2. Nutrition

Nutrition refers to the process by which an organism absorbs and utilizes food substances.

Food

Life cannot exist without energy. Energy is inevitable for the day-to-day life activities. This energy is derived from food. Food is defined as a ***composite mixture of various substances which sustain life activities.*** Foodstuff is defined as anything which can be used as food. The foodstuff of animals is composed of the following six components :

1. Carbohydrates
2. Proteins
3. Fats
4. Vitamins
5. Minerals and
6. Water

Role of Food

Food has four important functions in the life of animals. They are as follows :

1. It supplies ***energy*** which maintains the day-to-day life activities.
2. Food is essential for the ***growth*** and ***repair*** of body and its parts.
3. It gives ***temperature*** for the body.
4. Certain type of food materials like vitamins ***regulate*** the activities of animals.

1. Carbohydrates

Carbohydrates are the cheapest sources of energy in the animal food. Carbohydrates are ***hydrates of carbon*** with an empirical formula Cn (H_2O). Hydrogen and oxygen are combined in the same ratio as in water (H_2O). Hence they were named carbohydrates. But a number of carbohydrates, discovered later do not have H and O in the above proportion; again some carbohydrates contain N and S. Still the unsuitable name, carbohydrates, is retained. Carbohydrate is defined *as an organic compound that contains carbonyl group, namely aldehyde or ketone in addition to two or more alcohol groups or that yields such compounds on hydrolysis.*

Eg. Glucose, Fructose, Sucrose, Lactose Cellulose, Starch, Glycogen etc.

Physiological Role of Carbohydrate

Carbohydrate has the following functions :

1. It is the main source of energy. Energy is essential for day-to-day activities.

2. It plays main role in metabolism.

3. It provides ***roughage.*** Roughage is the undigestible part of carbohydrate e.g. cellulose diet. It gives bulk to the diet and hence it helps to satisfy the appetite.

4. It forms the main source of reserve food e.g. glycogen, starch, etc.

5. When sufficient amount of carbohydrate is provided in the diet, proteins are not utilized for energy purposes. As a result the entire protein taken in the diet can be utilized for the building of the body tissues. This is known as ***protein sparing action*** of carbohydrate.

6. Most of non-essential amino acids are synthesized from the intermediate products of carbohydrate.

2 Proteins

The term 'protein' is derived from a Greek word '***protes***' meaning 'prime' or 'first importance'. Proteins are complex organic nitrogenous compounds. They contain C, H_2, O_2, N_2 and S. Some proteins also contain P and Fe.

Proteins are defined as ***high molecular weight polymers in which the building blocks are the aminoacids.*** Amino acids are the basic units of proteins. Each protein is formed of several amino acids. *Eg. Albumen, Globulin, Haemoglobin etc.*

Physiological Role of Proteins

In the animal world, protein has the following functions:

1. Most of the ***enzymes*** are protein in nature. The enzymes are functioning as ***biocatalysts.***

2. The ***hormones*** secreted by endocrine glands are pro[tein in n]ature.

3. Haemoglobin transports gases.

4. Immunoglobin of blood plasma acts as *antibodies.*

5. Proteins are essential for the ***growth*** and ***repair*** of animals.

6. They supply ***energy*** and ***heat.***

7. Some proteins serve as ***structural materials*** of various body parts. Eg. myosin of muscles, keratin of skin and nail and collagen of connective tissue.

8. Nucleoproteins form important constituents of ***genes.***

3. Lipids

Lipids include *fats, oils, waxes,* etc. They are natural compounds of C, H and O. The term lipid is applied to a group of natural substances characterized by their insolubility in water and their solubility in *fat solvents* like ether, chloroform, boiling alcohol and benzene. ***Chemically lipids are either esters of fatty acid or substances capable of forming such esters*** (Ester is a combination of an alcohol with an acid).

Physiological Role of Lipids

1. Fats serve as the main source of energy in organisms.

2. It is a storage food in organisms.

3. They are responsible for cell permeability and cell organization.

4. They provide flavour and taste to the diet.

5. They serve as vehicles for the fat soluble vitamins A, D, E and K.

6. Adrenal corticoids and sex hormones are synthesized from fat derivatives.

7. The fat deposition below the skin acts as an insulator against excessive heat loss. Eg. Blubber in whales.

8. Fats supply essential fatty acids like linoleic acid, arachidonic acid, etc. Deficiency of essential fatty acids leads to ***follicular hyperkeratosis*** or ***phreniderma.***

9. Fats provide support for many organs in the body such as heart, kidney and intestine.

4. Vitamins

"A vitamin is something that makes us sick, when we do not eat it". This is the saying of ***Szent Gyorgyi*** on vitamins. Vitamins are defined as potent organic compounds, occurring in varying and minute proportions in food, which must be available to the organism from exogenous sources, in order that physiological processes essential to life may proceed normally. The salient features of vitamins can be summarised below :

1. Vitamins are organic compounds.
2. Plants synthesize vitamins; animals can synthesize a few.
3. Animals obtain the vitamins from the food stuffs.
4. Man requires about 15 or lesser vitamins.
5. They are required in very small quantities.
6. They function like hormones.
7. They do not provide any energy for the animals; but they regulate the physiological activities functioning as catalysts.
8. Vitamins are destroyed by high temperature and cooking for longer duration of time.
9. When vitamins are deficient in the food, they produce a set of diseases called ***deficiency diseases.*** These diseases can be cured only with the treatment with the particular vitamin which is deficient.

Dr. Funk introduced the term ***'vitamine'*** for these organic compounds. The vitamin which Funk extracted contained an amine and that is found to be essential for 'vital' activities. Hence he coined the name ***Vitamine.*** But later it was found that amine was not present in all the vitamins discovered. Hence 'e' was deleted and the term ***Vitamin*** was used instead of ***Vitamine.***

Classification

Vitamins are named with the alphabet with the order of their discovery. Thus there are vitamins A, B, C, D, K, Q, U, etc. The vitamins are classified into two groups according to their solubility. They are ***fat soluble*** vitamins and ***water soluble*** vitamins. Vitamins A, D, E and K are ***fat soluble*** and Vitamins B and C are ***water soluble.***

1. Vitamin A : Retinol or Antixerophthalmic Vitamin

It was discovered by ***Mc Collum*** in 1913. It is a ***fat soluble*** vitamin. It exists in two forms, namely Vitamin A_1 (Retinol$_1$) and Vitamin A_2 (Retinol$_2$). The empirical formula of A_1 is $C_{20}A_{23}OH$ and that of A_2 is $C_{20}H_{27}OH$.

Animals synthesize vitamin A from ***carotene.*** Hence carotene is called ***provitaminA.*** A single carotene is split into two molecules of vitamin A.

Sources : Leafy vegetables like amaranth, spinach, coriander, drumstick leaves, carrots, yellow pumpkins, fruits like mangoes, papayas, tomatoes, etc. Fish liver oils like cod-liver oil, halibut liver oil, milk, butter, ghee, egg, fish, etc.

Functions : 1. Vitamin A is an important component of rhodopsin of retina. Hence it is essential for vision.

2. It promotes growth.

3. It is essential for protein synthesis.

4. It maintains the normal growth and shape of bones.

5. It is essential for the synthesis of mucopolysaccharides.

6. It promotes fertility.

7. It has some specific functions on carbohydrate metabolism.

8. It is essential to the normal structure and functions of epithelial tissues.

9. It is essential for the metabolism of DNA.

Deficiency : 1. In children deficiency of vitamin A ***retards growth.*** It leads to loss of weight.

2. Vision in dim light is carried out by the rhodopsin pigment present in the retina of eye. Vitamin A is essential for the synthesis of rhodopsin. When vitamin A is deficient rhodopsin cannot be synthesized. This leads to a failure of vision in dim light. This type of eye defect is called ***night blindness*** or ***nyctalopia.***

3. The deficiency leads to reddening, dryness, and lusterless condition of the eye. This defect is called ***xerophthalmia.***

4. In extreme cases of deficiency the cornea becomes soft, disorganised and destroyed. This defect is called ***keratomalacia.***

5. Degeneration of lacrymal gland.

6. Sweat and sebaceous glands of skin degenerate.

7. The glands present in the alimentary canal and the epithelial lining degenerate.

8. The epithelium of the respiratory tract becomes stratified and degenerate.

Over dose of vitamin A is toxic to the body. It causes ***hyper vitaminosis*** which is characterized by drowsiness, sluggishness, severe headache, vomitting and peeling of the skin.

2. Vitamin D : Calciferol or Antirachitic Vitamin

This vitamin was discovered by ***Mc Collum*** in 1922. It is a ***steroid*** compound. It exists in five known forms. They are Vitamin D_1, D_2, D_3, D_4 and D_5. Vitamin D_2 is of common occurrence and is called ***ergocalciferol.*** Its molecular formula is $C_{28}H_{43}OH$. Vitamin D_3 is called ***cholecalciferol.*** Vitamin D is formed by the irradiation of sterols. Vitamin D_5 is derived from plant sterol ***ergosterol.*** The skin of man contains large amount of ***cholesterol.*** This is converted into vitamin D on exposure of the skin to sunlight.

Sources : Fish liver oils are the richest sources of vitamin D. Butter, milk and egg also contain vitamin D.

Functions : 1. It helps calcium absorption in the intesti..

2. It improves absorption of phosphate.

3. It is essential for calcium metabolism.

4. Helps in the normal development of bone and teeth.

5. It helps in the deposition of calcium and phosphates in the bones.

Deficiency : Deficiency of this Vitamin causes ***rickets*** in children and ***osteomalacia*** in adults.

Rickets

Rickets is a ***deficiency disease*** caused by the deficiency of Vitamin D. It commonly occurs in children. It is characterised by soft and weak bones and the leg bones are curved and ***bow-shaped.*** The ribs have a beaded appearance and ***pigeon breast*** develops.

Calcium is wasted in the faeces and hence it is not available for ossification of bones. Hence the bones are cartilaginous in nature. As vitamin D prevents rickets, it is called ***antirachetic vitamin*** Pigeon Chest develops.

Osteomalacia : It is a form of adult ricket. It is due to deficiency of Vit D and calcium salts in the diet. It occurs in women during pregnancy and lactation when a large amount of calcium is depleted from the mother.

3. Vitamin E : Tocopherol or Antisterility Vitamin

It was discovered by *Matill* and *Conclin* in 1920. It is a fat soluble vitamin. The word tocopherol is derived from two Greek words namely, *tokos* = Childbirth; *phero* = to bear. It is necessary to the fertility of male and the birth process of female. It exists in three forms namely α, β and γ tocopherols. Alpha tocopherol is the most potent form.

Sources : The richest sources of Vitamin E are wheat germ oils, cotton seeds oils and the germs of seeds. It is also found in the liver of horse and cattle muscles of heart, kidney, placenta, egg-yolk and milk. Man requires 15 to 20 mg daily.

Functions : 1. It functions as an ***antioxidant.*** It prevents oxidation of certain substances like Vitamin A, fatty acids and sulphur containing amino acids.

2. Essential for the normal reproduction of rats.

3. Essential for the normal functioning of muscles.

4. Essential for the biosynthesis of Co enzyme Q.

Deficiency : Deficiency of Vitamin E causes the following defects :

1. In the female rat the foetus dies some time after implantation. This defect is called ***resorption sterility.*** Prolonged deficiency in the female leads to loss of ability to conceive. In the male prolonged deficiency leads to the degeneration of testis and per-

2. In rats, guinea pigs and rabbits deficiency leads to degenerative changes in the muscles and paralysis. The defect is called ***nutritional muscular dystrophy.***

3. It leads to ***necrosis*** of the heart muscles.

4. In chicks it leads to ***embryonic mortality*** due to the disintegration of blood vessels.

5. ***Exudative diathesis***, is another defect in chicks. It is characterized by the appearance of large patches of subcutaneous oedema on the breast, abdomen, neck and legs.

6. A third deficiency disease in chicks is ***encephalomalacia.*** It is characterized by motor incoordination, head retraction and death.

7. Combined deficiency of Vitamin E and selenium causes ***hepatic necrosis.***

8. The physiological role of Vitamin E in man is not known accurately. However it is reported that deficiency of this Vitamin causes habitual abortion, muscular dystrophies, peripheral vascular disorders, heart disorders and menopause.

4. Vitamin K or Antihaemorrhagic Vitamin

This Vitamin was discovered by ***Dam*** in 1935. It is a fat soluble Vitamin. It is named K because it is essential for ***koagulation*** (coagulation) or blood clotting.

Sources : Vitamin K is synthesized by green plants and micro-organisms. Cabbage, spinach, alfalfa, tomato, soyabean, etc. are the richest sources. It is present in small amount in liver, fish, milk, ghee, egg, etc. Active forms of Vitamin K can be artificially synthesized.

Functions: 1. It is essential for the synthesis of prothrombin in the liver. Prothrombin is essential for the coagulation of blood. Hence Vitamin K is essential for the coagulation of blood. Hence it is called an ***antihaemorrhagic*** Vitamin.

2. It plays a key role in the respiratory chain mechanism and oxidative phosphorylation.

Deficiency Symptoms : When Vitamin K is deficient, coagulation is prevented; when there occurs an injury, generally bleeding is stopped within 5 to 8 minutes. This is due to coagulation of blood on the wound surface. When vitamin K is deficient. coagulation cannot occur. This leads to continuous bleeding from the wound and the victim dies because of loss of blood.

5. Vitamin Q

It is a new vitamin discovered by ***Dr. A.J. Quick*** in 1972. It is a phospholipid extracted from soyabeans. It is essential for the proper functioning of blood-clotting mechanism in man.

6. Vitamin U

It is another new vitamin isolated from curd by the researches at the Biochemistry Institute and the Moscow Technological Institute of Food Industry. It shows good curative effect on people suffering from *gastritis* and gastric and duodenal ulcers. It doubles the percentage of recoveries from gastro intestinal diseases.

7. Vitamin B Complex

It includes a set of water soluble vitamins. It is divided into four groups, namely B_1, B_2, B_6 and B_{12}. Again each group may be containing one or more vitamins and they are named according to their chemical nature. The important B complex vitamins are :

1. B_1 - Thiamine
2. B_2 - Riboflavin
3. B_3 - Pantothenic acid
4. B_5 - Niacin
5. B_6 - Pyridoxine
6. B_7 - Biotin
7. B_9 - Folic acid
8. B_{12} - Cobalamine
9. Inositol

1. Vitamin B_1, Thiamine

It is soluble in water. This vitamin was isolated in 1926 by ***Jansen*** and ***Donath*** and synthesized in 1936 by ***Williams***. It is prepared in cereals; this vitamin is concentrated in the outer germ and bran layers. During milling and polishing this vitamin is discarded. Hence unpolished rice is the richest source.

Functions: 1. It undergoes reaction with ATP in which two terminal phosphates from ATP are transferred to the thiamine molecule to form *thiamine pyrophosphate* (TPP).

Thiamine + ATP $\rightarrow$ AMP + Thiamine pyrophosphate.

The thiamine pyrophosphate acts as a coenzyme in glycolytic pathway as well as Krebs cycle.

2. It activates *carboxylase*. Carboxylase is essential for the oxidative decarboxylation of pyruvic acid, keto-glutaric acid and other keto acids. It is an important step in the final oxidation of sugar in the tissues and brain. When this vitamin is absent, pyruvic acid and lactic acid cannot be oxidised and hence they accumulate in the blood. This accumulation is the cause for the deficiency symptoms of vitamin B_1.

3. Thiamine pyrophosphate also acts as a coenzyme for cer-ain transketolase reactions in the phosphogluconate oxidative pathway of carbohydrate metabolism.

4. It also helps the enzyme system which is responsible for the synthesis of fats from carbohydrates and proteins.

Deficiency : The deficiency of this vitamin causes ***beriberi.*** The general symptoms of beriberi are :

1. Oedema especially in the legs.
2. Anorexia (loss of appetite).
3. Lactic and pyruvic acids accumulate in the blood, brain, cerebrospinal fluid and nerves.
4. It leads to ***polyneuritis.***
5. Heart becomes weak and enlarged.
6. Heart failure, in extreme cases.
7. Gastric atony, indigestion and constipation.
8. Muscular atrophy.
9. Tenderness of the feet and legs lameness and paralysis.

2. *Vitamin B_2, Riboflavin*

This vitamin was isolated in 1932 by ***Warburg*** and ***Christian.*** It is an orange-yellow compound containing D-ribose alcohol and flavin.

The important sources of this vitamin are milk, liver, kidney, muscle, egg, whole grains, green leafy vegetables, dry beans, peas, nuts, etc. They are found in large amounts in yeasts and fermenting bacteria.

Functions : 1. Riboflavin is a component of two important co-enzymes, namely flavin mononuculeotide (FMN) and flavin adenine dinucleotide (FAD). They play major roles in various enzyme systems.

2. It is essential for the metabolism of growth.
3. It is essential for growth.
4. It is an important component of acyl-CoA dehydrogenase.

Deficiency Symptoms : 1. ***Cheiolosis :*** It is characterized by the development of fissures developing in the lips and at the corners of the mouth.

2. Sore tongue.
3. Seborrheic dermatitis affecting the face (ears, nose and forehead).
4. Deficiency of riboflavin leads to a vascularization of the cornea. As a result the eye becomes itchy, light sensitive ***(photophobia),*** vision becomes poor in dimlight and leads to severe interstitial ***keratitis.***

5. The skin loses hair; it becomes dry and scaly.

6. Growth is arrested.

3. Pantothenic Acid (B_3)

It was discovered by ***Wildiers*** in 1901, isolated by ***Williams*** in 1933 and synthesized by ***Stiller*** in 1940. Chemically it is a dipeptide. Its empirical formula is $C_6H_{17}O_5N$.

The richest sources of this vitamin are yeast, liver, kidney, egg, peas, wheat, rice bran, etc. But this vitamin is present in all the food materials in moderate amount. The word pantothenic acid is derived from Greek meaning *from every where* because this vitamin has universal distribution.

Functions : This vitamin is a component of ***coenzyme A*** (CoA). It is essential for several basic reactions in metabolism.

Deficiency Symptoms : Its deficiency effect in man is not known because this vitamin occurs in all the foodstuffs. Recently it is found that ***burning feet syndrome*** is caused by the deficiency of pantothenic acid.

In other animals deficiency leads to dermatitis, fatty liver, degeneration of spinal cord, myelin degeneration, thymus degenerations, gastrointestinal disturbances, cornification of the skin and hypofunction of adrenal cortex.

4. Nicotinic acid or Niacin (B_5)

This vitamin was first obtained in 1807 by ***Huber*** by the oxidation of the alkaloid nicotine. Its presence in biological materials was first shown by ***Suzuki*** in 1912. It was isolated by ***Viceroy*** in 1926 from yeast. It is a crystalline substance. In the body nicotinic acid is converted into amide before it becomes active.

The richest sources of this vitamin are bran, germ, yeast, beef, liver, kidney, muscles, fish, barley, maize, nuts, peas, beans, greens, vegetables, coffee, tea, etc.

Functions : 1. It is essential for growth.

2. It plays an important role in oxidation and metabolism.

3. It promotes the formation of fats from carbohydrates.

4. It is the important component of two coenzymes, namely diphosphopyridine nucleotide (DPN) or coenzyme I and nicotinamide adenine dinucleotide phosphate (NADP) or coenzyme II. They control a large number of reactions.

5. It prevents ***pellagra*** (see below).

Deficiency symptoms : Deficiency of this vitamin causes ***pellagra***. Pellagra was first discovered by ***Casal*** in 1735. It is an

Italian word meaning ***rough skin***. This disease is characterized by three symptoms, namely ***dermatitis, diarrhoea*** and ***dementia***. The skin, especially the portion exposed to sunlight (face, neck, hands, etc) becomes bronzed, resembling sunburn and later becomes thickened. The tongue is swollen glossy and ***beefy***. Gastrointestinal disorders, polyneuritis, and various forms of mental disorders appear. Headache, irritability, confusion, inadequate growth, loss of weight and strength and anaemia are other symptoms.

In dogs it causes a disease called ***black tongue***.

5. Vitamin B_6 Pyridoxine

It was discovered by *Gyorgy* in 1934. It is a pyridine derivative. The compounds pyridoxol and pyridoxamine also function as vitamin B_6. Pyridoxol phosphate is the active form of this vitamin. The richest sources are yeast, rice polishing, germs of grains and cereals, leafy vegetables, liver, eggs, meat, kidney, etc.

Functions : 1. Pyridoxol phosphate acts as a coenzyme.

2. It helps in the synthesis of fats from carbohydrates and proteins.

3. It is involved in the active transport of aminoacids and certain metallic ions across cell membranes.

4. It is linked with the metabolism of central nervous system.

Deficiency symptoms : In rats deficiency of this vitamin causes a specific type of dermatitis called ***acrodynia***, anaemia and convulsions. Dermatitis occurs in the jaws, tail, nose, mouth and ears. It is characterized by scaliness, loss of hair, swelling, inhibition of growth and reduction in accessory reproductive organs.

The deficiency disease produced in man is not known.

6. Biotin (B_7)

It was discovered by ***Bateman*** in 1916. The richest sources are yeast, egg, yolk, kidney, liver, milk, cauliflower, peas, nuts, etc. However moderate amount is present in all the foodstuffs. Biotin can be synthesized by intestinal bacteria.

Functions : 1. It functions as a coenzyme for carboxylase. Hence it involves in the fixation of CO_2 and carboxylation.

2. It helps in the conversion of pyruvic acid to oxaloacetic acid.

3. It involves in deamination of certain amino acids like aspartic acid, serine and threonine.

4. It involves in the synthesis of carbamyl phosphate.

5. It is essential for the synthesis of lipids.

6. It prevents dermatitis in dogs and rats.

Deficiency Symptoms : 1. It causes *dermatitis* in dogs and rats.

In man the symptoms are as follows :

1. Dermatitis of extremities.
2. Symptoms resembling thiamine deficiency and
3. Blood cholestrol increases.

7. Folic acid (B_9)

It was discovered by ***Day***. It was isolated from spinach leaf.

The richest sources are green leafy vegetables, yeast; liver, kidney and beef. Other foodstuffs also contain it in small amount.

Functions : 1. It functions as a coenzyme.

2. It is essential for the synthesis of RNA.

3. Its main role is in the formation and maturation of red cells.

Deficiency Symptoms : Deficiency in man causes ***megaloblastic anaemia*** during pregnancy.

8. Vitamin B_{12} - Cyanocobalamine

Smith and ***Parker*** isolated this vitamin from liver in 1948. The richest sources of this vitamin are liver, egg, milk, meat and fish.

Functions : 1. In the living cells B_{12} is converted into a coenzyme called *coenzyme* B_{12}. It is involved in a number of metabolic reactions.

2. It is essential for the formation and maturation of RBC.
3. It is involved in the synthesis of nucleic acids.
4. It stimulates bone marrow to produce WBC and platelets.
5. It helps the growth of micro-organisms.
6. It synthezises lipids from carbohydrates.
7. It helps in the synthesis of methyl group.
8. It is involved in transmethylation process.
9. It prevents ***hyperglycaemia.***
10. It prevents ***pernicious anaemia.***

Deficiency Symptoms : 1. Deficiency of B_{12} causes ***pernicious anaemia.*** It is characterized by a drastic decrease in blood cell count.

2. Another deficiency sign is ***hyperglycaemia.***

3. In pigs and rats it causes slow growth, nervousness and irritability.

9. Inositol

It was isolated by *Scherer* in 1850 from muscles. It has sweet taste and is soluble in water. The main sources of this vitamin are yeast, brain, stomach, kidney, spleen, liver, milk, blood, muscles, soyabeans, citrus fruits, vegetables, grains, etc.

Functions : Its function in man is not known.

1. It prevents the deposition of fats and accelerates the rate of removal of fat from the liver. This phenomenon is called ***lipotrophic action.***

2. It is essential for normal reproduction.

3. It promotes growth.

Deficiency Symptoms : It causes ***alopecia*** in mice and ***spectacle eye*** in rats.

8. Vitamin C

Ascorbic acid or Antiscorbutic Vitamin

It was isolated by *Szent-Gyorgyi* (1928) and synthesized by *Reichstein* (1933). It is a derivative of carbohydrate. It is a white crystalline solid. It is destroyed by heat, cooking, etc.

Sources : It is found in abundance in ***citrus fruits*** like orange, lemon, tomato, pineapple, papaya, etc. grapes, guava, apples, bananas, etc. vegetables like cauliflower, cabbage, green peas, beans, tomatoes, spinach, properly sprouted pulses, germinating grams, etc. Animal tissues contain only a small amount of this vitamin e.g. milk, liver, kidney, heart, meat, fish and glands like adrenal, thymus, pituitary, etc.

Vitamin C is essential for the formation of fibroblasts, osteoblasts, etc. It plays a main role in ***wound healing*** by producing connective tissue. It involves in the maturation of RBC. It provides ***resistance*** powers against toxins and stress conditions. It is essential for the synthesis of ***intercellular cementing substances.***

Deficiency of this vitamin causes ***scury.*** It is characterised by ***internal bleeding.*** Bleeding is more common in the ***gums.*** It is due to fragility of capillaries. The symptoms of scurvy include swollen gums, loosening of the teeth, haemorrhage, poor healing, and increased susceptibility to infections and poor tooth formation. There are two types of scurvy, ***infantile scurvy*** and ***bachelor scurvy.*** Bachelors and widows who may prepare their own foods are prone to bachelors scurvy. Infantile scurvy appear in children.

Scurvy

Scurvy is a ***deficiency disease*** caused by the deficiency of vitamin C. Hence vitamin C is called antiscorbutic vitamin. Scurvy is characterised by ***bleeding*** from the gums and internal bleeding.

Table : 2-1 Vitamins

Vitamin	Name	Sources	Deficiency diseases of man	Daily requirement of man (mg)
A	Antixerophthalmic vitamin	Leaves, yellow foods, liver, carrot.	Night blindness, xerophthalmia, bone nerve abnormalities	1.5 - 2.0
D	Calciferol	Liver, fish, oils, milk, egg.	Rickets	0.025
E	Tocopherol	Oils and animal tissues.	Sterility, eye abnormalities, nerve, muscle disorder	30.0
K	Phylloquinone	Liver, green plants.	Delayed blood clotting	0.001
C	Ascorbic acid	Citrus fruits, tomatoes.	Scurvy	75.0
B_1	Thiamine	Seeds, yeast, egg, liver.	Beriberi	0.5 - 1.0
B_2	Riboflavin	Egg, legume seeds.	Pellagra	1.0
B_3	Pantothenic ac[illegible]	Egg, yolk, liver, yeast, green plants, cereals.	Burning foot syndrome	3 - 5.0
B_6	Pyridoxine	Milk, meat, green plants.	Unknown	2.0
B_7	Biotin	Cabbage, adrenal glands.	Very rare	0.25
	Nicotinamide	....	Pellagra	Own synthesis
B_9	Folic acid	Yeast, liver, plants.	Megaloblastic anaemia	1 - 2.0
	Cobalamine	Bacteria.	Pernicious anaemia	0.001
B_{12}	Choline	Plants and animals.	.....	....
	Inositol	Bacteria, moulds, yeast, plants.	Alopecia and Dermatitis	Unknown

There are two types of scurvy. **They are *infantile* scurvy and *bachelors scurvy*.** In-fantile scurvy appears in children who are fed with readymade milk formula without fruits and vegetables. Bachelors scurvy appears in bachelors, widowers and hostelers who depend on self-cooking.

In scurvy the gums are swollen. The capillaries become weak and they become fragile. Hence the capillaries rupture and bleeding occurs in the gums, under the skin, peritoneum, intestine, kidney etc. The bl[illegible]ding leads to ***anaemia.***

The skin shows ***eruptions.*** The teeth become loosened and they may fall. The teeth and bones are malformed.

The patient becomes susceptible to infections. Healing of wound is delayed.

4. Minerals

The organisms are constructed on organic components and inorganic elements. The organic components include carbohydrates, proteins and fats. These organic compounds themselves are derivatives of inorganic elements or minerals. The functions of minerals are immense in the biological world.

Animal tissues contain about 29 elements. These elements are classed into two groups. They are 1. essential elements and 2. non essential elements.

1. Essential Elements

The role of certain elements in organisms is known and they are indispensable for normal life activities. These elements are called essential elements. They are divided into two groups according to their actual amounts in the body. They are (a) macroelements and (b) microelements or trace elements.

a. Macroelements : Macroelements are those which are required to be present in the diet in amounts more than 1 mg. They constitute 60 to 80% of the elements present in the body. There are about 12 macroelements. They are :

Carbon	Nitrogen	Calcium	Phosphorus
Hydrogen	Sodium	Magnesium	Sulphur and
Oxygen	Potassium	Iron	Chlorine

b. Microelements or trace elements : These elements are required in very small amounts as in micrograms. The trace elements include copper, zinc, cobalt, manganese, molybdenum, iodine and fluorine.

2. Non-essential Elements

The role of certain elements in the body is not known. Hence these elements are called non-essential elements. These include bromine, boron, silicon, arsenic, nickel, aluminium, lead, stannic vanadium and titanium.

1. Calcium

Calcium is a major mineral component of man. An adult human weighing 50 to 70 kg contains about 850 to 1400 gm of calcium. 99% of calcium is present in the bones. The blood contains about 10mg per 100 ml of blood.

Sources : Milk and milk products form the main source of calcium. One litre of cow milk contains about 120[illegible] calcium.

One litre of human milk contains about 300 mg of calcium. Other sources are fish, vegetables like radish, beetroot, mustard, greens, curry leaves, drum stick leaves, soya beans and tamarind, fruits like sitaphal, cereals especially ragi, water and chewing betals. A single sitaphal contains about 800 mg of calcium. One sitaphal a day will meet the daily requirement of calcium.

Function : 1. It is essential for the formation and maintenance of bones and teeth.

2. It promotes coagulation of blood.
3. It is essential for muscle contraction.
4. It is an important component of enzymes.
5. It plays an important role in the transmission of impulse from the nerve to the muscles across the neuromuscular junction by helping the secretion of acetylcholine.
6. Calcium is essential for the excitation of nerves.
7. Membrane permeability is decreased by calcium and this effect balances the opposite action of sodium and potassium capillary permeability.

Deficiency Symptoms : No clearcut diseases are recorded on the deficiency of calcium. If vitamin D intake is sufficient, rickets and osteomalacia are not problems even when Ca is taken in low quantities.

No deleterious effects are observed as a result of prolonged intake of excess amount of calcium.

Hypocalcemia : It is a condition where calcium is below the normal level in the plasma. It is caused by the deficiency of parathyroid hormone, increased excretion of calcium or any other factor. Hypocalcemia is characterised by increased excitability of peripheral nerves. In extreme cases, there occurs convulsions followed by spasm of muscles of face and limbs. This condition is called tetany and can be cured by administering extracts of parathyroid.

Hypercalcemia : It is a condition where calcium level is higher than normal. This is characterized by the depression of nervous system, sluggish reflex activities weakness of muscles constipation and lack of appetite.

2. Iron

Iron is an important mineral in biology. The total amount of iron present in human body is 3 to 4 gm and 75% of this is found in the blood.

Sources : The richest sources are as follows :

liver	kidney	heart	fish	egg

poultry	beans	wheat	peas	spinacn
carrots	bananas	beef	cheese	tomatoes
apples	oranges	palm gur	jaggery	

The vegetables cut by rusty knives and cooked in the iron containers are also important sources of iron. Milk is a very poor iron source.

Storage : Iron is stored in the form of ferritin in the liver, spleen and intestinal mucosa.

Reutilization: RBC contains iron. About 3 millions RBC are broken down per second. The iron present in the RBC are not destroyed. But it is reused for the synthesis of new RBC.

Iron losses : The major routes of iron losses are

1. ***Haemorrhage :*** Women lose blood during menstruation and child birth. The loss of iron during menstruation is 1 mg per day. Hence women need more iron than men.
2. Excretion through urine, sweat and bile.
3. Through integumental tissues.

Function : In the form of haemoglobin iron transports oxygen from lungs to tissues and CO_2 from tissues to lungs.

2. The myoglobin, an iron compound stores oxygen in the muscles.

3. Iron is the main component of many enzymes like cytochrome, catalases and peroxidases.

4. Iron is inevitable for the synthesis of haemoglobin and RBC.

5. It plays an active role in metabolic oxidation.

Deficiency: Iron deficiency leads to ***anaemia.*** In India iron deficiency is prevalent in women. In one survey almost 100% of pregnant women are found to be iron deficient. In infants and children also iron deficiency is found to be common. The causes of iron deficiency are :

1. The high phytate and phosphate content of cereal rich diet.
2. Deficiency of Vitamin C.
3. Hookworm infestation.

The iron deficiency can be rectified by the additional intake of iron.

3. Phosphorus

Phosphorus, is present in almost all the foodstuffs. Hence phosphorus deficiency is very rare. It makes up 1% of the total weight. The P content of human body is about 700g out 700g.

Sources : Milk, cheese, almonds, beans, butter, nuts, meat and egg.

Function : 1. Energy is stored for immediate use in phosphorus compounds like ATP, ADP, etc.

2. They play an important role in metabolism. They take part in phosphorylation reactions.

3. They are important for the construction of bones and teeth.

4. With proteins they form phosphoproteins.

5. They form important components of nucleic acids like RNA, DNA, etc.

4. Magnesium

Adult man contains about 21 gms. of magnesium. Of these 11 gms are in the bones. It is found in all foodstuffs. The important sources are almonds, cereals, beans, green vegetables, potatoes and cheese. Absorption of magnesium closely resembles calcium in many respects.

Functions : 1. Magnesium ions function as activators of enzymes like phosphorylase, phosphoglucomutase, enolase peptidase, alkaline phosphatase, RNA polymerase, DNA polymerase, etc.

5. Sulphur

It constitutes about 0.25% of the total weight. The main sources of sulphur are the proteins found in the foodstuff.

Functions : 1. Organic sulphur compounds are utilized for the synthesis of hormones like insulin and anterior pituitary hormones.

2. It is involved in the formation of proteins like chondroproteins, keratins and heparin, coenzyme A and acyl carrier proteins.

3. It is involved in the formation of sulphhydryl groups (S-H) which act as the active centres of the enzymes and also play important role in tissue respiration.

4. It also forms disulphide linkages (S-S) in the protein molecules which are responsible for the maintenance of higher level of structure of the proteins.

5. A high energy sulphur bond similar to that of phosphate play an important role in metabolism.

6. Sodium, Potassium and chlorine

These are widely distributed in the plants and animals. The source of sodium and chloride is common salt. The sources of potassium are coffee, tea, cocoa, dried beans, molasses, most green vegetables, milk, fish, chicken, liver, beef, pork, bananas, oranges, pine apples, potatoes, etc.

Functions : 1. They maintain the osmotic pressure of the body and thereby protect the body from dehydration.

2. The sodium salts and potassium salts with the corresponding weak acids form the chief buffer systems respectively of extracellular and intracellular fluids. These buffer systems play an important role in maintaining pH.

3. They are involved in the transport of CO_2.

4. They are involved in the maintenance of neuro-buffer irritability and excitability.

5. They maintain a proper viscosity of blood.

6. Gastric hydrochloric acid is derived for sodium chloride.

7. Copper

An adult human contains 100 to 150 mg of copper. The sources of copper are milk, liver, nuts, legumes and leafy vegetables.

Functions : 1. It is a component of certain enzymes like cytochrome oxidase, catalase monoamine oxidase, uricase and ascorbic acid oxidase.

2. It helps in the absorption, transport and utilization of iron.

3. It helps in bone formation.

4. It is essential for the formation of myelin sheath in the nerve fibres.

5. It is an important component of haemocyanin, a blue pigment present in gastropods, arthropods and cephalopods.

Deficiency symptoms : Wilson'sdisease. It is characterized by an abnormal copper metabolism. Copper accumulates in large amounts in the liver and lenticular nucleus of the brain; copper in the urine increases; plasma copper decreases. This disease is due to considerable increase in the intestinal absorption of copper.

8. Iodine

An adult man contains about 20 to 30 mg of iodine. It is an important component of thyroid hormone. The sources of iodine are food and water. The richest sources are common salt, sea fish, cod liver oil, etc.

Deficiency of iodine leads to ***goitre.*** But all goitres are not due to iodine deficiency. The most practical method to supplement dietary iodine is by iodization of salt. The addition of potassium iodide to common salt (1:10000) is now an established prophylaxis of goitre.

9. Fluorine

It is found in the bones, teeth and hard tissues. It is never found free in nature. The main sources of fluoride are drinking water, sea fish, cheese, tea, etc. The daily intake of fluoride should not exceed 3 mg.

Fluoride is often called a two ***edged sword*** because high and low doses cause ill effects. High dose leads to ***dental*** and ***skeletal fluorosis***. Low dose causes dental caries. Dental fluorosis is characterized by mottling and corroding of teeth and skeletal fluorosis by sclerosis of the bones of the spine, pelvis and limbs, calcification of ligaments and ossification of tendinous insertions of muscles.

In optimum amounts, fluroine is beneficial to teeth and reduces the incidence of dental caries.

10. Cobalt

In human body, liver contains maximum cobalt and it is the storage organ for cobalt. The diet contains sufficient amount of cobalt. So special sources are not required.

It is an essential component of Vit. B_{12}(cyanocobalamine) which is required to maintain normal bone marrow function for producing erythrocytes. Hence deficiency of cobalt leads to ***anaemia***. Excess of cobalt leads to over production of erythrocytes causing ***polycythemia***.

11. Zinc

Zinc is found in the blood (RBC), hair, bone, liver, muscles, pancreas gastro-intestinal tract and spleen. The main sources are seafoods like oysters, liver, wheat, germ, yeast and lettuce.

It is an important component of several enzymes like carbonic anhydrase, carboxyl peptidase, uricase, kidney phosphatase, etc. Insulin contains zinc. In diabetes the total amount of zinc in pancreas is reduced to half.

12. Manganese

The human body contains about 10 mg of manganese. Most of the manganese of the body are found in the liver. As it is universally distributed, the diet contains sufficient amount of manganese.

Manganese activates a number of enzymes such as arginase, phosphoglucomutase, choline esterase and mitochondrial respiratory enzyme systems. In human beings it functions in the formation of haemoglobin.

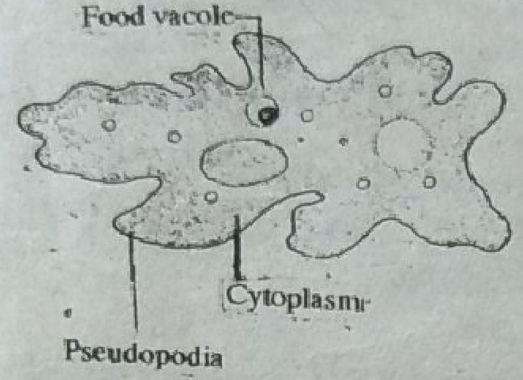
13. Molybdenum

It is found in the bones, liver and kidney. It is an essential component of certain metalloflavoprotein enzymes such as xanthine oxidase, aldehyde oxidase, nitrate reductase and hydrogenase.

Feeding

Feeding is the intake of food materials. Animals utilize different methods of feeding. Based on the feeding mechanism, animals are classified into 3 groups, namely

Extracellular digestion is the advanced type of digestion. The evolutionary trend has been towards the replacement of intracellular digestion by extracellular digestion.



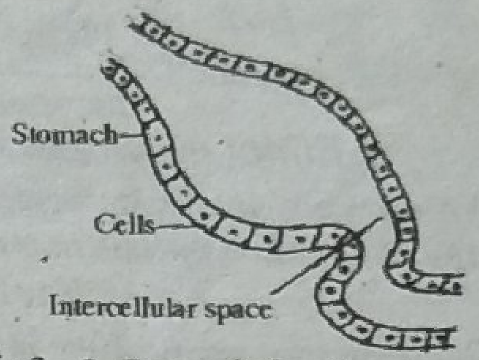


Fig 3 - 2 Extracellular digestion of food

Fig 3 - 1 Intracellular digestion in Amoeba

The animals possessing an alimentary canal exhibit extracellular digestion. Digestion occurs within the lumen of the alimentary canal.

Enzymes

Enzymes are ***biological catalysts*** produced by living cells. They catalyze metabolic reactions. They are soluble and colloidal substances characterized by great activity, specificity and susceptibility to the influence of pH, temperature and other environmental changes.

The term ***enzyme*** was first introduced by ***Kuhno*** in 1878.

The substance on which an enzyme acts is called ***substrate.*** The final product formed as a result of enzyme activity is called ***end product.***

Lactose	$\xrightarrow{\text{Lactase}}$	Glucose + Galactose
Substrate	Enzyme	End products

Some enzymes are formed of protein only Eg. amylase, urease, etc. But in most of the enzymes, in addition to protein, there is a non-protein group called ***prosthetic*** group and the protein part is called ***apoenzyme***. An enzyme composed of these two components is called a ***holoenzyme.***

Holoenzyme = Apoenzyme + Prosthetic group

Zymase and Zymogen

If an enzyme is secreted in a form which acts upon the substrate as such, it is called a ***zymase***. All endoenzymes are of this type.

Some enzymes are secreted in an inactive form called ***zymogens*** or ***proenzymes*** or ***pre-enzymes.*** Zymogens are converted into active enzymes by some activating agents.

For example *trypsin* is secreted in an inactive form called *trypsinogen*. It is transformed into active trypsin by previously formed trypsin or enteropeptidase.

Most of the enzymes are characterized by the reversibility of their actions. That is, the enzymes act in either directions.

$$\text{Glucose - 1-Phosphate} \xrightleftharpoons[\text{glucomutase}]{\text{Phospho}} \text{Glucose-6-Phosphate}$$

Effect of temperature on enzymes

An enzyme works its best in a particular temperature. This temperature is called ***optimum temperature.***

Effect of pH

Each enzyme works best in a particular pH. This pH is called pH ***optimum.***

Effect of enzyme-concentration

An enzyme works even when it is present in low quantity. The velocity of the reaction increases with the increase in the concentration of enzymes.

An increase of substrate concentration will result at first in a very rapid increase in the velocity of reaction. As the substrate concentration continues to increase, the increase in the rate of reaction begins to slow down.

There is ***one gene for one enzyme.*** Similarly there is one enzyme for one substrate. That is, each enzyme will react with only one type of substrate or a group of related substrates. This property of enzyme is called ***specificity*** of enzymes.

Classification of Enzymes

Enzymes are grouped into six major classes. They are :

1. Oxidoreductases
2. Transferases
3. Hydrolases
4. Lyases
5. Isomerases and
6. Ligases

1. Oxidoreductases

Oxidoreductases are enzymes which involve in biologica oxidations and reductions. ***Oxidation*** means addition of oxygen or removal of hydrogen. ***Reduction*** means addition of hydrogen or removal of oxygen. A very good example for oxidoreductase is ***lactic dehydrogenase.*** It converts lactic acid to pyruvic acid and vice versa. The following are the oxidoreductases :

1. Dehydrogenases : Dehydrogenases are enzymes that catalyze the removal of hydrogen from one substrate and pass it on to a second substrate.

$$AH_2 + B \xrightarrow{\text{Dehydrogenase}} A + BH_2$$

2. ***Oxidase :*** Oxidases are enzymes which catalyze the removal of hydrogen from a substrate and pass it directly to oxygen.

$$AH_2 + \frac{1}{2}O_2 \xrightarrow{\text{Oxidase}} AH_2O$$

3. ***Oxygenases :*** These are enzymes which catalyze the incorporation of oxygen directly into the substrate.

2. Transferases

These enzymes transfer a group from one substrate to another substrate. The reaction can be represented simply as follows :

$$AX + B \xrightarrow{\text{Transferase}} A + BX$$

3. Hydrolases

Hydrolases are enzymes which catalyze hydrolysis i.e. the direct addition of water molecule across a bond which is cleaved. The hydrolases are divided into many sub classes on the nature of the bond or group being hydrolysed. The various subclasses are esterases, etherases, peptidases, glycosidases, phosphatases, etc.

4. Lyases

Lyases are enzymes which can catalyze either the removal of a group of atoms from their substrate leaving double bonds or add groups to double bonds without hydrolysis, oxidation or reduction Eg. aldolase, enolase, fumarase, hydrolase, pyruvate decarboxylase, etc.

5. Isomerase or Mutase

This class includes all enzymes which catalyze isomerization. That is, they catalyze the interconversion of a compound to one of its isomers.

6. Ligases or Synthetases

These enzymes catalyze synthesis reactions by joining two molecules coupled with the breakdown of a pyrophosphate bond of ATP to ADP.

Coenzymes or Cofactors

Some chemical reactions require a substance other than the enzyme and substrate. This substance is called a ***coenzyme*** or ***cofactor.*** A coenzyme may be defined as ***a non-protein organic compound or a carrier molecule functioning in conjugation with a particular enzyme.*** The coenzyme may be tightly bound to the apoenzyme or may easily dissociate from it.

Salient features of Coenzyme

1. It is necessary for the active state of an enzyme.
2. Like enzymes, coenzymes also remain unchanged at the end of reaction

3. They are non-proteins.
4. They have low molecular weight.
5. They are heat stable.
6. A coenzyme cannot function without an enzyme; an enzyme can act without a coenzyme.
7. Many coenzymes are closely related to vitamins and are derivatives of vitamins. The important coenzymes are as follows :
   1. Nicotinamide adenine-dinucleotide (NAD).
   2. Nicotinamide adenine-dinucleo phosphate (NADP).
   3. Flavin mononucleotide (FMN).
   4. Flavin adenine dinucleotide (FAD).
   5. Coenzyme Q.
   6. Cytochromes.
   7. Coenzyme A.
   8. Acetyl coenzyme A and
   9. Thiamine pyrophosphate (TPP).

Role of enzymes in Carbohydrate Digestion

Carbohydrate is an important component of diet. Human diet contains 60 to 83% carbohydrates. They provide the main bulk of the energy for the organism. The breakdown of complex carbohydrates into monosaccharides is called *carbohydrate digestion.*

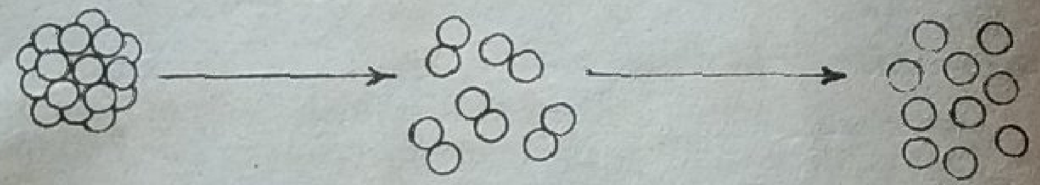


Fig. 3-3 Digestion of carbohydrates

Places of Carbohydrate Digestion

The digestion of carbohydrate occurs in the buccal cavity, stomach and intestine.

Glands involved in Carbohydrate Digestion

Carbohydrate digestion is helped by the following digestive glands:

1. Salivary glands
2. Pancreas
3. Gastric glands and
4. Intestinal glands

Enzymes involved in Carbohydrate Digestion

The breakdown of carbohydrate is brought about by a set of enzymes called *carbohydrases.* The following are the carbohydrases :

3. They may induce even reversible reactions.

4. They are very unstable compounds mostly soluble in water, dilute glycerol, sodium-chloride solution and in dilute alcohol as well.

5. They act actively at optimum temperature. At low temperature or with a fall of temperature enzyme activity decreases sharply but on heating to high temperature they become inactive.

6. Besides breaking down, enzymes are capable of rebuilding specific elements out of the final products either by reversible synthesis or else by specific synthesis by specific enzymes.

7. The activity of enzymes depends upon the acidity of the medium. Each enzyme is most active at a definite acidity which is optimal for it.

MECHANISM OF ENZYME-ACTION

Our knowledge about the mechanisms involved in the enzyme catalysis is very little. However, the view that has dominated all attempts to explain mechanisms of enzyme-action is that the enzyme forms an intermediate complex with the substrate or substrates. Before proceeding to a more detailed examination of this concept, it is desirable to summarize briefly some of the early experiments that led to this view.

1. In 1880, WURTZ observed that, after addition of the soluble proteinase **papain** to the insoluble protein, fibrin, repeated washing of the fibrin did not stop the proteolysis. He then concluded that the papain had formed a substance or complex with the fibrin.

2. In 1890, O'SULLIVAN and THOMPSON observed that the enzyme invertase could withstand higher temperatures in the presence of the substrate, sucrose, than in its absence. They also concluded the WURTZ'S observation that the invertase had formed a complex with its substrate, sucrose.

3. In 1890, EMIL FISCHER, after conducting so many experiments on different enzymes, quoted the following remark for the enzymes that "*inasmuch as the enzymes are in all probability proteins,... it is probable that their molecules also have an asymmetrical structure, and one whose asymmetry is, on the whole, comparable to that of the hexoses. Only if enzyme and fermentable substance have a similar geometrical shape can the two molecules approach each other close enough for the production of a chemical reaction. Metaphorically, we may say that enzyme and glucoside must fit into each other like lock and key.*

Keeping all these observations in knowledge, FISCHER, in 1894 suggested the **"lock and key"** hypothesis to explain that how do enzymes perform their activity. This hypothesis is still acceptable but in a modified way as **"induced fit"** hypothesis. These theories suppose the existence of **active-sites** on the surface of the enzyme molecules.

According to this hypothesis the substrate molecules are thought to fit into the active sites located on the surface of the enzyme molecules just as one particular kind of key fits into one particular kind of lock. This results in the rapid formation of intermediate compounds the so called **enzyme-substrate complexes** by reversible reaction **enzyme + substrate ⇌ enzyme-substrate complex**. These intermediate compounds are believed to be much less stable than the original substrate and so they break down spontaneously, the enzyme being again liberated.

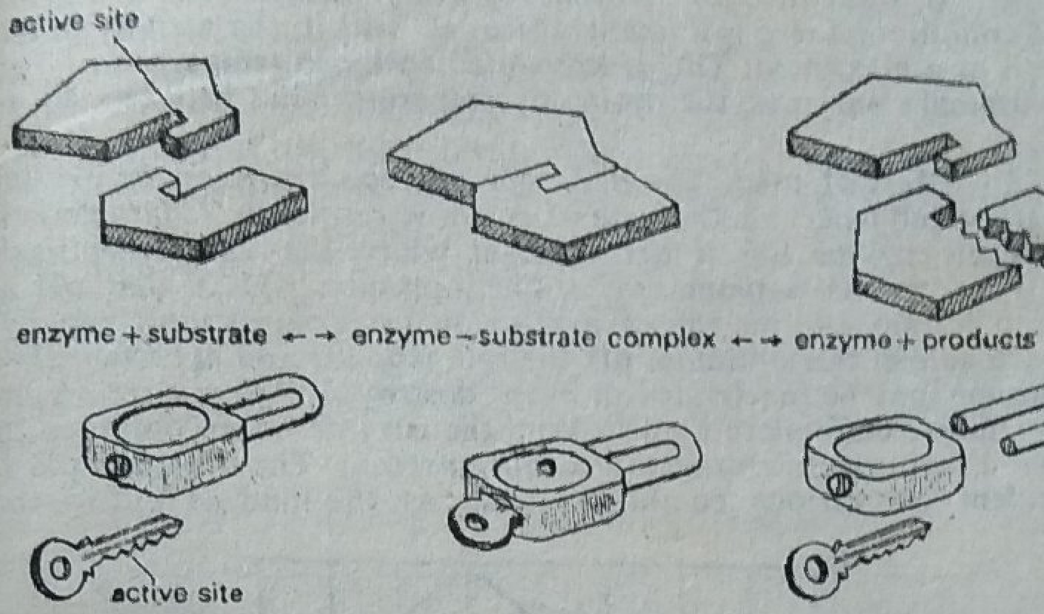


Fig. 6·1. A lock and key model for enzyme activity and specificity.

Recently in the year of 1958 FRUTON and SIMMONDE have also demonstrated that the **enzyme substrate** complex is an essential first step in enzyme action.

According to some workers the amino-acid residues comprising the active site of the enzyme are remained to be in direct contact with substrate molecule. Therefore, the size, shape and charge of the possible substrate are defined by the size, shape and charge of the active site, and it is these factors which determine the specificity of the enzyme towards certain substances only. Moreover there are three groups or constellations of amino-acids (perhaps more in some instances) on the enzyme which are actually involved and cause chemical changes. One group is responsible chiefly for binding the substrate to the enzyme, the second combining with another part of the substrate so as to reduce its stability and makes it more susceptible to reaction, while the third is responsible for specificity. This view has been developed particularly in connection with peptidases, esterases and other transferases.)

EFFECT OF VARIOUS CONDITIONS ON ENZYME ACTIVITY

There are many factors which influence the enzyme activity. The important factors are the following :

1. Influence of temperature : Temperature affects enzyme catacan be regarded as a process that renders food particles suitable for absorption.

Agents of digestion : **Enzymes** are said to be the agents of digestion. They are secreted on to the food at various points along the length of the digestive tract or alimentary canal. They act as biological catalysts, accelerating the rate at which food will react with water to form a large number of smaller soluble molecules, suitable for absorption into the body. Enzymes are very sensitive to the acidity or alkalinity of the surrounding medium, and different enzymes work best under different conditions. We shall see that the conditions vary along the length of the alimentary canal to suit the enzymes present at any particular point.

KINDS OF DIGESTION

The process of digestion is essentially of following two types, depending upon both the phylogenetic position of the animal and the character of the food.

1. Intracellular digestion,
2. Extracellular digestion.

1. Intracellular digestion : When digestion of the food materials occurs within the cells, then this sort of digestion is known as intracellular digestion. This type of digestion is generally found in lower animals such as protozoans, sponges and few other complex animals like coelenterates where in the digestion is partially extracellular but largely intracellular (see BARRINGTON, 1962 ; BEATON and MCHENRY, 1964–1966 ; MEGLITSCH, 1967).

2. Extracellular digestion : When digestion of the food-materials takes place outside the cells in a lumen of the tube known as digestive tube or alimentary canal, then this type of digestion is known as extracellular digestion. The digestive tube or alimentary canal includes those structures that do not actually receive undigested food but that act on food in the digestive tube by means of secretions delivered to the lumen by various ducts. Extracellular digestion is the characteristic of higher animals.

DIGESTIVE TUBE OR ALIMENTARY CANAL

General organisation of the alimentary canal : The alimentary canal of higher animals is a long muscular tube with dilations and constrictions at places. It is lined throughout by mucous membrane beginning from the mouth cavity and ending at the anus. It consists of two sets of muscles, an inner circular and outer longitudinal muscles. These muscles provide the peristaltic movement for the passage of the food. Inside the muscle layers are the mucosa and submucosa which enclose the lumen of the alimentary canal. The mucosa is glandular and has a very large surface area. Between the mucosa and submucosa, there is a muscularis mucosa.

The alimentary canal all along its length consists of numerous glands, some of which are of special type. All have their ducts opening into the mucous membrane and pour their secretions into the lumen. Gastric and intestinal glands are situated within the mucosa-membrane but the salivary glands (submaxillary, sublingual and parotid), the pancreas and the liver lie separately. These glands pour their secretions by their respective ducts into the lumen of alimentary canal.

Functional regions of the alimentary canal : The alimentary canals of the animals show striking adaptations to the nature of foods and the feeding habits of themselves. According to C. M. YONGE the alimentary canal in animals has the following important functional regions : 1. the region of reception 2. the region of conduction and storage 3. the region of internal trituration and digestion 4. the region of final digestion and absorption 5. the region of faeces formation.

1. **The region of reception :** This region includes the mouth and its associated appendages and cavity. This region is primarily meant for food selection and mechanical break-down of the food. Food selection is made by taste, smell and texture.

The mouth cavity often contains salivary glands which secrete enzymes in few mammals such as man but in rest cases secrete copious mucus which is by its nature known as lubricating fluid. Blood sucking animals such as mosquitoes, usually have an anticoagulant in their salivary secretion which prevent the blood from clotting, while carnivores feeding on live prey may secrete paralyzing toxins. Many insects and vertebrates secrete carbohydrate splitting enzymes, while some carnivores and cephalopods secrete protein-splitting enzymes, in addition to poison and mucus.

2. **The region of conduction and storage :** This includes the oesophagus and the crop of some animals. They are often muscular and are meant for storing up the food as in case of leeches and conduction as well.

3. **The region of internal trituration and digestion :** This region includes the gizzard and the stomach of some animals. They are modified in different animals in order to carry out the internal trituration and digestion of the ingested food.

Digestive enzymes may be secreted into the stomach by unicellular gastric glands situated in the lining or by glandular diverticula or caeca which help in digesting the food contents.

4. **The region of final digestion and absorption :** This includes the small intestine where the final digestion and absorption of the food materials take place. Digestion of the food materials takes place with the help of enzymes which are either liberated in the preceeding region as in most insects or in the same region as in most vertebrates.

5. **The region of faeces formation :** It is the last region of the alimentary canal where the absorption of water from the undigested food takes place and subsequently undigested food materials are twisted together with mucus into faeces. This region is very conspicuous in terrestrial animal as in insect hindgut and vertebrate colon.

MOVEMENT OF FOOD ALONG THE ALIMENTARY CANAL

The food is propelled along the alimentary canal at appropriate speed by ciliary action or muscular activity or by combination of both. The movement of food by ciliary action is the characteristic of small animals like ectoprocts, endoprocts and pelecypod molluscs whereas the muscular activity is involved to a greater or lesser extent in food propulsion in a wide variety of animals including the vertebrates. The muscular activity not only propells the food but also serves to triturate and mix the food with digestive juices.

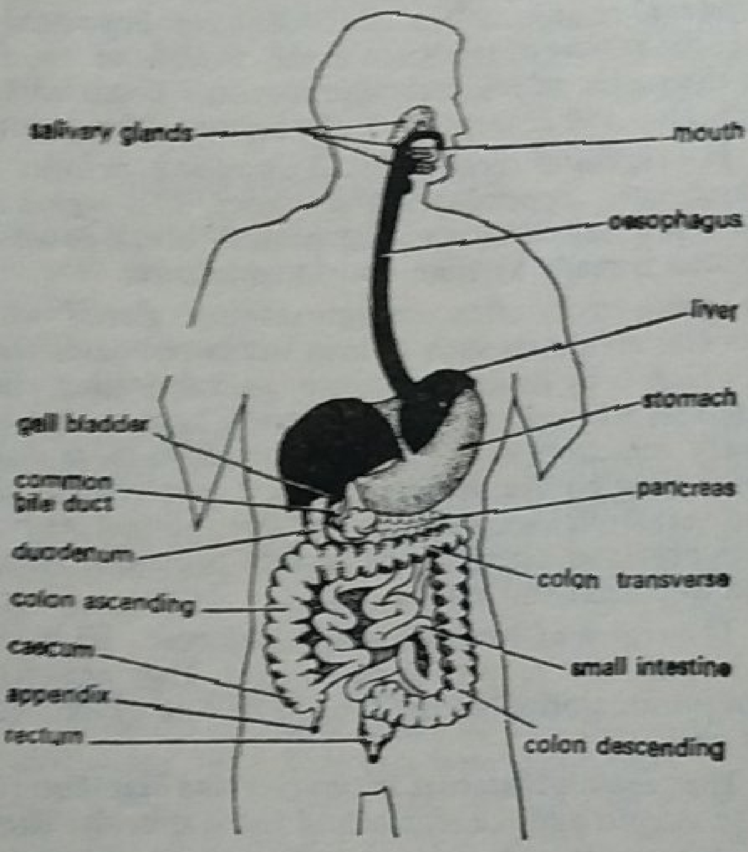


Fig. 5·1. The organs of digestion in the human body.

DIGESTION IN VERTEBRATES (MAMMALS)

All vertebrates possess alimentary canal as an organ for the digestion and absorption of the food materials. Digestion does not occur in a particular region of the alimentary canal but takes place in different regions of alimentary canal so that the digestion of the food materials may be completed. Hence the process of digestion in the alimentary canal can be classified into the following heads :

1. BUCCAL DIGESTION

Mouth—The first digestive structure : Mouth prepares the food for digestion. In higher animals, particularly in man, the digestion of nutritive substances of food stuffs begins in the buccal-cavity. As soon as the food is entered the mouth, the process of mastication starts with the help of teeth. Teeth break the food into smaller particles. During the process of mastication the food is thoroughly mixed with the fluid **saliva** secreted by the **salivary glands.**

Salivary glands : In the buccal cavity of most vertebrates four pairs of salivary glands are found. These are the infra-orbital, parotid, sublingual and submaxillary glands. In humans there are only three pairs, there being no infra-orbitals.

Salivary glands may contain either **mucous cells** or **serous cells**. **Mucous cells** contain large transluscent granules (consisting of a precursor of mucin) and such cells appear pale or translucent in histological sections. **Serous cells** contain opaque small zymogen granules (consisting of a precursor of amlase or ptyalin).

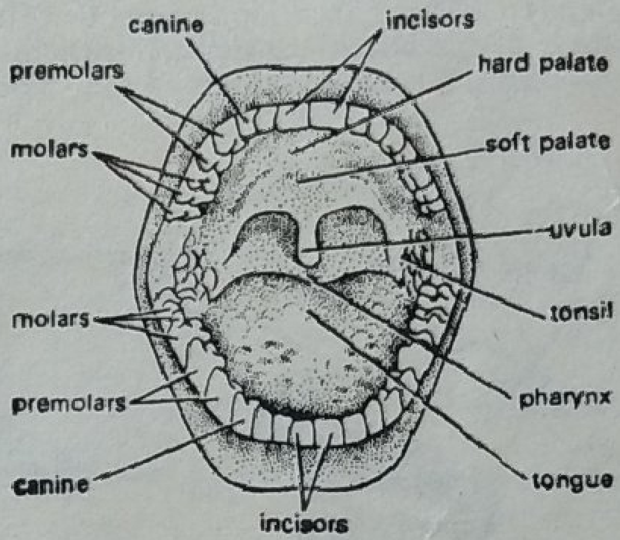


Fig. 5·2. Digestion begins in the mouth, the first organ of the alimentary canal.

Parotid glands : These are the largest of the salivary glands, found lying one on each side of the face below and in front of the ears. The secretion of each parotid gland passes via **Stensen's duct**

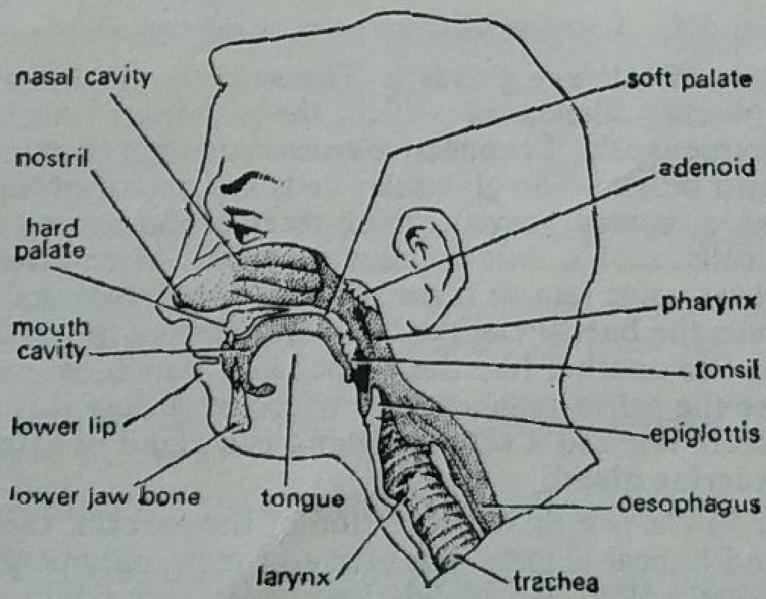


Fig. 5·3. A cross sectional view of the structure of the mouth and throat.

which opens into the mouth opposite the site of the second upper molar tooth. The disease called **mumps** is an infection of the parotid glands that causes swelling and irritation.

The parotid glands are purely serous and so they secrete zymogen granules.

Submaxillary glands : These glands are found within the angles of the lower jaws. These glands contain both types of cell, but predominantly serous. Their secretion passes via **Wharton's duct** into the floor of the mouth at the side of the frenulum linguae.

Sublingual glands : These are found embedded in the mucous membrane in the floor of the buccal cavity, under the tongue. Ducts of these glands open into the sublingual part of the mouth under the tongue.

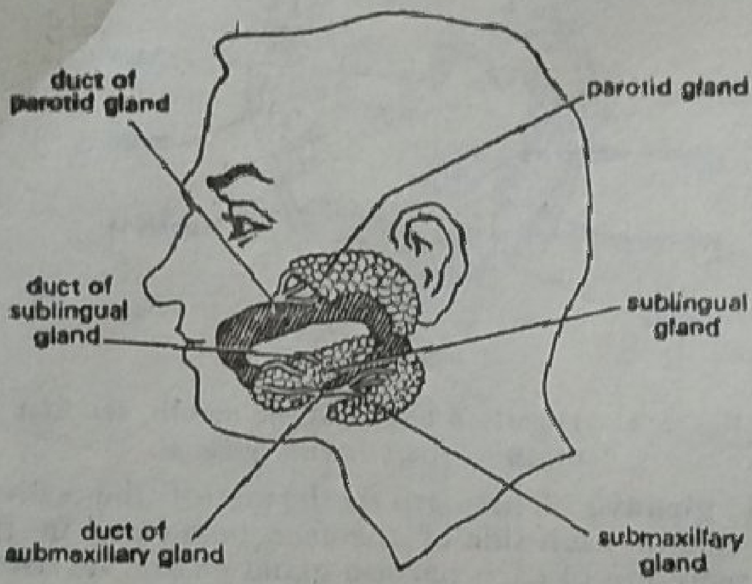


Fig. 5·4. Location of three pairs of salivary glands.

Structure of salivary glands : The salivary glands are typical compound tubular glands in which the glandular cells lie within a supporting frame work of connective tissue carrying the blood vessels, lymphatics and nerves. The glandular cells are arranged in a single layer around a central cavity which receives the secretion from the surrounding cells, such a unit is called an **acinus** or an **alvelous**. Small ducts from these acini join to form large duct which pours the secretion finally into the buccal cavity. This arrangement in which the acini are related to one another like the grapes in a bunch, is called **recemose**. Because the saliva reaches the surface by a duct it is said to be an external secretion and a salivary gland is a gland of external secretion or an **exocrine gland**.

Saliva : Saliva is a mixed secretion of the parotid, submaxillary, sublingual, and buccal glands. The saliva of man and many other animals is a viscous, colourless, cloudy and opalescent liquid. The average pH value is 6·8 with a range of 5·6 to 7·6 and specific gravity is 1·002 to 1·008. It is constantly secreted in small quantities to keep the buccal cavity moist, but when food is present the rate of secretion is increased because the saliva not only moistens the food, lubricating its subsequent passage through the alimentary canal but also begins the process of digestion.

It contains 98·5 to 99% water and 1 to 1·5% of a dense residue which includes the following :

(i) **Cellular components** : The cellular components of saliva are desquamated epithelial cells of the oral mucosa, leukocytes and numerous bacteria. Yeast cells and sometimes protozoans like *Amoeba salivaricus* are also found.

(ii) **Inorganic components** : Inorganic components of saliva include chlorides, sulphates, carbonates of sodium, potassium, calcium and magnesium and traces of ammonia as well. The saliva of man and some animals also has potassium sulphocyanate about 0·01%.

(iii) **Organic components** : Organic components of the saliva are chiefly **mucin** (which gives saliva its viscosity and lubricating properties) and **enzymes** which digest the food. Some other organic substances, such as urea, cholesterol, amino-acids, citrates and vitamins, have also been found in saliva. Glucose is practically absent.

Enzymes of saliva : Saliva contains a large number of enzymes such as **amylase, lysosome acid phosphotase, aldolase, cholesterase, lysozyme, maltase, catalase, lipase, urease** and **protease** of these probably only two namely **amylase and lysozyme** are of physiological importance.

Amylase : The saliva of cat, dog and some other animals lack salivary **amylase**, while the saliva of other animals such as man, pig and rats has strong **amylase activity**.

Salivary amylase was once named **ptyalin,** to distinguish it from pancreatic amylase (diastase), but these two enzymes are now known to be identical. It hydrolyses starch and glycogen to maltose, isomaltose, dextrin and some glucose.

Lysozyme : This enzyme is **polysaccharidase** which hydrolyses certain complex polysaccharides present in the cell wall of many different species of bacteria *(e.g., Micrococcus lysodeikticus)*, thereby killing and dissolving them. Its action is partially retarted by the presence of mucin.

Functions of saliva : The saliva subserves a number of functions :

1. It moistens dry food and facilitates swallowing by a lubricating action. Since water evaporates slowly from saliva it prevents desiccation of the oral mucosa.
2. It provides an enzyme called **salivary amylase** or **ptyalin** for the digestion of starch.
3. It keeps the mouth and teeth clean (according to PIGMAN and REID).
4. It dissolves the soluble substances such as sugar, and salts.
5. It makes the food delicious to taste.
6. Certain substances such as lead, mercury and iodides are

excreted in the saliva but they cannot be important since they are reabsorbed when the saliva is swallowed.

7. By facilitating movements of the tongue and lips it makes rapid articulation possible.

8. It subserves the sense of taste by acting as a solvent. The taste buds can be stimulated only when the sapid substances are actually present in solution.

9. It contains three buffering systems, bicarbonate, phosphate and mucin of which the first is most important. The concentration of bicarbonate and the buffering systems rises when salivary flow increases, particularly at the time of eating.

CONTROL OF SALIVA SECRETION

The secretion of saliva is generally coordinated by the intake of food. Olfactory and gustatory stimuli normally initiate the nervous reflex that results in the stimulation of salivary secretion. Secretion from the salivary gland cells is predominantly controlled by parasympathetic nerve fibres (HILTON and LEWIS, 1957).

SALIVARY DIGESTION

Mastication or chewing mixes the food with the saliva and brings **ptyalin** into intimate contact with the starch of the food. Due to the action of enzyme the starch-molecules are hydrolysed to dextrins and then to maltose. Hydrolysis is finally arrested by a fall in pH and destruction of **ptyalin** as the acid gastric juice gradually penetrates through the food mass in the body of the stomach.

MECHANICAL PROCESS IN THE BUCCAL CAVITY DURING EATING AND DIGESTION

In addition to being chemically changed in the buccal cavity, the food is ground up and saturated with saliva due to mechanical process.

Mastication : It is a voluntary mechanism which involves the play of many muscles of the mouth, tongue and cheeks, in a perfectly co-ordinated manner. It grinds the food into small particles and aids in moistening it with saliva and forming a **bolus**.

PASSAGE OF FOOD FROM THE MOUTH TO THE STOMACH (DEGLUTITION)

After mastication the food undergoes the process of deglutition which involves all such motor reactions by which the food is moved from the buccal cavity through the oesophagus to the stomach. The process of deglutition can be divided under the following three stages :

1. Movement of food from the buccal cavity to the pharynx.
2. Movement of food from the pharynx to the oesophagus.
3. Movement of food from the oesophagus to the stomach.

and prevent their collapse. In the lungs, each bronchus divides into still smaller branches known as bronchioles or air tubes. In the smallest branches the cartilages disappear. The bronchioles end in tiny sacs called airsacs or **alveoli.** There are about 300 million alveoli in each lung of a man. The alveoli have very thin walls and are surrounded by blood capillaries.

Tidal volume and Vital capacity

The volume of air inspired and expired during normal breathing is called **tidal volume.** The maximum volume of air which can be ventilated during forced breathing is called the **vital capacity** of the lungs.

Total lung capacity and Dead space

The **total lung capacity** of human lungs is about 5 to 6 litres. Although 500 ml of fresh air is breathed during each inspiration, only part of this air reaches the alveoli. The rest of the air fills the nasal cavity, trachea, bronchioles etc. The air cantained in these tubes, which is about 150 ml, is called **dead space.**

Respiratory Pigments

Respiratory pigments are coloured substances present in blood transporting O_2 and CO_2.

Salient features of respiratory pigments

1. They are coloured pigments.
2. They have special affinity for respiratory gases.
3. They are distributed either in the blood or in the body fluids.
4. They are the coloured proteins (chromoproteins) which contain a metallic ion.
5. They play an important role in the transport of O_2 and CO_2.

The following are the important respiratory pigments that are commonly met with in animals:

1. Haemoglobin
2. Haemocyanian
3. Chlorocruorin
4. Haemoerythrin
5. Pinnaglobin
6. Echinochrome
7. Vanadium and
8. Molpadin

1. Haemoglobin

1. Haemoglobin is a *respiratory pigment* present in the blood.

2. Haemoglobin occurs in all vertebrates, a few holothurians. several crustaceans, chironomus insects, *Planorbis*, annelids, parasitic nematodes, flatworms, protozoa and also in the root nodules of some leguminous plants.

3. It occurs in the blood corpuscles of vertebrates and plasma of invertebrates. The invertebrate haemoglobin is also called *erythrocruorin.*

4. The haemoglobin is also found in the muscles of birds and mammals.

The haemoglobin that is present in the muscles is called *myoglobin*. It helps to store oxygen temporarily in the muscles.

5. In *Urechis* haemoglobin occurs in the nerve cells.

6. It has molecular weight of 68000.

7. Haemoglobin is a *chromoprotein* (*conjugated protein*)

8. In a normal person, each 100 ml of blood contains 14 to 15 gms of haemoglobin. The total haemoglobin content is approximately 700 gms in a man.

9. It is composed of two components, namely a protein component called *globin* and a non-protein component (prosthetic group) called *haem*.

10. Globin is formed of four polypeptide chains. Of the four polypeptide chains, two are identical and called α *chains*. An α *chain* is formed of 141 aminoacids. The other two identical chains, are called β *chain*. Each chain contains 146 amino acids.

11. The haem is a non protein and it is formed of *iron* and *porphyrin*.

12. The iron is present in the ferrous condition Fe^{++}

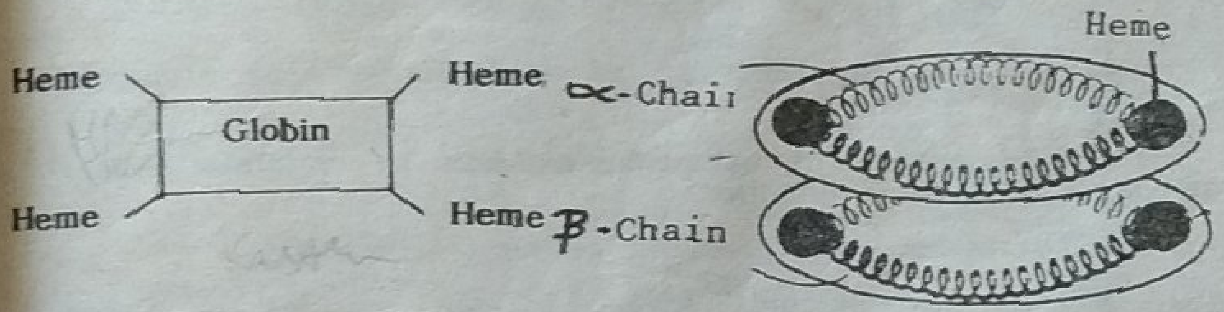


Fig.*4-1*: Haemoglobin

13. The porphyrin is the pigment and it gives red colour to haemoglobin.

14. There are *four* haem molecules in one haemoglobin.

Haemoglobin → Globin + 4 molecules of haem.

Haem → Porphyrin + Iron.

15. Haemoglobin combines with oxygen to form *oxyhaemoglobin*. This combination is loose. At low oxygen pressure, it leaves oxygen forming *reduced haemoglobin*. One haemoglobin molecule can bind with 4 molecules of O_2.

$$Hb + O_2 \underset{\text{In tissues}}{\overset{\text{In lungs}}{\rightleftharpoons}} HbO_2 \text{ (Oxyhaemoglobin)}$$

16. When haemoglobin is treated with hydrochloric acid, it forms a brown coloured pigment called *acid haematin*.

17. When haemoglobin is treated with galcial acetic acid, it forms *haemin crystals*.

18. When the R B C s are destroyed, the *haemoglobin* is destroyed. This process occurs in spleen, bone marrow, etc. During the destruction, haem is separated from globin. The haem undergoes further breakdown. The iron portion is returned to the bone marrow to be used again in the manufacture of new haemoglobin. A large proportion of the haem is converted into bile pigment, *bilirubin* and is excreted by the liver into the intestine. Some of it is reabsorbed and excreted in the urine as *urobilinogen*. Major portion of it is excreted in the faeces as *stercobilinogen* and *stercobilin* which are responsible for the brown colour of the stool.

Functions of haemoglobin

Haemoglobin has the following functions:

1. It transports O_2 from the lungs to the cells.

$$Hb + O_2 \longrightarrow HbO_2$$

2. It transports CO_2 from the cells to the lungs.

$$Hb - NH_2 + CO_2 \longrightarrow Hb\text{-}NH\text{-}COOH$$

3. Haemoglobin functions as **a buffer** in the transport of CO_2.

4. The protein of haemoglobin helps to maintain colloid and osmotic pressure of blood.

5. The haemoglobin gives red colour to the blood.

6. The haemoglobin present in the muscles is called **myoglobin**. It stores O_2 for future use.

4. Haemocyanin

1. It is a blue coloured pigment.
2. REDFIELD (1934) did much work on this pigment.
3. It is formed of copper and protein.
4. The melecule of haemocyanin is large and consisting of one copper atom associated with a peptide chain of about 200 amino acids.
5. Its molecular weight differs in different animal groups. For example for **Helix** it is 6,650000 and for **Palinurus** it is 447000.
6. Like all proteins, haemocyanin absorbs ultra-violet rays.
7. It is used in transport of gases and in storage.
8. Haemocyanin occurs in the blood plasma of Arthropods such as **Limulus** and **Daphnia** and molluscs such as **Sepia, Octopus** and **Helix.**

3. Haemoerythrin

1. It is a reddish-violet coloured pigment.
2. It is formed of iron and protein. The iron is directly attached to the protein and there is no porphyrin.

Table: 4-3: Distribution of Respiratory pigments in Animals

Pigment	Colour	Distribution	Location	Metallic group
Heamo-globin	Red	Prochordates, All vertebrates, Echinodermata, Mollusca, Arthropoda, Annelida	Corpuscles and Plasma	Iron
Chloro-cruorin	Green	Annelids	Plasma	Iron
Haemery-thrin	Red or Brown	Annelids, Sipunculoidea, Brachiopoda,	Corpuscles	Iron
Haemo-cyanin	Blue	Arthropoda, Mollusca	Plasma	Copper
Pinna-globin	Brown	Mollusca	Body fluid	Manga-nese
Echino-chrome	Red	Echinodermata	Coelomic fluid	Iron

3. The molecular weight varied from 66,000 to 120,000.
4. It occurs in the corpuscles of **Sipunculus** and the plasma of other organisms.
5. It is present in the brachiopod **Lingula**, sipunculids, priapulids and the polychaete **Magelona.**
6. When compared with other respiratory pigments, it is less efficient in oxygen carrying capacity.

4. Chlorocruorin

1. It is a green coloured pigment.
2. It was discovered by MILNE EDWARDS in Annelids.
3. It is an iron containing blood pigment.
4. It is closely allied to haemoglobin and cytochromes.
5. It occurs in the plasma.
6. It functions only at high oxygen tensions.
7. Its distribution is restricted to polychaete Annelids.

Eg: Sabella, Serpula.

5. Pinnaglobin

1. It is a brown coloured pigment.
2. It occurs in the body fluid of **Pinna.**
3. It is a manganese containing blood pigment.

6. Vanadium Chromogen

1. It is present in the blood cells (Vanadocytes) of **Ascidians.**

2. It also occurs in the plasma of several other organisms.

7. Echinochrome

1. It is a red coloured pigment.
2. It is an iron containing pigment.
3. It occurs in the coelomic fluid of ***sea urchin.***

8. Molpadin

It occurs in the holothurian called ***Molpadia.***

Functions of Respiratory Pigments

The following are the most important functions of respiratory pigments:

1. They are the oxygen carriers. In the absence of these pigments blood could carry only lesser amount of oxygen.

2. All the pigments have great affinity towards the respiratory gases. At high partial pressure they can combine with these gases and at low partial pressure they can dissociate.

3. The respiratory pigments show reversibility in their action. For example, reversibility of haemoglobin can be expressed as follows:

$$\text{Haemoglobin} + \text{Oxygen} \underset{\textit{Tissues}}{\overset{\textit{Respiratory organs}}{\rightleftharpoons}} \text{Oxyhaemoglobin.}$$

4. They also function as buffers in the transport of CO_2.

5. The proteins of respiratory pigments help to maintain colloid and osmotic pressure of blood.

Transport of Gases

Atmospheric air enters the lungs by inspiration. From the lungs oxygen diffuses into the blood. The blood carries the oxygen to the cells. The cells take up oxygen for oxidation. Oxidation releases carbondioxide. The CO_2 from the cells diffuses into the blood. The blood carries CO_2 to the lungs for removal. *The transport of O_2 from the lungs to the cells and the transport of CO_2 from the cells to the lungs are called **transport of gases.***

Oxygen Transport

The transport of O_2 from the lungs to the cells is called O_2 transport.

The lung contains atmospheric air. From the lung O_2 diffuses into the blood. The blood transports O_2 from the lungs to the cells. This is called ***oxygen transport.***

The O_2 is transported by haemoglobin (Hb) present in the RBC of blood.

The arterial blood contains 20 ml of O_2 per 100 ml of blood. The venous blood contains 15 ml of O_2 per 100 ml of blood.

The O_2 carrying capacity of blood will be higher when the blood contains more Hb.

The most important property of Hb is that it loosely attaches with O_2 to form ***oxyhaemoglobin*** (HbO_2) when the O_2 pressure in the blood is high. Similarly it dissociates (separates) readily with oxygen when the O_2 pressure is lesser in the blood.

$$Hb + O_2 \underset{\text{In tissues}}{\overset{\text{In lungs}}{\rightleftharpoons}} HbO_2$$

In alveolar capillaries of lungs, the O_2 pressure is higher. Hence here Hb combines with O_2 to form oxyhaemoglobin (HbO_2). Each Hb molecule combines with 4 moles of O_2.

The blood leaving the lungs has 99% of its Hb is fully loaded with O_2. When the blood is fully loaded with O_2, it carries 20ml. of O_2 per 100 ml. of blood.

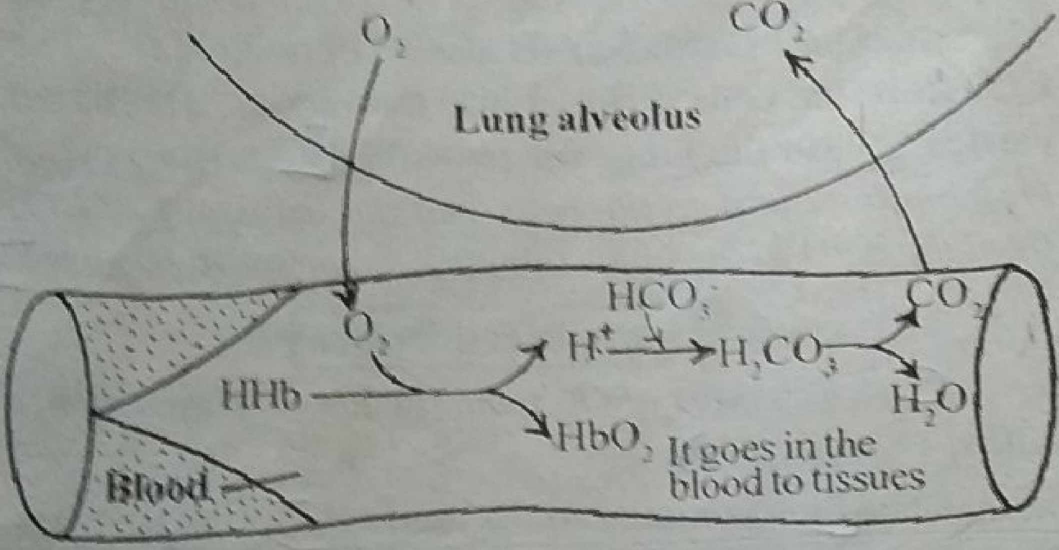


Fig. 4.2: O_2 is taken into the blood from the lungs and CO_2 is released into the lungs from the blood.

From the lungs, the oxygen-rich blood enters the heart and is then pumped to the various organs. The cells present in the tissues of various organs consume O_2 continuously. Hence the O_2 pressure in the tissues and organs will be lesser.

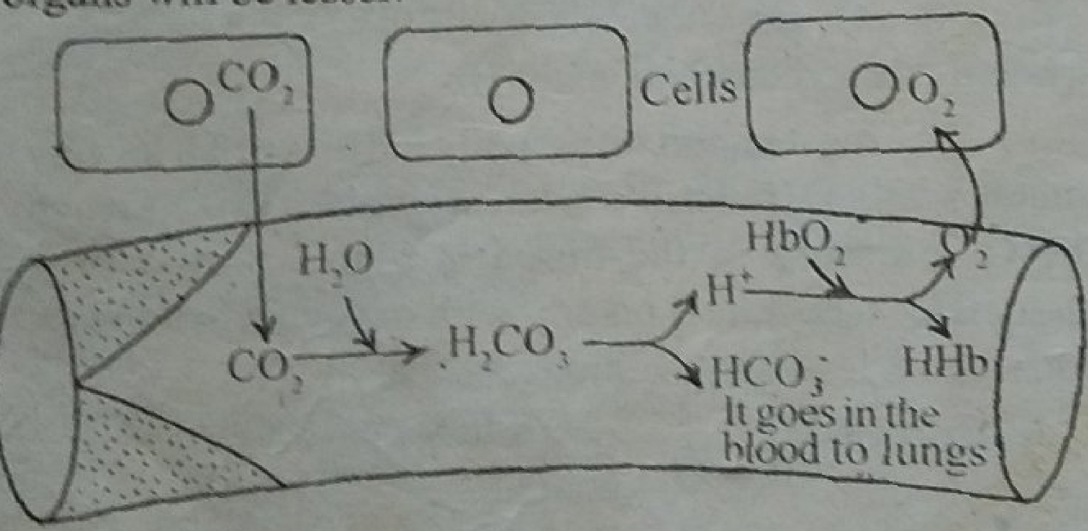


Fig. 4.3: CO_2 is taken into the blood from the tissues and O_2 is released into the tissues from the blood.

When the O_2 rich blood passes through the tissues, Hb dissociates from O_2. The O_2 diffuses out from the blood through the capillary wall and enters the tissues.

The Hb returns to the lungs and again transports new O_2 molecules.

The venous blood contains 15 ml. of O_2 per 100 ml. of blood.

O_2 Dissociation Curve

O_2 dissociation curve is a graph showing the proportion of oxyhaemoglobin and oxygen pressure. Hb can combine with O_2 to form HbO_2.

When the O_2 pressure is low, the percentage of HbO_2 formed will be also lesser i.e. at low O_2 pressure, the affinity of Hb for O_2 will be lesser. When the O_2 pressure is high the % of HbO_2 formed will be higher.

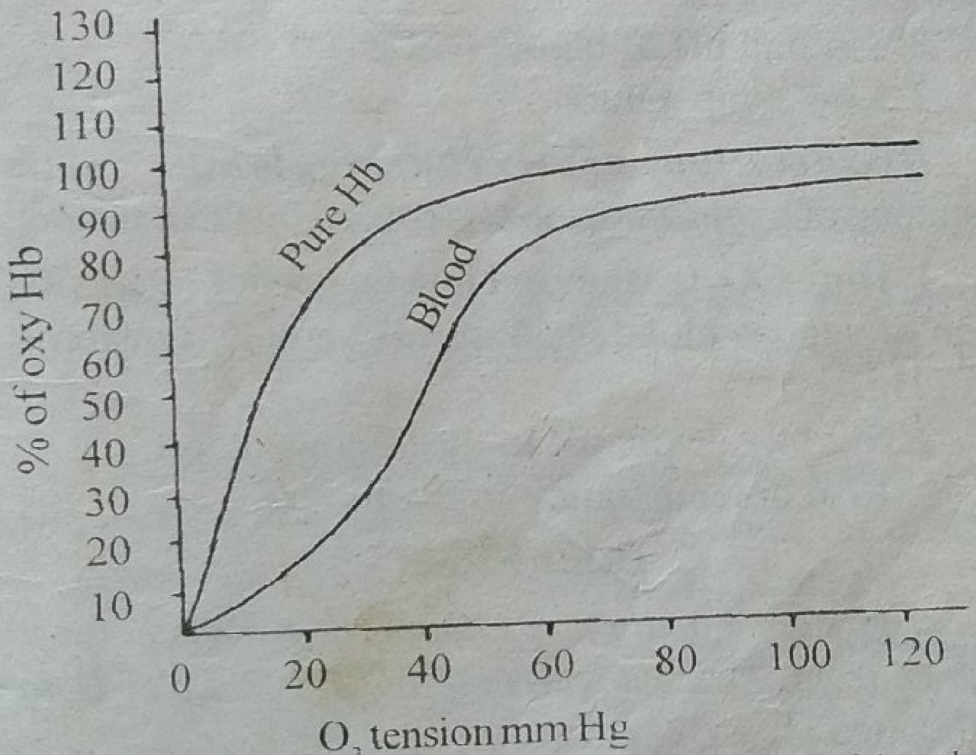


Fig. 4.4 : Oxygen dissociation curve for blood and haemo globin.

It is an S shaped curve. The dissociation curves for human blood and pure Hb are given in the figure.

The curve for blood clearly shows that at O mm Hg of O_2 pressure the % of HbO_2 formed is also O.

At 30 mm Hg of O_2 pressure, the % of HbO_2 formed is about 55.

At 70 mm Hg the % is about 90.

At 90 mm Hg the % of HbO_2 formed is 98%.

This curve clearly shows that when the O_2 pressure increases the % of HbO_2 formed is also increased. However above 100 mm Hg, there is only of a slight increase in the % of oxyhaemoglobin.

Formation of Oxyhaemoglobin: The formation of oxyhaemoglobin in the lungs is due to the following three factors:

1. High O_2 tension and low CO_2 tension. The O_2 tension in the arterial blood is 100 mm Hg and the CO_2 tension is 40 mm Hg.
2. Normal pH of blood, that is 7.4.
3. Low temperature.

Dissociation of Oxyhaemoglobin: The dissociation of oxyhaemoglobin is caused by three factors:

1. High CO_2 tension and low O_2 tension. The CO_2 tension of venous blood is 46 mm Hg and O_2 tension is 40 mm Hg.
2. Slightly acidic pH in the venous blood.
3. Rise in temperature in the tissues.

Bohr Effect

High concentration of CO_2 in the tissues helps to unload O_2 from oxyhaemoglobin (HbO_2). It is called ***Bohr effect*** named after ***Bohr.***

CO_2 concentration is higher in the tissues. When blood containing HbO_2 passes through the tissues, the affinity of Hb for O_2 is reduced because of higher concentration of CO_2 in the tissues. Hence Hb separates

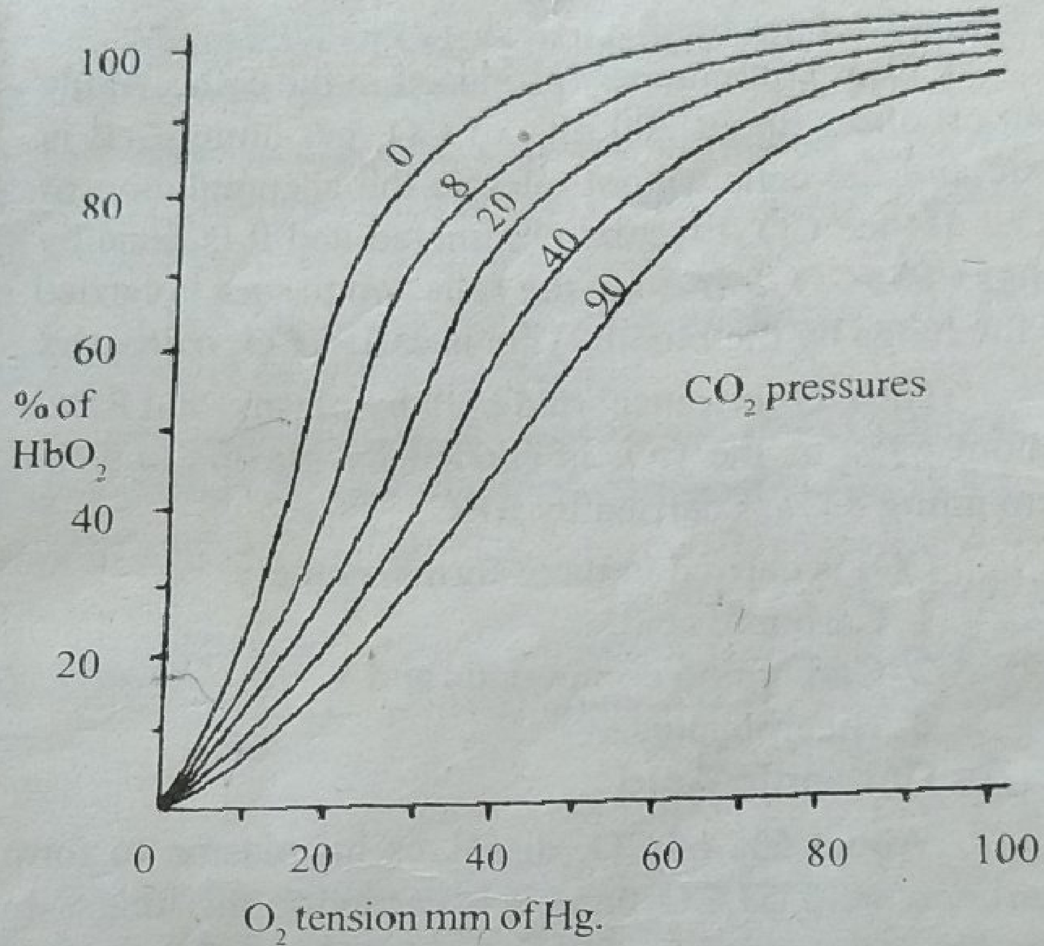


Fig. 4.5: Dissociation curves showing Bohr effect.

from O_2 and O_2 is released for the utilization of tissues. Thus increasing concentration of CO_2 helps to unload O_2 from Hb.

As a result of Bohr effect, the dissociation curves move to the right. The dissociation curves for different concentrations of CO_2 are given in the figure.

At high CO_2 pressures the oxygen pressure at which haemoglobin becomes saturated with O_2 is higher than it is at low CO_2 pressures. In the tissues, addition of CO_2 facilitates the unloading of O_2; in the lungs as CO_2 is given out from the blood, uptake of O_2 is facilitated.

CO_2 transport

The transport of CO_2 from the tissues to the lungs through the blood is called CO_2 transport.

CO_2 is continuously produced in the cells. Adult man produces about 200 ml. of CO_2 per minute. It is toxic and the cells cannot tolerate the accumulation of CO_2. Hence CO_2 must be eliminated and it is done by lungs. The CO_2 formed in the cells and tissues is carried to the lungs by the blood. This is called ***CO_2 transport.***

The CO_2 is transported both by plasma and RBC. About 67% of the CO_2 is carried by plasma and the remaining 33% is carried by RBC.

CO_2 is carried in three forms, namely

1. Carbonic acid.
2. Carbamino compounds and
3. Bicarbonates.

1. As Carbonic Acid

About 5% of CO_2 dissolves in plasma to form carbonic acid (H_2CO_3) and it is carried to the lungs. In the lungs the reaction is reversed to release CO_2.

$$CO_2 + H_2O \underset{Lungs}{\overset{Tissues}{\rightleftharpoons}} H_2CO_3$$

2. As Carbamino compounds

About 10% of CO_2 is carried as carbamino compound. CO_2 combines with the amino group of plasma proteins to form carbamino compounds. These compounds are carried to the lungs where the reaction is reversible.

$$R\text{–}NH_2 + CO_2 \underset{Lungs}{\overset{Tissues}{\rightleftharpoons}} R\text{–}NHCOOH$$

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3. As Bicarbonates

About 85% of CO_2 is transported as bicarbonates in RBC as well as in plasma.

Most of the CO_2 entering the blood from the tissues, diffuses into the RBC. In the RBC, CO_2 combines with water to form carbonic acid (H_2CO_3).

In the RBC this reaction is accelerated by an enzyme called ***carbonic anhydrase.***

The carbonic acid is unstable and immediately it dissociates into H^+ ions and bicarbonate ions (HCO_3)

$$CO_2 + H_2O \underset{Lungs}{\overset{Tissues}{\rightleftharpoons}} H_2CO_3 \underset{Lungs}{\overset{Tissues}{\rightleftharpoons}} H^+ + HCO_3^-$$

The hydrogen ions released from the carbonic acid cannot be retained as such in the RBC. It readily combines with HbO_2.

$$HbO_2 + H^+ \underset{Lungs}{\overset{Tissues}{\rightleftharpoons}} HHb + O_2$$

When H^+ combines with HbO_2, O_2 is released and HbO_2 is converted into ***reduced haemoglobin*** (HHb). Thus when H^+ combines with HbO_2, HbO_2 unloads O_2. The O_2 released from HbO_2, diffuses into the tissue cells where it is consumed.

The blood leaving the tissues contains large quantities of HCO^-_3 and reduced haemoglobin (HHb) and small amount of carbonic acid (H_2CO_3). No further changes take place until the blood reaches the capillaries of the lungs.

When the blood reaches the lungs all the above reactions are reversed. The reactions occurring in the lungs can be summarised as follows:

1. O_2 from alveoli diffuses into the plasma and RBC.

2. The O_2 combines with HHb to form HbO_2 and this releases H^+.

3. The H^+ combines with HCO^-_3 and forms H_2O and CO_2.

4. The CO_2 diffuses into the lung alveoli where it is expelled in the process of normal breathing.

Chloride shift (Hamburger phenomenon)

The diffusion of chloride ions into the RBC from the plasma and back is called chloride shift.

From the tissue cells CO_2 diffuses into the RBC via plasma. In the RBC, CO_2 combines with water to form carbonic acid (H_2CO_3). The H_2CO_3 immediately ionizes into H^+ and bicarbonate ions (HCO^-_3).

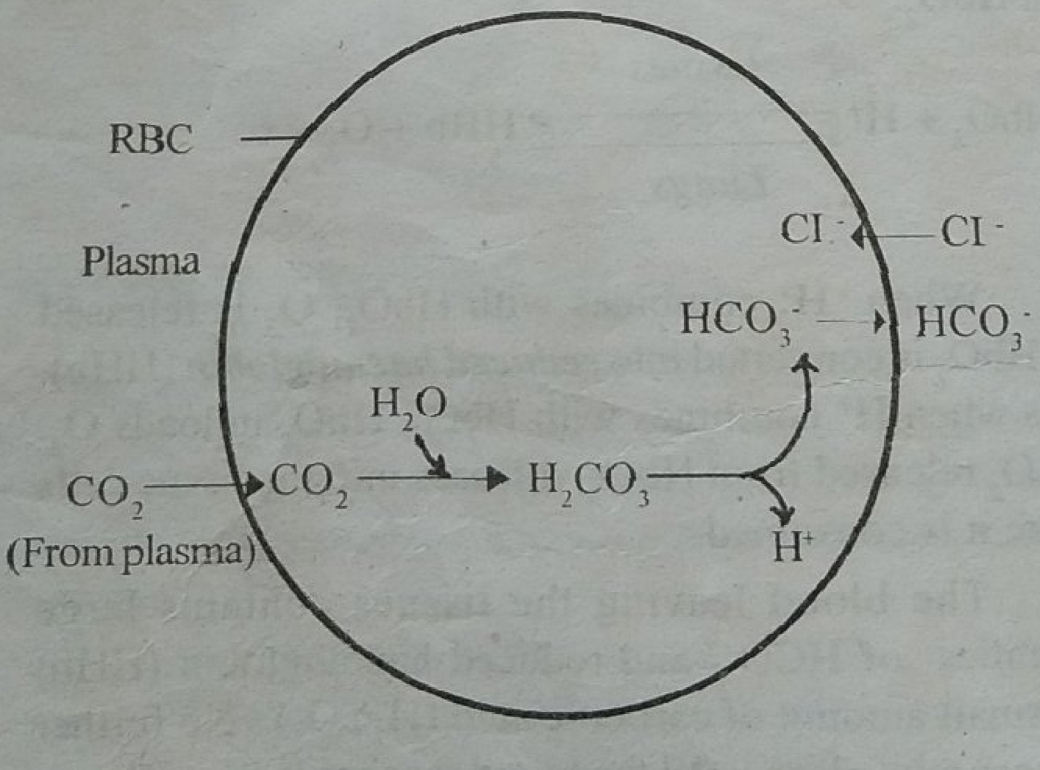

Fig. 4.6: Chloride shift.

R.Q of turtles increases from 0.52 at 1 C to 0.75 at 29°C. In human body during, violent exercises, excess of CO_2 is eliminated from the lungs and this makes the increase of R.O exceeding 2. The **diabetic patient** shows a low R.Q due to the increased dissimilation of fats and the decreased dissimilation of carbohydrate.

Anaerobiosis or Anoxybiosis

Life in the absence of free oxygen is termed **anaerobiosis** or **anoxybiosis.** Animals can be divided into two groups based on the mode of respiration. They are **aerobic** organisms and **anaerobic** organisms. Some animals adopt both types of respiration at one time or other during their life period. All cells are capable of temporary anaerobic existence. Many bacteria and protozoans tolerate anaerobiosis for prolonged periods. Cells in most tissues of the body can even tolerate anaerobiosis for brief periods. But the cells of the central nervous system of vertebrates suffer very quickly from oxygen lack.

Many animals acquired the capacity for life with little or no oxygen. The animals which live in some habitats where O_2 levels are continuously low, are able to live without oxygen for a long time. **Facultative anaerobes** are those organisms **which switch to aerobic metabolism when O_2 is available. Obligate anaerobes** never require O_2.

Anaerobic organisms: Anaerobiosis is common in protozoans, helminth parasites like **Ascaris** and tape worms. Among molluscs, the marine lamellibranchs which live in the intertidal zone where oxygen is not available during the low tide, have anaerobic adaptations. Many crustaceans and also insect larvae have been found to tide over periods of oxygen lack by anaerobic respiration.

Some symbiotic protozoans like those constituting the cellulose digesting fauna of the termite live under anaerobic conditions and are killed when the oxygen tension is raised. Protozoans in the rumen of a cow are completely under anaerobic conditions. Many bacteria such as butyric and lactic acid bacteria, and denitrifying bacteria like **Bacillus denitrificans** are capable of anaerobic existence. The carp fish **Carassius carassius** can live in an oxygen free environment for two to three months at temperatures of about 5°C.

Physiological aspects of anaerobiosis: In both plants and animals carbohydrates appear to be of primary importance in anaerobic respiration. Normally carbohydrates are split into lactic acid by chemical reactions that are non-oxidative and subsequently part of the lactic acid is oxidised to CO_2 and H_2O. About half the energy released is from the oxidation of lactic acid and half from non-oxidative process. The liberation of a large amount of CO_2 during the anaerobic existence utilizing the energy in sugar from which it makes alcohol and CO_2. Proteins and fats in anaerobiosis have little or no importance. ATP production in true anaerobiosis may be as high as 60% of the ATP yieldof oxidative phosphorylation. In vertebrate **skeletal muscle**, **glycogen** or glucose is converted to pyruvic acid by **glycolytic pathway**. Pyruvic acid is then oxidised to CO_2 and H_2O by Krebs cycle and oxidative phosphorylation. Under conditions of **moderate anaerobiosis**, pyruvic acid is reduced to lactic acid in the presence of lactic dehydrogenase.

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} \longrightarrow \underset{\text{(Lactic acid)}}{C_3H_6O_3} + \text{Energy.}$$

Succinic acid forms one of the major end products in anaerobic animals. The second important end product is the amino acid **alanine**. **Propionic acid** occurs as a third end product in many nematodes, cestodes, trematodes and the annelid **Alma emeni**. Acetic acid is the fourth end product in some parasitic helminthes. If these end products are not removed, they are toxic. The anaerobes eliminate them from their body but the method of elimination is unknown.

5. Biological Oxidation

Biological oxidation refers to ***enzyme catalysed chemical reactions which utilize oxygen or lose hydrogen or electrons*** **(e^-).** Biological oxidation is also called ***tissue oxidation*** or ***cellular respiration.*** Oxidations brought about by the loss of hydrogen or electrons are also directly or indirectly dependent upon the involvement of oxygen at one or the other stage. As a result of oxidation, nutrients of high-energy level are converted into compounds of low-energy level. Consequently, a portion of energy is released in the form of ***free energy. Free energy is the energy available to do work.*** The main bulk of the free energy is packaged in energy-