PHYSIOLOGY OF DIGESTION

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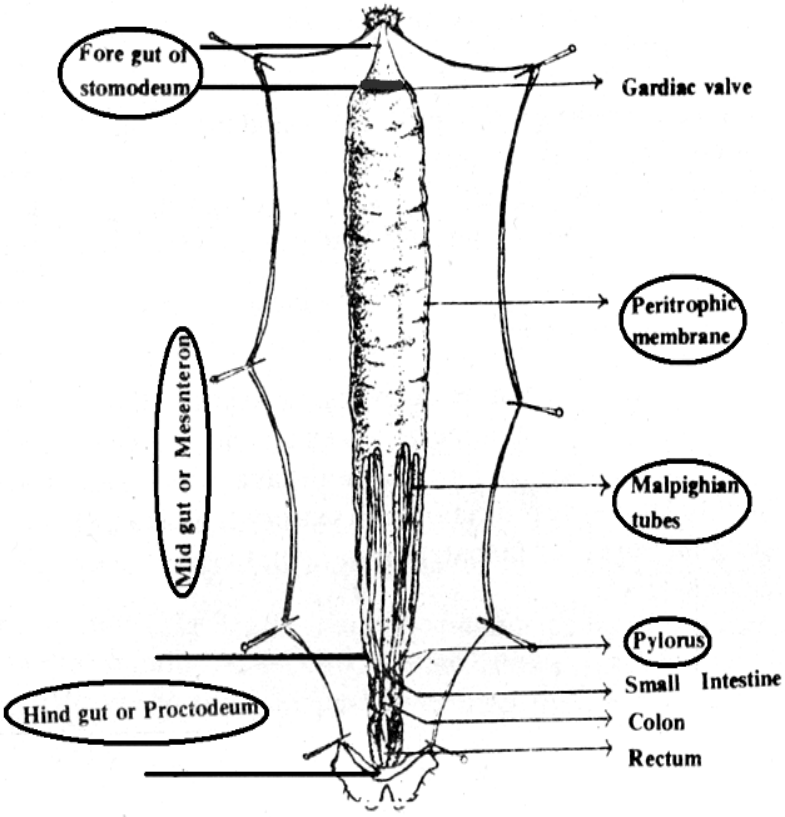
Physiology: The branch of biology that deals with the normal functions of living organisms and their parts. Or The way in which a living organism or bodily part functions.

Digestion: The process of digesting food.

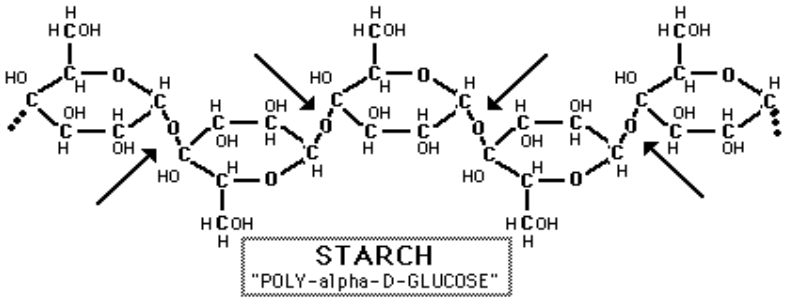


Digestive system of silkworm larva

In the silkworm larva the digestive system is more or less a straight tube from the mouth to the anus divided into three main parts: the fore-gut or stomodeum, mid-gut or mesenteron, and hind-gut or proctodeum. The fore gut is the anterior part of the digestive tract. It is composed of three parts, the buccal cavity, the pharynx and the oesophagus. The oral aperature opens into the mouth cavity which is followed by a narrow pharynx and oesophagus. A pair of salivary glands and salivary reservoirs usually reside in the thorax (adjacent to the foregut). Salivary ducts lead from the glands to the reservoirs and then forward, through the head, to an opening (the salivarium) behind the hypopharynx. Movements of the mouthparts helps to mix saliva (contains amylase) with food in the buccal cavity. The oesophagus is narrow at the anterior end and gradually widens towards the

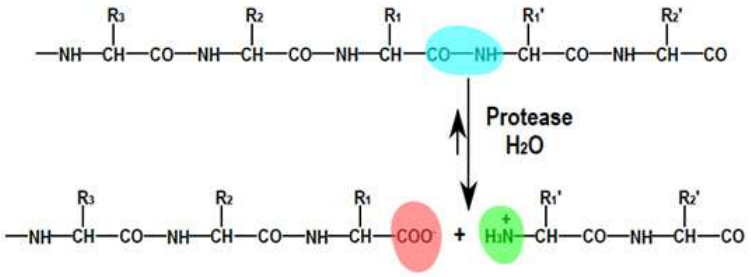
posterior end. From the pharynx, food passes into the oesophagus by means of peristalsis (rhythmic muscular contractions of the gut wall). Food remains in the oesophagus until it can be processed through the remaining sections of the alimentary canal and some digestion may occur as a result of salivary enzymes that were added in the buccal cavity. There is a cardiac or stomodeal valve at the end of the fore-gut that retains the chewed mulberry leaf bits in the oesophagus for some time and also prevents the regurgitation (backward flow) of food from mid-gut to fore-gut. The mid-gut is a long, wide cylindrical tube narrow at the posterior end. It is the largest part of the alimentary canal ranges from second thorasic to ninth abdominal segments. The wall of the midgut is composed of a muscular layer, basal membrane epithelium and peritrophic membrane. The midgut is derived from embryonic endoderm so it is not protected by an intima. Instead, the midgut is lined with a semi permeable membrane secreted by a cluster of cells (the cardial epithelium) that lie just behind the stomodeal valve. This peritrophic membrane consists of chitin fibrils embedded in a protein-carbohydrate matrix. It protects the delicate digestive cells from the mulberry leaf bits (food abrasion) and micro-organisms without inhibiting absorption of nutrient molecules. The posterior end of the midgut is marked by another sphincter muscle, the pyloric valve. It regulates the flow of material from the mesenteron to the proctodeum. Digestion and assimilation of food, take place mainly in the mid-gut. The digestive fluid is secreted principally from the goblet cells at the mid-gut epithelium and the cylindrical cells absorb the digested food. The goblet cells at midgut epithelium secretes digestive fluid, which is alkaline and yellow green in colour. This has many important enzymes.

Eg., 1. Amylase, which converts starch in to simple sugars as shown in the following figure.



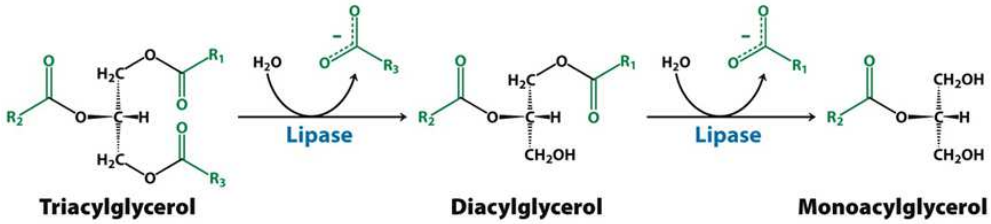
Starch ⟶ Glucose Molecules

2. Protease, which converts proteins in to amino acids as shown in the following diagramme.



Polypeptide ⟶ Amino Acid

3. Lipase, Which converts complex lipid/fat molecules in to simpler ones as follows.



The hind-gut consists of the small intestine, colon and rectum, and a pylorus valve near the anterior end of the small intestine which guards and regulates the passage of digested food from the mid-gut to the hind-gut. The pyloric valve serves as a point of origin for malpighian tubules. These long, spaghetti-like structures serve as excretory organs, removing nitrogenous wastes (principally ammonium ions, NH_4^+) from the haemolymph. The toxic NH_4^+ is quickly converted to urea and then to uric acid by a series of chemical reactions within the malpighian tubules. The uric acid, a semi-solid, accumulates inside each tubule and is eventually emptied into the hindgut for elimination as part of the fecal pellet. The hind gut is a passage for the absorption of a large portion of food moisture and elimination of digested food. In the anterioroposterior direction, the rectum has six muscles for pressing the excrements. The fecal matter is pressed in the rectum and expelled from the anus as fecal pellets bearing hexagonal marks. These organs remove more than 90% of the water from a fecal pellet before it passes out of the body through the anus.

PHYSIOLOGY OF RESPIRATION

In insects the intake of air for oxygen and distribution of air with in the body is performed by a fine network of tubules called tracheal system. The tracheae are invaginations of the cuticle, which branch everywhere, among the tissues which convey the O_2 directly to the site of utilization and the haemolymph is not concerned with gas transport.

A spiracle consists of peritreme, sieve plate and a atrium. The spiracles bordered by cuticular hard structure all around the spiracle called peritreme. The sieve plate is situated inside the peritreme ring and a slit can be seen along the median line of the sieve plate, which is perforated and prevents the entry of dust particles. The external opening of the spiracle leads into a cavity called atrium, which contains closing apparatus. There are two closing membranes can be observed if the sieve plate is taken off, they are called anterior and posterior valves.

The number of tracheal branches start radially from the spiracular cavity next to the atrium and looks like bushes called tracheal bushes. All the nine tracheal bushes get connected laterally by the longitudinal lateral tracheal trunks in each side of the body. And the two tracheal bushes in the respective segments get connected by means of transverse ventral tracheal commissures. The tracheae ramify repeatedly throughout the body and organs and ultimately forms tracheoles and their diameter is reduced to one micron. As the tracheal system is continuously exposed to the atmospheric air, there is every chances of moisture loss from the tracheal system. But to prevent this desiccation or moisture loss insects developed perispiracular glands. These perispiracular glands are distributed on the inner surface of the tracheal system. These are unicellular glands, secretes a hydrophobic oily substance all over the inner surface of the tracheal system, which keeps the surface oily and moist. These secretions prevent the entry of water in to the tracheal system. These trachea are lined by cuticle continuous with that of the body wall. This lining has a characteristic striated appearance due to thread like ridges which run helically around the inner circumference and form taenidium.

The function of this taenidium is to keep the tracheae distended *i.e.*, prevents from collapsing of trachea when the pressure increases or

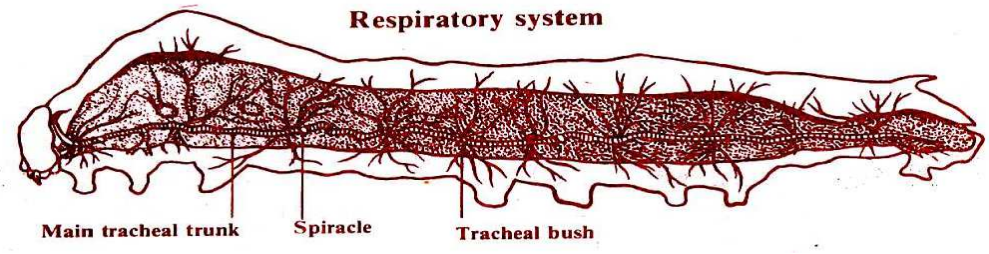
decreased and there by allowthe free passage of air. There is a membrane between the taenidia is called inter taenedial membrane, it is very thin and highly flexible. As a result the trachea can stretch to double length without breaking them. So the taenedia and thin membrane provide the necessary rigidity and flexibility to the tracheal system. The inter tracheal membrane is 0.01 to 0.02 micron thick.

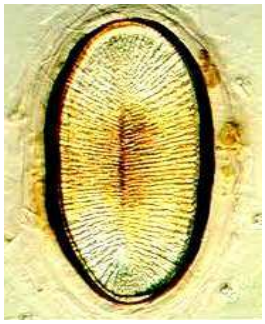
The mode of ending of tracheae shows an equal diversity. Typically when the trachea has been reduced by repeated branching to a diameter of 2-5 micron it enters a large satellite cell, the tracheal end cell or transitional cell and there breaks up abruptly into a number of tracheal capillaries or tracheoles, which are less than one micron in thickness. These tracheoles are inter connected with each other and form a mat over tissues.

On anatomical grounds it is possible that most of the oxygen taken up enters the tissues through the walls of the tracheoles; for those are always most abundant in such organs as the wing muscles, ovaries *etc*., with high oxygen requirements. On the other hand, the tracheal walls permeable to gases, and impossible to say how much O_2 consumed passes through them, but the volume of the tissue around the tracheae which could be supplied by diffusion through tissue fluids is insignificant in comparision with that of supplied by the tracheloes.

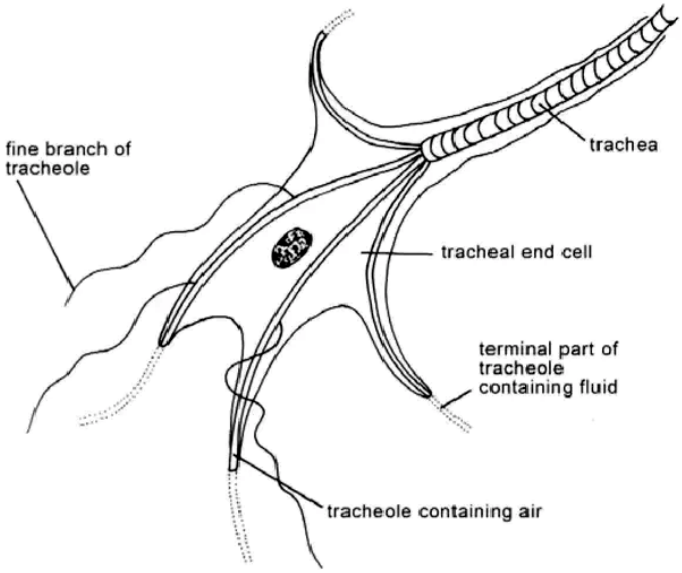
It is generally supposed that the passage of oxygen from tracheoles in to the tissue takes place by physical diffusion. But several authors have suggested that the tracheal epithelium, and particularly the tracheal end cells play a more active part.

Breathing occurs by the movement of body wall. According to Mori 1932 the spiracles serve the function of both inspiration and expiration. The tracheoles end in the tissues in various ways. In the gut and salivary gland they ramify and pass between the cells without penetrating them. In the fat body and rectal papillae, however they may enter the cells, while in the flight muscle there is a net work of intracellular tracheoles. A solitary exception is the fore part of the silk gland which has no tracheation.

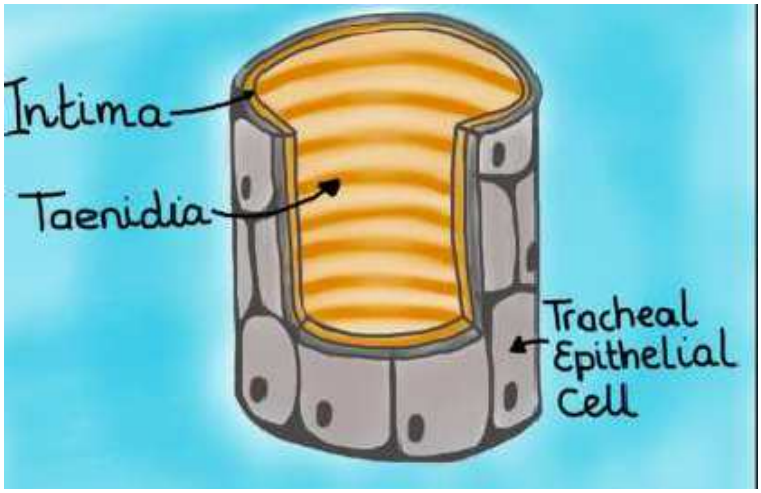




Spiracle



Structure of trachea, tracheoles and terminal part of tracheoles



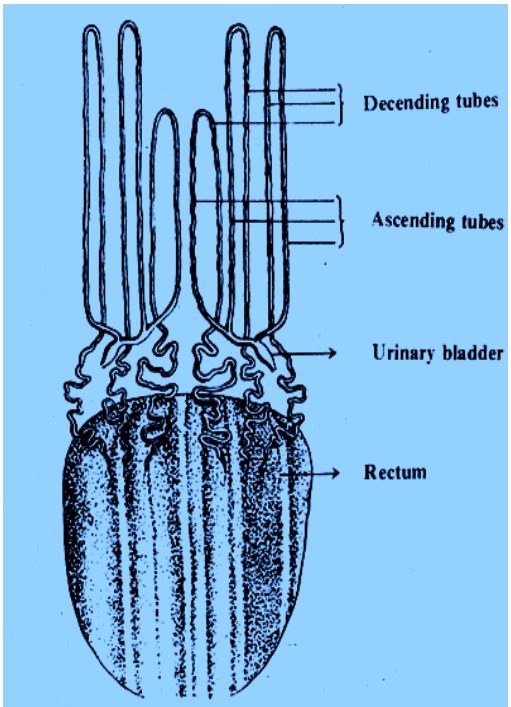
Internal structure of tracheal system

PHYSIOLOGY OF EXCRETION

The function of the excretory system is to maintain a constant internal environment in the body, by the elimination or segregation of un anted substances present in the blood, and by the retension or reabsorption of constituents needful to the organism.

In silkworm special excretory organs called Malpighian tubules perform this function. They are found attached to the alimentary canal at the junction between small intestine and colon. Paired Malpighian tubules arise from each side of the hindgut. The two branches are further divided in to three tubes. Each Malpighian tube (one group) emerges from the intestine is emerged in to a sac called excretory chamber or urinary bladder. From which two branches arise. One of them situated on the dorsal side branches further in to 2 tubes. Thus total three tubes are get arise in one side. Thus there are 3 pairs of Malpighian tubules in the silkworm body, which stick to the midgut and run towards the anterior side. One tube in one group runs along the dorsal wall of the midgut towards the anterior side and turns backwards at the 4^{th} abdominal segment and 2^{nd} tube runs along the midgut to laterally and turns backwards at the point of center of 4^{th} and 3^{rd} abdominal segments. And remaining one tube also pass along ventral wall of the midgut and turns backwards at the 3^{rd} abdominal segments. Then all three tubes are ultimately open in to the rectum. The tubes passing towards

the anterior side from the urinary bladder are referred as ascending limbs and the same tubes turns back and passing towards rectum are called descending limbs.



Excretory system of silkworm larva

In the larva waste products of metabolism are mainly excreted as urine together with faces. The excretion of urine takes place in both the mature larva and moth. The amount of excreted uric acid in adult urine is 5 to 15 mg per individual. The process of excretion is as follows: the winding tips of the Malpighian tubules which are bound to the rectum by a membrane have an active absorption function. Therefore water and some excreta diffused from the rectum are accumulated in the winding tips. Next, the winding long portion of the Malpighian tubules in the body cavity directly absorb uric acid, riboflavin, oxalic acid and other substances from the blood and then these substances are crystalised in the tubule. When the larval ecdysis occurs all the substances thus accumulated in the Malpighian tubules are discharged between the new and old cuticle through the urinary bladder of the tubule.

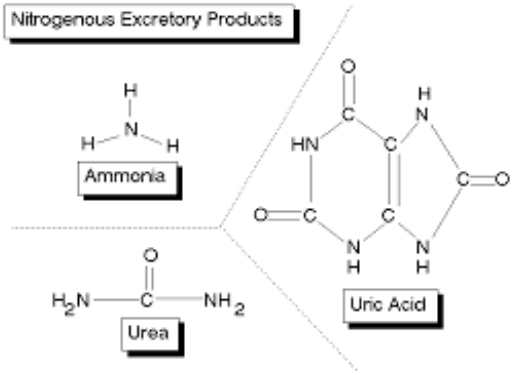
In conclusion,

The pyloric valve serves as a point of origin for Malpighian Tubules.

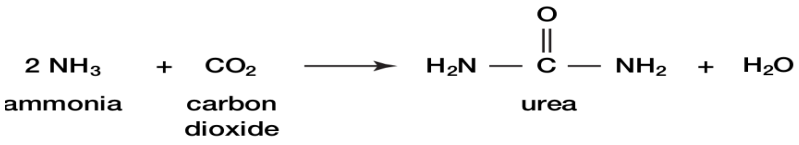
These long, spaghetti-like structures serve as excretory organs, removing nitrogenous wastes (principally ammonium ions, NH_4^+) from the hemolymph.

The toxic NH_4^+ is quickly converted to urea and then to uric acid by a series of chemical reactions within the Malpighian Tubules.

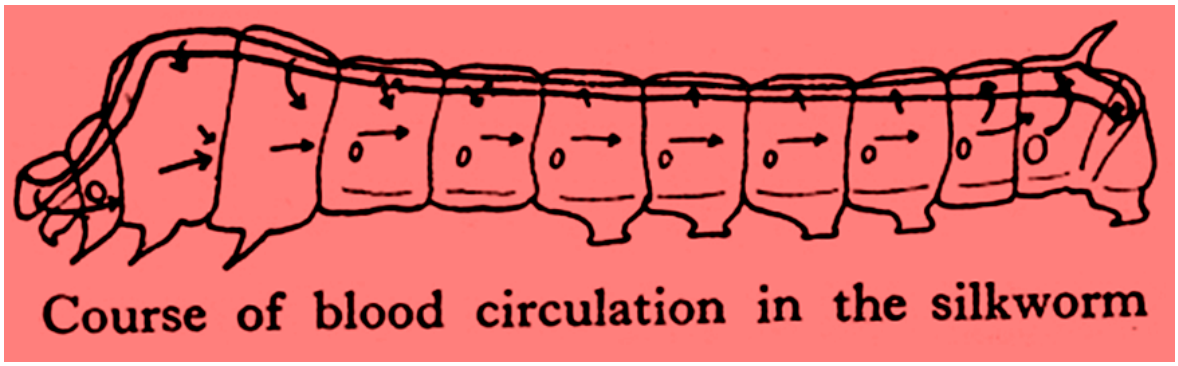
The uric acid, a semi-solid, accumulates inside each tubule and is eventually emptied into the hindgut for elimination as part of the fecal pellet.



Reaction of formation of Urea



PHYSIOLOGY CIRCULATION:

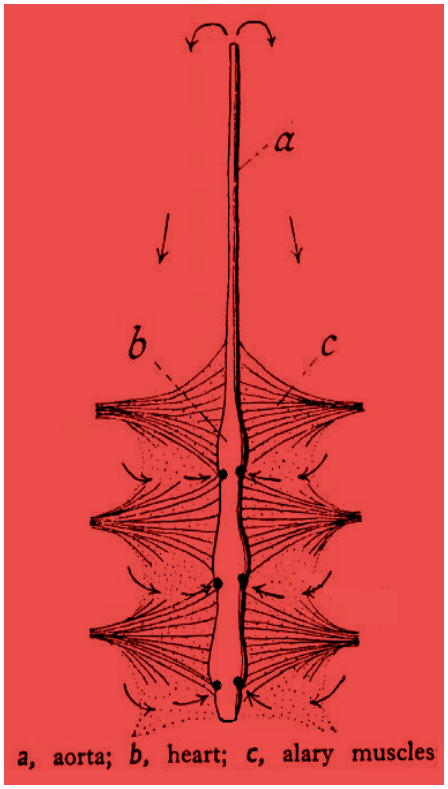


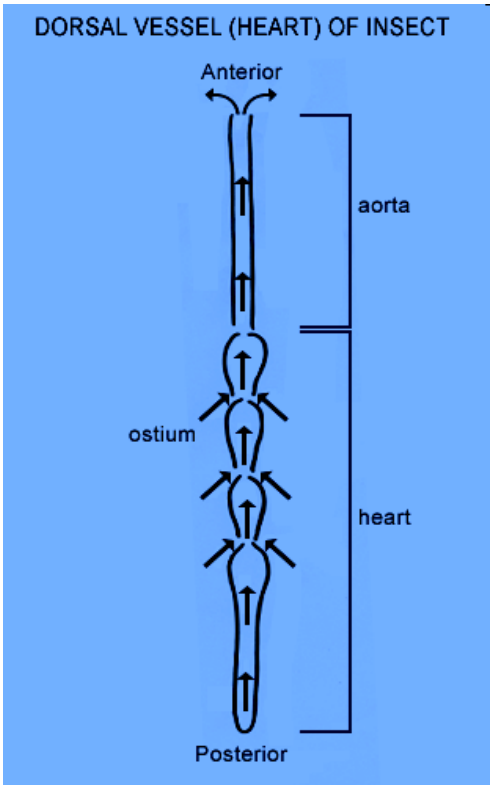
Circulatory System Enlarged

The circulatory system is an open one with a dorsal vessel, extending from the head to the last abdominal segment along the dorsal median line of the body. The dorsal vessel is associated with the circulation of the blood and is closed posteriorly while the front end opens in the head. The anterior portion of the dorsal vessel is a finely drawn-out tube and constitutes the aorta, while the posterior portion forms the heart. Each of the segments from the second thorax to the ninth abdominal segment contains a pair of ostia. There are eight pairs of alary muscles which are attached to the body wall along the lateral parts of the dorsum. Systole (contraction) and diastole (expansion) of the heart are affected by the eight pairs of alary muscles and the musculature of the heart. The alary muscles function more or less like an elastic band and cause diastole and systole.

The blood enters the heart mainly through the ostia in the seventh and eighth abdominal segments and to a slight extent only through the ostia in the first six abdominal segments during diastole, and is forced forward during systole. As the heart is filled with blood, a steady wave of contraction progresses in a posterior - anterior direction. Hence normally the direction of flow of blood in the dorsal vessel is from behind forward and the blood is carried to the head and discharged. It

leaves the dorsal vessel not only by the anterior end but also by the ostia in the meso and meta-thorax and sometimes by the ostia in the first and second abdominal segments. The blood flows backward through the body cavity. There is nothing to prevent the blood leaving the ostia, and the blood circulates throughout the body cavities and appendages transporting nutrients and removing waste products of the metabolism, and filling most of the space not occupied by the internal organs. In the silkworm, the blood cells or haemocytes do not enter the dorsal vessel through the ostia. Only cell-free plasma is circulated. The heart pulsates rhythmically and the frequency of pulsation varies with age, temperature, movements and the race of the larvae.





The dorsal diaphragm

- It is a septum :extends across the abdominal cavity enclosing the pericardial sinus , it contain the dorsal vessel.
- The dorsal diaphragm divides the haemocoel into the pericardial sinus and the visceral sinus.

Ventral diaphragm

- The ventral diaphragm forms a continuous ventral sheath .

- It extends from the prothorax to the end of the body .
- It encloses the perineural sinus.
- The perineural sinus encloses the nerve cord.

The Aorta

- It is slender anterior prolongation of the heart, it carries the blood from the heart .

The heart

- It is often restricted to the abdomen or it may extend as far as the prothorax .
- It is often a continuous tube that is not divided into chambers.
- The heart may be directly bound to the dorsal wall or suspended from it by elastic filaments.
- A pair of alary musclesare attached laterally to the walls of each chamber .

Incurrent ostia

- They are vertical, slit-like openings in the lateral wall of the heart.
- The maximum number may exist are 12 pairs, 9 abdominal and 3 thoracic.
- The anterior and posterior lips of each ostium are reflexed into the heart to form a valve which permits the flow of blood into the heart at diastole (expansion of the heart), but prevents its outward passage at systole.

Excurrent Ostia

- These are ventro- lateral openings in the wall of the heart.
- No internal valves.
- Externally each opening is surrounded by a papilla of a spongy multinucleate cells which expand during systole, so the hemolymph is forced out, and contracts during diastole, so that entry of blood is prevented.

Alary muscles

- These are muscles that are closely associated with the heart.
- In silkworm larva 8 pairs of alary muscles are present.
- In other insect species the number is reduced.
- They form integral part of the dorsal diaphragm which spreads between them as connective tissue membrane .

COMPOSITION OF HAEMOLYMPH

1. Haemolymph contains a fluid portion called plasma and cellular fractions called haemocytes.
2. Plasma is an aqueous solution of inorganic ions, lipids, sugars (mainly trehalose), amino acids, proteins, organic acids and other compounds.
3. pH is usually acidic (6-7).
4. Density is 1.01 to 1.06.
5. Water content is 84-92 per cent.
6. Inorganic ions present are `Na' in predators and parasites, `Mg' and `K‘ in phytophagous insects.
7. Blood lacks vitamin ‘K’
8. Carbohydrate is in the form of trehalose sugar.
9. Major proteins are lipoproteins, glycoproteins and enzymes. Lipids in form of fat particles or lipoproteins.
10. Glycerol is present which acts as a anti freezing compound.

HAEMOCYTES OF SILKWORM

The blood cells or haemocytes are of several types and all are nucleate. Insects have an open system with the blood occupying the general body cavity known as the haemocoel. The haemolymph of insects consists of liquid plasma and numerous haemocytes. Haemocytes perform various physiological functions in the body of an insect. They direct nutrients to various tissues and store them. They perform phagocytosis, encapsulation of foreign bodies in the insect body cavity, coagulation to prevent loss of blood, nodule formation, transport of food materials, hormones and detoxification of metabolites. According to the accepted morphological classification, five circulating types of hemocytes are recognized in *Bombyx mori* .

a. Prohaemocyte : Smallest of all cells with largest nucleus.

b. Plasmatocyte: (Phagocyte) aids in phagocytocis

c. Granular heamocyte: Contains large number of cytoplasmic inclusions. Granulocytes are involved in recognition of non-self, Plasmatocytes adhere to and spread over foreign bodies and wounds, and are the main capsule-forming hemocytes.

d. Spherule cell: Cytoplasmic inclusions obscure the nucleuse. The function of the spherule cells which contain a paracrystalline material (muco- or glycoproteins) is by no means clear.

e) Oenocytoids: Large cells with ecentric nucleus. The phenoloxidase activity found within the cytosol of oenocytoids appears effective against the natural monophenol and diphenol substrates. The involvement of oenocytoids in the complex metabolism of phenols and particularly in the production of plasma phenolases has been reported.

Process of blood circulation in silkworm

In the abdomen, the dorsal vessel is called the heart. It is divided segmentally into chambers that are separated by valves (ostia) to ensure one-way flow of hemolymph. A pair of **alary muscles** are attached laterally to the walls of each chamber. Peristaltic contractions of the these muscles force the haemolymph forward from chamber to chamber.

Heart mainly function as a pulsatile organ whose expansion and contraction leads to blood circulation.

It takes place generally in an anti clock manner starting from posterior end to the anterior end in a forward direction. Circulation of blood takes place in two phases due to the action of the alary muscles as well as the muscles of the walls of the heart.

The two phases are

1. Diastole: During which expansion of heart takes place.
2. Systole: Contraction of heart takes place.

1. Diastole: Expansion of heart (diastole).

It results in increase of volume of heart and decrease in the area of pericardial sinus. This creates a pressure on the blood in pericardial sinus forcing the blood to enter into the heart through the incurrent ostia. These incurrent ostia allow only the entry of blood from the sinus in to the heart and prevents its backflow from the heart to the sinus.

2. Systole: Contraction of heart (systole).

This creates pressure on the blood within the heart leading to its forward movement in to the aorta. From the aorta blood enters in to the head and flows back bathing the visceral organs in the visceral sinus and neural cord in the perineural sinus. In between diastole and systole there will be a short period of rest which is known as diastasis.

During each diastolic phase (relaxation), the ostia open to allow inflow of haemolymph from the body cavity. The heart's contraction rate varies considerably from species to species — typically in the range of 30 to 200 beats per minute. The rate tends to fall as ambient temperature drops and rise as temperature (or the insect's level of activity) increases.
