CC6-ANIMAL PHYSIOLOGY

Subject Code : 18KP2Z06

UNIT I

Carbohydrate metabolism is the whole of the biochemical processes responsible for the metabolic formation, breakdown, and interconversion of carbohydrates in living organisms.

Carbohydrates are central to many essential metabolic pathways.[1] Plants synthesize carbohydrates from carbon dioxide and water through photosynthesis, allowing them to store energy absorbed from the sunlight internally.[2] When animals and fungi consume plants, they use cellular respiration to break down these stored carbohydrates to make energy available to cells.[2] Both animals and plants temporarily store the released energy in the form of high-energy molecules, such as ATP, for use in various cellular processes.[3]

Although humans consume a variety of carbohydrates, digestion breaks down complex carbohydrates into a few simple monomers (monosaccharides) for metabolism: glucose, fructose, and galactose.[4] Glucose constitutes about 80% of the products and is the primary structure that is distributed to cells in the tissues, where it is broken down or stored as glycogen.[3][4] In aerobic respiration, the main form of cellular respiration used by humans, glucose and oxygen are metabolized to release energy, with carbon dioxide and water as byproducts.[2] Most of the fructose and galactose travel to the liver, where they can be converted to glucose.[4]

Some simple carbohydrates have their own enzymatic oxidation pathways, as do only a few of the more complex carbohydrates. The disaccharide lactose, for instance, requires the enzyme lactase to be broken into its monosaccharide components, glucose and galactose.

Glycolysis

Glycolysis is the process of breaking down a glucose molecule into two pyruvate molecules, while storing energy released during this process as ATP and NADH.[2] Nearly all organisms that break down glucose utilize glycolysis.[2] Glucose regulation and product use are the primary categories in which these pathways differ between organismsome tissues and organisms, glycolysis is the sole method of energy production.This pathway is common to both anaerobic and aerobic respiration.

Glycolysis consists of ten steps, split into two phases. During the first phase, it requires the breakdown of two ATP molecules.[1] During the second phase, chemical energy from the intermediates is transferred into ATP and NADH.[2] The breakdown of one molecule of glucose results in two molecules of pyruvate, which can be further oxidized to access more energy in later processes.[1]

Glycolysis can be regulated at different steps of the process through feedback regulation. The step that is regulated the most is the third step. This regulation is to ensure that the body is not over-producing pyruvate molecules. The regulation also allows for the storage of glucose molecules into fatty acids. [There are various enzymes that are used throughout glycolysis. The enzymes are what help upregulate, downregulate, and feedback regulate the process.

Gluconeogenesis

Gluconeogenesis is the reverse process of glycolysis. It involves the conversion of non-carbohydrate molecules into glucose. The non-carbohydrate molecules that are converted in this pathway include pyruvate, lactate, glycerol, alanine, and glutamine. This process occurs when there are lowered amounts of glucose. The liver is the primary location of gluconeogenesis, but some also occurs

in the kidney. The liver is the organ that breaks down the various non-carbohydrate molecules and sends them out to other organs and tissues to be used in Gluconeogenesis.

This pathway is regulated by multiple different molecules. Glucagon, adrenocorticotropic hormone, and ATP encourage gluconeogenesis.[7] Gluconeogenesis is inhibited by AMP, ADP, and insulin. Insulin and glucagon are the two most common regulators of gluconeogenesis.

Glycogenolysis

Glycogenolysis refers to the breakdown of glycogen. In the liver, muscles, and the kidney, this process occurs to provide glucose when necessary. A single glucose molecule is cleaved from a branch of glycogen, and is transformed into glucose-1-phosphate during this process. This molecule can then be converted to glucose-6-phosphate, an intermediate in the glycolysis pathway.

Glucose-6-phosphate can then progress through glycolysis. Glycolysis only requires the input of one molecule of ATP when the glucose originates in glycogen. Alternatively, glucose-6-phosphate can be converted back into glucose in the liver and the kidneys, allowing it to raise blood glucose levels if necessary.

Glucagon in the liver stimulates glycogenolysis when the blood glucose is lowered, known as hypoglycemia. The glycogen in the liver can function as a backup source of glucose between meals Adrenaline stimulates the breakdown of glycogen in the skeletal muscle during exercise In the muscles, glycogen ensures a rapidly accessible energy source for movement.[2]

Glycogenesis

Glycogenesis refers to the process of synthesizing glycogen In humans, excess glucose is converted to glycogen via this process. Glycogen is a highly

branched structure, consisting of glucose, in the form of glucose-6-phosphate, linked together. The branching of glycogen increases its solubility, and allows for a higher number of glucose molecules to be accessible for breakdown. Glycogenesis occurs primarily in the liver, skeletal muscles, and kidney. The Glycogenesis pathway consumes energy, like most synthetic pathways, because an ATP and a UTP are consumed for each molecule of glucose introduced.

Krebs Cycle Definition

The Krebs Cycle, also called the *citric acid cycle*, is the second major step in oxidative phosphorylation. After glycolysis breaks glucose into smaller 3-carbon molecules, the Krebs cycle transfers the energy from these molecules to electron carriers, which will be used in the electron transport chain to produce ATP.

Krebs Cycle Overview

Most organisms use glucose as a major fuel source, but must break down this glucose and store the energy in ATP and other molecules. **The Krebs cycle is contained within mitochondria.** Within the mitochondrial matrix, the reactions of the Krebs cycle adds electrons and protons to a number of electron carriers, which are then used by the electron transport chain to produce ATP.

The Krebs cycle starts with the products of glycolysis, which are two three-carbon molecules known as pyruvate. This molecule is acidic, which is why the Krebs cycle is also called the tricarboxylic acid cycle (TCA). Throughout a number of reactions, these molecules are further broken down into carbon dioxide. **Energy from the molecules is moved to other molecules, called electron carriers.** These molecules carry the stored energy to the electron transport chain, which in turn creates ATP.

Then, the cell uses this ATP to power various cellular reactions, such as the activation of enzymes or transport proteins. The Krebs cycle is the second of 4

different processes which must happen to extract the energy from glucose. Altogether, the Krebs cycle consists of 9 sequential reactions.

Krebs Cycle Products

The first step of utilizing glucose, *glycolysis*, produces a few ATP as well as the molecules which will be processed with the Krebs cycle. During glycolysis, a single glucose molecule is split into two smaller, three-carbon molecules called *pyruvate*. Pyruvate is then converted to *acetyl CoA*. **Acetyl CoA is then utilized within the Krebs cycle to produce several major products.** In turn, these products then drive the formation of ATP, the cell's main energy source.

Before the first stages of the Krebs cycle, pyruvate is converted into acetyl CoA. During this process, one molecule of CO_2 and one molecule of the electron carrier NADH are produced. The Krebs cycle involves converting this acetyl CoA into carbon dioxide. During the steps of the cycle, two molecules of CO_2 are released, in addition to 3 more molecules of NADH, one of $FADH_2$, and one of GTP.

So, for every 1 pyruvate molecule added, the Krebs cycle will produce:

- 2 molecules of CO_2
- 3 molecules of NADH
- 1 molecule of $FADH_2$
- 1 molecule of GTP

A molecule of glucose contains 2 pyruvate molecules, so 1 glucose molecule will produce double the amount of products listed above as it moves through the Krebs cycle. These products will then be converted to ATP in later stages of aerobic respiration. **Carbon dioxide is the only "waste" product and must be removed from the cell.** Large organisms must remove carbon dioxide from all their cells. In

these animals, carbon dioxide is typically exchanged in the gills or lungs for oxygen, which helps drive the final stages of aerobic respiration.

Where Does the Krebs Cycle Take Place?

The Krebs cycle happens only within the mitochondrial matrix. Pyruvate is formed in the cytosol of the cell, then imported into the mitochondria. Here, it is converted to acetyl CoA and imported into the mitochondrial matrix. **The mitochondrial matrix is the innermost part of the mitochondria.** The graphic below shows the different parts of mitochondria.

Fatty acids are released, between meals, from the fat depots in adipose tissue, where they are stored as triglycerides, as follows:

- Lipolysis, the removal of the fatty acid chains from the glycerol to which they are bound in their storage form as triglycerides (or fats), is carried out by lipases. These lipases are activated by high epinephrine and glucagon levels in the blood (or norepinephrine secreted by sympathetic nerves in adipose tissue), caused by declining blood glucose levels after meals, which simultaneously lowers the insulin level in the blood.[1]
- Once freed from glycerol, the free fatty acids enter the blood, which transports them, attached to plasma albumin, throughout the body.[4]
- Long chain free fatty acids enter the metabolizing cells (i.e. most living cells in the body except red blood cells and neurons in the central nervous system) through specific transport proteins, such as the SLC27 family fatty acid transport protein.[5][6] Red blood cells do not contain mitochondria and are therefore incapable of metabolizing fatty acids; the tissues of the central nervous system cannot use fatty acids,

despite containing mitochondria, because long chain fatty acids (as opposed to medium chain fatty acids[7][8]) cannot cross the blood brain barrier[9] into the interstitial fluids that bathe these cells.

- Once inside the cell long-chain-fatty-acid—CoA ligase catalyzes the reaction between a fatty acid molecule with ATP (which is broken down to AMP and inorganic pyrophosphate) to give a fatty acyl-adenylate, which then reacts with free coenzyme A to give a fatty acyl-CoA molecule.
- In order for the acyl-CoA to enter the mitochondrion the carnitine shuttle is used:[10][11][12]
    1. Acyl-CoA is transferred to the hydroxyl group of carnitine by carnitine palmitoyltransferase I, located on the cytosolic faces of the outer and inner mitochondrial membranes.
    2. Acyl-carnitine is shuttled inside by a carnitine-acylcarnitine translocase, as a carnitine is shuttled outside.
    3. Acyl-carnitine is converted back to acyl-CoA by carnitine palmitoyltransferase II, located on the interior face of the inner mitochondrial membrane. The liberated carnitine is shuttled back to the cytosol, as an acyl-CoA is shuttled into the mitochondrial matrix.
- Beta oxidation, in the mitochondrial matrix, then cuts the long carbon chains of the fatty acids (in the form of acyl-CoA molecules) into a series of two-carbon (acetate) units, which, combined with co-enzyme A, form molecules of acetyl CoA, which condense with oxaloacetate to form citrate at the "beginning" of the citric acid cycle.[2] It is convenient to think of this reaction as marking the "starting point" of the cycle, as

this is when fuel - acetyl-CoA - is added to the cycle, which will be dissipated as CO_2 and H_2O with the release of a substantial quantity of energy captured in the form of ATP, during the course of each turn of the cycle.

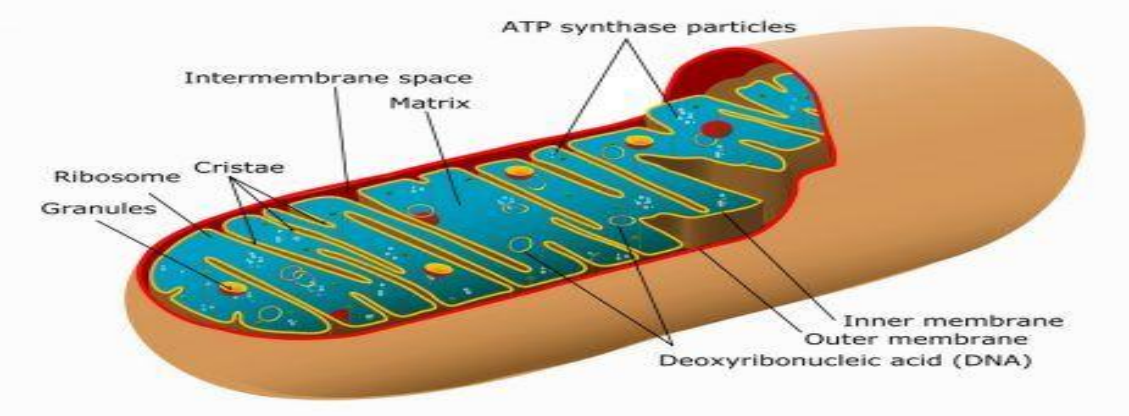
Briefly, the steps in beta oxidation (the initial breakdown of free fatty acids into acetyl-CoA) are as follows:[2]

1. Dehydrogenation by acyl-CoA dehydrogenase, yielding 1 $FADH_2$
2. Hydration by enoyl-CoA hydratase
3. Dehydrogenation by 3-hydroxyacyl-CoA dehydrogenase, yielding 1 NADH + H^+
4. Cleavage by thiolase, yielding 1 acetyl-CoA and a fatty acid that has now been shortened by 2 carbons (forming a new, shortened acyl-CoA)

This beta oxidation reaction is repeated until the fatty acid has been completely reduced to acetyl-CoA or, in, the case of fatty acids with odd numbers of carbon atoms, acetyl-CoA and 1 molecule of propionyl-CoA per molecule of fatty acid. Each beta oxidative cut of the acyl-CoA molecule yields 5 ATP molecules.

- The acetyl-CoA produced by beta oxidation enters the citric acid cycle in the mitochondrion by combining with oxaloacetate to form citrate. This results in the complete combustion of the acetyl-CoA to CO_2 and water. The energy released in this process is captured in the form of 1 GTP and 11 ATP molecules per acetyl-CoA molecule oxidized.[2][10] This is the fate of acetyl-

CoA wherever beta oxidation of fatty acids occurs, except under certain circumstances in the liver.



The mitochondrial matrix has the required enzymes and environment for the complex reactions of the Krebs cycle to take place. **Further, the products of the Krebs cycle drive the *electron transport chain* and *oxidative phosphorylation*, both of which occur in the inner mitochondrial membrane.** The electron carriers will dump their electrons and protons into the chain, which ultimately drives the production of ATP. This molecule is then exported from the mitochondria as the main energy source for the cell.Mitochondria are found in almost all organisms, especially multicellular organisms. Plants, animals, and fungi all use the Krebs cycle as an indispensable part of aerobic respiration.

Krebs Cycle Steps

The Krebs cycle has 9 main reactions, which happen quickly in succession. The image below shows these reactions.

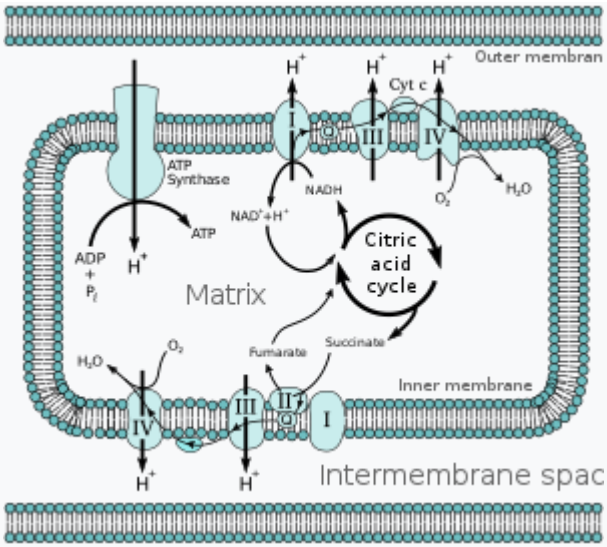
Note that citrate is the first molecule created after acetyl CoA is added. This is why the Krebs cycle is also known as the citric acid cycle. **The products of the cycle are in the image above.** This process is known as a “cycle” because it always ends

on *oxaloacetate* which can be combined with a new acetyl CoA to produce a new molecule of citrate for each cycle.

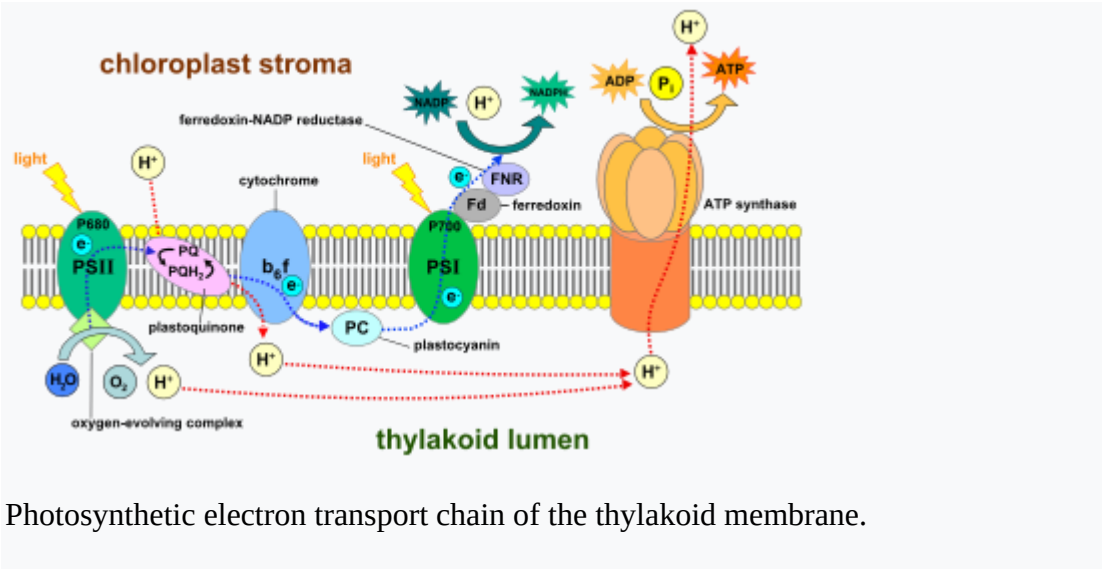
Krebs Cycle Function

The Krebs cycle is likely the most important part of the process of aerobic respiration because it drives the formation of electron carriers. These carriers are important. **They carry the energy used to create a large number of ATP molecules in the final steps of aerobic respiration.** The electron carriers produced (NADH and $FADH_2$) cannot provide energy to cellular process directly. Instead, the processes of the electron transport chain and oxidative phosphorylation will use the energy from these molecules to activate the enzyme complex *ATP synthase*, which produces ATP.

Electron transport



The electron transport chain in the mitochondrion is the site of oxidative phosphorylation in eukaryotes. The NADH and succinate generated in the citric acid cycle are oxidized, providing energy to power ATP synthase.



Photosynthetic electron transport chain of the thylakoid membrane.

The **electron transport chain** (**ETC**) is a series of protein complexes that transfer electrons from electron donors to electron acceptors via redox reactions (both reduction and oxidation occurring simultaneously) and couples this electron transfer with the transfer of protons (H^+ ions) across a membrane. The electron transport chain is built up of peptides, enzymes, and other molecules.

The flow of electrons through the electron transport chain is an exergonic process. The energy from the redox reactions create an electrochemical proton gradient that drives the synthesis of adenosine triphosphate (ATP). In aerobic respiration, the flow of electrons terminates with molecular oxygen being the final electron acceptor. In anaerobic respiration, other electron acceptors are used, such as sulfate.

In the electron transport chain, the redox reactions are driven by the Gibbs free energy state of the components. Gibbs free energy is related to a quantity called the redox potential. The complexes in the electron transport chain harvest the energy of the redox reactions that occur when transferring electrons from a low redox potential to a higher redox potential, creating an electrochemical gradient. It is the electrochemical gradient created that drives the synthesis of ATP via coupling with oxidative phosphorylation with ATP synthase.

The electron transport chain, and site of oxidative phosphorylation is found on the inner mitochondrial membrane. The energy stored from the process of respiration in reduced compounds (such as NADH and FADH) is used by the electron transport chain to pump protons into the intermembrane space, generating the electrochemical gradient over the inner mitochrondrial membrane. In photosynthetic eukaryotes, the electron transport chain is found on the thylakoid membrane. Here, light energy drives the reduction of components of the electron transport chain and therefore causes subsequent synthesis of ATP. In bacteria, the electron transport chain can vary over species but it always constitutes a set of redox reactions that are coupled to the synthesis of ATP, through the generation of an electrochemical gradient, and oxidative phosphorylation through ATP synthase

Protein metabolism

Protein metabolism denotes the various biochemical processes responsible for the synthesis of proteins and amino acids (anabolism), and the breakdown of proteins by catabolism.

The steps of protein synthesis include transcription, translation, and post translational modifications. During transcription, RNA polymerase transcribes a coding region of the DNA in a cell producing a sequence of RNA, specifically messenger RNA (mRNA). This mRNA sequence contains codons: 3 nucleotide long segments that code for a specific amino acid. Ribosomes translate the codons to their respective amino acids.In humans, non-essential amino acids are synthesized from intermediates in major metabolic pathways such as the Citric Acid Cycle.[2] Essential amino acids must be consumed and are made in other organisms. The amino acids are joined by peptide bonds making a polypeptide chain. This

polypeptide chain then goes through post translational modifications and is sometimes joined with other polypeptide chains to form a fully functional protein.

Dietary proteins are first broken down to individual amino acids by various enzymes and hydrochloric acid present in the gastrointestinal tract. These amino acids are absorbed into the bloodstream to be transported to the liver and onward to the rest of the body. Absorbed amino acids are typically used to create functional proteins, but may also be used to create energy.[3]

Proteins can be broken down by enzymes known as peptidases or can break down as a result of denaturation. Proteins can denature in environmental conditions the protein is not made for

Deamination is the removal of an amino group from a molecule. Enzymes that catalyse this reaction are called **deaminases**.

In the human body, deamination takes place primarily in the liver, however it can also occur in the kidney. In situations of excess protein intake, deamination is used to break down amino acids for energy. The amino group is removed from the amino acid and converted to ammonia. The rest of the amino acid is made up of mostly carbon and hydrogen, and is recycled or oxidized for energy. Ammonia is toxic to the human system, and enzymes convert it to urea or uric acid by addition of carbon dioxide molecules (which is not considered a deamination process) in the urea cycle, which also takes place in the liver. Urea and uric acid can safely diffuse into the blood and then be excreted in urine.

Transamination, a chemical reaction that transfers an amino group to a ketoacid to form new amino acids. This pathway is responsible for the deamination of most amino acids. This is one of the major degradation pathways which convert essential

amino acids to non-essential amino acids (amino acids that can be synthesized de novo by the organism).

Transamination in biochemistry is accomplished by enzymes called transaminases or aminotransferases. α-ketoglutarate acts as the predominant amino-group acceptor and produces glutamate as the new amino acid.

Aminoacid + α-ketoglutarate ↔ α-keto acid + Glutamate

Glutamate's amino group, in turn, is transferred to oxaloacetate in a second transamination reaction yielding aspartate.

Glutamate + oxaloacetate ↔ α-ketoglutarate + aspartate

Transmethylation is a biologically important organic chemical reaction in which a methyl group is transferred from one compound to another.

An example of transmethylation is the recovery of methionine from homocysteine. In order to sustain sufficient reaction rates during metabolic stress, this reaction requires adequate levels of vitamin B_{12} and folate. Methyl tetrahydrofolate delivers methyl groups to form the active methyl form of vitamin B_{12} that is required for methylation of homocysteine. Deficiencies of vitamin B_{12} or folate cause increased levels of circulating homocysteine. Elevated homocysteine is a risk factor for cardiovascular disease and is linked to the metabolic syndrome (insulin insensitivity).

Transmethylation is decreased sometimes in parents of children with autism.

Lipid metabolism

Lipid metabolism is the synthesis and degradation of lipids in cells, involving the breakdown or storage of fats for energy and the synthesis of structural and functional lipids, such as those involved in the construction of cell membranes. In animals, these fats are obtained from food or are synthesized by the liver.[1] Lipogenesis is the

process of synthesizing these fats. The majority of lipids found in the human body from ingesting food are triglycerides and cholesterol. Other types of lipids found in the body are fatty acids and membrane lipids. Lipid metabolism is often considered as the digestion and absorption process of dietary fat; however, there are two sources of fats that organisms can use to obtain energy: from consumed dietary fats and from stored fat.Vertebrates (including humans) use both sources of fat to produce energy for organs such as the heart to function.Since lipids are hydrophobic molecules, they need to be solubilized before their metabolism can begin. Lipid metabolism often begins with hydrolysis which occurs with the help of variousenzymes in the digestive system.[2] Lipid metabolism also occurs in plants, though the processes differ in some ways when compared to animals. The second step after the hydrolysis is the absorption of the fatty acids into the epithelial cells of the intestinal wall.[6] In the epithelial cells, fatty acids are packaged and transported to the rest of the body

The first step in lipid metabolism is the hydrolysis of the lipid in the cytoplasm to produce glycerol and fatty acids. Since glycerol is a three carbon alcohol, it is metabolized quite readily into an intermediate in **glycolysis**, dihydroxyacetone phosphate.

- Stages of FA Synthesis. Transfer of acetyl-CoA from mitochondria to cytosol. Activation of acetyl-CoA; synthesis of malonyl-CoA. **Five** step **elongation** cycle of FA synthesis via ACP intermediates.

  Elongation and Desaturation.
- Acetyl CoA Carboxylase and.
- Ethanol Metabolism and FA. Synthesis.

Fatty acid synthesis is the creation of **fatty acids** from acetyl-CoA and NADPH through the action of enzymes called **fatty acid** synthases. This process takes place in the cytoplasm of the cell. Most of the acetyl-CoA which **is** converted into **fatty acids is** derived from carbohydrates via the glycolytic pathway.

Acetyl-CoA carboxylase, which catalyzes synthesis of malonyl-CoA, is the only regulated enzyme in fatty acid synthesis. Its regulation involves both allosteric control and covalent modification. The enzyme is known to be phosphorylated by both AMP Kinase and **Protein** Kinase

Allosteric control occurs as feedback inhibition by palmitoyl-CoA and activation by citrate. ... Citrate acts to activate acetyl-CoA carboxylase under high levels, because high levels indicate that there is enough acetyl-CoA to feed into the Krebs cycle and produce energy.

Abnormally **high** levels of **free fatty acids** are associated with uncontrolled diabetes mellitus and with conditions that involve excessive release of a lipoactive hormone such as epinephrine, norepinephrine, glucagon, thyrotropin, and adrenocortocotropin.

UNIT – II

BLOOD

Blood is a fluid connective tissue that consists of plasma, blood cells and platelets. It circulates throughout our body delivering oxygen and nutrients to various cells and tissues. It makes up 8% of our body weight. An average adult possesses around 5-6 litres of blood.

Types of Blood Cells

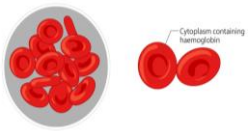
We have seen blood consist of cells known as formed elements of blood. These cells have their own functions and roles to play in the body. The blood cells which circulate all around the body are as follows:

Red blood cells (Erythrocytes)

RBCs are the biconcave cells and without nucleus in humans; also known as erythrocytes. RBCs contain the iron-rich protein called haemoglobin; give blood its red colour. RBCs are the most copious blood cell produced in bone marrows. Their main function is to transport oxygen from and to various tissues and organs.

White blood cells (Leucocytes)

Leucocytes are the colourless blood cells. They are colourless because it is devoid of haemoglobin. They are further classified as granulocytes and agranulocytes. WBCs mainly contribute to immunity and defence mechanism.



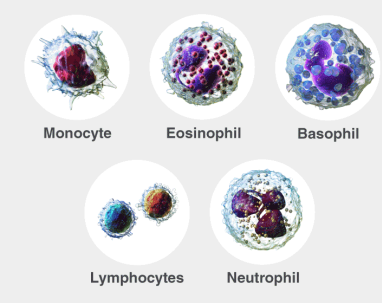
Red Blood Cells are red due to **Hemoglobin**, which is a **transport molecule** and also a **pigment.**

As a result, blood is red.

Types of White Blood Cells

There are five different types of White blood cells and are classified mainly based on the presence and absence of granules.

- Granulocytes
- Agranulocytes



There are **five types of white blood cells** present in the blood

Granulocytes

They are leukocytes, with the presence of granules in their cytoplasm. The granulated cells include- eosinophil, basophil, and neutrophil.

Eosinophils

- They are the cells of leukocytes, which are present in the immune system.
- These cells are responsible for combating infections in parasites of vertebrates and for controlling mechanisms associated with the allergy and asthma.
- Eosinophil cells are small granulocyte, which is produced in the bone marrow and makes 2 to 3 per cent of whole WBCs. These cells are present in high concentrations in the digestive tract.

Basophils

- They are the least common of the granulocytes, ranging from 0.5 to 1 per cent of WBCs.
- They contain large cytoplasmic granules, which plays a vital role in mounting a non-specific immune response to pathogens, allergic reactions by releasing histamine and dilates the blood vessels.
- These white blood cells have the ability to be stained when exposed to basic dyes, hence referred to as basophil.
- These cells are best known for their role in asthma and their result in the inflammation and bronchoconstriction in the airways.
- They secrete serotonin, histamine and heparin.

Neutrophils

- They are normally found in the bloodstream.
- They are predominant cells, which are present in pus.

- Around 60 to 65 per cent of WBCs are neutrophils with a diameter of 10 to 12 micrometres.
- The nucleus is 2 to 5 lobed and cytoplasm has very fine granules.
- Neutrophil helps in the destruction of bacteria with lysosomes, and it acts as a strong oxidant.
- Neutrophils are stained only using neutral dyes. Hence, they are called so.
- Neutrophils are also the first cells of the immune system to respond to an invader such as a bacteria or a virus.
- The lifespan of these WBCs extend for up to eight hours and are produced every day in the bone marrow.

Agranulocytes

They are leukocytes, with the absence of granules in their cytoplasm. Agranulocytes are further classified into monocytes and lymphocytes.

Monocytes

- These cells usually have a large bilobed nucleus, with a diameter of 12 to 20 micrometres.
- The nucleus is generally of half-moon shaped or kidney-shaped and it occupies 6 to 8 per cent of WBCs.
- They are the garbage trucks of the immune system.
- The most important functions of monocytes are to migrate into tissues and clean up dead cells, protect against the bloodborne pathogens and they move very quickly to the sites of infections in the tissues.
- These white blood cells have a single bean-shaped nucleus, hence referred to as Monocytes.

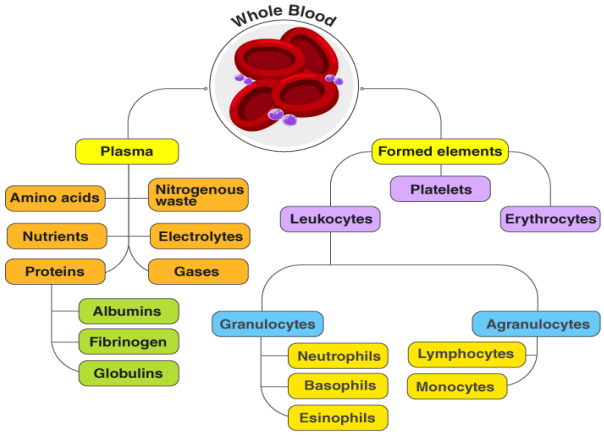
Lymphocytes

- They play a vital role in producing antibodies.
- Their size ranges from 8 to 10 micrometres.
- They are commonly known as natural killer cells.
- They play an important role in body defence.
- These white blood cells are colourless cells formed in lymphoid tissue, hence referred to as lymphocytes.

- There are two main types of lymphocytes – B lymphocytes and T lymphocytes.
- These cells are very important in the immune systems and are responsible for humoral and cell-mediated immunity.

Platelets (Thrombocytes)

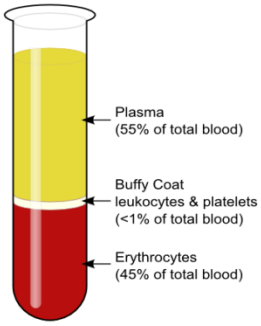
- Thrombocytes are specialized blood cells produced from bone marrow.
- Platelets come into play when there is bleeding or haemorrhage.
- They help in clotting and coagulation of blood. Platelets help in coagulation during a cut or wound.



Composition of Blood: Plasma, RBCs, WBCs and platelets

Components of Blood

There are many cellular structures in the composition of blood. When a sample of blood is spun in a centrifuge machine, they separate into the following constituents: Plasma, buffy coat and erythrocytes.



Plasma

The liquid state of blood can be contributed to plasma as it makes up ~55% of blood. It is pale yellow in colour and when separated, it consists of salts, nutrients,

water and enzymes. Blood plasma also contains important proteins and other components necessary for overall health. Hence, blood plasma transfusions are given to patients with liver failure and life-threatening injuries.

Red Blood Cells (RBC)

Red blood cells consist of Haemoglobin, a protein. They are produced by the bone marrow to primarily carry oxygen to the body and carbon dioxide away from it.

White Blood Cells (WBC)

White blood cells are responsible for fighting foreign pathogens (such as bacteria, viruses, fungi) that enter our body. They circulate throughout our body and originate from the bone marrow.

Platelets

Tiny disc-shaped cells that help regulate blood flow when any part of the body is damaged, thereby aiding in fast recovery through clotting of blood.

The above-stated elements form the composition of blood in humans. The only vertebrate without haemoglobin is the crocodile icefish. It derives its oxygen requirement directly from the cold, oxygen-rich water where it lives.

Functions of Blood

Blood is responsible for the following body functions:

- **Fluid Connective Tissue**

  Blood is a fluid connective tissue composed of 55% plasma and 45% formed elements including WBCs, RBCs, and platelets. Since these living cells are suspended in plasma, blood is known as a fluid connective tissue and not just fluid.

- **Provides oxygen to the cells**

  Blood absorbs oxygen from the lungs and transports it to different cells of the body. The waste carbon dioxide moves from the blood to the lungs and exhaled.

- **Transports Hormone and Nutrients**

  The digested nutrients such as glucose, vitamins, minerals, and proteins are absorbed into the blood through the capillaries in the villi lining the small intestine.

  The hormones secreted by the endocrine glands are also transported by the blood to different organs and tissues.

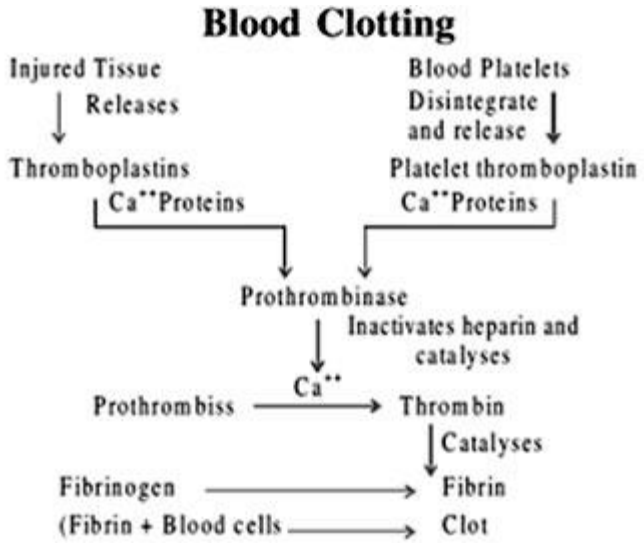
- **Homeostasis**

  Blood helps to maintain the internal body temperature by absorbing or releasing heat.
- **Blood Clotting at Site of Injury**

  The platelets help in the clotting of blood at the site of injury. Platelets along with the fibrin form clot at the wound site
- Transport of waste to the Kidney and Liver
- Blood enters the kidney where it is filtered to remove nitrogenous waste out of the blood plasma. The toxins from the blood are also removed by the liver.
- Protection of body against pathogens
- The White Blood Cells fight against infections. They multiply rapidly during the infections.

BLOOD CLOTTING:

- Injury to the blood vessel leads to loss of blood called **haemorrhage**.
- There is an intrinsic mechanism to stop haemorrhage is called **haemostasis** or **coagulation of blood** or **blood clotting**.



- Clot or coagulum is formed mainly of a network of threads called fibrins in which dead and damaged formed elements of blood are trapped or entangled.
- **Fibrin** is formed by the conversion of inactive **fibrinogens** in the plasma by an enzyme called **thrombin**.

- Thrombin formed from inactive **prothrombin** of the plasma due to presence of enzyme **thrombokinase**.
- All these activation required the initial clotting factor called **thromboplastin** either released from the injured tissue or platelets.
- Calcium ions play a very important role in the coagulation of blood.

Human Heart

The human heart is one of the most important organs responsible for sustaining life. It is a muscular organ with four chambers. The size of the heart is the size of about a clenched fist.

The human heart functions throughout a person's lifespan and is one of the most robust and hardest working muscles in the human body.

Besides humans, most of the other animals also possess a heart that pumps blood throughout their body. Even invertebrates such as grasshoppers possess a heart like pumping organ, though they do not function the same way a human heart does.

Position of Heart in Human Body

The human heart is located between the lungs in the thoracic cavity, slightly towards the left of the sternum (breastbone). It is derived from the embryonic mesodermal germ layer.

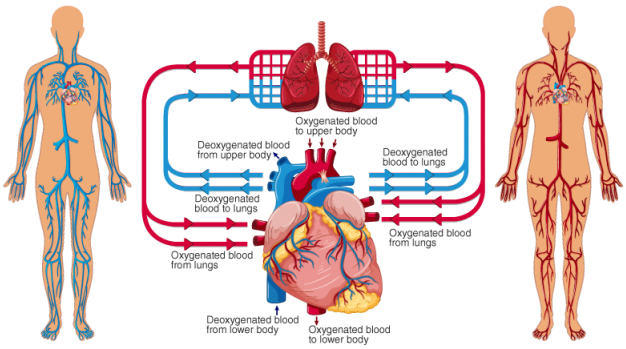
The Function of Heart

The function of the heart in any organism is to maintain a constant flow of blood throughout the body. This replenishes oxygen and circulates nutrients among the cells and tissues.

Following are the main functions of the heart:

- One of the primary functions of the human heart is to pump blood throughout the body.
- Blood delivers oxygen, hormones, glucose and other components to various parts of the body, including the human heart.
- The heart also ensures that adequate blood pressure is maintained in the body

There are two types of circulation within the body, namely pulmonary circulation and systemic circulation.



Pulmonary circulation (blue) and Systemic circulation (red)

Types of Circulation

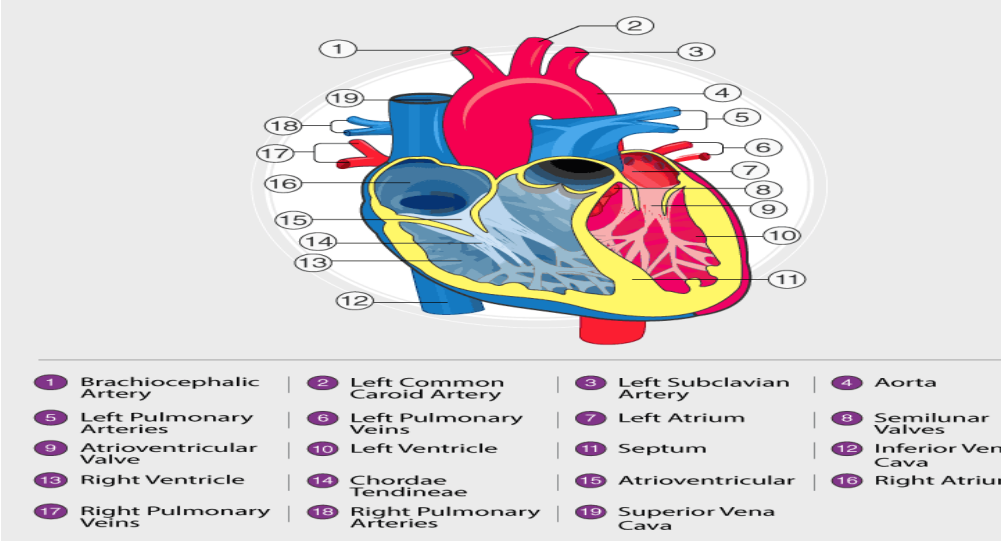
- **Pulmonary circulation** is a portion of circulation responsible for **carrying deoxygenated blood away from the heart**, to the lungs and then brings oxygenated blood back to the heart.
- **Systemic circulation** is another portion of circulation where the **oxygenated blood is pumped from the heart to every organ** and tissue in the body, and deoxygenated blood comes back again to the heart.

Now, the heart itself is a muscle and therefore, it needs a constant supply of oxygenated blood. This is where another type of circulation comes into play, the coronary circulation.

- **Coronary circulation** is an essential portion of the circulation, where oxygenated blood is supplied to the heart. This is important as the heart is responsible for supplying blood throughout the body.
- Moreover, organs like the brain need a steady flow of fresh, oxygenated blood to ensure functionality.

In a nutshell, the **circulatory system** plays a vital role in supplying oxygen, nutrients and removing carbon dioxide and other wastes from the body. Let us gain a deeper insight into the various anatomical structures of the heart:

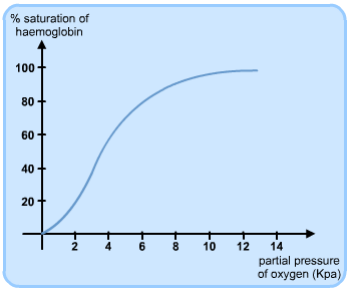
Structure of the Human Heart



Dissociation curves

The blood is then taken to tissues where the cells are respiring all the time, using oxygen. The pO_2 will be low. As the red blood cell enters this region, the Hb will start to unload the O_2, which will diffuse into the tissues and be used for further respiration. Since much of the Hb will have unloaded the O_2, a much lower percentage of the blood will be saturated with O_2

A graph of the percentage saturation of blood with O_2, i.e. the amount of HbO_2 as opposed to Hb at different pO_2 is shown below. It is called an **oxygen dissociation curve:**



- It is S-shaped because of the behaviour of the Hb in different pO_2.
- The first molecule of O_2 combines with an Hb and slightly distorts it. The joining of the first is quite slow (the flatter part of the graph at the beginning) but after the Hb has changed shape a little, it becomes easier and easier for the second and third O_2 to join. This is shown by the curve becoming steeper. It flattens off at the top because joining the fourth O_2 is more difficult.

- Overall, it shows that at the higher and lower end of the partial pressures, there isn't a great deal of change in the saturation of the Hb, but in the middle range, a small change in the pO_2 can result in a large change in the percentage saturation of the blood.

BLOOD PRESSURE

Blood pressure is a serious health problem which affects nearly 40 to 50 per cent of the total population.

Blood is a fluid connective tissue which is carried to all parts of our body with the help of arteries. It plays a key factor in providing blood (thus oxygen and energy) to organs.

Blood pressure is the force of blood against the arteries. An individual should maintain a normal blood pressure from 90 – 120 / 60 – 80 mm Hg. Blood pressure is given by two numbers, with one above or before the other – 120/80.120 – This is called systolic pressure and 80 – This is called diastolic pressure.

Types of Blood Pressure

- Systolic Blood Pressure.

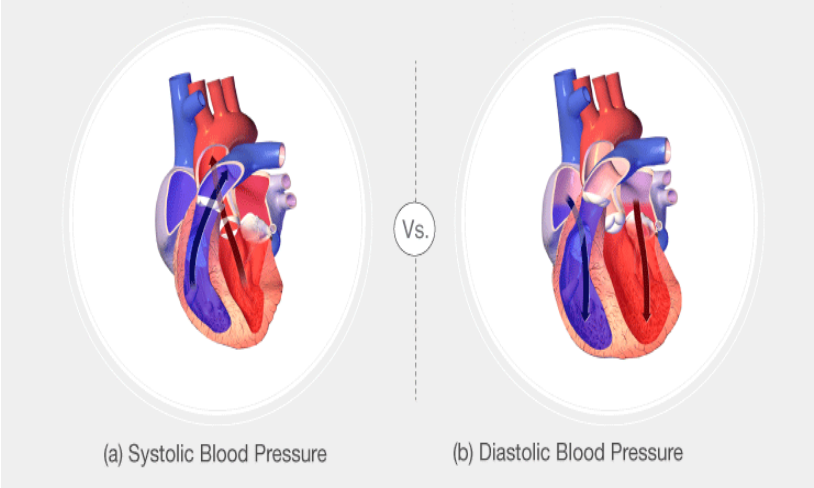
The normal range of systolic blood pressure should be 90 – 120 mm Hg.

- Diastolic Blood Pressure.

The normal range of diastolic blood pressure should be 60 – 80 mm Hg.

Both Diastolic and Systolic are derived from the Greek word. Diastolic meaning drawing apart and Systolic meaning a drawing together.

Differences Between Systolic and Diastolic Blood Pressure



Types	Systolic blood pressure	Diastolic blood pressure
Definition	The pressure exerted when the heartbeats	The pressure exerted on the walls of the arteries when the heart muscles relax in between two beats
Normal Range	In infants –95mmHg. In adults– 90-120 mmHg. Age 6 to 9 –100 mmHg.	In infants–65 mm Hg. In adults– 60-80 mmHg. Age 6 – 9 — 65 mmHg.
Ventricles of the Heart	Ventricles contract	Ventricles are relaxed
Reading of Blood Pressure	The systolic pressure is high	The diastolic pressure is low
Blood pressure inside the arteries	Maximum	Minimum.
Blood vessels	Contracts	Relaxed

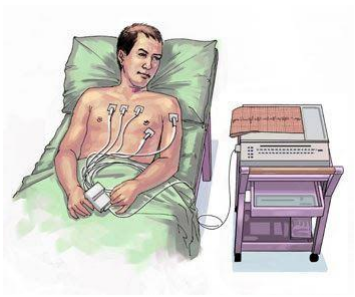
ELECTROCARDIOGRAPH (ECG)

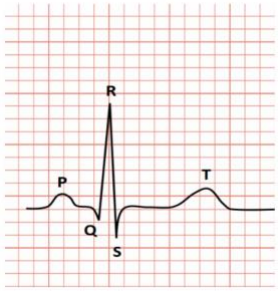
An electrocardiograph or ECG is a test used to measure the electrical activity of the heart. The test takes only about a few minutes and is devoid of any pain.

The electrical activity of the heart causes the heart muscles to contract that results in the pumping of the heart. The ECG is in the form of spikes and dips known as waves. The wave pattern helps in assessing the rate and rhythm of our heartbeat.

The human heart produces an electrical impulse by itself. As this electrical impulse passes through our heart, it generates an electrical current that spreads over our body and reaches the skin.

The patient is connected to the Electrocardiograph (ECG) machine with three electrical leads (one each to both wrists and the third to the left ankle of the patient), that is used to monitor the activity of the heart. This is standard ECG testing.





Process

The process of electrocardiograph includes:

- Small sticky electrodes are attached to the arms, chest and legs.
- These electrodes are connected to the ECG machine through wires that help in detecting the electrical impulses occurring at each heartbeat.
- These electrodes usually detect the very minute form of changes in an electrical path on the skin which arises from the heart muscles and the electrophysiologic patterns of the depolarizing during every heartbeat.

Explanation of the Electrocardiograph

P to T in the graph represents a specific activity of the heart. Let's break it down.

- The P wave is the electrical excitation of the atria, or depolarization, initiating atrial contraction.
- The QRS complex is the depolarization of ventricles, initiating ventricular contraction. Marking the beginning of the systole.
- T wave means the return of ventricles to the normal state (repolarization). Marking the end of the systole.

By counting the number of QRS complexes we can evaluate the heartbeat rate of the patient. Any deviations in this shape results in heart diseases or an abnormal heart rhythm which can either be slow, irregular or very fast heartbeats. Hence it is essential equipment in the field of medicine.

EXCRETION

Excretion in Humans

- Excretion is the process where all the metabolic wastes are removed from the body. Excretion in humans is carried through different body parts and internal organs in a series of processes.

- Diffusion is the most common process of excretion in lower organisms. A human body is an exceptional machine, where different **life-processes** (respiration, circulation, digestion, etc.) take place simultaneously. As a result, many waste products produced in our body are in various forms that include carbon dioxide, water, and nitrogenous products like urea, ammonia, and uric acid.

- In addition to these, the chemicals and other toxic compounds from medications and hormonal products are also produced. Simple diffusion is not sufficient to eliminate these wastes from our body. We need more complex and specific processes in order to eliminate waste products.

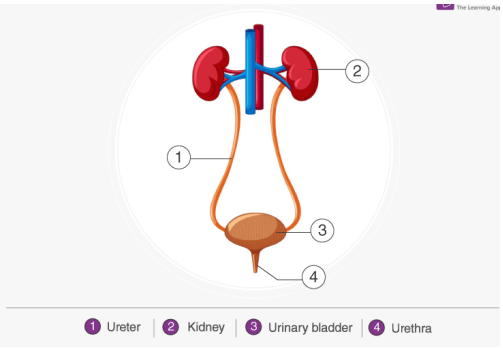
- Blood contains both useful and harmful substances. Hence, we have kidneys which separate useful substances by reabsorption and toxic substances by producing urine.

- Kidney has a structural filtration unit called nephron where the blood is filtered. Each kidney contains a million nephrons.

- Capillaries of kidneys filter the blood and the essential substances like glucose, amino acids, salts, and the required amount of water get reabsorbed and the blood goes into circulation.

- Excess water and nitrogenous waste in humans are converted to urine. Urine thus produced is passed to the urinary bladder via the ureters. The urinary bladder is under the control of the Central Nervous System. The brain signals the urinary bladder to contract and through the urinary opening called the urethra, we excrete the urine.

Kidneys



Kidneys are bean-shaped structures located on either side of the backbone and are protected by the ribs and muscles of the back. Each human adult kidney has a length of 10-12 cm, a width of 5-7 cm and weighs around 120-170g.

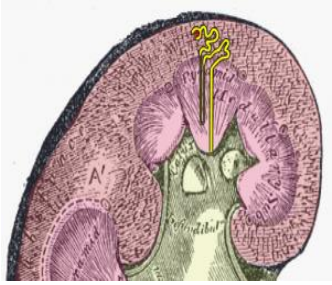
The kidneys have an inner concave structure. The blood vessels, ureter and nerves enter the kidneys through the hilum, which is a notch at the inner concave surface of the kidney. The renal pelvis, a large funnel-shaped space is present inner to the hilum, is has many projections known as calyces.

Structure of Kidney

Capsule

The outer layer is called the capsule. Inside the kidney, there are two zones- the outer zone is the cortex and the inner zone is the medulla. The cortex extends in between the medullary pyramids as renal columns called columns of Bertin.

Nephrons



Nephrons are the functional units of the kidney. Each nephron has two parts- glomerulus and renal tubule.
Glomerulus consists of a bunch of capillaries formed by afferent arterioles. Blood from glomerulus is carried away by efferent arterioles.

The renal tubule starts with a cup-like structure called Bowman's capsule and this encloses the glomerulus. The malpighian body consists of glomerulus and Bowman's capsule. The highly coiled structure in the tubule next to the Bowman's capsule is the proximal convoluted tubule.

Henle's loop

The next part of the tubule is Henle's loop which has an ascending and a descending limb. The ascending loop continues as a distal convoluted tubule. The distal convoluted tubules of many nephrons open into the collecting duct.
The cortical region of the kidney comprises of malpighian corpuscle, proximal convoluted tubule and distal convoluted tubule and the medullary region contains a loop of Henle.
There are two types of nephrons – cortical and juxtamedullary. In the case of cortical, the loop of Henle is very short and extends only a little into the medulla. In juxtamedullary, the loop of Henle is very long and runs deep into the medulla.

Ureter

A pair of thin muscular tubes called the ureter comes out of each kidney extending from the renal pelvis. It carries urine from the kidney to the urinary bladder.

Urinary Bladder

It is a muscular sac-like structure, which stores urine. The urinary bladder is emptied by the process of micturition, i.e. the act of urination.

Urethra

This tube arises from the urinary bladder and helps to expel urine out of the body. In males, it acts as the common route for sperms and urine. Its opening is guarded by sphincter muscles.

Mechanism of Excretion in Humans

The process of excretion in humans takes place in the following steps:

Urine Formation

The urine is formed in the nephrons and involves the following steps:

- Glomerular Filtration
- Tubular Reabsorption
- Secretion

Glomerular Filtration

It is the primary step in urine formation. In this process, the excess fluid and waste products from the kidney are filtered out of the blood into the urine collection tubules of the kidney and eliminated out of the body.

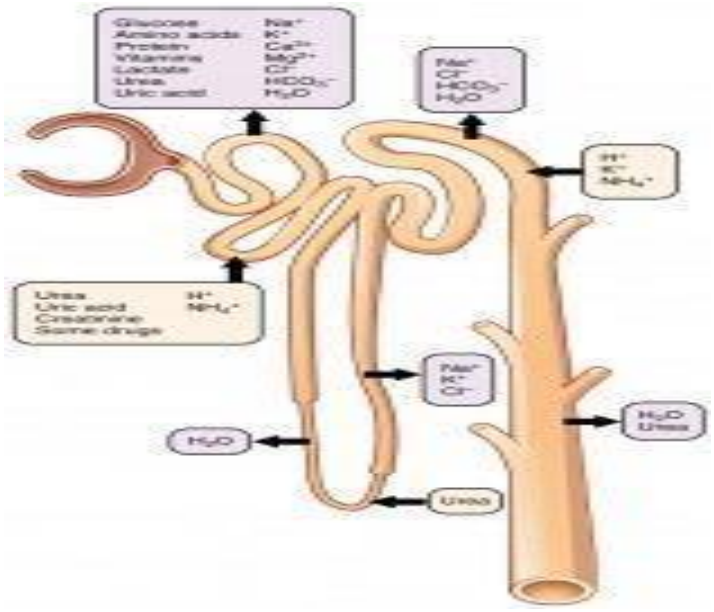
The amount of filtrate produced by the kidneys every minute is known as Glomerular Filtration Rate (GFR).

Tubular Reabsorption

It is the absorption of ions and molecules such as sodium ions, glucose, amino acids, water etc. Water involves passive absorption, while glucose and sodium ions are absorbed by an active process.

Secretion

Potassium ions, hydrogen ions, and ammonia are secreted out to maintain the equilibrium between the body fluids.



The functions of the various tubules involved in the process are:

- **Glomerulus-** filters the blood
- **Proximal Convoluted Tubules (PCT)-** reabsorb water, ions and nutrients. They remove toxins and help in maintaining the ionic balance and pH of the body fluids by secretion of potassium, hydrogen and ammonia to filtrate and reabsorbing bicarbonate ions from the filtrate.
- **Descending Loop of Henle-** is permeable to water and the filtrate gets concentrated as it is impermeable to electrolytes.
- **Ascending Loop of Henle-** it is impermeable to water and permeable to electrolytes. The filtrate gets diluted due to the movement of electrolytes from the filtrate to the medullary fluid.
- **Distal Convoluted Tubule (DCT)-** allows reabsorption of water and sodium ions. It also helps in maintaining pH and ionic balance by secretion and reabsorption of ions like PCT.
- **Collecting Duct-** a large amount of water is reabsorbed from the filtrate by the collecting duct.

Micturition

The urinary bladder is stretched and gets filled with urine formed in the nephrons. The receptors present on the walls of the urinary bladder send signals to the **Central Nervous System,** thereby, allowing the relaxation of sphincter muscles to release urine. This is known as micturition.

The major functions of the kidneys are to:

1. Maintains the body's pH
2. Reabsorption of nutrients
3. Regulates blood pressure
4. Excretion of wastes from the body
5. Removal of excess fluid from the body
6. Secret hormones that help in the production of red blood cell, acid regulation, etc.

The functional unit of the kidney is the nephron. Each kidney consists of millions of nephron which plays a significant role in the filtration and purification of blood. The nephron is divided into two portions, namely, the glomerulus and the renal tubule and helps in the removal of excess waste from the body.

Functions of Nephron

- The primary function of nephron is removing all waste products including the solid wastes, and other excess water from the blood, converting blood into the urine, reabsorption, secretion, and excretion of numerous substances.
- As the blood passes through the glomerulus with high pressure, the small molecules are moved into the glomerular capsules and travel through a winding series of tubules.
- The cell present in each tube absorbs different molecules excluding the glucose, water, and other beneficial molecules which are called ass the ultrafiltrate. As the ultrafiltrate molecules travel down the tubules they become more and more hypertonic, which results in more amount of water to be extracted from the ultrafiltrate before it exits the nephrons.
- The blood surrounding the nephron travels back into the body through the renal blood vessels, which are free of toxins and other excess substances. The obtained ultrafiltrate is urine, which travels down via the collecting duct to the bladder, where it will be stored and released through the urethra.

EXCRETION IN RELATION TO DIFFERENT HABITATS

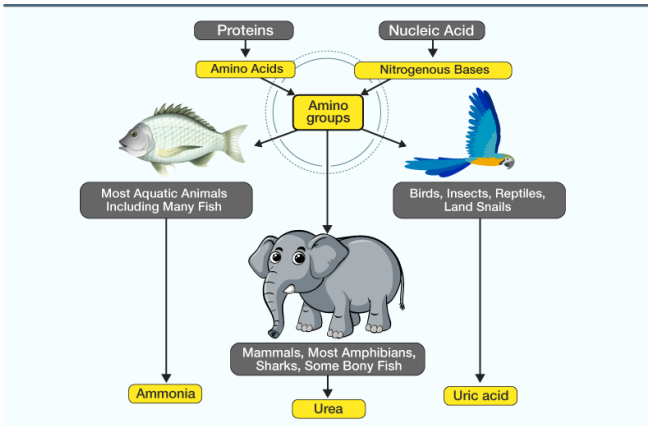
Organisms consume food for survival, growth and repair. Most of the food is digested and utilised by the body for the production of energy; the rest is expelled

out from the body by the digestive system in the form of faeces. This process is NOT called excretion, though; it is called **egestion** (also known as defecation).

Excretion Meaning

On the contrary, **excretion** is the process where **metabolic wastes** are eliminated from an organism. In humans, this function is performed through kidneys, lungs and skin. In animals, the **main excretory products** are:

- Ammonia
- Carbon Dioxide
- Urea
- Uric Acid
- Guanine
- Creatine



There are a few significant modes of excretion observed in living organisms.

Modes of Excretion

Based on the excretory product, five modes of excretion are known in animals. They are:

- Ammonotelism (Type of excretion- ammonia)
- Ureotelism (Type of excretion – urea)
- Uricotelism (Type of excretion – uric acid)
- Aminotelism (Type of excretion – amino acids)
- Guanotelism (Type of excretion – guanine)

Ammonotelism

The process of eliminating ammonia from the body is known as ammonotelism**,** and the organisms which exhibit this nature are called ammonotelic. Most fish, protozoans, echinoderms, poriferans and crustaceans fall into this category. Aquatic

animals excrete ammonia directly into the environment; where the compound is quickly diluted. It is also very toxic to tissues.

Ureotelism

In some mammals and amphibians, urea is excreted as the metabolic waste products. Such organisms are called **ureotelic**. In these organisms, ammonia that is produced is converted to urea in the liver of animals and is released back into the blood. The kidneys filter the urea and are expelled outside the body. Some of the urea is retained in the matrix of the kidney to maintain a desired osmolarity in the organisms. Humans are ureotelic as we expel the urea through urine. Moreover, urea is comparatively less toxic than ammonia.

Uricotelism

Uricotelic animals remove nitrogenous wastes as uric acid in the form of pellets or paste. Metabolically, this process is quite costly; however, the water loss is minimal, and it is the least toxic. Moreover, since uric acid is not readily soluble in water, the excrements form pasty white suspensions. Most reptiles, birds, and insects are classified as uricotelics.

Aminotelism

Certain molluscs and echinoderms excrete excess amino acids. This feature is called aminotelism**.**

Guanotelism

Spiders convert the ammonia into guanine before excretion. This characteristic is also found in some reptiles, birds and earthworms. It is also insoluble in water; hence no water is required for its excretion.

Excretion Examples & Structures

- All vertebrates have kidneys – Excretory product is urea
- Flame cells in planaria
- Earthworms have Nephridia
- Cockroaches have malpighian tubules
- Prawns have antennal glands or green glands

QUESTION BANK

2 marks	5 marks	10 marks
1. RBC 2. WBC 3. Plasma 4. Granulocytes 5. Agranulocytes 6. Eosinophils 7. Basophils 8. Neutrophils 9. Monocytes 10. Lymphocytes 11. Platelets 12. fibrinogens 13. Pulmonary circulation 14. Systemic circulation 15. oxygen dissociation curve 16. Systolic Blood Pressure 17. Diastolic Blood Pressure 18. ECG 19. Excretion 20. nephrons 21. Henle's loop 22. Urethra ***23.*** *Glomerular Filtration* ***24.*** *Tubular Reabsorption* ***25.*** *Secretion* ***26.*** *Micturition* 27. Ammonotelism 28. Ureotelism 29. Uricotelis 30. Aminotelism **31.** Guanotelism	1. Composition of blood 2. Functions of WBC 3. Mechanism of Blood clotting 4. Structure of heart 5. Oxygen dissociation curve 6. Blood pressure 7. Difference between Systolic Blood Pressure and Diastolic Blood Pressure 8. ECG 9. Structure of kidney 10. Excretion in relation to different organisms	1. Composition of blood and function 2. Structure of heart and working mechanism 3. Structure and functions of kidney 4. Structure of Nephron and urine formation