CONTENTS

1. Life Processes

CONCEPT MAP

LIFE PROCESS : Life processes are important to carryout day to day life activities as it help to produce energy and maintain homeostatis in the body.

- **NUTRITION:** It is a process of intake and utilization of nutrients by an organism
  - **Autotropic:** They synthesis their own food.
    - **Photo autotrophic:** Get energy from light *e.g.,* green plants
    - **Chemoautotrophic:** Get energy from chemical reaction e.g., some bacteria
  - **Heterotropic:** They depend on other organisms for food.
    - **Saprophytic:** Get nutrients from decaying matter *e.g.*, mushroom
    - **Parasitic:** Get nutrients from a living host *e.g.*, tape worm
    - **Holozoic:** Get complex organic food into body and then digests, absorbs and assimilates it *e.g.*, man
- **RESPIRATION:** It is an oxidative process involving the consumption of oxygen and liberation of CO_2 and H_2O
  - **Aerobic:** It occurs in the presence of O_2.
  - **Anaerobic:** It occurs in the absence of O_2.
- **TRANSPIRATION:** Loss of water from aerial parts of the plant. It is of four kinds: stomatal, cuticular, Lenticular, bark
- **TRANSLOCATION:** It is a transport of sucrose, hormones and minerals from the site of synthesis to utilization site in plants
- **EXCRETION:** It is removal of toxic material from the body e.g., CO_2 & NH_3
  - **Excretory waste:** It includes-respiratory wastes (CO_2), nitrogenous wastes (NH_3), Bile pigments.
  - **Excretory organ:** Kidneys (remove urea, uric acid), Lungs (remove CO_2) Liver (urea) & skin (salt urea).
- **TRANSPORTATION:** It includes the circulation of nutrients and O_2 through blood.
  - **Blood:** Consists of RBC, WBC, Platlets and plasma.
  - **Blood Vessels:** It includes– arteries (oxygenated blood) veins (deoxygenated blood) and capillaries.
  - ★ The Transporation of O_2 from lungs to tissues through blood is called **transport of gases**.

★ *Belongs to connecting topic.*

WHAT ARE THE LIFE PROCESSES ?

All living organisms perform some basic functions or processes in order to remain alive. These processes are – nutrition, respiration, transportation, excretion, sensitivity, movement, reproduction and growth. These processes which keep the living organisms alive and perform the functions of body maintenance are called **life processes**.
These maintenance functions occur whether the living organism is in motion or in rest. In all living organisms, energy is needed to prevent damage or break down.

NUTRITION

Every organism requires energy for life processes. This energy is released from the food that organism eats. **Nutrition is the process of intake and utilisation of nutrients/ food, by an organism for harvesting energy, building body substances for growth and development, etc.** The substance that is needed to keep them living is called **nutrient**.

Did You Know?

Nutrients are organic and inorganic substances which the organism obtains from its surroundings and uses it as a source of energy or for biosynthesis of its body constituents. These can be classified into two:

(i) Organic nutrients - These contain carbon in their structure e.g., carbohydrates, proteins, fats

(ii) Inorganic nutrients - These donot contain carbon in their structure except carbon dioxide, e.g., water, minerals (iron, copper, zinc, etc.)

Green plants get their nutrients from soil (water and minerals) and atmosphere (carbon dioxide). We get our organic food from plants in the form of fruits, vegetables, cereals, etc. and from animals in the form of milk, meat, egg, etc.

Various organisms live in different environmental conditions and they have different methods of obtaining nutrients from the environment. The method of obtaining food by the organism is called **mode of nutrition**. Depending on the mode of nutrition, it is of two types – **Autotrophic** and **Heterotrophic**.

Types of Nutrition

Autotrophic Nutrition

In Greek, *auto* means *self* and *troph* means nourishment or feeding hence, autotrophic nutrition is a mode of nutrition in which organisms prepare their own food from simple inorganic raw materials present in their surroundings.

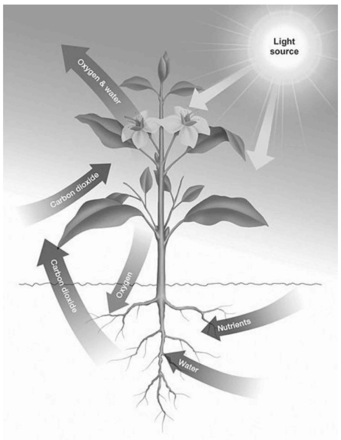

Fig. Autotrophic nutrition in green plants

Organisms which can make their own organic food from inorganic raw materials (carbon dioxide and water) and remain independent of obtaining external source of organic compound are called **autotrophs**. All green plants are autotrophs. Certain bacteria such as cyanobacteria or bluegreen algae are also autotrophs.

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Types of autotrophic nutrition

Autotrophic nutrition is of two types –

(a) Photoautotrophic nutrition :
In this autotrophic nutrition, the solar energy, trapped from sun rays with the help of chlorophyll, is used for the synthesis of nutrients. Here, inorganic substances (carbon dioxide and water) are converted into the organic molecules (glucose) using sunlight as a source of energy. This is exhibited by all chlorophyll-bearing organisms e.g. **green plants.**

(b) Chemoautotrophic nutrition : In this autotrophic nutrition, the energy required for the synthesis of nutrients is obtained from oxidation of inorganic chemicals such as hydrogen gas, ammonia, methane, CO, hydrogen sulphide (H_2S), nitrites, etc. rather than sunlight. Certain bacteria, like the sulphur bacteria (oxidises H_2S, and other S compounds), nitrifying bacteria (e.g. Nitrosomonas, Nitrobacter which oxidises NH_4 or NO_2), hydrogen bacteria (oxidises H_2), methane bacteria (oxidises CH_4), carbon monoxide bacteria (oxidises CO) are chemoautotrophs.
Certain types of bacteria in deep sea hydrothermal vents where there is no sunlight are also chemoautotrophic. These bacteria support the entire food web at such great ocean depths through chemosynthesis, as photosynthesis cannot occur due to the lack of sunlight.

Heterotrophic Nutrition

In Greek, *hetero* means other and *troph* means nourishment or feeding hence, heterotrophic nutrition is a mode of nutrition in which organism cannot synthesise its own food and depends on energy obtained from the intake and digestion of organic substances prepared by autotrophs and other organic sources.
Those organisms which cannot make their food from inorganic substances like carbon dioxide and water, and depend on other organisms for their food are called **heterotrophs**. e.g. animals, fungi, some protists, non-green plants, etc. Based on the method of obtaining food, heterotrophic nutrition is of three types:

(a) Saprophytic nutrition
The term *sapro* means rotten and *phyte* means to eat hence saprophytic nutrition is a mode of heterotrophic nutrition in which organism derives nutrients from dead and decaying organic matter (rotten bread, rotten leaves, dead animals, etc).

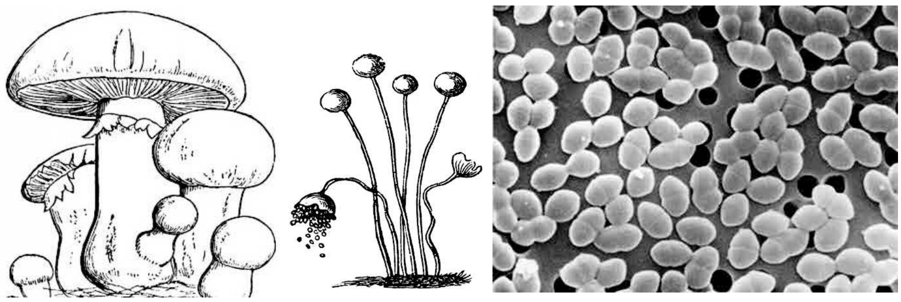


Fig. Saprophytes

Organisms having saprophytic mode of nutrition are called saprophytes, e.g., fungi (yeast, Mucor, mushroom) and bacteria. These organisms do not ingest solid food. They secrete digestive enzymes outside their body. These enzymes break down the complex organic molecules present in the decaying matter and convert it into simpler substances. These simpler substances are then absorbed by saprophytes through their body surface.

(b) Parasitic nutrition
The term *para* means other hence, parasitic nutrition is a mode of heterotrophic nutrition in which an organism (parasite) lives inside or outside the body of another living organism (host) and obtains nutrition from it without killing it.
A ***parasite*** is an organism which derives its food from the body of another living organism called its ***host***. The host is not benefitted by the parasite, instead it is harmed. A host can be plant or an animal. Most diseases which affect man, crops and domestic animals are caused by parasites, e.g., *Plasmodium* (causes malaria in man), *Ascaris* (roundworm), ticks, leeches, tapeworm, and lice. Plants like *Cuscuta* (Amarbel) are also parasites.

(a) (b)

Fig. : Parasites: (a) Cuscuta (b) Tapeworm in small intestine

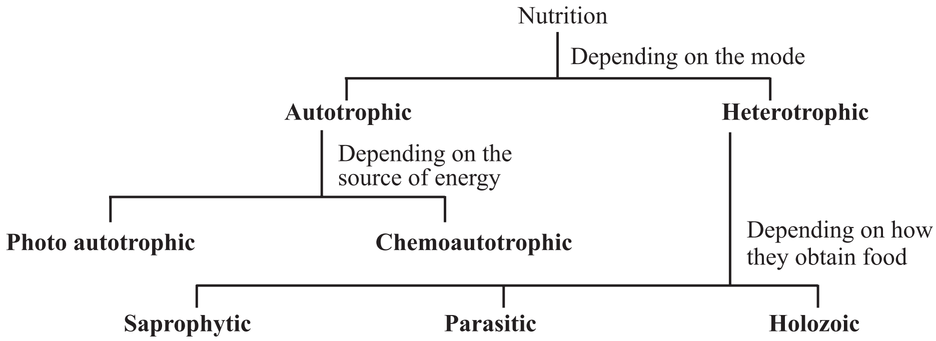
(c) Holozoic nutrition

Holozoic is derived from two Greek words, *holo* meaning whole and *zoic* meaning animal. This literally means feeding like an animal. Holozoic nutrition is a mode of heterotrophic nutrition in which an organism takes the complex organic food material into its body by the process of ingestion, and then digests the ingested food followed by absorption and assimilation of digested food. Holozoic organisms can be divided into following three types:

- **Herbivores** ingest autotrophs (producers) and their products. Examples are cattle and sheep – which are also known as ruminants.
- **Carnivores** eat other heterotrophs. Examples are cats and dogs.
- **Omnivores** eat both autotrophs and other heterotrophs. Example: human.

Table : Differences between Autotrophs and Heterotrophs

S. No.	Autotrophs	Heterotrophs
1.	They synthesise their own food materials.	They depend on other organisms (both autotrophs and heterotrophs) for their food.
2.	They use carbon dioxide as source of carbon for growth and development.	They use organic substrates to get their carbon for growth and development.
3.	They convert inorganic carbon dioxide and water into organic sugar–glucose.	They require nutrients already produced in organic form.
4.	They are producers in the food web and are placed at primary level.	They are the consumers in the food web and occupy secondary or tertiary levels.
5.	Motility is not required due to autotrophic mode of nutrition.	They move from one place to another. Main reason for motility is to obtain food.
6.	Example - all green plants and some bacteria	Examples - animals fungi, protists some bacteria and non-green plants.



Flow chart: Types of nutrition

Nutrition in Green Plants

Green plants are autotrophic i.e., they synthesise their own organic food from inorganic raw materials through the process of **photosynthesis**.

The word Photosynthesis can be separated into two words, **"*photo*"** means light and "***synthesis***" means to put together. Hence, ***photosynthesis*** can be defined as the process of synthesis of organic food from inorganic raw materials using light energy by the green plants. The process of photosynthesis takes place in the presence of green pigment **chlorophyll**. When water enters the guard cells, they swell causing the stomatal pore to open. Similarly, when water exits the guard cells, they shrink leading to the closing of pore. The reaction can be represented by the equation:

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{12H_2O} \xrightarrow[\text{Chlorophyll}]{\text{Light}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Water}}{6H_2O} + \underset{\text{Oxygen}}{6O_2}$$

Photosynthesis is the most important process in nature as it provides food for the biological world and purifies the atmosphere by consuming carbon dioxide and releasing oxygen.

Site of Photosynthesis

Photosynthesis primarily takes place in leaves. The section of the leaf under microscope shows many layers of cells. The layers of cells forming upper and lower surfaces of leaf are called upper and lower epidermis. Between the upper and the lower epidermis of the leaf, a tissue called the **mesophyll** is present. Mesophyll has two types of cells - the palisade parenchyma and the spongy parenchyma. The palisade parenchyma is made up of elongated cells, which are arranged vertically and parallel to each other. This layer is present below the upper epidermis. The spongy parenchyma is made up of oval or round cells which are loosely arranged below the palisade cells and extend to the lower epidermis. There are numerous large spaces and air cavities between these cells. Mesophyll cells possess chlorophyll containing cell organelles called chloroplasts. The actual site of photosynthesis in the leaf is the green coloured plastids or **chloroplast**. Chloroplasts are the cell organelles in green plants and contain chlorophyll, a green pigment.

Structure of Chloroplast

The chloroplast or the green plastids are disc-shaped organelles present in the cytoplasm of the mesophyll cells. A cell may contain 100 or more chloroplasts in it, and a leaf may contain thousands. Each chloroplast is a double membrane bound structure. The outer membrane is freely permeable whereas inner membrane is relatively less permeable. The space between two membranes is called intermembrane space. The inner membrane of the chloroplast encloses a space which is filled with a colourless matrix called **stroma**. It contains enzymes required for the synthesis of carbohydrates and proteins. It also contains small, double-stranded DNA molecules and ribosomes (70s) which are **smaller** than the cytoplasmic ribosomes (80s). Embedded in the stroma, is a system of lamellae or flattened disc-shaped structures called **smaller** that are arranged in stacks in certain regions known as **grana**. The grana are interconnected by a system of loosely arranged lamellae called the **stroma lamellae.** Chlorophyll molecules are located on the membrane of the thylakoid in such a way that they can trap maximum amount of light.

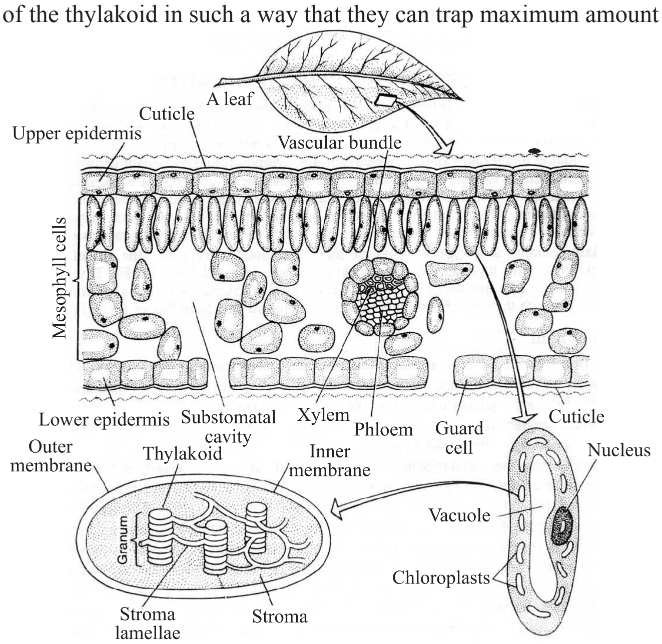


Fig.: Cross section of leaf showing mesophyll cells and location of chloroplast

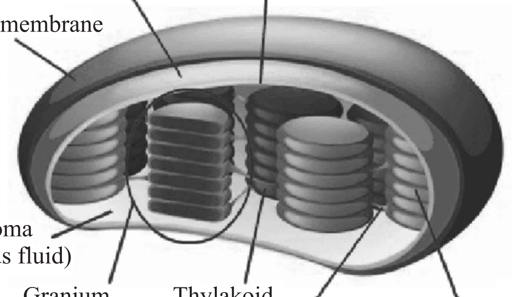


Fig. : Structure of chloroplast

Mechanism of Photosynthesis

Photosynthesis as a whole is nothing but an 'oxidation-reduction process' in which H_2O is oxidised and CO_2 is reduced to carbohydrates. The reduction of CO_2 to carbohydrate level needs ATP and $NADPH_2$ (reduced form of NADP-Nicotinamide adenine di nucleotide phosphate). Solar energy is trapped by chlorophyll, and is stored in the form of chemical energy (ATP-Adenosine triphosphate) and as reducing power $NADPH_2$. Reducing power of $NADPH_2$ and energy of ATP are utilised in conversion of CO_2 to carbohydrates (starch or sucrose). The production of ATP and $NADPH_2$ (also called assimilatory power) is a light dependent process while reduction of CO_2 to carbohydrate is light independent process.

The overall mechanism of photosynthesis occurs in two phases :

(1) Light reaction or Hill reaction or Light dependent phase : It occurs in the thylakoids or grana of chloroplasts. The chlorophyll molecules present in the thylakoid membranes absorb light energy and convert it into chemical energy with the hydrolysis of water. From hydrolysis of water, oxygen and hydrogen are produced. Light reaction leads to the production of three major substances i.e. oxygen, ATP, and $NADPH_2$.

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Steps in light reaction

Light reactions include light absorption, water splitting, oxygen release, and the formation of high-energy chemical intermediates, ATP and NADPH. These steps are discussed in detail below.

Light absorption: Photosynthetic pigments are bound to proteins forming pigment-protein complexes called photosystems or pigment systems. There are two photosystems - photosystem I (PS I) and photosystem II (PS II). This process requires light to be absorbed twice, once in each photosystem.

Light absorption in PS-I and NADPH foundation: When light energy is absorbed by chlorophyll of pigment system I (PSI), an electron gets excited.

$$\text{Chlorophyll} + \text{Light energy} \rightarrow \text{Chlorophyll} + e^-$$

This electron is accepted by an electron acceptor, which is ultimately involved in reduction of NADP to $NADPH_2$.

$$2NADP + H^+ + 4e^- \longrightarrow 2NADPH_2$$

Light absorption in PS-II and ATP synthesis: Simultaneously chlorophyll molecule of pigment system II, receives light and an electron gets excited. This electron goes to chlorophyll of pigment system I via a series of transporters. On the course of transfer of electron from PS-II to PS-I, some energy is lost. Some of the released energy is used to pump H+ ions from the stroma into the thylakoid lumen. When H+ ions flow down into the stroma, ADP gets converted to ATP (energy rich compound).

$$ADP + Pi\ (phosphate) \rightarrow ATP$$

Splitting of water: Now question arises that how chlorophyll of pigment system II compensates the electron deficiency. Compensation is done by photolysis (splitting through light) of water.

$$2H_2O \xrightarrow{\text{Light}} 4H^+ + 4e^- + O_2$$

$$4OH^- \longrightarrow 2H_2O + O_2 + 4e^- \quad \text{(electron goes to chlorophyll of pigment system II)}$$

After photolysis, two electrons, two hydrogen atoms, and one oxygen atom are produced. O_2 is released into atmosphere as a byproduct. Electron goes to compensate the chlorophyll of pigment system II. Hydrogen ion (H+) builds up inside the lumen of thylakoid. These ions also move from lumen to stroma leading to the synthesis of ATP from ADP and inorganic phosphate.

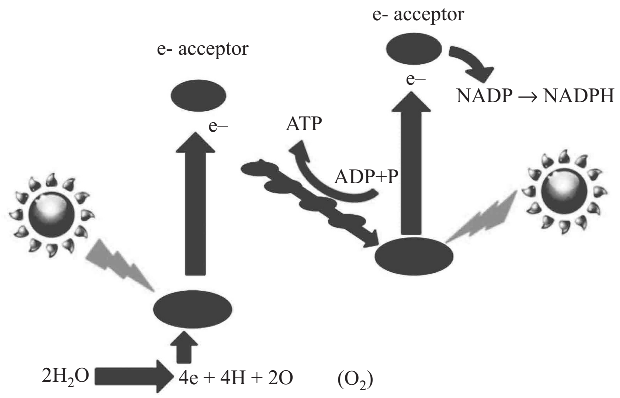


Fig.: Overall light reaction of photosynthesis

(2) Dark reaction : Dark reaction occurs in the **stroma** part of chloroplast. It involves a series of biochemical reactions occurring one after the other in a cyclic manner. It utilizes the assimilatory power of light reaction (i.e., ATP and $NADPH_2$) and convert carbon dioxide into carbohydrate. This process does not directly depend on the presence of light but is dependent on the products of the light reaction, i.e., ATP and NADPH. This is called dark reaction or light independent reactions.

The whole reaction can be studied in three stages:

(i) Acceptance of CO_2 by CO_2 acceptor (RuBP-Ribulose bisphosphate): During this stage, 6 molecules of CO_2 combine with 6 molecules of RuBP to make 12 molecules of a six-carbon compound that splits into 12 molecules of 3 carbon compound.

(ii) Utilisation of ATP and $NADPH_2$: In this stage, 18 molecules of ATP and 12 molecules of $NADPH_2$ are utilised and one molecule of glucose (6 carbon) is formed through a series of reactions from same molecules of 3 carbon compound.

(iii) Regeneration of RuBP (5 Carbon compound): In this stage, CO_2 acceptor RuBP is regenerated from left over molecules of 3 carbon compound using ATP. Regenerated RuBP accepts CO_2 and re-enters the new cycle. Final reaction is as follow :

$$6CO_2 + 12\,NADPH_2 + 18ATP \longrightarrow C_6H_{12}O_6 + 12NADP + 18ADP + 18Pi + 6H_2O$$

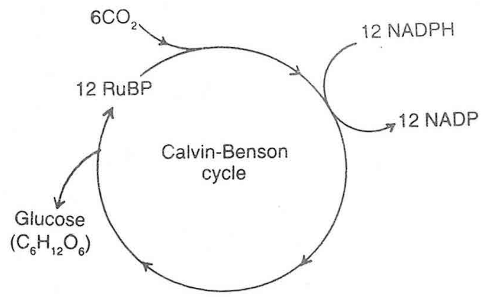


Fig. Calvin-Benson Cycle

At the end of the cycle, carbohydrate is synthesised and ribulose bisphosphate is regenerated. Melvin Calvin and Andy Benson discovered this cycle. Hence this cycle is known as **Calvin-Benson Cycle**.

Thus, combining the processes of light and dark reactions, the complete process of photosynthesis results in the formation of one molecule of glucose, 6 molecules of O_2 and gives back 6 molecules of H_2O.

The sugar synthesised during photosynthesis in green parts of the plants is transported to other plant parts through phloem. This sugar is utilised to get energy. The unutilised sugar is stored in the form of starch, which serves as the internal energy reserve to be used as and when required by the plant.

Requirements for Photosynthesis

Experimentally, it has been found that the conditions necessary for the process of photosynthesis are:

(i) Sunlight (ii) Chlorophyll (iii) Carbon dioxide (iv) Water

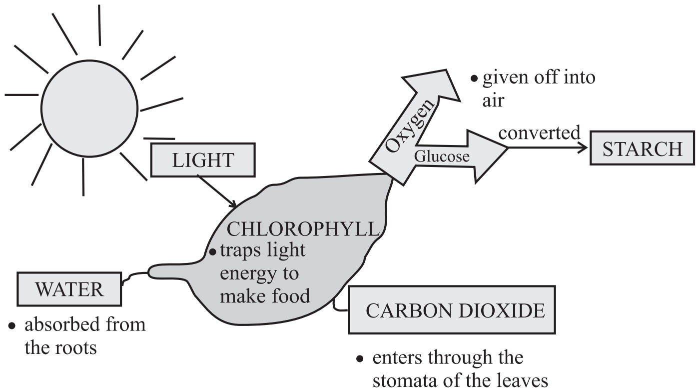


Fig.: Conditions necessary for photosynthesis

Starch Test

The experiments on photosynthesis depend on the fact that green leaves prepare starch as food, and starch gives blue-black colour with iodine solution. Ordinarily all plants have starch in their green leaves. Before we use a plant for photosynthesis experiment, the starch present in the leaves must be removed or the plant should be destarched. This can be done by placing the plant in a dark place. The plant will not be able to make more starch as no light is available. The plant will use all the stored starch in its leaves in about 3 days time. After about three days, the plant leaves will not have any starch in them– plant will be destarched. To test the leaf for starch, soften it by dipping in boiling water for 10 sec and then discolour the leaf by putting in boiling ethanol which removes chlorophyll. Soften the leaf again by putting in boiling water for 10 sec. Spread the leaf and add iodine solution. A blue- black colour indicates starch is present.

1. **Sunlight :** It is the ultimate source of light for photosynthesis in green plants. Only 2% of the total solar energy reaching the earth is used in photosynthesis.

Did You Know?

The visible spectrum of white light is composed of different wavelengths (380 mm to 760 mm) of light - violet, indigo, blue, green, yellow, orange and red. The green pigment chlorophyll absorbs mostly in blue and red region (400 to 700nm range of wavelength) of the spectrum and reflects green light. This 400–700 nm range of solar radiation that photosynthetic organisms use for photosynthesis is called Photosynthetically active radiation (PAR).

Let's Do Activity

Activity 1: Sunlight is necessary for photosynthesis.

Take a destarched potted plant. Take a thin strip of black paper. Wrap the centre of one leaf on both the sides with black strip using paper clips. The tip and the base of the leaf is uncovered, on both the sides. Keep this potted plant in bright sunlight for three to four days.

Pluck the partially covered leaf from the plant and remove its black strip. Decolourise the leaf and test this leaf for the presence of starch. The middle part of leaf which was covered with black strip does not turn blue-black on treatment with iodine. This is because sunlight could not reach this part of leaf and no photosynthesis took place to make starch.

The uncovered part of leaf turns blue-black on adding iodine showing that starch is present. This shows that the part of leaf which was exposed to sunlight could photosynthesise and make starch.

Hence, it can be concluded that sunlight is necessary for photosynthesis. Also, leaves make starch by photosynthesis.

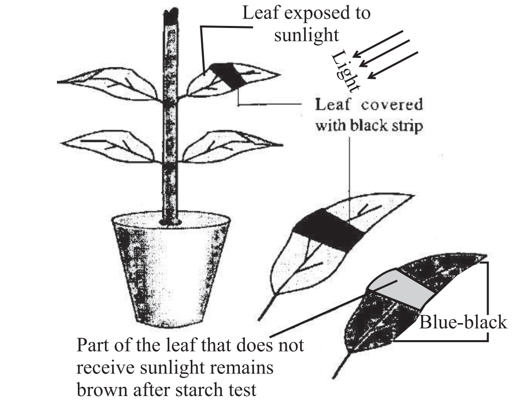


Fig. To show that sunlight is necessary for photosynthesis

2. **Chlorophyll -** It is the most important pigment molecule involved in photosynthesis. It is a green pigment found in chloroplast, embedded in the thylakoid membrane.

Learn More

Chlorophyll molecule consists of a central **magnesium atom surrounded by a porphyrin ring to** which is attached a long phytol chain. The structure is similar to haemoglobin.
There are five closely related chlorophylls that occur in higher plants and algae; chl a, chl b, chl c, chl d and chl e. Photosynthetic bacteria has bacteriochlorophyll (Bchl).

Let's Do Activity

Activity 2 : Chlorophyll is necessary for photosynthesis.

Take a potted plant with variegated leaves (money plant, croton, etc.). Destarch it for 3-4 days. Now keep the plant in sunlight for six hours. Pluck a leaf from this plant. Mark and trace out the green and non-green areas on a sheet of paper. Test this leaf for the presence of starch.
Observe the colour of the leaf and compare this with the tracing of the leaf done in the beginning. We observe that the green part of the leaf shows blue-black colour, showing starch is present. Yellow portion does not show presence of starch. This shows chlorophyll which imparts green colour to the leaf, is necessary for photosynthesis.

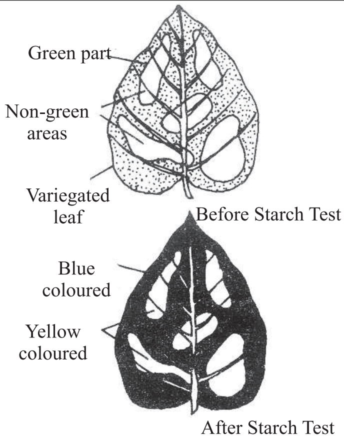


Fig. Variegated leaf of Money plant

3. **Carbon dioxide :** It is an important raw material for photosynthesis. Green plants take carbon dioxide from the surrounding and convert it into carbohydrates by the process of photosynthesis.
Land plants take carbon dioxide in gaseous form which enters the leaf though tiny pores called stomata present on its epidermal layer. The aquatic plants take carbon dioxide in dissolved form which is taken in through the general surface of the body.

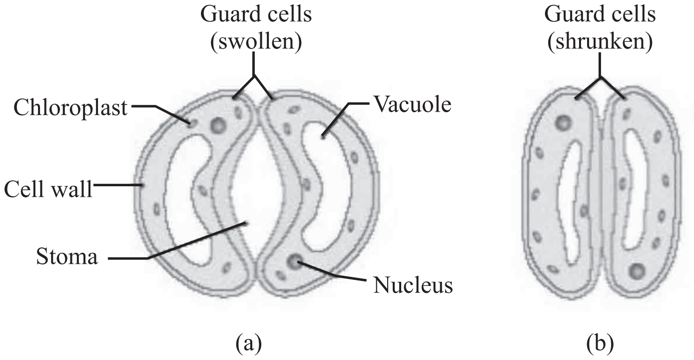


Fig.: Stomata (a) open (b) close

Each pore is guarded by two kidney shaped guard cells which regulate the opening and closing of stomatal pore. When water enters the guard cells, they swell causing the stomatal pore to open. Similarly when water exits the guard cells, they shrink leading to closing of the pore. Gaseous exchange in plants takes place through the stomata.

Let's Do Activity

Activity 3: Carbon dioxide is necessary for photosynthesis.

Take a potted plant having long and narrow leaves. Destarch it. Take a wide mouth glass bottle and put some potassium hydroxide solution in it. Potassium hydroxide will absorb all the carbon dioxide present in the air of the glass bottle. Close the bottle with a tight fitting rubber cork which is split in the middle.
Fix one leaf of the destarched potted plant in such a way that the half tip of the leaf is inside the bottle and the base half is outside. Place this set-up in sunlight for about three days.
Remove the experimental leaf and test for starch. We will see that the tip half of the leaf which did not get carbon dioxide does not turn blue-black, while the base half of leaf which was in carbon dioxide of the atmosphere turns blue-black showing that starch was synthesised, thus proving that carbon dioxide is necessary for photosynthesis.

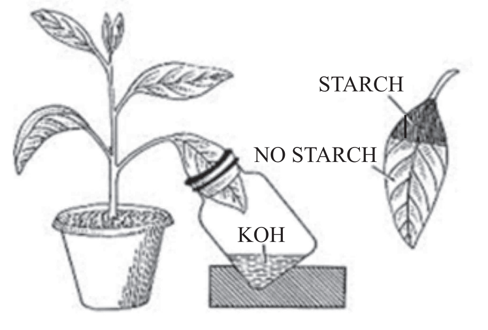


Fig. Moll's half leaf experiment

4. **Water :** It is an important raw material for photosynthesis. Water splits in the presence of light (photolysis) to release electrons and protons which move through the electron transport system to generate the assimilatory power ($NADPH_2$) required for carbohydrate formation. Molecular oxygen is released into the atmosphere through stomata.
   Plants absorb water from the soil through roots and then transport water upwards through the xylem vessels to the leaves, where it reaches the photosynthetic cells and is utilised in photosynthesis.

Did You Know?

- *Destruction of chlorophyll due to high light intensity is called solarisation.*
- *DCMU (Dichlorophenyl dimethyl urea) - a herbicide-inhibits oxygen release in light phase.*

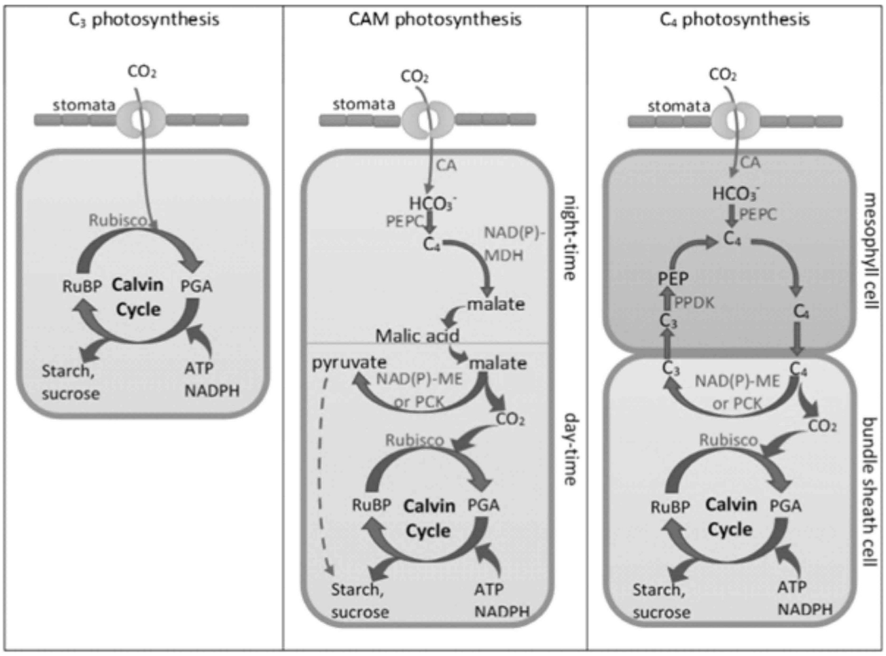
CONNECTING TOPIC

Spatial and temporal separation of steps of photosynthesis

In majority of plants, the initial product of the carbon fixation through photosynthesis is a 3-carbon compound, 3-phosphoglycerate. Such plants are called **C3 plants**. RuBisCO, an enzyme involved in this step of carbon fixation, combines oxygen in place of carbon dioxide with RuBP under high temperature and oxygen concentration, thus initiating a new process called **photorespiration**. This step results in formation of 2C compound, 2-phosphoglycolate and 3C compound, 3-phosphoglycerate (PGA) instead of two molecules of 3-phosphoglycerate. 3-PGA is a normal intermediate of the Calvin cycle, but phosphoglycolate cannot enter the cycle, so to recover some of the lost carbon, this compound passes through a series of reactions that also involve the use of ATP. During these reactions, three-fourths of the carbon that enters this pathway as phosphoglycolate is recovered, while one-fourth is lost as CO_2. So, this process uses up fixed carbon and wastes energy. To overcome the loss due to photorespiration, plants have evolved following adaptations:
C4 plants: In these plants, carbon fixation occurs in mesophyll cells where concentration of oxygen produced during light reaction is high. In mesophyll cells, carbon dioxide is combined with a 3C compound, phosphoenol pyruvate (PEP) instead of RuBP by an enzyme PEP carboxylase. This results in the formation of a 4-carbon compound, oxaloacetate or malate. Hence, these plants are called C4 plants. This malate is then transported into the bundle sheath cells where RuBisCO is present and oxygen concentration is low to avoid photorespiration. In bundle sheath cells, carbon dioxide is removed from the malate and combined with RuBP by RuBisCO in the usual way, and the Calvin Cycle proceeds as normal. So, in C4 plants, light reactions, initial CO_2 fixation and the Calvin cycle are spatially separated. Examples of C4 plants are maize, sugarcane etc.

Crassulacean Acid Metabolism (CAM) plants:

Plants such as cacti and pineapples living in hot, dry environments keep their stomata close during daytime to reduce water loss. Then how do they photosynthesise when CO_2 cannot enter the leaf during daytime? At night, CAM plants open their stomata, allowing CO_2 to diffuse into the leaves. This CO_2 is fixed into oxaloacetate by PEP carboxylase (the same step used by C4 plants), and then converted into malate. This organic acid is stored in the vacuoles until the next day. In the daylight, the CAM plants do not open their stomata. The organic acids are transported out of the vacuole and broken down to release CO_2 which enters the Calvin cycle. This controlled release maintains a high concentration of CO_2 around RuBisCO. By adopting this strategy, CAM plants not only avoid photorespiration, but are also very water-efficient.



(a) (b) (c)

Fig. : (a) C3, (b) CAM and (c) C4 pathway

Nutrition in Animals

Animals are heterotrophs i.e. they cannot synthesize their own food and obtain food from external sources like plants, animals or their products. Majority of the animals are holozoic. Depending on the food and the way it is obtained, different organisms have different digestive system.

Nutrition in *Amoeba*

Amoeba is a unicellular aquatic protozoan. The mode of nutrition is holozoic. It feeds on microscopic plants and animals, bacteria and decaying food particles floating in the water. Nutrition in this protozoan involves the following four steps:

1. **Ingestion:** It involves intake of food. There is no mouth or fixed place for intake of food. When a food particle comes near *Amoeba*, it sends out temporary finger-like projections called pseudopodia around it. The food particle gets surrounded by the encircling pseudopodia which touch each other by their tips. Next the membrane closer to the food particle gets dissolved and fuse over the food particle forming a **food vacuole** into the cytoplasm. This method of ingestion is called **phagocytosis**.

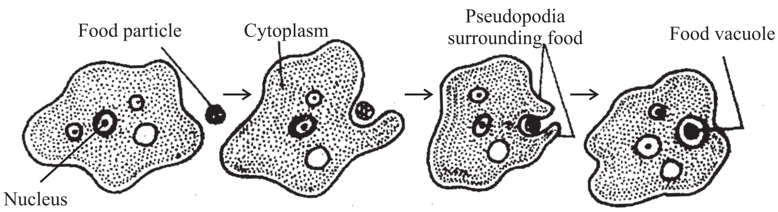


Fig. Phagocytosis in Amoeba

2. **Digestion:** The lysosome containing digestive enzymes fuses with the food vacuole. Enzymes break down the food into small and soluble molecules. Thus, digestion is intracellular.
3. **Absorption and Assimilation:** The digested food components easily diffuse into the cytoplasm through the membrane of the food vacuole. It is then utilized by the cell for obtaining energy, repair and growth.

4. **Egestion:** A portion of food which is not digested and assimilated, remains in the food vacuole. The vacuole slowly moves backward and comes in contact with plasma membrane. The plasma membrane reptures and the undigested food is thrown out of the body.

Nutrition in Human Beings

Human beings are heterotrophic omnivorous organisms and obtain food by holozoic mode of nutrition.

Digestive System

The human digestive system consists of 9 metre long alimentary canal and several accessory digestive glands which pour their secretion into the canal. The alimentary canal is a series of hollow organs joined in a long tube with muscular wall, glandular epithelial lining and has varying diameter.

The muscular wall of the canal from oesophagus to rectum contracts rhythmically in order to push the food forward. This is called **peristalsis**. The alimentary canal extends from the mouth to the anus. It consists of several organs:

1. Mouth
2. Buccal cavity
3. Pharynx
4. Oesophagus
5. Stomach
6. Small intestine
7. Large intestine
8. Anus

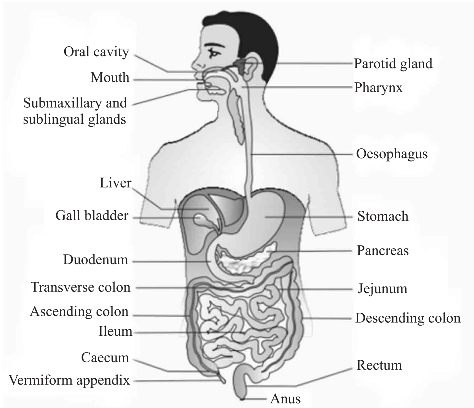


Fig. Digestive System of Human Being

1. **Mouth:** It is the uppermost opening of the human digestive track which gives passage for ingestion of food. It is guarded by two soft movable lips which open in the buccal cavity.
2. **Buccal cavity:** It is the oral cavity bound above by the palate, below by the throat and on the sides by the jaws. A muscular tongue forms the floor of this cavity and helps in ingestion of food. The upper surface of the tongue has small projections, called papillae, some of which bear taste buds. They help in tasting the food. This cavity also has a number of teeth. The teeth mechanically break down food by cutting and crushing them and help in swallowing and digestion of food.
   In humans, digestion begins in oral cavity where food is chewed. Saliva is secreted in large amounts (1-1.5 litres/ day) by three pairs of exocrine salivary glands in the oral cavity, and is mixed with chewed food by the tongue. Saliva serves to clean the oral cavity and moistens the food. Saliva contains digestive enzyme, **salivary amylase** which aids chemical breakdown of polysaccharide (starch) into disaccharide (maltose). It also contains mucous which helps soften the food into a **bolus**. It is passed into pharynx by swallowing.

$$\text{Strach} \xrightarrow[\text{Amylase}]{\text{Salivary}} \text{Maltose}$$

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TOOTH

Types of teeth and dental formula: A tooth is a hard structure, set in the upper and lower jaw's and is used for chewing. They also give shape to the face and aid in the process of speaking clearly. Each jaw has two pairs of incisors (I), one pair of canines (C), two pairs of premolars (PM) and three pairs of molars (M). Thus, each jaw posseses total sixteen teeth and an adult has thirty two permanent teeth.

The full dental formula of humans is represented as

I 2/2 , C 1/1, PM 2/2, M 3/3

Thus, dentition in humans is heterodont *i.e.,* possessing teeth of different types.

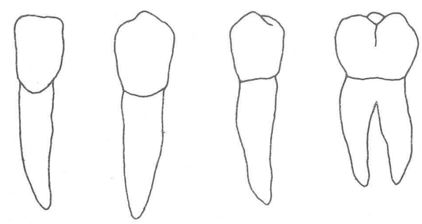

Fig.: Four Types of human teeth:
(a) Incisor (b) Canine (c) Premolar (d) Molar

Structure of a tooth:
Each tooth has a part attached to the jaw bone i.e., root, a part surrounding neck, i.e., neck and a part above the gum level exposed to buccal cavity i.e., crown. The crown is the biting surface and is covered by an outer layer of hardest material called **enamel**. The remainder of a tooth consists of a bone-like material called dentine and nerves and blood containing pulp cavity.
Case of teeth: The enamel that covers the crown in each tooth can be broken down by acids produced in the oral cavity. Tooth decay begins when bacteria *Streptococcus mutans* grow on food particles especially sugars and stick to teeth and produce acid. Acid causes tooth decay by softening or demineralisation of enamel. Bacterial colony grows in size and forms a plaque. Saliva has a property of neutralising acid but it cannot reach the area covered by plaque. Regular brushing of teeth removes plaque. If proper care is not taken, bacteria can invade the pulp and cause inflammation and infection.

Let's Do Activity

Activity 4: To study the activity of salivary omylase.

Take 1ml starch solution (1%) in two test tubes and mark them as A and B. Add 1ml saliva to test tube A. Leave both the test tubes undisturbed for 15-20 minutes. Now add a few drops of iodine solution to both the test tubes.
Test tube B gives blue- black colour while test tube A does not. This shows that starch in test tube A has been broken down to sugars by the salivary amylase enzyme present in the saliva.

3. **Pharynx:** It is a 12 cm funnel shaped passage from buccal cavity to oesophagus. It is a common passage for both food and air. A flap, **epiglottis** closes over the trachea to prevent the entry of food in it while swallowing.
4. **Oesophagus :** It is a narrow muscular tube about 25 centimeters long starting at the pharynx, passing through the thoracic diaphragm and ending at the stomach. The chewed food is pushed down the oesophagus to the stomach through peristaltic contraction of the muscular oesophagus. A ring-like muscle called muscular sphincter is present at the end of oesophagus where it meets at stomach. It regulates the passage of food from oesophagus into the stomach and also prevents the content of stomach from flowing back into oesophagus.
   The oesophagus opens into the stomach through an opening called cardiac orifice. No digestion of food takes place here.
5. **Stomach :** It is a small J-shaped pouch with walls made of thick elastic muscles.
   It is present on the left side of the abdomen. Food enters the stomach through the cardiac orifice site of complete digestion of carbohydrates, proteins and fats. Stomach serves following four main functions:
   (i) **Storage of food** takes place for variable duration. Carbohydrates remain in stomach for one or two hours, proteins up to three hours and fats for three to six hours. Storage enables us to take food at intervals.
   (ii) **Partial digestion** of food takes place here. Tubular glands called gastric glands in the wall of stomach secrete hydrochloric acid, protein digesting enzyme and mucus. These collectively form the gastric juice. Hydrochloric acid kills the microorganisms in the ingested food and also provides optimum pH for the enzyme pepsin which breaks down proteins into peptones. Gastric juice also contains some gastric lipase. The mucus lubricates the food and also prevents hydrochloric acid from acting on the walls of the stomach.
   (iii) **Mechanical churning** is brought about by periodic muscular contraction of the stomach so that food is churned and thoroughly mixed with the gastric juices. The food in the stomach is in semi-liquid form, which is known as **chyme**.
   (iv) **Regulation of exit of chyme** from stomach into the small intestine via the pyloric sphincter.

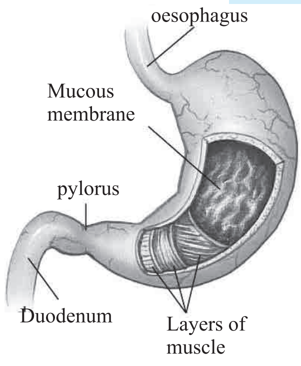

Fig. Anatomy of stomach

Stomach
↓
Gastric juice
↓

(Hcl,	Mucus,	Gastric enzymes)
↓	↓	Pepsin
Kills microorganism, provides optimum condition for enzyme pepsin to act	Lubricates food, Protects the inner lining of stomach from HCl	Protein → Small proteins

Flow Chart : Functions of gastric juice

6. **Small Intestine:** The small intestine is coiled and narrow tube (about 6.9 m in length). It is the site of complete digestion of carbohydrates, proteins and fats. It can be distinctly divided into three regions:
   (i) *Duodenum :* It is the proximal part of small intestine. It is a C-shaped structure that starts from pyloric end of the stomach and receives the secretion of common duct which brings secretion of liver and pancreas.
   (ii) *Jejunum :* It is 2.4 metre long and bears finger like projections called **villi** which increase the surface area of the inner lining of intestine.
   (iii) *Ileum :* It is longest part of small intestine about 3.5 metre long with **club-shaped villi.** It opens into large intestine.

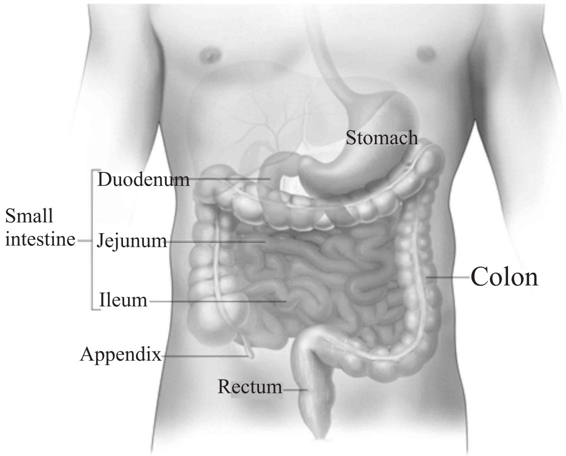

Fig. : Parts of small intestine and large intestine

7. **Large intestine:** It is roughly 1.5 meters long with three parts: the **caecum** at the junction of small intestine, the **colon**, and the **rectum**. The large intestine absorbs water from the food and stores faeces until it can be egested. Food products that cannot go through the villi, such as cellulose (dietary fibre), are mixed with other waste products and become hard and concentrated faeces. Faeces is stored in rectum for a certain time and then eliminated from the body by **peristaltic** movement, through the anus. The exit of faeces is regulated by anal sphincter.

Did You Know?

- ***The length of the small intestine varies in various animals depending on the food they eat. Herbivores eating grass need a longer small intestine to allow the cellulose to be digested. Carnivores like tigers have a shorter small intestine as meat is easier to digest.***
- ***Caecum is a small blind sac which hosts some symbiotic micro-organisms. From it, a narrow finger-like tubular projection called vermiform appendix, which is a vestigial organ, arises.***
- ***Many of the microbes living in the gut facilitate chemical digestion and absorption, and some synthesise certain vitamins, mainly biotin, pantothenic acid, and vitamin K.***

The process of digestion can take place between 24 and 72 hours.

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Digestive Glands

Digestive glands secrete digestive juice. They are :

(1) **Salivary Glands :** The three pairs of salivary glands secrete saliva 500 ml per meal and 1200 – 1500 ml per day in a normal human.

(2) **Gastric Glands :** Numerous simple or branched glands lie in the mucus membrane of the stomach. The glands are called gastric glands. They secrete gastric juice which is clear watery, strongly acidic and contains HCl, protein digesting enzymes and mucus.

(3) **Liver :** It is the largest gland. It is bilobed, with larger right lobe having gallbladder and smaller left lobe. It secretes bile 500-1000 ml per day. Cystic duct of gallbladder and right and left hepatic ducts of liver lobes unite to form a common bile duct. The bile secreted by the liver cells is normally stored and concentrated in gallbladder. It contains bile pigments (bilirubin and biliverdin) and bile salts. It emulsifies the fat present in the food.

(4) **Pancreas :** It is the second largest gland of body. It is mixed gland performing both exocrine (duct gland) and endocrine (ductless gland) function. It secretes pancreatic juice containing digestive enzymes (exocrine portion) and hormones (endocrine portion). It opens by main pancreatic duct. The common bileduct joins with the pancreatic duct and pours the bile into the duodenum.

(5) **Small Intestine :** Intestinal glands present in between villi in the epithelial lining of the small intestine produce intestinal juice which is slightly alkaline and contains various enzymes such as lipase, lactase, and amylase for complete digestion of food. The mucus protects the inner lining of intestine from acid and neutralising substances neutralise acid coming from stomach.

Digestive Enzymes : Sources, Substrates and Resultant Products

Part/Organ	***Source***	***Enzymes***	***Substrate***	***Resultant Products***
Mouth	Salivary glands	Amylase	Starch	Sugars
Stomach	Gastric glands	Pepsin	Proteins	Peptones and Amino acids
Pancreas	Acinar cells	Trypsin	Proteins	Peptones
		Carboxy peptidase	Proteins	Amino Acids
		Amylase	Starch	Sugars
		Lipase	Fats	Fatty Acids
Small Intestine	Intestinal glands	Amino peptidase	Peptides	Amino Acids
		Maltase	Maltose	Glucose

Digestion of food

- **Process of digestion**
  Digestion of food occurs in different parts of the digestive system by mechanical and chemical processes. Mechanical process involves breaking of large food into smaller pieces. It begins in the mouth as the food is chewed with teeth. Chemical process involves breaking down the food into simpler nutrients by enzymes so that it can be absorbed and used by the cells.

1. **Digestion is mouth**: Digestion in man starts in the mouth. In mouth, food is chewed and mixed up with saliva secreted by salivary glands by teeth and tongue. Saliva contains enzyme **ptyalin** which break starch into simple carbohydrate maltose. Lysozyme present in saliva kills the bacteria present in food.
2. **Digestion in stomach**: In stomach, food is churned by the action of muscles of the stomach. The food gets mixed with the gastric juice which contains dil. HCl and two enzymes namely **rennin** and **pepsin**. HCl softens the food and kills the bacteria present in the food. It provides acidic medium for the enzymes present in the gastric juice to act.
   Rennin enzyme present in infants helps in digestion of milk proteins called curdling of milk. Pepsin breaks proteins into proteoses and peptones.
3. **Digestion in small intestine**: In duodenum, bile, intestinal juice and pancreatic juice mix with the churned food called chyme. Bile juice emulsifies the fat i.e., breaks down the fat into small micelles. Pancreatic juice consists of three enzymes:
   (i) *Trypsin* breaks proteins, peptones and peptides into amino acids.
   (ii) *Amylase* breaks starch into sugar.
   (iii) *Lipase* breaks fats into fatty acids and glycerol.
   Intestinal juice consists of amylolytic, proteolytic and lipolytic enzymes.
   These enzymes act on the end products formed by pancreatic enzymes to convert them into simple absorbable forms.

Ingestion
↓
Mechanical digestion and motility : mixing & propelling
↓ Secretion : enzymes, water, mucus, buffers etc.
Chemical digestion: enzymatic hydrolysis
↓
Absorption : water soluble vs. fat soluble
↓
Assimilation
↓
Egestion

Flow Chart : Steps in digestion

- **Absorption of digested food:**
  Absorption is the process by which digested food is taken into blood stream. Digested food is mainly absorbed in the jejunum and ileum regions of the small intestine. The mucous membrane lining the jejunum and ileum is covered with millions of microscopic, finger-like projections called villi which contain many blood capillaries and lymph vessels called lacteals. The presence of villi greatly increases the surface area for absorption. Nutrients present in the lumen of small intestine pass from the villi either into capillaries or lacteals. Amino acids, sugars, vitamins, minerals and small amounts of fatty acids and glycerol pass into blood capillaries which join together to form a large blood vessel called hepatic portal

vein which carries the food to the liver. It stores and processes the food and then releases it in the blood as per the need of the body. Large amount of fatty acids and glycerol pass into lacteals.
From small intestine, undigested and unabsorbed substances are passed on to the large intestine. Some water, minerals and certain drugs are absorbed in the colon part of the large intestine.

- **Assimilation :**
  Assimilation is the process by which the absorbed substances finally reach the tissues which utilise them for their activities such as obtaining energy and for growth or repair of the body.
- **Egestion:**
  Egestion is the process of removal of undigested food from the body.
  The undigested food is collected as faeces in the rectum. Rectal wall absorbs water from it and the faecal matter is egested out through anus.

Time to Check Your Knowledge

1. A black smoker, a hydrothermal vent found on the seabed, contains higher levels of sulphur. Which type of organisms found here?
2. What are the end products of light reaction of photosynthesis?
3. Arrange the following parts in the order in which food passes after it is released from stomach. rectum, colon, jejunum, caecum, duodenum, ileum

SOLUTION

1. Since sunlight cannot penetrate to such depth in water, chemosynthetic bacteria can be found near the vent. These bacteria, instead of light, harvest chemical energy from the minerals and chemical compounds such as hydrogen sulfide, hydrogen gas, ferrous iron and ammonia releasing from vent to make their food.
2. ATP and $NADPH_2$
3. From stomach, food passes into small intestine and then into large intestine. The correct order of parts in which food passes through them during digestion is:
   Duodenum ⟶ jejunum ⟶ ileum ⟶ caecum ⟶ colon ⟶ rectum

RESPIRATION

Respiration is an oxidative process occurring within living cells by which the chemical energy of organic molecules e.g glucose is released in a series of metabolic steps involving the consumption of oxygen and liberation of carbon dioxide and water. This energy is not needed immediately so it is stored in the form of energy rich molecule ATP.
As the process of respiration takes place inside the cells, it is also known as **cellular respiration.** It is essential for life because it provides energy for carrying out all the life processes which are necessary to keep the organism alive.

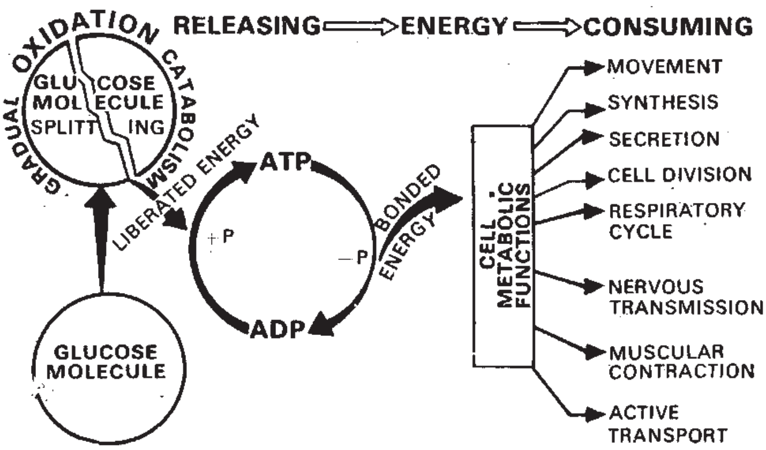

Fig. Respiration

It includes two processes (i) breathing which involves the process of exchange of gases, oxygen and carbon dioxide (ii) Oxidation of digested food occurring in the cell.

Breathing and Respiration

Both breathing and respiration are required for all living organisms. Generally, breathing and respiration are considered the same. However there is a great difference between these two terms.

"Breathing is a constant process where you breathe in and out constantly throughout the day. It is a process of taking in oxygen and expelling carbon dioxide".

"Respiration is a process where the body breaks down glucose with the help of oxygen. It is a part of metabolic process where energy is released while carbon dioxide and water are produced".

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Table : Differences between breathing and respiration

	Breathing	Respiration
1	It is a physical process involving taking in oxygen from the air and releasing carbon dioxide in the air.	It is a chemical process involving enzymatic breakdown of food into carbon dioxide and water along with the release of energy in the form of ATP.
2	It involves respiratory organs and muscles such as diaphragm.	It occurs inside the cells and involves cytoplasm and cell organelles such as mitochondria.
3	It is a voluntary process. We can take deep or shallow and fast or slow breathe.	It is involuntary and cannot be controlled.
4	It is non-enzymatic process.	It is an enzymatic process.
5	No energy is released in this process.	Energy in the form of ATP is released during this process.

Types of Cellular Respiration

So far, we have studied that respiration takes place in the presence of oxygen. What happens in organisms living in anaerobic (lack of oxygen) environment e.g. bacteria? These organisms are also surviving and carrying out various life processes. Based on the presence or absence of oxygen, cellular respiration is of two types:

1. **Aerobic respiration:** It is a type of cellular respiration that uses oxygen in order to break down respiratory substrate and releases energy in the form of ATP. 38 molecules of ATP are released for every glucose molecule broken down. It takes place in the cytoplasm (glycolysis) and mitochondria (Krebs cycle and Electron Transport Chain) of the cell. It involves complete break down of glucose molecule into carbon dioxide and water. The equation of aerobic breakdown of glucose is:

$$\underset{(6C\ \text{compound})}{\text{Glucose}} \xrightarrow[\text{In cytoplasm}]{\text{Glycolysis}} \underset{(3C\ \text{compound})}{\text{Pyruvic Acid}} \xrightarrow[\substack{\text{In mitochondria} \\ \text{presence of } O_2}]{\text{Krebs cycle}} CO_2 + H_2O + 38ATP$$

2. **Anaerobic respiration:** It is a type of cellular respiration that takes place in the absence of oxygen. There is an incomplete breakdown of respiratory substrate and little energy is released. 2 molecules of ATP are released for break down of every glucose molecule. It takes place in the cytoplasm of the cell, mitochondria is not involved. It involves incomplete breakdown of respiratory substrates and releases less energy. The end product of anaerobic respiration is either lactic acid as in muscle cells or ethanol as in yeast. The breakdown of glucose into lactic acid can be represented as:

$$\underset{(6C\ \text{compound})}{\text{Glucose}} \xrightarrow[\text{In cytoplasm}]{\text{Glycolysis}} \underset{(3C\ \text{compound})}{\text{Pyruvic Acid}} \xrightarrow[\substack{\text{In cytoplasm} \\ \text{of muscle cells}}]{\text{No oxygen}} \underset{(3C\ \text{compound}) + 2ATP}{\text{Lactic Acid}}$$

Table : Difference between Aerobic and Anaerobic Respiration

	Aerobic Respiration		**Anaerobic Respiration**
1.	Proceeds in the presence of oxygen	1.	Proceeds in the absence of oxygen
2.	Complete breakdown of glucose	2.	Incomplete breakdown of glucose
3.	End products are carbon dioxide and water	3.	End products are ethyl alcohol and carbon dioxide or lactic acid
4.	Energy liberated in large quantity (38 ATP) from one mole of glucose)	4.	Energy liberated in small quanity (2 ATP) from one mole of glucose
5.	Occurs normally throughout life	5.	Occurs temporarily for short periods
6.	Occurs first in cytoplasm (glycolysis) and then in mitochondria (Kreb's cycle)	6.	Occurs in the cytoplasm (glycolysis and fermentation)

MECHANISM OF RESPIRATION

Cellular respiration completes in following stages:

Glycolysis: This is the first step in both aerobic and anaerobic types of cellular respiration.

During this stage, glucose is partially oxidised in the body cells step-by-step to release energy. It occurs in the cytoplasm of the cell. This step does not require oxygen. One molecule of glucose (6 carbon compound) on glycolysis produces two molecules of 3 carbon compound, pyruvate or pyruvic acid. This process consumes two ATP molecules and produces four ATP molecules and two NADH molecules.

The pyruvate molecule produced during glycolysis contains a lot of energy in the bonds between their molecules. The fate of pyruvic acid is determined by the presence or absence of oxygen. **Krebs cycle:** If oxygen is available, the pyruvic acid enters into mitochondria and completely breaks down to release carbon dioxide and water. The process occurring inside the mitochondria is called the Krebs cycle. 38 ATPs (36 ATP from krebs cycle and 2 ATP from glycolysis) are produced per glucose molecule. **Fermentation:** If oxygen is not available, the pyruvic acid enters another pathway called fermentation. It occurs in the cytoplasm of the cell. There are different types of fermentation. During this pathway, each pyruvate molecule breaks down to produce either ethyl alcohol and water or lactic acid. There is incomplete break down of pyruvic acid molecule and only 2 ATPs are produced per glucose molecule.

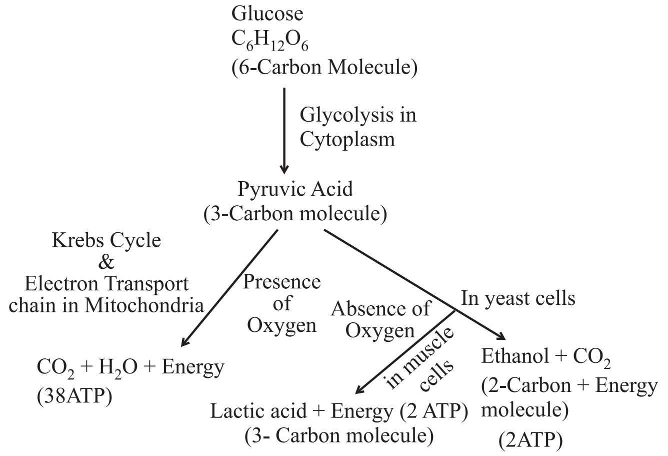

Fig. Mechanism of Cellular Respiration

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ATP

For your muscles, in fact, for every cell in your body - the source of energy that keeps everything going is called ATP. Adenosine triphosphate (ATP) is the biochemical way to store, and use energy. ATP is called energy currency of the cell.

Chemically, ATP is an adenine nucleotide molecule bound to three phosphates. There is a lot of energy equivalent to 30.5 kJ/mole stored in the bond between the second and third phosphate groups that can be used to fuel chemical reactions. When a cell needs energy it breaks this bond to form adenosine diphosphate (ADP) and a free phosphate molecule. In some instances, the second phosphate group can also be broken to form adenosine monophosphate (AMP).

ATP $\rightarrow$ ADP + Phosphate + Energy (for use in cell)

ADP $\rightarrow$ AMP + Phosphate + Energy (for use in cell)

ATP is required for all metabolic reactions, and it must be replaced in order to keep reactions going. For this, the body has several different systems (glycolysis, Krebs cycle, lactic acid fermentation, etc.) to create ATP. These systems work together in phases.

- Plants have no specialised organs for gaseous exchange. Each plant part is able to take in oxygen from air and gives out carbon dioxide.

Exchange of Gases by Roots :

Root hairs (which are tubular outgrowth of outer layer of cells called epidermis) are in contact with oxygen present in the spaces between soil particles. Oxygen diffuses from soil into root hair and passes into root cells. Carbon dioxide released from root cells after cellular respiration similarly moves out through root hair into the soil.

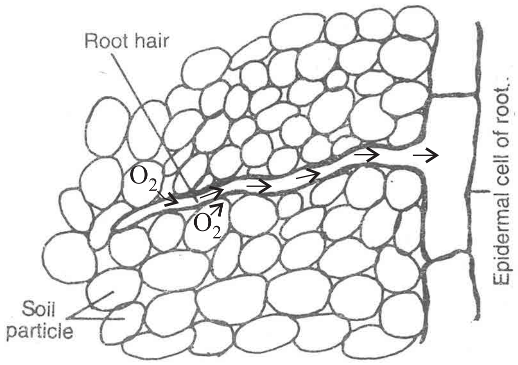


Fig. Gaseous exchange through root hair

Exchange of Gases by Stem :

The stem of the plant do not have root hairs instead have lens shaped openings called lenticels. These are aggregation of loosely packed dead cells with large intercellular spaces in bark of the stem. Through lenticels gaseous exchange occurs between the air and inner living cells. In woody plants, the bark has lenticels for gaseous exchange.

Exchange of Gases by Leaf :

The exchange of respiratory gases in leaves occur through tiny apertures called **stomata** found on leaf surface. The oxygen from air diffuses in through stomata and finds its way into cells of the leaf. When the concentration of carbon dioxide increases, stomata open to release it into the atmosphere.

Respiration in plants

- The respiration in plants is continuous day and night.
- The oxygen from the air spaces which come, through the stomata and lenticles, in the leaves and stems, diffuses into the tissues and cells of the plants after getting dissolved in the film of water present over the cells. In the cells, this oxygen oxidises the carbohydrates and other organic compounds into carbon dioxide and water to produce energy.
- Some amount of carbon dioxide is used in the process of photosynthesis. The rest of carbon dioxide and some of the water (in vapour form) collect in the air spaces from where they pass out to the exterior through lenticels and stomata.
- Process of respiration occurs at a faster rate in parts of plant having rapid growth like growing seeds, buds, apical meristem of root and shoot, because these parts require more energy to accomplish the growth process.
- The gaseous exchange in plants is not very evident during the day time as the products of respiration i.e. carbon dioxide and water are the reactants in the process of photosynthesis. So, the carbon dioxide and water produced in the respiration are utilised in photosynthesis, occurring in the day light.

Respiration in Animals

Animals also require a supply of energy to survive. They get their energy from the food they eat. Glucose is often the energy source but it may also come from other carbohydrates, proteins and fats. The energy is obtained from cellular respiration that takes place inside every cell. For this, we know, the cell needs to be supplied with oxygen and glucose. The waste product, carbon dioxide, which is poisonous to cells, needs to be removed. Oxygen enters the body from the air (or water in fish) and carbon dioxide is usually eliminated from the same part of the body.

Steps in Respiration

Following steps take place during respiration:

- Breathing i.e., intake of oxygen (inspiration or inhalation) and release of carbon dioxide (expiration or exhalation)
- External respiration or exchange of gases through blood in capillaries of respiratory organ across respiratory surface
- Transport of gases throughout the body
- Internal respiration i.e., exchange of gases between blood and cells
- Utilisation of O_2 by the cells for catabolic reactions and resultant release of CO_2.

Organs of the body carrying out the function of uptake of oxygen from the environment and getting rid of carbon dioxide are called **respiratory organs**. Different animals use different respiratory organs depending on their habitats and levels of organisation.

Table : Respiratory organs in different animals

S. No.	Respiratory organs	Animals/Animal groups
1	Skin	Earthworm, leech, frog
2	Gill or Ctenidia	Crustaceans (Prawn, Crab); Molluscs (Pila, Unio); Protochordates, Fishes, Amphibians (larvae and some aquatic salamanders)
3	Tracheal tube	Insects, Arachnids
4	Bucco-pharynx	Frog
5	Lungs	Ambhibians, Reptiles, Birds and Mammals

Respiration through Skin (Earthworm) :

There are no special organs designed for gaseous exchange in earthworm so it takes place by diffusion over the whole body surface or skin. Skin of worm is moist due to glandular secretion from the epidermis and highly vascularised. Blood capillaries are present in the epidermis immediately below the surface. So external air oxygen is dissolved in moist skin and then diffuses to blood capillaries. The blood contains haemoglobin (respiratory pigment) dissolved in plasma. The oxygen is picked up by the hemoglobin dissolved in the blood plasma and carbon dioxide is expelled from the body.

Respiration through Gills (Fish) :

In fishes, the respiratory organs are gills. Fish uses oxygen dissolved in water.

Gills are comprised of gill arches, a bony structure that is oriented vertically on the side of a fish, with hundreds of comb-like structures called gill filaments extending from them. Each gill filament produces many branches called primary lamellae and the primary lamellae branch out into tiny secondary lamellae. The secondary lamellae contain small blood capillaries and blood flows in the opposite direction of the water. In order to respire, a fish opens and closes its mouth along with opening and closing of the gill-slits (or the operculum which covers the gill-slits) behind their eyes. These movements of mouth and gill slits occur in a coordinated manner. Let's study how. Fish opens its mouth and gulps water containing dissolved oxygen. Then it closes its mouth to pump the incoming water through the gills. As water passes over the gill filaments, blood inside the capillaries picks up the dissolved oxygen from water. The circulatory system then transports the oxygen to all body tissues and picks up carbon dioxide, which is removed from the body through the gills. After the water flows through the gills, it exits the body through the openings in the sides of the throat or behind the fish's operculum (a flap, usually found in bony fish, that covers and protects the fish gills).

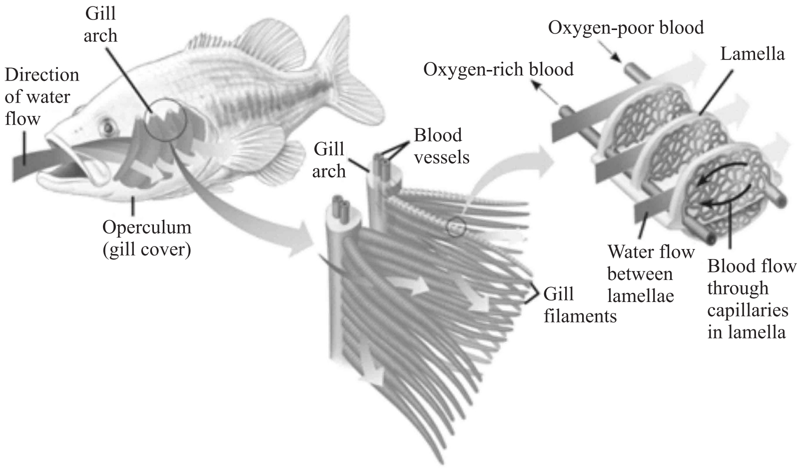


Fig. : Respiration in fish by gills

The rate of breathing in aquatic organisms is much faster than that seen in terrestrial organisms. This is because the amount of dissolved oxygen is fairly low as compared to the amount of oxygen in the air. So, in order to get more oxygen, aquatic organisms respire more.

Respiration through Air-tubes (Grasshopper) :

Gaseous exchange occurs through a system of tubes called tracheal system. This allows oxygen to diffuse from the outside air directly to the tissue without the need for transportation by blood. So respiratory system is well developed (much faster diffusion of oxygen) to compensate the poorly developed circulatory system. 10 pairs of holes called spiracles (2 thoracic + 8 abdominal) are found on the sides of body. Each spiracle opens in tracheal chamber or atrium. Each atrium gives off dorsal, ventral and lateral trunks. Each trunk divides in trachea that terminates in tracheoles filled with fluid. Each cell is very close to the end of tracheole. The respiratory movements are brought about by rhythmic expansion and contraction of abdomen. These draw the air into tracheal system and force it out through spiracles.

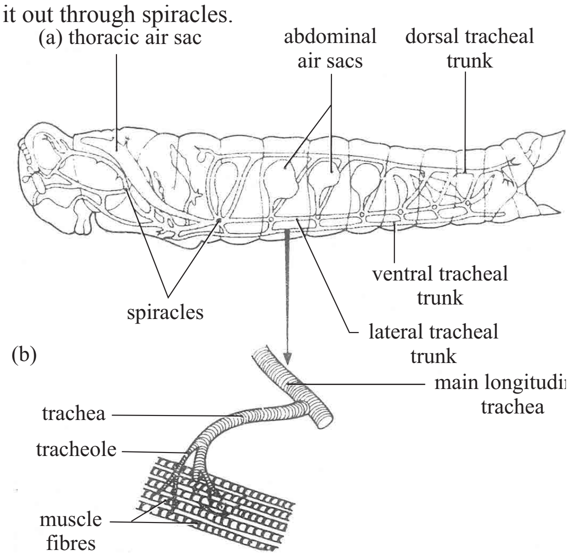


Fig. (a) Tracheal System of Grasshopper (b) Structure of Insect Trachea

All these respiratory organs have three features in common:

(i) They have large surface area to get maximum oxygen.

(ii) They have thin walls for easy diffusion of gases.

(iii) They have a rich supply of blood for transporting respiratory gases.

Table: Difference in Respiration of Plants and Animals

	Plants	Animals
1.	All parts of plants i.e. root, stem, leaves perform respiration individually.	Perform respiration as a single unit.
2.	No system for transport of respiratory gases.	Have a system to transport respiratory gases.
3.	Rate of respiration is slow.	Rate of respiration is fast.

Respiratory system in Human Beings

- Respiratory system is composed of **conducting part** and an **exchange part**.
- The **conducting part** provides a passage way for air and functions to condition the incoming air by warming, moistening and cleaning it. It consists of **nasal cavity nasopharynx, larynx, trachea, bronchi, bronchioles** and **terminal bronchioles**.
- The **exchange part** consists of **alveolar ducts** and **alveolar sacs,** which serves to get rid of CO_2 and picks up oxygen.

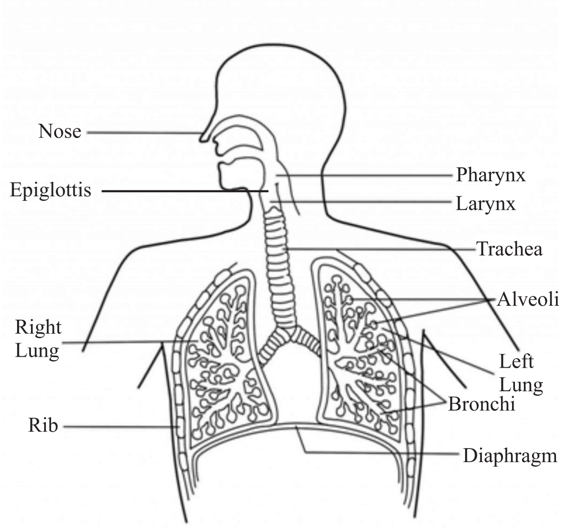


Fig. Human Respiratory System

Nasal Cavity

- It is a large cavity which is separated from buccal cavity by hard, bony palate. It is lined by epithelium which secretes mucus. The nasal cavity opens outside through a pair of external nostrils or nares.
- The nasal cavity is divided into two parts by a thin, cartilaginous and bony wall, called nasal septum. The cavity opens inside the pharynx through two internal nostrils. Air while passing through the nasal cavity is filtered, and only the clean air free from dust particles and foreign substances enters the pharynx. The air also gets warmed and moistened in this chamber. It is important to note that air can also be inhaled through mouth directly, but this is not advisable because the air will not be filtered, warmed and moistened.This gradually will harm the respiratory system.

Pharynx

- The nasal chamber opens into pharynx which is the common passage for food and air.
- It opens through **glottis** of the larynx region into the trachea.

Larynx

- Larynx is composed of cartilages, ligaments, muscles and a mucosal surface. It helps in sound production and hence called the **sound box**.
- It prevents indigested solids and liquids from entering the respiratory system.
- Larynx is also called **Adam's apple** in human males.
- During swallowing, glottis can be covered by a thin elastic cartilaginous flap called **epiglottis** to prevent the entry of food into the larynx.

Trachea

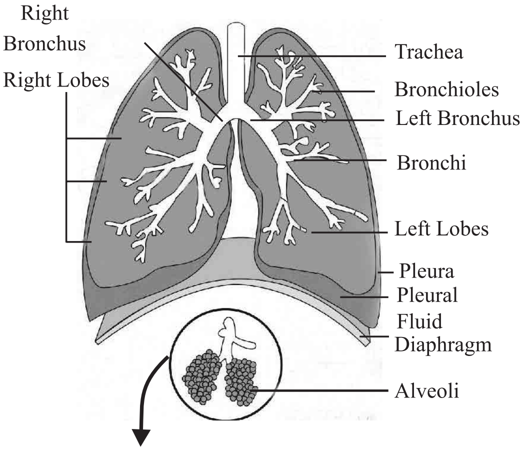
- Trachea (**wind pipe**) is a straight tube extending up to the mid-thoracic cavity and divides into right and left primary bronchi.
- It carries air between larynx and the bronchi and is supported by incomplete rings of C-shaped cartilage (hyoid bone) in its wall.
- The rings of cartilage **makes the wall non-collapsible**.

Bronchi, Bronchioles and Terminal Bronchioles

- Each bronchus undergoes repeated divisions to form the secondary and tertiary bronchi and bronchioles ending up in very thin **terminal bronchioles**.
- Each terminal bronchiole gives rise to a number of very thin, irregular walled and vascularised bag-like structures called **alveoli**.
- The walls of alveoli are very thin and covered by a network of blood capillaries. Thus, they provide a large surface for gaseous exchange.
- Number of alveoli is 300-400 million with surface area of 100 sq.m.

Lung

- Lungs are a pair of cone-shaped organs made up of spongy pinkish-gray tissue. The branching network of bronchi, bronchioles and alveoli coustitute the lungs.
- Lung is the **primary respiratory organ**.
- Lungs are covered by a double layered **pleura**, with **pleural fluid** between them. It reduces friction on the lung surface.



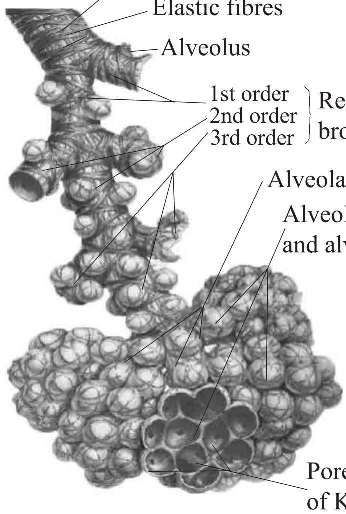


Fig.: Lung and the enlarged section of Bronchioles

- The **right lung** is divided into **three lobes** and **left lung** into **two lobes**.
- The **left lung is smaller than right lung**.
- It is protected by bony and muscular ribcage.
- Air enters into the lung in this way -
  Inhaled air → Mouth/Nose, or nasal chamber → Larynx → Glottis → Trachea → Right and left bronchi → Bronchioles → Alveoli

Diaphragm

- Diaphragm is a highly muscular and fibrous dome shaped muscle.
- Important function of diaphragm is to aid in respiration. It separates the thoracic and abdominal cavities. It is **also called phrenic muscles**.
- The contraction of diaphragm assists in **inspiration (breathing in), micturition (urination)**, **defaecation** and **parturition (delivery of fetus)**.

Control and Mechanism of Breathing

Movement of air from outside of the body into the lungs and from the lungs to the outside during breathing occurs when contraction and relaxation of diaphragm and muscles of ribs change the volume of thoracic cavity. These muscle movements are controlled by the respiratory centre of medulla oblongata in the human brain. Thus, the breathing movements are involuntary to a large extent. However, we can control the rate of breathing and the extent of breathing but not for a long time. The respiratory centre is stimulated by the carbon dioxide concentration of the blood. Breathing involves two stages:

1. **Inspiration or Inhalation (breathing in) :**
   Inspiration of air occurs when the volume of the thoracic cavity is increased. This occurs due to contraction of diaphragm and muscles attached to ribs. The contration of muscles attached to ribs causes rib cage to move upwards and outwards, thus increasing the volume of thoracic activity. When the volume increases, the pressure in the thoracic cavity becomes lower than the outside atmospheric air. Hence atmospheric pressure forces air into the lungs through the nose and trachea and finally to bronchi, bronchiole and alveoli.
2. **Expiration or Exhalation (breathing out) :**
   This occurs when thoracic cavity comes back to original size due to relaxation of diaphragm and rib muscles. When the volume of thoracic cavity is regained, the pressure of the air inside the thoracic cavity becomes greater than the atmosphere outside. Hence, air from inside the lungs is expelled through the trachea and nose to the outside to equalise the internal and external pressure.

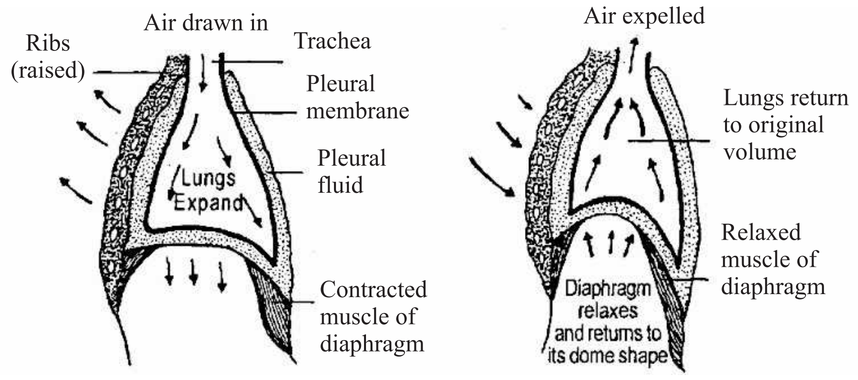


Fig. Mechanism of breathing: (a) Inspiration, (b) Expiration

Exchange and Transport of Gases

So, by above mentioned process air gets in the lungs and then alveoli (air sac) of lungs. After that the exchange of gases between blood and air sac occurs. Gases move from higher partial pressure to lower partial pressure (Unit of partial pressure is mm Hg). Oxygen from the air in alveloi passes into blood and carbon dioxide from blood passes into alveolar sac. Diffusion alone cannot deliver oxygen to all parts of the body specially in large organisms like humans. Thus we have a respiratory pigment haemoglobin, which has a very high affinity for oxygen. It is present in the RBC's and takes up oxygen from the air in the lungs and delivers it to different parts of the body. The terminal blood vessels i.e., the capillaries deliver the oxygen to the body cells or tissues where oxygen diffuses through their thin walls and in a similar way the capillaries pick up the carbon dioxide released by them.

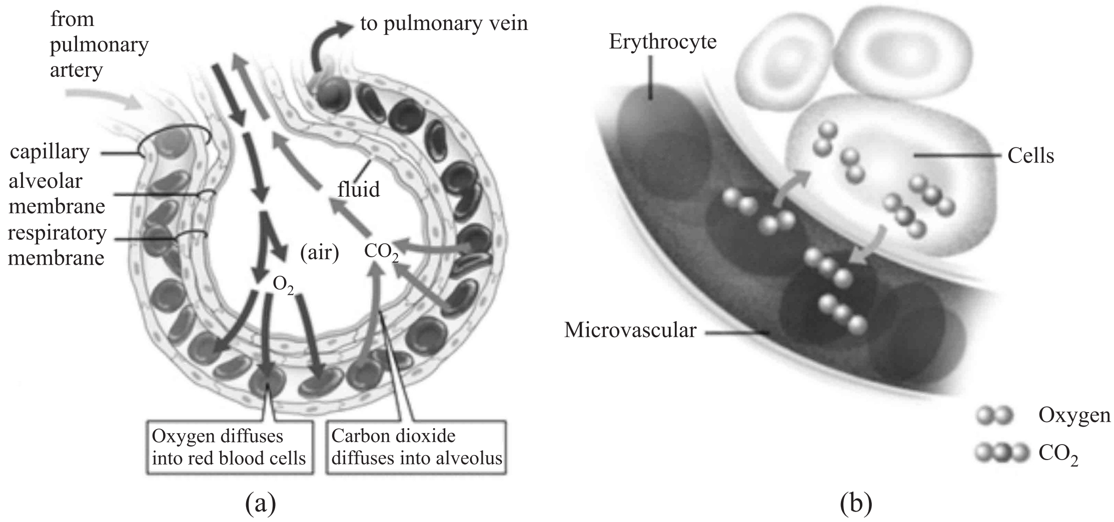


Fig. : (a) Gas exchange between air in alveolus and blood in surrounding capillaries
(b) Exchanges of gases between cells and blood

Table : Comparison of Exhaled and Inhaled air

	Inhaled air	Exhaled air
(i)	78% Nitrogen	78% Nitrogen
(ii)	21% Oxygen	17% Oxygen
(iii)	1% inert gas	1% inert gas
(iv)	0.04% carbon dioxide	4% carbon dioxide
(v)	Little water vapour	Saturated with water vapour

CONNECTING TOPIC

CONNECTING TOPIC

TRANSPORT OF OXYGEN AND CARBON DIOXIDE THROUGH BLOOD

The transport of O_2 from lungs to tissues and CO_2 from tissues to lungs through blood is called transport of gases.

(1) **Transport of oxygen :** It occurs in 2 ways –

(a) *By haemoglobin* : Haemoglobin (the pigment of blood) binds with 4 oxygen molecules and forms oxyhaemoglobin. 20.1 ml of O_2 is transported through haemoglobin of 100 ml of blood of normal man.

(b) *By plasma* : Due to low solubility, only 0.34 ml of O_2 is transported by 100 ml of blood plasma.

(2) **Transport of carbon dioxide :** It is transported in three forms:

(a) *As dissolved form in plasma* : 2.7 ml of CO_2 is transported in dissolved form in plasma of 100 ml blood from tissues to lung.

(b) *As carbamino compound* : 3.1 ml of CO_2 form *carbamino* compound with haemoglobin and other protein and is transported to lungs in 100 ml blood.

(c) *As bicarbonate form* : 45.7 ml of CO_2 is transported to lungs as sodium and potassium bicarbonate in 100 ml of blood.

Table : Functions of organs of human respiratory system

Organ	Function
Air Conducting part	
Nasal Cavity	Filters, warms, and moistens air; also transports air to pharynx.
Oral cavity	Transports air to pharynx, warms and moistens air; helps produce sounds
Pharynx	Transports air to larynx
Epiglottis	Covers the opening to the trachea during swallowing
Larynx	Produces sounds, transports air to trachea; helps filter incoming air, warms and moistens incoming air
Trachea and bronchi	Warm and moisten air; transport air to lungs, filter incoming air
Bronchioles	Control air flow in the lungs; transport air to alveoli
Gas exchange part	
Alveoli	Provide area for exchange of oxygen and carbon dioxide between blood and air in the alveolus

Did You Know?

On an average, a healthy human breathes 12-16 times per minute. During the breathing cycle (one sequence of inspiration and expiration), the lungs always contain a residual volume of air so that there is sufficient time for oxygen to be absorbed and for the carbon dioxide to be released.

Time to Check Your Knowledge

1. **Name the part of the root involved in exchange of gases.**
2. **Name the stage that is common for aerobic and anaerobic respiration.**
3. **Arrange the following events in the order of their occurrence during inspiration.**

- Increase in the volume of thoracic cavity
- Contraction of diaphragm and muscles attached to ribs
- Decrease in the pressure of thoracic cavity than atmospheric air
- Movement of air down the trachea to alveoli through bronchi and bronchioles
- Movement of rib cage upwards and outwards
- Expansion of lungs to fill the space created in thoracic cavity

SOLUTION

1. Root hair, the tubular extensions of outer layer of root cells are in direct with the oxygen present in the spaces between soil particles. Oxygen enters through root hairs into the root cells and carbon dioxide produced from cellular respiration moves out through root hair into the soil.
2. Glycolysis during which 6C glucose is broken down into two molecules of 3C pyruvate is common for both aerobic and anaerobic respiration.

3. The correct order of the events during inspiration is as follows:
- Contraction of diaphragm and muscles attached to ribs
- Movement of rib cage upwards and outwards
- Increase in the volume of thoracic cavity
- Expansion of lungs to fill the space created in thoracic cavity
- Decrease in the pressure of thoracic cavity than atmospheric air
- Movement of air down the trachea to alveoli through bronchi and bronchioles

TRANSPORTATION

All cells need oxygen, water, minerals and organic food for survival and maintenance. Lower organisms may be unicellular and they obtain it directly from the environment, but most of the organisms are multicellular and need specialised tissues to pick these substances from the environment. Some of these substances are synthesised in the organism by another group of specialised tissues and all body parts need them. So, these substances need to be distributed to the other parts of the organism. Thus, multicellular organisms have specialised system called transport system for distribution of substances.This process of carrying out proper distribution of materials from one place to another in the body is called **transportation**.

Transportation in Plants

Plants require water, CO_2 and minerals for their growth and development. They take in CO_2 directly from the air by diffusion, but other materials like nitrogen, phosphorus and other minerals which are absorbed from the soil through roots, cannot diffuse to leaves present at a large distance from roots. Also, food prepared in the leaves needs to be transported to other plant parts. Thus, a proper system of transportation is essential in plants. But transport system in plants is simple, less elaborative and is relatively slow because they do not move and have low energy needs due to presence of a large proportion of dead cells in many tissues.

Transport Systems in Plants

Plants have two transport systems:
- Xylem to transport water and minerals obtained from the soil.
- Phloem to transport photosynthetic products and other substances such as hormones from where they are synthesised to other parts of the plant.

Transport of Water and Minerals

The transport of water and minerals occur in the following stages:
- **Absorption of water and minerals by root hair:**

The minerals are first absorbed by thin-walled tubular extensions of epidermal cells of roots i.e., root hairs which are in contact with the soil. This leads to concentration difference of these ions between the root and the soil. Water, which is present as film in-between the soil particles, enters the root hair to eliminate this difference. It occurs through diffusion.
- **Movement of water from root hair to root xylem:**

From the root hair, water with dissolved minerals enters the tissues of the root and travels through intercellular spaces and cell wall or through interconnected protoplasts to move deeper to reach the root xylem.
- **Movement of water up a plant:**

Once inside the xylem of the root, water and minerals are pushed upward to other parts like stem, leaves, flowers etc. through two kinds of elements of xylem called xylem vessels and tracheids. These xylary elements of the roots, stems and leaves are interconnected to form a continuous system of water-conducting channels reaching all parts of the plant. Plants use two forces to move water upwards:

(i) **Root pressure:** It is the hydrostatic pressure in the root cells of some vascular plants when the soil moisture level is high either at night or when transpiration is low during the day. It is partially responsible for the rise of water in plants.

(ii) **Transpirational pull:** Water is present in the form of continuous column from mesophyll cells to the root xylem. As water evaporates from the cells of a leaf in the form of vapour from stomata through the process called transpiration, water is pulled, molecule by molecule, into the leaf from the xylem. Also, because of lower concentration of water vapour in the atmosphere as compared to intercellular spaces inside the leaf, water diffuses into the surrounding air. This creates a suction pressure called transpiration pull which is major driving force for upwards movement of water from the xylem. Thus, transpiration helps in the absorption and upward movement of water and minerals dissolved in it from roots to the leaves. It also helps in temperature regulation.

Transport of Food and Other Substances

Leaves synthesise food in the form of sucrose through the photosynthesis. The transport of soluble products of photosynthesis primarily sucrose from leaves to other plant parts such as storage organs of roots, fruits and seeds and to growing organs is called translocation. It occurs through sieve tubes of phloem with the help of adjacent companion cells both in upward and downward directions. Sieve tubes are long tubes which form long columns with holes in their end walls called sieve plates. Sieve tubes contain cytoplasm in them but have no nucleus. Each sieve tube cell associated with a companion cell to control its acitivities Besides the products of photosynthesis, the phloem transports amino acids and hormones synthesised in the apices of roots and shoot. Following steps are involved in the translocation of food:

- Sucrose prepared by mesophyll cells is transferred into companion cells and then into sieve tube elements using energy from ATP.
- This increases the osmotic pressure of the sieve tubes as a result water enters from adjacent xylem. This results in high pressure in the phloem tissue near the leaves.
- This pressure moves the material in the phloem to tissues which have lower pressure. This allows the phloem to move material according to the plant's needs. For example, in the spring, sugar stored in root or stem tissue would be transported to the buds which need energy to grow.

Transportation in Human Beings

Transport system in animals is called the **circulatory system**. Human beings have a high metabolic rate i.e., they require more nutrients and oxygen at a faster rate. They also produce more wastes that have to be removed from the cells in less time. Thus, they have efficient mechanisms so that movement of materials into and out of the system should be possible and also it should reach all the cells of the body and in time.

Materials to be transported include digested food, respiratory gases, hormones, excretory products, etc. Humans have two special fluids to transport materials. **Blood** is composed of 90% of water. Thus, only water soluble substances are transported through blood. For the transport of fatty substances, body uses another fluid called the **lymph**. Thus, there are two circulatory systems:

(1) Blood circulatory system **(2) Lymphatic circulatory system**

Learn More

Types of Blood Circulatory System

There are two types of blood circulatory systems:

(i) Open circulatory system: The blood enters and circulates in the interstitial spaces (space between the tissues). The exchange of materials between the cells and the blood is done directly. There are few blood vessels but they are not extensive. The blood vessels are open-ended as they open into the common cavities called the haemocoel, e.g. insects.

(ii) Closed circulatory System: The blood is always circulated through closed network of the blood vessels and never comes in direct contact with the cells. The materials enter and exit the blood vessels through the walls. The blood flows in the blood vessels under high pressure such that it reaches all the parts of the body in good time. The blood vessels are branched into fine capillaries which are actually involved in the exchange of materials e.g. mammals (including mean).

(1) Blood Circulatory System

It consists of following components:

(i) Blood

Blood is a liquid connective tissue. It is a complex liquid that performs a number of critical functions such as transport of respiratory gases, hormones, nutrients, regulation of body temperature, protection against blood loss (through the clotting process) and invasion of foreign microbes through antibody, and production. It is thicker and heavier than water. It is slightly alkaline and constitutes 8% of the total body weight.

Composition of Blood :

The blood consists of (1) a fluid part or plasma and (2) a cellular part or formed elements (red blood cells, white blood cells, platelets, etc.). Formed elements constitute about 40-45 per cent of the blood while the plasma constitutes the remaining 55-60 per cent.

CONNECTING TOPIC

Blood Components

Plasma :

It is the pale yellowish fluid with a total volume of 2-3 litres in a normal adult. Its contents are 90% water and the rest 10% includes proteins, inorganic ions and organic substances. Plasma is the medium in which the blood cells and other substances are transported around the body. It also maintains optimum body temperature. Plasma helps maintain an ideal balance of pH and electrolytes in the blood and tissues of the body.

Red Blood Cells (Erythrocytes) :

RBCs are the most abundant of all cells in the blood (5-5.5 million in each cubic millimetre of blood). They are minute biconcave disc like structures; flat in the centre, thick and rounded at the periphery.

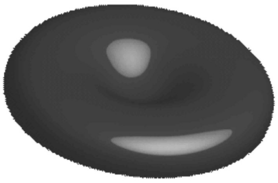


Fig.: Red blood cell

They do not have a nucleus. It has a diameter of 0.01 mm. They contain a red. iron containing protein known as **haemoglobin** which gives blood the red colour. RBCs are elastic because of which they are able to squeeze through narrow capillary. These cells are produced by the bone marrow and have a life span of 3-4 months. When they die, they are destroyed by macrophages in the liver and spleen. This process releases iron to be stored in the liver and bile pigments to be excreted.

RBCs are important for transport of gases. Oxygen readily combines with haemoglobin to form oxy-haemoglobin in the lungs where the concentration of oxygen is high. However, oxy- haemoglobin is an unstable compound and breaks down to release oxygen when the concentration of oxygen in the surrounding is low. RBCs also carry part of the carbon dioxide waste from the cells, though most of it is carried through plasma as soluble carbonates.

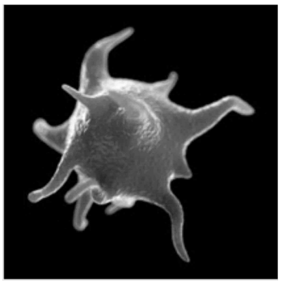


Fig.: Platelet

White Blood Cells (Leucocytes) :

WBCs are colorless, without haemoglobin. They contain nucleus and have an irregular shape. They are fewer in number than RBCs but they are much bigger in size. There are about 4000-8000 WBCs in each cubic millimeter of blood. These cells are also produced in the bone marrow. They have a life span of a couple of days. When they die, they are destroyed by surrounding WBCs and replaced with new ones. They can change their shape easily and this allows them to squeeze through the walls of the blood vessels into the intercellular spaces. They are responsible for the defense system in the body. Two types of WBCs are:

(i) **Granulocytes:** Cytoplasm has granules and nucleus which is usually constricted into lobes. These are of following types.

- **Neutrophils:** They contain a nucleus with 2-5 lobes. They are the most abundant cells (60-65 per cent) of the total WBCs. Neutrophils are a type of phagocyte and one of the first cell types to arrive at a site of infection, where they engulf and destroy the infectious microorganisms such as bacteria and fungus.
- **Eosinophils:** They have a nucleus with two lobes (bilobed) and cytoplasm filled with approximately 200 large granules. They account for 2-3 per cent of all WBCs and provide resistance against parasitic infections and are also associated with allergic reactions.
- **Basophils:** They contain large cytoplasmic granules which obscure the cell nucleus that has two lobes. They are the least (0.5-1 per cent) among granulocytes. They secrete histamine, serotonin, heparin, etc. and are involved in inflammatory reactions.

(ii) **Agranulocytes:** Cytoplasm is without granules and contains a single large nucleus.
They are of two types:

- **Monocytes:** They have a bilobed nucleus which appears as a U- or kidney-shaped. They are the largest cell and make up 6-8 per cent of white blood cells. Like neutrophils, they are also phagocyte but they are much larger and longer-lived than neutrophils. They engulf whole or killed microorganisms and cleanup cellular debris from sites of infection.
- **Lymphocytes:** They have round nucleus and account for 20-25 per cent of total WBC count. They are of two major types - 'B' and 'T' forms. Both B and T lymphocytes are responsible for specific recognition of foreign agents and immune responses of the body.

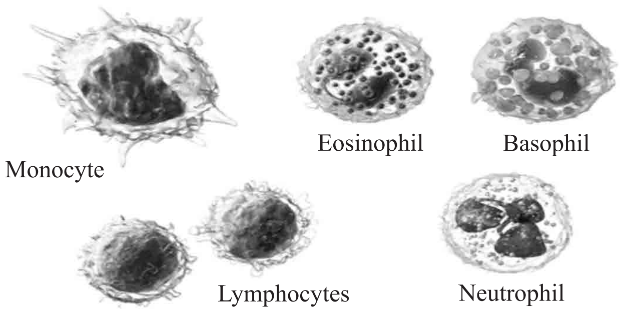


Fig.: Types of white blood cells

Blood Platelets (Thrombocytes) : They are cell fragments which are disc-shaped and have a diameter of 2-4 μm. They have many granules but no nucleus. There are about 150,000-400,000 platelets per microlitre of blood. They have a longevity of approximately 5-9 days. They facilitate blood clotting so as to prevent loss of body fluids.

CONSTITUENTS OF BLOOD

- Plasma (55%)
- Blood Cells (45%)
  - Red Blood Cells
  - White Blood Cells
    - Granulocytes
      - Neutrophils
      - Eosinophils
      - Basophils
    - Agranulocytes
      - Monocytes
      - Lymphocytes
  - Platelets

Functions of Blood

(a) Transport

- Dissolved gases (e.g, oxygen, carbon dioxide, etc.)
- Waste products of metabolism (e.g., water, urea)
- Hormones
- Enzymes
- Nutrients (e.g., glucose, amino acids, etc.)
- Plasma proteins (associated with defence, blood clotting, etc.)
- Blood cells (WBCs + RBCs)

(b) Maintain Body Temperature

(c) Control pH

(d) Regulation of Body Fluid Electrolytes

(ii) Blood vessels

These are hollow, tubular vessels which transport blood from the heart to the tissues and back to the heart. There are three types of blood vessels.

- **Arteries :** These are thick walled vessels which carry blood away from the heart. They are elastic in nature, have a narrow lumen, are deep seated in the body and have no valves in them. They have a diameter of 500 mm. They carry oxygenated blood in them, except the pulmonary artery which carries deoxygenated blood to the lungs. The blood passing through the arteries has a considerable pressure. The aorta is the biggest artery in the body.
- **Capillaries :** The arteries divide into arterioles which further divide and re-divide into smaller vessels called capillaries. They are the thinnest vessels (70 mm) and their walls are formed of a single layer of endothelial cells. These form a connective link between artery and vein. The wall of capillaries are peremable to water and dissolved substances so that exchange of material between the blood and body cells takes place. Slow flow of blood in the capillaries also facilitates this exchange.

- **Veins :** The arteriole capillaries join to form venous capillaries which then join to form the venules and veins. Veins are thin walled vessels which bring blood from the body back to the heart. They have widerlumen and can hold more blood than the arteries. They have less elastic walls, and are less muscular. Valves are present in most of the veins to prevent back flow of blood. Blood passing through wide lumen of veins is non-aerated (except in pulmonary vein) and has low pressure. The superior and inferior vena cava are the two main veins in the body.

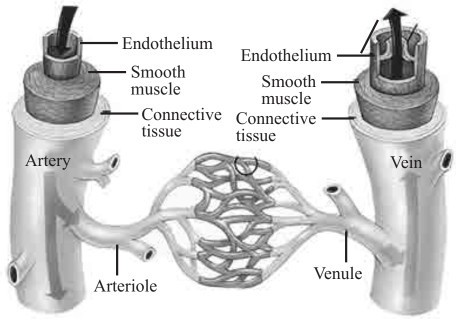


Fig.: Blood vessels

Blood clotting:

When the walls of blood vessels break due to injury, bleeding occurs for some time and then it stops to prevent the loss of blood due to the formation of reddish brown scum at the site of injury. It occurs when the liquid form of blood changes into a gel or clot at these points of injury. This process is called blood clotting. Following steps lead to the formation of blood clot at the site of injury:

- Platelets in the blood release a protein called thromboplastin which in the presence of Ca^{2+} converts prothrombin into thrombin.
- Thrombin in the presence of Ca^{2+} ions converts fibrinogen into fibrin threads which form a mesh-like network around the injury.
- This mesh of fibrin threads entraps blood cells and forms a jelly like mass called blood clot.
- Later liquid called serum oozes out and clot contracts and solidifies.

(iii) Heart

The human heart is a muscular, cone shaped, hollow organ about the size of a fist (12 cm in length and 9 cm in breadth). It is situated behind the sternum, between the lungs in the thoracic cavity slightly tilted towards the left.

The major part of the heart is made up of muscles - the **myocardium**. The inner lining of the heart is called **endocardium**. Heart is covered by double membrane called **pericardium**. The pericardial fluid is present between the two membranes of pericardium. It lubricates the inner membrane of pericardium and reduces the friction between the two membranes when the heart is beating. It acts as a pumping organ, i.e., it pumps blood through the network of blood vessels.

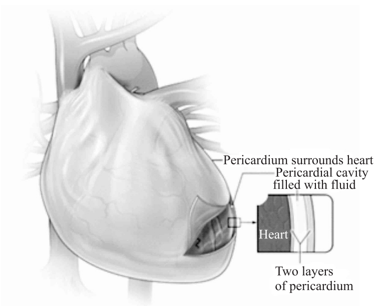


Fig.: Percardium and pericardial fluid

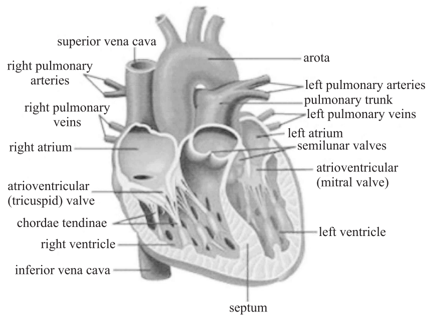


Fig.: Structure of human heart

Internal Structure : The human heart is four chambered. The upper two thin-walled chambers are called the auricles or the **atria** and the lower two thicker walled chambers are called the **ventricles**. The two auricles are separated by the interauricular septum and the two ventricles are separated from each other by the interventricular septum. The ventricles have thicker muscular walls than the auricles as they have to pump out blood to various parts of the body. The right auricle opens into the lower right ventricle. This opening is guarded by a **tricuspid valve**. The left auricle opens into the left ventricle. This opening is guarded by a **bicuspid valve**. Both these valves called atrioventricular valves (AV valves) prevent backflow of blood into the auricles from the ventricles.

The auricles are the receiving chambers. The deoxygenated blood from different parts of the body are collected by the two major veins - **superior vena cava** collecting from the upper body and the **inferior vena cava** collecting from the lower body. Blood from both the vena cave is poured into the right auricle. The left atrium receives oxygenated blood from the left and right pulmonary veins coming from the left and right lungs respectively.
The ventricles pump blood into the blood vessels. The right ventricle pumps blood into the pulmonary artery which takes deoxygenated blood to the lungs. The junction between the right ventricle and pulmonary artery is guarded by **semilunar valve** which prevents backflow of blood from artery into the ventricle.
The left ventricle opens into the major artery called the **aorta**. The junction between the aorta and left ventricle is also guarded by semilunar valves.
Therefore, the right side of the heart is concerned with the deoxygenated blood and the left side of the heart is concerned with the oxygenated blood.

Working of Heart

Heart beats in rhythmic manner to pump blood. This beating action of the heart is due to contraction and relaxation of its chambers. One complete contraction and relaxation of heart chambers constitutes one heartbeat. All these events that occur from the beginning of one heartbeat to the beginning of the next are referred to as **cardiac cycle**. There are two phases of the cardiac cycle: relaxation or diastole phase and contraction or systole phase. The details of these events are as follows:

- At the beginning of a cardiac cycle, both atria and ventricles are relaxed (joint diastole) and atrioventricular valves are open. Right atrium receives deoxygenated blood from different parts of the body through vena cavae. Since tricuspid valve is open, deoxygenated blood flows from right atrium to right ventricle. At the same time, left atrium receives oxygenated blood from lungs through right and left pulmonary veins. The oxygenated blood from left atrium flows into left ventricle due to opening of bicuspid or mitral valve.
- In the next phase, atria contract (atrial systole). This exerts pressure on blood forcing more blood through AV valves into ventricles.
- Then atria begin to relax and ventricles start contracting (ventricular systole). As ventricles contract, pressure in ventricles rises and AV valves close to prevent backflow of blood into atria. As ventricles continue to contract, pressure raises further causing semilunar valves to open. Now, deoxygenated blood from right ventricle flows into pulmonary artery which carries blood to lungs for oxygenation. At the same time, oxygenated blood from left ventricle flows into aorta which carries blood to different body parts to transport oxygen.
- Now ventricles also begin to relax (ventricular diastole). As pressure in the ventricles falls, semilunar valves close to prevent backflow of blood from blood vessels into respective ventricles. As pressure in ventricles falls further, AV valves open and blood starts flowing from atria to respective ventricles. The ventricles and atria are now again in a relaxed (joint diastole) state. This sequence of events in the heart cyclically repeats to pump blood continuously.

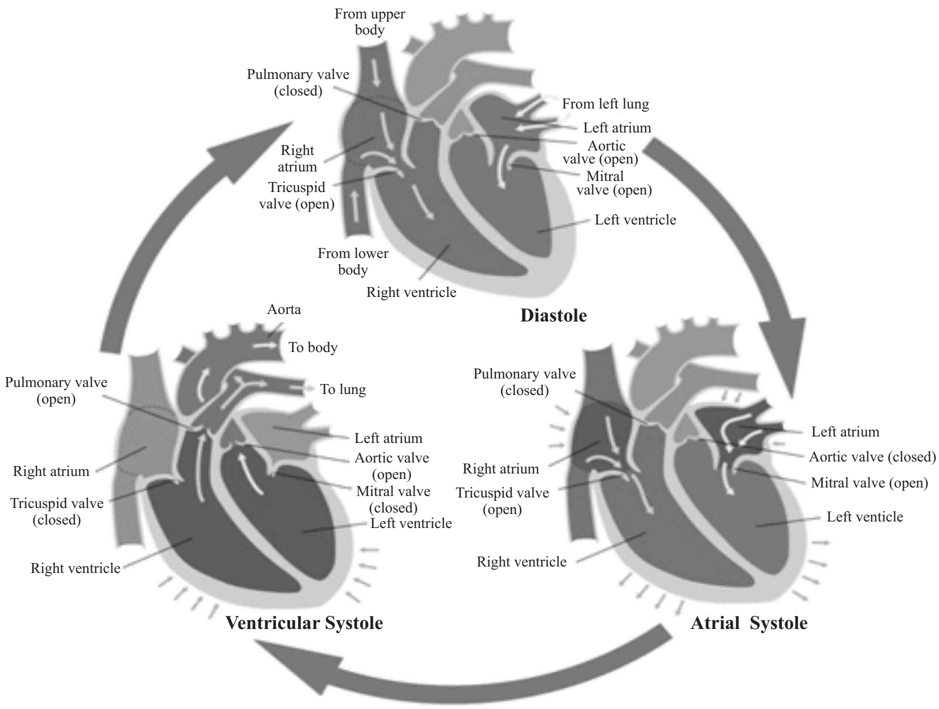


Fig.: Cardiac cycle

The number of times the heart beats per minute is called **heart rate**. For a normal adult human, it is about 72 times per minute. For infants, it is a higher figure. It also goes up during physical exercise.

Double Circulation:

Two circulatory pathways operate in man which are (i) **Systemic circulation** which accounts for supply of oxygenated blood to all parts of the body through arteries and arterioles from the left ventricle and return of deoxygenated blood from the tissues through veins and venules to the right atrium; and (ii) **Pulmonary** circulation which is the circulation of blood between heart and lungs for purification of blood. i.e., transport of deoxygenated blood from right ventricle to alveoli within lungs and return of oxygenated blood from lungs to left atrium.
In human beings, the circulation is called **double circulation** because the blood passes twice through the heart during one round of circulation.

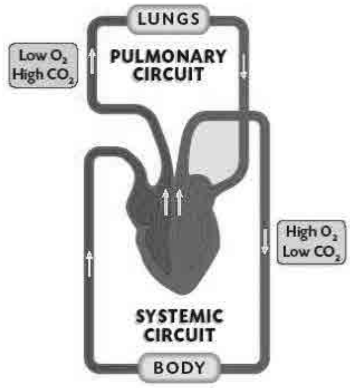


Fig. Diagrammatic representation of double circulation in Human being

Blood pressure :

Blood pressure is the pressure exerted by blood on the walls of blood vessels. It is required to prevent the blood vessels to collapse and for circulation of blood throughout the body.
The pressure inside the artery during ventricular systole i.e. when blood is pushed into arteries is called **systolic pressure** and is equal to that exerted by 120 mm column of mercury. The pressure created during ventricular diastole i.e. when ventricles are relaxing is called **diastolic pressure** and measures 80 mm of mercury.
Normal blood pressure is considered to be 120/80 mm of mercury. Blood pressure can be taken with the help of sphygmomanometer at the brachial artery, just above the elbow.

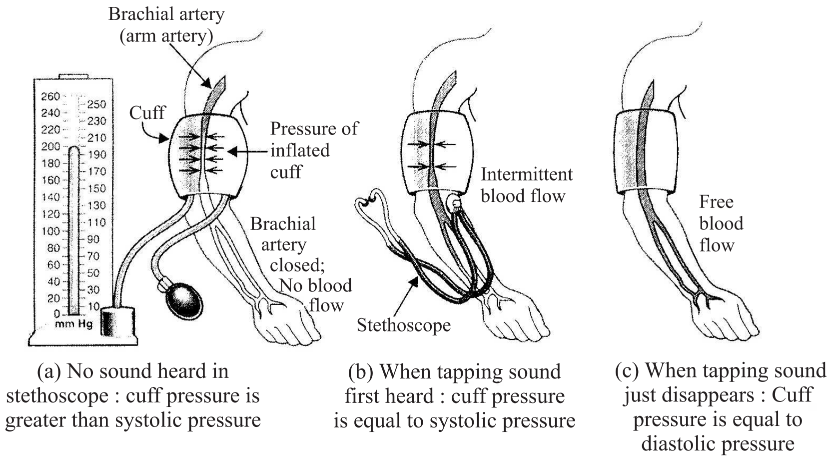


Fig.: Measuring of blood pressure by using a mercury sphygmomanometer

High blood pressure, also called hypertension, is the medical condition in which the force of blood flowing through arteries is very high. It is caused by the constriction of arterioles, which results in increased resistance to blood flow. It can lead to the rupture of an artery and internal bleeding.

CASE STUDY-1 : Circulatory System

CASE - I : *What happens if the aortic valve is reduced or blocked?*

Aortic valve is one of the semilunar valve that guards the opening between left ventricle and aorta. If it is reduced or blocked, the heart would need to work harder to pump the blood and can have serious health implications.

CASE - II : *What happens if the capillaries are not numerous and are broad?*

The main function of capillaries is to provide the maximum surface area to allow the exchange of materials between blood and the body cells. High diameter (broad) leads to high pressure and less number gives less surface area for exchange resulting in serious health problems

CASE - III : *What happens if the pressure in the left ventricle exceeds that in the left atrium?*

If the pressure in the left ventricle exceeds that in the left atrium then bicuspid or the mitral valve closes.

CASE - IV : *What happens to the atria during ventricular systole?*

During ventricular systole, the ventricles are contracting and pushing blood to the lungs and other body parts, while the two atria are relaxed.

Think Out of the Box

Q.1 Arteries carry oxygenated blood and veins carry deoxygenated blood. Is it true?
Q.2 Why is blood pressure measured in arteries and not veins?
Q.3 Blood sample is always drawn from vein. Why?

(2) Lymphatic System

Lymphatic system is an accessory circulatory system which transports lymph from the intercellular spaces of tissues to the blood. So, this system is open. This system is formed of the following components:

(i) Lymph : It is a straw coloured fluid connective tissue. It is formed by the passage of water along with some substances from the blood through the wall of the blood capillaries into the inter-cellular tissue spaces. It is formed by the process of diffusion and filtration from the blood. It is called extra- cellular fluid as it lies outside the cells. Exhange of materials i.e., nutrients and gases between blood and cells occur through this fluid. It carries digested and absorbed fat from intestine and returns excess fluid to the blood. It consists of two parts:

(a) **plasma** is the fluid matrix, in which the lymphocytes float.

(b) **lymphocytes** are special type of white blood cells which fight against infection. It differs from blood in lacking red blood corpuscles, platelets and some proteins.

About 120ml of lymph flows through the lymphatic system per hour into the blood.

(ii) Lymph Vessels : Lymph vessels have walls that are single celled in thickness. The lymph vessels begin as close ended capillaries which are embedded within interstitial space and gather fluid and carry it to the bigger lymph ducts. All vessels finally join together to form two large vessels (thoracic duct or left lymphatic duct and right lymphatic duct) which open into venous system at the subclavian vein of their side. The lymph vessels do not have any muscles but have valves that allow only unidirectional lymph flow. Lymph is circulated in the body with the help of the action of the muscles surrounding the lymph vessels.

(iii) Lymph nodes : Throughout the lymphatic system, the lymph vessels enlarge at certain places to form cavities called lymph nodes. The lymph nodes are lined with phagocytic cells and have numerous lymphocytes. The lymphocytes produce antibodies against bacteria and other germs and attack them. The lymphocytes become more active during an infection and this causes an increase in their size e.g., tonsils enlarge and become painful during bacterial infection.

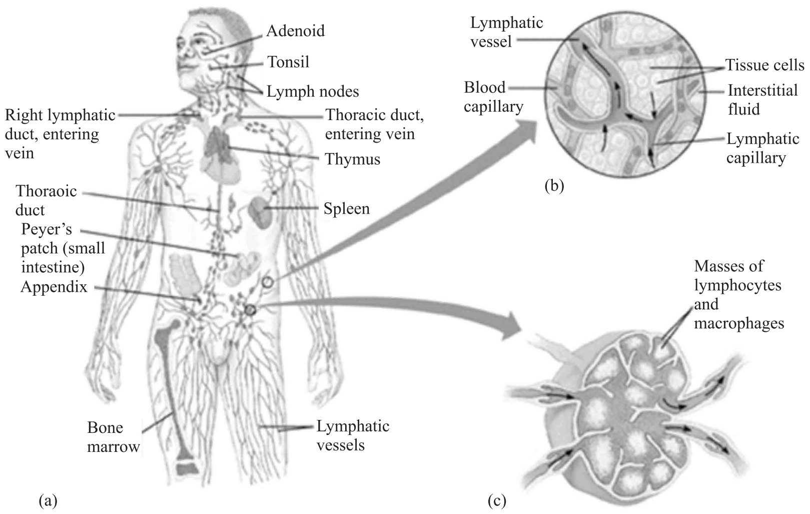


Fig. : (a) Lymphatic system (b) Lymphatic vessels and lymph (c) Lymph node

Time to Check Your Knowledge

1. **Name the substance that is transported by sieve tube elements.**
2. **During ventricular systole phase of cardiac cycle, ventricles expand and oxygenated blood from left ventricle flows into pulmonary artery and deoxygenated blood from right ventricle flows into aorta. Identify the mistakes in this statement and write down the correct statement.**
3. **What is the function of a type of blood cell having large cytoplasmic granules which obscure its bi-lobed nucleus?**

SOLUTION

1. Sugar primarily sucrose, amino acids and hormones are translocated by sieve tube elements with the help of companion cells.
2. The correct statement is:

During ventricular systole phase of cardiac cycle, ventricles contract and deoxygenated blood from right ventricle flows into pulmonary artery and oxygenated blood from left ventricle flows into aorta.

3. The blood cell having large cytoplasmic granules which obscure its bi-lobed nucleus is a type of granulocyte, basophils. They secrete histamine, serotonin, heparin, etc. and are involved in inflammatory reactions.

EXCRETION

Cells of every organism carry out many metabolic activities which generate many harmful waste products. These wastes are not only useless for the cells of the body, but could even be harmful. Thus, these waste byproducts are removed from the body and discarded outside by a process called excretion. The continuous production of metabolic wastes establishes a steep concentration gradient across the plasma membrane, causing wastes to diffuse out of cells and into the extra cellular fluid.

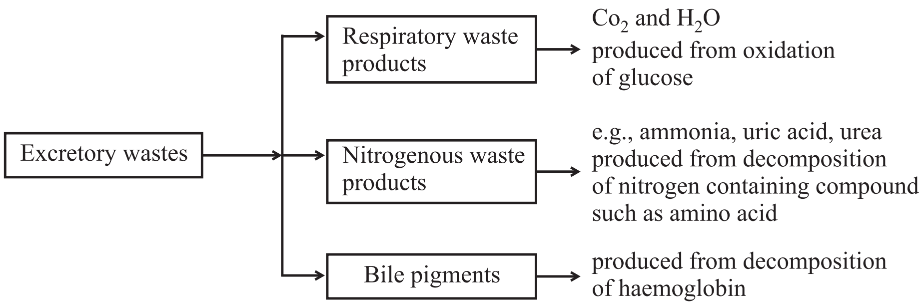


Fig.: Different types of excretory wastes

Different organisms use varied strategies to remove waste products. Single-celled organisms and plants have most of their wastes diffusing out into the outside environment. Multicellular organisms, and animals in particular have specialised organ system to concentrate and remove wastes from the interstilial fluid into the blood capillaries and eventually outside the body.

The excretory system is a passive biological system that removes excess unnecessary or toxic materials from an organism, so, as to help maintain homeostasis within the organism and prevent damage to the body. It is responsible for the removal of waste products of metabolism as well as other liquid and gaseous wastes. Though every functioning organ produces metabolic and other wastes, but only those specific organs, which are involved with removal of waste entirely from the body, are considered part of the excretory system.

Excretion in Plants :

Plants do not possess any specialised excretory organ for the removal of metabolic waste products. Carbon dioxide, a by- product of respiration, is an excretory product liberated at night. It is removed from the tissue cells by diffusion through a system of intercellular spaces in leaves, stem and roots. In leaves and young stems, the carbon dioxide escapes out into the atmosphere, through the stomata. In roots, carbon dioxide diffuses out through general root surface. Plants get rid of excess water by transpiration.

Other metabolic waste products may be deposited as harmless crystals in the plant body e.g., calcium oxalate is deposited in the form of crystals in stem and leaves of many plants e.g. spinach and balsam. In trees which shed their leaves every year, the excretory products are removed from the tree during leaf fall. Volatile oils occur in petals of many flowers and are responsible for their characteristic odour. This volatile oil is an excretory product but is beneficial in certain cases. The wastes produced by plants can also be stored in leaves, vacuoles or other parts. Other waste materials that are excreted by some plants are resins, saps, latex, etc which are forced from the interior of the plant by hydrostatic pressure inside the plant and by absorptive forces of plant cells. Excess salt is removed through hydathode along with guttation water.

Excretion in Animals

There are different specialised organs of excretion in different animals. In *Amoeba* and other unicellular animals, contractile vacuole serves the function of excretion and osmoregulation. In sponges and cnidaria, waste diffuses out through the osculum and the oral opening respectively. In flatworms, excretory units are called **flame cells**. In earthworm, tubular structures called nephridia help to remove nitrogenous wastes and maintain a fluid and ionic balance. In human beings, the microscopic thin tubules, **nephron**, participate in excretion.

Excretion in Human Beings

Main Excretory Organs: The human body has different organs for removal of wastes from the body. These organs are: Urinary System: Kidneys filter the blood to form urine, which is excess water, salt, urea and uric acid removal of carbon dioxide.

Accessory excretory organs

- Lungs: removal of carbon dioxide
- Liver: produces urea and uric acid as a by-product of the breakdown of proteins, bile pigments from haemoglobin of aged RBCs, and breaks down toxic substances in the blood.
- Skin: removal of excess water, salt, urea and uric acid.

Organs of Urinary System

The urinary system consists of following organs:

1. **Kidneys :** These are two bean- shaped reddish brown coloured organs located in the back of the abdominal cavity on either side of the backbone. It is the main organ of excretion through which the nitrogenous wastes are eliminated in the form of urine. An average size kidney is about 12 cm long, 6 cm wide and 2-3 cm thick, and weighs about 150 gm. The function of the kidney is to filter blood and form urine. The renal artery carries the blood containing waste substances to each kidney. Kidneys contain millions of complex tubular filtration units called nephrons. They filter 170 to 200 litres blood to produce 1-1.8 litres of urine daily. The renal vein carries filtered blood away from each kidney.
2. **Ureters :** These are two tubes which arise from each kidney and carry urine from kidneys to the bladder.
3. **Urinary bladder :** This is a muscular sac-like structure where urine is stored till it is released out.
4. **Urethra :** This is a short muscular tube that carries urine from the urinary bladder to the outside of the body.

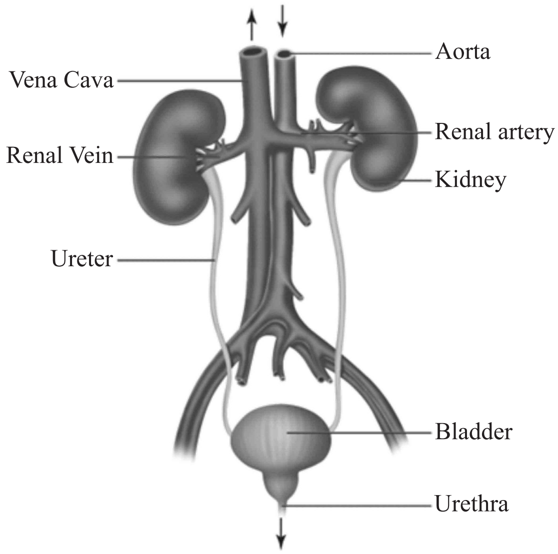


Fig.: Human Urinary System

Nephron

Nephron is the structural and functional unit of the kidney. Each nephron functions as an independent unit and produces a miniscule quantity of urine: A nephron can be differentiated into the following regions:

(i) **Malpighian corpuscle :** This consists of two parts –

(a) **Bowman's capsule :** This is a double walled, cup shaped structure with a network of capillaries called glomerulus.

(b) **Glomerulus :** This is a mass of blood capillaries with an incoming and an outgoing arterioles, fine branches of renal artery. The diametre of incoming arteriole called afferent arteriole is greater than that of outgoing arteriole called efferent arteriole. This difference in the diameter of arterioles creates resistance in blood flow. This causes blood pressure in glomerulus to become high to force the filterate from the blood into the Bowman's capsule.

(ii) **Renal Tubule :** This is the remaining tube-shaped part of the nephron, and is continuous with the Bowman's capsule. It is lined with ciliated epithelium and differentiated into the following regions:

Coiled tubular part called Proximal convoluted tubule, hair pin like part called Henle's loop and coiled tubular part called Distal convoluted tubule.

The distal convoluted tubule continues to form the collecting tubule. Several such tubules fuse to form large collecting ducts which pass downwards and open into a bread funnel-shaped space called pelvis of the kidney. From the pelvis, the urine moves through the ureter to the urinary bladder.

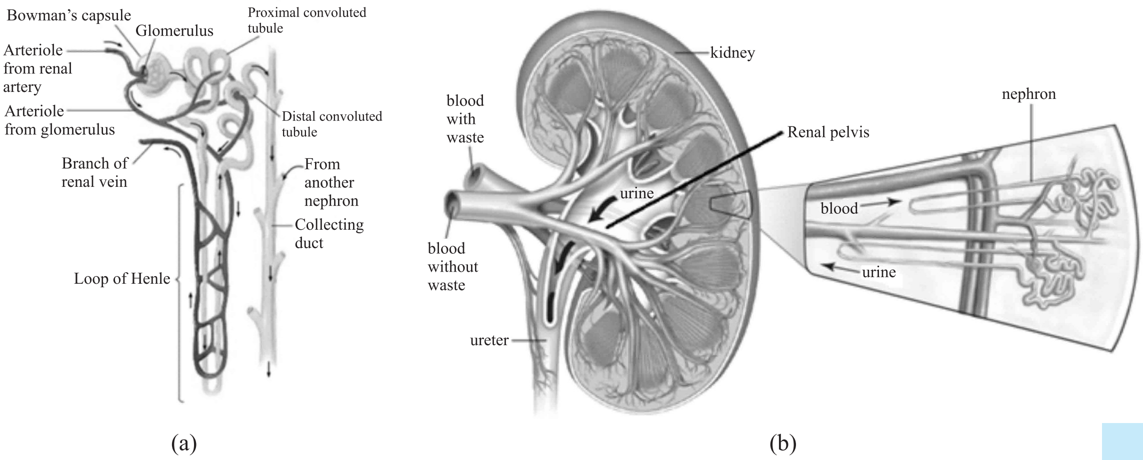


Fig. : (a) Structure of nephron (b) Flow of urine and blood in the kidney

Process of Urine formation

Kidney filters the blood, coming from the heart and form urine. This process of urine formation happens in the nephrons present in kidneys. This completes in three stages:

1. **Filtration:** This is the first step in the formation of urine. This occurs in the glomeruli. Blood pressure helps plasma of the blood to pass through the capillary walls in the glomerulus into Bouman's capsule and flows into proximal tubule. The filterate only contains water, glucose, amino acids, excess salts and urea.
2. **Reabsorption:** During this stage, the substances considered necessary in the filtrate i.e., water, glucose, amino acids and ions such as Na^+, K^+, etc. travel back into the bloodstream in the capillaries surrounding the renal tubule and it occurs in the renal tubules.
3. **Tubular Secretion:** This is the passage of unwanted substances such as H^+ ions, K^+ ions, ammonia and certain drugs out of the capillaries around the tubules directly into the renal tubules. This is an additional way of getting waste material into the urine. The fluid moving from distal tubules into collecting duct is a light yellow watery fluid called urine.

   The urine from the collecting ducts is then carried through ureters to urinary bladder and eventually pass out of the body through urethra. The process of release of urine is called **micturition**. On an average the urine output in a healthy person is 1 to 8 liters per day. Urine contains about 95% water and 5% nitrogenous substances, mostly urea, uric acid, etc.