentrations analyte in the assay. For example, glucose concentration in blood typically varies from 0.2mM to 20 mM. Working range of glucose sensors shouldn't be less.

6. Linear range is the range of analyte concentrations in which the sensor response changes linearly with the concentration.

7. Response time is time required to analyze the assay.

8. Regeneration time is the time required to return the sensor to working state after interaction with the sample.

9. Number of cycles is the number of times the sensor can be operated. Degradation of biological material is inevitable and it needs to be replaced. In some sensors (e.g. hand-held commercial glucose sensors) transducers are disposable, they need to be changed after each measurement. Other sensors can keep their characteristics for many cycles.

10. Reproducibility is the accuracy with which sensor's output can be obtained.

11. Life time is the time period over which sensor can be used without significant deterioration in performance characteristics.

12. Biosensor should be independent of temperature and pH.

13. Biosensors should be economical.

14. The complete biosensor should be cheap, small, portable and capable of being used by semi-skilled operators.

2.4.3Principle of Biosensors

The principle of the biosensor is quite simple. The biological material (enzymes) is firstly immobilized on the immobilization support. Then the sample is passed through the membrane so that analyte present in the sample can react with the immobilized material. After interaction, a biological signal will be produced. This biological signal is then converted by sensor element into electrical signal.

Flow chart:

Immobilized biological material

⇩

Sample passed through the membrane

⇩

Interaction of analyte and immobilized biological material

⇩

Biological signal

⇩

Transducer

⇩

Electrical signal

2.4.4 Components of a biosensor

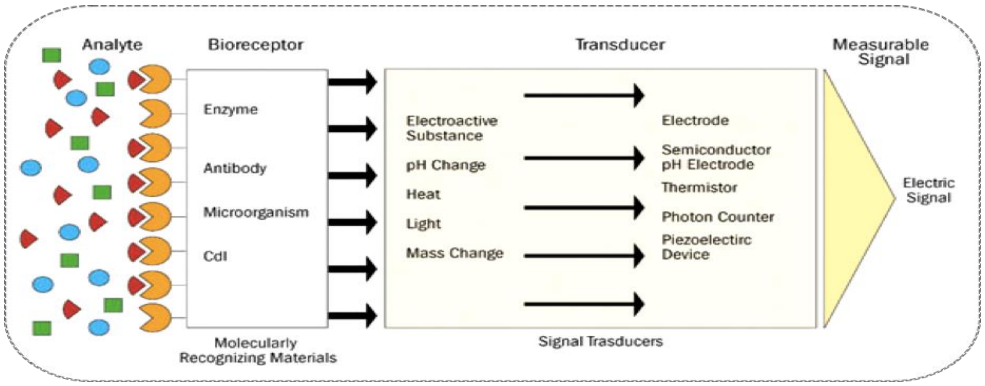


Fig 2.5 componenets of biosensor

a. Bioreceptor: An analyte present in the sample would bind to this component only. But it should be highly specific. e.g., glucose oxidase acts only on glucose to produce gluconic acid and hydrogen peroxide. Bioreceptor should be stable under storage conditions and it should be immobilized.

b. Transducer: acts as an interface since it is present between first and third component. It measures the physical change that occurs with the reaction at the bioreceptor then transforming that energy into measurable electrical output.

Product	Sensor
Heat	thermistor
Light	optical transducer
Mass	Piezo-electric transducer
current	Electrochemical transducer

c. Detector: Signals from the transducer are passed to a microprocessor where they are amplified and analyzed. The data is then converted to concentration units and transferred to a display or/and data storage device.

Biological and Physical Components of some biosensors and their uses

Biological component	Physical component	Substance measured
Glucose oxidase	Oxygen electrode	Glucose
hCG catalase	Oxygen electrode	Human chorionic gonadotropin
Trichosporon cutaneum	Oxygen electrode	BOD
NADH and dehydrogenase	Redox electrode	Ethanol
Methylomonas flagellata	Oxygen electrode	Methane
Nitrifying bacteria	Oxygen electrode	Nitrite and nitrate

2.4.5 Types of Biosensor:

1. Electrochemical Biosensors
    a. Amperometric Biosensors
    b. Potentiometric Biosensors
2. Optical Biosensors
3. Piezo-electric Biosensors
4. Calorimetric Biosensors

Potentiometric Biosensors:

Potentiometric biosensors make use of ion-selective electrodes in order to transduce the biological reaction into an electrical signal. In the simplest terms this consists of an immobilised enzyme membrane surrounding the probe from a pH-meter, where the catalysed reaction generates or absorbs hydrogen ions. The reaction occurring next to the thin sensing glass membrane causes a change in pH which may be read directly from the pH-meter's display. Typical of the use of such electrodes is that the electrical potential is determined at very high impedance allowing effectively zero current flow and causing no interference with the reaction

A semi-permeable membrane (a) surrounds the biocatalyst (b) entrapped next to the active glass membrane (c) of a pH probe (d). The electrical potential (e) is generated between the internal Ag/AgCl electrode (f) bathed in dilute HCl (g) and an external reference electrode (h). Here, the measured parameter is voltage.

Potentiometric biosensors are of three types:

I. Ion-sensitive electrodes
II. Gas-sensing electrodes
III. Field-effect transistors

I. Ion-sensitive electrodes : These are usually pH meter electrodes. Biosensors using these electrodes detect and measure many reactions which generate or use up H^+ ions.

II. Gas-sensing electrodes: detect and measure the amount of gas produced. These are also pH meter electrodes, but the electrode surface is covered by gas-permeable membrane selective for CO_2, NH_3 or H_2S. The diffusion of the gas through this membrane causes a change in pH of a sensing solution between the membrane and the electrode which is then determined

III. Field-effect transistors: These are usually solid state electrodes. The electrode surface is covered by a polymer layer. This polymer layer is selectively permeable for analyte ions. The ions diffuse through the polymer layer and in turn cause a change in the surface potential.

1. **Optical Biosensors**

Optical biosensors measure signal in the form of light. The major advantage of optical biosensors is that they do not have electrical interferences and therefore are biocompatible for in vivo and can detect changes which occur in the micro-environment that surrounds their surface. Optical biosensors are very useful for monitoring and testing down-well waters.

There are two main areas of development in optical biosensors. These involve determining changes in light absorption between the reactants and products of a reaction, or measuring the light output by a luminescent process. The former usually involves the use of colorimetric test strips. These are disposable single-use cellulose pads impregnated with enzyme and reagents. The most common use of this technology is for whole-blood monitoring in diabetes control. In this case, the strips include glucose oxidase, horseradish peroxidase (EC 1.11.1.7) and a chromogen (e.g. *o*-toluidine or 3,3',5,5'-tetramethylbenzidine). The hydrogen peroxide produced by the aerobic oxidation of glucose oxidises the weakly coloured chromogen to a highly coloured dye.

$$\text{chromogen(2H)} + H_2O_2 \xrightarrow{\text{peroxidase}} \text{dye} + 2H_2O \qquad \textbf{[6.24]}$$

A most promising biosensor involving luminescence uses firefly luciferase to detect the presence of bacteria in food or clinical samples. Bacteria are specifically lysed and the ATP released reacted with D-luciferin and oxygen in a reaction which produces yellow light in high quantum yield.

$$\text{ATP} + \text{D-luciferin} + O_2 \xrightarrow{\text{luciferase}} \text{oxyluciferin} + \text{AMP} + \text{pyrophosphate} + CO_2 + \text{light (562nm)}$$

The light produced may be detected photometrically by use of high-voltage or low-voltage cheap photodiode systems. Firefly luciferase is a very expensive enzyme, only obtainable from the tails of wild fireflies. Use of immobilised luciferase greatly reduces the cost of these analyses.

2. Piezo-electric Biosensors:

In this mode, sensing molecules are attached to a piezoelectric surface in which interactions between the analyte and the sensing molecules set up mechanical vibrations that can be translated into an electrical signal proportional to the amount of the analyte. Example of such a sensor is quartz crystal micro or nano balance. Piezo-electric crystals (quartz) vibrates under the influence of electric field. The frequency of oscillation depends upon thickness and cut of crystal. The change in frequency is proportional to the mass of absorbed material.

A simple use of such a transducer is a formaldehyde biosensor, utilising a formaldehyde dehydrogenase coating immobilised to a quartz crystal and sensitive to gaseous formaldehyde. The major drawback of these devices is the interference from atmospheric humidity and the difficulty in using them for the determination of material in solution. They are inexpensive and capable of giving a rapid response.

3. Calorimetric Biosensors:

Many enzyme catalysed reactions are exothermic, generating heat which may be used as a basis for measuring the rate of reaction and, hence, the analyte concentration. This represents the most generally applicable type of biosensor. The temperature changes are usually determined by means of thermistors at the entrance and exit of small packed bed columns containing immobilised enzymes within a constant temperature environment. Under such closely controlled conditions, up to 80% of the heat generated in the reaction may be registered as a temperature change in the sample stream. This may be simply calculated from the enthalpy change and the amount reacted.

Heat output (molar enthalpies) of enzyme catalysed reactions.

Reactant	**Enzyme**	**Heat output -□H (kJ mole^{-1})**
Cholesterol	Cholesterol oxidase	53
Esters	Chymotrypsin	4 - 16
Glucose	Glucose oxidase	80
Hydrogen peroxide	Catalase	100
Penicillin G	Penicillinase	67
Peptides	Trypsin	10 - 30
Starch	Amylase	8
Sucrose	Invertase	20
Urea	Urease	61
Uric acid	Uricase	49

Chemoreceptors

- A sensory cell or organ which is responsive to chemical stimuli.
- Sensory Receptor (Taste bud receptor)
- Internal peripheral chemoreceptor

Hot and Cold Receptors

- Non specialized sense receptor that codes absolute and relative changes in temperature.
- Peripheral Nervous System have warmth receptors.
- Warmth receptors are unmylinated C- fibre receptors that respond to cold have mylinated C-fibres

Baroreceptors

- These are pressure receptors are sensors located in the blood vessels that sense pressure of blood in blood vessels.
- They sense the blood pressure and relay the information to the brain, so that a proper blood pressure can be maintained.
- Two types:
- Arterial baroreceptors
- Low pressure baroreceptors

Sensors for smell and vision

- Sensors for Smell are also called olfactory receptors which are located in nasal cavity.
- Olfactory receptor sense smell and give signal to brain and then it is possible to detect smell.
- Optical receptors are present in eyes
- Taste receptors are for taste

Osmolarity receptors detect the osmolarity of blood and are found in hypothalamus

Chapter -3

3.Nervous system

3.1Introduction

- Nervous system is the master controlling and communicating system of the body.
- The nervous system controls and coordinates all essential functions of the human body
- It is a system of the body that in vertebrates includes the brain, spinal cord, nerves, and sense organs and receives, interprets, and responds to stimuli from inside and outside the body.

3.2 Parts of nervous system

3.3 The Central Nervous System

- The brain

- the spinal cord

3.3.1 Brain

The brain is found in the cranial cavity. Within it are found the higher nerve centers responsible for coordinating the sensory and motor systems of the body (forebrain). The brain stem houses the lower nerve centers (consisting of midbrain, pons, and medulla).

Medulla
The medulla is the control center for respiratory, cardiovascular and digestive functions

Fig 3.1 Parts of Brain

Pons

The pons houses the control centers for respiration and inhibitory functions. Here it will interact with the cerebellum.

Cerebrum

The cerebrum, or top portion of the brain, is divided by a deep crevice, called the longitudinal sulcus. The longitudinal sulcus separates the cerebrum in to the right and left hemispheres. In the hemispheres you will find the cerebral cortex, basal ganglia and the limbic system. The two hemispheres are connected by a bundle of nerve fibers called the corpus callosum. The right hemisphere is responsible for the left side of the body while the opposite is true of the left hemisphere. Each of the two hemispheres are divided into four separated lobes: the frontal in control of
specialized motor control, learning, planning and speech; parietal in control of somatic sensory functions; occipital in control of vision; and temporal lobes which consists of hearing centers and some speech.

Cerebellum
The cerebellum is the part of the brain that is located posterior to the medulla oblongata and pons. It coordinates skeletal muscles to produce smooth, graceful motions. The cerebellum receives information from our eyes, ears, muscles, and joints about what position our body is currently in (proprioception). It also receives output from the cerebral cortex about where these parts should be. After processing this information, the cerebellum sends motor impulses from the brainstem to the skeletal muscles. The main function of the cerebellum is

coordination. The cerebellum is also responsible for balance and posture. It also assists us when we are learning a new motor skill, such as playing a sport or musical instrument. Recent research shows that apart from motor functions cerebellum also has some emotional role.

3.4What is peripheral nervous system?

The peripheral nervous system consists of sensory receptors, nerves that branch out from the CNS and connect to other parts of the body, their associated ganglia, and motor endings.

Primary role:

to connect the CNS to the organs, limbs and skin. These nerves extend from the central nervous system to the outermost areas of the body.

3.4.1Somatic nervous system

The part of the peripheral nervous system responsible for carrying sensory and motor information to and from the central nervous system.

Responsible for transmitting sensory information as well as for voluntary movement contains two major types of neurons:

Sensory neurons (or afferent neurons) - carry information from the nerves to the central nervous system

Motor neurons (or efferent neurons) that carry information from the brain and spinal cord to muscle fibers throughout the body.

The sensory-somatic system consists of:

12 pairs of cranial nerves

31 pairs of spinal nerves.

Nerves	Type	Function
I **Olfactory**	sensory	olfaction (smell)
II **Optic**	sensory	vision (Contain 38% of all the axons connecting to the brain.)
III **Oculomotor**	motor*	eyelid and eyeball muscles

IV Trochlear	motor*	eyeball muscles
V Trigeminal	mixed	Sensory: facial and mouth sensation Motor: chewing
VI Abducens	motor*	eyeball movement
VII Facial	mixed	Sensory: taste Motor: facial muscles and salivary glands
VIII Auditory	sensory	hearing and balance
IX Glossopharyngeal	mixed	Sensory: taste Motor: swallowing
X Vagus	mixed	main nerve of the parasympathetic nervous system (PNS)
XI Accessory	motor	swallowing; moving head and shoulder
XII Hypoglossal	motor*	tongue muscles

What is autonomic nervous system?

is the part of the peripheral nervous system responsible for regulating involuntary body functions, such as blood flow, heartbeat, digestion and breathing.

further divided into two branches

sympathetic system regulates the flight-or-fight responses

parasympathetic system helps maintain normal body functions and conserves physical resources.

3.4 Reflex Arc

A reflex is a very rapid motor response that is not directed by the brain. In a reflex, nerve impulses travel to and from the spinal cord in a reflex arc. In this example, the person jerks his hand away from the flame without any conscious thought. It happens unconsciously because the nerve impulses by pass the brain. The somatic nervous system (SNS) controls mainly voluntary activities that are under conscious control. It is made up of nerves that are connected to skeletal muscles. Whenever you perform a conscious movement, from signing your name to riding your bike, your somatic nervous system is responsible. The somatic nervous system also controls some unconscious movements, called reflexes.

3.4.1 TYPES OF REFLEXES

UNCONDITIONAL REFLEXES: are inborn reflexes and are transmitted through heredity. They are also called inborn or inherited reflexes

e. g: swallowing in newly born babies and blinking of eyes

CONDITIONAL REFLEXES: These are acquired reflexes during the life time of an individual. They are absolutely an individual entity and are, therefore, not constant, *viz.*, they may disappear and reappear again.

Ian Pavlov , a Russian physiologist discovered for the first time the existence of conditional reflexes and therefore, he is called as **Father of conditional reflexes**

Characteristics of conditioned reflexes

1. They are acquired in life.
2. They depend on previous experience.
3. They are not transmitted by heredity
4. Cortical and subcortical centres are responsible for them.

Experiment conducted by Pavlov

- Pavlov (1902) started from the idea that there are some things that a dog does not need to learn. For example, dogs don't learn to salivate whenever they see food. This reflex is 'hard wired' into the dog. In behaviorist terms, it is an unconditioned response (i.e. a stimulus-response connection that required no learning). **Unconditioned Stimulus** (Food) > **Unconditioned Response** (Salivate) Pavlov showed the existence of the conditioned response by presenting a dog with a bowl of food and ringing a bell (conditioned stimulus) before presenting the food. then measuring its salivary secretions (conditioned response)

3.5 Nerve Impulse Conduction

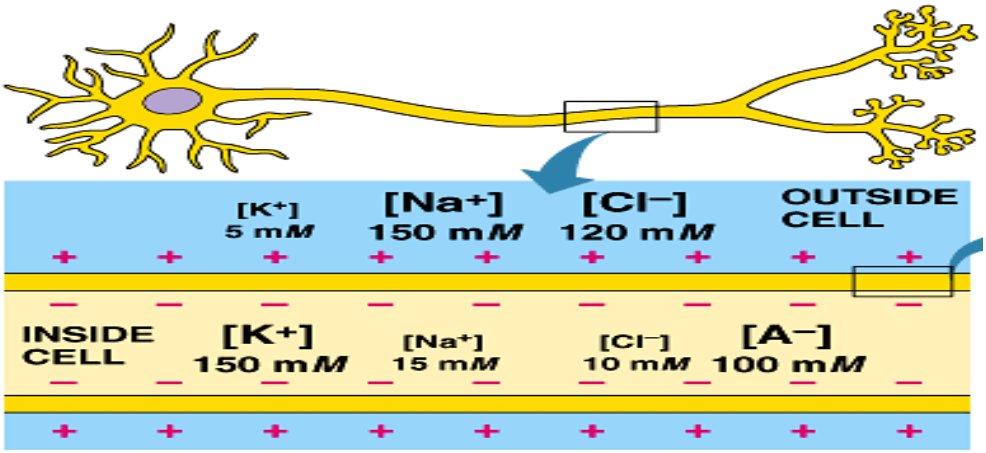
Overview: Neurons are excitable cells. Excitable cell means electrically active cells. Nerve cells (neurons) are specialized so that at one end there is a flared structure termed the dendrite. At the dendrite, the neuron is able to process chemical signals from other neurons and endocrine hormones. If the signals received at the dendrite end of the neuron are of a sufficient strength, and properly timed, they are transformed into action potentials that sweep down the neural cell body (axon) from the dendrite end to the other end of the neuron, the presynaptic portion of the axon that ends at the next synapse (the extra cellular gap between neurons)in the neural pathway.

The arrival of the action potential at the presynaptic terminus causes the release of ions and chemicals (neurotransmitters) that travel across the synapse, the gap or intercellular space between neurons, to act as the stimulus to create another action potential in the next neuron, and thus perpetuate the neural impulse.

Nerve impulses are transmitted through the synaptic gap via chemical signals in the form of a specialized group of chemicals termed neurotransmitters. Neurotransmitters can also pass the

neural impulse on to glands and muscles. Except where the neural synapses terminates on a muscle (neuromuscular synapse) or a gland (neuroglandular synapse), the synaptic gap is bordered by a presynaptic terminal portion of one neuron and the dendrite of the postsynaptic neuron. As the action potential sweeps into presynaptic region, there is a rapid influx of calcium from the extra cellular fluid into a specialized area of the presynaptic terminus termed the synaptic knob. Via the process of exocytosis, specific neurotransmitters are then released from synaptic vesicles into the synaptic gap. The neurotransmitters diffuse across the synaptic gap and specifically bind to specialized receptor sites on the dendrite of the postsynaptic neuron.

Inside the cell: more negatively charged



Nerve Impulse : Nerve impulse is the sum total of physical and chemical disturbances created by a stimulus (electrical, chemical or mechanical) in a neuron or nerve fibre which result in the movement of a wave along the nerve fibre.

The nerve fibre or axon is like a cylinder, the interior of which is filled with axoplasm (i.e., the cytoplasm of the nerve cell) and the exterior of which is covered with a thin membrane, the axon membrane or axolemma.

Nerve Impulse Transmission: As electrical impulses travel through neurons, there is a series of membrane potential shifts. These shifts are due to the movement of Na+ & K+ ions (charged molecules) across the membrane.
If a stimulus (e.g. pressure, sound, etc.) is strong enough, a nerve impulse is initiated => **action potential. Action potential**: when the membrane potential rapidly rises and falls - this acts as the signal/message to be repeated & sent along the neuron's axon.

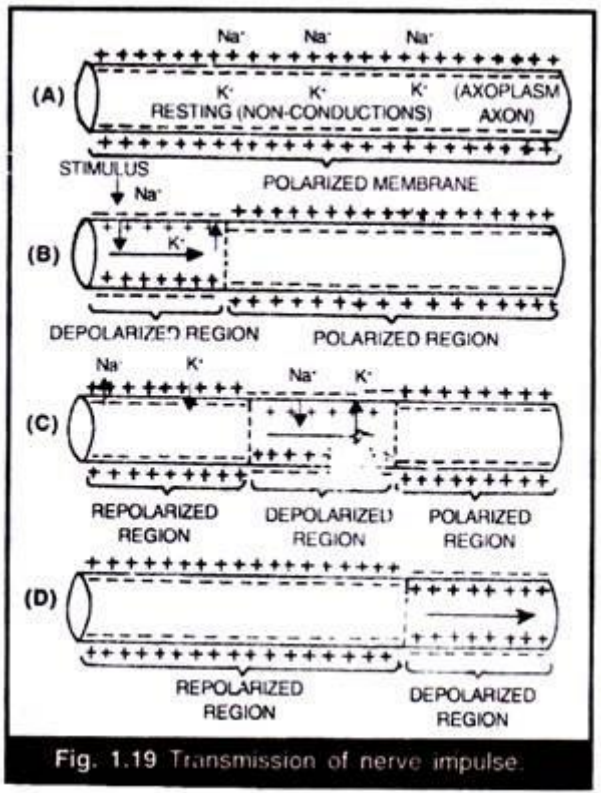


Fig. 1.19 Transmission of nerve impulse

The axon is immersed in the extracellular fluid (ECF). Through axolemma movement of solute takes place between the axoplasm and ECF. Generally the solutes in ECF and axoplasm are in ionic form. In the axoplasm -vely charged protein molecules are present which are neutralized due to the presence of large amount of K+ ions. In the ECF (outside the axon) the -vely charged CI– ions are neutralized by the presence of +vely charged Na+ ions.

Conduction of nerve impulse is an electro-chemical process. Membrane of a non-conducting nerve cell or neuron is positive on the outside and negative inside. The difference in charge is about 70 to 90 millivolts which is called as resting potential and the membrane is said to be polarized. To maintain resting potential, sodium potassium metabolic pump operates.

Resting Potential: The sodium & potassium voltage-gated channels in the membrane are **closed**. **Hence, membrane is not permeable to these ions - cannot move in or out of the neuron**. This pump which is located on the axon membrane pump Na+ from axoplasm to ECF and K+ from ECF to axoplasm. It pumps more positive charges (3 Na+) from axoplasm to ECF than in the reverse direction (2K+), and is run by an enzyme called Sodium Potassium-ATPase. The concentration of sodium ions will be about 14 times more in ECF (outside) and concentration of potassium ions will be about 28-30 times more in axoplasm (inside). Inside the cell become more negative and **Resting membrane potential is -70mV**. A stimulus triggers the opening of some sodium voltage-gated channels and Na+ flow into the neuron Inside the cell: becomes less negative. If the membrane potential reaches **-55mV** => threshold has been reached and an action potential is initiated.

Threshold: When a stimulus (may be mechanical, electrical or chemical) is applied to the membrane of the nerve fibre, its permeability changes and sodium potassium pump stop operating. Once a stimulus surpasses the threshold, an action potential is triggered.

Depolarization : When a stimulus reaches a resting neuron, the gated ion channels on the resting neuron's membrane open suddenly and allow the Na+ that was on the outside of the membrane to go rushing into the cell. As this happens, the neuron goes from being polarized to being depolarized.

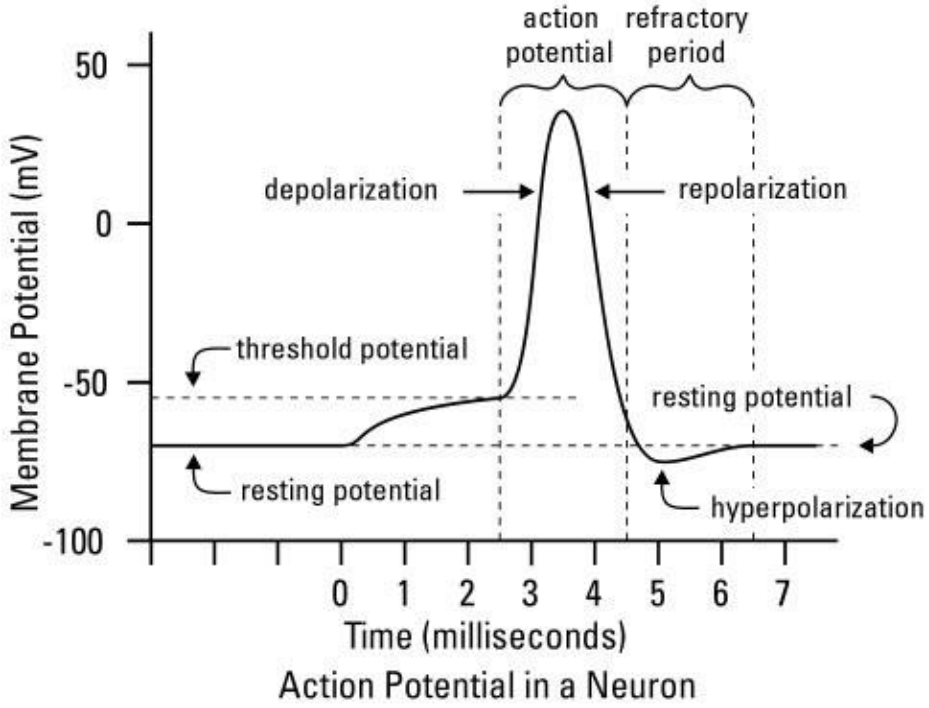
Each neuron has a threshold level — the point at which there's no holding back. After the stimulus goes above the threshold level, more gated ion channels open and allow more Na+ inside the cell. This causes complete depolarization of the neuron and an action potential is created. In this state, the neuron continues to open Na+ channels all along the membrane. When this occurs, it's an all-or-none phenomenon. "All-or-none" means that if a stimulus doesn't exceed the threshold level and cause all the gates to open, no action potential results; however, after the threshold is crossed, there's no turning back: Complete depolarization occurs and the stimulus will be transmitted.

When an impulse travels down an axon covered by a myelin sheath, the impulse must move between the uninsulated gaps called nodes of Ranvier that exist between each Schwann cell.

Repolarization: After the inside of the cell becomes flooded with Na+, the gated ion channels on the inside of the membrane open to allow the K+ to move to the outside of the membrane. With K+ moving to the outside, the membrane's repolarization restores electrical balance, although it's opposite of the initial polarized membrane that had Na+ on the outside and K+ on the inside. Just after the K+ gates open, the Na+ gates close; otherwise, the membrane couldn't repolarize.

Hyperpolarization.When the K+ gates finally close, the neuron has slightly more K+ on the outside than it has Na+ on the inside. This causes the membrane potential to drop slightly lower than the resting potential, and the membrane is said to be hyperpolarized because it has a greater potential. (Because the membrane's potential is lower, it has more room to "grow."). This period doesn't last long, though (well, none of these steps take long!). After the impulse has traveled through the neuron, the action potential is over, and the cell membrane returns to normal (that is, the resting potential).

Refractory period: Potassium returns inside, sodium returns outside.The refractory period is when the Na+ and K+ are returned to their original sides: Na+ on the outside and K+ on the inside. While the neuron is busy returning everything to normal, it doesn't respond to any incoming stimuli. It's kind of like letting your answering machine pick up the phone call that makes your phone ring just as you walk in the door with your hands full. After the Na+/K+ pumps return the ions to their rightful side of the neuron's cell membrane, the neuron is back to its normal polarized state and stays in the resting potential until another impulse comes along.The following figure shows transmission of an impulse.



Action Potential in a Neuron

Synapse: Like the gaps between the Schwann cells on an insulated axon, a gap called a *synapse* or *synaptic cleft* separates the axon of one neuron and the dendrites of the next neuron. Neurons don't touch. The signal must traverse the synapse to continue on its path through the nervous system. Electrical conduction carries an impulse across synapses in the brain, but in other parts of the body, impulses are carried across synapses as the following chemical changes occur:

- **Calcium gates open.** At the end of the axon from which the impulse is coming, the membrane depolarizes, gated ion channels open, and calcium ions (Ca^{2+}) are allowed to enter the cell.
- **Releasing a neurotransmitter.** When the calcium ions rush in, a chemical called a neurotransmitter is released into the synapse.
- **The neurotransmitter binds with receptors on the neuron.** The chemical that serves as the neurotransmitter moves across the synapse and binds to proteins on the neuron membrane that's about to receive the impulse. The proteins serve as the receptors, and different proteins serve as receptors for different neurotransmitters — that is, neurotransmitters have specific receptors.
- **Excitation or inhibition of the membrane occurs.** Whether excitation or inhibition occurs depends on what chemical served as the neurotransmitter and the result that it had. For example, if the neurotransmitter causes the Na^{+} channels to open, the neuron membrane becomes depolarized, and the impulse is carried through that neuron. If the K^{+} channels open, the neuron membrane becomes hyperpolarized, and inhibition occurs. The impulse is stopped dead if an action potential cannot be generated. If you're wondering what happens to the neurotransmitter after it binds to the receptor, you're really getting good at this anatomy and physiology stuff. Here's the story: After the neurotransmitter produces its effect, whether it's excitation or inhibition, the receptor releases it and the neurotransmitter goes back into the synapse. In the synapse, the cell "recycles" the degraded neurotransmitter. The chemicals go back into the membrane so that during the next impulse, when the synaptic vesicles

bind to the membrane, the complete neurotransmitter can again be released.

3.5 Urinary system

- The **urinary system**, also known as the **renal system** or **urinary tract**, consists of the kidneys, ureters, bladder, and the urethra. The purpose of the urinary system is to eliminate waste from the body, regulate blood volume and blood pressure, control levels of electrolytes and metabolites, and regulate blood pH. The urinary tract is the body's drainage system for the eventual removal of urine. The kidneys have an extensive blood supply via the renal arteries which leave the kidneys via the renal vein. Each kidney consists of functional units called nephrons. Following filtration of blood and further processing, wastes exit the kidney via the ureters, tubes made of smooth muscle fibres that propel urine towards the urinary bladder, where it is stored and subsequently expelled from the body by urination. The female and male urinary system are very similar, differing only in the length of the urethra.
- Urine is formed in the kidneys through a filtration of blood. The urine is then passed through the ureters to the bladder, where it is stored. During urination, the urine is passed from the bladder through the urethra to the outside of the body.
- 800–2,000 milliliters (mL) of urine are normally produced every day in a healthy human. This amount varies according to fluid intake and kidney function.

3.6 Digestive system

The **human digestive system** consists of the gastrointestinal tract plus the accessory organs of digestion . Digestion involves the breakdown of food into smaller and smaller components, until they can be absorbed and assimilated into the body. The process of digestion has many stages. The first stage is the cephalic phase of digestion which begins with gastric secretions in response to the sight and smell of food. The next stage starts in the mouth.

Chewing, in which food is mixed with saliva begins the mechanical process of digestion. This produces a bolus which can be swallowed down the esophagus to enter the stomach. Here it is mixed with gastric acid until it passes into the duodenum where it is mixed with a number of enzymes produced by the pancreas. Saliva also contains a catalytic enzyme called amylase which starts to act on food in the mouth. Another digestive enzyme called lingual lipase is secreted by some of the lingual papillae on the tongue and also from serous glands in the main salivary glands. Digestion is helped by the chewing of food carried out by the muscles of mastication, by the teeth, and also by the contractions of peristalsis, and segmentation. Gastric acid, and the production of mucus in the stomach, are essential for the continuation of digestion.

Peristalsis is the rhythmic contraction of muscles that begins in the esophagus and continues along the wall of the stomach and the rest of the gastrointestinal tract. This initially results in the production of chyme which when fully broken down in the small intestine is absorbed as chyle into the lymphatic system. Most of the digestion of food takes place in the small intestine. Water and some minerals are reabsorbed back into the blood in the colon of the large intestine. The waste products of digestion (feces) are defecated from the anus via the rectum.

3.7 Eye

Eyes are organs of the visual system. They provide organisms with vision, the ability to receive and process visual detail, as well as enabling several photo response functions that are independent of vision. Eyes detect light and convert it into electro-chemical impulses in neurons. In higher organisms, the eye is a complex optical system which collects light from the surrounding environment, regulates its intensity through a diaphragm, focuses it through an adjustable assembly of lenses to form an image, converts this image into a set of electrical signals, and transmits these signals to the brain through complex neural pathways that connect the eye via the optic nerve to the visual cortex and other areas of the brain

3.8 Ear

The **ear** is the organ of hearing and, in mammals, balance. In mammals, the ear is usually described as having three parts—the outer ear, middle ear and the inner ear. The outer ear consists of the pinna and the ear canal. Since the outer ear is the only visible portion of the ear in most animals, the word "ear" often refers to the external part alone. The middle ear includes the tympanic cavity and the three ossicles. The inner ear sits in the bony labyrinth, and contains structures which are key to several senses: the semicircular canals, which enable balance and eye tracking when moving; the utricle and saccule, which enable balance when stationary; and the cochlea, which enables hearing. The ears of vertebrates are placed somewhat symmetrically on either side of the head, an arrangement that aids sound localisation.

The ear develops from the first pharyngeal pouch and six small swellings that develop in the early embryo called otic placodes, which are derived from ectoderm.

The ear may be affected by disease, including infection and traumatic damage. Diseases of the ear may lead to hearing loss, tinnitus and balance disorders such as vertigo, although many of these conditions may also be affected by damage to the brain or neural pathways leading from the ear.

The ear has been adorned by earrings and other jewelry in numerous cultures for thousands of years, and has been subjected to surgical and cosmetic alterations.

The human ear consists of three parts—the outer ear, middle ear and inner ear.[2] The ear canal of the outer ear is separated from the air-filled tympanic cavity of the middle ear by the eardrum. The middle ear contains the three small bones—the ossicles—involved in the transmission of sound, and is connected to the throat at the nasopharynx, via the pharyngeal opening of the Eustachian tube. The inner ear contains the otolith organs—the utricle and saccule—and the semicircular canals belonging to the vestibular system, as well as the cochlea of the auditory system.