INSTRUCTIONAL MANUAL
ON
INSECT ANATOMY, PHYSIOLOGY AND NUTRITION
ENT 502
(Manual No 16)

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PREFACE
Physiology is the branch of biological science concerning with the functioning of living matter and living process at cell or tissue or organism as a whole. Physiology is a Greek word, Physis-Nature; Logos-Study. It is the science of life and therefore takes into consideration although mechanisms which give a matter of property of life. A mass of matter in the living state comprises of several chemical phenomenon and is regulated by physical laws and thus physiology is linked with biochemistry and bio physics. With the growth of physiology and its ever broadening scope of specialization, several branches exist now for e.g. cellular physiology, general physiology, comparative physiology, insect physiology, mammalian and human physiology etc. These branches deal in different animal groups investigate into the underlying physical principles with different aims. The present manuscript entitled "INSECT ANATOMY, PHYSIOLOGY AND NUTRITION" compiled by Dr. S.N. Upadhyay, Dr. S.B. Singh, Dr. R.K. Choudhary, and Dr. (Smt.) M. Sharma, Department of Entomology, RVSKVV, College of Agriculture, Indore will be a valuable guide to PG students as well as for JRF and SRF aspirants.

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The authors would welcome suggestions from the respective authorities to improve this manual.

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INDORE
1. SCOPE AND IMPORTANCE OF INSECT ANATOMY AND PHYSIOLOGY:

Physiology is the branch of biological science concerning with the functioning of living matter and living process at cell or tissue or organism as a whole. Physiology is a Greek word, Physis-Nature; Logos-Study. It is the science of life and therefore takes into consideration although mechanisms which give a matter of property of life. A mass of matter in the living state comprises of several chemical phenomenon and is regulated by physical laws and thus physiology is linked with biochemistry and bio physics. With the growth of physiology and its ever broadening scope of specialization, several branches exist now for e.g. cellular physiology, general physiology, comparative physiology, insect physiology, mammalian and human physiology etc. These branches deal in different animal groups investigate into the underlying physical principles with different aims.

Insect physiology is essentially a comparative physiology because of tremendous amount of diversity of functions in insects even at a very narrow taxonomic range. Their are over a million species of insects and between them they show an amazing diversity of adaptation to widely different modes of life. Many of them involving profound specialization at the physiological level, certain aspects of physiology are well documented for insects.

Three major characters of insects are most likely to affect their physiology viz; terrestrialness, smallness, and exoskeleton. Scope of physiology is to understand the underlying principle of all these lines such as digestive system of insect in which enzymes act, when chemicals are spread, it affect the nervous system of insect, in which pyrethroids affect more than peripheral nervous system. Physiology serve to rationalize the different existing procedures or to discover the weak spots in the ecological armour of a species. Hence a knowledge of ecology of the species is necessary to its effective control. So its ecology can be properly understood only when its physiology is known.

The shortcomings of chemical methods of insect control are well known, in order to circumvent some of their ill effects, use of juvenile hormone analogues, chemosterilants, sex attractants and resistant plant varieties have found to give promising result. Another hormone ec dysone which in active stage dissolves the old cuticle and become inactive after the formation of a new cuticle also can be used to control insect pests. Chitin synthesis is another process involving the chitin- synthetase enzyme during its formation. This has been studied extensively and application of chitin synthesis inhibitors which block the synthesis of chitin is used now a days to control the insect pests as it prevents integument formation due to its application on these insects. Pheromones are produced in micro quantity by the insects, both male and female produce different pheromones.

2. DIGESTIVE SYSTEM

Structure

The organs concerned with the taking food, collectively termed as the mouthparts. These, mouthparts enclose a pre oral cavity bound by the epipharyngeal wall of the labrum in front, the maxillae and the mandibles at the sides, and the labrum behind. This cavity is partially divided into

(a) An anterior cibarium provided with dilator muscles and partially sunk into the head and modified into a powerful sucking pump in Hemiptera.
(b) A posterior salivarium, which is hollow and pushing the posterior wall of the hypopharynx, on to which opens the common salivary duct.

In order to inject the saliva into the plant or animal tissue, the salivarium is modified as the salivary syringe in most of the Hemiptera.

**Salivary Glands**

The salivary glands are usually paired, racemose or branched structures with a number of lobes on either side of the foregut, generally in the thoracic region. The saliva secreted by these glands is often stored in reservoirs called salivary receptacles. The duct of these reservoirs open by a common duct into a median salivary duct which is formed by union of the salivary ducts of each gland.

[Fig. Salivary Glands](#)

In larvae of Hymenoptera and Lepidoptera the salivary glands are modified into silk producing organs.

In mosquitoes and bed bugs etc. the saliva contains anticoagulants substances. In some ants the saliva contains formic acid and toxic substances in some others. Other well defined glands are also present in many insects like mandibular glands, accessory labial glands etc. which are modifications of glands associated with the guts.

**General Structure of Alimentary Canal.**

The alimentary canal in insects is divided into three main regions, the foregut or stomodaeum, which is ectodermal in origin, the midgut or mesenteron, which is endodermal and the hind gut or proctodaeum which is again ectodermal.

In many insects these regions are sub divided into various functional parts, of which most usual are the pharynx, oesophagous, crop and proventriculus in the foregut, the Caeca and ventriculus in the midgut, and pylorus, ileum and rectum in the hindgut

**Foregut**

The foregut is ectodermal in origin and it is lined with a layer of cuticle, known as the intima which is shed at each moult. The foregut epithelium consists of flattened cells, and outside there is a layer of longitudinal muscle and a layer of circular muscle. The circular muscles are not inserted into the epithelium but are continuous all round the gut, so that their contraction leads to the development of even longitudinal folding. When the
gut is distended with food these folds are flattened out. In proventriculus, there may be six or eight permanent enfolding of the wall. The longitudinal muscles may be inserted into the circular muscles or into the epithelium. Outside the muscle layer is a delicate connective tissue sheath.

**Pharynx**

The pharynx is the first part of the foregut following the buccal cavity. The pharynx directly leads into the oesophagus. The pharynx has a series of dilator muscles inserted into it. These muscles arise ventrally on the tentorium and dorsally on the frons and are best developed in sucking insects.

**Oesophagus**

The esophagus is an undifferentiated part of the foregut and serving to pass food back from the pharynx to the crop.

**Crop**

The crop is an enlargement of the foregut in which food is stored. The crop is folded longitudinally and transversely when empty becoming distended when the insect feeds, but in case of *Periplaneta* the crop undergoes very little change in volume since, when it does not contain food, it is filled with air.

In general, secretion and absorption do not occur in the crop, being limited by the impermeable intima. The crop is followed by a muscular proventriculus.

**Proventriculus**

The proventriculus is variously modified in different insects. The proventriculus is often provided with strong cuticular plates or teeth, which serve to break up the food. In fluid feeders it is absent. The proventriculus as a whole controls the passage of food from the crop to the midgut.

The following variations are found in different species of the insects.

In Acridoidea there are six longitudinal folds with small cuticular teeth, and here the proventriculus serves simply as a valve retaining food in the crop while permitting the forward passage of enzymes. The proventriculus of the bee is very specialized. An anterior invagination into the crop ends in four mobile lips each armed with a number of spines. The proventriculus also able to remove pollen from a suspension in nectar in the crop while nectar is retained.
Fig. Digestive system of insects

Mid gut

Mid gut is lined by a delicate peritrophic membrane. The mid gut cells are tall and columnar with regular microvilli forming a striated border adjacent to the lumen. These columnar cells are concerned with enzyme secretion and with the absorption of the products of digestion.

In caterpillars and Ephemeroptera and Plecoptera goblet cells are distributed between the columnar cells. These cells are important in pumping excess potassium, derived from the food, out of haemolymph. They may also be concerned with deposit excretion.
In *Tineola* (Lepidoptera) metals and dyes accumulate in the goblet cavity and in the cytoplasm of the cell. The substances are discharged at the following moult when the whole of the epithelium is renewed.

Midgut cells also play some part in excretion in *Rhodnius*; here haemoglobin is broken down in the cells to haematin, a verdohaem pigment and biliverdin. The later is accumulated and then discharged into the lumen of the gut for disposal.

The regenerative cells divide and differentiated and forms new cells when the cells of midgut break down.

**Filter chamber:**

This is a characteristic arrangement of the midgut in hemipteran insects (*fluid feeders*). Anterior part of midgut forms a **thin-walled bladder** i.e **filter chamber** which is closely bound to either posterior part of midgut or the anterior hindgut and Malpighian tubules (Fig. 29). Filter chamber enables the **excess fluids** including sugar in the food to **pass directly** from the anterior part of the midgut to the hindgut without passing through the middle portion of midgut thus preventing excessive **dilution of haemolymph**, **enzymes** and facilitate better enzyme activity. In aphids, the **honey dew** (rich in sugars) is the substance that is being excreted after passing through the filter chamber.
**Anatomical differentiation**

Anatomically the mid gut is usually a simple tube, un differentiated except for the presence of four, six or eight caeca at the anterior end.

In some Diptera, the midgut is undifferentiated into an anterior cardiac chamber and a long ventriculus, and in Heteroptera there are four regions, the last giving rise to numerous caeca which house bacteria.

The Homoptera and some Heteroptera feed on plant fluids. In order to obtain adequate nourishment large quantities of fluid must be ingested and modifications of the gut occur which provide for rapid elimination of the excess water taken in.

In Lepidoptera, Hymenoptera and Diptera which feed on nectar as adults only need it for maintenance, growth is complete and the larval reserves often suffice for egg development so that only small amounts of fluid are taken in. This fluid is stored in the crop, from which small quantities are passed back to the mid gut is they are required.

The volumes ingested by bugs are too large for this and the insects have no crop, but they do have a large rectum to which water is passed as quickly as possible.

In insects of Cicadoidea the mid gut is mostly extensively elaborated which ensuring the rapid elimination of water.

In Fulgoroidea have the midgut enclosed in a sheath with oenocytes inside it and it is suggested that the sheath cells play an active role in limiting dilution of the haemolymph. An anterior, air-filled diverticulum of the midgut is not enclosed by the sheath & this may allow for the swallowing of air needed for expansion at each moult without damaging the sheath.

In plant sucking bug the midgut is divided in to four regions, as in other Heteroptera. It is believed that the caeca of the 4th region actively remove water from the haemolymph so that excessive dilution does not occur, and between the 3rd and 4th regions there is a constriction or a complete discontinuity which ensures the backward flow of this water to the rectum.

In some Bryocorine and Miridae the anterior midgut makes contact with a large accessory salivary gland. After feeding a clear fluid is exuded from the mouthparts suggesting that water is withdrawn from the midgut to the salivary glands and then eliminated via the mouth parts.

In *Glossina* (Blood sucking insects), the water is removed from the blood in the anterior half of the midgut and very quickly eliminated via malpighian tubules so that a very clear urine may be passed while the insect is still feeding.

**Peritrophic membrane**

The peritrophic membrane forms a delicate lining layer to the midgut and is found in most insects, whether they eat solid food or feed only on fluids. It is apparently not present in many insect feeding on plant juices, notably the Homoptera and Heteroptera,
while in Diptera it is only formed as a result of gut distension, usually following feeding. The membrane nearly always contains chitin and protein.

**Hind gut**

The hindgut is lined by a layer of cuticle which is thinner and more permeable than that of the foregut. The epithelium is generally thin, but the cells are more cuboid than in the foregut. The cells of the rectal pads are tall with a clear cytoplasm. The musculature is poorly developed except rectum.

1. **Pylorus**: The pylorus is the first part of the hind gut and from it the malpighian tubules often arise. In some insects it forms a valve between the midgut and hind gut.
2. **Ileum**: In most insects the ileum is an undifferentiated tube running back to the rectum. In some termites it forms a pouch in which, the flagellates concerned with cellulose digestion live, and in scarabaeoidea there is a comparable fermentation chamber in which intima is produced into spines. In Heteroptera it is suggested that the ileum is concerned with the removal of water from the haemolymph and in blowfly larvae certain cells are concerned in the excretion of ammonia. The hormone proctodome is secreted by the cells of the ileum of *Ostrinia*.
3. **Rectum**: The rectum is often an enlarged sac and is thin walled except for certain regions, the rectal pads, which have a columnar epithelium. There are usually six rectal pads and they may extend longitudinally along the rectum or they may be papilliform as in Diptera.

**Head Glands**

- **Mandibular Glands**: Apterygota, Dictyoptera, Isoptera, Coleoptera and Hymenoptera.
- **Maxillary Glands**: Protura, Collembola, Heteroptera Neuroptera, & Hymenoptera.
- **Pharyngeal Glands**: Hymenoptera,
- **Labial Glands**: Majority of insects & absent from some Coleoptera.

**Physiology of digestion**

**Digestion and Absorption**

The alimentary canal is concerned primarily with the digestion and absorption of foodstuffs.

**Digestion**

A large part of the food ingested by insects is macromolecular in the form of polysaccharides & proteins and lipids are present as triglycerides, phospho lipids and glyco lipids. Only relatively small molecules can pass into the tissue and larger molecules
must be broken down into components of a suitable size before absorption occurs. Enzymes concerned with digestion are present in the saliva and in the secretions of the midgut.

**Extra – Intestinal Digestion**

Since saliva contains enzymes, digestion often starts before the food is ingested. This is particularly true for fluid feeding insects where enzymes are injected into the host. In many phytophagous Homoptera and Heteroptera, the pectinase is injected. This enzyme causes disruption of the middle lamellae of the plant cell walls.

The saliva of carnivorous Heteroptera such as *Platymerus* contains hyaluronidase, which attacks the mucopolysaccharides of connective tissues and so acts as a spreading agent facilitating the entry of the other salivary enzymes, proteinase and phospholipase into the host tissues.

In other insects, such as Orthoptera, the salivary enzymes contribute to the early stages of digestion within the gut. An amylase is commonly present.

Extra-intestinal digestion also occurs in *Dytiscus* larvae. These have no salivary glands, so that midgut enzymes must be involved. The enzymes are injected into the prey through the mandibles, which are perforated by a narrow tube and when, in a short time, the contents of the prey have been digested, the resulting fluids are withdrawn via the same route. A similar mode of feeding is employed by larval Neuroptera and Lamphyridae.

Proteolytic enzymes persist in the excreta of larval blowflies and so the meat in which they live is partially liquified before it is ingested. In *Bombyx* moth, the extra-intestinal digestion occurs. The moth secretes protease which attacks the sericin of silk so that the moths escape from cocoon.

**Internal Digestion**

Most digestion occurs in the midgut, in which the enzymes are secreted. In Orthoptera, the bulk of digestion occurs in the crop. In *Scistocerca* the greatest α-glucosidase activity occurs in the lumen of foregut.

Irrespective of whether an insect is carnivorous, herbivorous, parasitic or saprophagous, digestion of carbohydrates, proteins and lipids involves all these insects, regardless of their feeding habits, possess a range of enzymes in the midgut. But where the diet is specialized, the enzymes present are commonly adopted to it. If an insect, like a larval blowfly, feeds on a primarily protein diet proteases are important, whereas in an adult, nectar feeding Lepidoptera they are absent.

In aphids feeding on phloem containing no polysaccharides or proteins the presence of amylase and proteinase has not been confirmed but invertases do occur.

Micro-organisms may produce enzymes which are utilized, directly or indirectly by the insects. This is the case in cellulose and wax digestion.

**Carbohydrates**

Carbohydrates are generally absorbed as monosaccharides, so that before they are absorbed, disaccharides and polysaccharides must be broken down to their component monosaccharides. This may be a complex reaction taking place partly in the
gut wall and variety of enzymes in involved. Different enzymes are usually necessary to hydrolyze different series of sugars.

**Disaccharides**

The common disaccharides, maltose, trehalose, furanose, melezitose, lactose and cellobiose are converted into monosaccharides by following enzymes:

(I) $\alpha$ glucosidases split all $\alpha$ glucosides including sucrose, maltose, furanose, trehalose and melezitose by attacking the $\alpha$ link of a glucose residue.

(II) $\beta$ glucosidases splits $\beta$ glucosides such as lactose and cellobiose by attacking the $\beta$ link of a glucose residue.

**Polysaccharides**

The polysaccharides are attacked by enzyme amylase which hydrolyses 1:4 glucosidic linkages. Two type of amylase has been found in insects:

(I) Exo-amylase which splits off maltose residue from the end of the starch molecule.

(II) Endo-amylase which attacks the bonds within the starch molecule.

Although many insects feed on plants and wood, only a minority of them has an enzyme, cellulose capable of hydrolyzing cellulose, where there is no cellulose the insects must either feed on cell contents without digesting the cell walls or they must rely on micro-organisms to digest the cellulose for them.

**Proteins**

Protein digesting enzymes produced by the mid gut are of two types:

(I) Endo peptidases which convert proteins to polypeptides.

(II) Exo peptidases which degrade polypeptides by splitting individual amino acids.

The exo peptidases are further divided into following:

(a) Carboxypeptidases which remove amino acids from the carboxylic end of a polypeptide.

(b) Amino peptidases which cause hydrolysis at the amino end.

**Lipids**

Lipids are usually ingested in the form of triglycerides i.e. glycerol in combination of three fatty acid molecules. Digestion involves the conversion of triglycerides to di- and monoglycerides and fatty acids.

In insects two types of enzymes responsible for digestion of lipids have been identified.

(I) Lipase, which act on glycerides of long chain fatty acids.

(II) Esterase which on glycerides of short chain fatty acids.

**Enzyme activity**

Enzymes only exhibit maximum activity under certain conditions, in which pH; redox potential and temperature play a large part.
Enzymes exhibit maximum activity within a limited range of pH. The pH of the fore gut is greatly influenced by food and varies with the diet. Thus with a cockroach fed with a protein diet the fore gut pH 6.3, fed with maltose it is 5.8 and with glucose 4.5--4.8. The more acid pH with the sugars results from micro-organisms producing organic acids. The mid gut is usually buffered so that pH is maintained relatively constant.

In *Apis* there are two buffering systems; one is a complex of organic acids and their salts having its maximum effect at pH 4.2, the other a series of mono and di-hydrogen phosphates with a maximum effect at pH 6.8. These two systems tend to maintain the pH at about 6.3.

In cricket, grass hopper and Lepidoptera larvae, however phosphate has little buffering effect and here the main buffers are probably weak acids, including amino acids and their salts and proteins.

In the mid gut the pH is usually in the range of 6.00 to 8.00 but in larval Lepidoptera and Trichoptera pH 8-10.0 is usual. An alkaline pH is more usual in phytophagous insects than in carnivorous ones.

The hind gut is usually slightly more acidic than the mid gut, partly due to the secretions of the Malpighians tubules.

**Redox potential**

The redox potential is an important factor in digestion and absorption. It is a measure of the oxidizing or reducing power of a substance expressed in terms of its tendency to lose or gain electrons. A negative potential characterises a reducing substance, a positive potential an oxidizing substance, while the greater the potential, positive or negative, the stronger the oxidizing or reducing powers of the substance. Usually the potential in the mid gut is positive and it may reach as much as +200mv.

**Temperature**

The enzyme activity increases with temperature and in *schistocerca* the rate of increase in activity of α glucosidase for a 10°C rise in temperature (Q10) is 2.25. The greatest activity occurs at 45°C-50°C but only for short periods because enzymes are denatured at high temperatures and long periods over 40°C result in inactivation of this enzyme.

In *Tenebrio* (Coleoptera) larva changes of protease activity occur to compensate for changes in temperature. If the larva is transferred from 23°C to 13°C protease activity first falls and then increases, so that after ten days protease activity is twice as high as it was initially. On returning to 23°C, protease activity returns to its original level. Amylase activity shows so comparable compensating changes.

**Control of enzyme secretion:**

There are three possible regulatory mechanisms of enzyme secretion. These are:

(I) Secretagogue mechanism, where enzyme secretion or production is induced by food or its products directly stimulating the mid gut cells.
(II) Neural control mechanism, where information passes directly to mid gut via stomatogastric nervous system.

(III) Hormonal control mechanism, where the stretching of the gut wall (foregut) results in the production of appropriate enzyme.

Absorption

The absorption of digested food takes place mainly in the mid gut especially the anterior portion including the caeca and to a lesser extent in the hind gut.

Absorption may be a passive or an active process. Passive absorption depends primarily on the relative concentration of a substance inside and outside the gut, diffusion taking place from the higher to the lower concentration.

Active absorption depends on some metabolic process for movement of a substance against concentration or electrical potential gradient. Movement of water involves movement from a solution of lower osmotic pressure to one of higher osmotic pressure.

Carbohydrates

Carbohydrates are absorbed as monosaccharide. The absorption depends on diffusion from high concentration of glucose in the gut to lower concentration of glucose in the haemolymph. The low concentration of glucose in the haemolymph is maintained by immediate conversion of glucose to trehalose in the fat body which surrounds the gut. The other fact is that water is absorbed from gut lumen so that the haemolymph becomes more dilute.

The Glucose and fructose are absorbed in a similar manner to close, but rather more slowly because their conversion to trehalose is less rapid and thus their concentration gradients across the gut wall are less marked.

Proteins

The proteins are absorbed after degradation to amino acids but in some cases they are absorbed unchanged. Absorption takes place passively through the walls of caeca and anterior mid gut. The amino acids present in the digested food are in higher concentration than in the haemolymph and thus are absorbed by passive diffusion.

In Schistocerca the amino acids such as glycine and serine are absorbed by caeca.

In case of Rhodnius and Pediculus (Siphunculata), are known to absorb haemoglobin unchanged in the mid gut cells.

Lipids

Very little is known about the absorption of fats, but it is possible that they are sometimes absorbed unchanged. The products of wax hydrolysis are absorbed in a phosphorylated form and dephosphorylation follows in the epithelium. Cholesterol is esterifies as a preliminary to absorb.

The absorption takes place mainly in the mid gut instance in the caeca in Periplanata, the anterior in Aedes larva, and the anterior and posterior mid gut in blowfly larva; evidence for the absorption of fats from the hind gut of adult Hymenoptera.
Water

Water is absorbed in various parts of the mid gut. In *Schistocerca* and *Aedes* larva, water is absorbed in the caeca.

In *Glossina* water is absorbed in the anterior mid gut and in *Lucilia* larva in the middle zone of mid gut.

In many insects water is reabsorbed from the urine via the rectal pads. But, where there is little need for water conservation, as in fresh water insects, Homoptera, Heteroptera and Holometabolous larvae living on a fluid diet, re-absorption does not occur and rectal pads may be absent.

Water may be absorbed passively if the osmotic pressure of haemolymph exceeds that of the gut fluids.

Inorganic ions

Inorganic ions are absorbed in the mid gut and reabsorbed from the fluids in the rectum. There may be specific zones for the absorption of different ions in the mid gut.

In *Lucilia* iron is absorb in the centre of the mid gut, while Cu is absorbed in two spall zones characterized by a mosaic of cuprophilic and lipophilic cells.

Metabolism

Metabolism comprises all the chemical reactions that a living organism. It includes anabolism and catabolism. Anabolism comprises those reactions which result in the formation of more complex molecules from simple molecule. These reactions require energy.

Catabolism on the other hand comprises those reactions which result in the formation of simple molecules from the complex substances. In these reactions energy is released.

Intermediate Metabolism

Intermediate Metabolism includes all the cellular reactions which are not immediately concerned with the release of energy. These reactions are concerned with the formation of special secretions and the synthesis and breakdown of cellular constituents. Only the better known processes and substances will be considered.

Carbohydrate metabolism

Trehalose is a disaccharides derived from glucose via glucose 6-phosphate in the fat body. It occurs in all insects, and found in haemolymph, muscle, midget epithelium and to a lesser extent in gut lumen. It is hydrolysed by enzyme trehalase into glucose which is used as fuel for flight and also for chitin synthesis.

Glycogen

Glycogen is a polysaccharide found in fat body and flight muscles. It forms the major energy reserve in many insects. Synthesis of glycogen may be directly from glucose but it can also be formed from amino acids. It is converted to glucose by phosphorylase. Glucose is then utilized as fuel for the production of energy.
Chitin

Chitin, a constituent of insect cuticle, is a polymer of acetyl glucose mine units. The synthesis of chitin possibly involves uridine diphosphate acetyl glucosamina (UD PAG) followed by condensation to form chitin.

Much of cuticular material is digested by the moulting fluid and reabsorbed by the insect when it moult. The carbohydrate present in the old cuticle may thus be synthesized and re-used in the new one.

Lipids

Lipids are not precisely defined substances, but they are mostly fatty acid esters and their derivatives, insoluble in water, but soluble in organic solvents.

(a) Triglycerides and fatty acid:
Most of the lipid in insect tissue is in the form of glycerides. The fatty acids combined in the glycerides are usually long chain acids, both saturated and unsaturated.

Fatty acids are obtained in the diet, but in phytophagous insects the lipids content of the food is low and fatty acid synthesis occurs in the fat body.

The metabolism of lipid in the fat body entails the hydrolysis of triglycerides to diglycerides by a lipase. The diglycerides then associate with proteins to form lipoproteins which enter the haemolymph.

On entering muscles, the diglycerides are hydrolysed and the fatty acids progressively oxidized to produce acetyl coenzyme A, which enters the citric acid cycle.

(b) Sterols
All insects require a source of sterol and in most cases, have a specific requirement for cholesterol. Sterols can not be synthesized by insects, but phytophagus species are able to produce cholesterol from the commonly occurring phytosterol such as B - sitosterol. Cholesterol forms the starting points for the synthesis of the moulting hormones (ecdysones). Sterols are excreted as sulphates.

(C) Waxes
Waxes are complex mixtures of lipids varying from species to species and even in different stages of the same species. The wax in the cuticle provides the waterproofing layer and may also have some structural significance.

Very large amounts of wax are produced by coccids and related insects. Bee wax contains 12% parafins, 72% esters and 13 % free long chain fatty acids. The fat cells and oenocytes play a major part in the synthesis of bee wax and in the process material passes from fat cells to the oenocytes and from both these to the wax glands in the abdomen.

Amino acid and Protein metabolism

The simpler substances of proteins called amino acids occur as free amino acids give rise to compounds like butyric acid, ornithine and taurine. A number of amino acids like glutamate proline, aspartate and alanine are synthesized in the fat body, the transfer
of amino groups from an amino acid to a keto acid without the production of ammonia is known as transamination. In Bombyx 19 amino acids function as donors in transamination. Malpighian tubules show the greatest transaminase activity. Glutamate plays a major role in the transfer of nitrogen from one compound to another. This central role aids in incorporating and distributing nitrogen.

Body proteins get synthesized from amino acids. RNA acts as template for protein synthesis. Functionally proteins form essential components of cells, secretions, blood proteins, material like silk, etc.

Respiratory Metabolism

In general, carbohydrates such as glucose and glycogen form the initial substance for oxidation and energy production. At normal body temperatures oxidation occurs as a series of small steps each facilitated by a specific catalyst or enzyme. By this means much of the free energy of the reaction can be conserved, where as if the breakdown was direct most of this energy would be dissipated as heat.

First part of this breakdown is an anaerobic process known as glycolysis which occurs in the extra mitochondrial cytoplasm. Glycolysis commonly leads to the formation of pyruvate, which is then oxidised within the mitochondria by the enzymes of the citric acid cycle also known as tricarboxylic acid or Krebs cycle. The energy released in these reactions is finally conserved in a terminal oxidase system involving the cytochromes.

Release and Conservation of Energy

Before sugars enter into metabolic reaction they are phosphorylated by the addition of phosphate group. Their subsequent oxidation usually involves the removal of hydrogen, a process known as dehydrogenation. This result in structural changes in the molecule which are accompanied by a redistribution of the intrinsic energy in the system so that most of it is concentrated in a bond linking a phosphate radical to the rest of the system. In this way an energy rich bond is created. By the process of dephosphorlation this bond energy is transferred to a molecule of adenosine diphosphate (ADP) converting it to adenosine triphosphate (ATP).

The hydrogen which is removed in dehydrogenation is not transferred directly to oxygen, but passes to some other hydrogen accepter, which is usually NAD or nicotinamide adenine dinucleotide phosphate (NADP).

In accepting hydrogen these are converted to the reduced forms NADH₂ and NADPH₂. These in turn pass the hydrogen to flavoproteins (FP), which then become reduced (FPH₂), but Ú - glycerophosphate formed in glycolysis and succinate formed in the citric acid cycle, transfer hydrogen directly to the flavoproteins, from the flavoproteins electrons (e) are passed to the cytochrome system and H⁺ ions are released into solution.
3. INSECT NUTRITION

Like other animals, insect also require a balance diet having appropriate amount of protein, amino acid, carbohydrates, lipids, vitamins, minerals etc. the dietary requirement of the insect is species specific. For the proper development and growth, the insects derived most of the nutrients either by taking food, or from the stores inside the body (e.g., fat bodies) or as a result of synthesis. Certain moths do not feed as adult, and the food accumulated during larval stages is used for their metabolic processes. All insects are able to synthesis nucleic acids, however, only some insects are able to synthesise vitamins, non- essential amino acids.

1. Amino acids- Amino acids are the building blocks of protein making the tissues and enzymes. Different insects have different requirements, depending upon which amino acids are capable of synthesizing. In addition to essential amino acids, few insects need glycine (e.g., flies) or alanine (e.g., Blatella), however, in these cases methionine is not essential.

2. Carbohydrates- Carbohydrates are not considered to be essential nutritive substances for most insects, but they are probably the most common source of chemical energy utilized by insects. However, many insects (e.g., many moths) do, in fact, need them if growth and development are to occur normally. The carbohydrates may be converted to fats for storage, or to amino acids.

3. Lipids- Lipids or fats, like carbohydrates are, good sources of chemical energy and are also important in the formation of membranes and synthesis of steroid harmones. Most insects are able to synthesis lipids from carbohydrates and protein sources. However, some insects species do require certain fatty acids and other lipids in their diets.

4. Vitamins- Vitamins are unrelated organic substances that are needed in very small amount in the diet for the normal functioning of insects as they cannot be synthesized. They provide structural components of coenzymes. Vitamin A is required for the normal functioning of the compound eye of the mosquito. Insects principally require water- soluble vitamins (e.g., B complex vitamins and ascorbic acid). In the absence of ascorbic acid (Vitamin C) locusts undergo abortive moults and dies.

5. Minerals- Like vitamins several minerals are required in traces by insects for normal growth and development, e.g., potassium, phosphorus, magnesium, sodium, calcium, manganese, copper, iron, chlorine, iodine, cobalt, nickel and zinc. The aquatic larvae of mosquitoes are able to absorb mineral ions from the water through the thin cuticle.

6. The nucleic acids- Nucleic acids (DNA and RNA) constitute the genetic material. Like other animals, insects are also able to synthesise them. However, dietary nucleic acids (e.g., RNA) have been shown to have an influence on growth of certain fly larvae.
7. Water- Like all animals, insects require water. Insects fulfil their water requirements from food, by drinking, from absorption through the cuticle (in aquatic forms), or from a by-product of metabolism. Insects vary greatly with respect to amounts of water needed.

**Micro organism and nutrition:**

Some insects require the presence of certain microbes (yeast, fungi, bacteria, and protozoans) for normal growth and development and, in some instances, for survival. In some insects the microbes are housed in specialized cells, mycetocytes, and the tissues composed of these cells, mycetomes, are associated with the gut, fat body, or appropriately, the gonads. The presence of microbes in the gonads ensures the infection of any egg produced, thus transferring the microbes in next generation. Microbes are commonly found in the alimentary canal of insects, often in the various diverticula of the midgut. The microbes probably benefit the insect in various ways, e.g., fix atmospheric nitrogen, synthesise protein from nitrogenous waste materials, and supply vitamins (B group), sterols, and amino acids in addition to digestion of cellulose.

The association of microbes with the insects may either be casual or constant. The microbes are almost present in food and are ingested by the insects during feeding, e.g., locusts. Such casual association with microbes are important in the nutrition of dung beetles that have fermentation chamber in the hind gut in which decaying food with its content of microbes is retained. The insects may have constant association with the microbes, e.g., insects feeding on wood, dry cereal, feather, and hair.

4. **THE CIRCULATORY SYSTEM**

Insects have an open blood system in which circulation is produced by the activity of a dorsal longitudinal vessel comprising a posterior heart and an anterior aorta.

When the heart relaxes blood passes into it through valve openings while, waves of contraction which normally start at the back, pump the blood forwards and put through the aorta.

**Structure**

Insects have an open blood system with the blood occupying the general body cavity known as haemocoel. The heart is usually cut off from the major part of the body cavity by a muscular diaphragm known as dorsal diaphragm. There is a fibro muscular septum over the nerve cord known as ventral diaphragm having the ventral or the perineural sinus. The sinus in which dorsal vessel and heart are situated known as pericardial sinus and the sinus below the dorsal diaphragm and above ventral diaphragm is known as perivisceral sinus.
Dorsal Vessel

The dorsal vessel runs along the dorsal midline, just below the terga, for almost the whole length of the body. The dorsal vessel is divided into two regions. Heart: A posterior heart in which the wall of the vessel is perforated by incurrent Ostia and sometimes also by ex current Ostia. Aorta is an anterior region of the dorsal vessel which is a simple, imperforated tube. It is opened anteriorly. The wall of the dorsal vessel is contractile and consists of a single layer of visceral muscles cells with a circular or spiral arrangement.
1) Heart:

The heart is often restricted to the abdomen, but may extend forward as the prothorax as in case of Dictyoptera. In Orthopteroids it has a chambered appearance. The alary muscles arise from terga and connected with heart chambers. Thus these muscles form the dorsal diaphragm also. Each chamber possesses a pair of vertical slits laterally called incurrent ostia one on each side. The numbers of these heart chambers varies with the insect species in Periplanata, the heart shows 13 chambers, in Japyx 10, in Lucanus 7, and in Musca 3. The ostia are lateral and the wall of the heart is reflected towards at each ostium to form an articular valve preventing back flow of blood into the dorsal sinus.

Nutting (1951) has described ex current ostia in the Orthopteriods and also in Thysanura. These are usually paired ventro lateral openings in the wall of the heart without any internal valves. The number of ex current ostia varies. In Acridoidea these are two thoracic and five abdominal pairs. Externally each opening is surrounded by a papilla of spongiform multinucleate cells which expands when the heart contracts, so that blood passes out and contracts when the heart relaxes, so that the entry of blood is prevented.

Histologically, the heart is composed of a single layer of cardiac cells carrying large nuclei. The cytoplasm contains within it striated muscles fibrillae which are absent in the periphery. The muscles are arising from the terga and attached to the heart chambers over dorsal diaphragm. These muscles are called alary muscles and looks wing like shape. These muscles show a paired arrangement, roughly corresponding to the number of cardiac chambers, Periplanata shows 12 pairs, the honey bee 4 and Chironomus 2. In most insects the posterior end of the heart is closed.

2) Aorta: The aorta is the slender anterior continuation of the heart into the head and terminating near the brain it forms the principal and the only artery. Its function with the heart is provided with aortic valves. In some insects the anterior end terminates like a funnel, in others it bifurcates to form the cephalic arteries, which may or may not further divide. In some insects the aorta gives off diverticula in the thorax as in Odonate nymphs and Dytiscus, called aortic ampullae. In general aorta is non pulsatile, but is pulsatile in Dytiscus and in certain Lepidoptera the diverticula perform rhythmic contractions independent of the heart.

Pulsatile Organs

Besides the principal pulsatile heart, there are other accessary pulsatile organs in many insects.

In the mesothorax and sometimes also in metathorax there is a pulsatile organ concerned with the circulation through the wings. The veins of the posterior part of the wings connect with a blood space beneath the tergum via the axillary cord. In Odonate the blood space, or reservoir, open through a terminal ostium into an ampulla at the end of a dorsal diverticulum of the aorta.

Orthoptera and probably many other insects have a small ampulla at the base of each antenna. Other pulsating organs occur in the legs of Heteroptera.
Blood Composition

The blood of insects consists of liquid plasma and several nucleated cells are known as haemocytes. The plasma serves as a mean by which substances may be transported round the body, it play little part in respiration. It may also provide a store of substances such as sugars and proteins, while water acts as a reservoir for the maintenance of the tissue fluids.

The volume of blood may vary at different stages in the life cycle and according to the physiological condition of the insect. The plasma is nearly 90 percent water though the water content may vary. The blood volume increases prior to a moult and decreases just after moult. Increase in volume is by discharging water into blood from tissues and decrease by return of water to the tissues.

Of the inorganic anions in blood, chlorides are most abundant especially in apterygotes and hemimetaboloous. Carbonates and phosphates also do occur in fairly large quantity, phosphates more so in Carausius. Except in Lepidoptera and Hymenoptera the most abundant cation is sodium. Potassium is lower and sodium/potassium ratio which though variable, has been explained to have phylogenetic significance. The concentration of Mg is high in plasma, traceable to the high Mg content of chlorophyll eaten. In Phasmid it completely replaces Na. Calcium is less important but is valuable in the development of the end plate potential at the muscles.

*Bombyx* larva shows 15:46:24:101 as ratio for Na: K: Ca: Mg, while in the adult the ratio is 14: 36: 14: 47. The metallic trace elements of Cu (a constituent of tyrosine), Fe (present in cytochromes), Zn and Mn have also been found in insect blood.

Organic constituents of the blood of insects comprise a high level of amino acids, trehalose and glycerol. Trehalose is the source of energy. Glucose and Fructose occur in the plasma of *Apis*. About 35 - 65 % of non protein nitrogen of blood is due to amino acids and most insects have a high concentration of glutamine, proline, arginine, lysin, and histidine. An increase in tyrosine before moulting, which also aids in tanning of skin has been observed. Rise in glutamic acid aspartic acid in the larval Bombyx help in silk production. A number of proteins are available in blood, as much as 21 in Lucusta some enzymic proteins are also seen in blood at various times like tyrosinase, trehalase etc. End product of N metabolism also will be seen in blood like uric acid and sometimes allantoin urea and ammonia.

Three arrangements in plasma constitution have been suggested, viz ;

1. A basic type, seen in Ephemerids, Odonates, Orthoptera, and Homoptera where Na and chloride decide the osmolar concentration.
2. Where the chloride content is low relative to Na and amino acids present in high concentration as is met with in Trichoptera, Mecoptera, Diptera and many Coleopteran.
3. Amino acids accounting for over 40% of total osmolar concentration seen as in Lepidoptera and Hymenoptera.
Pigments occur in plasma like haemoglobin in Chironomus which is helpful in respiration. The blood may be coloured due to green insectoverdin in Lepidoptera and locusts blue meso biliverdin in starving locusts, purplish red protoaphin in aphids and carotene, xanthophyll and flavings in Bombyx larva.

**Haemocytes**

The various types of nucleated structure are suspended in blood plasma. They are known as haemocytes.

**Types of Haemocytes**

1. **Prohaemocytes** These are small rounded with relatively large nuclei and intensively basophilic cytoplasm. They divide at frequent intervals and give rise to other types of haemocytes.
2. **Plasmatocytes** These are most abundant having basophilic cytoplasm, many ribosomes and mitochondria. They are phagocytic in nature.
3. **Granular Haemocytes** These are phagocytic but are characterised by the possession of acidophilic granules. The cells contain abundant rough endoplasmic reticulum.
4. **Cystocytes or Coagulocytes** They are small with sharply defined nucleus and a pale, hyaline cytoplasm containing scattered black granules.

**Functions**

1. Phagocytosis of foreign particles, micro organisms and tissue debris.
2. Encapsulation of such organism which are too large for phagocytes.
3. Secretion and metabolism, haemocytes are concerned in the formation of connective tissues. They are also involved in the formation of fat bodies are concerned in intermediate metabolism.
4. Wound healing and coagulation.

**Dynamics of Blood Circulation**

The circulation is mainly effected by the pulsation of the heart. The heart rhythmically contracts in the antero-posterior direction. The cardiac cells possess an automatic capacity to contract and relax irrespective of nervous excitation. The contraction is simply myogenic. The cardiac cells which brings about the automatic activity of contraction. The contraction begins in the last segment and proceeds forward. Though the contraction is initiated by myogenic means, its rate and rhythm are controlled by nervous means. But the activity and control of the accessory hearts are not known.

When the heart expands, during diastole, a negative pressure forces the blood from the pericardial sinus enter the heart through the ostia.

During systole, a positive pressure is set up and the ostia get closed and blood is driven forward to the chamber in front. The blood is forced forward by the heart from behind into the aorta and thus into the head. Here the blood circulates and then percolates into the visceral sinus where it flows due to the gentle movement of the
diaphragm. An undulating movement of the ventral diaphragm forces blood back along the perineural sinus. The diaphragms and septa continuously move up and down, thus maintaining circulation. The blood is finally drowned into the dorsal sinus by the contractions of the alary muscles. From there it again enters the heart and the circulation continuous. The rate of the heart beat is variable in insects. In *Periplaneta* it is 49/min, in *Oryctes* 18/min and in *Hippobosca* 120/min. There is a pattern for the fall in pulse rate: pulse rate which is 82/min in the 1st instar, falls to 63/min in the 3rd instar, to 45/min in the 4th instar and 39/min in the adult. The rate increases as an insect become active increase of temperature also increases pulse rate. In diapause the pulse rate falls to minimum.

5. THE RESPIRATORY SYSTEM

In the vast majority of insects respiration takes place by means of internal air-tubes known as trachea. The latter ramify through the organs of the body and appendages, the finest branches being termed tracheoles. The air generally enters the tracheae through paired and usually lateral openings termed spiracles (or stigmata), which are segmentally arranged along the thorax and abdomen. More rarely the spiracles are closed or wanting, respiration in such cases being cutaneous. In the immature stages of many aquatic insects special respiratory organs known as gills (or branchiae) are present and these may or may not co-exist with open spiracles. The respiratory organs of insect are always derived from ectoderm, the tracheae are developed from solid ingrowths or tubular invaginations of that layer and the gills arise as hollow outgrowth. Histologically, both types of organs are composed of a layer of cuticle, the hypodermis and usually a basement membrane, all of which are directly continuous with similar layers forming the general body-wall. All or most of cuticular lining of trachea-spiracular system is shed at ecdysis. A tracheal system is absent in most Collembola, some Protura and some endoparasitic Hymenopteran and Dipteran larvae.

Fig. Tracheal system (dorsal tracheal trunks)
The Spiracles
Number and Position of Spiracles

The spiracles are, morphologically, the mouths of ectodermal invaginations which give rise to the tracheal system. They are normally placed pleura of thoracic and abdominal segments, but their exact position is very variable. In the abdomen of most insect they are seen to lie in the soft membrane between the terga and sterna, sometimes towards the front or back of their segments. In many insects, particularly on the thorax, spiracles occupy an intersegmental position, being situated just in front of each of segments to which they come to lie on the terga, near the side margins of the letter, as is seen in the abdominal spiracles of Apis and Musca.

An evanescent pair of spiracles is present on the labial segment of the embryo of Apis (Nelson, 1915) but, with the possible exception of some Collembola mentioned below, there is no other record of cephalic spiracles in the insects. In the developing embryo the spiracles appear as series of ingrowths lying to the outer side of the rudiments of the appendages. Twelve evident pairs of spiracles are said to be present in the embryo of Leptinotarasa, being situated on each of the thoracic and the first nine abdominal segments. In the embryos of most insects, however, the prothoracic pair is wanting and frequently the pair on 9th abdominal segment is likewise absent. The resulting number of two thoracic and eight abdominal pairs is the maximum found in the postembryonic stages of any insect apart from some Diptera and it is portable that their primitive position was intersegmental, the most anterior pair lying between the pro- and the last pair between the 7th and 8th abdominal segments (Keilin,1944). Deviations from the number and arrangement of spiracles in such a primitive isopneustic system have evolved through the migration of the spiracles, to the adjacent segment (usually the posterior one) and the reduction of some or all of the spiracles. These either becomes closed or remains visible as small scars or is lost completely.

According to the number and arrangement of functional spiracles it is possible to classify respiratory systems as follows (Palamen, 1877; De Gryse, 1926; Keilin, 1944; Hinton, 1947):

1. The Holopneustic Respiratory System
   This is the most primitive arrangement found in living insects, 10 pairs of functional spiracles being present, on the first 8 abdominal segments, the metathorax and either the prothorax or mesothorax. It is characteristic of nymphs and imagines of many orders and of the larvae of Bibionidae (Diptera) and some Hymenoptera.

2. The Hemipneustic Respiratory System
   This form of respiratory system is the prevalent one among insect larvae and is derived from the holopneustic type through one or more pairs of spiracles becoming non-functional. The following terms are in use to indicate the different distribution of spiracles:
   Peripneustic
   Spiracles in a row along each side of the body. In typical examples the prothoracic and abdominal spiracles are open, that of the metathorax being closed. This condition is found in the terrestrial larvae of the orders Neuroptera, Mecoptera,
Lepidoptera, of many Hymenoptera, Symphyta, and of many Coleoptera. Among Diptera it is prevalent in larvae of some Bibionidae and most Mycetophilidae and Cecidomyiidae.

**Amphipneustic** Only the Prothoracic and the posterior abdominal spiracles are open. This type is a common among larval Diptera.

Metapneustic - Only the last pair of abdominal spiracles are open. The prevalent type in larval Ciliidae and Tipulidae and in Hypoderma among the Oestridae; also found in the first larval instar of most Cyclorrhapha and in the aquatic larvae of certain Coleoptera (Dystiscidae, Helodidae, etc.).

The last three types may together be denoted as oligopneustic systems and represent an adaptive modification to life in a liquid or semi-liquid medium.

**3. The Apneustic Respiratory System** Here none of the spiracles are functional, air entering the closed tracheal system by diffusion through the general body surface or specialized extension of it known as gills or branchiae (q.v.). Like the oligopneustic types, the apneustic system is an adaption to life submerged in fluids and is therefore characteristic of aquatic and endoparasitic forms. It occurs for example, in the nymphs of Ephemeroptera and Odonata, the larvae of Trichoptera, of such Dipteran families as the Blepharoceridae, Simuliidae, Chironomidae and Ceratopogonidae and of some Coleoptera (e.g. Elmidae, Halipidae, and Hymenoptera). It is also found in some larval instars of endoparasitic Hymenoptera and Tachinidae.

In all the above types of respiratory system, the total of functional and non-functional spiracles is equal to 10 pairs. In contrast to them, the term Hypopneustic is used to denote system, in which one or more pairs of spiracles have disappeared completely. For example:

- The Mallophaga and Siphunculata have 1 thoracic and 6 abdominal pairs;
- The Thysanoptera have 2 pairs of thoracic and 2 pairs of abdominal spiracles;
- In the Hemiptera Sternorrhyncha their number is very variable and is reduced to 2 pairs in many Coccoidea.
- Among Coleoptera, the Scarabaeoidea and Curculionoidea have from 1 to 3 of the hindmost abdominal spiracles wanting.
- The Diptera usually exhibit a reduction in the number of abdominal spiracles and, among the Cyclorrhapha, a sexual difference is evident in this respect, the females often having 5 pairs and the males 6 or 7 pairs.
- Among the parasitic Hymenoptera reduction is frequently evident and in the Calcidoidea, there are commonly only 3 pairs which are suited on the thorax, propodeum and 8th abdominal segment, respectively.
- The Diplura and those Collembola with a tracheal system exhibit and typical arrangement of spiracles.
Structure of spiracles

Fig. Structure of spiracle

In general, the spiracles not only permit gaseous respiratory exchange but are also a major site of water loss and at ecdysis are put apertures through which the old tracheal lining is pulled out. They show many adaptations to these diverse functions but a typical functional spiracle includes not only the external opening, and the annular sclerite or Peritreme which surrounds it but, also the atrium or vestibule into which the opening leads, together with the closing apparatus. The latter consists of one or more muscles with associated cuticular parts and, by closing the spiracular aperture, prevents excessive loss of water vapour. The atrium is a specialized region leading from the spiracular opening: it lacks taenidia and its walls are variously sculptured or are provided with hairs, trabeculae and similar cuticular outgrowths. These help to reduce water loss and prevent the entry of dust. Closely connected with spiracles are frequently peristigmatic glands which secrete a hydrophobe material preventing the wetting of those organs. The structure of the spiracles present an enormous range of variety among different groups of insect: it is also usually different in the thoracic and abdominal spiracles of same insect and may be greatly modified in different instars. It will therefore, be readily appreciated that their classification is a matter of much difficulty (Krancher, 1881; Mammen, 1912; Steinke, 1919; Bergold, 1935; Hussan, 1944; Keilin, 1944).

The most generalized type of spiracles is devoid of lips and closing apparatus and is little more than a simple crypt as in Sminthurus. No special chamber or atrium is developed and spiracle opens directly into the tracheae.

In most Hemiptera, more especially in abdomen, the spiracles are simple apertures surrounded by a peritreme. A well developed atrium is present and between the letter and the trachea is the closing apparatus (absent from the Cryptocerata). This type of spiracle is also found in the Mallophaga, Siphunculata (Webb, 1946), Siphonaptera and in other insect.

In the Acrididae the thoracic spiracles each have a slit like opening guarded by two external valves or lips. The metathoracic spiracles have movable lips united by a ventral lobe: they open their own elasticity but are closed by an occlusor muscle arising from a process on the margin of mesocoxal cavity. The abdominal spiracles have no projecting
lips, the integument being inflected to form two hardened walls of the atrium — one wall being movable and other fixed. The movable wall is prolonged into a process or manubrium to which the occlusor and opening muscles are attached.

In spiracles of Lepidopterous larvae the lips are fringed with repeatedly branched processes, whose finest divisions often require a high magnification for their detection, thus forming a most efficient guarding mechanism to the tracheal system. At the inner end of atrium is the closing apparatus. The latter consists of cuticular bow, which partly encircles the trachea, while on the opposite side of the latter is a sclerotized band; a closing lever or rod is closely connected with the band. The occlusor muscle is attached at one end to the bow and at the other to the lever: when the muscle contracts the lever presses the band against the bow, thus closing the entrance into the trachea. The latter is opened partly by means of the elasticity of the cuticular part which regain their former position, and partly by the aid of an antagonist muscles or an elastic fibre.

In the larvae of Melolotha and other scarabaeidae the spiracles are circular: each consist of a creascentic sieve plate and a projecting tegumentary fold or bulla which almost completely surrounded by it. The true opening is a curved slit situated near the margin of the bulla and running concentrically with it, the sieve plates consists of an outer pore membrane supported beneath by a layer of trabeculae.

In larvae of the Elateridae, Cleridae, Nitidulidae and other Coleoptera are biforous spiracles. Each has two contiguous opening which slit are more or less like and seperated by a partition wall. Each opening communicates either by means of tubular passage with common atrium or opens directly into the trachea.

In Dipterous larvae the spiracles are without closing apparatus (Keillin, 1944). In the third stage larvae of the higher Cyclorrhapha the posterior spiracles consist of a pair of cuticular plates. Each plate is surrounded by a peritreme and bears as a rule three openings which may be pyriform (Muscina) or in the form of straight slits (Calliphora) or sinuous slits (Musca). Each opening is transversed by a number of fine cuticular rods presenting the appearance of grating, and all three opening communicate with a common atrium. Just internal to openings there is a system of branch cuticular trabeculae which form along with the grating previously eluded to an efficient barrier to the entrance of foreign particles. The walls of the atrium are also lined with fibrous processes and form so called felt-chamber which probably reduces water loss in the absence of a closing mechanism. The anterior spiracle each consists of a variable number of digitate processes whose apices are perforated by openings. Each opening communicates with a small atrium and the atria of each spiracle all join with the main tracheal trunk of their side. In the larvae of Oestrus, Hypoderma and other of the Oestridae instead of three openings to each spiracle there are multiples pores. In Glossina there are about 500 of these pores to a side which form the sculpturing on the lobe like posterior abdominal spiracles (Newstead 1918). The pores are connected by means of tubular continuations with a tripartite felt chamber. A similar arrangement obtains in the larva of Hippobosca.
Except that the pores are much less numerous while in Melophagus there are only three to each lobe.

The shedding of the old spiracles at ecdysis and formation of new ones takes place in three different ways. In most primitive type, where the new spiracular aperture is sufficiently wide to allow withdrawal of the old tracheae and atrial apparatus, the new structures are formed around the old ones after the latter have separated from the hypodermis. The remains of the old spiracles and tracheal lining are then pulled out through what becomes the new aperture. This method of moulting is the most common one, but where the aperture or atrium of the new spiracle is so obstructed by cuticular processes that withdrawal is mechanically impossible, one or other the following of the following methods is adopted. In the Mecoptera and some Diptera the spiracle opens by numerous small apertures arranged around a central solid area. Before moulting occurs a new spiracles forms around the old one so that the former processes a central edysial aperture through which the old structures are drawn out and which then closes by hardening and contraction of the cutical to form the solid central part. In other Diptera and many Coleoptera there develops around the old spiracle a simple cuticular tube connected with which and situated to one side of the old structures is the new spiracle. The old spiracle and tracheae are then pulled out through the unobstructed edcysial tube at moulting and tube later shrivels, its former opening giving to the stigmatic scar.

In the apneustic and hemipneustic systems of immature forms all or some of the spiracle are non-functional. They consist of surface scare from the inside of which a more or less solid, cuticular stigmatic cord (Palmen, 1877) run to an adjacent part of the tracheal system. Before moulting an ecdysial tube continuous with the new tracheal system forms around the stigmatic cord and the appropriate of the old tracheal lining is later pulled out through the ecdysial tube by means of the stigmatic cord. The tube then shrivels to form the stigmatic cord and scare of the new instar. If however, this new instar is to have a functional spiracle in that position the necessary structure form around the old stigmatic cord and remain functional after moulting. The function of the stigmatic cords is therefore: (a) to anchor the tracheal system to the cuticle, (b) to draw out tracheal lining at ec dysis and (c) to form a structure around which an ecdysial tube new functional spiracle can develop.

The Tracheae and Tracheoles

Fig. Structure of trachea
The Tracheae are elastic cuticular tubes and when filled with air present a silvery appearance. The innermost lining of a trachea is a layer of cuticle known as the intima (endotrachea) which is directly continuous with the cuticle of the body-wall though chitin is not present in the finer tracheal branches of all species or in large trunks of some insects. Most of the tracheal system is shed at ecdysis but the finer branches are sometimes completely dissolved before moulting while in sciara larvae there is no casting off the cuticle in small and remote branches (Keister, 1948). When examined microscopically a trachea present a very characteristic striated appearance which is due to the fact that the intima is specially thickened at regular intervals to form closely arranged thread like ridges which project into lumen. These bands or thickenings are known as taenidia and, as a general rule, they pass round the trachea in a helical manner although their continuity is frequently interrupted: in other cases they form independent rings. The function of the taenidia is to keep the tracheae distended, and thereby allow the free passage of air. If a trachea be reased out the intima will tear between the taenidia and the latter will uncoil after the fashion of an unwound wire. In some insects several taenidia exist side by side and in teased preparations a ribbon-like band uncoils which is formed of several parallel thickening. In some insect (Zaitha, Lampyris, Luciola, etc.) cuticular piliform processes arise from the taenidia and project into the cavity of the tracheae.

An epithelial layer (ectotrachea) lies outside the intima and is composed of pavement cells with relatively large nuclei. The larger tracheae of some insect are faintly coloured with reddish-brown or violet pigment which is lodged in the cells of the epithelial layer. A delicate basement membrane forms the outermost coat of the tracheae.

The ultimate branches of the tracheal system are termed tracheoles and are cannals with a diameter of 0.2-0.3µ whose thin wall bear helical or circular taenidia visible only under the electron microscope (Richard & Korda, 1950). They may contain liquid or air, end blindly or in anastomosis with each other and their walls are freely permeable to water. The tracheoles are intracellular structure, developing in almost all cases from large, stellate end cells (Tracheoblasts) and later becoming joint to a developing trachea. The tracheoblasts, though ectodermal, develop independently of the tracheal epithelium and their processes commonly anastomose to form a fenestrated membrane over the surface of various viscera- the tracheated peritoneal layer Tracheoles also ramify between the cells of the insect tissues and even penetrate the cells of muscle, and perhaps other tissues, to end intracellularly. In the fat-body of the larvae of Gastrophilus, the tracheoles lie holly within the cytoplasm of large tracheal cells of a special type which contain haemoglobin and act as an oxygen store (Dinulescu, 1932).

The general arrangement and distribution of tracheae present important difference among the various groups of insects (Lehmann, 1926). In many Apterygotes, such as Machilis, Campodea and the Sminthuridae, the tracheae arising from each spiracle remain unconnected with those from the others, but the Lepismatidae and japygidae resemble the majority of Pterygotes in having a system developed from union of a series of tracheospiracular metameres by transverse and longitudinal trunks. Clear indication of
such a metanumeric arrangement are present from the earliest postembryonic stages, though growth is accompanied by an increase in the complexity of the branches present. A metameric basis is evident not only in holopneustic forms but also in hemipneustic and apneustic system owing to their retention of non-functional spiracles. The most constant features of well developed tracheal system are the presence of lateral longitudinal (spiracular) trunks (rarely absent, as cimex), of dorsal longitudinal trunks connected with lateral trunks by palisade tracheae, and less frequently, of ventral longitudinal trunks. Transverse dorsal or ventral commissures connect the systems of each side.

The dorsal longitudinal trunks give off segmental branches which pass to heart the dorsal musculature. Visceral branches, which supply the digestive canal and reproductive organs, take their origin from the palisade tracheae or directly from the spiracular tracheae. The nerve cord and ventral musculature are supplied by branches derived from the ventral transverse commissures. Tracheae supplying the legs arise from spiracular (or, in Odonata, the dorsal) longitudinal trunks in thoracic region and the basal tracheae of the developing wings usually take their origin in close association with those of the leg tracheae of meso- and metathorax (Comstock, 1918). The head and mouthparts are principally supplied by branches derived from the anteriormost spiracle and the dorsal longitudinal trunk.

Hypopneustic tracheal systems deviate to varying degree from the segmental arrangement, longitudinal trunks and transverse commissures tend to be reduced or disappear and each of the few spiracles gives rise directly to a greater or lesser number of branches which supply different parts of the body. The hypopneustic system may be markedly reduced, as in some Coccoidea.

The Air-Sacs

In many winged insects the tracheae are dilated in various parts of the body to form thin-walled vesicles or air-sacs. For the most part they are extremely delicate in structure and usually lack the teanidia which ordinarily keep a tracheal tube open. The air sacs are consequently distensible and, when inflated, are easily seen as glistening white vesicles. When collapsed and empty they are generally exceedingly difficult to detect. In Melontha, for example, the air sacs are dilatations of the secondary tracheae and are relatively small in size but exceedingly numerous. In _Melanoplus_ there is a pair of large thoracic airsacs and five pair in the abdomen which are likewise dilatations of the secondary tracheae: there are also many smaller vesicles among the miscles. The airsacs attain great development in _Volucella, Musca_ and other Cyclorrhapha and in _Apis_ and _Bombus_ among Hymenoptera. In these instances the abdominal air-sacs are especially large and are dilatations of the main longitudinal tracheal trunks. Air sacs are also met with among Lepidoptera and Odonata.

The principle function of air-sacs is respiratory one as they serve to increase the volume of tidal air which is changed when respiratory movements occur, but other functions are also known. An insect with air-sacs has a lower specific gravity than a similarly sized one without them and they may therefore, make easier the flight of large
species. In some higher Cyclorrhapha the sacs occupy a space in the abdomen of the newly emerged fly which is available for later expansion of the ovaries while, their occurrence beneath tympanal organs permits the membrane to vibrate more freely than would otherwise be possible. The air-sacs of the larvae of Chaoborus and Mochlonyx act as hydrostatic organs, enabling the insect to float at any level in the water it inhabits while it has been suggested that the pair in the abdomen of the littoral Carabids Aepus and Aepopsis acts as an air storage organ when it processor is submerged.

**Physiology of Respiration**

Two types of gaseous exchange are observed in insects; diffusion or passive ventilation.

1. **Diffusion or passive ventilation:** Simple diffusion from the outside of smaller insects and from well ventilated air sacs in larger insects can supply sufficient oxygen to the body tissues to maintain life. It is a passive form of ventilation in which the gases are not pumped in the tracheae and tracheoles. Diffusion is also regulated by the opening and closing of the spiracles. The spiracles respond to decreased oxygen or CO2 in the air by remaining open for longer periods of time. Spiracular opening and closing are under both neural and hormonal control.

2. **Active ventilation:** In larger and active insects passive ventilation does not bring adequate amount of oxygen to the tissues. In these insects, air sacs, if present and larger tracheae are often ventilated by rhythmical pumping movements of the body which is called as active ventilation. Peristatic waves over the abdomen, telescoping or dorsoventral flattening of the abdomen, and, in some, movements in the thorax or even protraction and retraction of the head cause the inspiration and expiration of gases. In addition, heartbeat and the gut movement, assist ventilation by pressing against adjacent tracheae. Both tracheae that are oval in cross section and air sacs are collapsible and hence can serve to increase the volume of tidal air.

3. **Elimination of CO2:** In tissues CO2 diffuses about 35 times more rapidly than O2. Because of this, CO2 is much more likely to be eliminated from the body through the tracheal linings and integument than is O2 to be absorbed along the same routes. Thus, although most of the CO2 produced by respiration is eliminated via the tracheae and tracheoles, some of it may escape through the general body surface of soft bodied insects and the intersegmental membranes of hard bodied insects.

In some insects CO2 is not continuously eliminated through the spiracles, but in regular bursts, while O2 consumption remains constant. Between these bursts the spiracles remain fully closed or half closed. The spiracles open completely during a CO2 bursts. As oxygen is removed from the tracheoles and tracheae by respiration, at least a portion of the CO2 produced presumably goes into solution as bicarbonate in the haemolymph. A CO2 burst probably indicates the previous buildup of CO2 (in the haemolymph and tracheae) to a threshold above which complete spiracular opening occurs. The ability to release CO2 periodically allows an insect to keep its spiracles
partially or entirely closed most of the time and hence is thought to be an adaptation that favours the conservation of water by diminishing the rate of transpiration.

**Respiration in aquatic insects:**

Many insects spend all or part of their lives in an aquatic environment. These insects must either be able to utilize O2 in solution or have some means of tapping a source of undissolved O2 whether it be at an air-water interface or from aquatic vegetation.

1. **Use of dissolved O2 in water:** Aquatic insects with closed tracheal systems depend entirely upon the diffusion of dissolved O2 through the integument. These insects obtain O2 in a variety of ways. May fly and damselfly nymph possess tracheal gills, which are integumental evaginations covered by a very thin cuticle and are well supplied with tracheae and tracheoles. Other aquatic insects with closed tracheal systems possess spiracular gills or cuticular gills.

2. **Use of aerial O2:** Aquatic insects having open tracheal systems obtain O2 at the surface of water and for this they come at the surface of the water periodically. Some aquatic insects may remain submerged for an indefinite period of time and have certain structures that help them in obtaining aerial O2. These structures are as follows:
   - **Respiratory siphon:** eg Mosquitoes and *Eristalis*.
   - **Hydrofuge structures:** eg *Notonecta*.
   - **Air stores:** eg Many bugs and adult beetles.
   - **Physical gills:** eg Many aquatic insects.
   - **Plastron:** eg Aquatic beetles *Elimis*.
   - **Use of plant surface:** eg certain mosquito larvae, other flies, and some beetle larvae.

**Respiration in endoparasitic insects**

Most of the endoparasitic insects are parasitic only in the immature stages, eg parasitic wasps. The environment of these insects presents problems similar to those of the aquatic insects. In several insects, the tracheal system is nonfunctional and respiration is cutaneous, gaseous exchange occurring directly between the tissues of the parasite and body fluids of the host. Some endoparasitic insects have tracheal gills. The larvae of *Cotesia* (Hymenoptera, Braconidae) possess caudal vesicle which is an everted structure of the hindgut. The wall of the vesicle is very thin and is associated with the heart so that O2 passing in is quickly carried round the body. Others depend, at least partly, on aerial O2, obtaining it either by tubes or other structures that communicate with the tracheal system and that extend out of the host to the atmosphere.

**6. THE EXCRETORY SYSTEM**

In insects, the function of excretion is chiefly concerned with the elimination of several types of substances such as mineral salt and water, and products of the metabolism of nitrogenous substances, sulphur and phosphorus; certain complex
compounds that are produced incidentally as a result of certain accident or as a byproduct in case of certain chemical changes and the acids and alkalies. Thus, it is a process by which the internal environment of the insect is regulated at a constant level by removing surplus and injurious materials.

In general, the organs responsible for elimination of the substances, mentioned above are known as excretory organs. There are several types of excretory organs in insects chief of them are malphighian tubules.

1. The malpighian tubules

Malpighian tubules are found in all insects but are absent in Collembola and the family Aphididae of the order Homoptera. They are long, slender, blind tubules, which are often convoluted. They originate at the junction of mid and hind gut (the pyloric region) and have been regarded ectodermal in origin. But according to savage (1956) they are endodermal in Scistocerca gregaria.

These tubules in insects in general are free at their distal ends but in some insects the distal ends of these tubules is known as cryptonephridial condition that constitute cryptonephridial system in insects. All the lepidopteran and coleopteran insects have a cryptonephridial condition. The cryptonephridial condition helps in the conservation of water and other useful ions by absorbing them from the faecal matter.

On the basis of arrangement and their nature, Wigglesworth (1931) had broadly classified malpighian tubules system into 4-types viz. ABC and D. the type A is basic one and the remaining three BC and D represents the variations met within different insect orders. In the basic type (A) the tubues are fairly large; highly coiled and their distal ends float freely in the haemolymph. Oftenly the tubules are associated with alimentary canal and richly supplied with tracheoles and muscles fibers.

In the majority of Orthopteroid insects no visible difference exists in the appearance of malpighian tubules over their entire length. In the second type, the malpighian tubules differ from the first in that the distal ends of the tubules are attached to the rectal wall and are enveloped by a thin sheath. As remarked above, the tubules of this type have been termed as cryptonephridic or cryptosolenic and are found in Coleoptera and Lepidoptera. In Coleoptera, there exist no visible differentiation over the entire length but in Lepidoptera the malpighian tubules are clearly differentiated into two zones. The distal part is filled with a clear fluid and proximal part has solid particles. In the order hemiptera each tubule consist of two segments, an upper or distal containing 2/3 of the tubules, made up of granular epithelium containing clear fluid in lumen and a lower or proximal segment containing 1/3 of the tubule, in which the epithelium is almost free of granules and the lumen is filled with uratic spheres.

The number of malpighian tubules varies from group to group. The number of these tubules is 4 in Anoplura, Thysanoptera, Hemiptera, Diptera and Siphonaptera; 4-6 in Psocoptera and Coleoptera; 2-8 in Isoptera, and Lepidoptera, Mecoptera and Trichoptera have 6 malphighian tubules. In Dermaptera 8-20, in Ephemeroptera 8-100, in Odonata 50-200, in Orthoptera 30-200 and in Hymenoptera 6-20. In Mosquitoes the
number of malpighian tubule is five and in Coccoidea and parasitic Hymenoptera only 2. Further, in some insects for example in Gryllidae, all malpighian tubules coverage to open into a common urater. The malpighian tubules are white, yellow or cream coloured and they may have a smooth or beaded structure.

**Histology**

The malpighian tubules are composed of 2-8 cells and are of various shapes and sizes. They are either provided with distinct cell boundaries or are syncitial. The cells are either smooth, or have a brush or honeycomb border towards the lumen. The cell rest on a thin basement membrane covered by a peritoneal membrane occasionally containing fine muscle fibres which bring about the peristaltic movement of the tubules. The movement caused by the muscles of the tubules assures the mixing of the contents. The tubule carries the contents towards the hind gut for final disposal.

**Physiology of Nitrogenous Excretion**

Ammonia is the primary end product of nitrogen metabolism, but it is highly toxic except in extreme dilutions. Consequently ammonia is only excreted in any quantity by insects with an ample supply of water, such as those living in fresh water and others, like blowfly larvae, which live in extremely moist environments. Ammonia comprises a relatively large proportion of the nitrogen excreted by Periplaneta, which stores uric acid in the fat body.

For most terrestrial insects water conservation is essential and loss by excretion must be reduced to a minimum. Hence it is necessary to produce a less toxic substance than ammonia so that less water is required for its safe elimination. The substance produced is uric acid, which is in addition to being relatively harmless, is also highly insoluble. As a result it tends to crystallize out of solution and can be retained as a solid, non-toxic waste substance for long periods. Further, uric acid contains less hydrogen per atom of nitrogen than any other nitrogenous end product produced by animals and since hydrogen may be derived from water this means that less water is needed in its production.

Because of these various advantages, most insects excrete 80 ñ 90% of their waste nitrogen as uric acid, although it has the possible disadvantage of containing more carbon per atom of nitrogen than urea.

Uric acid is often present as the free acid, which, for instance, constitutes 80 ñ 90% of the uric spheres formed in the malpighian tubules of *Rhodnius*. In larval Tinea (Lepidoptera) ammonium urate occurs, while in the Meconium of Deilephila (Lepidoptera) a good deal of potassium urate is present. Sodium and calcium urates may also occur.

Other substances may occasionally from the bulk of the nitrogenous waste, reflecting the circumstances of the particular insect. Dysdercus (Heteroptera), for instance, excretes a great deal of allantion but no uric acid, although the latter is present in the haemolymph. Allantoic acid is often present in quantity in the Meconium of Lepidoptera and more nitrogen may be excreted in this form than as uric acid (Raxet, 1956). Urea is commonly present, but only in relatively small amounts.
Apart from these end products of metabolism, other nitrogen containing substances are sometimes present in the excreta. Thus in Glossina (Diptera), arginine and histidine from the blood of the host are excreted unchanged after absorption. These are substances with high nitrogen contents which would require a considerable expenditure of energy if they were to be metabolized along the normal pathways. Smaller amounts of other amino acids and proteins may be lost though not being fully resorbed in the rectum. Apart from ammonia, *Periplaneta* excretes some derivatives of tryptophan (Mullins and Cochran, 1973).

**Excretion from the Malpighian tubules**

The products of nitrogenous excretion are, in most insects, eliminated from the haemolymph via the Malpighian tubules. The movement into the tubules is probably passive, the rate depending on the size of the molecule and the rate of fluid secretion (Maddrell and Gardiner, 1974). As a consequence urea passes into the tubules more rapidly than uric acid. Since fluid secretion is an osmotic process dependent on the active movement of potassium, the outward movement of urea and uric acid are related to potassium excretion.

Subsequently, in the more proximal parts of the system, water and salts are resorbed to a greater or lesser extent and uric acid or a urate may precipitate out. In Rhodnius, and other insects in which the tubules have an anatomical differentiation, this process is initiated in the proximal parts of the Malpighian tubules, uratic spheres first appearing at the bases of the filaments of the brush border. In Carausius the bulk of the uric acid appears only in the rectum since the whole of the tubules are concerned with secretion, while in dipterous larvae uric acid may appear throughout the tubules, suggesting either a change in the direction of secretion by the cells or the interspersion of different types of cell throughout the tubule. The separation of the uratic spheres is accompanied by a change in pH from weakly alkaline to weakly acid. A continuous flow of water down the Malpighian tubules to rectum carries the uric acid with it, so that ultimately the nitrogenous waste is excreted with the faeces via the anus.

**Storage Excretion**

Waste materials may be retained in the body in a harmless form instead of being passed out with the urine. This known as storage or deposit excretion. It is observed in Collembolla, which lack Malpighian tubules, in the larva of Apis, where excretion would foul the cell in which it lives, and in embryonic insects, where normal excretion is not possible. In these instances uric acid accumulates in the fat body, although in the egg of Schistocera it is present in the yolk before the fat body has differentiated.

Although Periplaneta has Malpighian tubules they are not involved in the excretion of uric acid. Instead this accumulates in the fat body when there is ample nitrogen in the diet. The store is depleted if the insect feeds on the diet deficient in nitrogen and it is possible that symbionts are involved in the metabolism of the uric acid.
Even in insects which have normally functional Malpighian tubules, uric acid may accumulate in unspecialized cells in various tissues. It occurs, for instance, in the ordinary fat body cells of Culex (Diptera) and in the fat and epidermal cells of caterpillars. In these cases the uric acid may be the end product of metabolism of the individual cells. Subsequently, in the pupa, it is transferred to the Malpighian tubules and excreted with the meconium. Uric acid also accumulates in the epidermis of Rhodnius during molting; being removed after each moult is completed.

In Dysdercus permanent deposits of uric acid accumulate in the epidermis and contribute to the colour pattern of the insect. The progressive increase in uric acid throughout life accounts for the increase in the extent of the white markings in later instars of this insect. Similarly in Peiris (Lepidoptera) 80% of the uric acid produced during the pupal instar is stored, mainly in the scales of the wings.

Larvae of phytophagous Diptera accumulate calcospherites in the fat, while Rhodnius stores iron from the haemoglobin in the gut epithelium and bilin in the nephrocytes. Nephrocytes in general accumulate particles of colloidal proportions. The goblet cells in the mid gut of the caterpillars accumulate heavy metals as sulphides.

7. THE NERVOUS SYSTEM

The nervous system transmits electrochemical impulses from one part of the body to another, and functions as a connecting link between the sense organs and effector organs, thus acting as a coordinating centre.

Nerve cells

The nervous system is composed of nerve cells or neurons which are ectodermal in origin. The nerve cell consists of a cell body containing the nucleus and long cytoplasmic projections or axons which extend to make contact with other neurons. Frequently, the axons have branches and collaterals and end in a terminal arborisation. Nerve impulses are transmitted from one neuron to the next via axons. Part of each nerve cell is specialized for the reception of stimuli which initiate conduction in the axon. This is known as dendrite and it may arise directly from the cell body or represent the distal endings of an axon in which case there is no anatomical differentiation between axon and dendrite.
I. Based on their structure
1. Unipolar / monopolar: Have a single axon without collaterals and dendrites
2. Biopolar: Have either collaterals and dendrites in addition to axon
3. Multipolar: Neurons have an axon with several collaterals and dendrites.

II. Based on function: 3 kinds of neurons.
1. Sensory / afferent: Present just beneath the integument and associated with sensory organs. Carry impulses from sense organs to the central nervous system.
2. Motor / efferent neurons: Always unipolar / monopolar carry impulses from central nervous system to the organs.
3. Association / internuncial neurons: Associated in between sensory and motor neurons, usually present in ganglia, consists of axons of sensory neurons and soma of motor neurons. The transverse commissures are also formed with these neurons.

The points at which neurons receive information from or convey to another neuron is known as synapse. Synaptic gap is approximately 100\text{\textmu}A

Generally the nerve cells of insects are monopolar having only one axon. The peripheral sense cells are bipolar with a short distal dendrite receiving stimuli from the
environment and a proximal axon extending to the central ganglia. The hypocerebral ganglion and frontal ganglion have some cells with more than two axons and represent the multipolar cells.

The nervous system can be distinguished into three distinct parts viz., (1) central nervous system (2) sympathetic nervous system and (3) peripheral nervous system and all the three parts are connected with each other.

(1) Central Nervous System

It consists of an anterior median brain, located in the head above the alimentary canal, sub-oesophageal ganglion below the oesophagus and ventral ganglionated nerve cord situated in the mid ventral part of the body, in which the ganglia are united lengthwise by interganglionic connections.

**Fig. Central nervous system**

**Brain**: It is situated in the head, just above the oesophagus region and therefore, it is also known as supraoesophageal ganglion. It is always differentiated into three parts viz;

1. Protecerebrum.
2. Deutocerebrum.
3. Tritocerebrum.
(a) Protocerebrum: The Protocerebrum is the largest part of the brain and it represents a fused pair of preantennal ganglia. Normally, the optic lobe is not a part of the brain but in the adult stage it get associated with the protocerebrum. The important fibrous structures present in the protocerebrum are pons cerebaliis, corpus pedunculatum and corpus centrale. In addition to these fibre tracts, the two lobes are connected with the protocerebral commissural tract.

**Pars intercerebralis**

It is also known as Protocerebral Bridge. It lies in the dorsal and posterior part of the pars intercerebralis. It is composed of fibrous mass or neuropile mass. It has been regarded as the posterior dorsal commissure by C.B. Thompson (1913) but according to Snodgrass (1935) it is an association centre, since fibres enter it from many parts of the brain. Associated dorsally with pars intercerebralis are two masses of dorsal globuli cells, the neurite of globuli form the body of pars intercerebralis.

**Corpus Pedunculatum**

The corpus pedunculatum is situated in the dorsal part of the brain on either side of the pars intercerebralis. These are also known as mushroom bodies due to their appearance like a mushroom with stalked cap. The cap or calyx is composed of globuli cells where as the stalk is made up of nerve fibres. The fibres of stalk divide posterirly into inner and outer lobes. The corpora pedunculata are the largest and the most highly developed association centre in the brain of Pterygote insects and are one of the most conspicuous features of the internal cerebral structure. It is regarded as the centre of all activity i.e. the cyclic centre of the brain.

Between these two stalked bodies, there are a number of small lobes which are connected with one ocelli and are called the ocellar lobes. They give out the ocellur nerves. The ventral bodies are situated in the ventrolateral parts of the brain just above the deutocerebrum. They are united with each other by means of commissural tract. These ventral bodies are not universally present though they appear to be of large size in Coleoptera and Lepidoptera.

**Central body**

The central body lies in the centre of anterior portion and is made up of compact mass of the nerve fibres which collectively from an oval mass. Although it is not directly connected with the neurons but it has been regarded as another important centre of association between the terminals of the fibres from all other parts of the brain.

**Optic lobes**

These are the largest nervous bodies associated with the brain. Originally they are separated from the protocerebrum. In adult insect they get so closely associated with the protocerebrum. They are very complex in structure and contain the optic ganglion. According to the distribution of the nerve tracts, optic lobe is divided into three distinct region viz.,
(1) **Periopticon**: This is the ganglionic plate which is nearest to the layer of ommatidia. Periopticon is connected with epiopticon by crossing fibres. It is these crossing fibres which form the outer chiasma.

(2) **Epiopticon**: It forms an external medullary mass. Sometimes it is also called as medulla extrema. It is connected with periopticon by means of the outer chiasma.

(3) **Opticon**: It is subdivided into 2 fibrous masses which are connected to fibres that cross with those from epiopticon to form the inner chiasma. Within its substance there are 4 layers of stratified fibres. It has an elaborate fibre connections through the optic tract with various parts of the brain.

(b) **Deutocerebrum**: These are situated as prominent swellings on the ventral aspect of protocerebrum. The deutocerebrum consists of fused paired lobes derived from the antennary segment containing the centres of the antennal nerves. The two deutocerebral lobes are joined together by means of deutocerebral commissural tract. Antennal lobe is connected with corpus pedunculatum of its side by corpus central, forming optico-olfactory-chiasma.

(c) **Tritocerebrum**: This is the smallest part of the brain and is divided into two separate lobes. These two lobes are joined to each other by means of a tritocerebral commissure. Embryologically the tritocerebral lobes of the brain represent the first paired ganglia of the primitive ventral nerve cord; the union with the brain is secondary. An important feature of tritocerebral ganglion is that it is connected with stomodaeal nervous system. The main nerves arising from tritocerebrum are the frontal ganglion connectives and the labral nerves.

**Sub oesophageal ganglion**

The sub oesophageal ganglion lies below the oesophagus. It is formed by the fusion of ganglia of primitive gnathal segments. It innervates the mouth parts viz. mandibles, hypopharynx, maxillae, labium, salivary duct and the neck muscles. The longitudinal nerve tract associated with the suboesophageal ganglion contains the connecting fibres between the sensory centres of the body parts.

**Ventral nerve cord**

It consists of a series of ganglia, which are connected together by means of a pair of connectives thus forming a longitudinal trunk or chain. It starts from posterior border of the sub oesophageal ganglion and lies on the ventral part of the floor of the thorax ans the rest are abdominal lying in the abdomen. From each thoracic ganglion two pairs of main nerves are given out, of which one supplies the general musculature and the other to the muscles of the leg. An additional pair of nerve is found in the pterothorax which controls the wing movement.

The number of abdominal ganglia varies, from order to order. Generally the first abdominal ganglion fuses with metathoracic and the terminal ganglion is always a composite structure formed by the fusion of at least 3-primitive ganglia. A pair of nerves supplying to muscles of its segment is generally given out from each abdominal ganglion.
**Structure of ganglion**

Histologically all the ganglia of the ventral nerve cord are similar. Each ganglion is invested in a sheath - the neurilemma. Neurilemma is composed of two layers, (1) the outer non-cellular neural lamella and (2) the inner cellular perineurium. The neural lamella is continuous over the connectives, the nerves and all the ganglia. The neural lamella is secreted by the perineurium cells. The neural lamella contains neutral mucopolysaccharides and collagen fibres and is primarily a supporting structure. The perineurium helps to form a physiological barrier between the ionic and other constituents of the haemolymph and to those of nervous tissue.

The cortex of the ganglion if formed by a group of monopolar neurons which are of two types i

1. Ordinary neurons and.
2. Neurosecretory neutrons.

The latter perform a variety of functions in different insects. The central part of the ganglion is occupied by the neuropile mass.

In each ganglion there are six principal groups of nerve elements.

1. The cell bodies and roots of the motor fibres of the lateral nerves;
2. The roots of the sensory fibres of the lateral nerves;
3. The cell bodies and fibres of the intraganglionic association neurons,
4. The cell bodies and collaterals of the interganglionic association neurons,
5. The cell bodies and roots of the motor fibres of the median nerve and
6. The roots of the sensory fibres of the median nerve.

(2) **Sympathetic Nervous System**

It can be divided into (1) stomodaeal nervous system, (2) ventral sympathetic nervous system and (3) caudal sympathetic nervous system.

i. **Stomodaeal nervous system**

It is also known as stomatogastric nervous system or anterior sympathetic nervous system. It lies on the dorsal surface of the foregut and consists of frontal, gypocerebral and visceral or stomachic ganglia and recurrent nerve. It is connected with the brain directly through nerves and innervates the foregut, midgut, heart, aorta, corpora allata and certain other tissues of the regions.

Cazal (1948) has described various type of arrangement of structures in this system. Two types of arrangements are very common in the Pterygota. The one constant feature of this system is the presence of a small triangular ganglion situated on the dorsal wall of the oesophagus, a short distance in front of the brain. This is the frontal ganglion. Anteriorly it gives off a frontal nerves which passes to the clypeus. It is also connected with tritocerebral lobes by a pair of frontal ganglion connectives. Posteriorly the frontal the frontal ganglion gives off a recurrent nerve which runs along the mid dorsal wall of the oesophagus, and expands into a hypocerebral ganglion. The hypocerebral ganglion is either absent or only occasionally present in Lepidoptera.

The hypocerebral ganglion in a number of insects lies in between the corpora cardiac and either it is closely associated or connected with the nerves. From the
hypocerebral ganglion, the recurrent nerve passes backward either as median or as paired lateral nerves to the hinder region of the foregut. On the foregut it terminates in a ventricular or stomachic ganglion which innervates the posterior part of the foregut. Behind the brain pair of oesophageal ganglia is present on the dorsolateral aspect of oesophagus. These ganglia are also known as corpora cardiaca and are connected with hypocerebral ganglion and protocerebrum. The corpora cardiaca include both nervous and endocrine cells. The corpora cardiaca are also connected with non-nervous epithelioid glandular bodies, the corpora allata by the nervi coporis allati. In the Cyclorrhaphan Diptera i.e. Fleshfly, Housefly, blowfly larvae, hypocerebral ganglion, corpus cardiacum, corpus allatum and prothoracic glands fuse together to form a composite ringshaped structure known as Weismann’s ring encircling the aorta. This system is variable and reduced in Apterygota but a frontal ganglion is always present.

ii. **Ventral sympathetic nervous system**

Zawarzin (1924) has mentioned that in a typical condition this system consists of a pair of transverse nerves lying in association with each nerve cord ganglion. There is a median longitudinal nerve which connects the transverse nerve with the proceeding ganglion. These transverse nerves innervate the spiracles of their segment. The transverse nerves along their course give out one or more minute ganglionic swellings. These swellings, store and release neurosecretory material and are called perysympathetic neurohaemal organs.

iii. **Caudal sympathetic nervous system**

From the last ganglion of the nerve cord in the abdominal region, nerves are given to the reproductive organs, posterior portion of the alimentary canal, and the malpighian tubules which constitute the caudal sympathetic nervous system.

3. **Peripheral Nervous System**

It consists of all the nerves radiating from the ganglia of the central and sympathetic nervous system. This system comprises of the distribution of all the nerves in the body there are two types of sensory neurons in the peripheral system (1) bipolar neurons formed from the hypodermal cells and connected with the cuticular sensory hairs and (2) the multipolar neurons which are present just below the integument.

**Modification of Nervous System**

Various modifications have taken place in the nervous system of insects. These modifications are correlated with the degree of development of the special instincts and activities e.g. there are structural differences in the brain of drone, worker and queen honey bees which are correlated with activities of these three forms. Similarly the optic lobes are developed in proportion to the size of the eyes, and antennary lobes to the development of the antennal sense organs. Even in the same order there are differences of development of the brain.

Varying degrees of fusion of the thoracic and abdominal ganglia are to be seen by a comparative study of the nervous system of different insects. The most generalized type
of ventral nerve cord is found in the Thysanura, many larvae and lower Pterygotes. In these forms there is:
1. A suboesophageal ganglion.
2. 3- thoracic ganglia and
3. 8- Abdominal ganglia.
4. There is some concentration in Mecoptera, Trichoptera, Hymenoptera and most of the Orthoptera, where the metathoracic ganglion generally fuses with the first three abdominal ganglia and the 7th one is along with the following ganglia forms a composite structure. In many Heteroptera, the suboesophageal and prothoracic ganglia are distinct but all other have fused together. There is only the suboesophageal ganglion and a single compound thoracico abdominal-ganglion in many sternorrhynchan-Homoptera and higher Diptera. Similarly in Coccoidea, Aphidoidea and some Coleopteran larvae, all the ventral ganglia including the suboesophageal, are united together forming a single ganglionic mass.

4. Physiology of the nervous system

Stumuli may be perceived in a number of ways depending on the nature of the stimulus and the characteristics of sense organs. The energy received by the sense cell as a result of stimulation is then transformed (transuded) to electrical energy and this leads to the production of nerve impulse travels along the nerve axon to the CNS.

Reception and transduction of the stimulus:

Mechanical stimuli appear to cause some mechanical distortion of the receptor dendrite. Chemical stimuli may act in a number of unknown ways, but it is suggested that sugars form complexes with specific receptor molecules at the receptor site.

The visual perception involves the breakdown of some light sensitive pigment. In all these the energy received by the sense cell is transformed to electrical energy which ultimately produce nerve impulse.

The stimulus received by the dendrite of the sense organ affects the permeability of its plasma membrane so that it becomes depolarized. The potential produced in the dendrite by this depolarization is called receptor potential. The receptor potential is graded according to the strength of the stimulus, a weak stimulus produces a weak receptor potential.

The receptor potential leads the development of generator potential, which is believed to arise in the region of perikaryon. The generator potential is also graded and it is exceeds a certain threshold value it triggers off nerve impulse in the initial segment of the axon.

In the resting (unstimulated) state of an axon, there is an excess of sodium ions external to the membrane and an excess of potassium ions in the axon cytoplasm A Donnan equilibrium is set up across the plasma membrane with a high concentration of potassium ions inside and high concentration of chloride ions outside. As a result of the equilibrium the inside of the axon becomes negatively charged with respect to the outside.
and potential produced in this way as known as resting potential or membrane potential. Normally nerve axons have a resting potential of about 70 mv.

Generator potential produces change in the permeability and leads to action potential. The first change is the increase in permeability to sodium, as a result of which sodium ions flow into the axon. This produces positive charge inside the membrane. This represents the rising phase of the action potential. Adjacent areas of axon are negatively charged, so a current flows in a local circuit away from the point of depolarization. When this current reaches an area of resting membrane it produces depolarization. It causes the increase in the permeability to sodium producing positive charge inside the membrane. In this way a wave of increased permeability, and hence a nerve impulse, is propagated along the axon.

The period of permeability to sodium is short lived and is followed by the increase in permeability to potassium, as a result of which potassium flows out of the axon. This again becomes negatively charged on the inside. This is called repolarisation or the falling phase of the action potential. Thus the total duration of the spike or action potential is very brief, only one or two milliseconds.

After the potential has returned to its resting level it over shoots slightly because of the high permeability to potassium. This is known as positive phase.

After positive phase the potential again swing back again to a level slightly higher than normal.

![Diagram of the changes in potential difference across the plasma membrane of an axon occurring during the passage of an impulse.](image)

**Fig. 1** – Diagram of the changes in potential difference across the plasma membrane of an axon occurring during the passage of an impulse.

This phase is called, the negative after potential. This results from the potassium which is released in the falling phase of action potential, accumulating just out side the axon membrane so that the tendency for potassium to move out is reduced. In insects the negative after potential is short lived as compare with vertebrates.
With the disappearance of the negative after potential, though the resting potential is achieved yet the resting ionic status is not established. It is achieved by the action of Na\(^+\) pump mechanism in which Na\(^+\) begins to come out from inside the membrane creating negativity again. The K\(^+\) ions now diffuse back to the interior. In this way the normal ionic status is established which is called reorientation.

**Transmission at the Synapse**

When an impulse has passed along an axon it must cross a synapse in order to affect a response in another neuron or an effector. This effect may be excitatory or inhibitory.

Transmission across the synapse involves a chemical which is stored in the presynaptic fiber in the synaptic vesicles. On the arrival of an impulse the membranes bounding the vesicles fuse with cell membrane so that the transmitter substance is released into the synaptic gap. The transmitter substance becomes attached at receptor sites on the post synaptic membrane which become depolarized if the synapse is excitatory or hyperpolarized if is inhibitory. The magnitude of depolarization or hyperpolarization is proportional to the number of vesicles released. As soon as the post synaptic membrane is depolarized or hyperpolarised the transmitter substance is hydrolysed by an appropriate enzyme.

At excitatory synapses within CNS the chemical transmitter is acetylcholine, but at nerve /muscles junctions this is replaced probably by L \(\alpha\)-glutamate. Acetylcholine is destroyed post synoptically by the enzyme acetylcholine esterase; it is synthesized in the presynaptic fiber in a two stage reaction, the second involving the acetylating of choline from acetyl co enzyme A in the presence of choline acetylase.

An inhibitory synapses \(\gamma\)- amino butyric acid is probably the transmitter which leads to hyperpolarization of the postsynaptic fiber. Other transmitter substances may also occur in specific neurons. For example, monoamines are present in parts of the brain and octamines produced by some fiber in the thoracic ganglia of Schistocerca.

**Role of Brain**

The role of brain is not well understood. An important function of brain is certainly the integration of inputs from various sensory systems so that appropriate behavior patterns are expressed. The appropriate motor systems are then activated via inter neurons from brain to segmental area.

**8. THE SENSE ORGANS**

The sense organs or receptors are those structures whereby the energy of a stimulus arising outside or, less obviously, within the insect, is transformed into a nervous
impulse which, after transmission to one of the control ganglia, usually result in a change in the behavior of the insect or in the maintenance of some exciting activity.

The majority of sense organs are composed of two types of cells; receptor cells and accessory cells. Receptor cells are usually bipolar neurons that perform the actual detection of stimuli and generation of the nervous impulse. Accessory cells surround the receptor cells and are usually involved with or actually secrete the specialized cuticular structures that make up the most obvious parts of the sense organs.

According to the broadest aspects of their functions; receptors may be divided into two classes.

(a) **Exteroceptors**: perceiving stimuli which arise in the external environment.

(b) **Interoceptors**: which are excited by stimuli arising within the body.

Insect sense organs are divided into five main headings as per the functions.

1. **Mechano receptors**
2. **Auditory organs**
3. **Chemo receptors**
4. **Temperature and Humidity receptors**
5. **Visual organs**

(1) **Mechanoreceptors**: Mechanoreceptors are excited by processes involving the mechanical deformation of some part of the receptor or from the impact of vibrations borne through air, water or sub stratum.

Three main structural types of mechano receptors may be distinguished:

(I) **Articulated sensory hairs**: Each sensory hair comprises the trichogen and termogen cells which secreted the hair and its socket.

(II) **Campaniform sensilla**: These are comparable in structure to the innervated hairs. The distal process of the sensory neuron forms a rod like structure which is inserted into or touches the cuticular dome. This type of sensilla found in cerci, wings, basal parts of appendages etc.

(III) **Chordotonal organs**: These are usually compound structures composed of the number of specialized sensilla.

(2) **Auditory Organs**: These are the sound receptor organs. Three types of sound receptors may be recognized

(I) **Tympanal Organs**: These are specialized chordonotal organs consisting of a thin area of cuticle, the tympanic membrane. It is generally backed by an air sac so that it is free to vibrate. These organs are found in legs, thorax, abdomen and wings.

(II) **Auditory hairs**: Hairs on cerci of orthoptera act as displacement receptors of sound vibrations having a frequency of less than about 3,000 cycles per second. The impulse in the cercal nerves synchronize with the frequency of the stimulus.

(III) **Johnston’s Organs**: It is found in adults of all insects except in Collembola and Diplura. It is situated in the second segment of the antenna with its distal insertion in the articulation between the second and third segments. Johnston’s organ perceives monuments of the antennal flagellum. In different insects its function is
different. In Calliphora it acts as a fly speed indicator and controls the speed of the flight, Notonecta it is concerned with the orientation in the water.

(3) **Chemoreceptors:**
In insects the stimulation by chemicals occur by three methods:

(1) Olfaction or Smell: - Smell is defined as chemo stimulation by compounds in very low concentration but volatile at physical temperatures.

(II) Gestation or Taste: - Taste is the chemo stimulation by higher concentration of liquid that are not volatile at physical temperatures.

(III) Common chemical sense: - In addition to smell and taste, insects have third method of detecting chemical stimuli called common chemical sense. This is the response of an insect (always avoiding reaction) to high concentration of noxious chemicals.

The chemo sensilla of taste are common on mouth parts, especially the palps but they have also been identified on the antenna (Hymenoptera), tarsi (Diptera and many Lepidoptera).

The sensilla of smell are located on antennae.

(4) **Temperature and Humidity receptors:** Insects are able to monitor the amount of water vapors in the surrounding air. Tribolium castaneum for example has humidity detectors on the antennae.

Parasitic insects such as Rhodnius and mosquitoes which feed on mammalian blood and are able to orient to heat source. In these insects antennae and legs probably carry specialized sensilla in the form of thick walled hairs. Temperature perception is least understood in insects.

(5) **Visual organs:** Responses to light are mediated by
(a) Dermal light sense: -
Several insects (Lepidopterous larvae, Periplaneta, Tenebrio larvae) react to light even after the eyes and ocelli have been removed or covered with opaque material. The general body surface appears to be sensitive to light and localized receptors have not been identified.

(b) Dorsal Ocelli: -
The dorsal ocelli are innervated from the ocellar lobes which are located in the protocerebrum, between the mushroom bodies. When typically developed they are three in number disposed in a triangle.

In Plecoptera they are forned on the frons, while the paired ocelli are located in the suture between that region and the vertex. In more specialized orders the ocelli are usually situated on the vertex.

In blattoidea they are either absent or, with very few exceptions represented only by degenerative structure known as fenestrae.

The dorsal ocelli vary greatly in structure in various insects, but exhibit certain common essential features and following parts can be distinguished.
(a) Cornea:
   It is part of cuticle which is arched or raised to form the external investment of
   the ocellus. In this region the cuticle is transparent.

(b) Corneagen layer:
   This layer is directly continuous with the hypodermis. This layer have colour
   less transparent cells.

(c) The Retina:
   The retina is composed of visual cells which are sensory neurons which are
   connected, with a fiber of the ocellar nerve. The visual cells are associated
   together in groups of two, three or more cells, each group being termed a
   retinula, which surrounds a longitudinal optic rod or rhadom.

(d) Pigment cells:
   In some ocelli there is access any cells loaded with pigment situated between
   the retinulae.

   The function of the dorsal ocelli is not entirely clear. Though the lens is optically
   capable of forming an image, it does so at a level for below the retina and form perception
   is therefore impossible.

(I) Lateral Ocelli (Stemmata)
   The lateral ocelli are with very few exceptions, the only eyes present in
   insect larvae. They are located on the sides of the head. The number is not always
   constant in the same species in some group there is a single ocellus present on
   either side, while in others there may be six, seven or more ocelli. The lateral ocelli
   differ from the dorsal ocelli in the facet.
   (a) They are innervated from the optic lobes of the brain.
   (b) The refractive body may sometimes be developed beneath the corneal lens.
   (c) The pigment granules are sometimes absent.

(II) Compound Eyes
The compound eyes are formed of aggregations of separate visual elements known as omatidia. Each ommatidium corresponding with a single facet of the cornea. Compound eyes are also innervated from the optic lobes of the brain. The number and size of the facets of the compound eye vary within wide limits. The ant *Ponera punctatissima* each eye is composed of a single facet. According to Ford there are 6-9 facets in the same caste of *solenopsis fugax*, while among other ants the number varies between about 100 and 600 in the workers, 200 and 830 in the females, and between 400 and 1,200 in the males.

In *Musca* the eye consists of about 4,000 facets.
In some *Lepidoptera* the eyes consist of 12,000 to 17,000.
In *Odonata* it is between 10,000 to 28,000 or more.
In most insects the facets are closely packed together and assume a hexagonal form, but in some instances, where they are fewer in number and less closely packed they are circular.

**The structure of an Ommatidium**

The structure of ommatidia varies in different insects but in all cases the differences are modifications of a common type the various parts of compound eyes are described below.

(I) **The Cornea**
The cornea is the transparent area of cuticle forming the facet or lens of an ommatidium and is often more or less biconvex in form. It is cast off during each act of ecdysis.

(II) **The Corneagen Layer**
The part of the hypodermis which extends beneath the cornea is known as the corneagen layer. It consists of two cells which in some insects, are only to be detected with difficulty. In other cases they are wanting and in these instances the cornea is secreted by the outer ends of the cells of the crystalline cone.

(III) The crystalline cone cells
Beneath the corneagen layer of the cornea, as the case may be; there is a group of four cells which in the eucone eyes secrete a transparent body termed the crystalline cone. The nuclei of these cells are sometimes known as the nuclei of simper.

(IV) The primary iris cells
These are densely pigmented cells which are disposed in a circle surrounding the cells of the crystalline cone and the corneagen layer.

(V) The Retinula
The retinula forms the basal portion of an ommatidium and is composed of a group of usually seven pigmented visual cells, each of the letters being continuous with a post retinal fiber. The visuals cells collectively secrete an internal optic rod of rhabdom and the portion of the latter contributive by each cell is termed a rhabdomere. Each rhabdomere is stated to exhibit an extremely fine fibrillar structure.

(VI) The secondary iris cells
These are commonly elongated pigment cells which surround the primary iris cells and the retinula, thus serving to isolate an ommatidium from its neighbors.

The types of compound eyes:
The four types of compound eyes described:

(VII) Eucone eyes
In this type each ommatidium contains a true crystalline cone, which is a hard refractive body formed as an intracellular product of the cone cells. E.g. Thysanura, Lepidoptera, Orthoptera, Odonata, Ephemeroptera, Trachoptera, Hymenoptera, Chrysophidae, certain of the Hemiptera & in the Cicindelidae, Carabidae, Dytiscidae and Scarabididae among Coleoptera.

(I) Pseudocone eyes
In this type there is no true crystalline cone and the four cone cells are filled with a transparent semi liquid material which lies in front of the nuclei. E.g. Brachycera and Cyclorrhapha among Diptera.

(II) Acone eyes
In this type there is a group of elongate, transparent cone cells but the latter do not secrete any kind of cone whether crystalline or liquid. E.g. Dermaptera, Hemiptera, certain of the Diptera, Nematocera and in the Staphylinidae, Histeridae, Silphidae, Coccinellidae and Curculionidae among Coleoptera.
(III) Exocone eyes
In this type the crystalline cone is replaced by a cone of Extracellular cuticular origin which appears as deep in growth from the inner aspect of the corneal facet, in front of the unmodified cone cells. E.g. Dermestidae, Elateridae, Byrrhidae and Cantharidae.

9. REPRODUCTIVE SYSTEM AND ITS PHYSIOLOGY
The male reproductive system includes the following organs:-
(i) Paired testis
(ii) Paired Vasa differentia and seminal vesicles.
(iii) Median ejaculatory duct and aedeagus
(iv) Accessory glands.

The testes lie above or below the gut in the abdomen and are often close to the mid line. Each testis consists of a number of testis tubes called follicles bound together by connective tissue sheath. From each follicle a fine and short vas efferent connects with the vas deferens which is muscuarised. The vas deferens runs backwards to lead into distal end of the ejaculatory duct. The ejaculatory ducts are separate. The cases as in Acriditidae, the seminal vesicles are separate. The ejaculatory duct leads to aedeagus. Where spermatophore is produced, the ejaculatory duct may be divided into specialized regions. The accessory glands may be endodermic (ectodermic) or mesodemia in origin and are connected with either the lower part of the vasa deferentia or the upper end of the ejaculatory duct. These glands produce a variety to facilitate sperm transfer. Some secretions may increase egg production or decrease receptivity of the female.

The formation of spermatozoa from germ cells is called spermatogenesis. At the distal end of each testis follicle is the germarium in which the germ cells divide to produce spermatogonia. As more spermatogonia are produced they push these which develop earlier down the follicle. Below germarium these zones of development are commonly recognized. These are (i) zone of growth (ii) zone of maturation and (iii) Zone of transformation.

As each spermatogonium moves proximally into in to the zone of growth. If becomes enclosed within a layer of the somatic cells forming a cyst. The spermatogonia enclosed in the cyst divide and increase in the size and now called spermatocytes. The spermatocytes move to the Zone of maturation where they undergo two meiotic divisions so that from each spermatocyte four haploid speratids are formed. These spermatids move to the zone of transformation where they develop into flagellated spermatozoa. At this time the cyst flagellated spermatozoa. At this time the cyst wall is ruptured but the sperms are held together by a gelatinous cap with is lost as the sperms enter the vasa differentia.

The formation of spermatozoa from spermatids is called spermogenesis. The mature sperm in most insects are filamentous in from about 300um long and less than
one micron in diameter. The head and tail of the sperm are of the same diameter approximately. The cell wall is three-layered the greater part of the head is occupied by the nucleus. In front of the nucleus is acrosome occupied by which is the egg, in Neuroptera and some other orders acrosome is absent. When the sperm is attached to egg the acrosome is dissolves the egg membrane thus permitting sperm entry. Immediately behind the nucleus there is the axial filament or axoneme. It consists of two central tubules with a ring of nine doublets and nine accessory tubules the number of doublets and accessory tubules may vary from insect to insect but the accessory tubules are absent in Collembola. Mecoptera and Siphonaptera. It is presumed that the axial filament caused undulating movements of the tail which derive the sperm forwards.

The female reproductive organs of insects are:-
(i) Paired ovaries
(ii) Paired lateral and median oviduct
(iii) Genital chamber and vagina
(iv) Accessory glands.

![Female reproductive system](image)

The ovaries lie in the abdomen above or lateral to the gut. Each ovary consists of a number of egg-tubes called ovarioles comparable with the testis follicles in the male. From each ovary a lateral oviduct arises and both joins to from a median oviduct opening posteriorly into a genital chamber, sometimes the genital chamber form a tube, the vagina and this is most of the females a spermatheca is present which serves for the storage of sperms. The spermatheca opens into the genital chamber in most of the females a spermatheca is present which serves for the storage of sperms. The
spermathea open into the genital chamber independently in lower orders, as in Orthoptera but where the genital chamber forms a vagina it opens into vagina as in Lepidoptera. The accessory glands arise from genital chamber or vagina but in Acrididae they are simply anterior extention of lateral oviducts. Often the glands produce a substance or attaching the eggs to the substratum hence they are also called glands these glands also secrete forthy secretion which from egg pods of grasshoppers and gelatinous sheath of Chironomus eggs. The accessory glands produce silk which form the cocoon in each eggs are laid.

Each ovariole consists of germarium, vitellarium and pedicel at its terminal end each ovariole has a filament. The filaments of the ovarioles unite together to form a suspensory ligament. The ligment is attached to the body wall or to dorsal diaphargam thus help the ovaries to remain suspended at the proper place. The number of ovarioles varies with the insect. In aphid only one, in tsetse fly 2 and in some species of temites the number is more than 2000.

Germinarium- this is the anterior most region below the terminal filament containing primordial or undifferentiated cells. These give rise to three types of cells

(i) germ cells developing into oogonia and finally into oocyte or egg cell
(ii) nutritive nurse cells or trophocytes and
(iii) Follicle cells or oocytes

Vitellarium - It occupies the major part of the ovariole and contains large number of oocytes (which finally form ova or eggs) in different stages of development in the anterior of vitellarium the nurse cells and oocytes remain mixes up and assume an axial position but the follicle cells take the peripheral position in the posterior region. Oocytes are enclosed by the follicle cells to from a definite Sac. The nurse cells or trophocytes absorb the nutrients from the haemolymph through the follicle cells and transit them to oocytes. The follicular cells secrete the follicular cells and Trans it them to oocytes. The follicular cells secrete the material which forms the egg shell. The follicular cells provide nutrients to oocytes in insect where nurse cells are wanting.

Pedicel - The pedicel or stalk of the ovariole is the short duct communicating the egg tubes with lateral oviduct.

In insects there are two broad catagories of ovarioles based on the presence or absence of nutritive cells.

(I) Panoistic- in which the nutritive cells are absent and oocytes are nourished by follicular cells. This type is regarded as a primitive and is found in Diptera, Orthoptera, Isoptera, and siphonaptera.
Meroisitc - in which nurse cells or trophocytes are present. This is again divided in two categories i (a) Acrotrophic, in which nutritive cells are crowded at the apex of each ovariole sometimes protoplasmic connections extend from the nutritive cells to the developing oocytes; through this connection nourishment is transmitted. This type of arrangement is found in many Coleoptera and Heteroptera. (b) Polytrophic i in which nutritive cells are present and alternate with oocytes. This type of ovarioles is found in Neuroptera, Hymenoptera, Coleoptera, Diptera and Lepidoptera.

The developmental phenomenon in which the primordial cells in the ovariole pass through different stagensis.

The primordial cells in the ovariole divides to give raise one oocyte. Trophocytes (nutritive nurse cells) and follicular cells. The oocytes at the expenses of the secretion provided by the nutritive cells and in due course of time become surrounded by follicular cells the oocyte proceeds backword in the growth and enlarges in size. The nucleus of oocyte grows into enormous size and is often called as germinal vesicles in most insects. The maturation division is not complete in oocyte while in ovariole but in some insect like Bed bug maturation division is completed in the ovary.

The deposition of yolk in the oocyte is called vitellogenesis. It occurs in the more proximal parts of the ovariole and it results in a very rapid increase in size of the oocyte. When vitellogenesis is completed then a vitellin membrane is formed round the oocyte.
The part of the shell secreted by the follicle cells is known as chorion. The chorion typically consists of two layers. An inner endochorion and an outer the exochorion. First in the production of endochorion, a polyphenol is secreted in droplets over the viteline membrane. This is followed by a protein which subsequently becomes fanned and resistant due to the addition of polyphenol layer over the protein. Then amber i coloured layer is produced by the addition of oil to the fanned protein. The exochorion is added during a second phase of secretion by follicle cells first a layer of soft lipoprotein is added to the outside of the endochorion. Subsequently a uniform thin layer of resistant lipoprotein is added to complete the chrorion.

In some insects the sperms are enclosed in a special structure called spermatophore, which may be formed sometimes before copulation or more often, as copulation proceeds.

Spermatophores are not produced by males of many species of endopterygotes especially higher Diptera.

According to Gerber (1970) these are four general methods of spermatophore formation which form a distinct evolutionary series. In the most primitive method (first male- determined method ) found in many orthopteroid species, the spermatophore is complex and formed either at the anterior end of the ejaculatory duct or within the male copulatory organ. In the second male i determined method, the spermatophore is less complex and is formed within a special spermatophore sac of the copulatory organ. Rest of the two methods are female i determined in the first male accessory gland secretions are poured directly into the vagina or bursa either before or after transfer of sperms the sperms are encapsulated in the secretion. The spermatophore produced by the second method is the least complex. In this method male accessory glands produce does not encapsulate the sperm but becomes harden to form a mating plug which prevents backflow and loss of semen, it also prevents further mating. this method is seen in mosquitoes, honeybee and some Lepidoptera , Gerber (1970) speculates that the next step in the evolutionary sequence would be complete loss of the spermatophore and concurrently , the development of more elongate penis for depositing sperms close to spermatheca.

Viviparity is unusual type of development where the female insects instead of laying eggs. Produce either larva of nymphs. It can be grouped into 4 main Categoricals.

(i) Ooviviparity - Whrer the eggs are retained in the genital tracts so that are laid. The embryos have reached the advanced stage of development with the result that the larvae hatch immediately after oviposition. This is found in Cimex and some Diptera.

Adenotrophic Vivparity - Where eggs are retained in enlarged Vagina (uterus) the embryo develops inside eggs and larva on hatching is retained.
in the uterus where it is nourished by secretion of accessory glands modified into milk glands. The larva when fully developed is laid outside for pupation. This type is found in Glossina and pupiparous Diptera.

(ii) Psudoplacental Viviparity- Where eggs. Being devoid of chorion and yolk, are provided with special structures called pseudoplacenta formed by the embryonic or oatmeal tissues. In the initial stages the egg is nourished inside the ovariole by a single nurse cell. As the embryo advance in age pseudoplacentae are formed larva derives nourishment through theses these structures. The is found in Aphidiate.

(iii) Haemocoelous Viviparity- Where the development of embryo occurs in the mother, it is found in order Strepsiptera. In this type the oviducts of females are absent and the mature oocytes escape into the heemocole by the rupture of ovarian walls. The sperms enter the haemocole through the genital canal for fertilization.

Sometimes an egg instead of giving rise to a single larva may produce two or more this process is called polyembryony. It is a regular phenomenon in endoparasitic insects.

Some insects species capable of producing either the eggs or larval forms parthenogenetically. This mode of reproduction by the immature forms before attaining the adult stage is paedogemesis.

The development of egg without being fertilized is known

The male reproductive system includes the following organs:-

(v) Paired testes
(vi) Paired Vasa differentia and seminal vesicles.
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![Fig Male reproductive system](image)

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The testes lie above or below the gut in the abdomen and are often close to the mid line. Each testis consists of a number of testis tubes called follicles bound together by connective tissue sheath. From each follicle a fine and short vas efferent connects with the vas deferens which is muscarised. The vas deferens runs backwards to lead into distal end of the ejaculatory duct. The ejaculatory duct is often are dilated to form seminal vesicles are separate. The cases as in Acriditidae, the seminal vesicles are separate. The ejaculatory duct leads to aedeagus. Where spermatophore is produced, the ejaculatory duct may be divided into specialized regions. The accessory glands may be academia (ectodermic) or mesodenia in origin and are connected with either the lower part of the vasa deferentia or the upper end of the ejaculatory duct. These glands produce a variety is to facilitate sperm transfer. Some secretions may increase egg production or decrease receptivity of the female. The formation of spermatozoa from germ cells is called spermatogenesis.

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10. METAMORPHOSIS

Insects like other Arthropods attain their maximum size by undergoing a succession of moults or ecdyses. The number of moults through which an insect passes is fairly constant for a species. The form assumed by the insect between any two ecdyses is termed as instar. Thus the life history of insect is made up of succession of instars culminating in the adult form. In many of the simple and generalized insects, the several instars are very similar to one another and only differ from their appropriate adults in the absence of wings and the incomplete development of their reproductive system. However, in the majority of the winged insects the adult is in sharp contrast to the wingless young stage. It is these forms that are said to undergo metamorphosis. It is thus clear that the term metamorphosis relates to the development of these insects in which the young stage is completely different in form, size and structure from the adults.

During larval development, there is usually no marked changing body from, each successive instar being essentially similar to the one preceding it, but the degree obtain from last instar to the adult varies considerably and may be very marked. This change is called metamorphosis. In physiological terms, it is a change which accompanies a moult in the absence of juvenile hormone. According to Highnam and Hill (1969) the overall change in form between the first larval instar and the adult is called metamorphosis.

Types of Metamorphosis

The developmental process by which a first instar immature stage is transformed into the adult is called metamorphosis, which means literally change in the form. Types of metamorphosis depending upon the degree of metamorphosis. The insects may be grouped as ametabolous, hemimetabolous or holometabolous.

1 Ametamorphosis: Apterygote insects like silverfishes do not undergo any change in form; the immature instars differ from the adults only in size, gonadial development and external genitalia. The insects are known as ametabolous. Both developing stages and the adults live in the same habitat.

2 Paurometamorphosis: In certain exopterygote insects like termites grasshoppers, cockroaches, most of the bugs, the development is gradual and the change in form is slight. The immature resemble the adults in much respect, including the presence of compound eyes, but they lack wings, gonads and external genitalia. During the course of development the wings become externally apparent as wing pads. The immature instars in this group of insects are commonly known as nymphs, although they may also be correctly referred to as larvae. The insects are known as paurometabolous. Both developing stages and the adults live in the same habitat like ametabolous insects.

3 Hemimetamorphosis: In certain exopterygote insects like mayflies, dragonflies and stoneflies, the immature instars pass in an aquatic habitat while the adults enjoy either terrestrial or aerial habitat. The immature appear to be quite different from the adult stage. The immature stages are called naiads. The insects are known as hemimetabolous.
In recent terminology, paurometamorphosis has been abandoned and is merged under the heading hemimetamorphosis.

4 **Holometamorphosis:** The type of metamorphosis also known as complete metamorphosis, takes place in endopterygote insects in which the immature instars are distinctly different from the adults and generally are adapted to different environmental situations. The larvae typically lack of compound eyes. They have biting and chewing mouth parts. There is a pupal instars between last larval instars and adult. The pupa is typically a resting stage protected in some way (within cocoon, in a puparial case, etc), but the pupae of some insects are quite active (the pupae of mosquitoes). The insects are known as holometabolous.

5 **Hypermetamorphosis or heteromorphosis:** In most holometabolous insects, all the larval instars are alike except for a few minor morphological details, however, some holometabolous insects pass through one or more larval instars that are distinctly different from the others. This phenomenon is called hypermetamorphosis or heteromorphosis and
has been described in certain species of ant-lions, beetles, flies, wasps and in all species of strepsiptera.

**Types of Larvae**

The larvae of Hemimetabolous insects essentially resemble the adults and they are sometimes called nymphs to distinguish them from the larvae of holometabolous insects. The most conspicuous difference between hemimetabolous and holometabolous larvae is in the development of the wings.

![Types of larvae](image.png)

Fig. Types of larvae

In Hemimetabola, the wings develop as external buds which become larger at each moult finally enlarging to form the adults wings. In Holometbola the wings developed as invaginations beneath the larval cuticle and so are not visible externally. The invaginations are finally everted so that the wings become visible externally when larva mouls to pupa. There are many different larval forms amongst the Holometabolous insects viz.

1) **Protopod Larvae:** The larvae represent a very early stage of development in which little segmentation of the body has occurred and cephalic and thoracic appendages are either absent are rudimentary. These larve are found among certain parasitic hymenoptera that larviposit in the haemocoel of other insect placing the embryo in the only kind of environment possible for survival, e.g., larvae of platygaster.

2) **Polypod or eruciform larvae:** This larva assumes the polypod phase of the embryonic development and in addition to thoracic legs has abdominal prolegs. It is generally poorly sclerotized and is a relatively inactive form lying in close contact with its food. The larvae of Lepidoptera, Mecoptera, are of the polypod types.
3) **Oligopod larvae:** This corresponds to oligopod phase of the embryonic development. The larva of this type has a well developed head capsule and mouth parts similar to adult but has no compound eyes. They are of two subtypes viz.

   **A Campodeiform larvae:** which is well sclerotized, dorsoventrally flattened and with prognathous head. The compodieform larva occurs in the Neuroptera, Trichoptera, and some Coleopteran etc.

   **B Scarabaeiform larvae:** the larva is robust or fat with a poorly sclerotized thorax and abdomen and has got burrowing habit in wood or soil. The scarabaeiform larvae are found in scarabaeoidea and some other coleoptera.

   **C Apodous larva:** As the name indicates, the larva has no legs and is very poorly sclerotized. They have been classified into 3- subtypes on the basis of sclerotization of the head of capsule viz.

       a. **Acephalous:** without head capsule but with cephalopharyngeal apparatus e.g. Cyclorrhapha (Diptera).

       b. **Eucephalous:** with a well sclerotized head capsule as found in Nematocera, Bupertidae, Cerambycidae and Aculeata.

       c. **Hemicephalous:** with a reduced head capsule which can be retracted within the thorax e.g. Tipulidae, Brachycera.

**Types of pupae**

The pupa is a resting of quiescent stage, characteristic features of all holometabolous insects. Pupae of some of the insect are quite active e.g. Mosquitoes.

Fig. Types of pupae

Three types of pupae have been recognized.

1) **Coarctate:** it is a free or exarate pupa enclosed in a puparium, formed from the preceding larval exoskeleton (cuticle). The puparium is barrel shaped and is segmented but there is no outward sign of appendages e.g. Cyclorrhaphous Diptera (flesh flies, Blow flies, house flies etc.)
2) **Obtect pupa**: in this type, the appendages are glued down to the body of pupae by a secretion produced at the larval/pupal moult. The object pupae are usually more heavily sclerotized than the free pupae or exarate pupae e.g. Lepidoptera, some Coleoptera, Neuroptera and Trichoptera.

3) **Exarate pupa**: in this type, the appendages i.e. legs, antennae and wing-pads lie free and are not glued to the body e.g. Hymenoptera, Coleoptera, Neuroptera and Trichoptera.

Further, a number of insects retain parts or nearly complete portion of the previous moulted skin, this phenomenon is called the pharate condition. The pupae in general exhibit only limited movement and most are sessile, found in protected environment such as in the ground, under bark, in cases or retreats, fashioned by the larvae or in silken cocoons produced by last instar larvae.

The changed that occur in the transformation of the larva to the adults may be more or less extensive depending on the degree of difference between the larva and the adult. Where the larva and adult are similar metamorphosis is relatively slight, but if the larva differs markedly from the adult a pupal instar may precede the adult. The pupa is probably to be regarded as the greater divergence of larval and adult forms, permitting the larva to invade entirely new habitats. During the pupal period reconstruction of the tissues takes place involving particularly the eversion and growth of the wings and the development of the flight muscles.

Since the pupa is generally immobile and therefore vulnerable most insects pupate in a concealed cell or cocoon and they employ various means of escaping from this when they emerge as adults. Adult eclosion is often synchronized.

Insect pupae and their significance are considered by Hintion (1946, 1948, 1963), the morphological aspects of metamorphosis by Snodgrass (1954), the biochemical aspects by Agrell and Lundquist (1973) and Thomson (1975), and the physiological aspects by Wigglesworth (1964). Gehring and Nothiger (1973) review the development of imaginal discs in Drosophila.

### 11. ENDOCRINE SYSTEM

Endocrinology is a comparatively new branch of scientific development of biology. The endocrine organs secrete their hormones which perform important functions in invertebrates. Both endocrine and the nervous system are integrative in function. Impulses are transmitted from nerve through mediation called Neuro transmitter. The endocrine system is more slow acting and elicits a sustained response in a distant target organ. The chemicals produced by the endocrine system known as the hormones reach the target organ by the circulatory system. Hormones control many activities like reproduction, colour change, metabolism, growth and development etc.

In insects too, the nervous and endocrine system form a functional and integrated system. This is best illustrated by \( \text{Neurosecretory cells} \) (NS) referred to as \( \text{Doubly Specialised Cells} \). They are characterised by the presence of secretory material
detectable histologically as chromophylic granules, which represent neurohormones associated with career proteins.

Axons of neurosecretory cells usually terminate in neurohaemal organs, which store neurohormones and release them in blood stream in response to appropriate stimuli. There is significant change in NS cell size, their nucleocytoplasmic ratio, and their NS material load in various physiological states. These observations help us to understand the activity of NSC. Heavily loaded cell can be in the period of intense secretory activity or be in a storage phase. The NS cells release relatively large quantities of their chemical mediators; the neuropeptides or neurohormones into the general circulation. Some of these cells innervate endocrine or neuroendocrine system and modulate the nerve and muscle activity. These are called neuromodulators.

**Endocrine Organs**

Endocrine organs of insects are of two types. The neuro secretory cells found in the brain and various ganglia of the nervous system and the endocrine organs like corpora cardiaca, corpora allata and ec dysial glands. In some insects the cephalic aorta is also associated with the endocrine organs.

**Neuro Secretory Cells**

The neuro secretory cells are present in brain and all ganglia. The neuro secretory cells are glandular nerve cells which show cytological evidence of secretory activity. The product of these neuro secretory cells is called Neurosecretion (or) neuro secretory material. The neuro secretory cells of the brain secrete a hormone known as brain hormone, which in fact is a mixture of several hormones secreted by different types of neuro secretory cells. The brain hormone activates other endocrine glands and also directly (or) indirectly almost all life processes. These neuro secretory cells are stained with specific neurosecretory stains like chromalum haematoxylin phloxin (CAHP), Aldehyde Fuchsin (AF), Paraldehyde Fuchsin (PH), Performic acid acin blue (PAAB), Performic acid resoscin Fuchsin (PARF) etc.

The neuro secretory cells in the brain region are grouped and paired. First pair pars intercerebralis Medialis present on protocerebrum near the middle line of brain. Presence of neuro secretory cells in the pars intercerebralis was first described by Weyer (1935) in honey bee.

**Neurosecretory cells in the suboesophageal ganglion**

The suboseophageal ganglion consists of numerous types of neurosecretory cells, which are located in the middle or posterovertral part of the ganglion in Hemiptera.

**Neurosecretory Cells in other Ganglia**

All the ganglia of the ventral nerve cord consist of neurosecretory cells. The cells are arranged in several clusters. These cells also secrete specific hormones, which are stored in the perysympathetic neurohaemal organs.

The neuro secretory cells have also been reported from the frontal and hypocerebral glands in Dictyoptera and Lepidoptera.

**Synthesis of Neurosecretory Material**
The raw material for the synthesis of neuro secretory material (NSM) is synthesized in the granular endoplasmic reticulum. From here it is transported to the golgi cisternae. In the golgi bodies elaboration of NSM takes place through the mediation of alkaline phosphates and finally the membrane bound vesicles are budded off in the form of neuro secretory granules. These granules are stored in the perikarya and transported to the neuro haemal organs via axons.

**Neurohaemal (or) Storage Release Organs**

The neurohaemal organs are those which store the neuro hormone secreted by the neuro secretory cells of the brain and other ganglia and release them in to the haemolymph. The neuro secretory material (NSM) is stored for a longer (or) shorter duration in the neuro haemal organs.

Two Principal types, one is corpora cardiaca, cephalic aorta and other subtypes of neurohaemal organs have been recognized in insects.

**Hormones** The term hormone was introduced by Starling in 1905. Insect hormones belong to several classes of different compounds. These are sterolids, and lipid like compounds, peptides and biogenic amines, which are produced by neuroendocrine organs, those products of neuroendocrine organs are called hormones. Hormones are chemicals with physiological activities carried through blood secreted by ductless glands. It is distinguish 3 types of hormones mainly : (1) Tissue hormones (2) Neuro hormones (3) Glandular Hormones. Tissue hormones are produced by various non-gladular tissue. It is purely a secondary function. Neuro hormones originate in special cells of CNS namly neuro secretory cells and travel via axons of these cells in the form of neurosecretory granules to special glandular organells. Glandular hormones are produced by the glands like the prothoracic glands. The hormones, which directly or indirectly influence growth, development, metamorphosis and reproduction, are of many types like brain hormone, juvenile hormone, moulting hormone etc.

**Corpora cardiaca:**

Situated in close association with the aorta behind the brian. The corpora cardiaca serve as neurohemal organ are a pair of small gland located behind the brain in close association with the aorta.Inaddition to containing intrinsic secretory cells the corpora cardiaca receive axons from the neuro secretory cells in the brain and serve as storage and release sites for their secretions the intrinsic secretory cells produce hormones which are concerned with the regulation of the heart beat.

**Corpora allata:** The corpora allata are glandular bodies, generally oval or elliptical in outline, and situated behind the brain or in the neck on the sides of the oesophagous. These are usually paired but in higher diterans they may be fused to a single body. Each corpus allatum is connected with the corpus cardiacum of the same side by a nerve which carries fibres from the neurosecretory cells of the brain. The size of the gland varies with the cycle of its activity.
The corpora allata produce juvenile hormone (JH) that regulates the metamorphosis and yolk deposition in the eggs.

**Prothoracic or Ecdysial glands:** The prothoracic glands found only in immature insects with the exception of the apterygotes, are irregular masses of tissue of ectodermal origin that are usually intimately associated with trachea. They may or may not be innervated. The glands show the cycles of development associated with secretion. At rest the nuclei are small and oval, but in the active gland they become enlarged and lobulated and the cell has more extensive cytoplasm. They secrete the moulting hormone, ecdysone under the influence of ecdysiotropin (PPTH or prothoracicotropic hormone) from neuro secretory cells in the brain.

**Ring glands or Weisman’s ring:** In maggots of the higher Diptera (suborder Cyclorrhapha), there is a small ring of tissue, supported by tracheae, called the ring gland, or Weisman’s ring. It is formed by the fusion of the corpora cardiac, and the thoracic glands. The ring gland connected to the brain by a pair of nerves.

### 12. EXOCRINE GLANDS

Morphologically, exocrine glands are either simple unicellular, simple bicellular, simple multicellular, complex multicellular or compound glands. A single secretory cell secretes toxic substances and usually contains an intracellular ducteole. Most of the exocrine glands are ectodermal in origin and are scattered over the insect body. Some of the major kinds of exocrine glands are wax glands, lac glands, cephalic glands, silk glands, repugnatorial gland, attractant glands, poison glands, accessory reproductive glands, salivary glands etc., which can be grouped as follows.

1. **Glands secreting structural materials**

   Certain insects secrete substances that are used in constructing their houses (e.g., beehive) are protecting them (lac or cocoon). Following glands are recognised to secrete such substances.

   - **Wax Glands**- These are mostly found amongst homoptera and honey bees and are uni or multi cellular structure distributed in various parts of the integument. They are especially found in Coccoidea and Aphidoidea in Homoptera and Apoidea in Hymenoptera. The wax is secreted either in form of powder or filament. The wax secreted by dermal glands located ventrally between the overlapping sternal plates of the fourth through the seventh abdominal segments of honey bees is used to construct honey comb. The wax is secreted as fluids and exuded through fine cuticular pores and accumulating and hardening in the form of thin plates which are removed by the hind legs.

   - **Lac Glands**- Lac is secreted by certain Coccoidea mostly Tachardiidae and in particular by *Kerria lacca* which yields commercial lac. Lac is a resinous substance produced in large amount by the female and in less amount by the male insect as a protective covering. The secreting cells are distributed throughout the integument.
• **Silk Glands** - In Lepidoptera and Tricoptera the labial glands are modified into organs of producing the silk utilized in the formation of larval shelters and cocoons. Other groups like Neuroptera and Hymenoptera, Siphonaptera larvae also possess silk glands. In the silk worms, silk is secreted by labial gland in the form of fibrinogen which undergoes denaturation on extrusion to form the tough, elastic protein fibroin and is surrounded by an outer layer of a water soluble gelatinous protein, the sericin.

2. **Glands secreting defense materials**

Insects secrete a variety of chemical substances that are used to defend them from their natural enemies as they have a pungent smell and other repellent properties. Following glands are recognised that secrete such substances.

• **Repugnatorial Glands** - A large variety of noxious substances are secreted by the repugnatorial glands which are variable in number, location, and morphology. The secretion of these glands initiates the escape response among the predators and other potential enemies. The chemicals are discharged from storage reservoir associated with the glands by a variety of mechanisms. The scent (stink) glands located on the dorsum of the abdomen in stink bugs, secrete a number of odoriferous chemicals (hexanal, hexanol, acetic acid, hexyl acetate, etc.,) that repel their natural enemies. Bombardier beetles eject a hot spray, containing quinones, from glands in the posterior part of the abdomen with a distinctly audible explosion. Similarly, ants secrete formic acid which is used as defense substance.

• **Frontal Glands** - The frontal gland is an unpaired characteristic organ of the termite's nasute soldiers. It is a sac like gland and opens by means of frontal pore. It secretes a sticky defensive material.

• **Pygidial Glands** - Among certain beetles pygidial glands are located at the posterior end of the body and open near the anus. It secretes pungent or corrosive materials.

• **Poison Glands** - These organs are peculiar to bees and wasps where they are modified accessory reproductive glands associated with the ovipositor or sting. The secretions are generally a complex mixture of several substances like melittin (bees venom) and kinin (wasps venom). Several Lepidopteran larvae are provided with epidermal poison glands associated with seta or spines which when broken allow the discharge of a secretion causing urticaria in man.

• **Alarm pheromone glands** - The aphids secrete mainly triglycerides of hexanoic and other acids that are liberated through the cornicles when the aphid is attacked by a predator and act as alarm pheromone. This causes the aphids in the vicinity to drop off the plants.

**Glands secreting materials for communication**

Many insects possess glands that secrete chemicals (infochemicals) that serve as signals of various sorts for other members of the same (intraspecific) or different species (interspecific). Intraspecific substances are called pheromones whereas interspecific substances are known as semiochemicals.
(1) **Pheromone gland**: The pheromones are concerned with the co-ordination of individual in a population. Mostly, the integumentary glands of the abdomen produce them. They are following types.

(a) **Aphrodisiac scent glands (androconia)**: The androconia or scent scales are found on the wings, legs or abdomen of butterflies and have an elongated form and terminate in a row of processes or fimbriae. At the base of the scale, glandular cells are present. In moths particularly in *Bombyx mori*, the pheromone glands are formed by the invagination of epidermal glands lined by cuticle and opens on either side of the genital pore. The scent is emitted via the terminal opening.

(b) **Mandibular glands**: These glands in queen and worker honey bees are sac like with an epithelium of secretory cells lined by a thin cuticle. The duct from the gland opens at the base of the mandible and produces the "queen substance" which inhibits the workers from constructing queen cells and stimulates various other behaviours in workers.

(c) **Nassanoff’s gland**: These glands are mainly found in the worker honey bees beneath the intersegmental membrane between sixth and seventh abdominal tergites and secrete pheromones.

(d) **Dufour’s gland**: Dufour's gland in worker ant open into the poison duct near the base of the sting. It is a small, simple sac with their glandular walls and a delicate muscular sheath. The gland secretes trail pheromone.

2. **Pheromones as sex attractants** The pheromones are secreted mostly by females, less frequently by males. In some species both sexes produce pheromones. Eg.,

(a) Pheromones attracting male insects
(b) Pheromones attracting female insects
(c) Pheromones attracting both sexes

3. **Pheromones of social insects.** In social insects, the pheromones are either concerned with communication between workers (e.g., ants, bees) or with the maintainance of colony structure (e.g., termites).

(a) Ant trails
(b) Termite pheromones
(c) Queen substance

**Glands secreting materials involved in physiology**

Secretion of salivarys glands and accessory reproductive glands are involved in the digestive and reproductive physiology of the insects respectively.

(a) **Salivary glands**- maxillary glands and labial glands are the principal salivary glands in the insects. The major function of these glands is to secrete digestive enzymes that help in the digestion of food material.

(b) **Accessory reproductive glands**- In female and male insects, there are generally one or two pairs of accessory glands associated with genital ducts.